Tongue River Stream Improvement Concept Plan

Prepared for
Sheridan County Conservation District

August 2014

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Tongue River Stream Improvement Plan

August 2014

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1.0 Introduction

1.1 Project Background

In 2011, prolonged high flows on the Tongue River, upstream of Dayton, Wyoming, generated concern among landowners about increased erosion along the river and unstable stream banks. Several landowners contacted the Sheridan County Conservation District (SCCD) and Sheridan County Public Works Department (SCPWD), reporting their observations and concerns. During the fall of 2011, the SCCD and SCPWD worked with landowners to determine whether there was interest in conducting an assessment of the reach.

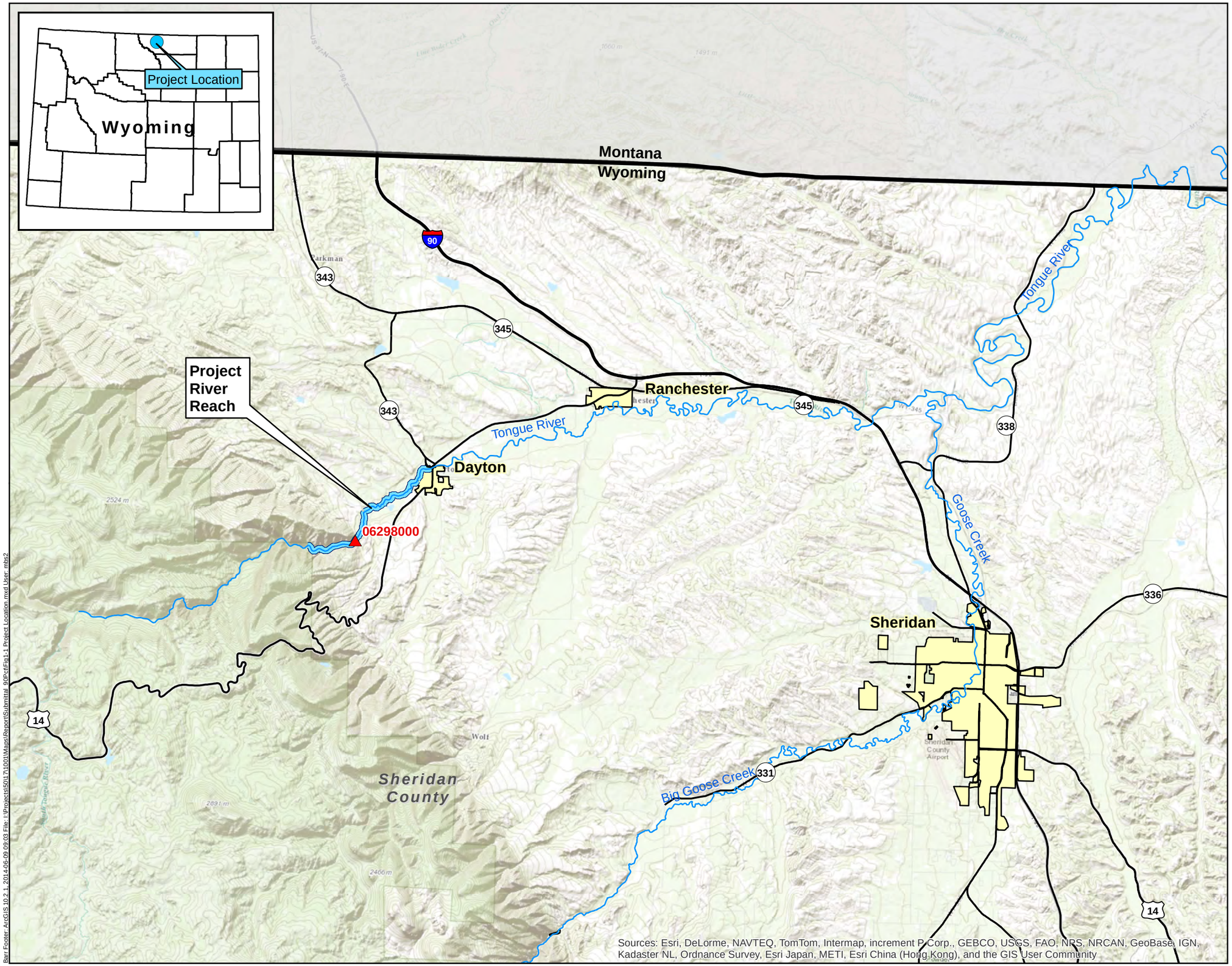
Funding assistance via a 205(j) grant from the Wyoming Department of Environmental Quality was received to pursue an assessment and stream improvement concept plan for the river upstream of Highway 14 to the mouth of the Tongue River Canyon (approximately 5 miles). In September 2013 the District contracted with Barr Engineering and subcontractors Paul Starkey and Mark Opitz, P.E., to perform the assessment and develop the stream improvement concept plan for approximately 3.3 miles of the river upstream from Highway 14. Landowner knowledge, concerns, and desired conditions for the river were key elements of the assessment and plan development.

The SCCD, in partnership with the USDA Natural Resources Conservation Service (NRCS), has administered a water resource improvement program in the Tongue River Watershed since 1996. This program includes watershed assessment (including interim monitoring), watershed planning, information and education activities, and installation of improvement projects. SCCD collected water quality data from 1996–1999 for the initial Tongue River Watershed Assessment. Subsequent interim monitoring occurred in 2003, 2006, 2010, and 2013. The purpose of the interim monitoring is to evaluate long-term changes in water quality. The original Tongue River Watershed Plan was submitted to the Wyoming Department of Environmental Quality in September 2000 and revised in 2007. The plan was revised again in 2013 to meet the requirements of an EPA Watershed-Based Plan. These plans have been and will continue to be implemented using a variety of funding sources, including federal and state grants, USDA program funds, and landowner contributions.

Approximately 1.6 miles of the upstream river reach (above USGS gage 06298000) were mostly excluded from this assessment to prioritize the lower reach, which has the most active erosion and bank stability issues. The upper reach is quite stable with bedrock valley walls and large, less mobile, boulder-dominated bed materials. Although the upstream 1.6 miles of the river were not a high priority for erosion assessment and possible future stabilization, some cross-section and profile data was collected in this area to aid in developing a range of stream geometry values, particularly with respect to pool dimensions and spacing.

1.1.1 Project Location

The Tongue River is a tributary of the Yellowstone River that begins in the Bighorn Mountains and flows from northern Wyoming to southeastern Montana. The project area is entirely within Sheridan County, Wyoming, and consists of 5 miles of the Tongue River between the town of Dayton and the mouth of the Tongue River Canyon at the end of Tongue Canyon Road. A site map of the project area is shown in Figure 1-1.



USGS Gage Location
Project River Reach
Major Rivers
Municipal Boundary
State Boundary

Miles
2.5 0 2.5

Figure 1-1

PROJECT LOCATION
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT
BARR

Barr Footer: ArcGIS 10.2.1, 2014-06-09 09:03 File: I:\Projects\50\17\001\Maps\Report\Submittal_90PctFig1-1 Project Location.mxd User: mbs2

The Tongue River within the project area consists of two distinct sections. The upstream section is within the Tongue River Canyon and upstream of the USGS gage. This section has a steeper slope and generally different morphology than the lower section, which begins at the USGS gage and ends at the Highway 14 Bridge crossing in downtown Dayton. The two river sections, study sub-reaches, and major surface water features are shown in Figure 1-2.

1.1.2 Landownership Status

The majority of land in the Tongue River basin (83%) is privately owned (*SCCD 2012*). The distribution of public and private land immediately adjacent to the project area is shown in Figure 1-3. The high percentage of private ownership, combined with high public interest in addressing the erosion, sedimentation, and habitat issues within the project area, made soliciting information and input from public stakeholders critical to the project's success.

1.2 Project Objectives

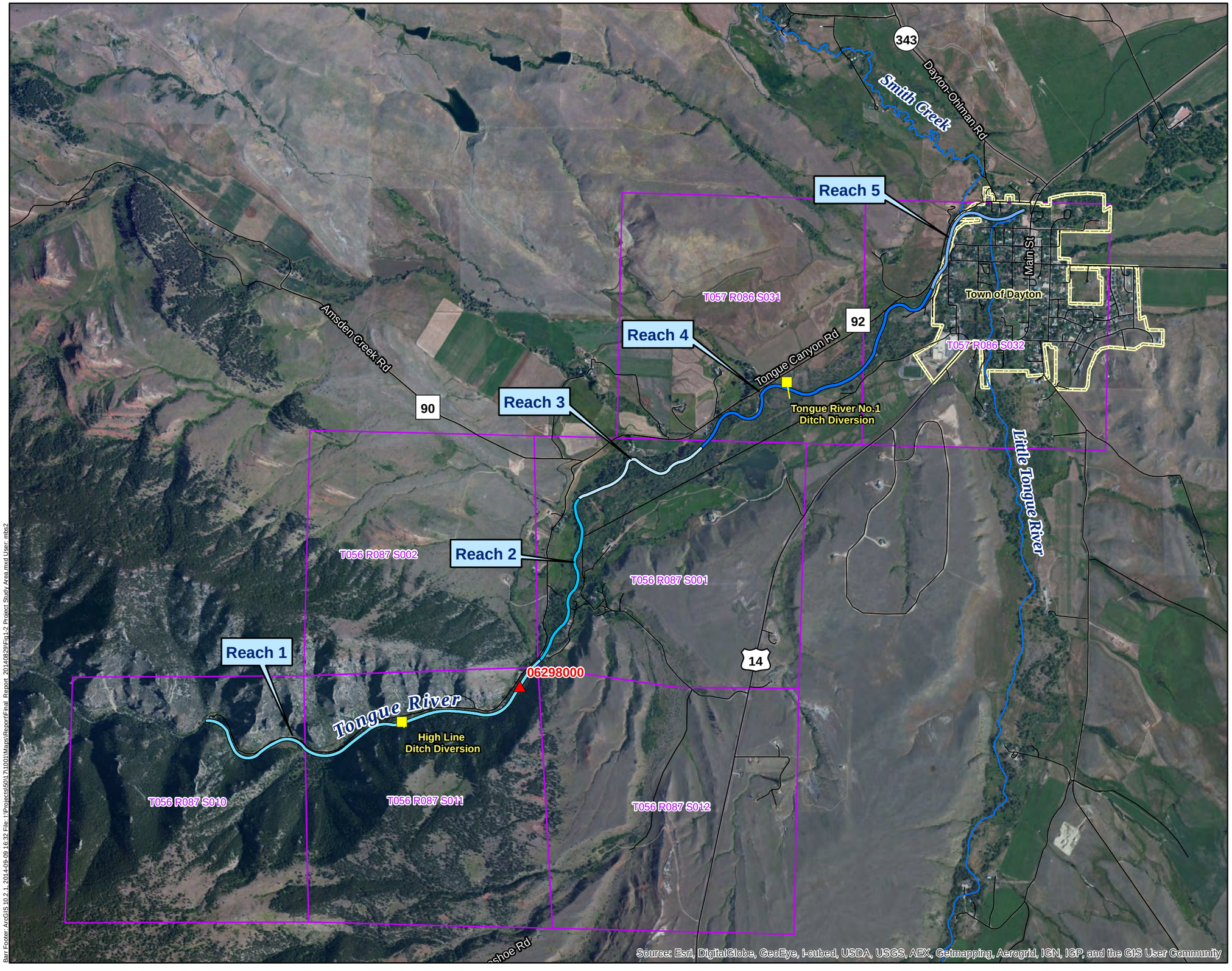
1.2.1 Compilation and Review of Existing Data

Recent studies of the Tongue River in or near Dayton have been conducted for various purposes. Most note concern about rates and locations of erosion and deposition, the need for diversity of fish habitat, and river aesthetics. The design team reviewed data sources that included stream geometry from the *Padlock Ranch Stream Improvement Plan* (Delk 2008), *Scott Bicentennial Park Stream Improvement Plan* (Pearson 2011), and regional curve development reports by the SCCD (SCCD 2005) and United States Geological Survey (USGS) (Foster 2012). The design team consulted these data sources both before and after channel surveys were conducted to understand the existing conditions in the Tongue River basin, the geomorphic factors which influence the river's behavior, and previously considered design solutions.

1.2.2 Landowner and Public Participation

Landowner communications and public meetings were part of the assessment process. Landowner participation in the assessment and stream improvement concept plan was crucial, as future actions to address bank stability, erosion, fish habitat, etc., will take place primarily on private lands. In addition to the SCCD and SCPWD, public entities involved in the assessment, field work, and survey strategy included the Wyoming Game and Fish Department and the Natural Resources Conservation Service (NRCS).

The NRCS Stream Visual Assessment Protocol (SVAP) (NRCS 2009) was employed in onsite meetings with individuals and groups to assist the project team and landowner(s) in identifying specific areas of concern within the project reaches.



USGS Gage Location
Tongue River Diversion Headgate
River Centerline

Project River Reaches

Reach 1
Reach 2
Reach 3
Reach 4
Reach 5
Municipal Boundary
PLS Section Boundary

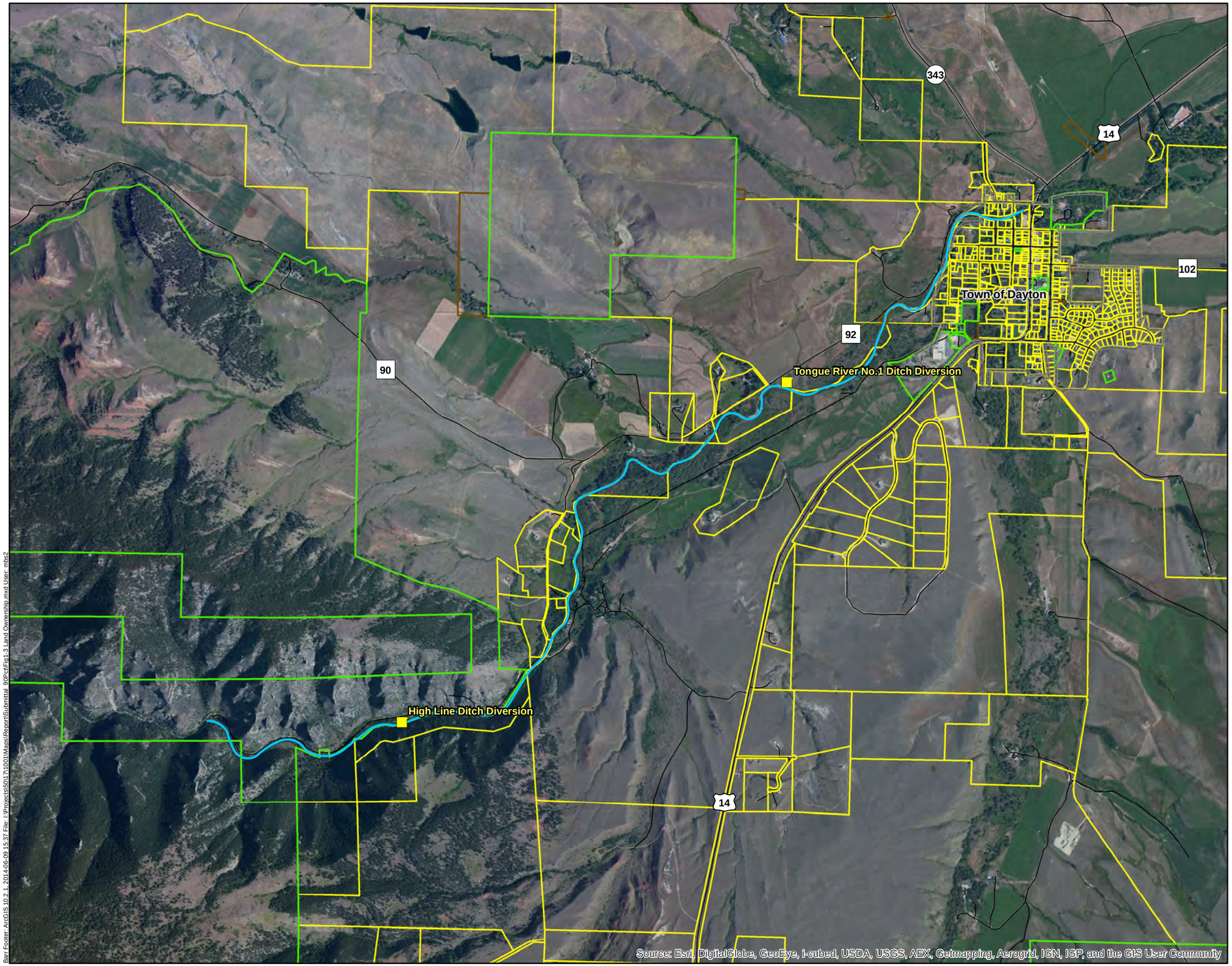
Feet
2,000 0 2,000

Figure 1-2

PROJECT STUDY AREA
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT
BARR

Barr Footer: ArcGIS 10.2.1, 2014-09-09 16:32 File: I:\Projects\5017\10011\Mxds\Report\Final Report 20140829\Fig1-2 Project Study Area.mxd User: mbs2



Tongue River Centerline
Tongue River Diversion Headgate
Municipal Boundary

Land Ownership

Public Land
Private Land
Other/Unknown Land

N

Feet
2,000 0 2,000

Figure 1-3

LAND OWNERSHIP
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-06-09,15:37, File: I:\Projects\51\71001\Mxds\Report\Submittal_90Pct\Fig1-3 Land Ownership.mxd User: mbs2

1.2.3 Field Survey, Data Selection, and Evaluation

The primary purpose of the field survey was to collect geometry data on the Tongue River within the project area to facilitate Rosgen classification (Rosgen 1996). Collecting stream geometry measurements and slope information at various locations allowed the project team to develop a range of values for pertinent geometry measurements and suitable dimensionless ratios to guide stabilization and habitat improvement planning efforts. The cross-section location was chosen to accommodate specific sites where landowners have concerns about erosion and bank stability.

The second purpose of the field survey was to collect data for development of erosion-potential maps. In conjunction with information gained from the SVAP meetings, these were used to quantify erosion rates and volumes in highly erosive areas and prioritize banks for future stabilization efforts.

1.2.4 Development of Stream Improvement Concept Plan

The final product of this project was a stream improvement concept plan. This document recommends actions for each sub-reach to address landowner concerns, while considering stream planform, current and potential bank erosion, and appropriate fish habitat improvements. These recommendations are based on the aggregate information collected during the SVAP meetings, field survey, and evaluation of prior studies on the Tongue River. The stream improvement concept plan does not contain sufficient detail for project design; the development of such site-specific documents as construction plans and technical specifications is outside the scope of a concept plan.

2.0 Evaluation of Existing Information

2.1 Watershed Characteristics

2.1.1 Land Use and Topography

The Tongue River originates on the eastern side of the Bighorn Mountains and flows generally to the north and east before crossing the Wyoming-Montana border to its confluence with the Yellowstone River. As it passes through the project area, including the town of Dayton, it is considered a fifth-order stream (Strahler 1957), with a drainage area of approximately 206 square miles. Land in the lower drainage area is primarily rangeland, irrigated pasture, and hay land; the upper drainage area is part of the Bighorn National Forest, used for cattle grazing and recreational purposes.

The area included in this study encompasses a major landform transition in the Tongue River watershed, which is clearly visible in Figure 2-1. The topography of the Tongue River upstream of the USGS gage is dominated by the foothills of the Bighorn Mountains. The channel slope in this section is higher than anywhere else in the study area, and the surrounding landforms are also steeper and more confining. The USGS gage station generally marks the entrance of the Tongue River into a flatland/prairie-dominated landscape. Here the channel is less confined; Figure 2-1 shows the width of the available valley along Tongue Canyon Road, in contrast to the defined valley walls visible within the canyon.

The landform transition from mountain to prairie manifests itself in the Tongue River channel characteristics. Above the transition, the channel is characterized by a step-pool system and a boulder/cobble-dominated bed material. In contrast, the downstream channel has fewer grade controls (such as boulder-dominated riffles and plunge pools) and a smaller average sediment size.

2.1.2 Geology and Soils

Bedrock and surficial geology in the project study area are shown in Figure 2-2 and Figure 2-3. Geology and soil types correspond to the transition in topography and landform as noted in Section 2.1.1. The Tongue River Canyon above the USGS gage is dominated by bedrock with surficial geology composed of colluvial material. This material is likely to be transported to the river during periods of high surface runoff.

Downstream of the USGS gage the reach is dominated by gravelly, sandy loams. These soil types are well-drained and not subject to ponding of water (NRCS 2014). Alluvial and colluvium materials along both banks of the river within the prairie landscape are subject to lateral erosion during high-water periods.

Tongue River Centerline
Municipal Boundary

Feet
2,000 0 2,000

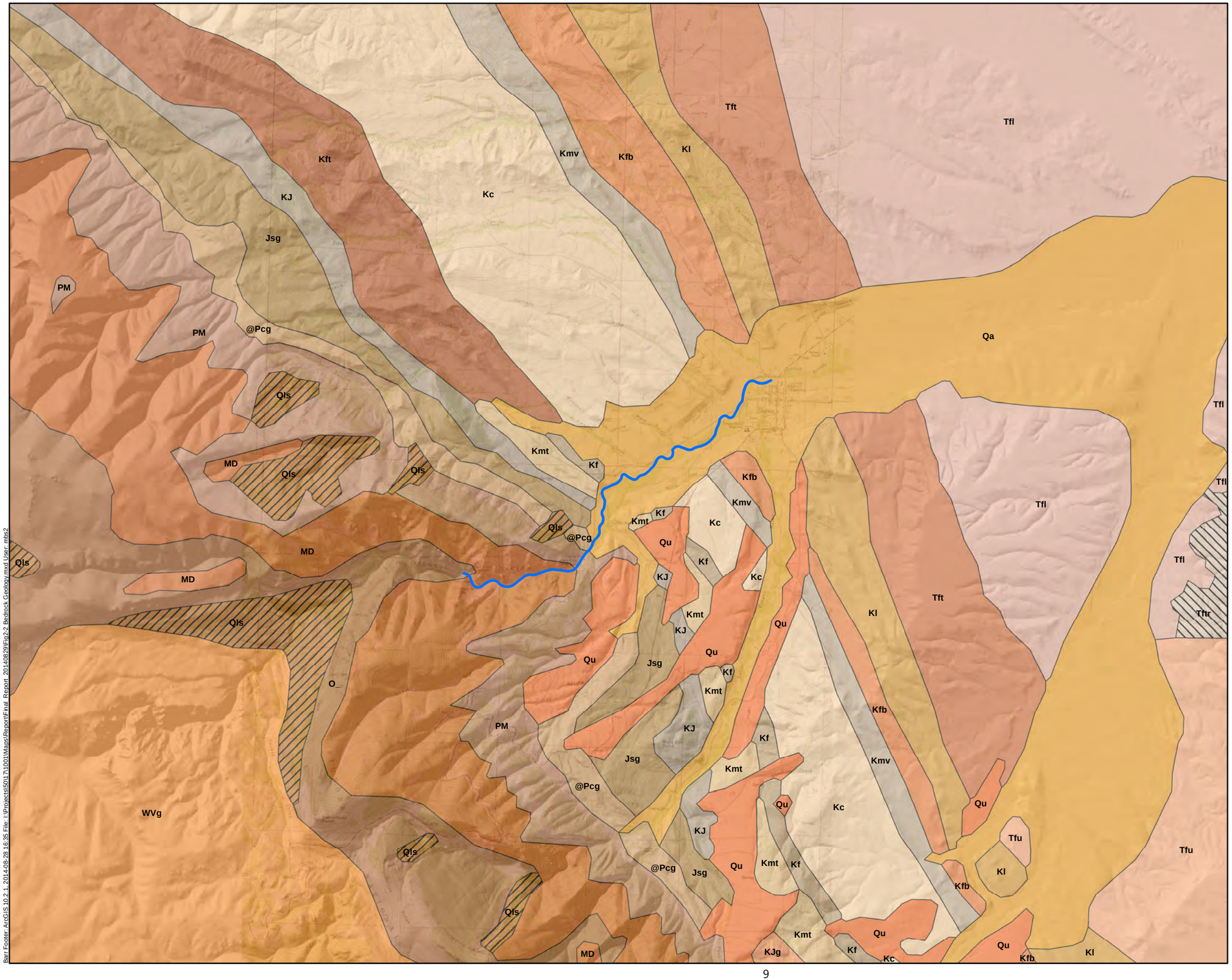
Figure 2-1

LOCAL TOPOGRAPHY
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:34 File: I:\Projects\50\17\1001\Mats\Report\Final_Report_20140829\Fig2-1 Local Topography.mxd User: mbs2



Tongue River Project Extents

Bedrock Geology

- Qa--Alluvium and colluvium
- Qls--Landslide deposits
- Qu--Undivided surficial deposits
- @Pcg--Chugwater and Goose Egg Fms
- Jsg--Sundance and Gypsum Spring Fms
- KJ--Cloverly and Morrison Fms (N, S) or Cloverly Fm (Hartville uplift), or Inyan Kara Gp (Black Hills), and Morrison Fm (NE)
- KJg--Cloverly, Morrison, Sundance, and Gypsum Spring Fms
- Kc--Cody Shale
- Kf--Frontier Fm
- Kfb--Fox Hills Sandstone and Bearpaw Shale
- Kft--Frontier Fm, and Mowry/Thermopolis Shales
- Kl--Lance Fm
- Kmt--Mowry and Thermopolis Shales
- Kmv--Mesaverde Fm (N) or Mesaverde Gp (S)
- MD--Madison Limestone or Gp, and Darby Fm, or Madison Gp, and Three Forks and Jefferson Fms
- O_--Various
- PM--Tensleep Sandstone and Amsden Fm
- Tfl--Lebo Member of Fort Union Fm
- Tft--Tullock Member of Fort Union Fm
- Tftr--Tongue River Member of Fort Union Fm
- Tfu--Fort Union Fm
- WVg--Plutonic rocks

Data Source:
US Geological Survey. Bedrock Geology for Wyoming. 1994.

