



Stream Channel Monitoring for Theodore Roosevelt National Park

2022 Data Report

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



**ON THIS PAGE**

View of THRO SCM 001, facing downstream toward Cottonwood campground and congregating bison, August 2022.
Photograph courtesy of NGPN, National Park Service.

ON THE COVER

THRO SCM 001's full banks in May 2022.
Photograph courtesy of Northern Great Plains Network, National Park Service.

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The Natural Resource Data Series is intended for the timely release of basic data sets and data summaries. Care has been taken to assure accuracy of raw data values, but a thorough analysis and interpretation of the data has not been completed. Consequently, the initial analyses of data in this report are provisional and subject to change.

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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Contents

	Page
Figures.....	iv
Tables.....	v
Executive Summary	vi
Acknowledgements.....	viii
Abbreviations and Acronyms	ix
Introduction.....	1
Methods.....	4
Site Selection	4
Data Collection.....	4
Watershed Characteristics	6
NHD Plus-HR method of delineation.....	8
20-ha method of delineation.....	9
StreamStats method of delineation.....	9
National Land Cover Database.....	9
Results.....	10
Watershed Characteristics	10
Reach Characteristics	14
Detailed Transects	14
Reach-level Transects.....	18
Physical Characteristics.....	25
Further Analysis.....	28
Literature.....	29
Appendix A.....	31

Figures

	Page
Figure 1. Map of stream channel monitoring site THRO SCM 001 and associated watershed.	2
Figure 2. Layout of sampled reach of THRO stream channel monitoring site THRO SCM 001. Transects number 1-11 running from down to upstream.	6
Figure 3. Flowlines associated with THRO stream channel monitoring site THRO SCM 001. Panel ‘a’ shows the extent of the watershed. NHD flowlines are in light blue while NHD ephemeral flowlines are in purple in panel ‘b’ concentrated in the southwest corner and were removed from consideration. Panel ‘c’ shows the pattern of flowlines near THRO SCM 001 and the park.....	11
Figure 4. THRO stream channel monitoring site SCM 001 at T10 (near upstream) end on the left bank.....	14
Figure 5. THRO stream channel monitoring site SCM 001 at T1 (downstream) end from right bank during bank-full conditions in May 2022. The right bank is largely covered in vegetation with good access to the floodplain.	15
Figure 6. 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.	17
Figure 7. Elevational profile of THRO SCM 001. Slope is -.1%.	17
Figure 8. Bank and channel features from T1 looking upstream, taken August 2022.....	19
Figure 9. Transect 2 shows little erosion and has bank stability of score of 11.5 on the left bank (a) and 9.50 on the right bank (b) and is considered “at-risk” overall. Transect 3 has a bank stability of score of 17 on the left bank (c) and 13 on the right bank (d) and is considered “unstable”.	23
Figure 10. Site overview from right bank at T11 looking downstream.	24
Figure A-1. THRO geological map (GRI 2007). The river flows through QAl deposits (quaternary alluvium) in yellow.....	31

Tables

	Page
Table ES-1. Summary table for stream channel data in Theodore Roosevelt NP. Current values are based on data from 2022 alone.	vii
Table 1. Benchmark locations at T1, T6, T11.....	5
Table 2. Stream lengths and metrics of THRO SCM 001 watershed.....	10
Table 3. Watershed Characteristics from elevation-derived delineated watershed using NHD-Plus stream length within HUC 12s upstream of THRO SCM 001.....	12
Table 4. Flow Characteristics derived from StreamStats application.	12
Table 5a. National land cover dataset applied to NHDPlus HR- delineated watershed for THRO SCM 001.	13
Table 5b. 2019 National land cover dataset summarized categories applied to delineated Little Missouri River watershed.....	13
Table 6. Detailed transects at THRO SCM 001 derived from total station measurements.....	16
Table 7. Thalwegs at 11 transects at site THRO SCM 001 in August 2022.	18
Table 8. Widths at transects at site THRO SCM 001 in August 2022.	18
Table 9a. Score range by Bank Stability Index scoring categories.....	20
Table 9b. Bank Stability Index scores by components range and type.....	20
Table 11. Reach-scale bank characteristics for THRO SCM 001, Little Missouri River.	21
Table 12. Transect-scale bank characteristics.	22
Table 13a. Transect-scale geomorphic channel units.	25
Table 13b. Calculated geomorphic channel metrics for all transects.....	25
Table 14. Sediment diameters from a representative riffle- transect 6-7.	25
Table 15. Dominant particle size class and percent fines in reach.....	26
Table 16. Canopy cover in reach.....	26

Executive Summary

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring on the Little Missouri River at Theodore Roosevelt NP 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 THRO for the collected data during 2022. Indices, benchmarks, and other studies are provided in the table for informational purposes to help put the Little Missouri River's measurements in context but should not be considered as a reference condition. Upland characteristics of the watershed indicate majority range land use cover: cropland (9.62%), shrubland (35.51%) and grassland (50.64%) with little development (.75%) or forest (2.39%) in the watershed area. Reach characteristics include bank cover, heights, bank stability index, and vegetative cover. Angles are moderate and the fine, sandy banks are incohesive and easily erodible. 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. Fine 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 the Little Missouri River at THRO. The reach data contained in this report are specific to an 860-m segment of the Little Missouri River and cannot be extrapolated to conditions elsewhere on the river or to the park in general.

Table ES-1. Summary table for stream channel data in Theodore Roosevelt NP. 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 Grassland= 50.64%, Forest= 2.39%, Shrubland =35.51%	2001 land cover: Grassland= 52.65%, Forest= 2.64%, Shrubland=35.73%
	Land Development Change	.75 % of watershed developed in 2019	.98 % of watershed developed in 2001
Reach Level	Mean Bank Angle	37.05 ° water to bankfull bank angle	Bank Stability Index (BSI): <30° is good, <60° fair, >60° poor according to BSI
	Erosion	16 out of 22 bank transects (72%) show erosion in 2 m bank segments. Additional quantification of erosion showed 51% of bank eroded.	TBD
	Mean. Bank Heights	1.36 m	BSI: <1 m bank is considered good
	Mean Bankfull width	53.82 m	TBD
	Bank Vegetation Cover %	51.82%	BSI: Vegetative cover>80% is "good", 50-80% fair, 20-49% poor, <20% very poor
	Bank Stability Index	12.75 on BSI index	<7.99 is considered stable, 8-10.99 at risk, 11-15.99 unstable, >16: very unstable
	Max Distance of Bank Migration	NA	TBD
	Cross-sectional Area	Mean bankfull area 56.73 m ² ; Mean channel full area 178.81 m ²	TBD
Physical Habitat	Median Particle Size of Representative Riffle	11mm, medium gravel	TBD
	Percentage fine substrate	Gravel dominant in 7 out of 11 transects. Four transects were graded as sand. Expanded analysis concurred with 29% of reach covered in fine sediment (sand or silt).	Median sand percentage was 100% in large NGPN rivers (Rust, 2006)
	Geomorphic units	Dominated by run, (63%) pool (6%) and riffle (32%) habitats	Reach has a good number and variety of habitats.
	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
$\geq$:	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
CWA:	Clean Water Act
°C:	degrees Celsius
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
I&M:	Inventory & Monitoring
IRMA:	Integrated Resource Management Applications
km ² :	square kilometers
mi ² :	square miles
mL:	milliliters
MT:	Montana
NARS:	National Aquatic Resource Surveys
NAWQA:	National Water Quality Assessment (USGS)
ND:	North Dakota

