



Stream Channel Monitoring for Knife River Indian Villages NHS

2022 Data Report

Natural Resource Data Series NPS/KNRI/NRDS—2023/xxx



**ON THIS PAGE**

Setting up measurements for a detailed transect at T1 at KNRI SCM 001.

Photograph courtesy of Northern Great Plains Network, National Park Service.

ON THE COVER

White pelicans flying by downstream portion of KNRI SCM 001 reach.

Photograph courtesy of Northern Great Plains Network, National Park Service.

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2022 Data Report

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

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Executive Summary

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring in Knife River Indian Villages, NHS in 2022. This data report summarizes the data collected during the 2022 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 KNRI for the collected data during 2022. Indices, benchmarks, and other studies are provided in the table for informational purposes to help put Knife River's measurements in context but should not be considered as a reference condition. Upland characteristics of the watershed indicate moderate agricultural land use cover: cropland (32%), shrubland (29%) and grassland (27%) with little development (3%) in the watershed area. Agriculture is more dominant closer to KNRI rather than the headwaters which are in rangeland. Reach characteristics include bank cover, heights, bank stability index, and vegetative cover. Angles are steep, and there are some sandy banks that are unstable however there is excellent access to the floodplain throughout the reach. 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. Sand covers much of the stream and 'runs' are the dominant geomorphic channel unit. While there is an absence of large woody debris and canopy cover is low, many grassland rivers 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 Knife River. The reach data contained in this report are specific to a 620-m segment of Knife River and cannot be extrapolated to conditions elsewhere on the river or to the park in general. Bank erosion and bank instability were observed along the majority of transects at site KNRI SCM 001.

Table ES-1. Summary table for stream channel data in Knife River Indian Villages NHS. Current values are based on data from 2022 alone.

Indicator	Measure	Status	Indices, Benchmarks, other Studies
Upland Land Use	Upland Land Cover Change	2019 NLCD cover Cropland= 31.85%, Pasture=6.75% Grassland= 27.42%, Shrubland=29.08%	2001 land cover: Cropland= 29.41%, Pasture=5.95 % Grassland= 30.43%, Shrubland=29.61%
	Land Development Change	2.66 % of watershed developed in 2019	2.45 % of watershed developed in 2001
Reach Level	Mean Bank Angle	43.14 ° water to bank-full bank angle	Bank Stability Index (BSI): <30° is good, <60° fair, >60° poor according to BSI
	Erosion	12 out of 22 bank transects (54%) show erosion in 2-m bank segments. Additional quantification of erosion showed 49% of bank length eroded.	TBD
	Mean. Bank Heights	1.06 m	BSI: <1 m bank is considered good
	Mean Bank-full width	27.80 m	TBD
	Bank Vegetation Cover %	47.32%	BSI: Vegetative cover>80% is "good", 50-80% fair, 20-49% poor, <20% very poor
	Bank Stability Index	12.14 on BSI index	<8 is considered stable, 7-10.99 at risk, 11-15.99 unstable, >16: very unstable
	Max Distance of Bank Migration	na	TBD
	Cross-sectional Area	Mean bank-full area 21.17 m ² ; mean channel-full area 112.66 m ²	TBD
Physical Habitat	Median Particle Size of Representative Riffle	2mm, sand	TBD
	Percentage fine substrate	100% sand, dominant in 11 out of 11 transects. Expanded analysis concurred with 98% of reach covered in fine sediment (sand).	Median sand percentage was 100% in large NGPN rivers (Rust, 2006)
	Geomorphic units	Dominated by run (97%), marginal pool (1%) and riffle (3%) habitats.	Large NGPN Rivers are dominated by runs, few pool-riffle habitats (Rust 2006).
	Canopy cover	0% canopy cover from center of stream.	0% cover was median for large NGPN rivers (Rust 2006).

1 National Land Cover Dataset

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Abbreviations and Acronyms

>:	greater than
≥:	greater than or equal to
<:	less than
≤:	less than or equal to
#:	number
303(d) list:	List of Impaired Waters, under the CWA
BSI:	Bank Stability Index
cfs:	cubic feet per second
CWA:	Clean Water Act
°C:	degrees Celsius
DEM:	digital elevation model
DEQ:	Department of Environmental Quality
DO:	dissolved oxygen
<i>E. coli</i> :	<i>Escherichia coli</i>
EMAP:	Environmental Monitoring and Assessment Program (USEPA)
EPA:	Environmental Protection Agency
HR:	High Resolution
HUC:	hydrologic unit code
I&M:	Inventory & Monitoring
IRMA:	Integrated Resource Management Applications
km ² :	square kilometers
KNRI:	Knife River Indian Villages NHS
LBM:	left benchmark
mi ² :	square miles

mL:	milliliters
NAWQA:	National Water Quality Assessment (USGS)
ND:	North Dakota
NGPN:	Northern Great Plains Network
NHD:	National Hydrography Dataset
NHDPlus HR:	National Hydrography Dataset Plus High Resolution
NHS:	National Historic Site
NLCD:	National Land Cover Database
NPS:	National Park Service
NWIS:	National Water Information System (U.S. Geological Survey)
SECN:	Southeast Coast Network
SOP:	standard operating procedure
TCP:	traditional cultural property
USACE:	U.S. Army Corps of Engineers
USEPA:	U.S. Environmental Protection Agency
USGS:	U.S. Geological Survey
VAA:	NHDPlus HR Value-Added Attribute table
WBD:	Watershed Boundary Dataset
WICA:	Wind Cave NP
ws:	water surface

Introduction

Knife River Indian Villages National Historic Site (KNRI) was established in 1974 on the Knife River above the confluence of the Missouri River just north of the town of Stanton, ND and approximately 45 miles northwest of Bismarck, ND. The Knife River originates in the Badlands of west-central North Dakota and flows about 200 miles (193 km) until it reaches the Missouri River (Figure 1). KNRI is in a semi-arid region that averaged 19 inches of precipitation annually from 1995-2015, but extreme variation in temperature and precipitation is common in this region.

KNRI has a mission to commemorate the culture and history of the Northern Great Plains Indian peoples and to preserve, study, and interpret the historic and archeological resources of the site. Native people have called Knife River home for up to 12,000 years. Village sites within KNRI including Big Hidatsa Village, Lower Hidatsa Village, and Awatixa Village containing earthlodge dwellings which were clustered along the Knife River's rich floodplains. Over 65 archeological sites at KNRI are listed in the National Register of Historic Places as well as potential traditional cultural properties (TCPs). The floodplains produced abundant crops such as squash, corn, and beans (NPS 2018) and the river facilitated trade. The Mandan, Hidatsa, and Arikara tribes displaced from the immediate vicinity of the park consider KNRI a living homeland (NPS 2013). Fundamental resources and values of KNRI include the archeological resources, cultural landscape, the museum collection, and traditional and contemporary cultural significance (NPS 2013). The Missouri and Knife Rivers are listed as important resources as well as the viewshed, the night sky, native prairie, and soundscape. KNRI sits on 1,758 acres of upland mixed-grass prairie and riparian forests, above the confluence of the Knife and the Missouri River.

The Knife River flows through 3.5 miles of the park, and many of the archeological sites are on or close to the banks of the river (National Park Service 2013). Though meander migration is a natural process, riverbank erosion is a high priority threat to preservation of archeological resources and the cultural landscape. In this area, river flow tends to peak between March and May, while annual low flows occur in November and December (NPS 1997). In recent years there have been some significant fall spikes in precipitation as well (USGS 2023), though notably not in 2022. The river is dynamic and continues the natural meander process. Unfortunately, County Road 18 constrains the river on the north side of the park and archeological remains occur on the high banks which continue to erode and shift. The park's unique cultural resources are at risk from erosion due to the failing banks and meander migration (National Park Service 2013 and 2018b, Nadeau et al 2014).

The river within the park is impacted by Garrison Dam, completed in 1953, and located just ten miles upstream of the confluence of the Knife with the Missouri River. The Missouri River experienced an 89% reduction in sediment from 48.6 million megagrams in 1949-52 to 5.3 million megagrams in 1959 (Williams and Wolman 1984) as largely sediment-free water was released from the dam after construction. The presence of the dam and removal of sediment has degraded the channel downstream of the dam, starving it of sediment (Williams and Wolman 1984, Pokrefke 1998). The zone within 50 km of the dam has simplified habitat, leading to loss of bar and island habitat (Skalak 2013). While the flow regime on the Knife River remains largely unchanged since the dam was built,

the Missouri River's flow regime has completely changed causing an asynchrony between the two rivers (Ellis 2005). Downcutting and erosion in the Missouri can affect tributaries, with erosion and headcutting often traveling up downstream tributaries of dams (Poff et al 1997).

Skalak 2017 suggests that the Missouri River is an alternate stable state and will not revert to pre-dam conditions even in the presence of a large 500-year flood such as in 2011. A return to pre-dam conditions would require pre-dam flow and sediment supply. The construction of the Garrison Dam across the Missouri caused extreme bed degradation immediately downstream. The Knife River at KNRI also is within the zone of degradation as part of the dam proximal zone (Ellis 2005, Skalak 2013). Dam releases coupled with the lowered bed elevation can cause the Knife River to back up when high amounts of water are released from the dam at high flows (Ellis 2005, Rust 2006, NPS 2013).

The Knife River is the second largest contributor of sediment to the Missouri River between Garrison Dam and Lake Oahe (Macek-Rowland 2000) and has an average sediment yield of 91.1 tons per mile. The Knife River is characterized by having a high sediment load (Tronstad 2013) with sandy substrate (Rust 2006). In one study, the Knife River was found to transport 1,690 tons of sand per day and 270 tons of clay and silt (Berkas 1995), transporting even more than the Missouri River just above the confluence. At low flows, the Knife contributes proportionally little sediment to the Missouri River but the sediment load increases greatly at streamflows above 32 cfs (Macek-Rowland 2000). There is no clear temporal trend in modeled sediment loads for Knife River (Macek-Rowland 2000) and sediment yield is closely tied to streamflow which has great annual variability.

In addition to Missouri River degradation and seasonal floods, ice jams cause bank erosion as well (Nadeau et al 2014). Saturation of banks due to melting ice, heavy precipitation, abrasion from ice jams as well as the backwater effect from the dam contribute to bank instability and erosion (Ellis 2005). Ice impacts the banks during ice jam events. River bends and mouths such as at Knife River are especially conducive places for ice to build up (Beltaos et al 2000). Abrupt narrowing of the channel or changes in bed elevation may also be places where ice jams can be problematic. The park experienced a large flood event in 2009 (Cummings 2011, Nadeau 2014) where 3- 120 feet of bank were lost. The river flooded due to an ice jam and park infrastructure and archeological resources were impacted. This event and prior flooding in 1997 spurred the need for more bank stabilization projects (Sturdevant 2009, Cummings 2011) to protect vulnerable resources many of which are less than 1 meter from the edge of the bank (Nadeau 2014).