N

Miles

1 0 1

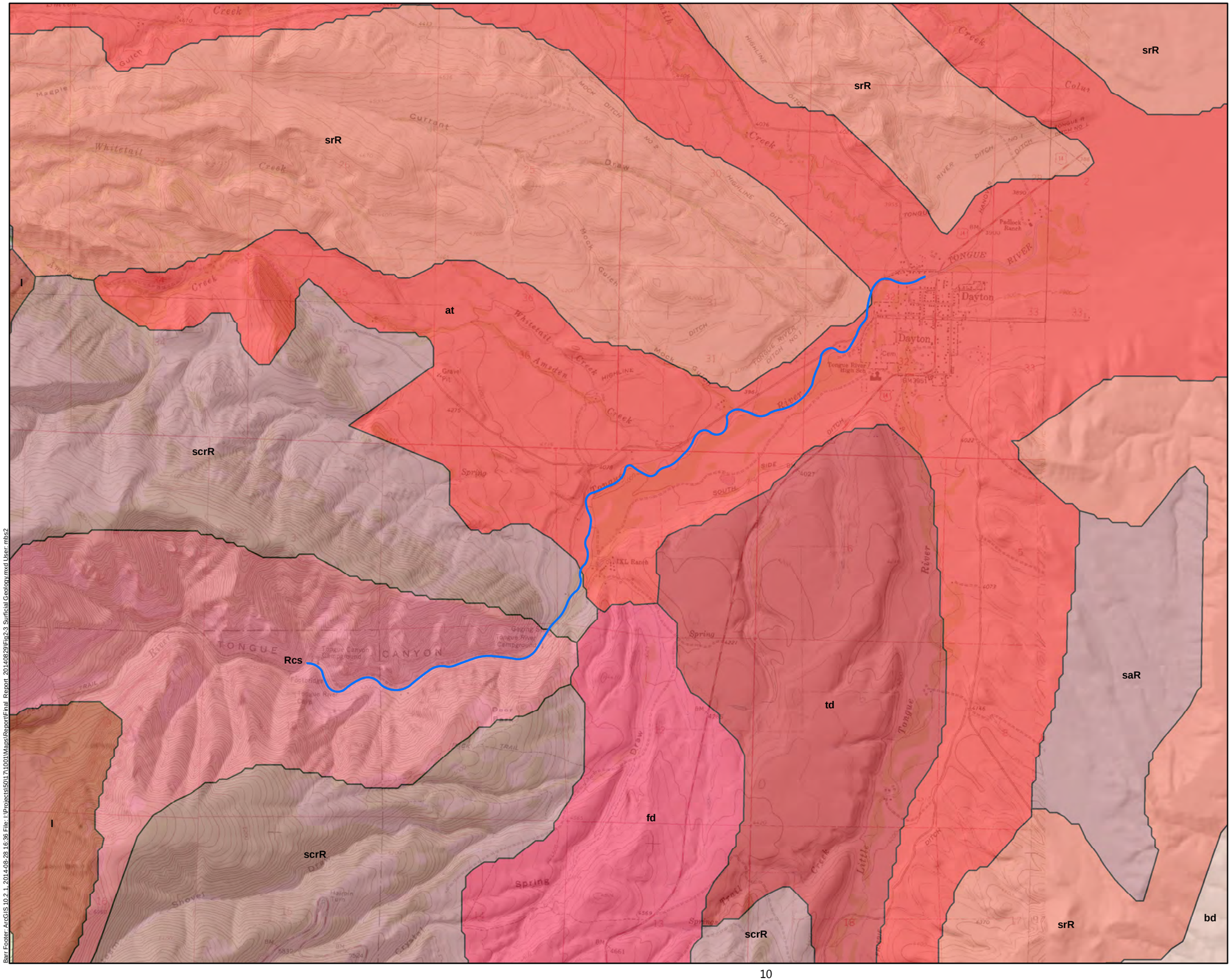
Figure 2-2

BEDROCK GEOLOGY
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:35 File: I:\Projects\50171001\Maps\Report\Final Report_20140829\Fig2-2 Bedrock Geology.mxd User: mbs2



Tongue River Project Extents

Surficial Geology

- Rcs - Bedrock mixed with colluvium, slopewash and/or grus
- at -- Alluvium mixed with terrace deposits
- bd -- Dissected bench deposits occ. mixed with residuum
- fd -- Alluvial fan
- l -- Landslides occ. mixed with slopewash
- saR, scrR -- Slopewash mixed with alluvium, residuum, and/or colluvium
- srR -- Slopewash mixed with scattered bedrock outcrops and residuum, alluvium, colluvium, and/or clinker
- td -- Terrace deposits

Data Source:
Case, James C. et al. Surficial Geology for Wyoming. Wyoming Spatial Data and Visualization Center. 1998
http://www.wsgs.uwyo.edu/data/gis/shapefiles/surgeol_500k.zip

Miles
0.5 0 0.5

Figure 2-3

SURFICIAL GEOLOGY
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT
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Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:36 File: I:\Projects\5017\1001\Maps\Report\Final Report 20140829\Fig2-3 Surficial Geology.mxd User: mbs2

2.1.3 Surface Drainages

The Little Tongue River has its confluence with the Tongue River in the town of Dayton. The drainage area of the Little Tongue River is approximately 26 square miles south of Dayton. This stream is ungauged, but its volumetric flow rate is much less than that of the Tongue River and it likely has little effect on erosion patterns or flow rates of the Tongue River through town.

Photo 2-1 Little Tongue River at its confluence with the Tongue River in Dayton

Smith Creek also joins the Tongue River in Dayton, approximately 9,500 feet upstream of the confluence with the Little Tongue River. The drainage area of Smith Creek is approximately 11 square miles northwest of Dayton. Like the Little Tongue River, Smith Creek is ungauged, but its drainage area and flow rate are much smaller than that of the Tongue River in these locations. Flows from Smith Creek are unlikely to have a significant effect on erosion through Dayton.

As discussed in Section 2.1.2, the project area is dominated by well-drained, gravelly, sandy loams. This allows rainfall within the basin to infiltrate easily, though the precise amount of infiltration within the Tongue River basin is not well understood. The Tongue River also receives large amounts of snowmelt from the Bighorn Mountains; in most years the largest runoff events occur between May 1 and June 30. According to flow records from USGS gage 06298000, 40% of yearly maximum flow values are recorded from June 1–30 and 58% from May 1–31.

2.1.4 Water Diversions

Major water diversions currently present upstream of Dayton on the Tongue River are shown in Table 2-1. Neither diversion volumes shown (1cfs/70A) nor those up to twice the amount statutorily permitted by Wyoming when excess water is available are likely to impact channel-forming processes. In-stream activities related to maintenance actions or existing conditions at some diversion points were identified as having high erosion potential. The push-up dam that is part of the diversion at the Tongue River No. 1 Ditch is one such location.

Table 2-1 Major active water diversions on the Tongue River upstream of Dayton

Diversion Name	Diversion Volumes (cubic feet per second, cfs)
Highline Ditch	13.81 cfs
Dayton Municipal	4.12 cfs
South Side Tongue River Ditch	22.45 cfs
Tongue River No. 1 Ditch	7.57 cfs
Hanover Ditch* *located at the downstream terminus of study area	26.05 cfs

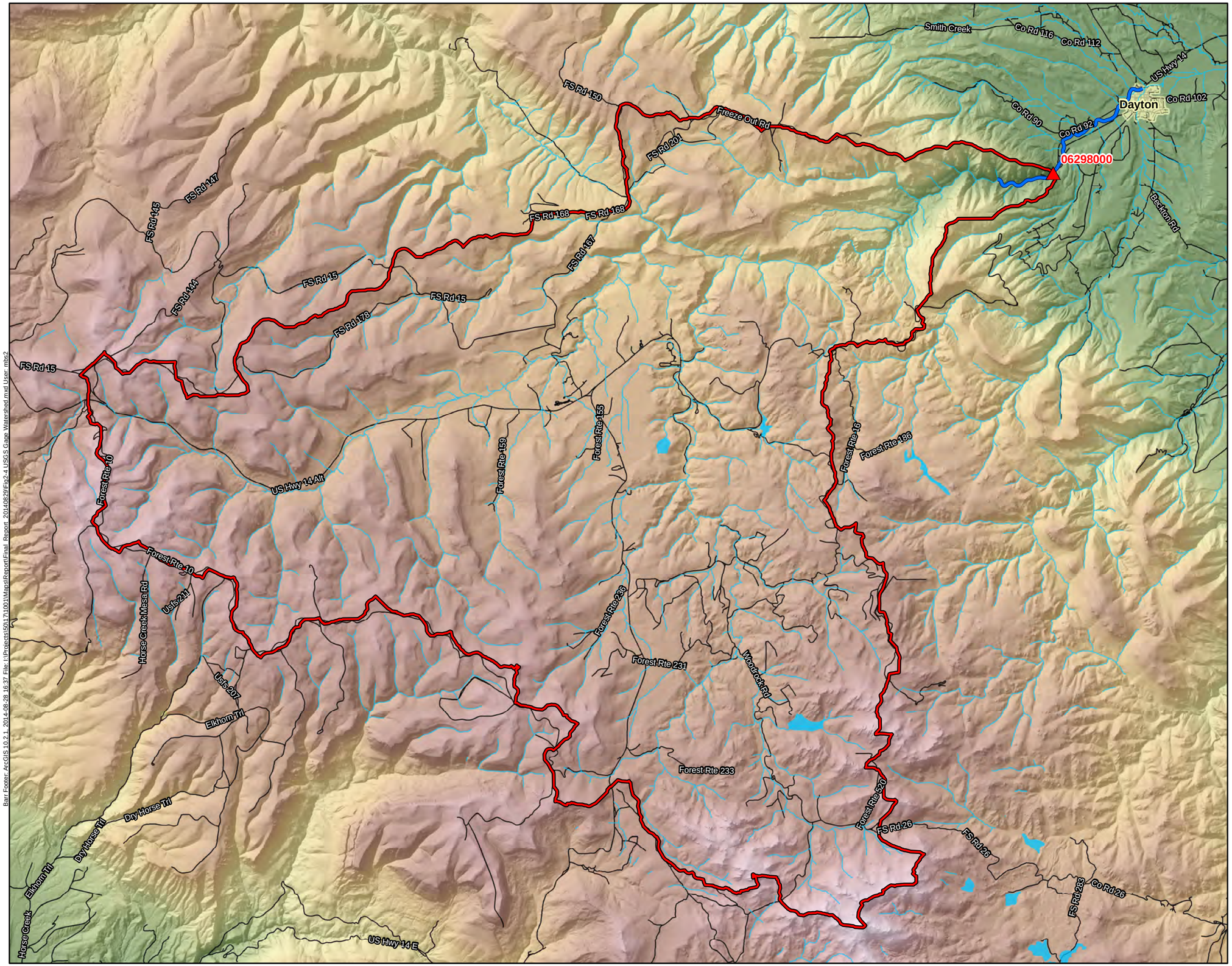
2.1.4.1 USGS Gage Data Analysis

USGS streamflow gage #06298000 is located on the Tongue River north of Dayton. The watershed area for this gage is shown in Figure 2-4. This gage currently measures flow every 15 minutes, but additional datasets are available through the National Water Information System. Barr conducted a preliminary gage analysis based on yearly peak flow data to estimate bankfull flow and stage before beginning the field survey.

The Log-Pearson Type III Distribution was used to calculate the frequency of specific flow rates using yearly peak flow data from the USGS. Flow with a 2-year-return period was estimated at 1,660 cfs at the gage; flow with a 1.5-year-return period was 1,360 cfs. This estimation is within the range of other estimates of bankfull flow from other sources. See Table 2-2 for comparison of values and summary of methods.

Table 2-2 Comparison of bankfull flow estimates between sources, Tongue River near Dayton

Source	Bankfull Flow Value (cfs)	Method
Regional Curves	~1,400	Figure 4B; estimate based on 250-square-mile drainage area
Pearson Report	1,361	Gage data analysis
Padlock Ranch SIP	1,114	SCCD 2005 study
Barr Gage Analysis	1,360–1,660	Gage data analysis



USGS Gage Location

Tongue River Project Extents

Municipal Boundary

Watershed Boundary to USGS Gage 06298000

Miles

2 0 2

Figure 2-4

USGS GAGE WATERSHED
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Foster: ArcGIS 10.2.1, 2014-08-28 16:37 File: I:\Projects\50\17\10011\Maps\Report\Final Report_20140829\Fig2-4 USGS Gage Watershed.mxd User: mbs2

2.2 Previous Channel Geometry Evaluation

2.2.1 Tongue River Regional Curves

In 2012 the USGS published regional curves for the Rocky Mountains Hydrologic Region of Wyoming, an area which includes the Tongue River basin. Data from USGS gage #06298000 on the Tongue River was used to develop the published curves, indicating that the curves are applicable for use on the Tongue River itself. The paper provides two sets of curves for the region, depending on whether the watershed mean annual precipitation is greater or less than 25 inches. The published regional curves cite the Tongue River watershed as receiving an average of about 27.7 inches of precipitation per year.

2.2.2 Padlock Ranch Stream Improvement Plan

A stream improvement plan was prepared for the Padlock Ranch on the Tongue River (Delk 2008) to address issues of erosion, sedimentation, and fish habitat, among other concerns. This plan, which focused on the river from the Highway 14 Bridge to the east boundary of the Padlock Ranch (approximately 2 miles downstream), suggested that existing efforts to armor the bank were unsuccessful. In-stream structures such as root wads and log vanes were recommended to provide suitable bank protection while creating fish habitat.

2.2.3 Scott Bicentennial Park Project

In 2011 the town of Dayton, the SCCD, the NRCS, and the Wyoming Game and Fish Department collaborated to research issues related to the section of the Tongue River that flows through Scott Bicentennial Park in Dayton. The town was interested in reducing stream bank erosion and point bar formation inside the park. Pearson (2011) suggested that the Tongue River was mostly stable through Scott Bicentennial Park, but recommended reshaping the stream channel and installing in-stream structures to enhance stability and restore access and aesthetic value.

2.3 Reach Characteristics

2.3.1 Map-Based Division by Slope

Prior to the channel survey, Barr established stationing on the entire length of the Tongue River within the project area. This allowed team members to reference specific locations or lengths of stream bank. Station 0+00 is the upstream end of the Tongue River within the project area and station 263+00 is the downstream end at the Highway 14 Bridge in downtown Dayton. The stationing is in 500-foot increments as shown in Figure 2-5.

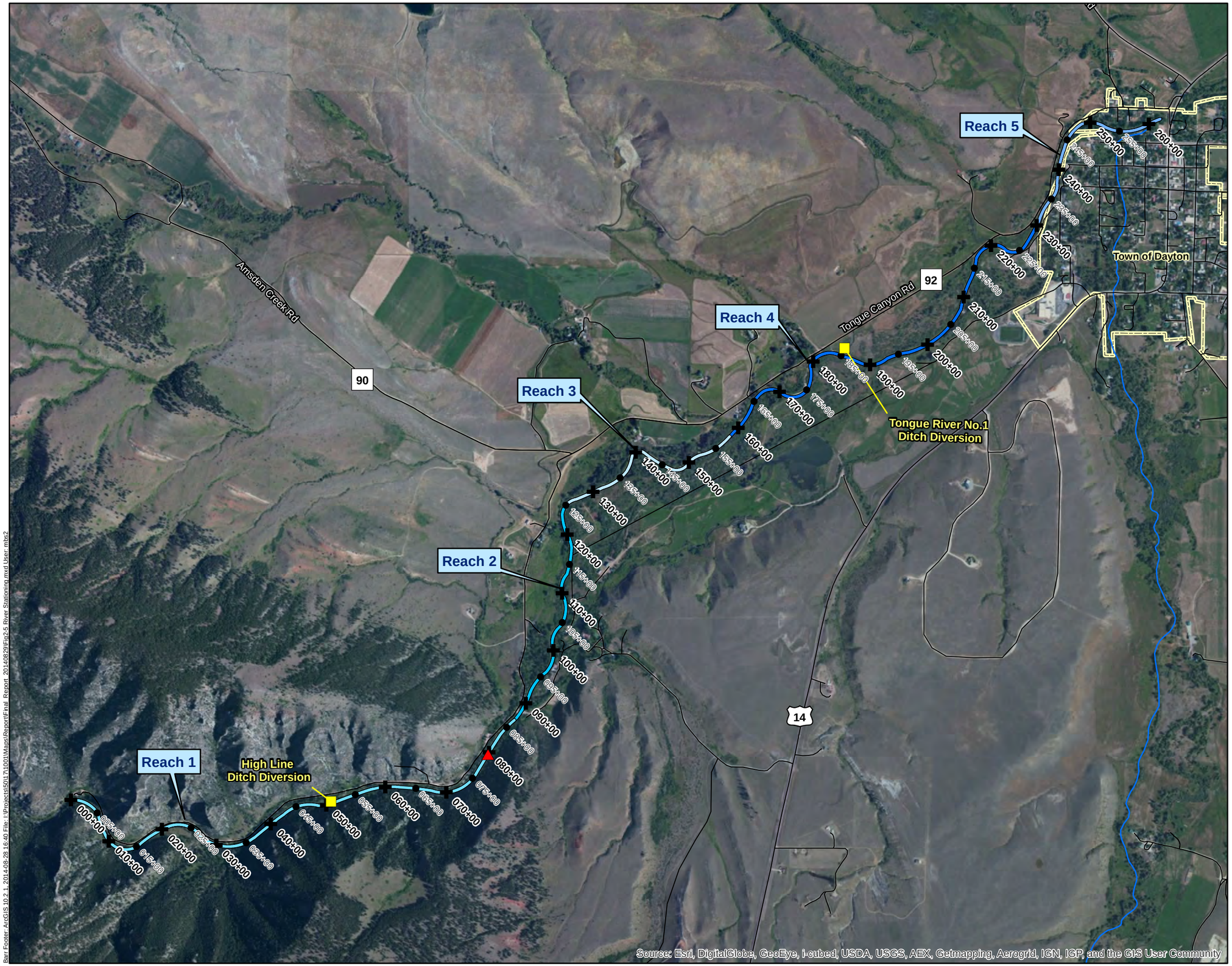
Stationing provides information on horizontal distance, but no information on change in elevation over that distance. After establishing stationing along the reach, Barr used 10-foot contour data from the NRCS to draw a profile of the Tongue River. Based on this profile, Barr segmented the Tongue River below the USGS gage into five distinct reaches, shown in Figure 2-6 and Figure 2-7 and summarized in Table 2-3. Reaches 1, 2, and 4 are considered areas of relatively high bed slope, with estimated overall slope values of approximately 1% or greater. Reaches 3 and 5 are considered areas of relatively low bed slope, with estimated overall slope values of 0.6% or less. The slopes in Figure 2-6 should be considered approximate and are meant to represent general values; each reach will have specific areas with slopes higher and lower than those used for this preliminary classification.

Table 2-3 Summary of reach characteristics

Reach Name	Estimated Slope (%)	Extent
1	1.5	0+00 to 86+00
2	1.2	86+00 to 125+00
3	0.3	125+00 to 158+00
4	1.1	158+00 to 230+00
5	0.6	230+00 to 263+00

Dividing the Tongue River into reaches based on slope had two purposes. First, it was a way to select areas for detailed survey based on a comprehensive dataset which accurately describes the Tongue River on a larger scale. Existing erosion and sedimentation issues must be addressed, but understanding their causes in the context of larger scale geomorphic processes can help inform appropriate solutions.

Second, the division by slope allowed us to analyze reaches which behave (or may behave) in a similar manner together. Slope is a primary driver of geomorphic processes and directly proportional to shear stress (the primary force in sediment transport). This makes it a very useful metric for comparing sections of the river that may benefit from similar recommendations—whether for stabilization, habitat restoration, or other purposes.



- USGS Gage Location
- Tongue River Diversion Headgate
- River Centerline

River Stationing (ft)

- 1000' River Station
- 500' River Station

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

1,500 0 1,500

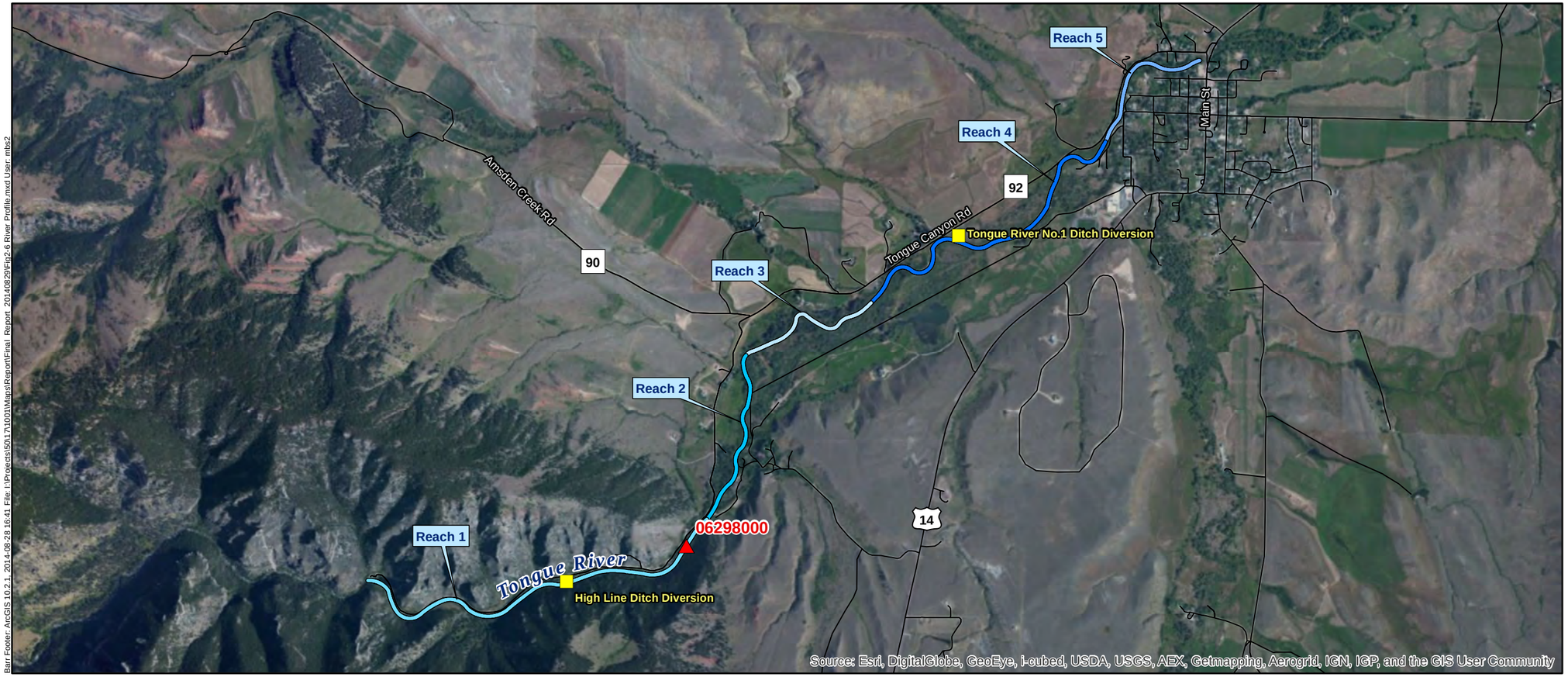
Figure 2-5

RIVER STATIONING
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:40 File: I:\Projects\50\17\10\01\Mapsi\Report\Final Report_20140829\Fig2-5 River Stationing.mxd User: mbs2

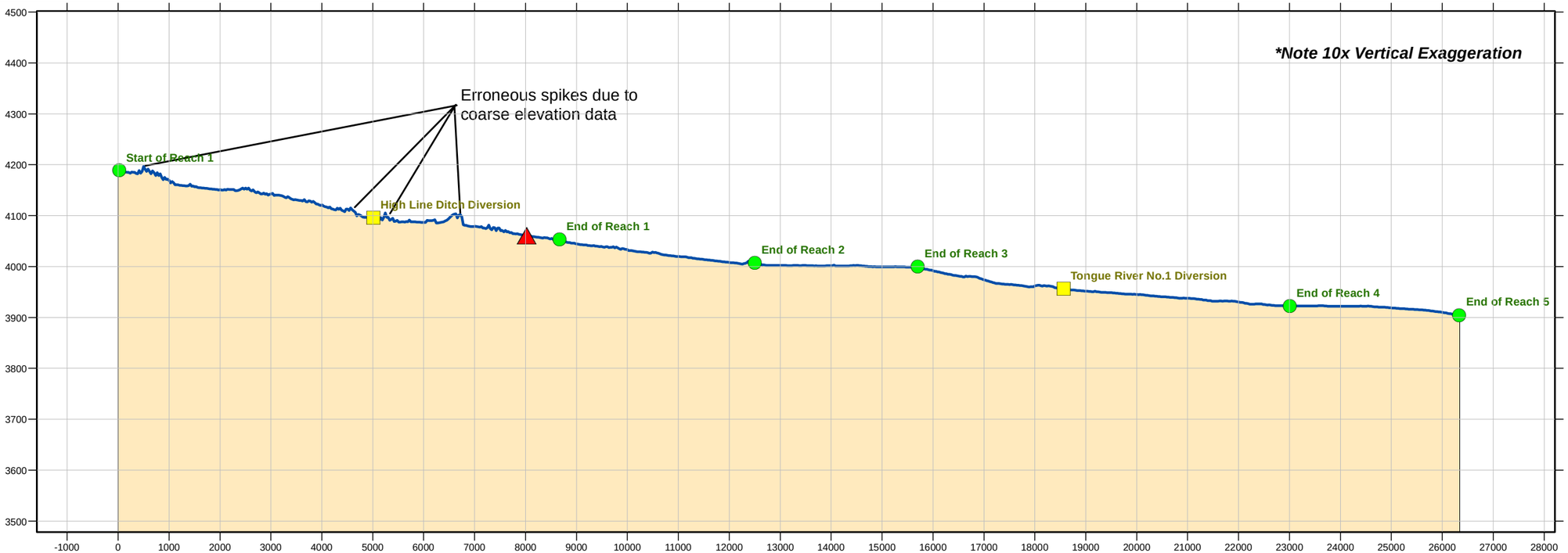


Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:41 File: I:\Projects\50\17\1001\Maps\Report\Final_Report_20140829\Fig2-6 River Profile.mxd User: mbs2