NGPN:	Northern Great Plains Network
NHD:	National Hydrography Dataset
NHS:	National Historic Site
NPS:	National Park Service
NWIS:	National Water Information System (U.S. Geological Survey)
SD:	South Dakota
SECN:	Southeast Coast Network
SOP:	standard operating procedure
THRO:	Theodore Roosevelt National Park
USACE:	U.S. Army Corps of Engineers
USEPA:	U.S. Environmental Protection Agency
USGS:	U.S. Geological Survey
WY:	Wyoming

Introduction

Located in southwestern North Dakota, Theodore Roosevelt National Park (THRO) encompasses 70,477 acres of the Little Missouri Badlands. THRO is composed of three discrete management units, each of which is a patchwork of mixed-grass prairie, clay buttes, bottomland forest, and open shrublands. The three park units (North, Elkhorn Ranch, and South) are connected by the Little Missouri River, an undammed tributary of the Missouri River with headwaters located in northeastern Wyoming, making it the major hydrologic feature for THRO. The Little Missouri flows, free of dams, for approximately 560 miles from south to north through parts of Wyoming, Montana, South Dakota, and the badlands of North Dakota and is the only designated state scenic river in North Dakota. The Little Missouri River is a fundamental resource and value of THRO, in addition to native wildlife and habitat, geologic and paleontological resources, scenic views and clean air, wilderness, the Elkhorn Ranch, and the Maltese Cross Cabin and Roosevelt-related museum collections (NPS 2014). Approximately 28 miles of river run through the park (Figure 1). The 269 miles of intermittent streams within the park provide substantial flow to the Little Missouri River during spring snowmelt and summer rainfall events (Gitzen et al. 2010).

THRO lies in the Northwestern Great Plains ecoregion (Omerik 1987, Bryce 1996), and experiences variable temperatures and precipitation (Griffith 2010, Amberg 2012). The park has hot summers (average July maximum temperature is 30.7° C/87.2°F) and very cold winters (average January minimum is -16.7°C/ 2°F) is with about 14.6 inches precipitation on average (Amberg 2012). Much of the park has badland features and mixed grass prairie. The monitoring site lies within 43b, the Little Missouri Badlands Ecoregion level 4 region which has soft clays and silt which erode easily from dramatic badlands features. Erosion results in substantial sediment loads in the streams. Juniper dominates the uplands while cottonwood and green ash grow in the bottomlands. Animals such as bison, elk, feral horses, pronghorn, bighorn sheep, porcupine, beaver, and prairie dogs call the park home.

The Little Missouri 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 Little Missouri that runs through the North Unit (ND-10110205-001-S_00) is listed as an impaired waterway under section 303(d) of the Clean Water Act for exceedances of *Escherichia coli* (ND Department of Health 2019). A small part of the Little Missouri River within the THRO South Unit boundary (Figure 1) is also listed as impaired for *E. coli* (ND-10110203-025-S_00 which is south of Andrews Creek near the I-94 bridge). No regular bacteria sampling occurs within the major south unit reach and it is likely the high *E. coli* counts found in ND-10110203-025-S_00 continue into the unassessed reach ND-10110203-057-S_00 which is the major reach in the South Unit of THRO. Current water quality levels can be accessed at [How's My Waterway – Community \(epa.gov\)](#). Current water quality monitoring and gage information can be accessed at [Little Missouri River at Medora, ND – USGS Water Data for the Nation](#).

[illegible]

The Northern Great Plains Inventory & Monitoring Program (NGPN) began monitoring stream channel characteristics at THRO in August 2022 at the THRO SCM 001 site. 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 THRO in August 2022. THRO SCM 001's 860-m reach was established between an impassable badland bordering the river and Cottonwood campground.

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 (National Water Quality Assessment 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 THRO, the site was placed downstream of the gage with a relatively accessible floodplain between the campground and a badland. 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. Reach length was based on initial wetted width, which was 43 meters. With a total reach length of twenty times the initial mean stream width, the reach length is 860 meters. Permanent benchmarks indicating the starting and ending points of the three detailed transects were located with a high accuracy GNSS receiver and temporarily marked with short stakes, but no rebar was placed permanently in the ground.

Data Collection

The Northern Great Plains Inventory and Monitoring Network (NGPN) began stream channel monitoring in Theodore Roosevelt NP in August 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 THRO SCM 001 in August 2022. An Arrow Gold receiver was used to obtain high accuracy benchmark locations, summarized in Table 1 below.

Table 1. Benchmark locations at T1, T6, T11.

Point Name	Northing_m	Easting_m	Elevation-Ortho height_m	Datum	Lat_WGS84	Long_WGS84
THRO_SCM_001_RT1	147099.576	369059.507	686.67	NAD83 (2011)	46.94989	-103.534572
THRO_SCM_001_RT6	146672.668	369061.049	687.202	NAD83 (2011)	46.94605	-103.534335
THRO_SCM_001_RT11	146265.965	368907.462	688.06	NAD83 (2011)	46.94234	-103.536144
THRO_SCM_001_LT1	147101.801	368981.92	684.271	NAD83 (2011)	46.94988	-103.535591
THRO_SCM_001_LT6	146679.612	368960.818	686.486	NAD83 (2011)	46.94608	-103.535654
THRO_SCM_001_LT11	146306.005	368828.495	685.992	NAD83 (2011)	46.94267	-103.537201
THRO_SCM_001_T1_IP	147092.753	369057.834	686.847	NAD83 (2011)	46.94983	-103.53459
THRO_SCM_001_T1_BS	147059.537	369070.324	686.722	NAD83 (2011)	46.94953	-103.534409
THRO_SCM_001_T6_IP	146654.886	369054.675	688.117	NAD83 (2011)	46.94589	-103.53441
THRO_SCM_001_T6_BS	146629.4	369061.994	688.685	NAD83 (2011)	46.94566	-103.534301
THRO_SCM_001_T11_IP	146289.23	368912.726	687.254	NAD83 (2011)	46.94255	-103.536087
THRO_SCM_001_T11_BS	146305.763	368937.119	687.933	NAD83 (2011)	46.94271	-103.535775

All locations are recorded in North Dakota South coordinate system (SPC 3302, WKID= 3635) though geographic coordinates in Web Mercator are also provided. 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 late August 2022.

The NGPN crew performed stream channel measurements in late August 2022. Discharge, photos, geomorphic channel units (pool, riffle, run, etc.), representative pebble count at the riffle between transects 6 and 7, 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 longer yellow lines at T1, T6, and T11 show the permanent detailed transects where the total station was used.