The Knife River flows through recent alluvial deposits (Figure A-1) with the river making some dramatic bends throughout the park. Mean bank erosion between 1965 and 2011 was estimated to be between .9 and 4.9 ft/year in cross-sections throughout the park (Sexton 2012, Figure B-1) and banks continue to erode as meanders shift. Bed and bank erosion is a natural part of river morphology. To what extent the erosion on the cutbank at KNRI SCM 001 is natural or human-induced is beyond the scope of this data report. The high cut banks at KNRI are largely inactive channel banks and these continue to fail and erode (Ellis 2005). This high floodplain however, was accessed during the flooding in 2009 as water overtopped them and the high banks eroded spectacularly (Cummings 2011). Though they can be destructive, periodic floods have benefits to the ecology of KNRI. Floods

maintain the health of floodplains, providing new habitat for floodplain adapted species (Poff 1997). They scour fine sediment and create new depositional habitat. Floods can transport woody debris to create new fish habitat and maintain habitat complexity allowing life in diverse forms to flourish. Living with disturbance was something the early people of KNRI were well-acquainted with, indeed, they depended on rich soil deposited by floods for their farming. This is the first in a series of visits to document stream bed and bank morphology changes at KNRI.

KNRI has water resources including Knife River which flows through the park and the Missouri River which forms the eastern boundary. The Knife River is designated as a Class II water in North Dakota. Class II waters are similar to Class I waters which are defined as “water suitable for propagation or protection, or both, of resident fish species and other aquatic biota and for swimming, boating and other water recreation”. Class II waters may require additional treatment to meet drinking water requirements (NDDEQ 2021). The stretch of the Knife River that runs through KNRI, ND-10130201-002-S_00, is listed as an impaired waterway under section 303(d) of the Clean Water Act and is listed for *Escherichia coli* (ND Department of Health 2019). Fecal coliform concentrations were found to be as high as 2419 cfu / 100 ml in 2011, which is almost ten times the maximum concentration for recreation (Tronstad 2013). The source of the *E. coli* and fecal coliform is not known, but livestock feeding operations, agriculture, and failing septic systems are likely contributors to bacteria impairments in North Dakota.

For more details and current impairment information visit the North Dakota Department of Environmental Quality website and [How's My Waterway – Community \(epa.gov\)](https://www.epa.gov/334/334-how-my-waterway-community). Bacteria counts collected by NDDEQ were not taken in the park, but there was some sampling approximately 13 km upstream from 06340590, from the same reach, ND-10130201-002-S_00, available from [Water Quality Data Home](#). Three of 5 geomeans of bacteria counts at that station, 21NDHDWQ_WQX-380088, violated the water quality standard in 2021. NGPN water quality monitoring found no impairments on the Knife River within KNRI in 2019 (Rosse and Cramer 2022), 2016 (Ashton and Rockwood 2020b), or 2013 (Ashton and Rockwood 2020a). Water quality is measured through a partnership with USGS and NGPN every three years at the park at [USGS 06340590 KNIFE RIVER NR STANTON, ND](#) and there is a permanent gage outside the park at Hazen [USGS 06340500 KNIFE RIVER AT HAZEN, ND](#).

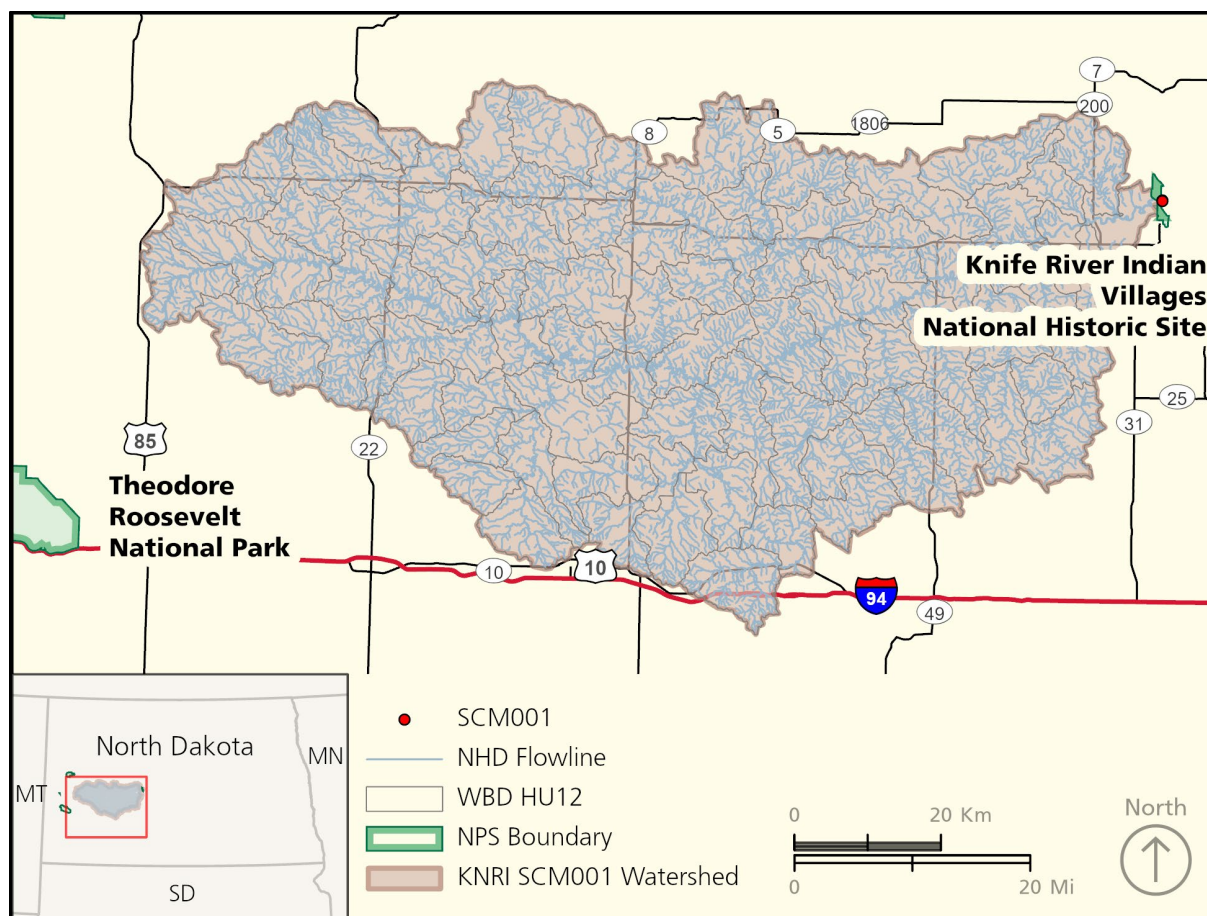


Figure 1. Map of Knife River in KNRI with stream channel monitoring site KNRI SCM 001 and associated watershed. Data: NPS, USGS, ESRI.

The Northern Great Plains Inventory & Monitoring Program (NGPN) first began monitoring stream channel characteristics at WICA 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.

NGPN conducted the first survey at KNRI in September 2022. KNRI SCM 001 was established at Unnamed Bend. Sexton 2012 estimated erosion along this section of river ranged from .8 ft per year at the upstream end to 6.5 feet a year at about 80% of the distance through the curve, then decreasing

slightly to 4.7 feet/year at the downstream end of the bend. Mean rate of bank movement was estimated to be 3.9 feet/year. Other bends studied in the park include Taylor Bend (mean bank movement is .9 ft/yr), Noname Bend (mean bank movement is 4.9ft/yr), Elbee Bend (mean bank movement is 2.2ft/yr), and Loop Bend (4.2 ft/yr) (Nadeau et al 2014).

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 – Water Quality Monitoring in Northern Great Plains Network \(nps.gov\)](#) , 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, was sampled in 2021 when it was the only site sampled. FOLA, and MNRR- Bow Creek are scheduled to be included with it when next sampled in 2024. DETO, KNRI, and THRO were sampled near their WQM gages in 2022. AGFO and NIOB will be sampled near their WQM stations in 2023 along with MORU which does not have a WQM station.

At KNRI, the site was placed downstream of the gage with a relatively accessible floodplain. The bend KNRI SCM 001 occurs on is referred to as Unnamed Bend. The bend was measured by 2012 by Chad Sexton and bank movements along the bend are estimated at >1.5-3.0 ft per year on the upstream end to 6-7.50 ft/yr on the downstream end. The banks at KNRI are very steep and sandy. Bank restoration projects at KNRI are planned for the future so those areas were avoided and archeologically significant village sites were avoided. 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. Reach length was based on initial wetted width, which was 31 meters. With total reach length twenty times initial mean stream width, the reach was 620 meters. Permanent benchmarks indicating the starting and ending points of the three detailed transects were located with a high accuracy GNSS receiver.

Data Collection

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring in Knife River Indian Villages NHS in 2022. Data collected during the 2022 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 KNRI SCM 001 in August 2022 with temporary plastic stakes marking the GNSS occupation points. An Arrow Gold receiver was used to obtain high accuracy benchmark locations, summarized in Table 1 below.

Table 1. Left bank benchmark locations at T1, T6, T11 and TP1 (tie-in point 1).

Point_Name	Northing_m	Easting_m	Elevation_Ortho_height_m	Datum	Lat_WGS84	Long_WGS84
KNRI_SCM_001_LT1	187929.66	533520.627	512.559	NAD83 (2011)	47.35395	101.38
KNRI_SCM_001_LT6	187809.475	533282.822	509.469	NAD83 (2011)	47.35284	101.3831
KNRI_SCM_001_LT11	187961.899	533045.052	510.065	NAD83 (2011)	47.35419	101.3863
KNRI_SCM_001_TP1	187905.627	533485.332	509.83	NAD83 (2011)	47.35373	101.3804
KNRI_SCM_001_RT1	187849.17	533553.204	510.385	NAD83 (2011)	47.35323	101.3795
KNRI_SCM_001_RT6	187739.009	533260.768	513.923	NAD83 (2011)	47.35221	101.3834
KNRI_SCM_001_RT11	187940.296	532984.653	515.004	NAD83 (2011)	47.35399	101.3871

All locations are recorded in North Dakota S State Plane coordinate system (WKID= 3635). 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 mid-September 2022.

The NGPN crew performed stream channel measurements in September 2022. Discharge, photos, geomorphic channel units (pool, riffle, run, etc.), representative pebble count at the riffle between transect 10-11, 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 bank full height. Figure 2 shows the layout of the reach. The thicker yellow lines at T1, T6, and T11 show the permanent detailed transects where the total station was used.