- USGS Gage Location
- Tongue River Diversion Headgate
- Start/End of River Reach

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5



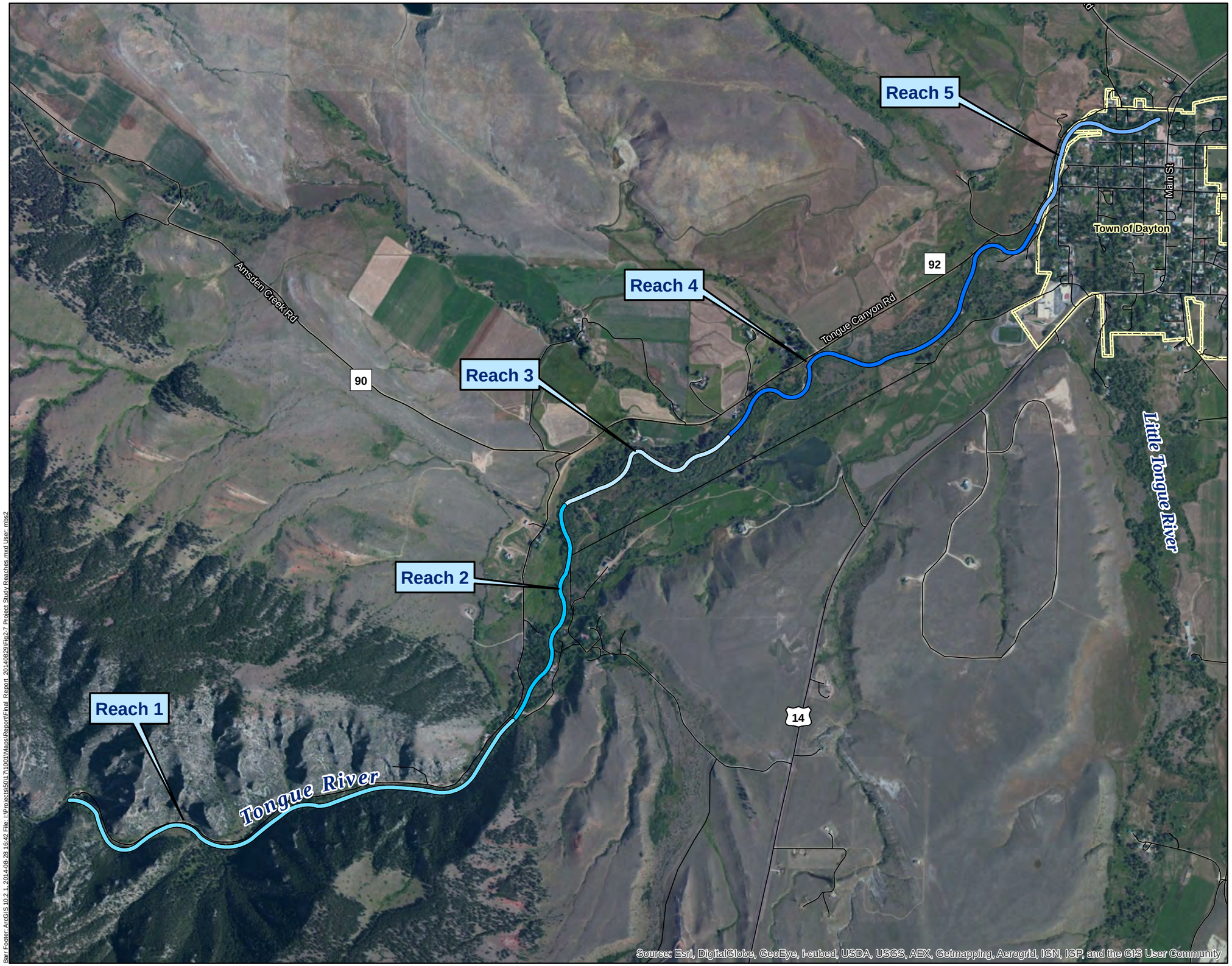
Feet

2,500 0 2,500

Figure 2-6

RIVER PROFILE IN FEET

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming



Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

N

Feet

1,500 0 1,500

Figure 2-7

PROJECT STUDY REACHES
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:42 File: I:\Projects\50\17\1001\Maps\Report\Final Report_20140829\Fig2-7 Project Study Reaches.mxd User: mbs2

2.3.2 Historic and Current Channel Alignment

Historic data on channel alignment can provide very useful information about the geomorphic processes of a stream. Changes in sinuosity, channel width, radius of curvature, and other planform characteristics can provide clues about a stream's evolution over time, even if no other data is available. Barr analyzed aerial photos of the Tongue River project area taken in 1954, 1979, and 2012 to observe changes in channel alignment—both natural and man-made.

2.3.2.1 Historical Aerial Photo Evaluation

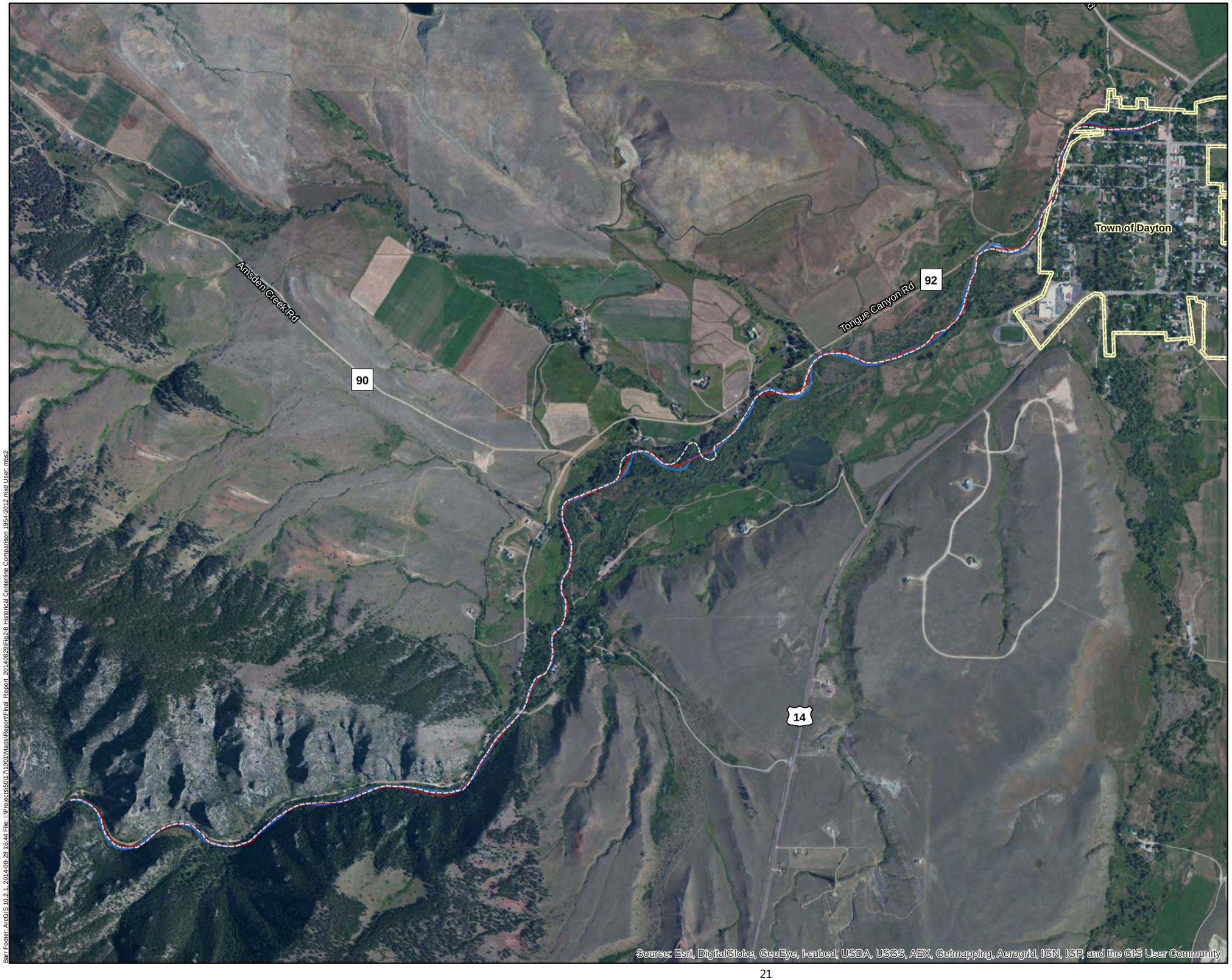
Photos in the project area were available from the downstream boundary of the project reach (station 263+00) to approximately the upstream end of Reach 2 (station 90+00). Barr staff digitized the centerline of the river in each year and then used the reach divisions based on slope (discussed in Section 2.3.1) to qualitatively compare the planform features and changes in length between years. The four sections analyzed are shown in Figure 2-8.

Figure 2-8 shows that, overall, the Tongue River has had a net loss of length since 1954. The oldest centerline shows several meanders that have been cut off, and some of the existing meanders have decreased in radius of curvature, decreasing their overall length. Station 140+00 is an example of a meander that was not cut off but has shortened naturally in the past 60 years. The 1954 aerial photo in Figure 2-9 shows a reach that extends from upstream of the bridge at Highway 14 to a point near Station 248+00. The photo appears to corroborate anecdotal information from local landowners regarding a channelization project constructed during the early-to-mid 1950s. However, the design team was unable to independently verify the existence of this project. Some residents also provided anecdotal information about private channelization projects completed by past landowners.

Table 2-4 Comparison of channel length changes on the Tongue River, 1954–2012

Tongue River Centerline Changes in Length, 1954–2012										
Year	**Reach 2 Length (ft)**	**Reach 2 Change (ft)**	**Reach 3 Length (ft)**	**Reach 3 Change (ft)**	**Reach 4 Length (ft)**	**Reach 4 Change (ft)**	**Reach 5 Length (ft)**	**Reach 5 Change (ft)**	**Total Length (ft)**	**Total Length Change (ft)**
1954	3893		3915		6317		3688		17813	
1979	3853	-40	3449	-466	6254	-63	3671	-17	17227	-586
2012	3830	-23	3500	51	6503	249	3700	29	17533	306

Every reach was shorter in 1972 than in 1954. However, between 1979 and 2012, every reach except Reach 2 had gained back some of its lost length, and Reach 4 was actually longer in 2012 than it was in 1954. However, between 1954 and 2012 the net change in channel length within the project area was a loss of 280 feet.



1954 River Centerline
1979 River Centerline
2012 River Centerline
Municipal Boundary

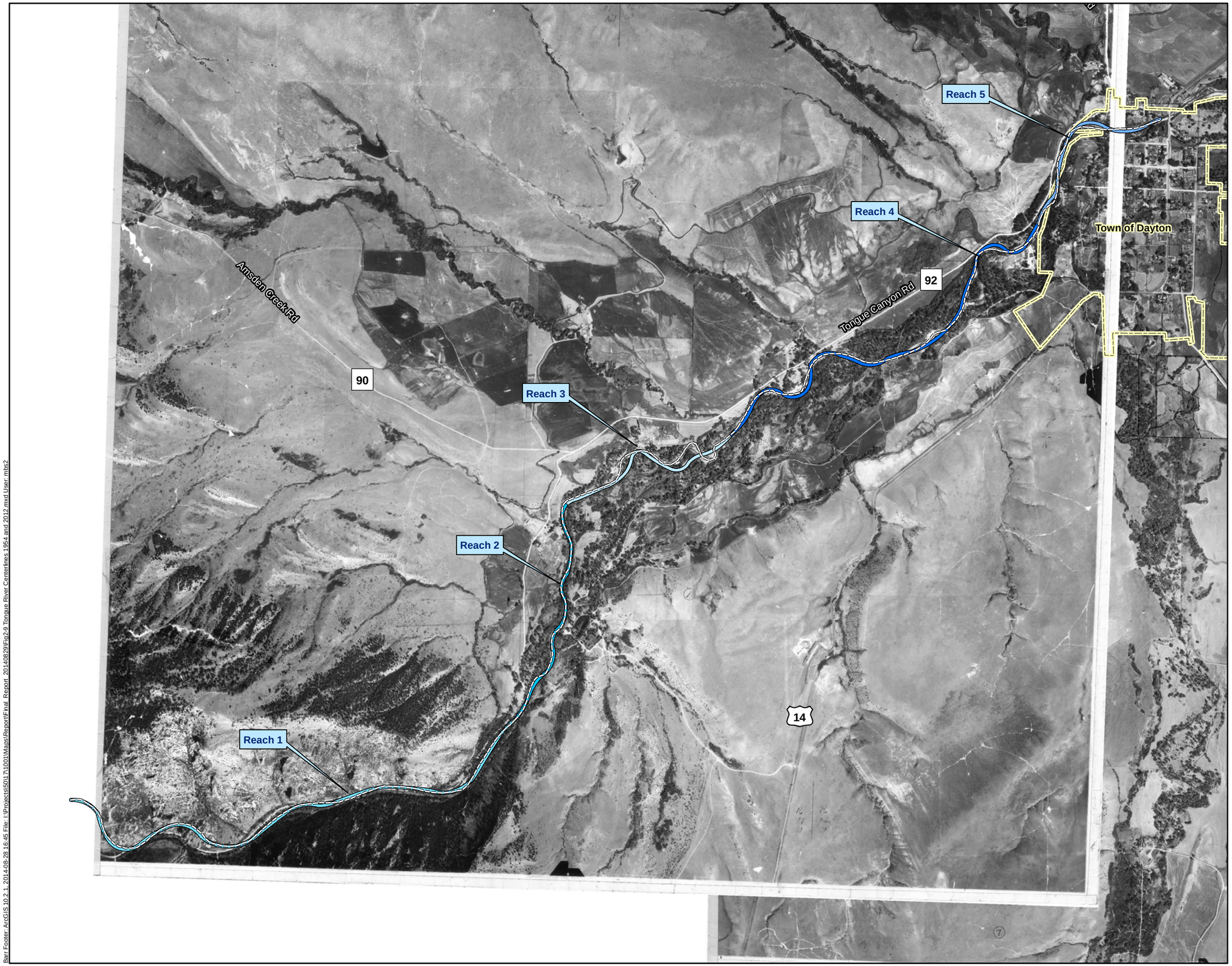
Feet
1,500 0 1,500

Figure 2-8

HISTORICAL CENTERLINE COMPARISON, 1954 - 2012
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT
BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:44 File: I:\Projects\5017\1001\Mxds\Report\Final Report_20140829\Fig2-8 Historical Centerline Comparison 1954-2012.mxd User: mbs2



1954 River Centerline

Project River Reaches (2012)

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

1,500 0 1,500

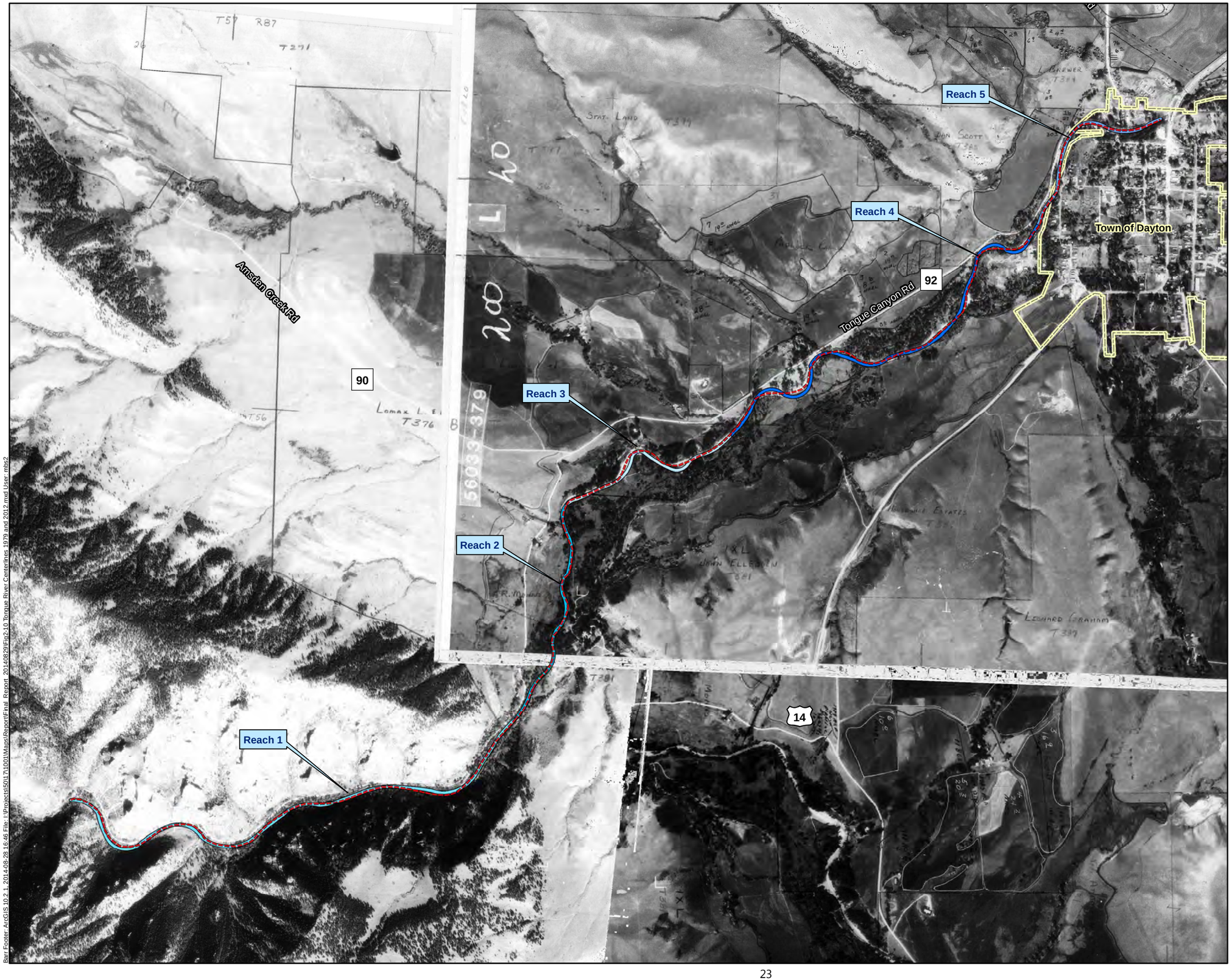
Figure 2-9

TONGUE RIVER
CENTERLINES, 1954 and 2012
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:45 File: I:\Projects\5017\10001\Maps\Report\Final Report 20140829\Fig2-9 Tongue River Centerlines 1954 and 2012.mxd User: mbs2



1979 River Centerline

Project River Reaches (2012)

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

1,500 0 1,500

Figure 2-10

TONGUE RIVER CENTERLINES, 1979 and 2012

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:46 File: I:\Projects\50\17\10\01\Maps\Report\Final Report_20140829\Fig2-10 Tongue River Centerlines 1979 and 2012.mxd User: mbs2

3.0 Landowner and Public Participation

3.1 Landowner and Stakeholder Outreach

A project start-up meeting was held in October 2013 in the town of Dayton to: (1) hear the concerns of landowners and other stakeholders, (2) begin scheduling the SVAP meetings, and (3) describe the team's proposed approach to the assessment. The meeting also provided an opportunity to update landowner contact information and facilitated coordination with landowners to access private land for the stream survey. SVAP meetings immediately followed the October meeting and were used to develop the field survey schedule as high-priority areas of concern were identified.

Landowners were updated and informed regularly about the assessment progress. Updates were provided during the SVAP meetings (October 2013–April 2014), at the February 6, 2014, Tongue River Watershed Planning Meeting, and during an April 2014 meeting where a group of landowners gathered with the field team to discuss possible actions to reduce impacts from high flows anticipated in the spring. Two information meetings held in Dayton on June 24, 2014, provided an opportunity for landowners and government agency stakeholders to comment on the draft stream concept improvement report, ask questions, and provide input prior to finalization of the assessment report. On July 2, 2014, the SCCD sent follow-up letters to all landowners of record, requesting additional comments for inclusion in the final report. SCCD had not received or recorded any additional comments by August 13, 2014.

3.2 SVAP Process

The SVAP process provided landowners with the opportunity to use both a ranked system of metrics and a more personal, in-depth perspective to rate the channel, bank, and in-stream conditions of the river (Appendix B). Metrics used in the SVAP process include indicators of channel and bank condition, water quality, fish habitat, connectivity, and invertebrate habitat. During SVAP data collection, team members and SCCD personnel met with individual and/or groups of land owners to discuss and evaluate existing areas of sedimentation and erosion. SVAP scoring worksheets and hand-drawn site maps were completed during each meeting. SVAP landowner meetings were completed on an irregular schedule; the final landowner meeting was completed in April 2014. Compiled SVAP data is available in Appendix B.

Each landowner was provided a personal copy of the SVAP assessment protocol book during the project start-up meeting or at a site meeting. The SVAP, as developed by the NRCS, uses a series of metrics ranked 1–10, with low numbers indicative of degraded or poor conditions. Metrics receiving a numerical score below 5 are considered low. A cumulative reach score (total score/number of scored metrics) below 6 is considered poor. SVAP meetings and associated rankings were applicable to specific areas on the river as shown in Table 3-1.

A common theme among participating landowners was the desire for increased fish habitat and improved angling conditions. The fish habitat complexity metric from the SVAP quantifies this need; however, all of the in-person and group interviews highlighted this concern.

Table 3-1 SVAP summary information

SVAP Number	River Station	Reach Cumulative Score	Primary Concerns	Primary Future Desire
SVAP 1	85+00 to 87+00	7.2	Localized bed aggradation and lack of bank and in-stream cover and pools	Address erosion near small diversion
SVAP 2	102+00 to 103+00	6.0	Active localized lateral bank movement, lack of riparian woody cover, few pools, width/depth (W/D) ratio	Maintain viewscape, address localized flooding due to overland flow from upland area
SVAP 3	100+00 to 215+00	6.1	Active lateral bank movement, lack of riparian and in-stream woody cover, few pools, W/D ratio	Address erosion near diversion, potential channel avulsions
SVAP 4	125+00 to 150+00	6.7	Active lateral bank movement, lack of riparian and in-stream woody cover, few pools, W/D ratio	Address localized erosion issues, potential channel avulsions
SVAP 5	215+00 to 235+00	6.4	Active bank erosion, lack of riparian woody cover, possible headcut, long reach with rock armor	Address active bank erosion and establish a more stable planform
SVAP 6	230+00 to 245+00	6.5	Active lateral erosion, lack of shrubs, channel incision, deposition	Address active lateral erosion, hope for better fish habitat
SVAP 7	235+00 to 250+00	7.0	Channel incision, lack of shrubs, road encroachment, lack of in-stream cover	Improve riparian zone, address storm sewer discharge, better fish habitat

4.0 Field Survey and Site Evaluations

4.1 Survey Methodology

4.1.1 Field Survey

Following the review of the existing data and site-specific concerns developed during the start-up meeting and completed SVAP meetings, the project team conducted a multi-part field survey, collecting data on the Tongue River throughout the project area. The first phase was conducted in October 2013 and consisted of walking the river from the USGS gage at the upstream end to the Highway 14 Bridge in downtown Dayton, documenting areas of erosion and deposition in field notes, and obtaining geo-referenced photographs. Data for Levels 1 and 2 of Rosgen channel classification included 17 cross sections, two bar samples, and four pebble counts (Wolman 1954). Data for Level III Rosgen classification included Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) evaluations at eight locations along Reaches 2–5. All cross section, BEHI, bar sample, pebble count, and longitudinal profile locations are shown in Reserved for:

Figure 4-1, Figure 4-2, and Figure 4-3. The October survey was conducted assuming a relative vertical datum that was later converted to North American Vertical Datum of 1988 (NAVD 88), based on a second field survey conducted in December 2013 with a survey-grade GPS system.

4.1.2 Profile Surveys

Cross-section spacing from the survey in October 2013 for Cross Sections 1–7 allowed development of a rough longitudinal profile for this sub-reach. The second phase of the survey was conducted to collect longitudinal profiles in three specific areas.

The first longitudinal profile, measured in the Tongue River Canyon, began at station 58+00 and continued downstream to station 61+00. This profile describes the pool-riffle structures in the higher slope reaches of the Tongue River; it contains two cross sections, as well as measured dimensions to describe pool and riffle size. The design team surveyed this area for reference information to aid in developing step-pool spacing and riffle slopes for use at higher slope locations. The location for this profile is shown in Figure 4-1.