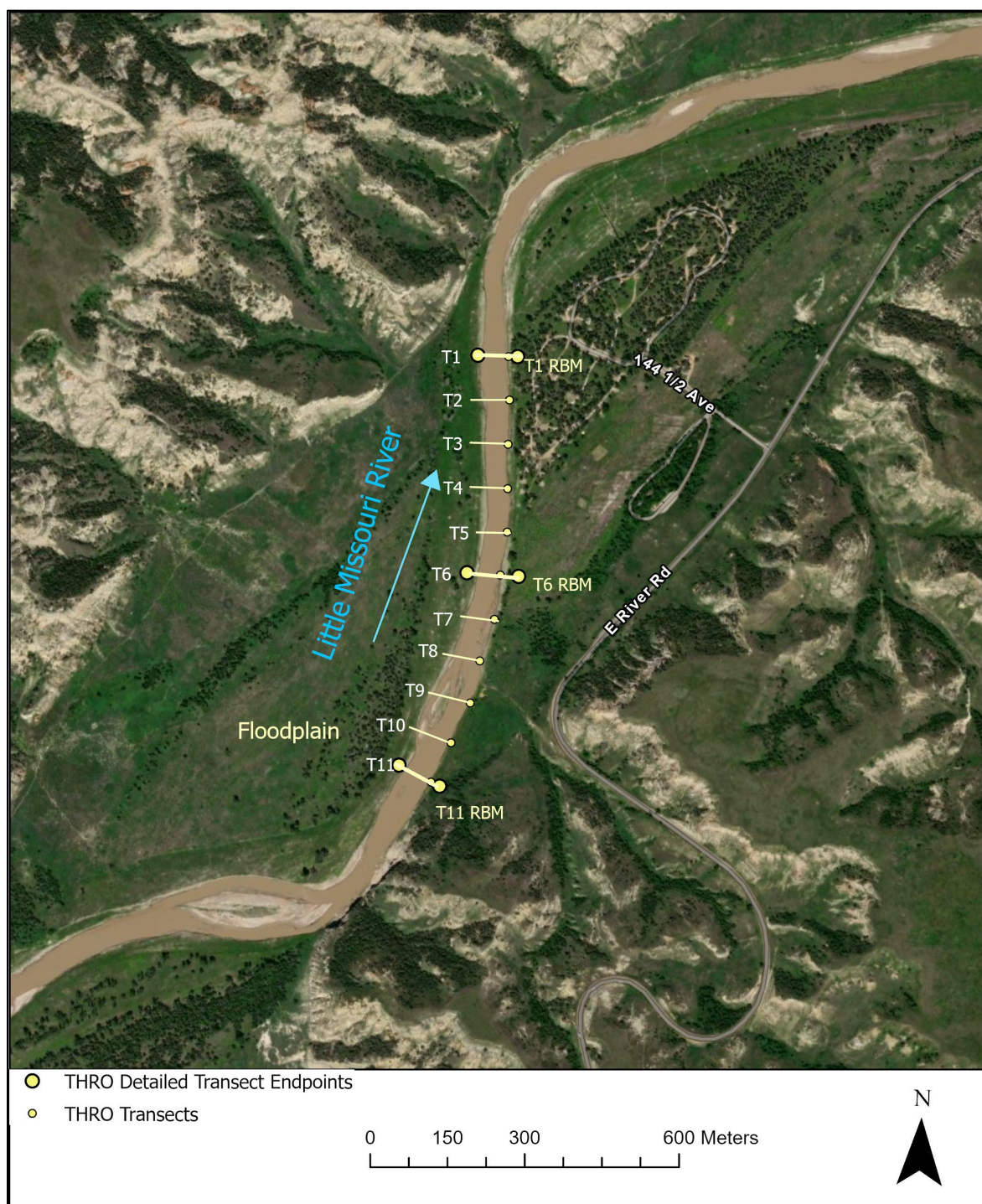


Figure 2. Layout of sampled reach of THRO stream channel monitoring site THRO SCM 001. Transects number 1-11 running from down to upstream.

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. Additionally, changes to the delineation procedure were made. Three methods used included 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. However, this method failed in certain parks such as THRO and FOLA. The third method uses 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 especially in the northern Great Plains where intermittent streams dominant. Instead, ephemeral streams were removed from the flowlines considered as these seemed to cluster unevenly and only carry water a small portion of the year. 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, refer 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 THRO 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-6-level (hydrologic unit) area number 101102. 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 THRO 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 USGS 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 ran adequately in the Watershed tool. This initial “fdr”-derived watershed was useful for the shape of the watershed near the pour point. 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. The NHD-Plus HR flowlines in this region produced a

disproportional number of stream segments in the southwest quadrant (Figure 3). Those stream segments were reduced by excluding the ephemeral streams, selected out by using Fcode= 46007.

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 failed at this watershed scale and could not be used to compare to the NHD Plus-HR method.

StreamStats method of delineation

The USGS StreamStats application [StreamStats \(usgs.gov\)](#) 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 THRO SCM 001 watershed and summarized by land cover class. Data from 2001, 2006, 2013, 2016, and 2019 were downloaded and summarized.

Results

Watershed Characteristics

The watershed was delineated across four states: ND, SD, WY, and MT using the three methods: NHDPlus HR, the 20-ha workflow, and the StreamStats methods. Total stream length was initially based on NHD-Plus HR stream segment lengths (28973.75 km) but streams coded as ephemeral were excluded from the watershed, especially as they were bunched unevenly in the southern end of the watershed (Figure 3). The final total stream length did exclude ephemerals and was 28220.17 km. The 20-ha watershed failed repeatedly and could not be used. Ultimately the best delineation was based on the NHDPlus HR dataset. The NHDPlus HR watershed and the StreamStats watershed (16,343 km²) yielded very similar results, about .001% difference from the NHDPlus- watershed (16,330 km²), 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.