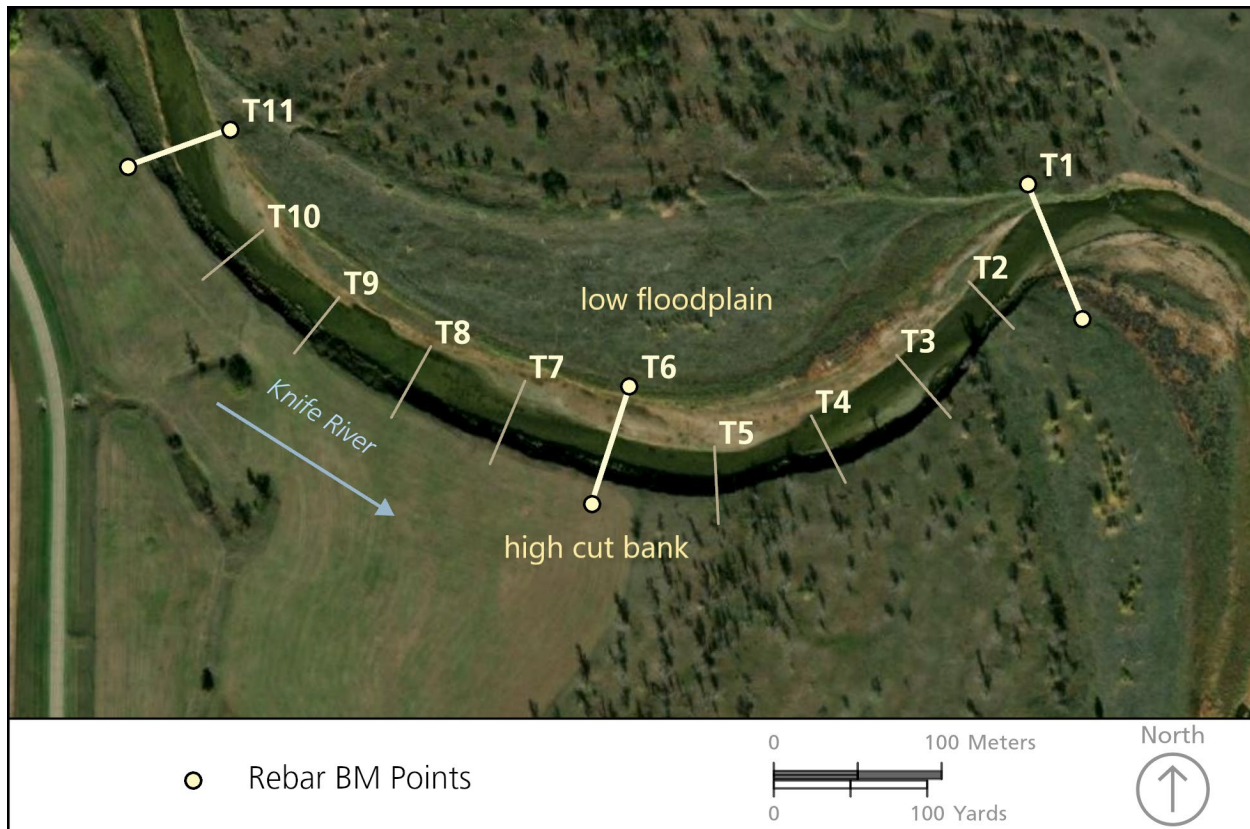


Figure 2. Layout of sampled reach of KNRI stream channel monitoring site KNRI SCM 001. Transects number 1-11 running from down to upstream. The dominant geomorphic channel unit between all reaches is “run.” Data: NPS, ESRI.

Watershed Characteristics

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 scientist-in-park GIS Assistant under the supervision of NGPN Aquatic Ecologist during the winter of 2022-23. The Watershed and Segment Scale Analysis SOP [DataStore – Standard Operating Procedure – \(Code: 2259868\) \(nps.gov\)](#) is in the process of being updated. The first major change is that the workflow required is being updated to Arc Pro rather than ArcMap. Secondly, watershed parameters need to be redefined and clarified, ie references to the term ‘basin’ were removed and replaced with ‘watershed’, ‘gradient’ and other terms were specifically defined. Also changes to the delineation procedure were made. Three methods used were: the NHDPlus HR method, the 20- ha stream delineation method, and the StreamStats web application. Ultimately the best delineation was based on the NHDPlus HR method. The NHD Plus HR method uses NHD flowlines to select the HUC 12s to include in the watershed delineation. NHD products and NED datasets are integrated to help define the watershed. The 20-ha method is the original procedure from the SOP. It uses a user-defined 20-ha threshold to delineate streams. This method failed in certain parks. The third method is using the StreamStats web

application from USGS to delineate the watershed. Nebraska and Wyoming are undergoing some major changes in the application currently. Lastly, the requirement of using only of perennial streams was removed as perennial streams can be rare in areas and are poorly defined.

The following parameters were be calculated or extracted for each reach:

- **Watershed Drainage Area (km):** refers to the area within which precipitation, sediment, and dissolved constituents are funneled to a common outlet point (Dunne and Leopold 1978).
- **Total Stream Length (TSL km):** is the length of all streams that flow to a common outlet.
- **Drainage density (km/km²)** is the ratio of total stream length to drainage watershed area.
- **Watershed shape** is calculated by dividing watershed area by watershed length squared. Be careful to use consistent units.
- **Watershed length (km):** the distance as-the-crow-flies from the pour point to the drainage divide, uphill of the upper reach of the main path stream.
- **Watershed Relief** is the maximum amount of relief (maximum elevation minus minimum elevation) found within the watershed.
- **Watershed Relief Ratio** is calculated by dividing watershed relief by watershed length. Be careful to use consistent units.
- **Standard Deviation of Elevation (sdZ)** is the standard deviation of elevation within the watershed.
- **Watershed (CV):** coefficient of variation of slope for entire watershed. No units.
- **Slope** will be characterized by determining the average, standard deviation, and coefficient of variation of slope within the watershed.
- **Entire Stream Gradient** is calculated by determining the difference in elevation at 85% and 10% of the main stem stream length divided by the stream length between the two points.
- **Segment Gradient** is the difference in the upstream elevation of the stream segment minus the downstream elevation of the stream segment divided by the length of the stream segment.
- **Stream order** classifies streams based on the number and character of their tributaries (Strahler 1957). This SOP describes how to determine Strahler stream orders. NHDPlus HR provides a modified Strahler stream order in the Value-Added Attribute table included in the geodatabase.
- **Bifurcation ratio** is the ratio of the number of streams in a given Strahler order to the number of streams in the stream order above it (e.g., number of first order streams/number of second order streams). An average watershed bifurcation ratio can be determined by adding these individual ratios and dividing by the highest stream order minus one.

- **Land Use/Land Cover** will be calculated from the most recent NLCD dataset. This dataset classifies land cover using a modification of Anderson et al. 1976.

For more details regarding watershed and segment scale characterization and a complete definition of the above terms, the reader is referred to Fitzpatrick et al. 1998, the protocol and associated SOPs in [DataStore – Published Report – \(Code: 2260277\) \(nps.gov\)](#), and Monitoring Wadeable Stream Habitat Conditions in Southeast Coast Network Parks: Protocol Narrative (McDonald et al. 2018a).

NHD Plus-HR method of delineation

The basic workflow specific to KNRI is described here: A 10-m digital elevation model (DEM), with corresponding NHDPlus HR geodatabase and NHDPlus HR rasters were downloaded for the region of Watershed Boundary Dataset (WBD) HUC-4-level (hydrologic unit) area number 1013. A large area was chosen so as not to mistakenly leave off distant headwaters. NHDPlus HR rasters were clipped to the outline of the DEM tile, then all rasters and the DEM were reprojected to the NAD83 (2011) Contiguous USA Albers coordinate system. NHDPlus HR Flowlines, Sinks, and WBD HUC-12 features were similarly reprojected. The site of KNRI SCM 001 was used as the pour point. The Snap Pour Point tool was used to align it with the reprojected Flowlines. The DEM was filled, then a flow direction raster was produced. The ArcGIS Pro Watershed tool which was used on the flow direction raster failed to produce a useable watershed, yielding a raster trending for a short distance only to the northeast, with no length along the stream’s path. The USGS, however, has integrated elevation and hydrography GIS data with the National Hydrography Dataset Plus High Resolution (NHDPlus HR 2023), which includes the WBD (watershed boundary dataset). NHDPlus HR products include a hydro-conditioned “fdr” flow direction raster.

This “fdr” raster did run adequately in the Watershed tool, though it still created a hole-filled, somewhat restricted watershed, perhaps due to numerous local sinks. This initial “fdr”-derived watershed was useful for the shape of the watershed near the pour point, but the upstream area was deemed not useable. To determine the shape of the upstream area, we needed to see all the upstream connections. The NHDPlus HR HydroNet geometric network was run through the Converted Geometric Network to Trace Network tool. The result was run through the Enable Network Topology tool. The Trace tool (upstream) was run on this network to select all connecting flowlines up from the pour point. The Trace tool did not select either disappearing streams (or ponds or sinks), but it did give a good estimation of the full area of the watershed. Polygons from the WBD HUC-12 level features were Selected by Location via intersection with the traced flowline results. The Erase tool was used on the selected HUC-12 polygons to remove the portion downstream of the boundary of the “fdr”-derived watershed. Extraneous edge slivers were manually edited out where the watershed and HUC-12 polygons met to create a more precise overlay. The edited HUC-12 polygons were dissolved to create the final watershed shape. This new watershed outline captured disappearing streams within the watershed and filled in the large holes around substantial sink areas.

20-ha method of delineation

The NHDPlus HR-derived watershed was confirmed by running the stream production sequence of the old SOP 20-ha workflow [DataStore – Standard Operating Procedure – \(Code: 2259868\) \(nps.gov\)](#). A flow accumulation raster, a flow accumulation >2415 raster (cells which accumulate

from at least a 20 ha catchment), then stream link and stream order rasters were created. The stream order raster was converted to lines via the Stream to Feature tool. The 20-ha stream layer very closely approximated the final watershed boundary used. This old workflow, however, created more than 1000 additional km of stream length even when clipped to the KNRI SCM 001 watershed, an increase of 11% in stream length.

StreamStats method of delineation

The USGS StreamStats application [StreamStats \(usgs.gov\)](https://www.usgs.gov/streamstats) was used to generate a watershed area as an additional check on our procedures (USGS 2019). This application does rely on a DEM and watershed tool like the one used in ArcGIS Pro. The procedure is very simple. One accesses the site, zooms in to an area of interest and clicks on the stream segment closest to the most downstream point of the watershed, approximating the same pourpoint as the previous methods. Annual exceedance probabilities for flow were constructed as well using associated regional regression equations (Williams-Sether 2015). The area generated by Streamstats was compared to the NHD watershed area and is discussed later in the report.