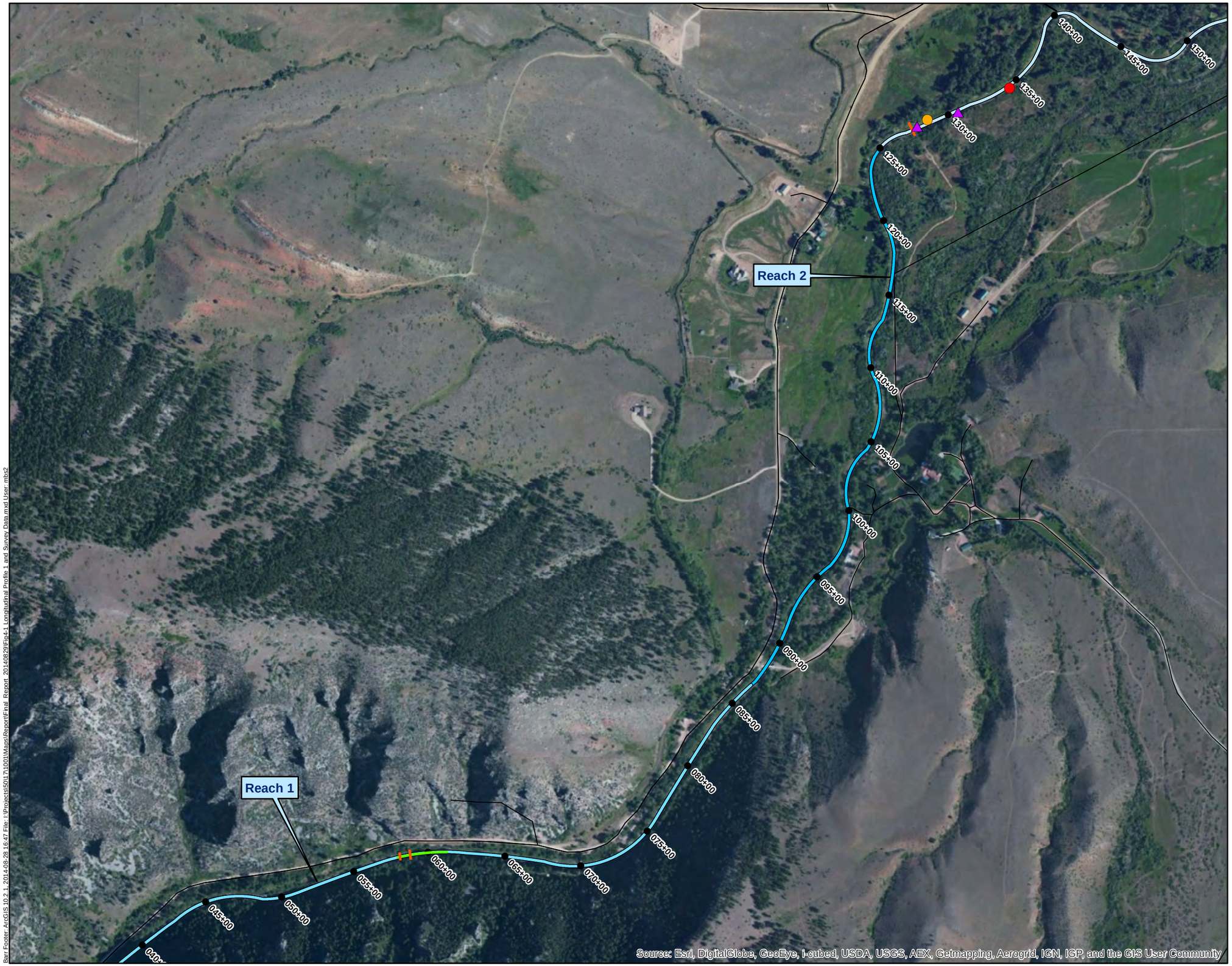
The second longitudinal profile began at station 164+00 and ended at station 180+00, just upstream of the Tongue River No. 1 Ditch. This profile describes lower slope reaches, which have less defined pool-riffle structures, higher sinuosity, and visible point-bar development. This profile also contains one of the only areas in the project reach with a naturally occurring meander pattern—a major factor in selecting this site for a detailed profile study. The location for this profile is shown in Figure 4-2.

The third longitudinal profile began at station 220+00 and ended at station 227+00. This profile contains several features which the survey team wished to study in greater detail, including scour pools on the outside of meander bends, point bars, and a developing transverse bar. The location for this profile is shown in Figure 4-3.

Because the primary focus of the assessment was the immediate channel, cross-sectional survey data focused on the bankfull channel and confining riverbanks. Where necessary, cross sections were extended in GIS for classification purposes (i.e., determining the width of the flood-prone area) based on NRCS 10-foot topography. A more extensive floodplain survey may be conducted in the future if re-meandering of the river or reconnection of the oxbow is pursued.

Table 4-1 Survey tasks completed by reach

Reach (Station)	Survey Task				
	Profile	Cross Section	Walk	Photo Survey	Pebble Count
1 (0+00 to 86+00)	X	X	Limited	Limited	
2 (86+00 to 125+00)			X	X	
3 (125+00 to 158+00)		X	X	X	X
4 (158+00 to 230+00)	X	X	X	X	X
5 (230+00 to 263+00)	X	X	X	X	X



500' River Station

Bank Erosion Hazard Index

- Extreme
- Very High
- High
- Moderate

Sediment Sample Site

- Bar Sample
- Pebble Count
- Cross Sections
- Longitudinal Profiles

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

600 0 600

Figure 4-1

LONGITUDINAL PROFILE 1 AND SURVEY DATA

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:47 File: I:\Projects\50\17\10\01\Maps\Report\Final_Report_20140829\Fig4-1 Longitudinal Profile 1 and Survey Data.mxd User: mbs2

- 500' River Station

Bank Erosion Hazard Index

- Extreme
- Very High
- High
- Moderate

Sediment Sample Site

- Bar Sample
- Pebble Count
- Cross Sections
- Longitudinal Profiles

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

400 0 400

Figure 4-2

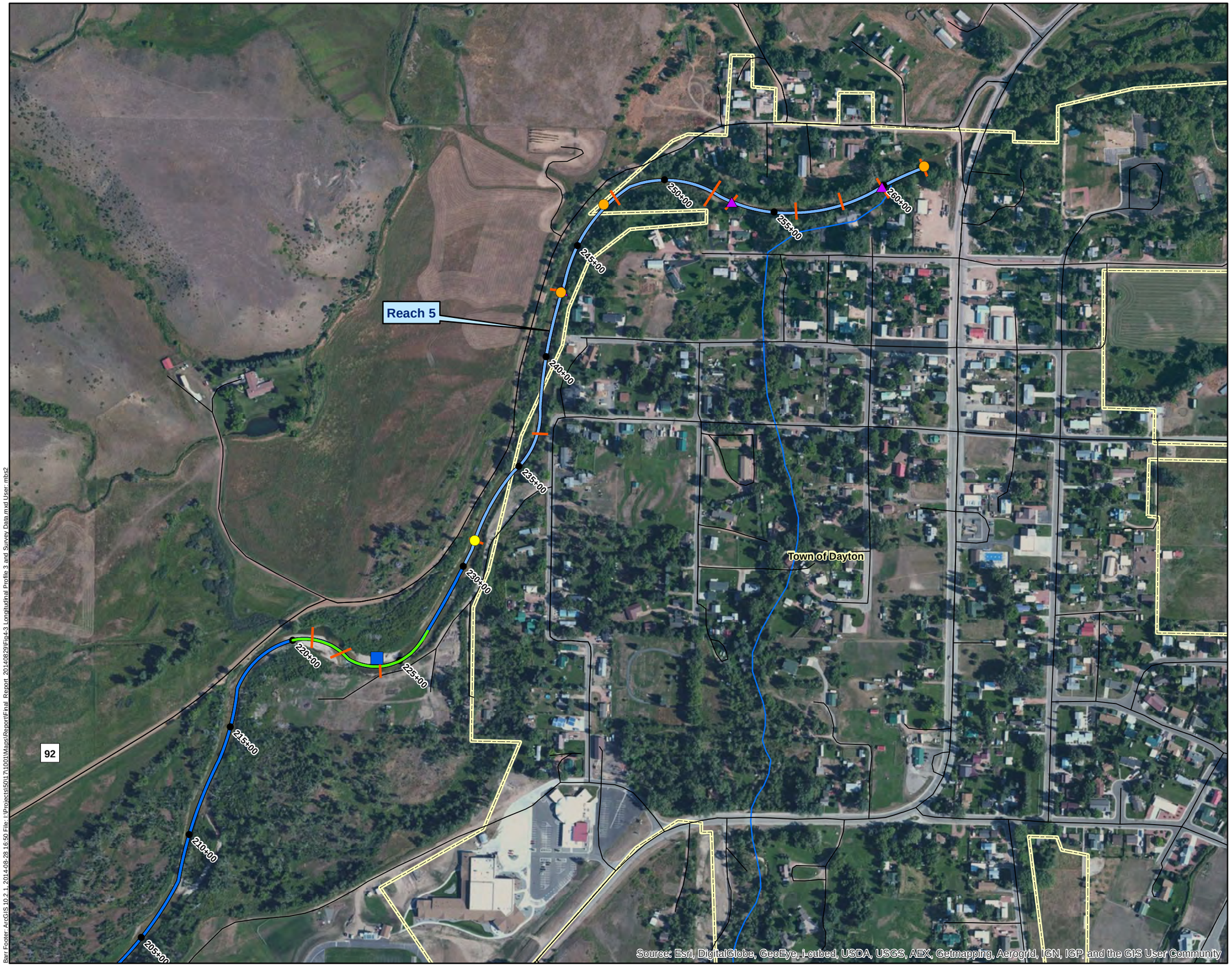
LONGITUDINAL PROFILE 2 AND SURVEY DATA

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:48 File: I:\Projects\5013\10011\Maps\Report\Final_Report_20140829\Fig4-2 Longitudinal Profile 2 and Survey Data.mxd User: mbs2



- 500' River Station

Bank Erosion Hazard Index

- Extreme
- Very High
- High
- Moderate

Sediment Sample Site

- Bar Sample
- Pebble Count
- Cross Sections
- Longitudinal Profiles

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

400 0 400

Figure 4-3

LONGITUDINAL PROFILE 3 AND SURVEY DATA

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:50, File: I:\Projects\5017\10011\Maps\Report\Final_Report_20140829\Fig4-3 Longitudinal Profile 3 and Survey Data.mxd User: mbs2

4.2 Observations

4.2.1 Morphology and Rosgen Classification

The Rosgen method of stream classification was developed by Dr. Dave Rosgen in the 1990s. The first two levels of classification allow for a stratification of streams by morphology (Rosgen 1994). Stream reach classification using the Rosgen method was the basis for communicating the reach types and conditions and for describing the river geomorphology and expected behavior based on documentation of similarly classified streams.

4.2.1.1 Cross-Section Data

Reach 1

Reach 1 is 8,600 feet long and extends from station 0+00 to station 86+00. This reach begins at the upper end of Tongue Canyon Road and ends 600 feet below the USGS gage above Dayton (#06298000). Tongue Canyon Road runs parallel to this reach for its entire length, and the land ownership around it is a combination of public and private lands, with the north bank being almost exclusively public land.

Reach 1 is outside the primary focus area since this section has minimal erosion. However, a longitudinal profile and cross sections were surveyed by the team at the request of the NRCS and other project partners. The reasons for the survey were: (1) to develop dimensions and ratios for stabilization structures in higher slope areas, and (2) to improve the understanding of the slope and channel dimensions on this stretch of the Tongue River. As such, Reach 1 contains two of the 22 cross sections surveyed. A typical cross section for Reach 1 is shown in Figure 4-4.

Cross section 26 is one of two cross sections surveyed in Reach 1 to describe the higher slope sections of the Tongue River. Its area and bankfull width are consistent with regional curves, and the dominant shape is similar to sections previously discussed in other reaches. The banks are still nearly vertical, but lower than those observed elsewhere along the Tongue River. The valley in Reach 1 can be described as Rosgen Type II; it has moderately steep side slopes made primarily of loose, unconsolidated sediments that have been deposited by the river at the base of the Big Horn Mountains.

Reach 1 is classified as a B-type channel; it is less entrenched than Reach 3, but more entrenched than Reaches 4 and 5. No pebble counts were completed in Reach 1, so it is not possible to officially classify the reach based on channel material. However, due to the dominance of large boulders in the channel, the survey team feels confident in assigning this reach a B-2 classification. A reach classification worksheet is provided in Table 4-2.

Photo 4-1 The Tongue River within Reach 1

Reach 1 is very different from Reaches 3, 4, and 5. It has a higher slope, larger dominant materials, more confining valley walls, and different channel structure. While distinct pool structures were less common in Reaches 3–5, Reach 1 is dominated by the step-pool system. Along with nearly immovable bed material, this provides extremely competent grade control.

The survey team did not walk the entire Reach 1, but the survey did include a longitudinal profile between stations 58+00 and 61+00. This profile covered two complete step-pool patterns and allowed the survey team to develop a classification and dimensionless ratios applicable to this distinct area of the Tongue River.

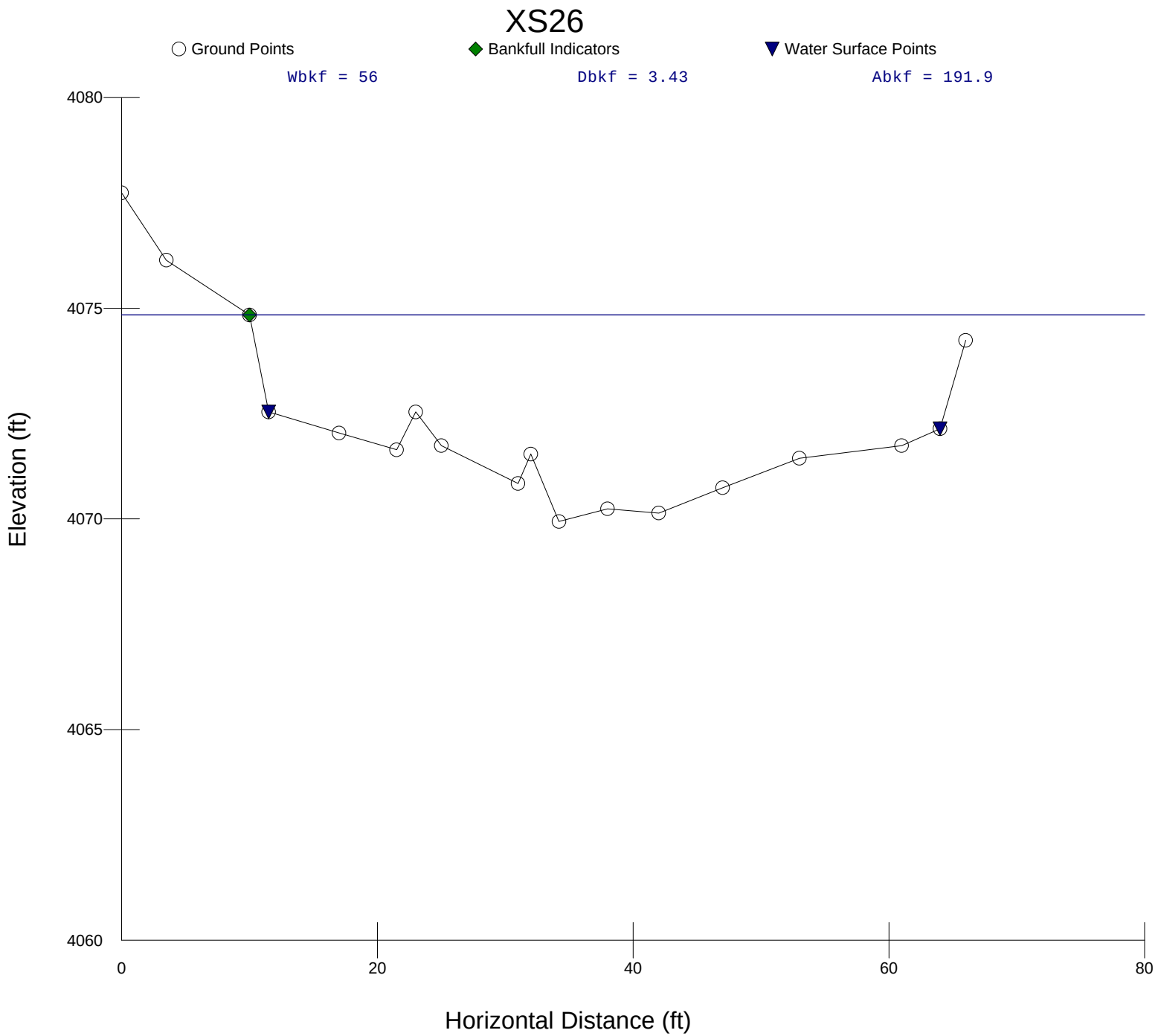


Figure 4-4 Typical Cross Section Reach 1

Table 4-2 Reach 1 classification worksheet

Worksheet 5-3. Field form for Level II stream classification (Rosgen 1996, Rosgen and Silvey 2005)

Stream:	**Tongue River**			
Basin:	**Powderhorn River**	Drainage Area: **131840** acres	**206**	mi^2
Location:	**Reach 1, XS 26**			
Twp.&Rge:	**T56N R87W**	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):			Date:	**4/14/14**
Observers:	**Starkey, Burke, Koth**		Valley Type:	II

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**56**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**3.43**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**191.9**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**16.33**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**4.9**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**75**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.34**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**101**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.01**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.1**	

Stream Type **B-2** (See **Figure 2-14**)

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Reach 2

Reach 2 is 3,900 feet long and extends from station 86+00 to station 125+00. The upstream end of this section is 600 feet downstream of the USGS gage above Dayton (#06298000). There are several private homes along the west bank of this reach; most of the east bank is owned by a single private owner.

Reach 2 is an area of channel and valley-type transition for the Tongue River. At the upstream end it is in a confined mountain valley (Rosgen Type 1). At the downstream end it transitions to a wider, less confining alluvial valley (Rosgen Type VIII). This change in valley type is accompanied by a slope transition—from a steeper slope typical of the upstream Reach 1 (S=1.5%) to the lower slopes typical of the downstream reaches. Reach 2 has an average slope of 1.2%, the highest slope of those studied, with the exception of Reach 1. Reach 2 and Reach 1 are both dominated by boulders and a step-pool system.

There are no surveyed cross sections within Reach 2. During the October survey, the team walked the river from Cross Section 18 to approximately station 92+00 and observed several areas of minor bank erosion—some of which had been discussed during the public meetings or the SVAP process. The survey team evaluated the reach conditions as a whole and determined that the existing erosion issues on Reach 2 were localized, rather than widespread. Because of the similarities in slope and bed material, the team applied the same classification to Reach 2 as Reach 1, making it a B-2 channel. To account for the geomorphic transition occurring in this reach, bank stabilization solutions would be composites of those proposed in Reaches 3–5 and those suitable for use in Reach 1.

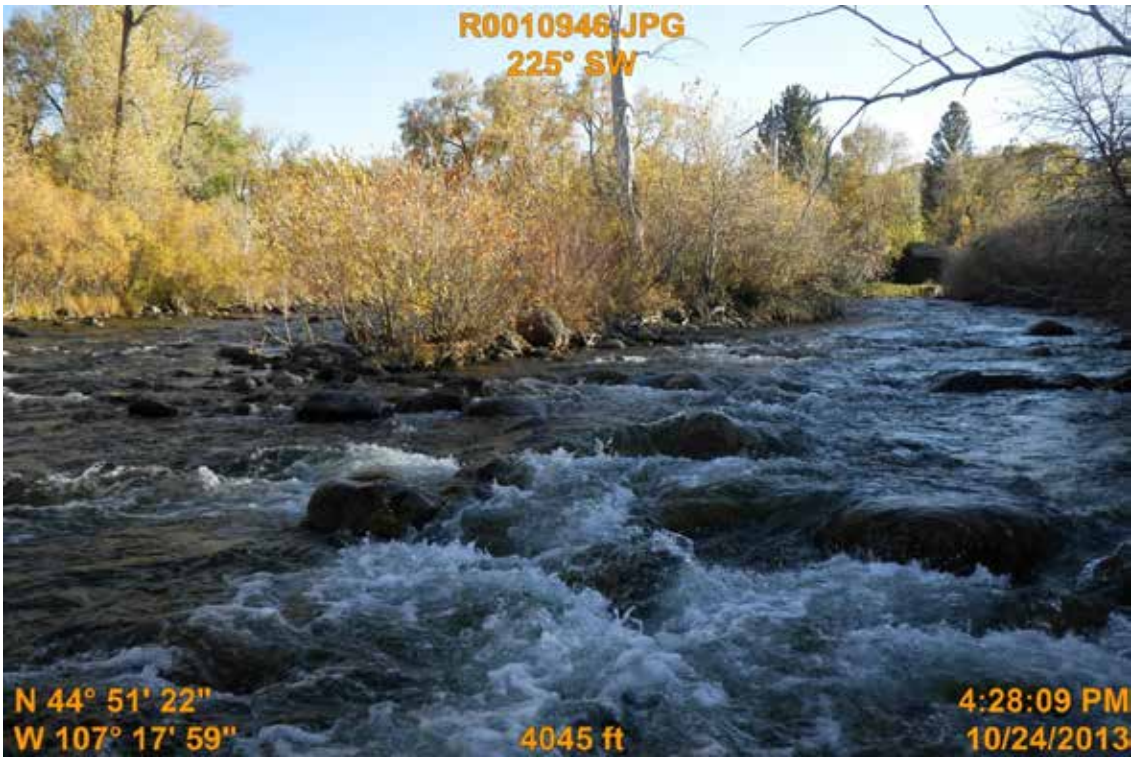

Photo 4-2 The Tongue River within Reach 2

Reach 3

Reach 3 is 3,300 feet long and extends from station 125+00 to 158+00. Here, the river is bordered or within two private land parcels and not particularly close to Tongue Canyon Road. Reach 3 contains one of the 22 surveyed cross sections, shown in Figure 4-5. Reach 3 also contains a backwater channel, which the river has begun to abandon, beginning at station 148+00. Anecdotal evidence from the current landowner suggests that this cutoff was constructed decades ago by his father, but the backwater channel still receives a significant amount of flow and has been able to maintain a moderately sinuous pattern and stable stream banks. Photo 4-3 shows the diversion of flow between the straightened channel on the left and the original channel on the right.

Photo 4-3 Flow diversion on the Tongue River around an island within Reach 3

Cross section 18 has steep banks and is relatively wide (high width/depth ratio). However, the channel dimensions in Reach 3 differ slightly from those in Reaches 1 and 2; the base flow channel width is closer to 70 feet than 60 feet, and the bankfull width is nearly 80 feet. These differences result in a more entrenched channel and a smaller flood-prone area. The bed material is also smaller than in Reaches 1 and 2 (D_{50} of 101 mm), and the slope is relatively low.

Reach 3 is classified as an F channel; it has a similar width-depth ratio as a C channel, but is considered entrenched. This means the channel has less access to its floodplain compared to channels with a higher entrenchment ratio, and it takes a larger event to cause overbank flooding. Despite the larger D_{50} value, the system is still considered cobble-dominated, leading to a classification of F-3. (Table 4-3 provides a reach classification worksheet.) Reach 3 has a modest riffle-pool structure, but it is vulnerable to bank erosion because of the unconfined and heterogeneous nature of the bank sediment (Rosgen 1996). Vegetation is less effective at stabilizing the banks in these reaches because the banks are relatively high, leaving root systems farther from the normal waterline and less able to hold soil material in place, particularly on steep slopes.

There are no existing stabilization efforts on Reach 3, but analysis of historical aerial photography shows that there has been channelization in the past, resulting in a loss of channel length (see Section 2.3.1 for further detail).

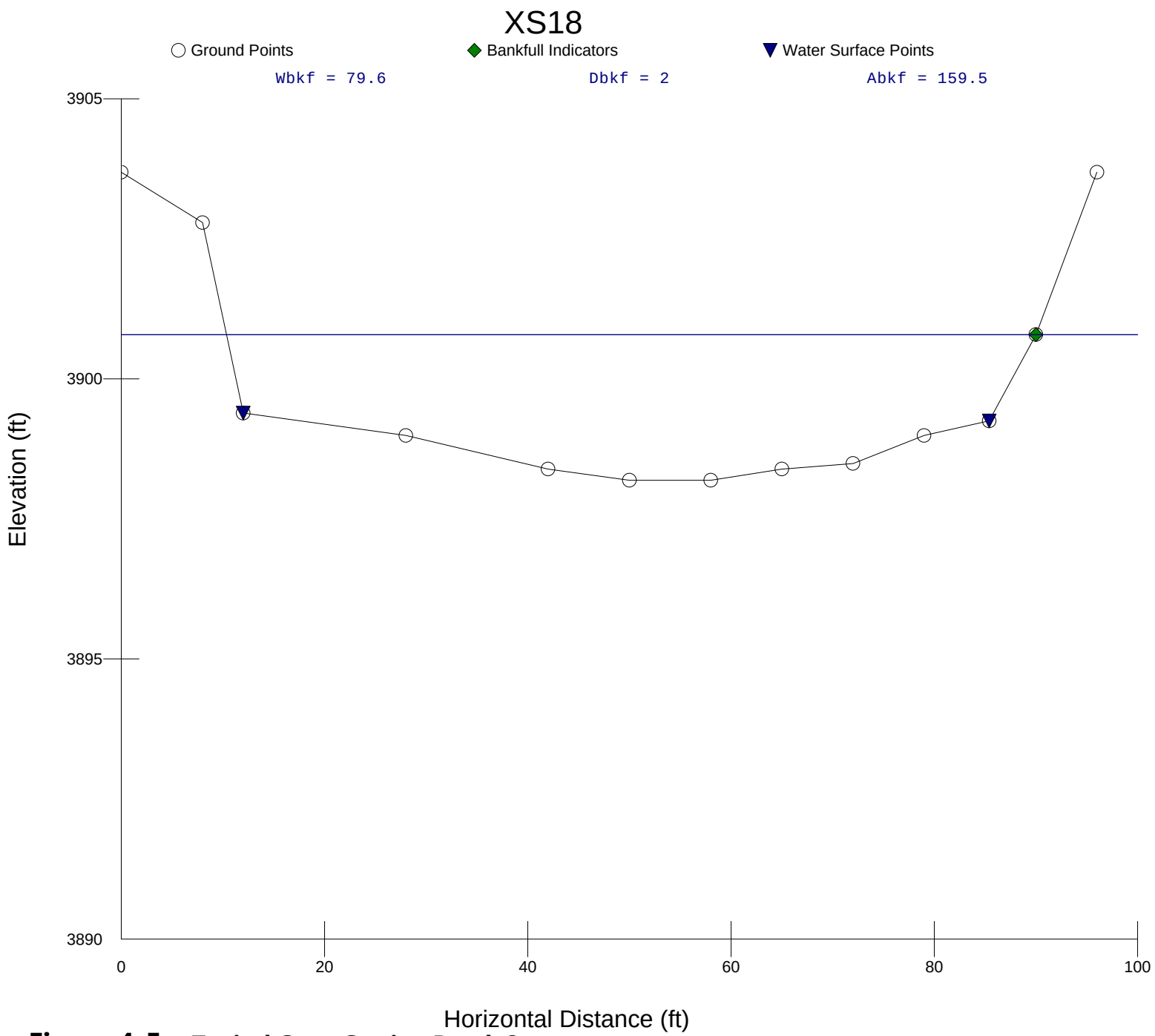

Figure 4-5 Typical Cross Section Reach 3

Table 4-3 Reach 3 classification worksheet

Worksheet 5-3. Field form for Level II stream classification (Rosgen 1996, Rosgen and Silvey 2005)

Stream:	**Tongue River**			
Basin:	**Powderhorn River**	Drainage Area: **131840** acres	**206**	mi^2
Location:	**Reach 3, XS 18**			
Twp.&Rge:	**T56N, R87W**	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):			Date:	**10/25/13**
Observers:	**Starkey, Mikus, Burke**		Valley Type:	VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**79.65**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**2**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**159.48**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**39.83**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**2.6**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**92.71**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**1.16**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**101**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.004**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.1**	

Stream Type **F 3** (See **Figure 2-14**)

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Photo 4-4 The Tongue River within Reach 3

Reach 4

Reach 4 is mostly upstream of the primary residential areas in Dayton; in some sections it is very close to Tongue Canyon Road. The reach is 7,200 feet long and extends from station 158+00 to 230+00. It contains nine of the 22 surveyed cross sections. A typical cross section for Reach 4 is shown in Figure 4-6.