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

Data source	Total stream length (km)
NHD-Plus High	28973.75
NHD- Plus High minus ephemerals	28220.17
20-ha Derived Stream	NA

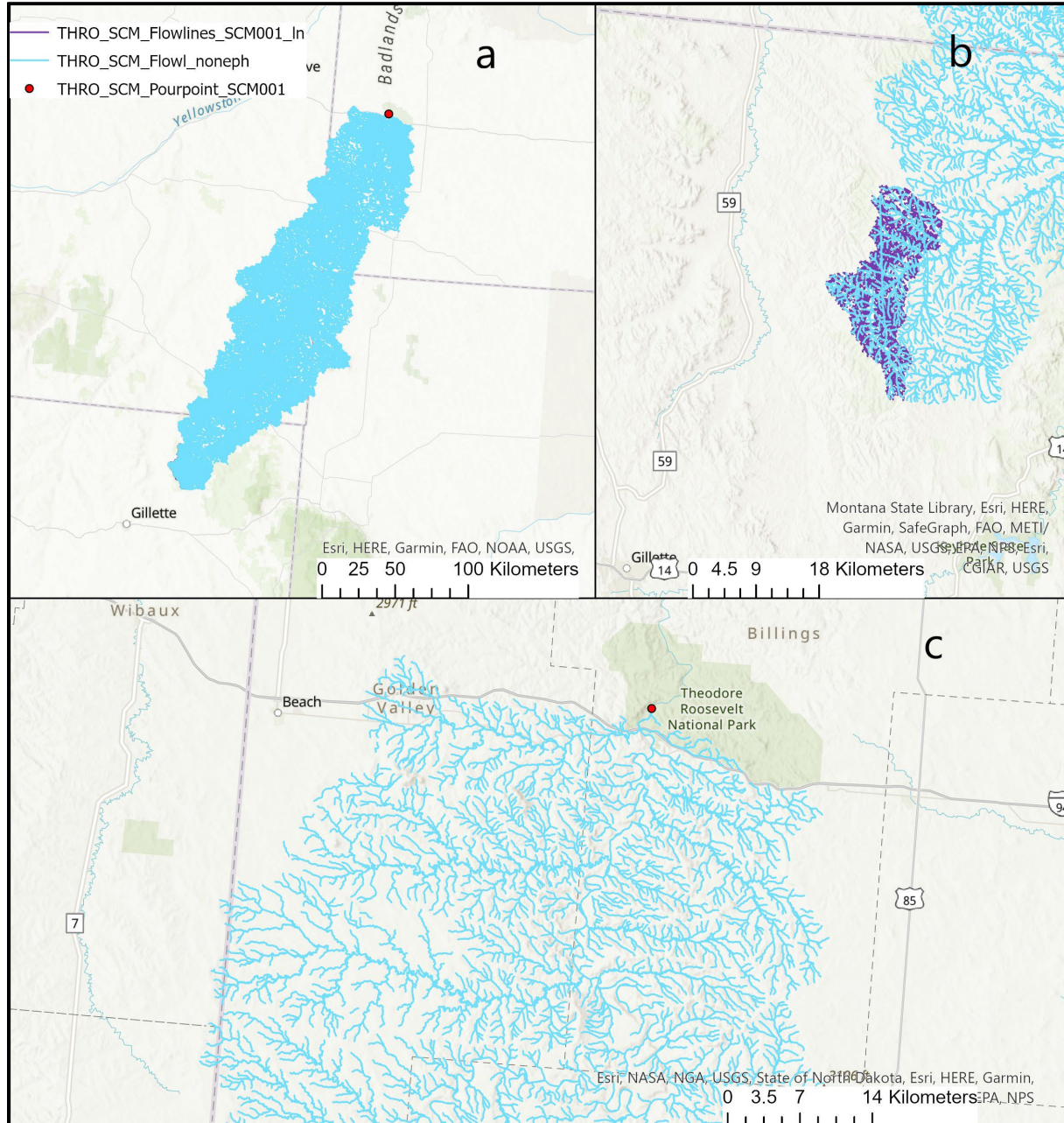


Figure 3. Flowlines associated with THRO stream channel monitoring site THRO SCM 001. Panel 'a' shows the extent of the watershed. NHD flowlines are in light blue while NHD ephemeral flowlines are in purple in panel 'b' concentrated in the southwest corner and were removed from consideration. Panel 'c' shows the pattern of flowlines near THRO SCM 001 and the park.

Table 3. Watershed Characteristics from elevation-derived delineated watershed using NHD-Plus stream length within HUC 12s upstream of THRO SCM 001.

Watershed Characteristics	THRO SCM 001
Watershed Drainage Area (km ²)	16330.68
Total Stream Length (km)	28220.17
Drainage Density (km/sqkm)	1.73
Watershed Length (km)	291.20
Watershed Shape	0.19
Watershed Slope- Average °	4.24
Watershed- Std. Dev °	5.02
Watershed- CV	1.18
Watershed Relief (m)	774.17
Elevation - Std. Dev (m)	125.52
Watershed Relief Ratio	0.0027
Entire Stream Gradient (m)	0.6322
Strahler Order	7
Bifurcation Ratio	2.08
Stream Gradient (m)	0.8730
Flow Accumulation Threshold	NHDPlus HR - ephemerals

Table 3 shows the basin characteristics from the THRO SCM 001 watershed. The watershed was derived using the NHDPlus HR method outlines in the Methods section. Results are above in Table 3 and recorded here with an explanation. Watershed drainage area was 16330.68 km². Watershed area can also be checked using the StreamStats application, [StreamStats | U.S. Geological Survey \(usgs.gov\)](https://streamstats.crk.usgs.gov/). Wyoming and Nebraska will be getting refined in the next few years which will make the site better. Table 6 shows the flow characteristics which can be available from StreamStats. We also included mean annual flow in this table, derived from USGS NWIS records [USGS Surface Water data for USA: USGS Surface-Water Annual Statistics](https://waterdata.usgs.gov/nwis/). We use the period of record, 1903-2022, to calculate mean annual flow.

Table 4. Flow Characteristics derived from StreamStats application.

Flow Characteristics	THRO SCM 001
Stream Stats Area (sq mi)	6310
Stream Stats Area (sq km)	16343
Mean Annual Flow (cfs)	463
2 year flood (50-percent AEP flood, cfs)	6140
50 year flood (2-percent AEP flood, cfs)	41500
100 year flood (1-percent AEP flood, cfs)	50100

The NLCD was downloaded and applied to the THRO 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 50.64 % including pasture, forest cover was 2.39 %, shrubland cover was 35.51 %, and developed land cover was .75 %. Grassland cover in 2001 was 52.65%, forest cover was 2.64%, shrubland cover was 35.73%, and developed land cover was .71 % (Tables 5a and 5b).

Table 5a. National land cover dataset applied to NHDPlus HR- delineated watershed for THRO SCM 001.

NLCD Class	2001 percent of watershed	2006 percent of watershed	2011 percent of watershed	2016 percent of watershed	2019 percent of watershed
Open Water	0.27	0.25	0.28	0.19	0.25
Developed - Open ¹	0.54	0.55	0.54	0.55	0.56
Developed - Low ¹	0.14	0.15	0.15	0.15	0.15
Developed - Medium ¹	0.02	0.03	0.03	0.04	0.04
Developed - High ¹	0.00	0.00	0.00	0.00	0.00
Barren	0.04	0.04	0.04	0.04	0.04
Deciduous	0.40	0.39	0.39	0.39	0.39
Evergreen	2.12	1.99	2.00	1.89	1.89
Mixed Forest	0.12	0.10	0.10	0.10	0.10
Shrub	35.73	34.89	35.19	35.19	35.51
Grassland	50.26	50.92	50.19	49.05	48.09
Pasture	2.39	2.39	2.39	2.42	2.56
Cultivated	7.16	7.46	7.89	9.16	9.62
Woody Wetland	0.15	0.18	0.16	0.17	0.17
Herbaceous Wetland	0.65	0.66	0.63	0.66	0.62

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

Table 5b. 2019 National land cover dataset summarized categories applied to delineated Little Missouri River watershed.