National Land Cover Database

Land cover classification rasters were downloaded, reprojected, clipped to the KNRI SCM 001 watershed and summarized by land cover class. Data from 2001, 2006, 2013, 2016, and 2019 were downloaded and summarized.

Results

Watershed Characteristics

Three methods were used for watershed delineation: the NHDPlus HR method, the 20-ha stream delineation method, and the StreamStats web application. Ultimately the best delineation was based on the NHDPlus HR dataset. The watershed delineation methods according to the [DataStore – Standard Operating Procedure – \(Code: 2259868\) \(nps.gov\)](#) were based on regular 10-meter resolution elevation data (Thornburgh 2019) , and failed in the case of KNRI to create a useable watershed outline. The SOP’s 20-ha stream drainage workflow could not reflect the numerous sinks, ponds and disappearing streams in the area. It created stream connections where none existed on the surface, which might also have artificially increased the stream order of downstream segments. The USGS’s hydro-conditioned “fdr” raster produced a preliminary watershed. Merging this watershed with the upstream WBD HUC-12 polygons allowed for a final watershed outline, called the NHDPlus HR watershed. The StreamStats web application is available in North Dakota, but it is not fully available in Wyoming or Nebraska in 2023 and so cannot yet be used consistently across the network. The NHDPlus HR watershed and StreamStats watershed yielded very similar results, less than .08% difference, which is practically negligible. The Streamstats method may include some flow characteristics which are helpful to report. However, the Streamstats method also does not generate flowlines, only the watershed area.

We relied on the NHDPlus HR Flowlines joined with their Value-Added Attribute (VAA) table for the modified Strahler stream order; and NHD Plus HR Flowlines were used to calculate total upstream stream length, as well as the subsequent measurements of such as drainage density and bifurcation ratio. We submit that this method described water on the landscape better than the old SOP workflow which could not accommodate the unique situation of having 2,005 sinks documented within the watershed (per the USGS NHDPlus Sinks GIS feature layer). Use of NHDPlus HR standard GIS features and rasters should allow for more fidelity when trying to duplicate the method in the future.

Total stream length was based on all upstream NHDPlus HR stream flowlines (9971.34 km), rather than the 20-ha derived stream network (11,068.3 km, see Table 2). This is an 11% difference in stream length. Similarly in the Wind Cave data report, the 20-ha watershed delineation method generated 7.4% more stream length than NHDPlus HR flowlines (Rosse 2022). The stream length measure included disappearing streams and intermittent channels and draws which contain waters “only part of the year, but more than just after rainstorms and at snowmelt” (NHD 2023). Table 2 shows the stream lengths, stream order, and bifurcation ratio of the different watershed delineation methods.

Table 2. Stream lengths and metrics of KNRI SCM 001 watershed.

Data source	Total stream length (km)	Stream Order at SCM 001	Bifurcation Ratio
NHDPlus HR flowlines	9971.34	7	2.21
20-ha derived streams clipped to final watershed	11,068.30	8	1.92
20-ha derived streams including everything upstream	11,092.90	8	1.92

Figure 3 shows the 20-ha stream network and where it crossed the WBD line for Knife River HUC-8 (10130201).

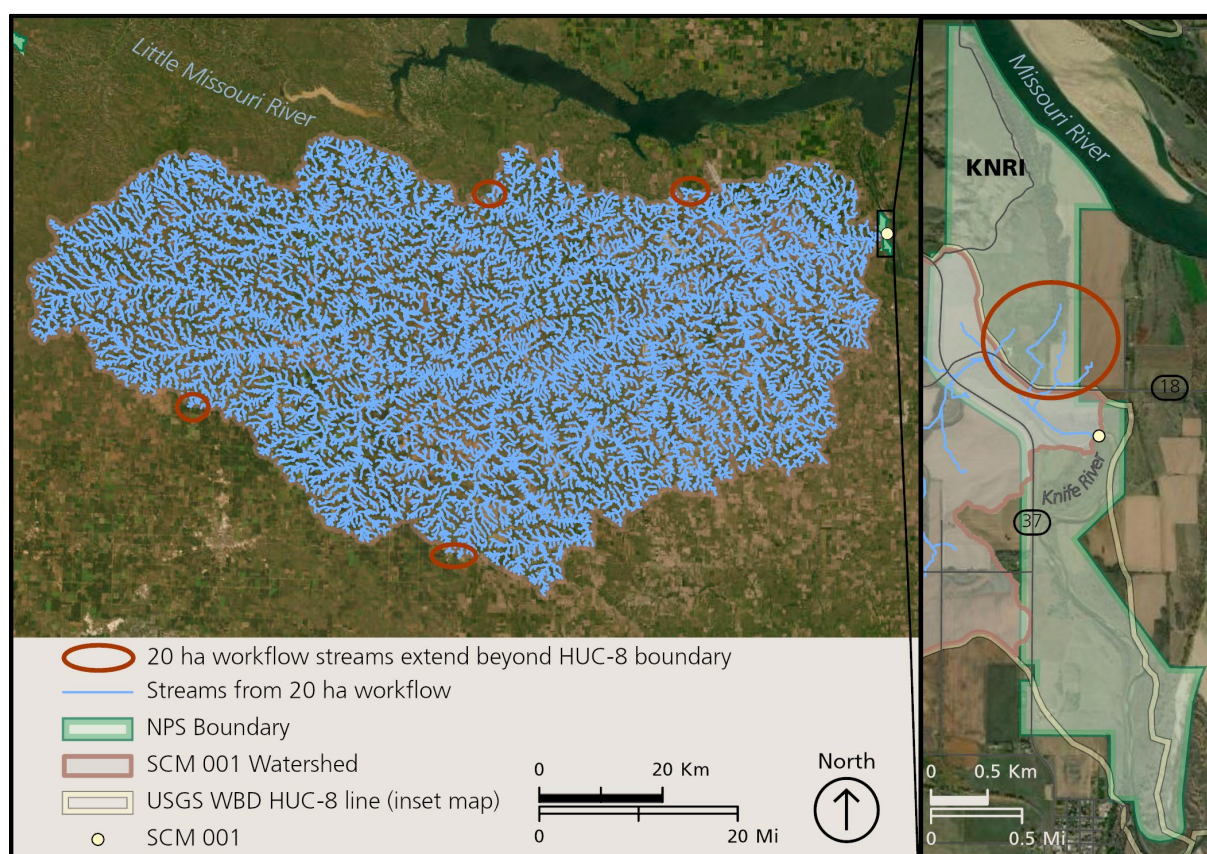


Figure 3. KNRI stream channel monitoring site SCM 001. The derived 20-ha stream network shown in blue generated 11% higher total stream length than the NHDPlus HR flowlines in the same area. Data: NPS, USGS, ESRI.

Table 3a shows the basin characteristics from the KNRI SCM 001 watershed. The watershed was derived using NHDPlus HR rasters and flowlines, and WBD polygons. NHDPlus HR flowlines were clipped to the watershed area, joined to the VAA (value-added attribute) tables, and used for Strahler order. Geometric area and length calculations were not taken from NHDPlus HR attributes, but from

Calculate Geometry tools on new fields in attribute tables. Area and length calculations were performed in NAD83(2011) Contiguous USA Albers projection.

To describe the variables in brief, total stream length (TSL) is the length of all NHDPlus HR flowline segments clipped to the watershed. Drainage density is the ratio of stream length to drainage area. Strahler order is a stream order derived from the number of tributaries. Strahler order may be calculated in ArcGIS Pro using the Stream Order tool on rasters or is assigned in the VAA tables. NHDPlus HR includes the FCode assignments of perennial, intermittent, and ephemeral stream classifications but the results may be inconsistent. Where streams reach a certain width, the FCode is found in the NHD Area or Waterbody polygon attributes rather than the coincident flowlines, which will then indicate “artificial path” as the FCode for the flowline. 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. Ephemeral streams were not found within the watershed, but if they had been, they would be excluded from total stream length. Indeed, in mesic areas, the NHD-generated streams tended to underestimate total stream lengths, but in arid or semi-arid areas, it overestimated total stream lengths (Fritz 2013). Figure C-1 shows the NHDPlus HR FCode attributions of perennial and intermittent streams, as well as the abundant sinks found within the watershed.

Bifurcation ratio is the ratio of number of stream segments of given stream order divided by the number of stream segments in the stream order above it. An average bifurcation ratio is calculated by adding up all the bifurcation ratios and dividing by the maximum stream order minus one. 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. Watershed length is the length as-the-crow-flies from the pour point KNRI SCM 001 to the drainage divide uphill from the upper reach of the main path stream. This differs from the SOP which used a measure which followed the sinuous main stem path to the upper watershed divide. Watershed shape is the watershed area divided by the square of the watershed length. For a complete definition of these terms, see the protocol and associated SOPs [DataStore – Published Report – \(Code: 2260277\) \(nps.gov\)](#).

Table 3a. Characteristics of watershed derived from NHDPlus HR flow direction “fdr” raster and NHDPlus HR Flowlines within the watershed.

Watershed Characteristic	KNRI SCM 001
Watershed Drainage Area (km ²)	6479.98
Total Stream Length (km)	9971.34
Drainage Density (km/sqkm)	1.54
Watershed Length (km)	139.60
Watershed Shape	0.33
Watershed Slope- Average °	3.49
Watershed- Std. Dev °	3.39
Watershed- CV	0.97
Watershed Relief (m)	496.43
Elevation - Std. Dev (m)	57.60
Watershed Relief Ratio	0.0036
Entire Stream Gradient (m)	0.6618
Strahler Order	7
Bifurcation Ratio	2.21
Stream Gradient (m)	0.8849
Flow Accumulation Threshold	NHDPlus HR

Table 3b. Flow characteristics of watershed derived from Stream Stats application.

Flow Characteristic	KNRI SCM 001
Stream Stats area (sq.miles)	2500
Stream Stats area (sq.km)	6474.97
Mean Annual Flow (cfs) ¹	169
2 year flood (50-percent AEP flood)	3320
50 year flood (2-percent AEP flood)	26400
100 year flood (1-percent AEP flood)	32200

¹ based on annual data at Hazen gage 06340500; 1929 to 2022

As an additional check on the data, the Stream Stats tool from USGS which is available in North Dakota was used. A basin was generated when clicking on the clicked point below which is analogous to our most downstream point, T1 (Figure 4). The watershed area generated in Table 3b (6474.97 km²) showed less than .08% difference from our KNRI SCM 001 watershed (6479.98 km²). Annual exceedance probabilities were calculated via regional regression equations and are listed in Table 3b.