The channel in Reach 4 has steep banks and an average width at base flow of approximately 60 feet. The channel is slightly entrenched and has a moderate width-to-depth ratio. The D_{50} particle size is approximately 58 centimeters.

Reach 4 is classified as a C-4 channel and falls within the expected range of sinuosity values for a C channel; the 1.21 value is an average for the reach, which has both sinuous sections (stations 164+00 to 184+00) and straighter sections (190+00 to 210+00). A reach classification worksheet is shown in Table 4-4.

Photo 4-5 The Tongue River within Reach 4

The morphological description of a C-4 channel suggests that it is often found in Valley Type VIII. This valley type is characterized by a broad valley, the presence of alluvial materials, and a well-developed floodplain. This is the classification of the Tongue River valley once it has left the confining Type II valleys of the Bighorn Mountains. The description also predicts that the banks will consist of "unconsolidated, heterogeneous, non-cohesive, alluvial materials which are finer than the cobble-dominated bed material" and that this channel type is "susceptible to accelerated bank erosion" (Rosgen 1996).

Existing stabilization efforts on Reach 4 were designed to protect roads and diversion structures. Gabion baskets are in use to protect Tongue Canyon Road in the vicinity of the Tongue River No. 1 Diversion. At the time of the October survey, riprap was being placed along Tongue Canyon Road between stations 217+00 and 220+00.

Photo 4-6 Unconsolidated, heterogeneous bank material typical of banks in Reach 4

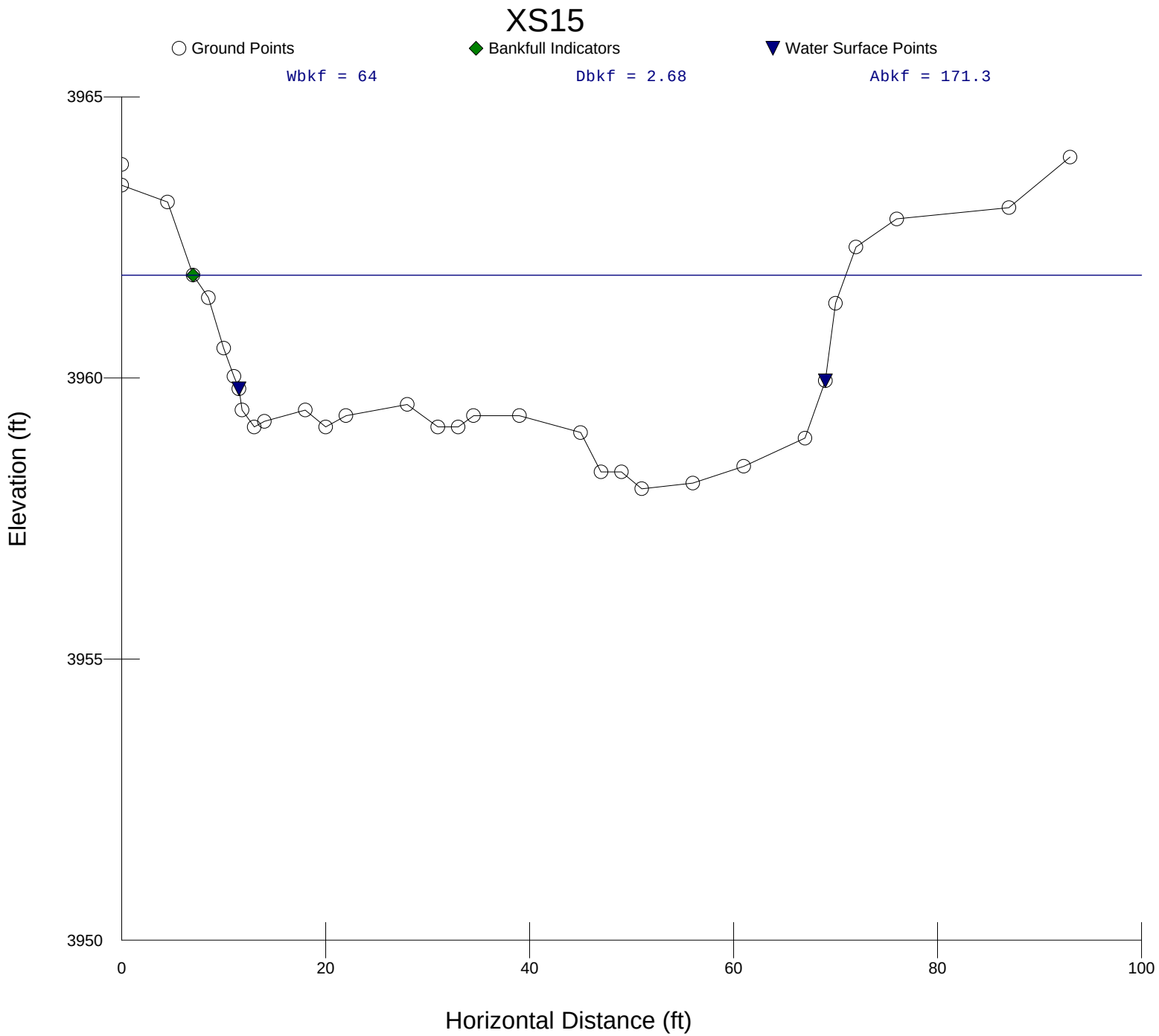

Figure 4-6 Typical Cross Section Reach 4

Table 4-4 Reach 4 classification worksheet

Worksheet 5-3. Field form for Level II stream classification (Rosgen 1996, Rosgen and Silvey 2005)

Stream:	**Tongue River**			
Basin:	**Powderhorn River**	Drainage Area: **131840** acres	**206**	mi^2
Location:	**Reach 4, XS 15**			
Twp.&Rge:	**T56N R86W**	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):			Date:	**10/23/13**
Observers:	**Starkey, Mikus, Burke**		Valley Type:	VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**64**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section (d_{bkf} = A / W_{bkf}).	**2.68**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**171.32**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**23.88**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.8**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or (2 x d_{mbkf}) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**300**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**4.69**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**56.87**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.009**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.3**	

Stream Type **C 4** (See **Figure 2-14**)

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Reach 5

Reach 5 is the most downstream section of the project area and passes directly through Dayton. It is 3,300 feet long (station 230+00 to 263+00) and contains 10 of the 22 surveyed cross sections, one of which is shown in Figure 4-7.

The Tongue River through Dayton tends to have steep (though not vertical) banks and an average width of approximately 60 feet at base flow and 80 feet at bankfull. Bankfull indicators are not very evident due to active erosion and some use of bank armoring materials; however, the surveyed indicators agree well with the predicted width, depth, and area suggested by the regional curves. The completed classification worksheet for Reach 5, based on Cross Section 2, is shown in Table 4-5. Based on the classification, this reach was determined to be a C-4-type channel. The C-type channel is slightly entrenched with a moderate-to-high width-to-depth ratio.

The most critical descriptors of Reach 4 also apply to Reach 5; the bank materials are heterogeneous and non-cohesive, making them vulnerable to erosion. The bank materials are also finer than the predominantly cobble bed material, meaning that high shear stresses will move bank material faster than bed material. However, the bed material in Reach 4 appears to be more mobile than in Reach 5, indicated by the frequent presence of cobble-dominated point bars and a transverse bar developing between station 225+00 and 227+00. Similar to Reach 4, Reach 5 is vulnerable to accelerated bank erosion and may, in fact, be more vulnerable due to a higher slope and associated increased stream power.

Photo 4-7 The Tongue River through Reach 5, within the town of Dayton

Within Reach 5, the Tongue River channel does not fit a C classification in terms of sinuosity. C channels tend to have a sinuosity greater than 1.2, but the average sinuosity (calculated in three 1,000 foot sections) of Reach 5 is 1.04, and no section has a sinuosity greater than 1.1. This departure, combined with the prediction of accelerated bank erosion, suggests that this reach of the Tongue River would be more stable if it were more sinuous; the river may be trying to achieve this through lateral migration via bank erosion. Currently, there are few point-bar or pool features in the reach and no visible gravel-cobble point bars developing.

The Tongue River in Reach 5 has several areas of bank erosion. In some cases landowners have acted to address this erosion using various hardening methods, including installing concrete retaining walls made from highway barriers and riprap. These methods can provide short-term protection to the individual property owner; however, they frequently divert the erosive forces across the bank or downstream, affecting other property owners. As such, a more comprehensive approach is needed for the Tongue River through Dayton.

Previous projects have been constructed to address bank stability in Dayton using in-stream structures. There are several boulder vanes installed between stations 238+00 and 241+00. These structures deflect high flows away from the banks and also create diversity in the available channel habitat by forming well-aerated plunge pools on their downstream sides. These vanes appear well-designed and stable and would be a suitable method for addressing bank erosion in other locations along the Tongue River.

Photo 4-8 **Vanes within Dayton directing flow to the center of the channel and protecting banks**

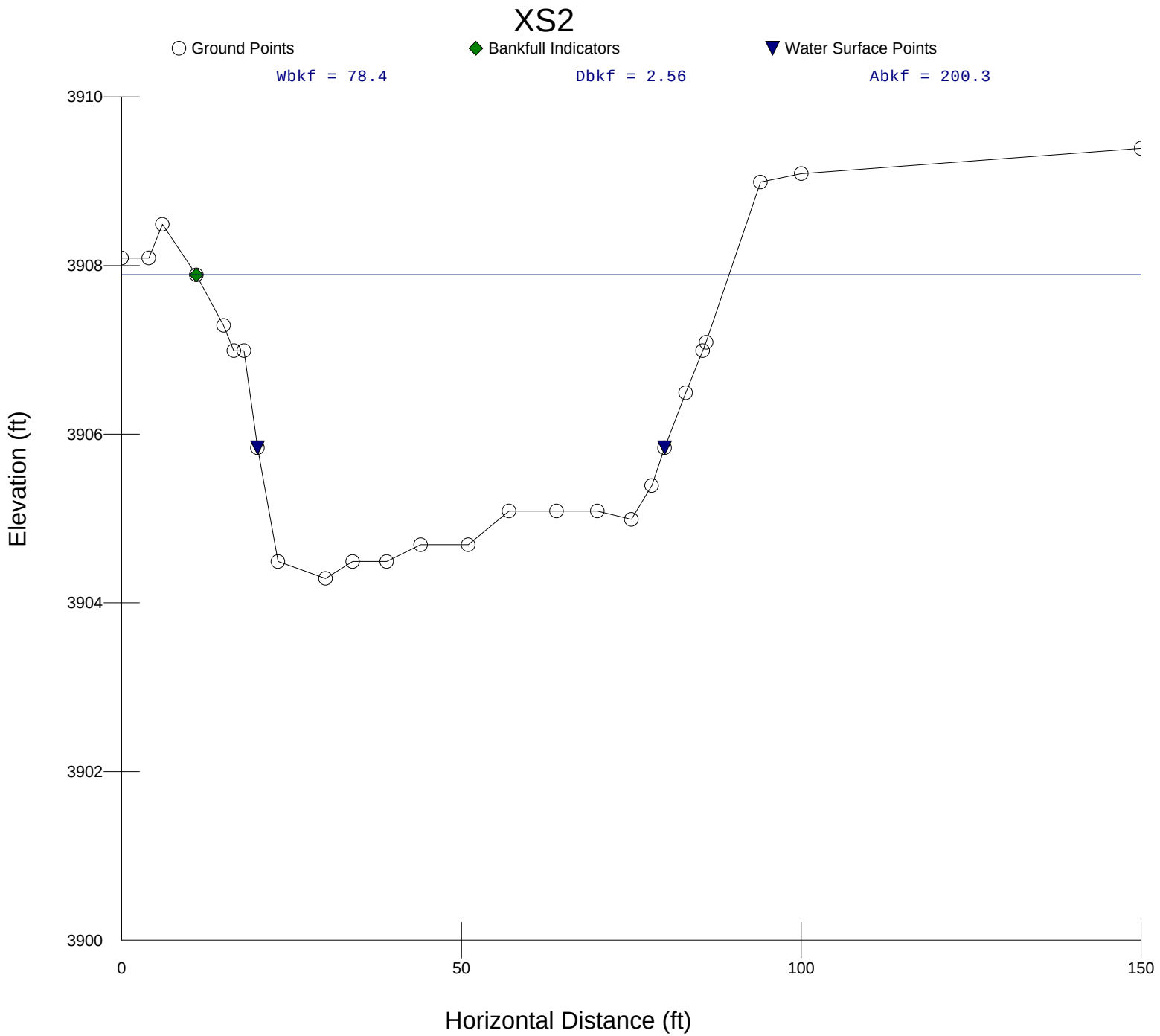

Figure 4-7 Typical Cross Section Reach 5

Table 4-5 Reach 5 classification worksheet

Worksheet 5-3. Field form for Level II stream classification (Rosgen 1996, Rosgen and Silvey 2005)

Stream:	**Tongue River**			
Basin:	**Powderhorn River**	Drainage Area: **131840** acres	**206**	mi^2
Location:	**Reach 5, XS 2**			
Twp.&Rge:	**T57N R86W**	Sec.&Qtr.:		
Cross-Section Monuments (Lat./Long.):			Date:	**10/21/13**
Observers:	**Starkey, Mikus, Burke**		Valley Type:	VIII

Bankfull WIDTH (W_{bkf}) WIDTH of the stream channel at bankfull stage elevation, in a riffle section.	**78.37**	ft
Bankfull DEPTH (d_{bkf}) Mean DEPTH of the stream channel cross-section, at bankfull stage elevation, in a riffle section ($d_{bkf} = A / W_{bkf}$).	**2.56**	ft
Bankfull X-Section AREA (A_{bkf}) AREA of the stream channel cross-section, at bankfull stage elevation, in a riffle section.	**200.27**	ft^2
Width/Depth Ratio (W_{bkf} / d_{bkf}) Bankfull WIDTH divided by bankfull mean DEPTH, in a riffle section.	**30.61**	ft/ft
Maximum DEPTH (d_{mbkf}) Maximum depth of the bankfull channel cross-section, or distance between the bankfull stage and Thalweg elevations, in a riffle section.	**3.6**	ft
WIDTH of Flood-Prone Area (W_{fpa}) Twice maximum DEPTH, or ($2 \times d_{mbkf}$) = the stage/elevation at which flood-prone area WIDTH is determined in a riffle section.	**350**	ft
Entrenchment Ratio (ER) The ratio of flood-prone area WIDTH divided by bankfull channel WIDTH (W_{fpa} / W_{bkf}) (riffle section).	**4.47**	ft/ft
Channel Materials (Particle Size Index) D_{50} The D_{50} particle size index represents the mean diameter of channel materials, as sampled from the channel surface, between the bankfull stage and Thalweg elevations.	**56.2**	mm
Water Surface SLOPE (S) Channel slope = "rise over run" for a reach approximately 20–30 bankfull channel widths in length, with the "riffle-to-riffle" water surface slope representing the gradient at bankfull stage.	**0.005**	ft/ft
Channel SINUOSITY (k) Sinuosity is an index of channel pattern, determined from a ratio of stream length divided by valley length (SL / VL); or estimated from a ratio of valley slope divided by channel slope (VS / S).	**1.05**	

Stream Type **C 4** (See **Figure 2-14**)

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4.2.1.2 Bed Material Sampling

Channel bed material affects several characteristics of the river system. The roughness of the channel material affects the hydraulics of flow and how fast storm events move through the system. The material size affects stability and erosion potential; sand-bed streams are naturally mobile, whereas coarser streams, made primarily of gravel or cobbles, are less so. A pebble count is a way to sample stream bed material to determine its size distribution, estimate roughness, and assist in classification.

During the survey Barr conducted six pebble counts (Wolman 1954): three in Reach 5, one in Reach 4, and two in Reach 3. The results of one pebble count from each reach were used in the classifications discussed in Section 4.2.1.1. Table 4-6 presents the median grain size (D_{50}) in millimeters for all six pebble counts.

Table 4-6 Pebble Count Summary

Reach	Pebble Count Location	Median Grain Size (D_{50}), mm	Used in Classification?
5	Cross Section 2	56.2	Yes, Reach 5
5	Cross Section 5	94.5	No
5	Cross Section 8	73.9	No
4	Cross Section 14	56.9	Yes, Reach 4
3	Cross Section 18	101.6	Yes, Reach 3
3	Station 130+50	85.0	No

Table 4-6 shows that grain size can vary significantly, even within a reach; Reach 5 has median grain sizes ranging from coarse gravel to small cobbles, and Reach 3 contains sections dominated by both fine and medium-sized cobbles. Because there are multiple pebble counts in two reaches, the design team selected representative pebble counts for use in classification of these reaches. When there were multiple pebble counts, the team used the count closest to the section used in classification (Cross Section 2 was the classification section for Reach 5 and Cross Section 18 was the classification section for Reach 3; see Figure 4-5 and Figure 4-7).

4.2.1.3 Rosgen Classification by Reach

Table 4-7 Rosgen classification by reach

Reach	Classification
1*	B-2
2**	B-2
3	F-3
4	C-4
5	C-4

* B classification based on cross-sectional data; level III classification (B-2) based on visual inspection of boulder-dominated channel
** Assigned same classification as Reach 1 without survey

4.2.1.4 Dimensionless Ratios

The purpose of dimensionless ratios is to quantify the relationships between channel attributes. Dimensionless ratios are typically used to describe the stable form of a channel and provide the basis for design of in-stream structures in non-stable reaches. Not all of the ratios calculated from the Tongue River survey data are from stable reaches, but they do provide empirical data on channel shape and form.

Reaches 1 and 2

Reach 2 contained no surveyed cross sections; Reach 1 contained one pool cross section and one riffle cross section. This means there are only single values for all dimensionless ratios in this reach and no range of values.

Reach 1 has a larger bankfull depth than Reaches 4 and 5, but its bankfull area is approximately the same and the width is smaller. This is to be expected as the classification changes from a C channel (moderate-to-high width-to-depth ratio) to a B channel (moderate width-to-depth ratio). Pools in Reaches 1 and 2 are narrower and deeper than in Reaches 4 and 5 and their maximum depth is larger.

Profile 1 (Figure 4-8) is located between station 58+00 and 61+00 in Reach 1, a B-2 channel in the foothills of the Bighorn Mountains. This is the steepest section of the Tongue River within the project area, and its morphology is dominated by a step-pool structure which provides high amounts of grade control, visible in the profile as steep, positive slopes below pool structures (see station 58+50 and 60+80 for examples).

Table 4-8 Reach 1 and 2 dimensionless ratios—Summary 2

Worksheet 5-4. Morphological relations, including dimensionless ratios of river reach sites (Rosgen and Silvey 2007, Rosgen 2008)

Stream: **Tongue River** Location: **Reaches 1 and 2**

Observers: **Starkey, Burke, Koth** Date: **4/14/14** Valley Type: **II / VIII** Stream Type: **B-2**

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})	**7.09**	ft/sec	Estimation Method	**V = Q / A**	
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})	**1360**	cfs	Drainage Area	**206**	mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)	**1500**	**1400**	**1600**	ft	Linear Wavelength to Riffle Width (λ / W_{bkf})	**26.786**	**25.000**	**28.571**
Stream Meander Length (L_m)	**1550**	**1200**	**1900**	ft	Stream Meander Length Ratio (L_m / W_{bkf})	**27.679**	**21.429**	**33.929**
Radius of Curvature (R_c)	**330**	**240**	**420**	ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})	**5.893**	**4.286**	**7.500**
Belt Width (W_{blt})	**253**	**105**	**400**	ft	Meander Width Ratio (W_{blt} / W_{bkf})	**4.509**	**1.875**	**7.143**
Arc Length (L_a)	**750**	**700**	**800**	ft	Arc Length to Riffle Width (L_a / W_{bkf})	**13.393**	**12.500**	**14.286**
Riffle Length (L_r)	**35.5**	**26**	**45**	ft	Riffle Length to Riffle Width (L_r / W_{bkf})	**0.634**	**0.464**	**0.804**
Individual Pool Length (L_p)	**35**	**29**	**41**	ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})	**0.625**	**0.518**	**0.732**
Pool to Pool Spacing (P_s)	**175**	**0**	**0**	ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})	**3.125**	**0.000**	**0.000**

Channel Profile

Valley Slope (S_{val})	**0.011**	ft/ft	Average Water Surface Slope (S)	**0.012**	ft/ft	Sinuosity (S_{val} / S)		**0.916667**
Stream Length (SL)	**2100**	ft	Valley Length (VL)	**1968**	ft	Sinuosity (SL / VL)		**1.067073**

Low Bank Height (LBH)	start	**0**	ft	Max Depth (d_{max})	start	**0**	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start
	end	**0**	ft		end	**0**	ft		end

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	**0.010**			ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	**0.833**		
Run Slope (S_{run})	**0.020**			ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	**1.667**		
Pool Slope (S_p)	**0.006**			ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	**0.500**		
Glide Slope (S_g)	**0.003**			ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	**0.250**		
Step Slope (S_s)	**0.010**			ft/ft	Step Slope to Average Water Surface Slope (S_s / S)	**0.833**		

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	**2.1**			ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	**0.612**		
Max Run Depth (d_{maxrun})	**1.98**			ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	**0.577**		
Max Pool Depth (d_{maxp})	**2.66**			ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	**0.776**		
Max Glide Depth (d_{maxg})	**1.3**			ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	**0.379**		
Max Step Depth (d_{maxs})	**0.8**			ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})	**0.233**		

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay				D_{16}					mm
% Sand				D_{35}					mm
% Gravel				D_{50}					mm
% Cobble				D_{84}					mm
% Boulder				D_{95}					mm
% Bedrock				D_{100}					mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.

[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

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Reach 3

Reach 3 contained one surveyed cross section; therefore, there are no ranges of dimensionless ratios available for this reach, only single values.

Reach 3 has much longer and wider riffles than Reaches 1 and 2; the ratio of riffle length to width is approximately 2.0 on Reach 3 but less than 1.0 on Reaches 1 and 2. The radius of curvature on Reach 3 is smaller than on Reaches 1 and 2, indicating a more sinuous reach. This is supported by longer wavelength and meander length values in Reaches 1 and 2 than in Reach 3. These differences in dimensionless ratios emphasize the transition occurring in Reach 3 from the grade-controlled, step-pool system typical of a mountain stream to a more mobile stream with longer and flatter riffle-pool structures such as those in Reach 3.

Table 4-9 Reach 3 dimensionless ratios—Summary 2

Worksheet 5-4. Morphological relations, including dimensionless ratios of river reach sites (Rosgen and Silvey 2007, Rosgen 2008)

Stream: **Tongue** Location: **Reach 3**

Observers: **Starkey, Mikus, Burke** Date: **10/24/13** Valley Type: **VIII** Stream Type: **F 3**

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})	**8.53** ft/sec	Estimation Method	**V = Q / A**	
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})	**1360** cfs	Drainage Area	**206**	mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)	1305	0	0	ft	Linear Wavelength to Riffle Width (λ / W_{bkf})	16.384	0.000	0.000
Stream Meander Length (L_m)	1700	0	0	ft	Stream Meander Length Ratio (L_m / W_{bkf})	21.343	0.000	0.000
Radius of Curvature (R_c)	150	0	0	ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})	1.883	0.000	0.000
Belt Width (W_{blt})	395	0	0	ft	Meander Width Ratio (W_{blt} / W_{bkf})	4.959	0.000	0.000
Arc Length (L_a)	250	0	0	ft	Arc Length to Riffle Width (L_a / W_{bkf})	3.139	0.000	0.000
Riffle Length (L_r)	160	0	0	ft	Riffle Length to Riffle Width (L_r / W_{bkf})	2.009	0.000	0.000
Individual Pool Length (L_p)	0	0	0	ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})	0.000	0.000	0.000
Pool to Pool Spacing (P_s)	0	0	0	ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})	0.000	0.000	0.000

Channel Profile

Valley Slope (S_{val})	0.015 ft/ft	Average Water Surface Slope (S)	0.001 ft/ft	Sinuosity (S_{val} / S)	1.3	
Stream Length (SL)	0 ft	Valley Length (VL)	0 ft	Sinuosity (SL / VL)		
Low Bank Height (LBH)	start 0 ft / end 0 ft	Max Depth (d_{max})	start 0 ft / end 0 ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start / end	

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	0.000	0.000	0.000	ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	0.000	0.000	0.000
Run Slope (S_{run})	0.000	0.000	0.000	ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	0.000	0.000	0.000
Pool Slope (S_p)	0.000	0.000	0.000	ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	0.000	0.000	0.000
Glide Slope (S_g)	0.000	0.000	0.000	ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	0.000	0.000	0.000
Step Slope (S_s)	0.000	0.000	0.000	ft/ft	Step Slope to Average Water Surface Slope (S_s / S)	0.000	0.000	0.000

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	0	0	0	ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	0	0	0
Max Run Depth (d_{maxrun})	0	0	0	ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	0	0	0
Max Pool Depth (d_{maxp})	0	0	0	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	0	0	0
Max Glide Depth (d_{maxg})	0	0	0	ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	0	0	0
Max Step Depth (d_{maxs})	0	0	0	ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})	0	0	0

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay		0		D_{16}		36.27			mm
% Sand		2.78		D_{35}		75.93			mm
% Gravel		25		D_{50}		101.57			mm
% Cobble		68.52		D_{84}		192.92			mm
% Boulder		3.7		D_{95}		249.33			mm
% Bedrock		0		D_{100}		511.98			mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.