NLCD Class (2019)	THRO SCM 001
Developed Open & Low (%)	0.71
Developed Med. & High (%)	0.04
Forested (%)	2.39
Grassland (%)	50.64
Shrubland (%)	35.51
Wetland (%)	0.79
Cultivated (%)	9.62

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. 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. Access to the floodplain is maintained throughout the reach.

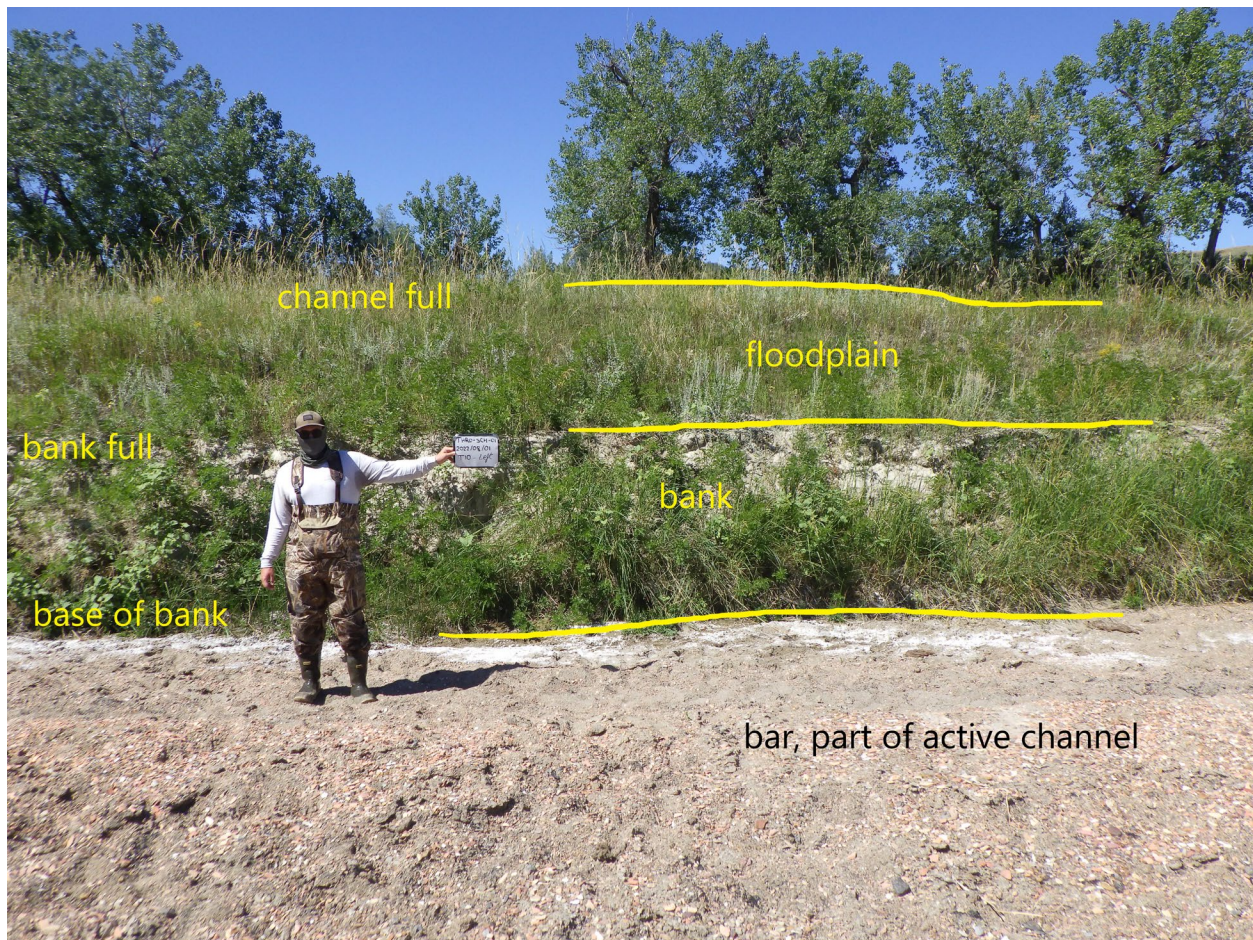


Figure 4. THRO stream channel monitoring site SCM 001 at T10 (near upstream) end on the left bank.



Figure 5. THRO stream channel monitoring site SCM 001 at T1 (downstream) end from right bank during bank-full conditions in May 2022. The right bank is largely covered in vegetation with good access to the floodplain.

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 bankfull area pinches in at T6, then widens at T1.

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 56.73 m² and mean channel-full area was 178.81 m² (Table 6).

Table 6. Detailed transects at THRO SCM 001 derived from total station measurements.

Transect	Type	Area (m²)	Perimeter (m)	Hydraulic Radius (m)	Width (m)	Depth (m)	Width/ Depth
T1	Bank-full	63.36	53.70	1.18	52.87	1.76	30.00
	Channel-full	116.40	65.70	1.77	64.59	2.69	24.03
	Ratio	1.84	1.22	1.50	1.22	1.53	0.80
T6	Bank-full	43.37	45.09	0.96	44.53	1.17	38.03
	Channel-full	220.65	83.76	2.63	82.51	3.89	21.23
	Ratio	5.09	1.86	2.74	1.85	3.32	0.56
T11	Bank-full	63.47	54.83	1.16	53.85	1.46	36.98
	Channel-full	199.39	77.81	2.56	76.26	3.52	21.63
	Ratio	3.14	1.42	2.21	1.42	2.42	0.58
Average	Bank-full	56.73	51.21	1.10	50.41	1.46	35.00
	Channel-full	178.81	75.76	2.32	74.45	3.37	22.30
	Ratio	3.36	1.50	2.15	1.50	2.42	0.65

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 6 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 7 shows the position of the ws at each transect and how the slope changes when moving downstream. Slope was -.1% from the top to the bottom of the reach.