StreamStats Report

Region ID: ND
Workspace ID: ND20230303185033188000
Clicked Point (Latitude, Longitude): 47.35343, -101.38175
Time: 2023-03-03 11:51:01 -0700

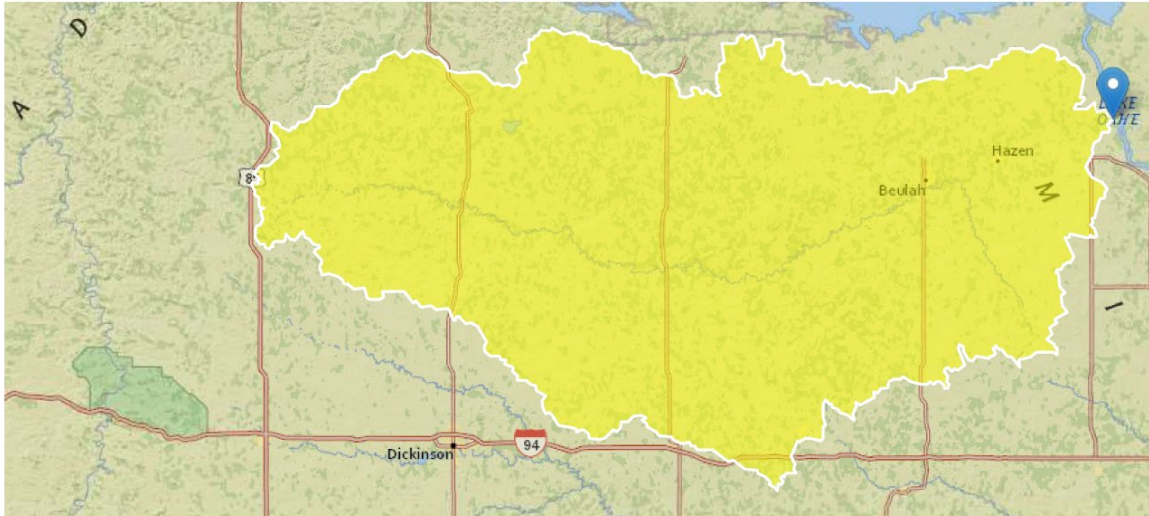


Figure 4. StreamStats watershed area derived from [StreamStats | U.S. Geological Survey \(usgs.gov\)](https://streamstats.crk.usgs.gov/).

The National Land Cover Database (NLCD) raster, a satellite-based 30-m resolution land cover classification data product, was downloaded, reprojected, and clipped to the KNRI SCM 001 watershed. The most recent dataset, 2019, showed the watershed area is a mix of 31.85 % cultivated crops, 29.1% shrubland cover, 34.18% herbaceous grassland and pasture, 2.6% total developed area, and less than 1% each of forest and wetlands (Tables 4 and 5). There are two roads of note near our study area, County Roads 18 and 37. County Road 18 in one area closely parallels the Knife River. County Road 37 crosses the river within the boundary of KNRI.

Table 4. National Land Cover Dataset percent cover by class applied to 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	0.19	0.19	0.29	0.24	0.23
Developed – Open ¹	1.74	1.74	1.74	1.77	1.75
Developed – Low ¹	0.60	0.60	0.65	0.68	0.68
Developed – Medium ¹	0.09	0.11	0.13	0.17	0.19
Developed – High ¹	0.02	0.02	0.03	0.04	0.04
Barren	0.24	0.24	0.29	0.28	0.34
Deciduous	0.68	0.68	0.67	0.67	0.67
Evergreen	0.03	0.03	0.03	0.02	0.03
Mixed Forest	0.02	0.02	0.02	0.02	0.02
Shrub	29.62	29.58	29.56	29.19	29.08
Grassland	30.43	29.64	29.11	28.11	27.42
Pasture	5.96	5.98	6.01	6.34	6.76
Cultivated	29.41	30.17	30.57	31.55	31.85
Woody Wetland	0.31	0.31	0.31	0.31	0.31
Herbaceous Wetland	0.66	0.69	0.59	0.62	0.64

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

Table 5. 2019 Summary of National Land Cover Dataset land cover categories applied to delineated watershed.

NLCD Class (2019)	KNRI SCM 001
Developed Open & Low (%)	2.44
Developed Med. & High (%)	0.23
Forested (%)	0.72
Grassland (%)	34.18
Shrubland (%)	29.08
Wetland (%)	0.94
Cultivated (%)	31.85

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. Bank-full is the top of the first “terrace, also associated with the 1.5-year discharge recurrence interval, but can most simply be defined as the stage at which water overflows onto the floodplain. More discussion follows on where this point is located on the cross-section (see Figure 10 for a visual). Active fluvial erosion is

occurring within a relatively small area between the water and bank-full; the angle can be steep on cut banks and difficult to capture with the total station. Bank failure is omnipresent on steep sandy banks however the cause of that bank failure can be due to other factors than direct river erosion such as river ice and precipitation on the banks (Ellis 2005). The bank stability index used did not seem to correspond directly to rapidly eroding banks indicated by Sexton 2012, probably because of the index's sensitivity to substrate and the emphasis on measurements at the point of contact with the water instead of at the top of bank where the erosion is likely originated. On KNRI SCM 001, vegetation is restabilizing the toe slopes of the bank (Figure 5). Access to the floodplain is maintained throughout the reach. The total station, because it does require putting the prism on the bank and capturing it visually with the total station, may not be the best mechanism for capturing the most eroded banks. The direct laser method was unsuitable due to vegetation on the banks. The steep and crumbling sandy banks were impossible to scale with the station and so detailed transects were situated on scalable banks which could be accessed, though not without great difficulty (Figure 6). The scan from T1 may prove to be more useful at estimating areas of great change and estimating those rates of changes. Transect 6 (T6) was the most difficult to access with the total station due to the steep bank which necessitated walking around either up or downstream rather than scaling directly (Figure 7). T6 was in the middle of the cutbank rather than on the side like T1 and T11.



Figure 5. KNRI stream channel monitoring site SCM 001 at T3 (downstream) end. This is one of the fastest eroding banks on Unnamed Bend according to Sexton 2012 while it had a moderate BSI score for bank stability (11.5).



Figure 6. KNRI stream channel monitoring site SCM 001 at T11 (upstream) end. Despite the high banks (8m), the bank is largely covered in vegetation and has a small floodplain forming atop eroded material at the base. It scored a 15 on BSI index for bank instability (“unstable”). Good access to the floodplain is available on the left bank.



Figure 7. View of detailed transect from the LBM at T6 showing the steep right bank which is located in the middle of the cutbank meander.

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 ([DataStore - Standard Operating Procedure 2.2.14 Wadeable Stream Data Processing and Analysis—Version 1.1 \(nps.gov\)](#) SECN 2022) . From the detailed (SX-10 derived measurements) transects, mean bank-full area was 21.17 m² and mean channel-full area was 112.66 m² (Table 6).

Table 6 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. The channel-full and bank-full areas became smaller at T6 due to the channel and bank depths becoming smaller, possibly putting more stress on this cross-section.

Table 6. Detailed transects derived from total station measurements.

Transect	Type	Area (m ²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/Depth
T1	Bank-full	29.81	39.15	0.76	38.51	1.07	36.16
	Channel-full	131.3	58.97	2.23	55.5	3.1	17.93
	Ratio	4.4	1.51	2.92	1.44	2.91	0.5
T6	Bank-full	15.41	40.09	0.38	39.74	0.88	45.42
	Channel-full	94.26	51.87	1.82	50.52	2.67	18.95
	Ratio	6.11	1.29	4.73	1.27	3.05	0.42
T11	Bank-full	18.29	32.59	0.56	31.8	0.99	32.06
	Channel-full	112.43	46.64	2.41	44.18	3.42	12.91
	Ratio	6.15	1.43	4.29	1.39	3.45	0.4
Average	Bank-full	21.17	37.28	0.57	36.69	0.98	37.88
	Channel-full	112.66	52.49	2.15	50.07	3.06	16.6
	Ratio	5.56	1.41	3.98	1.37	3.13	0.44

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 8 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 9 shows the position of the ws at each transect and how the slope changes when moving downstream. Slope was -.03% from the top to the bottom of the reach. In the future we will also have bank retreat measurements taken from the benchmark.

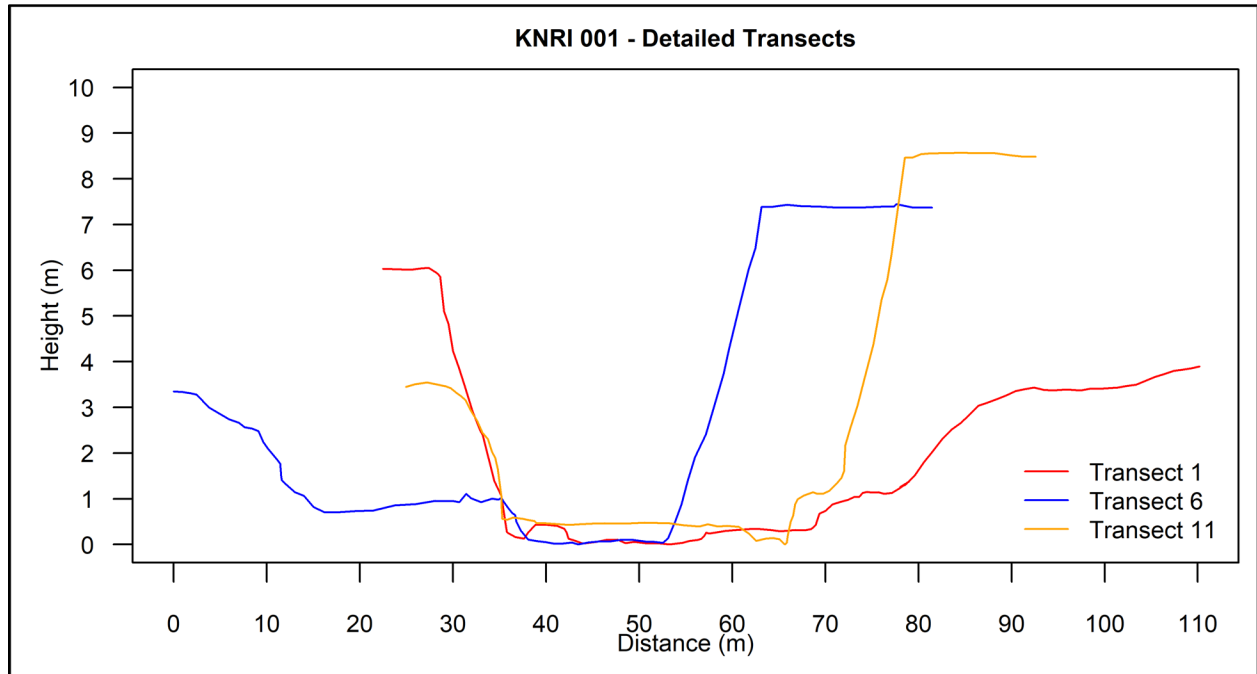


Figure 8. Detailed transects cross sections, plotting height above thalweg vs distance from the left benchmark (LBM). Axes were adjusted so that left bank-full begins at the same relative position for all three transects.