[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

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Reach 4

Bankfull width and depth values in Reach 4 are in line with those estimated from the regional curves and previous work performed on the Tongue River. An average bankfull area of approximately 175 square feet is slightly lower than expected based on published curves, but still within the 95% prediction interval.

Reach 4 has pools occurring mostly at the outside of meander bends (e.g., station 210+00 and 174+00). Because pools in Reach 4 are more distinct than in Reach 3 or Reach 5, there are larger differences in depth, width, and area between pools and riffles in this reach. The dimensionless ratios in Reach 4 may be useful for creating additional pool habitat in Reach 4 or Reach 5.

Profile 2 (Figure 4-9) begins at station 164+00 and ends at station 180+00 in Reach 4, classified as a C-3 channel. This profile contains a complete meander and developed riffle-pool structures, making it possible to collect a variety of longitudinal data that is harder to find in more homogenous reaches.

Profile 3 (Figure 4-10) is also within Reach 4, beginning at station 220+00 and ending at station 227+00. This profile is shorter than Profile 2, but still contains three riffle-pool patterns which have developed through a meander bend.

Table 4-10 Reach 4 dimensionless ratios—Summary 2

Worksheet 5-4. Morphological relations, including dimensionless ratios of river reach sites (Rosgen and Silvey 2007, Rosgen 2008)

Stream: **Tongue River** Location: **Reach 4**

Observers: **Starkey, Mikus, Burke** Date: **10/23/13** Valley Type: **VIII** Stream Type: **C-4**

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})	**7.78**	ft/sec	Estimation Method	**V = Q / A**	
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})	**1360**	cfs	Drainage Area	**206**	mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)	**1028**	**995**	**1060**	ft	Linear Wavelength to Riffle Width (λ / W_{bkf})	**12.557**	**15.547**	**10.547**
Stream Meander Length (L_m)	**1185**	**1040**	**1330**	ft	Stream Meander Length Ratio (L_m / W_{bkf})	**14.481**	**16.250**	**13.234**
Radius of Curvature (R_c)	**163**	**130**	**195**	ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})	**1.986**	**2.031**	**1.940**
Belt Width (W_{blt})	**313**	**295**	**330**	ft	Meander Width Ratio (W_{blt} / W_{bkf})	**3.819**	**4.609**	**3.284**
Arc Length (L_a)	**550**	**400**	**700**	ft	Arc Length to Riffle Width (L_a / W_{bkf})	**6.721**	**6.250**	**6.965**
Riffle Length (L_r)	**153**	**105**	**201**	ft	Riffle Length to Riffle Width (L_r / W_{bkf})	**1.870**	**1.641**	**2.000**
Individual Pool Length (L_p)	**142**	**84**	**200**	ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})	**1.735**	**1.313**	**1.990**
Pool to Pool Spacing (P_s)	**255**	**224**	**285**	ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})	**3.110**	**3.500**	**2.836**

Channel Profile

Valley Slope (S_{val})	**0.01**	ft/ft	Average Water Surface Slope (S)	**0.007**	ft/ft	Sinuosity (S_{val} / S)		**1.43**
Stream Length (SL)	**2100**	ft	Valley Length (VL)	**1680**	ft	Sinuosity (SL / VL)		**1.25**

Low Bank Height (LBH)	start	**0**	ft	Max Depth (d_{max})	start	**0**	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start
	end	**0**	ft		end	**0**	ft		end

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	**0.004**	**0.003**	**0.005**	ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	**0.571**	**0.429**	**0.714**
Run Slope (S_{run})	**0.008**	**0.006**	**0.009**	ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	**1.071**	**0.857**	**1.286**
Pool Slope (S_p)	**0.003**	**0.002**	**0.003**	ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	**0.357**	**0.286**	**0.429**
Glide Slope (S_g)	**0.003**	**0.004**	**0.002**	ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	**0.429**	**0.571**	**0.286**
Step Slope (S_s)				ft/ft	Step Slope to Average Water Surface Slope (S_s / S)			

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	**3.650**	**2.7**	**4.6**	ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	**1.667**	**1.233**	**2.10046**
Max Run Depth (d_{maxrun})	**3.7**	**3.7**	**3.7**	ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	**1.689**	**1.689**	**1.6895**
Max Pool Depth (d_{maxp})	**4.550**	**3.9**	**5.2**	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	**2.078**	**1.781**	**2.37443**
Max Glide Depth (d_{maxg})	**2.7**	**2.7**	**2.7**	ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})	**1.233**	**1.233**	**1.23288**
Max Step Depth (d_{maxs})				ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})	**0**	**0**	**0**

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay		**0**		D_{16}		**7.23**			mm
% Sand		**8.82**		D_{35}		**37.34**			mm
% Gravel		**47.06**		D_{50}		**56.87**			mm
% Cobble		**41.18**		D_{84}		**119**			mm
% Boulder		**2.94**		D_{95}		**216.06**			mm
% Bedrock		**0**		D_{100}		**511.98**			mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.

[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

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Reach 5

Reach 4 and 5 share a classification (C-4), so it is not surprising that their dimensionless ratios are similar. Like Reach 4, Reach 5's values for cross-section width, depth, and area at bankfull flow rates are in line with values published elsewhere.

Pool average values for this reach are non-typical. In this reach, pools are ill-defined. Because sinuosity is low and radius of curvature is large, even the outsides of meander bends have very limited pool structures. Therefore, the depth of pools and riffles at bankfull is nearly the same and the ratios of depth, width, and area between these two features are quite close to 1.0. Due to the lack of fully formed pool structures, no glides were surveyed in this reach.

Because the profile data in this section is coarse, slope values in this section are presented as single values (as opposed to a range of values). Also, this section has some pools present; however, they are less distinct than the pools in profiles 2 and 3. Pool values in this section should not be seen as representative for the entire project reach, nor should they be used to design future pool structures.

Table 4-11 Reach 5 dimensionless ratios—Summary 2
Worksheet 5-4. Morphological relations, including dimensionless ratios of river reach sites (Rosgen and Silvey 2007, Rosgen 2008)

Stream: **Tongue River** Location: **Reach 5**

Observers: **Starkey, Mikus, Burke** Date: **10/21/13** Valley Type: **VIII** Stream Type: **C-4**

River Reach Summary Data…..2

Hydraulics

Streamflow: Estimated Mean Velocity at Bankfull Stage (u_{bkf})	**7.64**	ft/sec	Estimation Method	**V = Q / A**	
Streamflow: Estimated Discharge at Bankfull Stage (Q_{bkf})	**1360**	cfs	Drainage Area	**206**	mi^2

Channel Pattern

Geometry	Mean	Min	Max		Dimensionless Geometry Ratios	Mean	Min	Max
Linear Wavelength (λ)	**566**	**400**	**731**	ft	Linear Wavelength to Riffle Width (λ / W_{bkf})	**7.657**	**5.936**	**9.328**
Stream Meander Length (L_m)	**612**	**455**	**768**	ft	Stream Meander Length Ratio (L_m / W_{bkf})	**8.280**	**6.753**	**9.800**
Radius of Curvature (R_c)	**475**	**350**	**600**	ft	Radius of Curvature to Riffle Width (R_c / W_{bkf})	**6.432**	**5.194**	**7.656**
Belt Width (W_{blt})	**133**	**115**	**150**	ft	Meander Width Ratio (W_{blt} / W_{bkf})	**1.794**	**1.707**	**1.914**
Arc Length (L_a)	**588**	**400**	**775**	ft	Arc Length to Riffle Width (L_a / W_{bkf})	**7.955**	**5.936**	**9.889**
Riffle Length (L_r)	**167**	**150**	**183**	ft	Riffle Length to Riffle Width (L_r / W_{bkf})	**2.255**	**2.226**	**2.335**
Individual Pool Length (L_p)	**63**	**51**	**75**	ft	Individual Pool Length to Riffle Width (L_p / W_{bkf})	**0.853**	**0.757**	**0.957**
Pool to Pool Spacing (P_s)	**450**	**450**	**450**	ft	Pool to Pool Spacing to Riffle Width (P_s / W_{bkf})	**6.093**	**5.742**	**6.679**

Channel Profile

Valley Slope (S_{val})	**0.008**	ft/ft	Average Water Surface Slope (S)	**0.006**	ft/ft	Sinuosity (S_{val} / S)	**1.33**
Stream Length (SL)	**1423**	ft	Valley Length (VL)	**1345**	ft	Sinuosity (SL / VL)	**1.06**

Low Bank Height (LBH)	start	**0**	ft	Max Depth (d_{max})	start	**0**	ft	Bank-Height Ratio (BHR) (LBH / d_{max})	start	
	end	**0**	ft		end	**0**	ft		end	

Facet Slopes	Mean	Min	Max		Dimensionless Facet Slope Ratios	Mean	Min	Max
Riffle Slope (S_{rif})	**0.005**			ft/ft	Riffle Slope to Average Water Surface Slope (S_{rif} / S)	**0.833**		
Run Slope (S_{run})	**0.007**			ft/ft	Run Slope to Average Water Surface Slope (S_{run} / S)	**1.167**		
Pool Slope (S_p)	**0.002**			ft/ft	Pool Slope to Average Water Surface Slope (S_p / S)	**0.333**		
Glide Slope (S_g)	**0.002**			ft/ft	Glide Slope to Average Water Surface Slope (S_g / S)	**0.333**		
Step Slope (S_s)				ft/ft	Step Slope to Average Water Surface Slope (S_s / S)			

Max Depths[a]	Mean	Min	Max		Dimensionless Depth Ratios	Mean	Min	Max
Max Riffle Depth (d_{maxrif})	**3.2**	**2.9**	**3.5**	ft	Max Riffle Depth to Mean Riffle Depth (d_{maxrif} / d_{bkf})	**1.33**	**1.203**	**1.45**
Max Run Depth (d_{maxrun})	**3.4**	**3.1**	**3.6**	ft	Max Run Depth to Mean Riffle Depth (d_{maxrun} / d_{bkf})	**1.41**	**1.286**	**1.49**
Max Pool Depth (d_{maxp})	**4.85**	**4.3**	**5.4**	ft	Max Pool Depth to Mean Riffle Depth (d_{maxp} / d_{bkf})	**2.01**	**1.784**	**2.24**
Max Glide Depth (d_{maxg})				ft	Max Glide Depth to Mean Riffle Depth (d_{maxg} / d_{bkf})			
Max Step Depth (d_{maxs})				ft	Max Step Depth to Mean Riffle Depth (d_{maxs} / d_{bkf})			

Channel Materials

	Reach[b]	Riffle[c]	Bar		Reach[b]	Riffle[c]	Bar	Protrusion Height[d]	
% Silt/Clay		**0**		D_{16}		**15.88**			mm
% Sand		**12.5**		D_{35}		**40.09**			mm
% Gravel		**43.75**		D_{50}		**56.18**			mm
% Cobble		**43.75**		D_{84}		**104.86**			mm
% Boulder		**0**		D_{95}		**156.62**			mm
% Bedrock		**0**		D_{100}		**256**			mm

[a] Min, max & mean depths are measured from Thalweg to bankfull at mid-point of feature for riffles and runs, the deepest part of pools, & at the tail-out of glides.
[b] Composite sample of riffles and pools within the designated reach. [c] Active bed of a riffle. [d] Height of roughness feature above bed.

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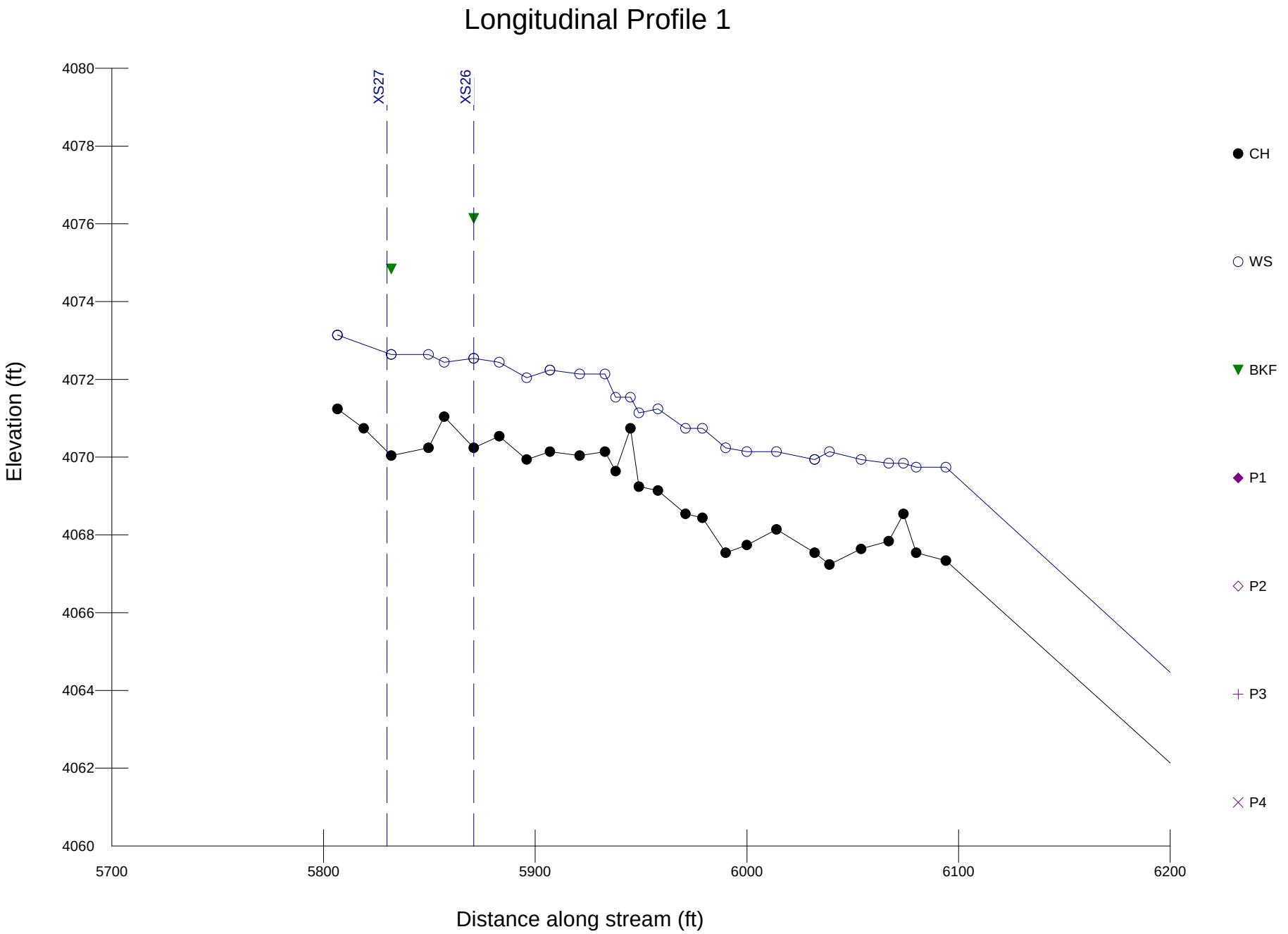


Figure 4-8 Longitudinal Profile 1

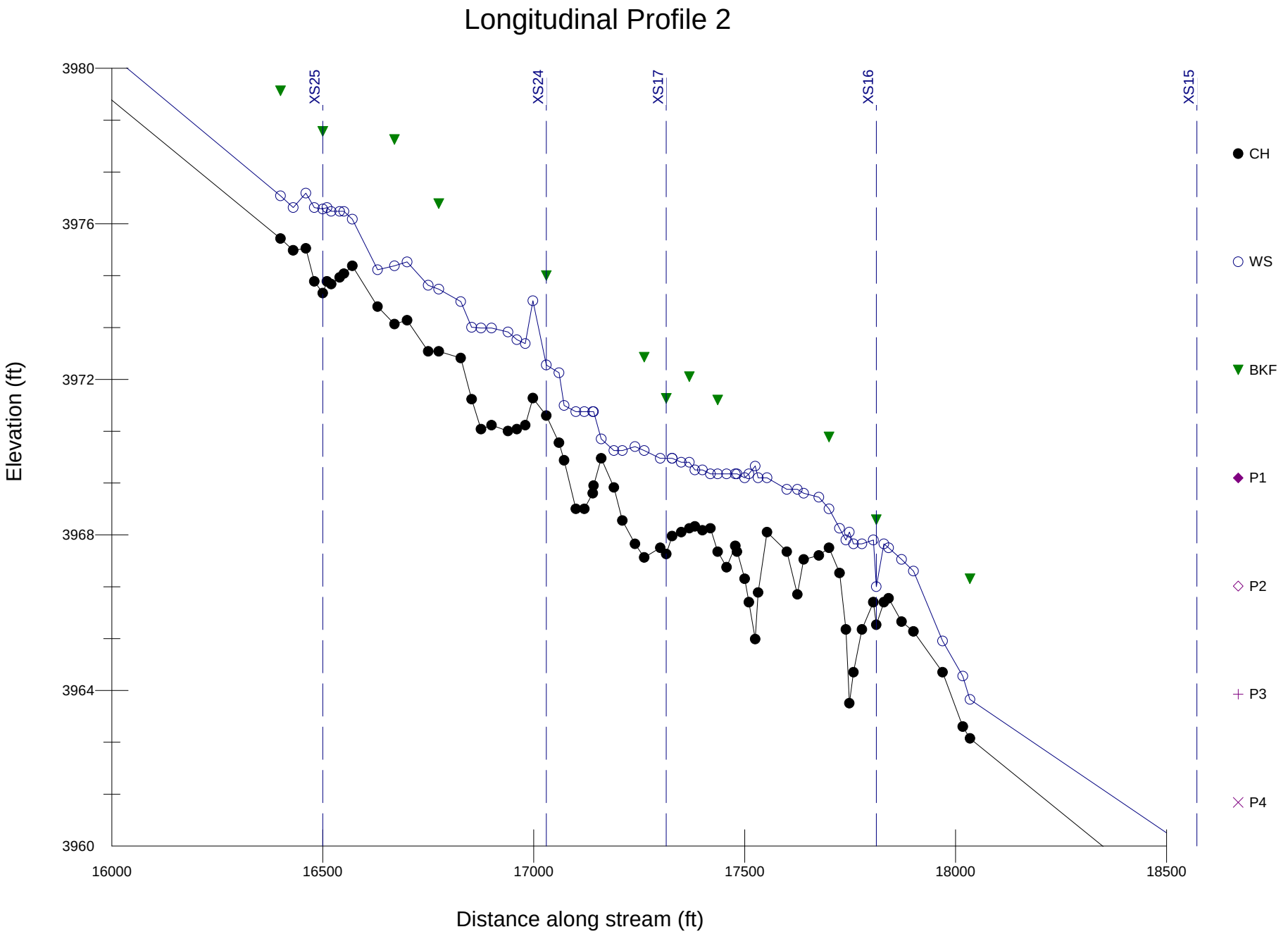


Figure 4-9 Longitudinal Profile 2

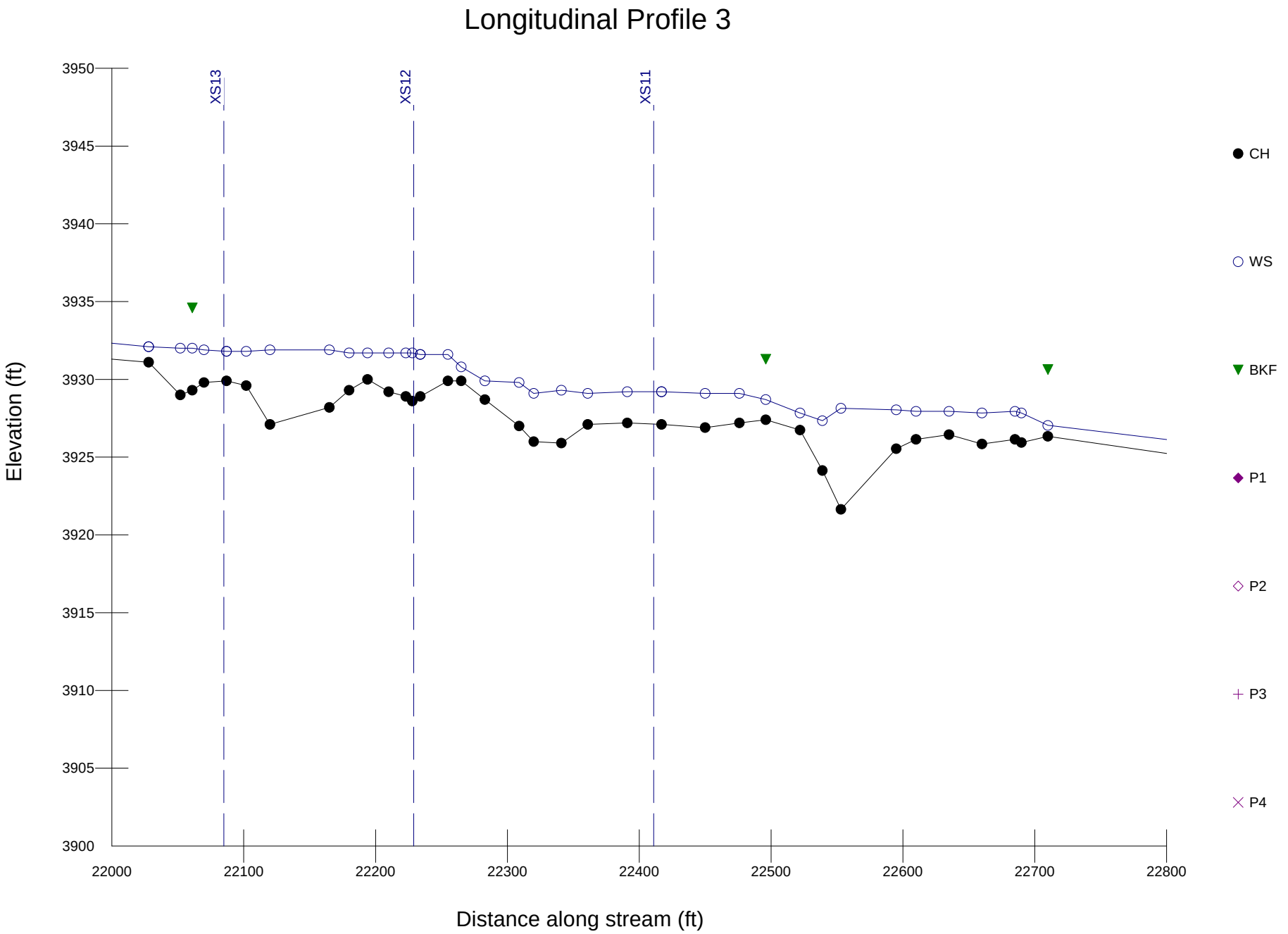


Figure 4-10 Longitudinal Profile 3

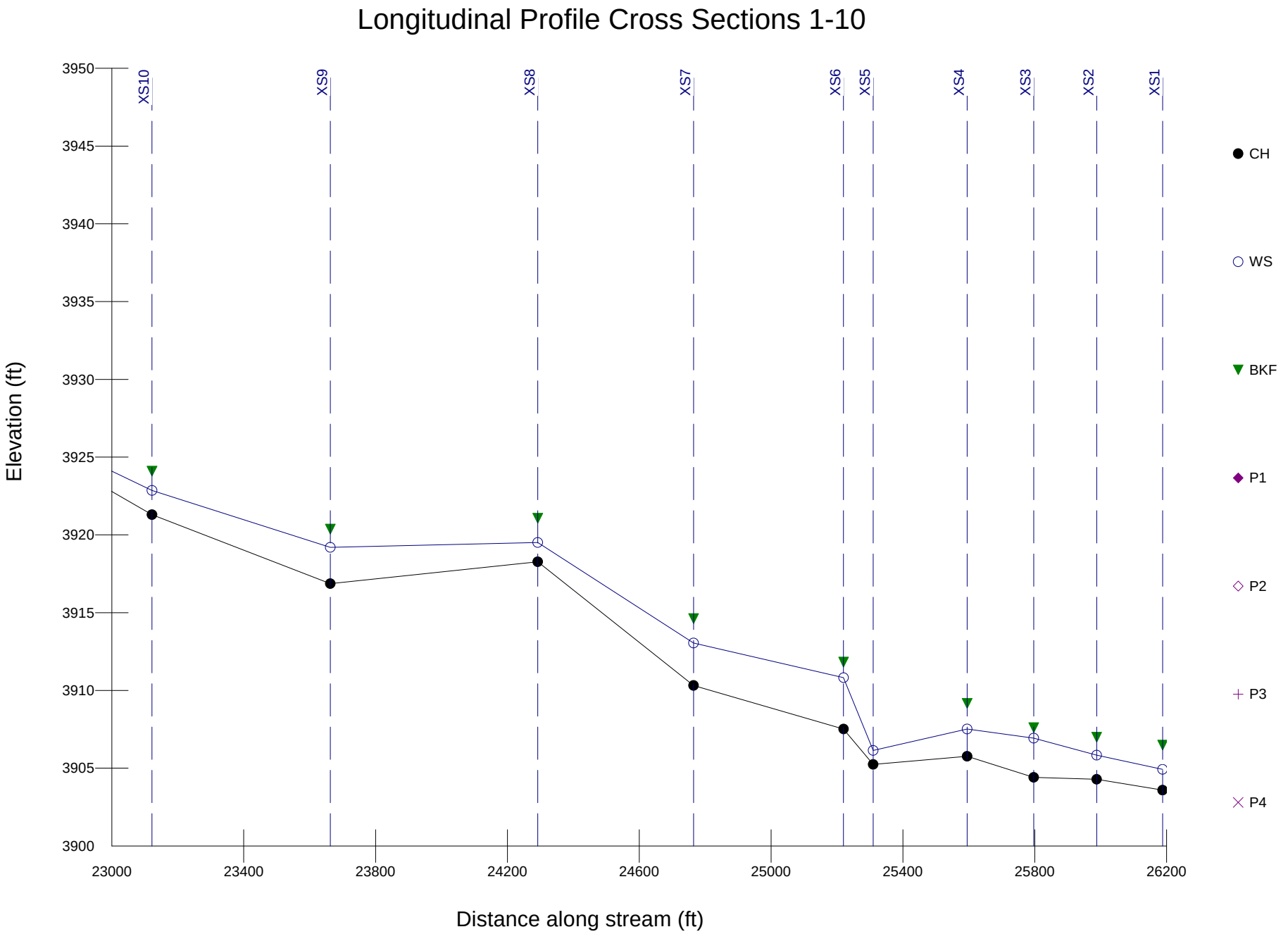


Figure 4-11 Longitudinal Profile of Cross Sections 1-10

4.2.1.5 Channel Pattern

In addition to dimensionless ratios for channel geometry and profile, Table 4-8, Table 4-9, Table 4-10, and Table 4-11 also include minimum, maximum, and average values for planform geometry features such as meander length, belt width, and radius of curvature. Table 4-12, below, compares the average values of these measurements across the study reach.