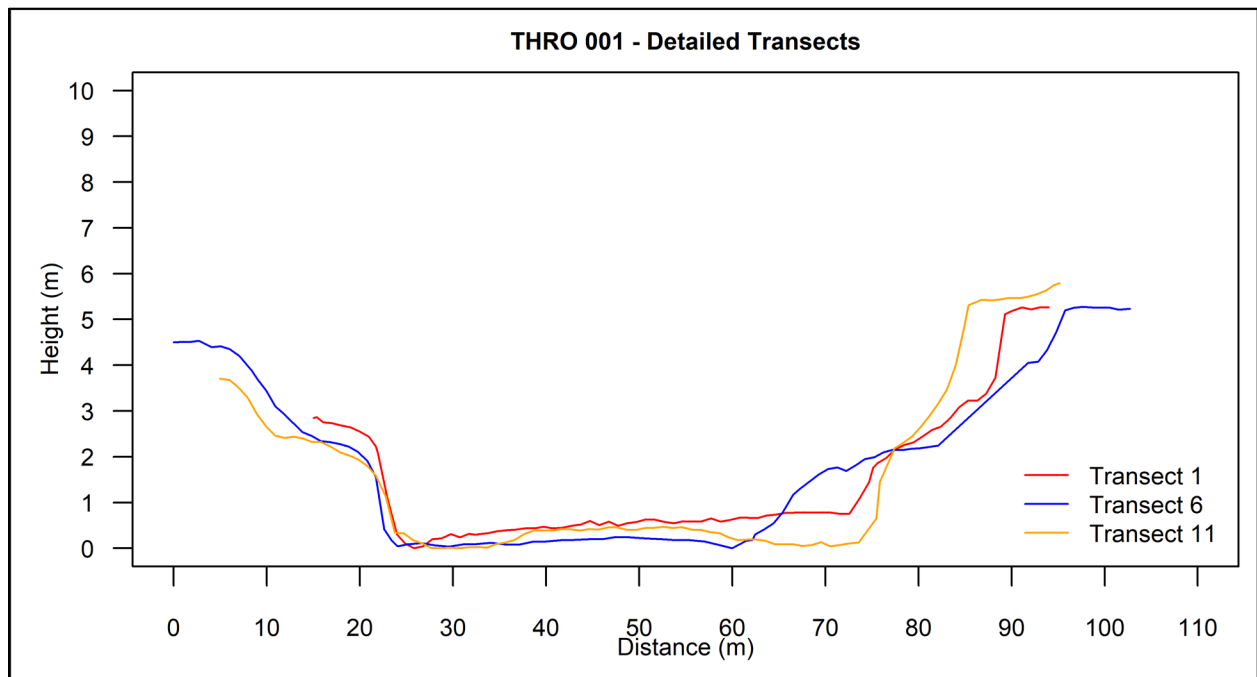


Figure 6. Detailed transects cross sections, plotting height above thalweg vs distance from the left benchmark (LBM). Axes were adjusted so that left bank-full begins at the same relative position for all three transects.

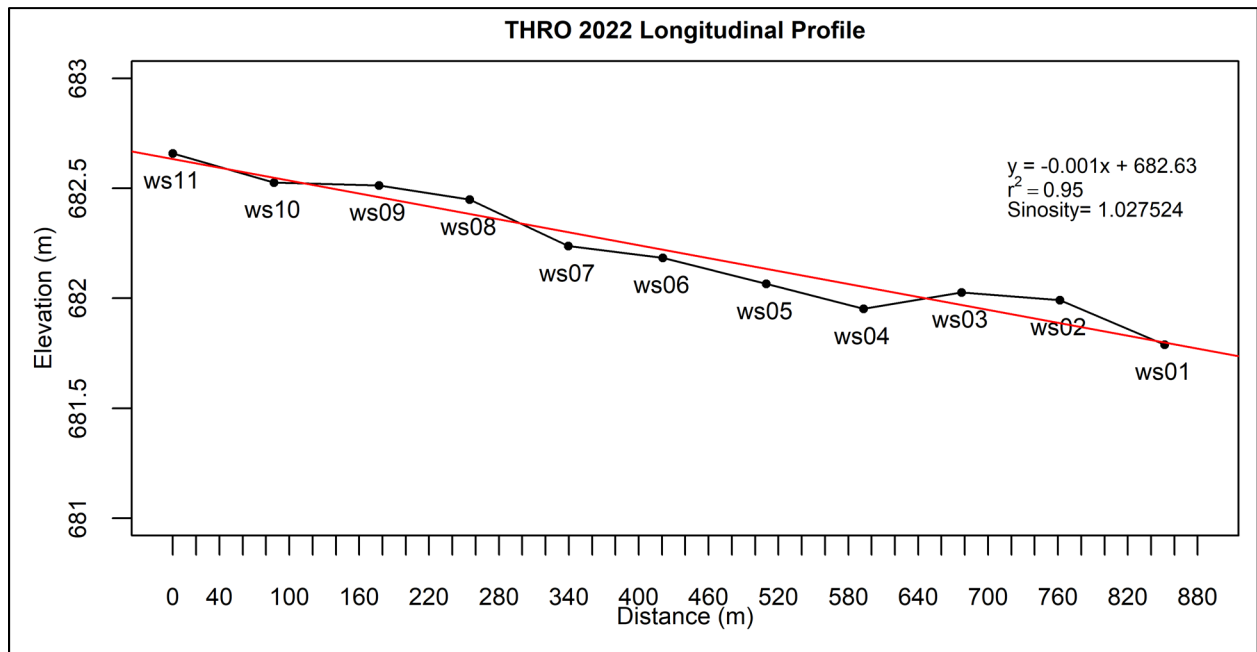


Figure 7. Elevational profile of THRO SCM 001. Slope is -.1%.

Reach-level Transects

The detailed transect survey was performed in August of 2022 while the water levels were very low, 1.55 ft gage height at [Little Missouri River at Medora, ND – USGS Water Data for the Nation](#) when the median for that time of year is 1.89 ft. Water depths remained relatively low throughout the reach with a mean thalweg (deepest spot of a stream along its cross-section) of 0.30 m. Table 7 shows the thalwegs or maximum water depth at each transect.

Table 7. Thalwegs at 11 transects at site THRO SCM 001 in August 2022.

Thalweg	n	Min	Max	Mean	Median	SD	CV
Depth (m)	11.00	0.18	0.45	0.30	0.32	0.09	0.30
Position ¹ (%)	11.00	5.00	95.00	52.73	50.00	35.45	0.67

¹ position is percent distance from left bank

Channel widths were wide throughout the site as shown in Table 8. Due to 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 THRO SCM 001 ‘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 THRO SCM 001 in August 2022.

Widths	n	Min (m)	Max (m)	Mean (m)	Median (m)	SD (m)	CV
Wetted	11	9	41	28.94	30.40	8.81	0.30
Active Channel	11	39	66	46.82	42.00	8.40	0.18
Bank-full	11	41	71	53.82	53.00	9.67	0.18
Channel-Full	11	65	91	76.82	82.00	8.90	0.12
Floodplain	11	0.75	25	10.28	10.00	6.99	0.68

Figure 8 shows channel diagnostic features from T1 looking upstream.



Figure 8. Bank and channel features from T1 looking upstream, taken August 2022.

Bank stability index (BSI) is an important measure of the banks that incorporates bank angle, vegetative cover, bank height, and bank sediment. 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. The bank stability index is confined to the bank full elevation. Tables 9a and 9b display the bank stability scoring and components. The left bank stability index was 14.05 and the right bank scored 11.45 for an average of 12.75 (Tables 9a and 9b). BSI is extremely sensitive to substrate. A bank with "silt-clay" is scored 3.5 points lower than a bank scored as "sand". A BSI score of 8-10.99 is in the "at-risk" category while 12-15.99 is in the "unstable" category (Table 9a). The metrics are based on the likelihood of that bank collapsing as the stream widens. Bank collapse should not be thought of as a strictly desirable or undesirable event. Indeed, meandering streams necessarily will destroy the current bank as they move through the floodplain. Meanders and new floodplain creation is necessary to maintain cottonwood stands and channel stabilization is a factor in the disappearance of cottonwood forests from the upper Missouri basin (Friedman and Griffin 2017).