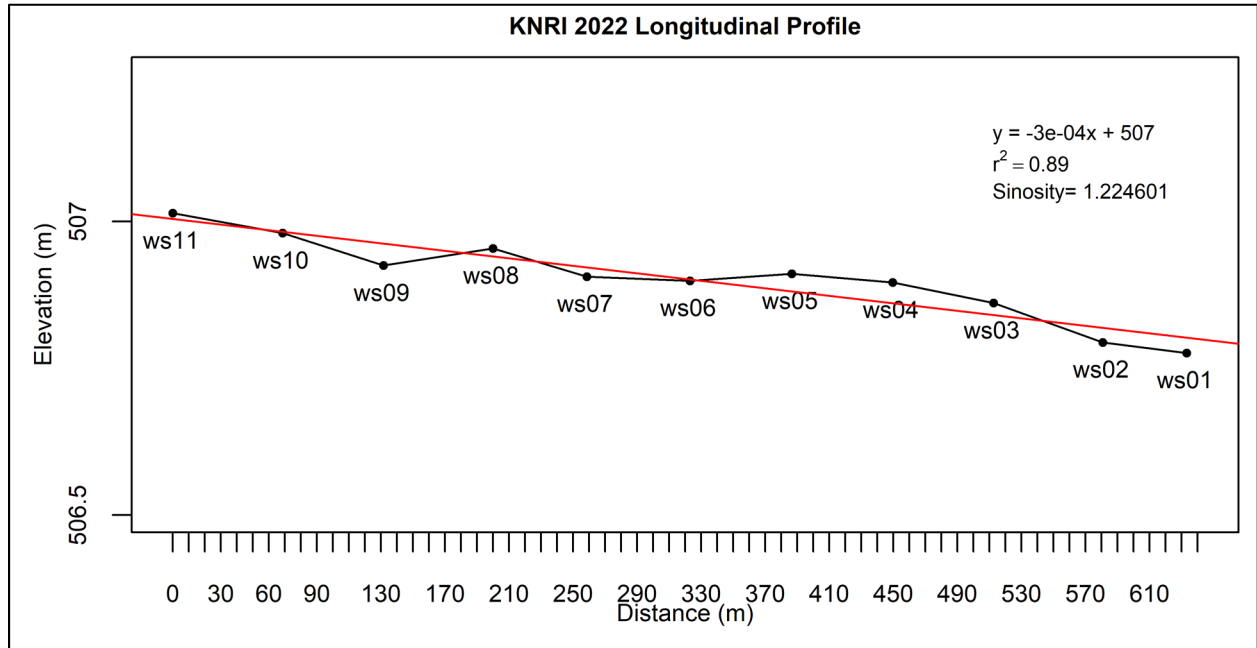


Figure 9. Elevational profile of KNRI SCM 001. Slope is -.03%.

Reach-level Transects

Water depths remained relatively low throughout the reach with a mean thalweg (deepest spot of a stream along its cross-section) of 0.36 m. Table 7 shows the thalwegs or maximum water depth at each transect.

Table 7. Thalwegs at 11 transects at site KNRI SCM 001 in September 2022.

Thalweg	n	Min	Max	Mean	Median	SD	CV
Depth (m)	11	0.24	0.62	0.36	0.30	0.12	0.33
Position ¹ (%)	11	20	95	74	90	27	0.37

¹ position is percent distance from left bank

Channel widths were wide throughout the site as shown in Table 8. Due to extensive bars, wetted width was smaller than active channel width. Active channel refers to the unvegetated portion of the channel between the base of banks. 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 can cause confusion. In all cases at Knife River ‘top of bank’ was synonymous with bank-full. Bank stability measurements are restricted then to the banks at bank-full. The portion of the bank continuing up to the channel-full top may be considered separately.

Table 8. 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	13.00	29.20	19.81	18.89	5.60	0.28
Active Channel	11	15.96	32.00	23.95	22.00	5.28	0.22
Bank-full	11	20.00	38.00	27.80	27.93	5.28	0.19
Channel-Full	11	44.90	61.90	52.61	52.92	4.19	0.08
Floodplain	11	0.00	22.00	5.97	1.49	7.63	1.28

Figure 10 shows crew taking bank-full measurements at Transect 5.

Bank stability index (BSI) is an important measure of the banks that incorporates bank angle, vegetative cover, bank height, and bank sediment. Tables 9a and 9b display the bank stability scoring and components. The left bank stability index was 13.14 and the right bank scored 11.14 for an average of 12.14 (Tables 9a and 9b). The difference is due to sand accumulated on the left bank, while the right bank did contain some more cohesive material, mainly silt-clay. BSI is extremely sensitive to substrate. A bank with “silt-clay” is scored 3.5 points lower than a bank scored as “sand”. While it is unexpected that the right bank which is largely the cutbank would be more unstable, much of the mass wasting from the upper part of the banks has fallen into the channel and restabilized below as another surface. This is the surface that bank stability is assessed upon. Whether this material will remain in place via ice scouring events will be seen as the material is still sandy. A BSI score of 8-10.99 is in the “at-risk” category while 12-15.99 is in the “unstable” category (Table 9a). These scores are based on national metrics (Fitzpatrick 1998) and what is appropriate for large

Northern Great Plains rivers with sandy substrate remains to be seen. The bank stability index is confined to the bank full elevation. 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. Knife River cuts through Holocene alluvial layers which erode easily (Carlson 1973).



Figure 10. NGPN crew takes bank-full measurements at Transect 5. One crew member stands at bank-full, while the other is at the back of the floodplain.

As more stream channel monitoring takes place at NGPN parks and more years of data are collected, what is appropriate for Knife River 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. 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.

Table 9a. 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 9b. 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 10 and 11 shows the reach-level bank stability index values.

Table 10. Reach-level bank characteristics for KNRI SCM 001, Knife River.

Bank Characteristics	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)
Bank Height ^{1,2} (m)	0.78	0.60	2.04	1.89	1.02	1.11	0.93	1.05
Bank-full Height ^{2,3} (m)	0.78	0.60	2.04	1.89	1.02	1.11	0.93	1.05
Channel-full Height ^{2,3} (m)	2.13	2.74	6.59	9.17	3.48	6.80	3.58	7.12
Water Depth at Base ⁴ (m)	-0.21	-0.03	0.00	0.08	-0.11	0.02	-0.15	0.01
Bank Undercut (m)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bank Angle ^(o)	5	10	93	77	35	51	19	58
Vegetation Cover (%)	0	15	100	95	38	56	30	60
Bank Stability ⁵	Unstable	At-Risk	Very Unstable	Unstable	Unstable	Unstable	Unstable	At-Risk

¹ Bank height is at bank-full throughout the KNRI 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. Reach-scale bank characteristics.

Reach-scale	n	Min	Max	Mean	Median	SD	CV
Bank Height ^{1,2} (m)	22.00	0.60	2.04	1.06	0.97	0.36	0.33
Bank-full Height ^{2,3} (m)	22.00	0.60	2.04	1.06	0.97	0.36	0.33
Channel-full Height ^{2,3} (m)	22.00	2.13	9.17	5.14	4.73	2.25	0.44
Water Depth at Base ⁴ (m)	22.00	-0.21	0.08	-0.05	0.00	0.09	-1.88
Bank Undercut (m)	22.00	0.00	0.00	0.00	0.00	0.00	0.00
Bank Angle ^(o)	22.00	5.00	93.00	43.14	47.00	27.13	0.63
Vegetation Cover (%)	22.00	0.00	100.00	47.32	52.50	31.95	0.68
Bank Stability ⁴	22.00	8.50	16.00	12.14	11.75	2.01	0.17

¹ Bank height is at bank-full throughout the KNRI 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 12 below shows the transect-level bank characteristics.

Table 12. Transect-scale bank characteristics.

Transect-scale	Bank Height^{1,2} (m)	Bank-full Height^{1,2} (m)	Channel-full Height^{1,2} (m)	Water Depth at Base³ (m)	Bank Undercut² (m)	Bank Angle^(o)	Vegetation Cover (%)	Left Bank Stability⁴	Right Bank Stability⁴
1	0.89	0.89	4.67	-0.02	0.00	36.00	57.50	12.50	12.00
2	0.87	0.87	3.77	-0.06	0.00	27.00	60.00	11.50	8.50
3	1.13	1.13	4.26	-0.09	0.00	72.00	45.00	15.00	11.50
4	0.80	0.80	5.25	-0.09	0.00	32.00	75.00	11.00	9.50
5	1.21	1.21	4.64	-0.06	0.00	43.00	42.50	14.00	10.50
6	1.16	1.16	4.50	0.01	0.00	50.00	32.50	16.00	10.50
7	1.01	1.01	5.35	-0.04	0.00	35.50	32.50	14.00	10.50
8	1.05	1.05	5.39	-0.06	0.00	27.00	67.50	11.00	12.50
9	1.97	1.97	5.84	-0.07	0.00	33.50	57.50	14.00	9.50
10	0.89	0.89	6.31	-0.06	0.00	36.00	8.00	14.00	12.50
11	0.73	0.73	6.58	0.00	0.00	82.50	42.50	11.50	15.00

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

Transects 3, 6, 10, and 11 were the worst scoring transects overall for stability, while Transect 2 was the best. Pictures comparing transect 2 and 3 banks are below (Figure 11). Bank sediment—especially those containing sand and gravel primarily and lack of bank vegetation secondarily—contributed to the transects with higher bank instability.