Table 4-12 Comparison of average channel pattern measurements

	Reach 1	Reach 2	Reach 3	Reach 4	Reach 5
Linear Wavelength (ft)	1500	853	1090*	1028	566
Stream Meander Length (ft)	1550	900	1400	1185	612
Radius of Curvature (ft)	330	420	190	163	475
Belt Width (ft)	253	105	370*	313	133
Arc Length (ft)	750	300	400*	550	588
Riffle Length (ft)	35.5	N/A	N/A	153	167
Individual Pool Length (ft)	35	N/A	N/A	142	63
Pool-to-Pool Spacing (ft)	175*	N/A	N/A	255	450*

*Not an average value, only one value available

A high radius of curvature, such as those in Reaches 1, 2, and 5, indicates a relatively straight channel. Reaches 3 and 4 have similar values for meander length, radius of curvature, wavelength, and belt width. This indicates a planform pattern that may be stable across the variations in slope occurring between these reaches. Data on riffle and pool structures was not available in Reaches 2 and 3 due to an insufficient number of cross sections and no profile data.

4.2.2 Stability and Erosion Potential

One of the objectives of the *Tongue River Stream Improvement Concept Plan* was to evaluate existing areas of erosion and deposition. To make a comprehensive plan for addressing erosion on the Tongue River, it was necessary to evaluate not just existing problems, but the overall stability of the Tongue River study reach and the potential for additional erosion. The SVAP process provided qualitative information on erosion issues, and the team used three additional tools to quantitatively evaluate existing bank stability and erosion potential: (1) analyzing the size distribution of the material being deposited on the developing point bars (known as point-bar sampling), (2) the BEHI and NBS evaluations, developed by Dave Rosgen, and (3) the Pfankuch Rating, developed by D.J. Pfankuch of the U.S. Forest Service.

4.2.2.1 Bar Sampling

Part of completing a Level III Rosgen analysis is point-bar sampling to determine the largest particle size in transport by the stream. Barr collected two point-bar samples, one at Cross Section 12 and one at

Cross Section 17. Both of these locations are within Reach 4, the only reach with visible point-bar development. Barr collected these samples following the Barr Sample Field Procedure laid out in the *River Stability Field Guide* (Rosgen 2008). The samples were sent to American Engineering Testing in Rapid City, South Dakota, for lab analysis instead of being sieved and weighed in the field. The results of these tests are shown in Figure 4-12 and Figure 4-13. A comparison of bar sample results is shown in Table 4-13.

Table 4-13 Bar sample results comparison

Particle Distribution	Cross Section 17	Cross Section 12
D_{10}	1.32 mm / 0.04 in	1.08 mm / 0.04 in
D_{35}	12 mm / 0.47 in	10 mm / 0.39 in
D_{50}	28 mm / 1.1 in	21 mm / 0.83 in
D_{84}	125 mm / 4.9 in	50 mm / 1.97 in
D_{100}	152 mm / 5.9 in	102 mm / 4 in

The test results show that the material available at Cross Section 17 is nominally coarser than the material at Cross Section 12. This is likely because Cross Section 17 is approximately 5,000 feet upstream of Cross Section 12. The parent material in the Tongue River basin comes from boulders and even weathered bedrock within the Bighorn Mountains; these large rocks erode into smaller rocks and move downstream extremely slowly. Smaller materials are carried farther downstream by large floods, leading to geologic material being sorted roughly by size going from upstream to downstream within the same river system.

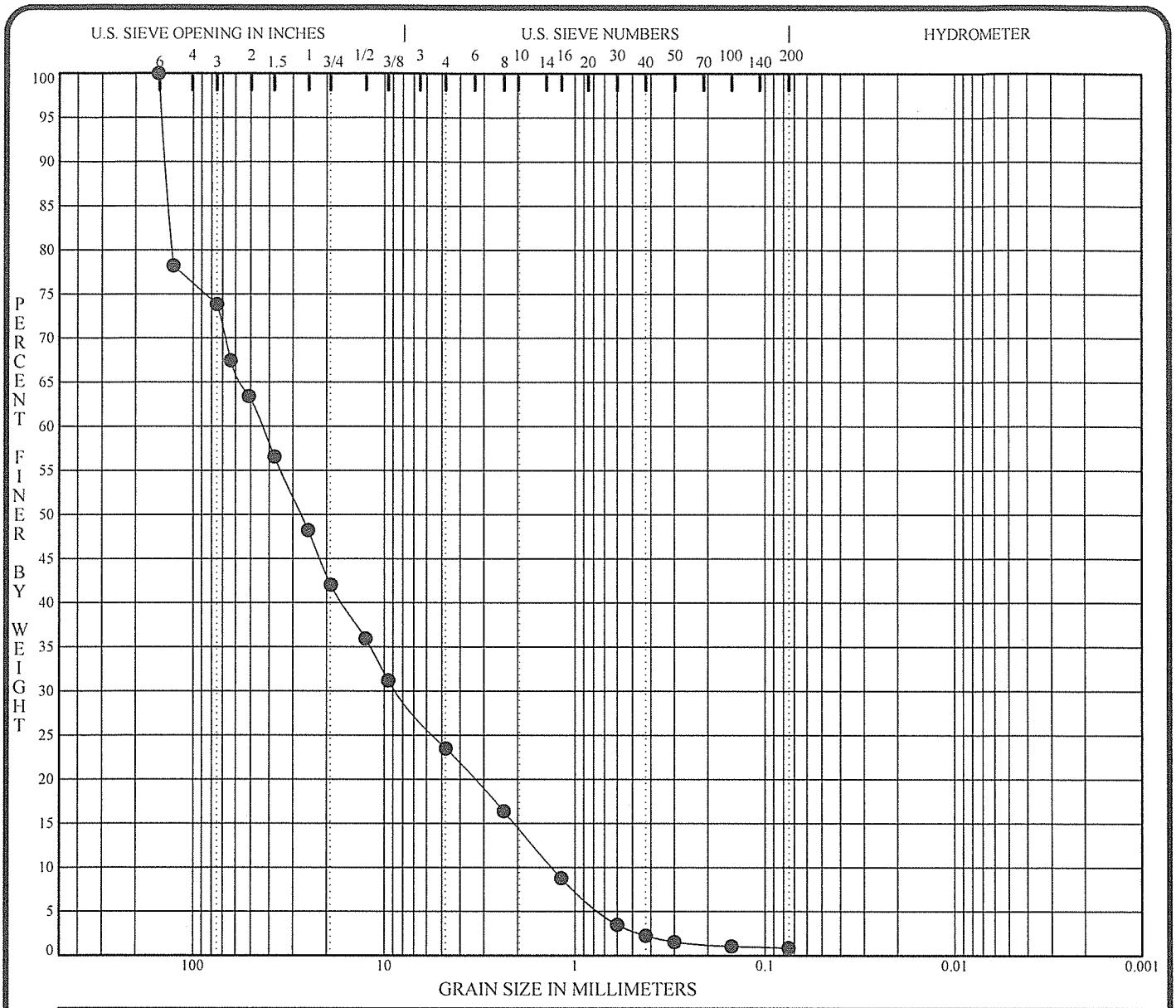
4.2.2.2 BEHI and NBS Assessments

The goal of a BEHI and NBS assessment is to estimate current erosion rates and volumes by considering channel bank material, bank slope, presence and type of vegetation, and channel geometry factors which may direct high amounts of shear stress towards the banks. These rates, which range from very low to extreme, can help quantitatively assess bank stability issues and prioritize where stabilization projects should be installed.

BEHI and NBS assessments took place at eight locations within the project reach. Data was collected for both metrics at locations shown for BEHI assessments in Figure 4-1, Figure 4-2, and Figure 4-3. Four evaluations were in Reach 5, two were in Reach 4, and two were in Reach 3. No stability evaluations were conducted in Reaches 1 and 2; erosion issues in these reaches were considered localized rather than reach-wide.

Following the field survey, BEHI assessments were used to generate a probable erosion index for Reaches 2–5. The eight BEHI evaluations, along with the channel classification and GPS photos, were used as calibration data for a desktop assessment of erosion vulnerability for all river banks within these four reaches. The desktop assessment considered the same factors as the on-site BEHI evaluation: presence, density, and type of vegetation; bank height and material; bank slope; and any stabilization or other existing bank protection measures. The result of this desktop assessment was the assignment of a likely BEHI value to both banks of the Tongue River from the USGS gage to the Highway 14 Bridge. The erosion index maps distinguish areas where a formal BEHI assessment was completed with measured values and

areas where the BEHI value was estimated using desktop methods (estimated values). The results are shown in Figure 4-14 and Figure 4-15.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
● #17	**WELL-GRADED GRAVEL with SAND**					**1.26**	**33.2**

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● #17	**152.00**	**43.78**	**8.530**	**1.3203**	**50.4**	**22.6**	**0.9**	

D_{16} - 2.36 mm = .09 in
D_{35} - 12 mm = .47 in
D_{50} - 28 mm = 1.1 in
D_{84} - 125 mm = 4.9 in
D_{95} - 147 mm = 5.8 in

PROJECT **Game Fish & Parks;**

AET JOB NO. **17-01831**

DATE **11/5/13**

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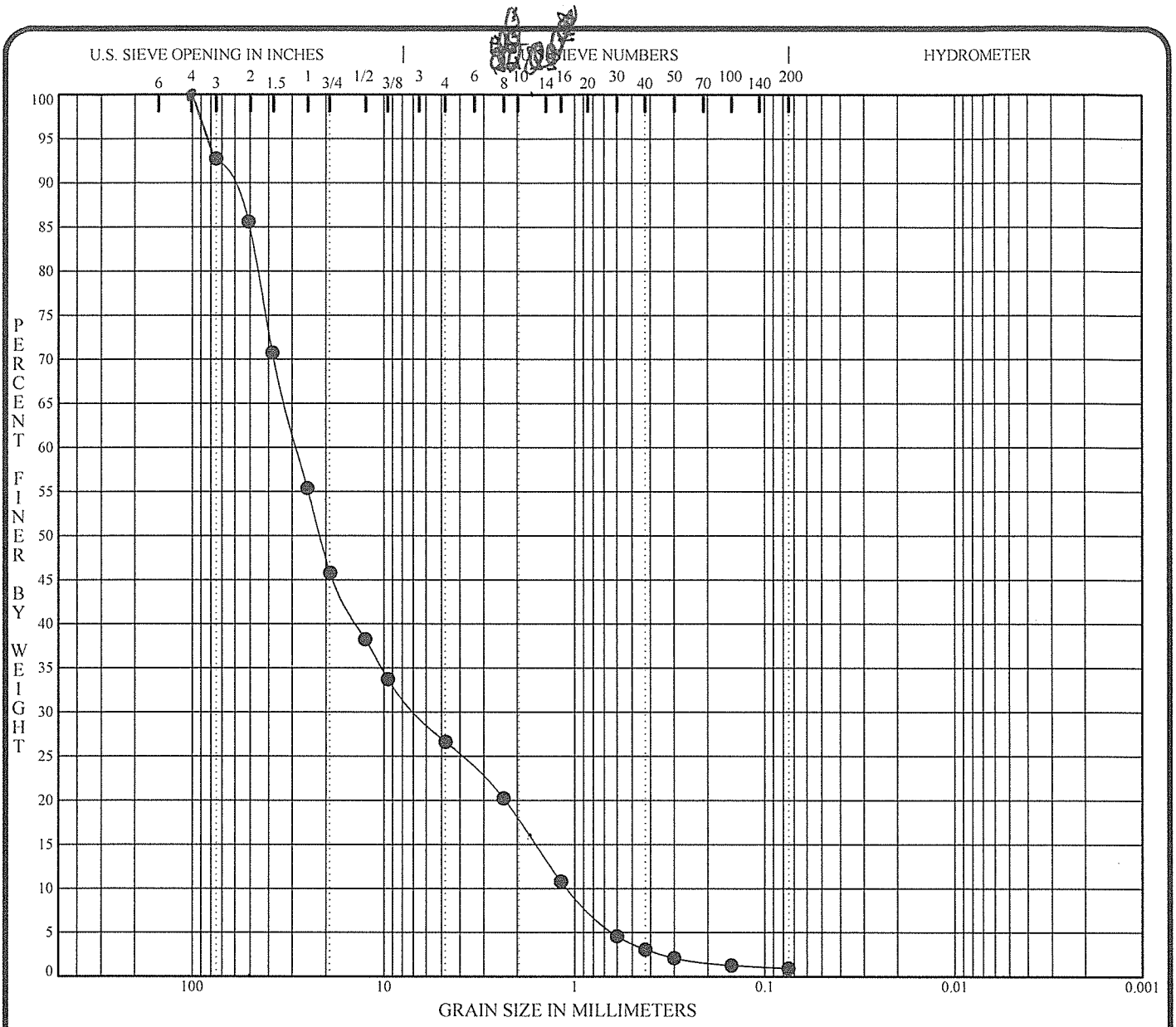
GRADATION CURVES



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification	Classification	MC%	LL	PL	PI	Cc	Cu
● #12	**WELL-GRADED GRAVEL with SAND**					**1.42**	**26.2**

Specimen Identification	D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● #12	**75.00**	**28.38**	**6.607**	**1.0833**	**66.1**	**25.7**	**0.9**	
	D_{16} - 1.7mm = .06in							
	D_{35} - 10mm = .39in							
	D_{50} - 21mm = .83in							
	D_{84} - 50mm = 1.97in							

PROJECT **Game Fish & Parks;**

AET JOB NO. **17-01831**

DATE **11/6/13**

D_{95} - 90mm = 3.54in

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GRADATION CURVES

4.2.2.3 Pfankuch Evaluation

Modified Pfankuch channel stability ratings were conducted on Reaches 3–5. Pfankuch ratings are numeric scores indicative of the stability of the river bed and upper and lower banks. Scores are adjusted for stream types per Rosgen (1996) to generate a qualitative reach stability rating of *Good*, *Fair*, *or Poor*. These evaluations took place at the same eight locations as the BEHI and NBS evaluations.

The Pfankuch evaluation for Reach 3 comes from station 134+00. The upper banks at this location are in Fair condition but received one score of Poor, primarily because the steep slopes exceed 60%. The lower banks are in generally Good condition, with an Excellent score for lack of deposition processes. The bottom of the channel is in Excellent-to-Good condition, with moderately consolidated bottom sediments and mostly stable materials. The overall Pfankuch score for this site was 84; for an F-3 channel, this indicates a stream in Good condition that can generally be considered stable.

The Pfankuch evaluation for Reach 4 comes from Cross Section 17. The upper banks in this area are in Poor condition; they lack vegetative protection, have evidence of mass wasting, and are nearly vertical. The lower banks are generally in Fair condition, having sufficient channel capacity and moderate obstruction. The high rock content in the lower third of the bank does provide one Excellent rating. The channel bottom is in Good condition, being moderately consolidated with little area affected by scour or deposition. The overall Pfankuch score for this site was 104; for a channel classified as C-3, this indicates a stream that is in Fair condition and may be moderately unstable.

The Pfankuch evaluation for Reach 5 comes from Cross Section 1. The upper banks are generally rated in Good-to-Fair condition, with a Poor rating for the steepness of the bank slopes, which exceed 60%. The lower banks are also in Good to Fair condition; the lowest score is for the bank rock content of boulders and small cobbles. The channel bottom is in Good condition on average, with a score of Excellent for the lack of scouring and deposition. The overall Pfankuch score at this site was 91; for a channel classified as C-4, this indicates a stream in Fair condition and suggests the reach is moderately unstable.

Table 4-14 Representative Reach 3 Pfankuch evaluation

Worksheet 19. Modified Pfankuch Channel Stability Rating Procedure Summary

Stream: Tongue River Reach: 3 Date: 10-24-13 Observers: ARM Comments:

Location	Key	Category	Excellent		Good		Fair		Poor	
			Description	Rating	Description	Rating	Description	Rating	Description	Rating
Upper Banks	1	Landform Slope	Bank slope gradient <30%.	2	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	6	Bank slope gradient 60%+. ≈ 80°	(8)
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	(6)	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep, dense soil binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	(9)	<50% density plus fewer species & less vigor indicating poor, discontinuous, and shallow root mass.	12
Lower Banks	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1	Adequate. Bank overflows are rare. W/D ratio = 8-15.	(2)	Barely contains present peaks. Occasional overbank floods. W/D ratio = 15-25.	3	Inadequate. Overbank flows common. W/D ratio > 25.	4
	6	Bank Rock Content	65%+ w/ large angular boulders. 12"+ common.	2	40-65%. Mostly boulders and small cobbles 6-12".	(4)	20-40%. With most in the 3-6" diameter class.	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	(4)	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	6	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	12	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	(16)
	9	Deposition	Little or no enlargement of channel or point bars.	(4)	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	12	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	(2)	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	(1)	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, ie 35-65% mixture range.	3	Predominantly bright, 65%+, exposed or scoured surfaces.	4
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	(4)	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom Size Distribution	No size change evident. Stable material 80-100%.	4	Distribution shift light. Stable material 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	12	Marked distribution change. Stable materials 0-20%.	16
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	(6)	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic Vegetation	Abundant growth moss-like, dark green perennial. In swift water, too.	1	Common. Algae forms in low velocity and pool areas. Moss here, too.	(2)	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perrenial types scarce or absent. Yellow-green, short term bloom may be present.	4
				Excellent Total = 11		Good Total = 26		Fair Total = 24		Poor Total = 24

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**		
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107		
Fair (Mod. unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120		
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+		

Grand Total = 85

Stream Type = F3

Modified Channel Stability Rating = Good

Table 4-15 Representative Reach 4 Pfankuch evaluation

Worksheet 19. Modified Pfankuch Channel Stability Rating Procedure Summary

Stream: Tongue River XS 17 Reach: 4 Date: 10-23-13 Observers: AKM Comments:

Location	Key	Category	Excellent		Good		Fair		Poor	
			Description	Rating	Description	Rating	Description	Rating	Description	Rating
Upper Banks	1	Landform Slope	Bank slope gradient <30%.	2	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	6	Bank slope gradient 60%+.	(8)
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	9	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	(12)
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	6	Moderate to heavy amounts, predominantly larger sizes.	(8)
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep, dense soil binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	6	50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species & less vigor indicating poor, discontinuous, and shallow root mass.	(12)
Lower Banks	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1	Adequate. Bank overflows are rare. W/D ratio = 8-15.	2	Barely contains present peaks. Occasional overbank floods. W/D ratio = 15-25.	(3)	Inadequate. Overbank flows common. W/D ratio > 25.	4
	6	Bank Rock Content	65%+ w/ large angular boulders. 12"+ common.	(2)	40-65%. Mostly boulders and small cobbles 6-12".	4	20-40%. With most in the 3-6" diameter class.	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	(6)	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new ~~gravel and coarse sand~~ cobblet on old and some new bars.	(12)	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	2	Corners and edges well rounded in 2 dimensions.	(3)	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	(1)	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, ie 35-65% mixture range.	3	Predominantly bright, 65%+, exposed or scoured surfaces.	4
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	(4)	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom Size Distribution	No size change evident. Stable material 80-100%.	4	Distribution shift light. Stable material 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	12	Marked distribution change. Stable materials 0-20%.	16
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	6	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	(12)	30-50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic Vegetation	Abundant growth moss-like, dark green perennial. In swift water, too.	(1)	Common. Algae forms in low velocity and pool areas. Moss here, too.	2	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perrenial types scarce or absent. Yellow-green, short term bloom may be present.	4
			Excellent Total =	4	Good Total =	24	Fair Total =	36	Poor Total =	40

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**		
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	80-85	80-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107		
Fair (Mod. unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120		
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+		

Grand Total = 104

Stream Type = C4

Modified Channel Stability Rating = Fair

Table 4-16 Representative Reach 5 Pfankuch evaluation

Worksheet 19. Modified Pfankuch Channel Stability Rating Procedure Summary

Stream: Torgue River Reach: Reach 5 Station 150 Date: 9/24 Observers: Oakley Comments:

Location	Key	Category	Excellent		Good		Fair		Poor	
			Description	Rating	Description	Rating	Description	Rating	Description	Rating
Upper Banks	1	Landform Slope	Bank slope gradient <30%.	2	Bank slope gradient 30-40%.	4	Bank slope gradient 40-60%.	6	Bank slope gradient 60%+.	(8)
	2	Mass Wasting	No evidence of past or future mass wasting.	3	Infrequent. Mostly healed over. Low future potential.	6	Frequent or large, causing sediment nearly year long.	(9)	Frequent or large, causing sediment nearly yearlong OR imminent danger of same.	12
	3	Debris Jam Potential	Essentially absent from immediate channel area.	2	Present, but mostly small twigs and limbs.	4	Moderate to heavy amounts, mostly larger sizes.	(6)	Moderate to heavy amounts, predominantly larger sizes.	8
	4	Vegetative Bank Protection	90%+ plant density. Vigor and variety suggest a deep, dense soil binding root mass.	3	70-90% density. Fewer species or less vigor suggest less dense or deep root mass.	(6)	50-70% density. Lower vigor and fewer species from a shallow, discontinuous root mass.	9	<50% density plus fewer species & less vigor indicating poor, discontinuous, and shallow root mass.	12
Lower Banks	5	Channel Capacity	Ample for present plus some increases. Peak flows contained. W/D ratio <7.	1	Adequate. Bank overflows are rare. W/D ratio = 8-15.	2	Barely contains present peaks. Occasional overbank floods. W/D ratio = 15-25.	(3)	Inadequate. Overbank flows common. W/D ratio > 25.	4
	6	Bank Rock Content	65%+ w/ large angular boulders. 12"+ common.	2	40-65%. Mostly boulders and small cobbles 6-12".	(4)	20-40%. With most in the 3-6" diameter class.	6	<20% rock fragments of gravel sizes, 1-3" or less.	8
	7	Obstructions to Flow	Rocks and logs firmly imbedded. Flow pattern w/o cutting or deposition. Stable bed	2	Some present causing erosive cross currents and minor pool filling. Obstructions fewer and less firm.	4	Moderately frequent, unstable obstructions move with high flows causing bank cutting and pool filling.	(6)	Frequent obstructions and deflectors cause bank erosion yearlong. Sediment traps full, channel migration occurring.	8
	8	Cutting	Little or none. Infrequent raw banks <6".	4	Some, intermittently at outcurves and constrictions. Raw banks may be up to 12".	6	Significant. Cuts 12-24" high. Root mat overhangs and sloughing evident.	(12)	Almost continuous cuts, some over 24" high. Failure of overhangs frequent.	16
	9	Deposition	Little or no enlargement of channel or point bars.	4	Some new bar increase, mostly from coarse gravel.	8	Moderate depostion of new gravel and coarse sand on old and some new bars.	(12)	Extensive deposit of predominantly fine particles. Accelerated bar development.	16
Bottom	10	Rock Angularity	Sharp edges and corners. Plane surfaces rough.	1	Rounded corners and edges, surfaces smooth, flat.	(2)	Corners and edges well rounded in 2 dimensions.	3	Well rounded in all dimensions, surfaces smooth.	4
	11	Brightness	Surfaces dull, dark or stained. Generally not bright.	1	Mostly dull, but may have <35% bright surfaces.	2	Mixture dull and bright, ie 35-65% mixture range.	(3)	Predominantly bright, 65%+, exposed or scoured surfaces.	4
	12	Consolidation of Particles	Assorted sizes tightly packed or overlapping.	2	Moderately packed with some overlapping.	(4)	Mostly loose assortment with no apparent overlap.	6	No packing evident. Loose assortment, easily moved.	8
	13	Bottom Size Distribution	No size change evident. Stable material 80-100%.	4	Distribution shift light. Stable material 50-80%.	(8)	Moderate change in sizes. Stable materials 20-50%.	12	Marked distribution change. Stable materials 0-20%.	16
	14	Scouring and Deposition	<5% of bottom affected by scour or deposition.	(6)	5-30% affected. Scour at constrictions and where grades steepen. Some deposition in pools.	12	30-50% affected. Deposits and scour at obstructions, constrictions and bends. Some filling of pools.	18	More than 50% of the bottom in a state of flux or change nearly yearlong.	24
	15	Aquatic Vegetation	Abundant growth moss-like, dark green perennial. In swift water, too.	1	Common. Algae forms in low velocity and pool areas. Moss here, too.	(2)	Present but spotty, mostly in backwater. Seasonal algae growth makes rocks slick.	3	Perrenial types scarce or absent. Yellow-green, short term bloom may be present.	4
				Excellent Total = 6		Good Total = 26		Fair Total = 51		Poor Total = 8

Stream Type	A1	A2	A3	A4	A5	A6	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	D3	D4	D5	D6
Good (Stable)	38-43	38-43	54-90	60-95	60-95	50-80	38-45	38-45	40-60	40-64	48-68	40-60	38-50	38-50	60-85	70-90	70-90	60-85	85-107	85-107	85-107	67-98
Fair (Mod. unstable	44-47	44-47	91-129	96-132	96-142	81-110	46-58	46-58	61-78	65-84	69-88	61-78	51-61	51-61	86-105	91-110	91-110	86-105	108-132	108-132	108-132	99-125
Poor (Unstable)	48+	48+	130+	133+	143+	111+	59+	59+	79+	85+	89+	79+	62+	62+	106+	111+	111+	106+	133+	133+	133+	126+
Stream Type	**DA3**	**DA4**	**DA5**	**DA6**	**E3**	**E4**	**E5**	**E6**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**		
Good (Stable)	40-63	40-63	40-63	40-63	40-63	50-75	50-75	40-63	60-85	60-85	85-110	85-110	90-115	80-95	40-60	40-60	85-107	85-107	90-112	85-107		
Fair (Mod. unstable	64-86	64-86	64-86	64-86	64-86	76-96	76-96	64-86	86-105	86-105	111-125	111-125	116-130	96-110	61-78	61-78	108-120	108-120	113-125	108-120		
Poor (Unstable)	87+	87+	87+	87+	87+	97+	97+	87+	106+	106+	126+	126+	131+	111+	79+	79+	121+	121+	126+	121+		

Grand Total = 91

Stream Type = C4

Modified Channel Stability Rating = Fair

4.2.2.4 BEHI and NBS Evaluations

Reach 3

Reach 3 is classified as an F-3 channel with a BEHI score of Extreme and an NBS evaluation of Very Low. The representative evaluation was conducted at station 134+00, the same location as the Pfankuch evaluation.