Meander evolution, floodplain construction, floodplain destruction and high magnitude flood events are integral parts of northern Great Plains streams which are very dynamic and high-disturbance environments (Dodds 2004, Friedman and Griffin 2017) especially in an area such as THRO where

enormous amounts of sediment move through the stream system. Sandy banks or banks with sand and gravel are predisposed to instability. The Little Missouri River cuts through alluvial layers which erode easily (GRI 2008) and carries heavy loads of sediment from the erodible uplands (Bryce 1996).

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 show the reach-level bank stability index values.

Table 10. Reach-level bank characteristics for THRO SCM 001, Little Missouri River.

Bank Characteristics	n (L)	n (R)	Min (L)	Min (R)	Max (L)	Max (R)	Mean (L)	Mean (R)	Median (L)	Median (R)
Bank Height ¹ (m)	11	11	0.75	0.86	2.81	1.95	1.46	1.26	1.29	1.22
Bankfull Height ^{1,2} (m)	11	11	0.75	0.86	2.81	1.95	1.46	1.26	1.29	1.22
Channel-full Height ^{1,2} (m)	11	11	1.71	3.35	4.35	6.03	3.08	4.29	3.01	4.08
Water Depth at Base ^{3,4} (m)	11	11	-0.49	-0.13	0.03	0.08	-0.11	-0.03	0.00	0.00
Bank Undercut ² (m)	11	11	0.00	0.00	0.05	0.30	0.00	0.04	0.00	0.00
Bank Angle ^(o)	11	11	10	5	75	75	46	28	42	20
Vegetation Cover (%)	11	11	20	35	80	85	46.36	57.27	45	50
Bank Stability ⁵	11	11	At-Risk	At-Risk	Very Unstable	Unstable	Unstable	Unstable	Unstable	Unstable

¹ Bank height is at bank-full throughout the THRO 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 9a for explanation of scores.

Table 11. Reach-scale bank characteristics for THRO SCM 001, Little Missouri River.

Reach-scale	n	Min	Max	Mean	Median	SD	CV
Bank Height ¹ (m)	22.00	0.75	2.81	1.36	1.27	0.50	0.37
Bankfull Height ^{1,2} (m)	22.00	0.75	2.81	1.36	1.27	0.50	0.37
Channel-full Height ^{1,2} (m)	22.00	1.71	6.03	3.68	3.80	1.08	0.29
Water Depth at Base ^{3,4} (m)	22.00	-0.49	0.08	-0.07	0.00	0.13	-1.99
Bank Undercut ² (m)	22.00	0.00	0.30	0.02	0.00	0.07	3.09
Bank Angle ^(o)	22.00	5.00	75.00	37.05	37.50	24.94	0.67
Vegetation Cover (%)	22.00	20.00	85.00	51.82	47.50	20.79	0.40
Bank Stability ⁵	22.00	9.50	18.00	12.75	12.50	2.49	0.20

¹ Bank height is at bank-full throughout the THRO 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 9a for explanation of scores

Table 12. Transect-scale bank characteristics.

Transect-scale	Bankfull Height ^{1,2} (m)	Channel-full Height ^{1,2} (m)	Water Depth at Base ³ (m)	Bank Undercut ² (m)	Bank Angle ^(o)	Vegetation Cover (%)	Left Bank Stability ⁴	Right Bank Stability ⁴
1	2.21	3.55	-0.02	0.00	47.50	62.50	14.50	9.50
2	1.19	3.34	-0.11	0.00	9.00	45.00	11.50	9.50
3	1.26	3.99	0.01	0.00	26.00	37.50	17.00	13.00
4	0.90	2.89	0.01	0.08	57.50	52.50	9.50	11.50
5	1.59	4.67	-0.07	0.00	22.50	60.00	15.00	10.50
6	1.12	4.33	0.00	0.00	37.50	27.50	18.00	11.50
7	1.77	3.32	-0.06	0.00	25.00	60.00	17.00	12.50
8	1.35	3.68	-0.16	0.00	17.50	65.00	12.50	9.50
9	1.65	4.23	-0.25	0.00	50.00	37.50	14.50	13.50
10	0.84	3.68	-0.13	0.03	60.00	72.50	12.50	11.50
11	1.09	2.86	0.02	0.15	55.00	50.00	12.50	13.50

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 9a for explanation of scores

Transect 3 was the worst scoring transect overall for stability, while Transect 2 was the best. Pictures comparing transect 2 and 3 banks are below (Figure 9). Unstable substrate (gravel-sand) contributed most to the transects with higher bank instability as well as bank height and bank angle.



Figure 9. Transect 2 shows little erosion and has bank stability of score of 11.5 on the left bank (a) and 9.50 on the right bank (b) and is considered “at-risk” overall. Transect 3 has a bank stability of score of 17 on the left bank (c) and 13 on the right bank (d) and is considered “unstable”.

Bank erosion is measured in the original protocol in a qualitative manner by recording erosion and type (none, slump, animal, or lateral) within a meter up and downstream of each transect. 72% of bank measurements according to this method showed erosion. There was more erosion on the left bank which showed 82% of the bank eroding, while the right showed only 64% of the bank eroding. We did record ‘animal erosion’ to include banks that were trampled by ungulates. Rust 2006 methods which actually only directly measured erosion on smaller streams, not on large rivers like the Little Missouri at THRO, but NGPN has modified the protocol to measure erosion on all wadeable streams. Therefore, 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. We recorded 113.25 m out of 220 m bank length as eroded, representing 51.4 % of the streambank. 53.25% of the left bank was eroding, while 60 % of the right 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 \(nps.gov\)](#).

This site will be revisited in 3 years to see if channel widening is occurring. Channel change can be regarded as a redistribution of the imbalance between sediment and water (Thorne and Lewin 2020). 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 10. 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 1-2, $d_{50}=11$ mm, Table 14), fine substrate (sand or silt/clay which was dominant in 4 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	75	20	0	5	0
2 - 3	15	80	0	5	0
3 - 4	0	95	0	5	0
4 - 5	0	95	0	5	0
5 - 6	0	90	0	10	0
6 - 7	85	10	0	5	0
7 - 8	85	10	0	5	0
8 - 9	60	40	0	0	0
9 - 10	0	90	0	10	0
10 - 11	0	95	0	5	0

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

Metric	(%) Riffle	(%) Run	(%) Glide	(%) Pool	(%) Step
Frequency	5	10	0	9	0
Max (%)	85	95	0	10	0
Mean (%)	32	63	0	6	0
Median (%)	8	85	0	5	0
SD (%)	39	38	0	3	0

Table 14. Sediment diameters from a representative riffle- transect 6-7.