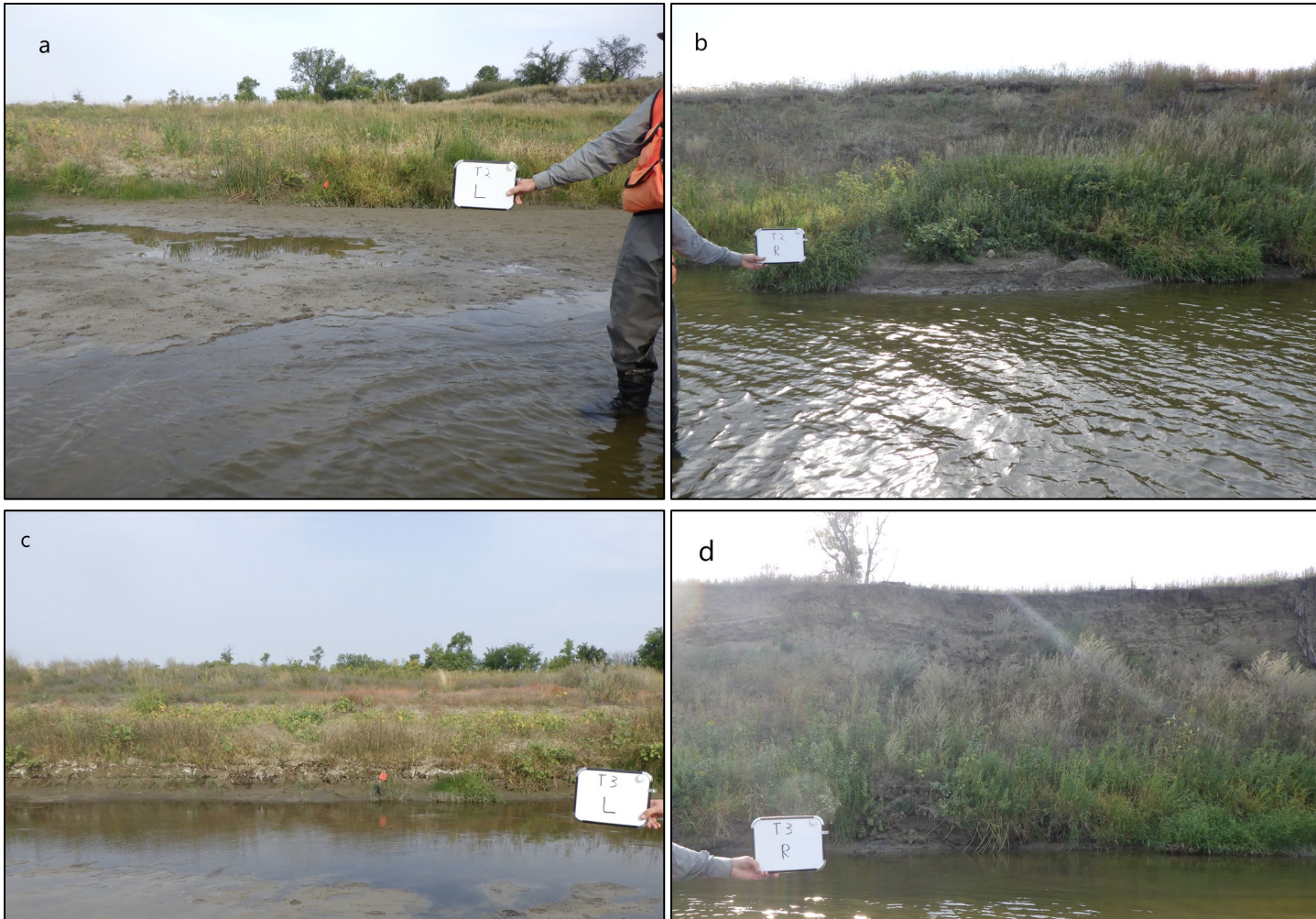


Figure 11. Transect 2 shows little erosion and has bank stability of score of 11.50 on the left bank (a) and 8.50 on the right bank (b). Transect 3 shows high areas of erosion and has bank stability of score of 15.00 on the left bank (c) and 11.50 on the right bank (d).

Bank erosion and bank failure are not directly incorporated into the bank stability index which includes bank height, water depth at base, undercuts, bank angles, vegetative cover, and substrate. Surprisingly the left bank has higher mean erosion (13.14) than the right bank which is actively eroding (11.14). This is due to the fact a bench is forming at the base of the right bank and that the right channel slope is a leftover terrace from when the river had more flow. It will continue to erode and fail but it is not measured as part of the active channel bank stability index. Actual erosion of the banks may be better measured by the percent of transects that have eroding banks and by measuring length of bank showing erosion.

Bank erosion is measured in the original protocol in a qualitative manner by recording erosion and type (none, slump, or lateral) within a meter up and downstream of each transect. 54% of bank measurements according to this method showed erosion. Overwhelmingly erosion was on the right bank which had 81.8% of the banks eroding while the left showed only 18% of the bank eroding. 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. 108 m out of 220-m bank length were recorded as eroded, representing 49.1 % of the streambank. 84.5% of the right bank was eroding, while only 13.6 % of the left bank was eroding. This more quantitative measure of erosion was included in the 2022 revision of the Wadeable Stream Field Data Collection protocol [DataStore – Wadeable Stream Reach Scale Field Data Collection: Stream Channel Monitoring \(nps.gov\)](#). Figure 12 shows the right bank restabilizing at the base.

This site will be revisited in 3 years to see if bed degradation is occurring or if the channel morphology has changed (Figure 13). Channel change can be regarded as a redistribution of the imbalance between sediment and water (Thorne and Lewin 1974, Schmidt and Wilcock 2008, Skalak et al 2013). The revisits will allow us to better identify areas of sediment deposition and erosion and if these areas have changed from the 2022 visit.



Figure 12. Restabilized base of right bank (outside bend) looking downstream toward T1. Note silt clay substrate, cobble-sized rock and vegetation stabilizing the lower bank.



Figure 13. Site overview from right bank at T11 looking downstream.

Physical Characteristics

Physical characteristics include geomorphic units (Table 13a and 13b), median particle size in a representative riffle (measurements taken between transect 7-8, $d_{50}=2$ mm, Table 14), particle size and embeddedness (Table 15), 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 13a. Transect-scale geomorphic channel units.

Transect	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
1 – 2	0	100	0	0	0
2 – 3	10	90	0	0	0
3 – 4	0	100	0	0	0
4 – 5	0	100	0	0	0
5 – 6	0	100	0	0	0
6 – 7	0	100	0	0	0
7 – 8	0	100	0	0	0
8 – 9	0	95	0	5	0
9 – 10	0	95	0	5	0
10 – 11	15	85	0	0	0

Table 13b. Calculated geomorphic channel metrics for all transects.

Metric	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
Frequency	2	10	0	2	0
Max (%)	15	100	0	5	0
Mean (%)	2.5	96.5	0	1	0
Median (%)	0	100	0	0	0
SD (%)	5.4	5.3	0.0	2.1	0.0

Table 14. Sediment diameters from a representative riffle- transect 10-11.

Statistic (n = 100)	Diameter (mm)
Min	2
D5	2.00
D16	2.00
D50	2.00
D84	2.00
D95	2.00
Max	22.6

Table 15. Dominant particle class, particle size (mm) and percent fines from channel cross-section.

Transect	Dominant Particle Class	Left	Left Center	Center	Right Center	Right	Percent Fines¹
1	Sand	2	2	2	2	2	100
2	Sand	2	2	2	2	2	100
3	Sand	2	2	2	2	2	100
4	Sand	2	2	2	2	2	100
5	Sand	2	2	2	2	2	100
6	Sand	2	2	2	2	2	100
7	Sand	2	2	2	2	2	100
8	Sand	2	2	2	2	2	100
9	Sand	2	2	2	2	2	100
10	Sand	4	2	2	2	2	80
11	Sand	2	2	2	2	2	100
Percent Fines for All Transects	100	—	—	—	—	—	98.18

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	0.00
2	0.00
3	0.00
4	0.00
5	13.24
6	0.00
7	0.00
8	0.00
9	0.00
10	0.00
11	0.00
Min (%)	0.00
Max (%)	13.24
Mean (%)	1.20
Median (%)	0.00
SD (%)	3.99
CV	3.32

Sand substrate overwhelmingly covers the streambed (Table 15) and run habitat dominates (Tables 13a and 13b). While there is an absence of large woody debris (0%) and canopy cover is low (mean canopy cover was 1.2%; Table 16), many grassland and rivers streams in good condition can have similar characteristics (Rust 2006).

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 10 and 11 was selected as the representative riffle. Diameters are summarized in Table 14, with the median particle size (D_{50}) corresponding to 2mm, classified as sand. Particle size decline over time can be evidence of siltation and increased embeddedness. The pebble count is taken solely from the riffle and does not account for changes in depositional areas which may accumulate high sediment. Rust 2006 had recorded a higher percentage of fines (37%) and boulder (3%) at her particular reach which included Unnamed Bend but extended downstream of it an additional 2 miles (Rust 2006).

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 15). 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 Field Data Collection SOP [680235 \(nps.gov\)](#) was updated to continue to measure five sediment particles across the transect to more accurately determine the percentage of fine sediment.

Canopy cover was low across the reach (Table 16) with mean value of 1.20%. Rust found that at NGPN large river sites, mean canopy cover was 11%. 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 four center measurements and we 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 along the T1 transect. Measured discharge was measured with a Marsh-McBirney flow meter and was 19.46 cfs using the velocity area method (Figure 14). The river was extremely shallow and the sensor was not always fully submerged, and so it was not an optimal place or time to take a measurement. As part of the protocol we measured it, also we wanted a rough idea of how the velocity varied across the stream. The measured discharge at the gage at the time was 27.8 cfs. Cross section mean stream velocity at KNRI SCM 001 was 0.74 ft/s (0.22m/s). In the future, taking velocity measurements at all of the detailed transects would be useful to better understand how stream velocity changes throughout the reach. Where the channel is narrow and straight, ie channelized, we would expect stream velocity to be greater than in a meandering stream. In a meandering stream, we would expect velocity to be greater toward the outside bends on the meanders (Gordon 2007).



Figure 14. Discharge was measured at the downstream end of the site, along the T1 detailed transect.

Further Analysis

This Data Report is intended to provide a basic review of the data collected during the 2022 stream channel monitoring at Knife River. All data included in this report are available upon request from the [Northern Great Plains Inventory & Monitoring Network \(U.S. National Park Service\) \(nps.gov\)](https://www.nps.gov/ngpn/).

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 /water quality portal. 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.