Statistic (n = 100)	Diameter (mm)
Min	0.062
D5	2
D16	2
D50	11
D84	16
D95	31.53
Max	180

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

Transect	Dominant Particle Class	Left	Left Center	Center	Center Right	Right	Percent Fines ¹
1	Gravel-medium	45	22.6	16	11	11	0
2	Gravel-medium	16	22.6	16	11	8	0
3	Gravel-fine	22.6	8	8	8	0.062	20
4	Gravel-fine	11	16	2	90	45	20
5	Sand	2	2	16	5.6	0.062	60
6	Gravel-fine	45	22.6	11	11	0.062	20
7	Gravel-fine	11	45	32	16	0.062	20
8	Gravel-medium	8	8	16	64	2	20
9	Sand	22.6	2	22.6	22.6	2	40
10	Sand	4	16	2	32	2	40
11	Sand	2	2	8	2	2	80
Percent Fines for all Transects	36.36	—	—	—	—	—	29.09

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
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
Min (%)	0
Max (%)	0
Mean (%)	0
Median (%)	0
SD (%)	0
CV	—

Substrate was a mix of gravel and sand (Table 15). ‘Run’ habitat dominates but there are also riffles and pools (Tables 13a and 13b). While there is an absence of large woody debris (0% in active channel) and canopy cover is low (mean canopy cover was 0%; 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 6 and 7 was selected as the representative riffle. Diameters are summarized in Table 14, with the median particle size (D_{50}) corresponding to 11 mm, classified as medium gravel. Particle size decline over time can be evidence of siltation and increased embeddedness. Increases in particle size indicate armoring. Water supply can also have temporary effects on sediment size as fines build up on the stream bed until a flood event is big enough to wash them away. 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 (Tables 16 and 17). 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. Rust 2006 had recorded a higher percentage of fines (<2mm) and sand (2mm) (58 % then vs 29% in 2022) and boulders or particles larger than 256 mm (6% then vs 4% in 2022) in three reaches which did not include THRO SCM 001 but were still within the South Unit (Rust 2006). Gravel (greater than 2mm to 64 mm) was the highest percentage of substrate particles (67 % in 2022 vs 33% by Rust in 2004-2005).

Canopy cover was low across the reach (Table 16) with mean value of 0%. Rust found that at NGPN large river sites, mean canopy cover was 11%, though it was 9% at the three reaches she studies at THRO. 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 along the T1 transect in August. Measured discharge was measured with a Marsh-McBirney flow meter and was 17.3 cfs using the velocity area method. The measured stage at the gage at the time was 1.55 feet with a discharge of 20.3ft/s. Cross section mean stream velocity at THRO SCM 001 was 1.04 ft/s (.30 m/s).

Further Analysis

This Data Report is intended to provide a basic review of the data collected during the 2022 stream channel monitoring in the Little Missouri River at THRO. 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 /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.

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Appendix A

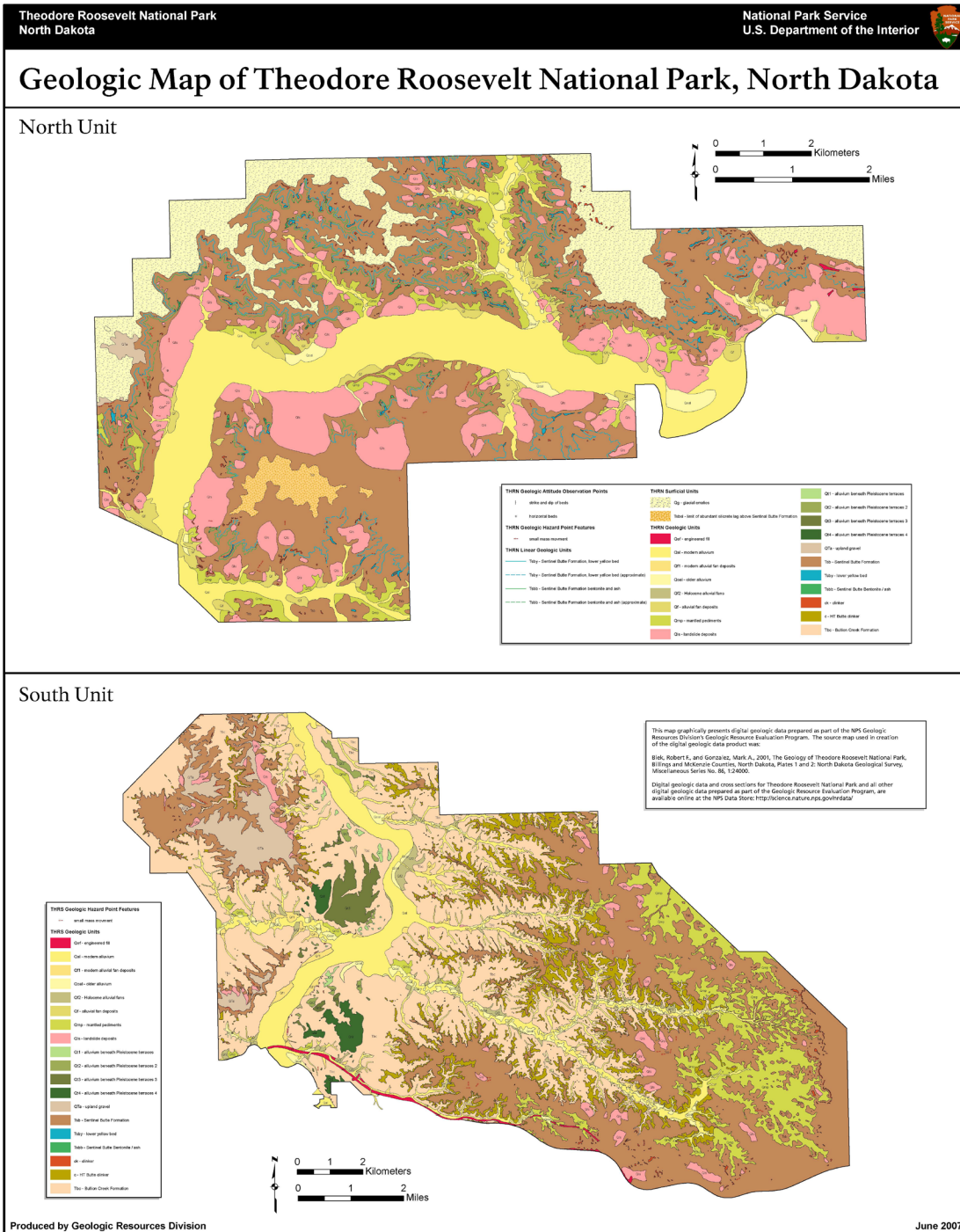


Figure A-1. THRO geological map (GRI 2007). The river flows through QAI deposits (quaternary alluvium) in yellow.

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