Literature

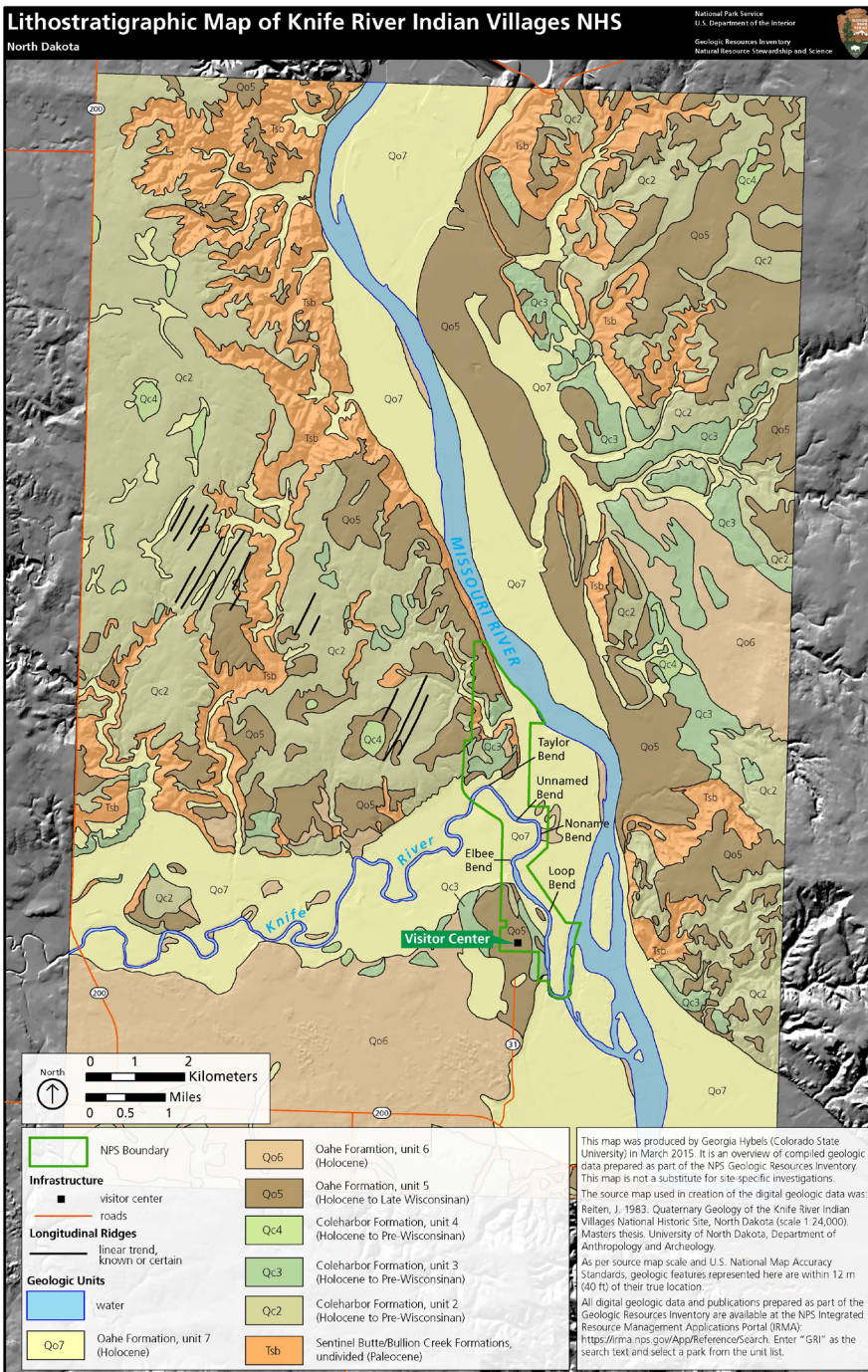
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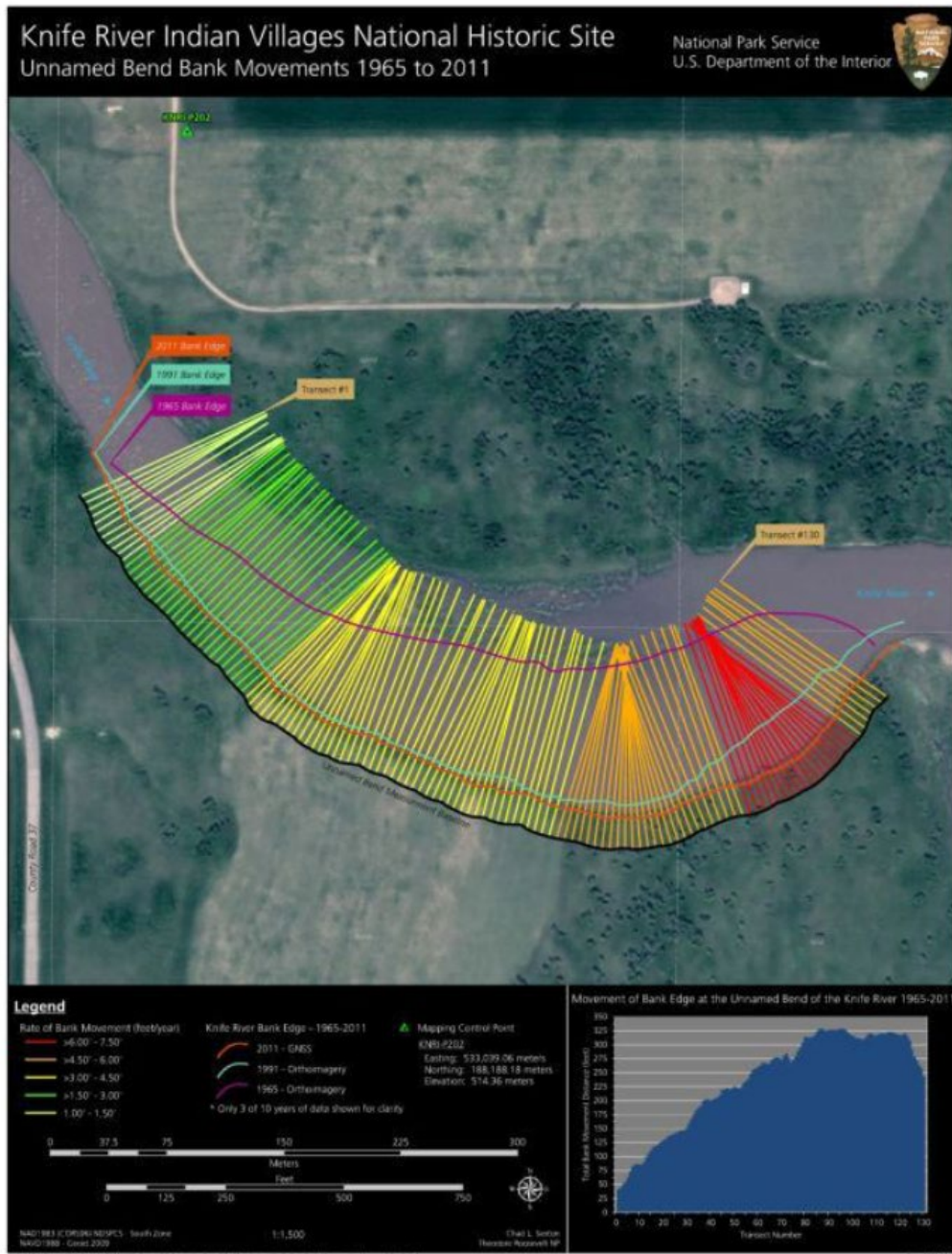
Appendix A

Figure A-1. KNRI geologic map (Hybels 2015). The box shows recent Qal(alluvium) deposits underlying the park, and around the unnamed bend on Knife River. (GRI Team)



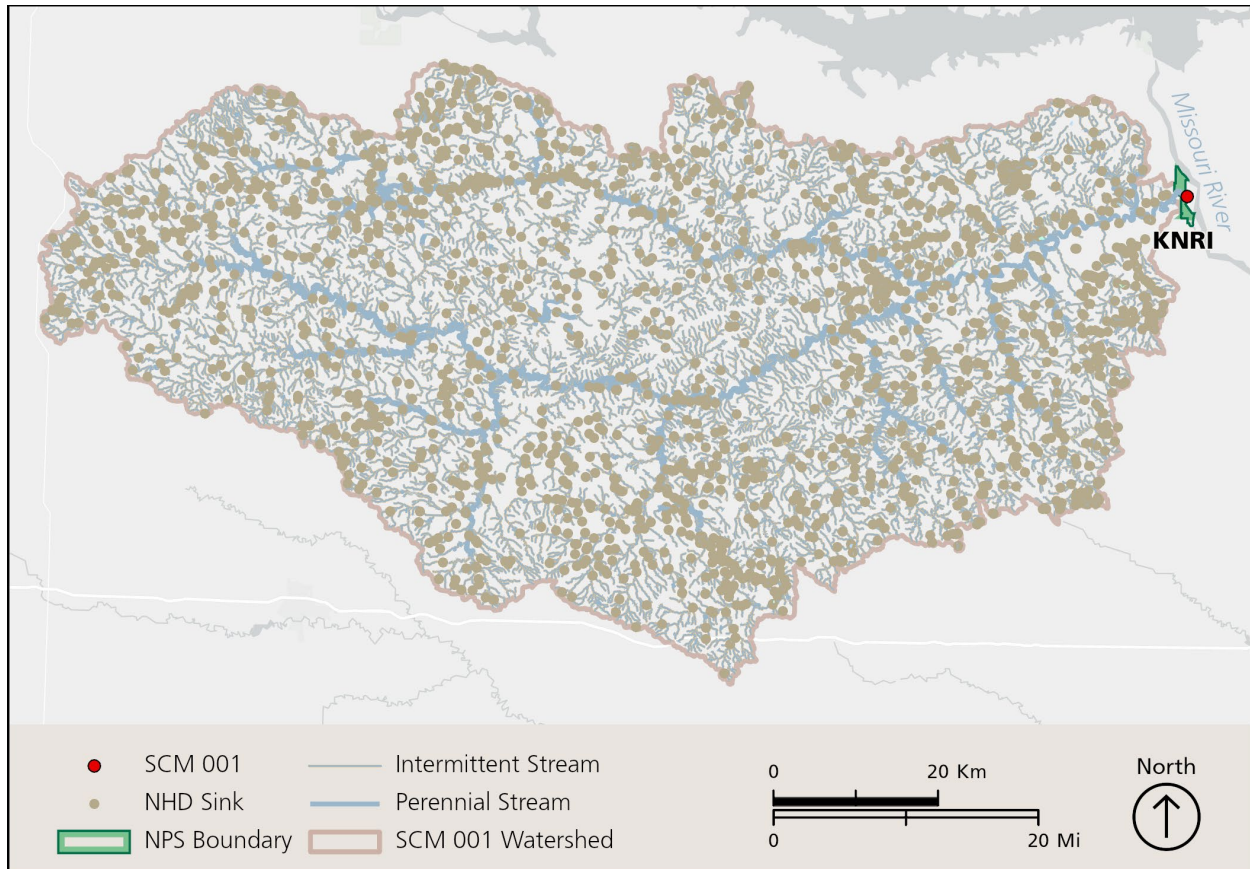
Appendix B

Figure B-1. KNRI erosion mapping study (Sexton 2012, Nadeau 2014). The box shows erosion rates 1965-2011 at Unnamed bend calculated by Sexton.



Appendix C

Figure C-1. KNRI SCM 001 watershed NHD stream flow classes (FCodes).



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