The BEHI score of Extreme comes primarily from the large ratio between the overall bank height and the bankfull height, the stratification of the bank material, and the low value of root density. Root depth scores are in the Moderate range, indicating that the existing shrubs and immature trees along the banks may be able to protect the top of the banks; however, there are several feet of exposed soil between the end of the roots and the cobble-dominated lower banks. The NBS score of Very Low indicates that while the banks may be highly erodible, the near-bank stress is not high enough to cause excessive erosion or damage.

Table 4-17 Representative Reach 3 BEHI evaluation

Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use Figure 3-7 with BEHI variables to determine BEHI score.

Stream: **Tongue River**		Location: **Reach 3**	
Station: **XS18 RB**		Observers: **Starkey, Mikus, Burke**	
Date: **10/24/13**	Stream Type: **F-3**	Valley Type: **VIII**	

							BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)							
Study Bank Height (ft) =	6 (A)	Bankfull Height (ft) =	1.5 (B)	(A) / (B) =	4.00 (C)		10.0
Root Depth / Study Bank Height (E)							
Root Depth (ft) =	3 (D)	Study Bank Height (ft) =	6 (A)	(D) / (A) =	0.50 (E)		3.9
Weighted Root Density (G)							
Root Density as % =	30 (F)			(F) x (E) =	15 (G)		7.9
Bank Angle (H)							
Bank Angle as *Degrees* =	80 (H)						5.9
Surface Protection (I)							
Surface Protection as % =	30 (I)						5.9

Bank Material Adjustment:

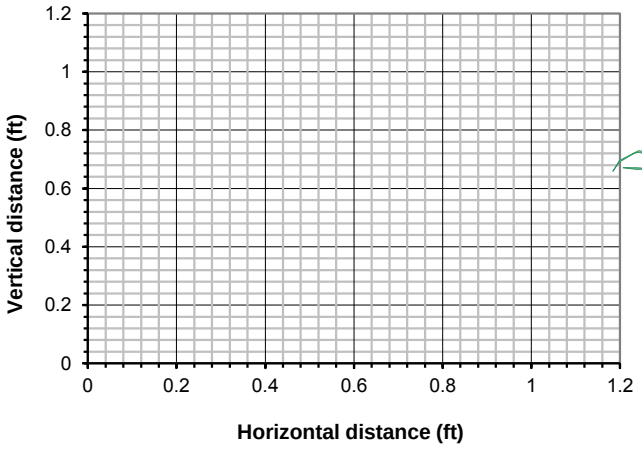
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 10

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Extreme 48.6

Bank Sketch



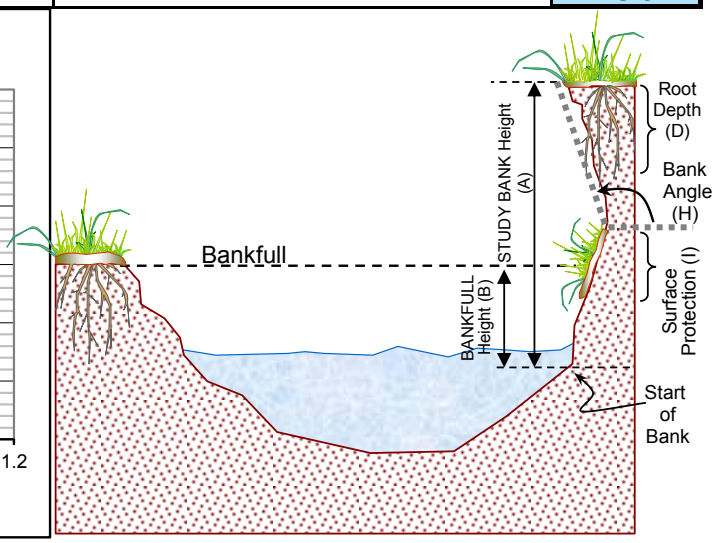


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Table 4-18 Representative Reach 3 NBS evaluation

Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Tongue River** Location: **Reach 3**

Station: **XS18 RB** Stream Type: **F-3** Valley Type: **VIII**

Observers: **Starkey, Mikus, Burke** Date: **01/22/14**

Methods for Estimating Near-Bank Stress (NBS)

(**1**) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(**2**) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(**3**) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(**4**) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(**5**) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(**6**) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(**7**) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I **(1)**

Transverse and/or central bars-short and/or discontinuous……..NBS = High / Very High

Extensive deposition (continuous, cross-channel)……..NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow……..NBS = Extreme

Level II **(2)**

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
150	**79.7**	**1.88**	**High**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress

Moderate

Level III **(5)**

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
2.6	**2**	**1.3**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)

Level IV **(7)**

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40

Overall Near-Bank Stress (NBS) rating **Very Low**

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Reach 4

Reach 4 is classified as a C-3 channel with a BEHI score of Very High and an NBS evaluation of High. The representative evaluation is from Cross Section 17, a location where the Tongue River displays a very archetypal C-3 form: a tall bank on the outside of a meander with a point bar building on the opposite bank. These BEHI and NBS evaluations were intended to score the vertical right bank where the erosion hazard and stress values were expected to be higher than the more stable left bank.

In this location, both bank height ratios point to a BEHI value of Very High. The weighted root density suggests a BEHI value of Extreme, because the vegetation at the top of this bank consists of grasses and forbs which are browsed by cattle. This keeps their root depth very low compared to the bank height. The root density of these plants is also quite low, meaning that they provide little resistance to soil loss. The bank angle suggests a hazard index of Moderate because it is not quite vertical. Like Reach 5, the bank material at this location is unconsolidated, homogeneous, and highly stratified—all of which make it prone to erosion and limit the amount of bank protection it can provide.

Table 4-19 Representative Reach 4 BEHI evaluation

Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use Figure 3-7 with BEHI variables to determine BEHI score.

Stream: **Tongue River**		Location: **Reach 4**	
Station: **XS17**		Observers: **Starkey, Mikus, Burke**	
Date: **10/22/14**	Stream Type: **C-4**	Valley Type: **VIII**	

						BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)						
Study Bank Height (ft) =	5.3 (A)	Bankfull Height (ft) =	2.2 (B)	(A) / (B) =	2.41 (C)	8.4
Root Depth / Study Bank Height (E)						
Root Depth (ft) =	0.6 (D)	Study Bank Height (ft) =	5.3 (A)	(D) / (A) =	0.11 (E)	8.3
Weighted Root Density (G)						
Root Density as % =	10 (F)			(F) x (E) =	1.13208 (G)	10.0
Bank Angle (H)						
Bank Angle as *Degrees* =	70 (H)					4.9
Surface Protection (I)						
Surface Protection as % =	5 (I)					10.0

Bank Material Adjustment:

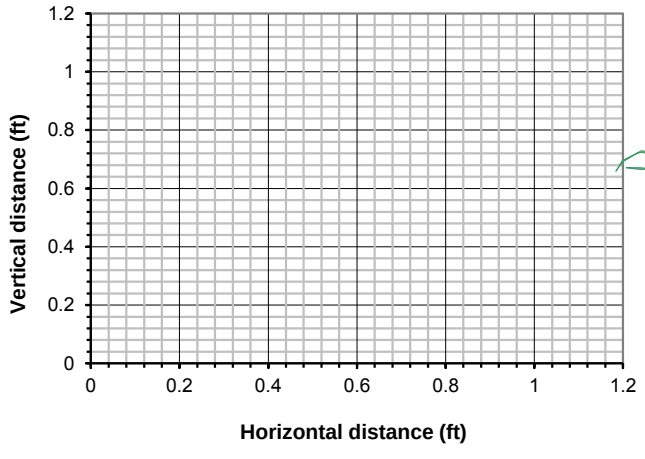
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: -10

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 10

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Very High / 41.7

Bank Sketch



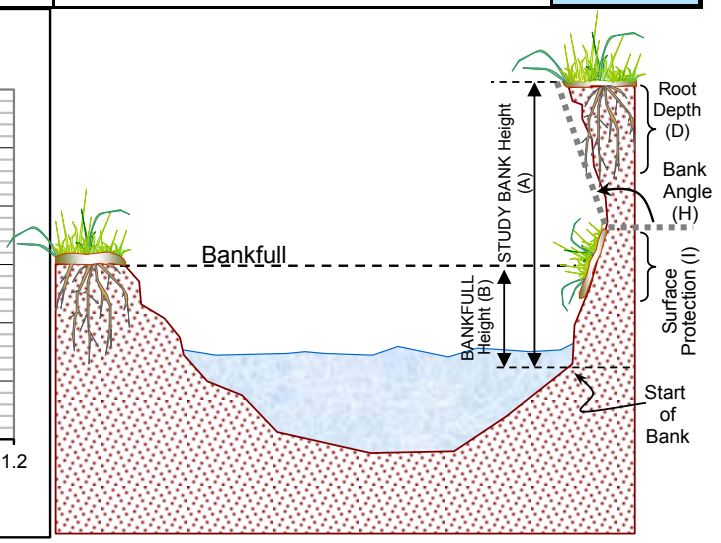


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Table 4-20 Representative Reach 4 NBS evaluation

Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Tongue River** Location: **Reach 4**

Station: **XS17** Stream Type: **C-4** Valley Type: **VIII**

Observers: **Starkey, Mikus, Burke** Date: **10/23/14**

Methods for Estimating Near-Bank Stress (NBS)

(**1**) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(**2**) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(**3**) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(**4**) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(**5**) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(**6**) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(**7**) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I **(1)**

Transverse and/or central bars-short and/or discontinuous……..NBS = High / Very High

Extensive deposition (continuous, cross-channel)……..NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow……..NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
163	**81.8**	**1.99**	**High**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress
High

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
3.1	**1.53**	**2.03**	**High**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
3.1			**1.53**				

Level IV **(7)**

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40
					Overall Near-Bank Stress (NBS) rating		**High**

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Reach 5

Reach 5 is classified as a C-3 channel with a BEHI score of Very High and an NBS evaluation of Very High. The representative evaluation was conducted at Cross Section 1, approximately 140 feet upstream of the end of the project reach at the Highway 14 Bridge. The Tongue River in this area is laterally constrained and, as discussed in Section 4.2.1.1, highly vulnerable to accelerated erosion. The BEHI and NBS values corroborate this finding; the bank material, bank height, and bank angle all contribute to an unstable bank prone to erosion.

The lone BEHI criterion which does not yield a score of Very High is the root depth/study bank height ratio, rated Low. This suggests that the presence of brush and trees along the banks within Dayton is critical to maintaining these banks in their present location.

Table 4-21 Representative Reach 5 BEHI evaluation

Worksheet 3-11. Form to calculate Bank Erosion Hazard Index (BEHI) variables and an overall BEHI rating. Use Figure 3-7 with BEHI variables to determine BEHI score.

Stream: **Tongue River**		Location: **Reach 5**	
Station: **XS1**		Observers: **Starkey, Mikus, Burke**	
Date: **11/07/13**	Stream Type: **C-4**	Valley Type: **VIII**	

							BEHI Score (Fig. 3-7)
Study Bank Height / Bankfull Height (C)							
Study Bank Height (ft) =	5 (A)	Bankfull Height (ft) =	2 (B)	(A) / (B) =	2.50 (C)		8.6
Root Depth / Study Bank Height (E)							
Root Depth (ft) =	3 (D)	Study Bank Height (ft) =	5 (A)	(D) / (A) =	0.60 (E)		3.4
Weighted Root Density (G)							
Root Density as % =	10 (F)			(F) x (E) =	6 (G)		8.9
Bank Angle (H)							
Bank Angle as *Degrees* =	80 (H)						5.9
Surface Protection (I)							
Surface Protection as % =	20 (I)						7.2

Bank Material Adjustment:

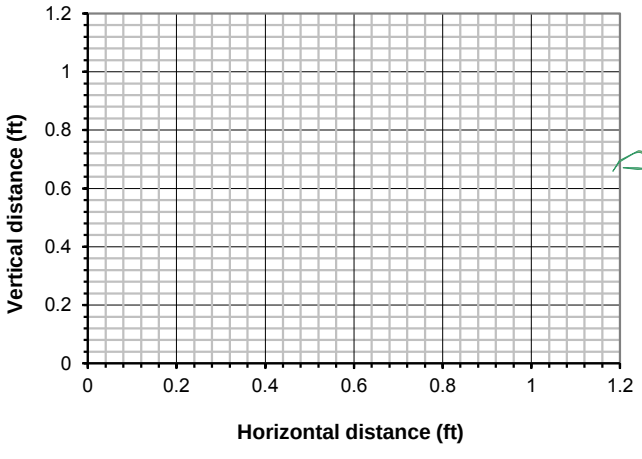
Bedrock (Overall Very Low BEHI)
Boulders (Overall Low BEHI)
Cobble (Subtract 10 points if uniform medium to large cobble)
Gravel or Composite Matrix (Add 5–10 points depending on percentage of bank material that is composed of sand)
Sand (Add 10 points)
Silt/Clay (no adjustment)

Bank Material Adjustment: 5

Stratification Adjustment
Add 5–10 points, depending on position of unstable layers in relation to bankfull stage: 5

Very Low	Low	Moderate	High	Very High	Extreme	Adjective Rating and Total Score
5 – 9.5	10 – 19.5	20 – 29.5	30 – 39.5	40 – 45	46 – 50	Very High / 44.0

Bank Sketch



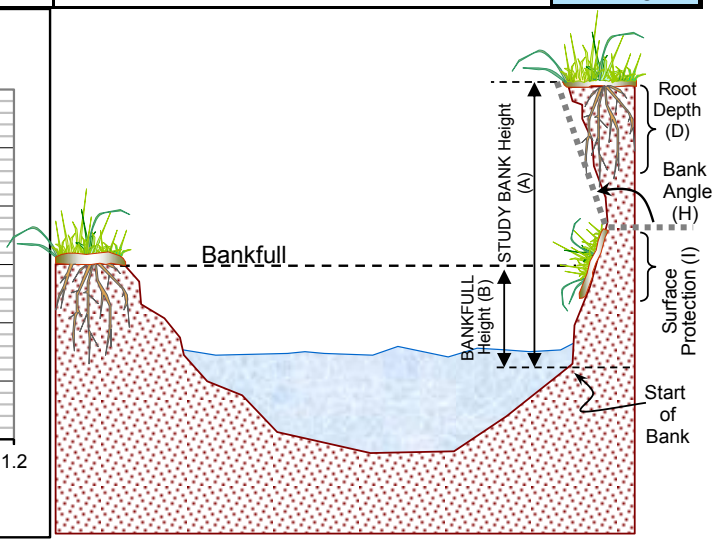


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Table 4-22 Representative Reach 5 NBS evaluation

Worksheet 3-12. Various field methods of estimating Near-Bank Stress (NBS) risk ratings to calculate erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: **Tongue River** Location: **Reach 5**

Station: **XS1** Stream Type: **C 4** Valley Type: **VIII**

Observers: **Starkey, Mikus, Burke** Date: **11/07/13**

Methods for Estimating Near-Bank Stress (NBS)

(1) Channel pattern, transverse bar or split channel/central bar creating NBS	Level I	Reconaissance
(2) Ratio of radius of curvature to bankfull width (R_c / W_{bkf})	Level II	General prediction
(3) Ratio of pool slope to average water surface slope (S_p / S)	Level II	General prediction
(4) Ratio of pool slope to riffle slope (S_p / S_{rif})	Level II	General prediction
(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb} / d_{bkf})	Level III	Detailed prediction
(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb} / τ_{bkf})	Level III	Detailed prediction
(7) Velocity profiles / Isovels / Velocity gradient	Level IV	Validation

Level I

(1)

Transverse and/or central bars-short and/or discontinuous……NBS = High / Very High

Extensive deposition (continuous, cross-channel)……NBS = Extreme

Chute cutoffs, down-valley meander migration, converging flow……NBS = Extreme

Level II

(2)

Radius of Curvature R_c (ft)	Bankfull Width W_{bkf} (ft)	*Ratio* R_c / W_{bkf}	Near-Bank Stress (NBS)
475	**73.9**	**6.43**	**Low**

(3)

Pool Slope S_p	Average Slope S	*Ratio* S_p / S	Near-Bank Stress (NBS)

(4)

Pool Slope S_p	Riffle Slope S_{rif}	*Ratio* S_p / S_{rif}	Near-Bank Stress (NBS)

Dominant Near-Bank Stress

Low

Level III

(5)

Near-Bank Max Depth d_{nb} (ft)	Mean Depth d_{bkf} (ft)	*Ratio* d_{nb} / d_{bkf}	Near-Bank Stress (NBS)
2.97	**2.08**	**1.43**	**Low**

(6)

Near-Bank Max Depth d_{nb} (ft)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d_{bkf} (ft)	Average Slope S	Bankfull Shear Stress τ_{bkf} (lb/ft^2)	Ratio τ_{nb} / τ_{bkf}	Near-Bank Stress (NBS)
2.97			**2.08**				

Level IV

(7)

Velocity Gradient (ft / sec / ft)	Near-Bank Stress (NBS)
0	**0**

Converting Values to a Near-Bank Stress (NBS) Rating

Near-Bank Stress (NBS) ratings	Method number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N / A	> 3.00	< 0.20	< 0.40	< 1.00	< 0.80	< 0.50
Low	N / A	2.21 – 3.00	0.20 – 0.40	0.41 – 0.60	1.00 – 1.50	0.80 – 1.05	0.50 – 1.00
Moderate	N / A	2.01 – 2.20	0.41 – 0.60	0.61 – 0.80	1.51 – 1.80	1.06 – 1.14	1.01 – 1.60
High	See	1.81 – 2.00	0.61 – 0.80	0.81 – 1.00	1.81 – 2.50	1.15 – 1.19	1.61 – 2.00
Very High	(1)	1.50 – 1.80	0.81 – 1.00	1.01 – 1.20	2.51 – 3.00	1.20 – 1.60	2.01 – 2.40
Extreme	Above	< 1.50	> 1.00	> 1.20	> 3.00	> 1.60	> 2.40
	Overall Near-Bank Stress (NBS) rating					**Very High**	

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4.2.2.5 Estimated Lateral Erosion Rates

The purpose of BEHI and NBS evaluations is to evaluate the existing banks for their erosion potential and the amount of shear stress they face. However, the results of these evaluations can also be used to estimate the erosion rates of the banks. Barr used the BEHI and NBS ratings, along with the 1989 Yellowstone National Park curves (Rosgen 1996), to convert each site's NBS rating and BEHI rating into an approximate bank erosion rate (BER) in feet/year. The estimated lateral erosion rates for Reaches 2–5 can be seen in Figure 4-14. Figures showing lateral erosion rates by individual reach can be found in Appendix I.

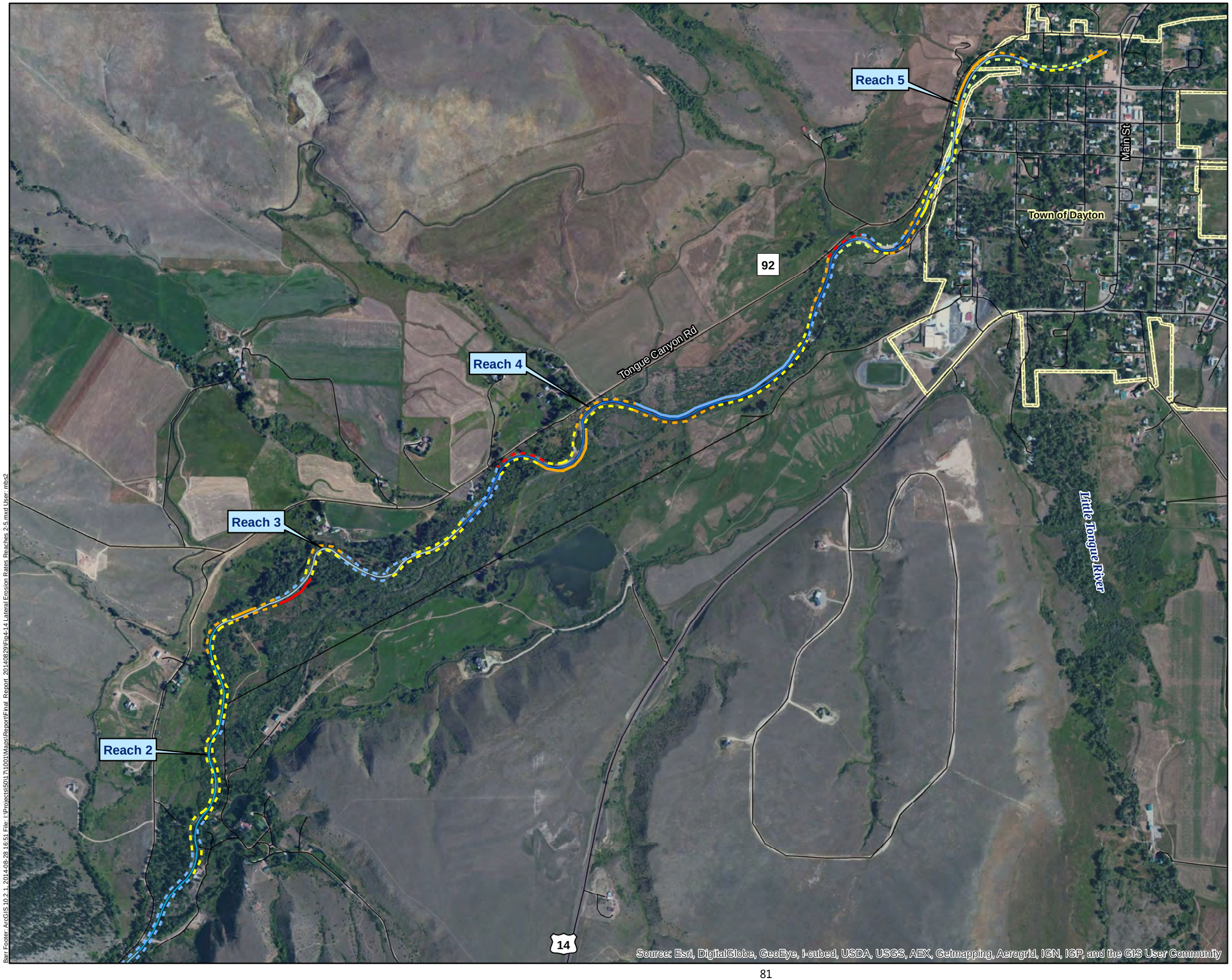
The final step in the stability analysis was to convert bank erosion rates in feet/year to a sediment load to the Tongue River. These values are reported in tons/ft/year, meaning each foot of bank length will yield a certain volume of sediment to the Tongue River annually. Since bank heights vary widely within the project area, the estimates below assume a unit bank height ranging from 1 or 2 feet to over 6 feet. Estimated sediment loads on Reaches 2–5 are plotted in Figure 4-15. Figures showing the estimated sediment loads by individual reach can be found in Appendix J.

Despite its relatively high slope, most of Reach 2 has only a moderate risk of erosion. Boulders are the dominant bed material, meaning the channel bottom can be considered mostly immobile. The banks usually have low slopes and a combination of vegetation that includes trees and shrubs, as well as grasses and forbs. Areas in this reach with likely BEHI values of High tend to have more turf grass at the river's edge or a relatively high bank with unconsolidated sediments, leading to a lack of stability and vulnerability to erosion.

The stability of Reach 3 varies widely; some areas are extremely vulnerable to erosion, while others are only moderately so. The stretch of the river near Cross Section 18 has a very high, vertical right bank with immature willows, while the left bank is lower, flatter, and populated by large willow and ash trees. The left bank at station 140+00 is developing a vertical bank and is rated Very High on the index; it is at the toe of a major slope and may quickly develop an escarpment if not addressed. Most of the rest of the reach is rated a High-to-Moderate erosion hazard.

Reach 4 is most stable in sections with low sinuosity (e.g., stations 158+00 to 164+00 or 194+00 to 206+00). Sinuous stretches (e.g., 164+00 to 185+00) tend to have Very High or Extreme ratings on the outside of meanders and High-to-Moderate ratings on the inside of meanders. As noted in section 4.2.1.1, Reach 4 is classified as a C-3 channel, considered susceptible to lateral erosion regardless of sinuosity.

Like Reach 3, the erosion indices on Reach 5 also vary widely. Reach 5 has fairly low sinuosity, but in areas of curvature the risk of erosion is higher on the outer bank and lower on the inner bank (e.g., stations 243+00 to 252+00 and 253+00 to 259+00). A BEHI evaluation at station 247+00 near the Tongue Canyon Road rates this stretch as a Very High erosion risk despite the use of concrete and riprap to stabilize the banks; further efforts may be needed here to protect Tongue Canyon Road.



Lateral Erosion Rate*

- 0.1-0.3 ft/yr, Estimated
- 0.3-0.8 ft/yr, Estimated
- 0.3-0.8 ft/yr, Measured
- 0.8-1.1 ft/yr, Estimated
- 0.8-1.1 ft/yr, Measured
- 1.1-1.8 ft/yr, Estimated
- 1.1-1.8 ft/yr, Measured
- >1.8 ft/yr, Estimated
- >1.8 ft/yr, Measured

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

*To convert from feet/yr to cubic ft/year, multiply by bank length and height

*To convert from feet/year to tons/ft/year, multiply by bank height and by 0.048

Notes:
Lateral erosion rates calculated based on Bank Erosion Hazard Index (BEHI) and Near Bank Stress (NBS) values, per Rosgen curves from Yellowstone National Park

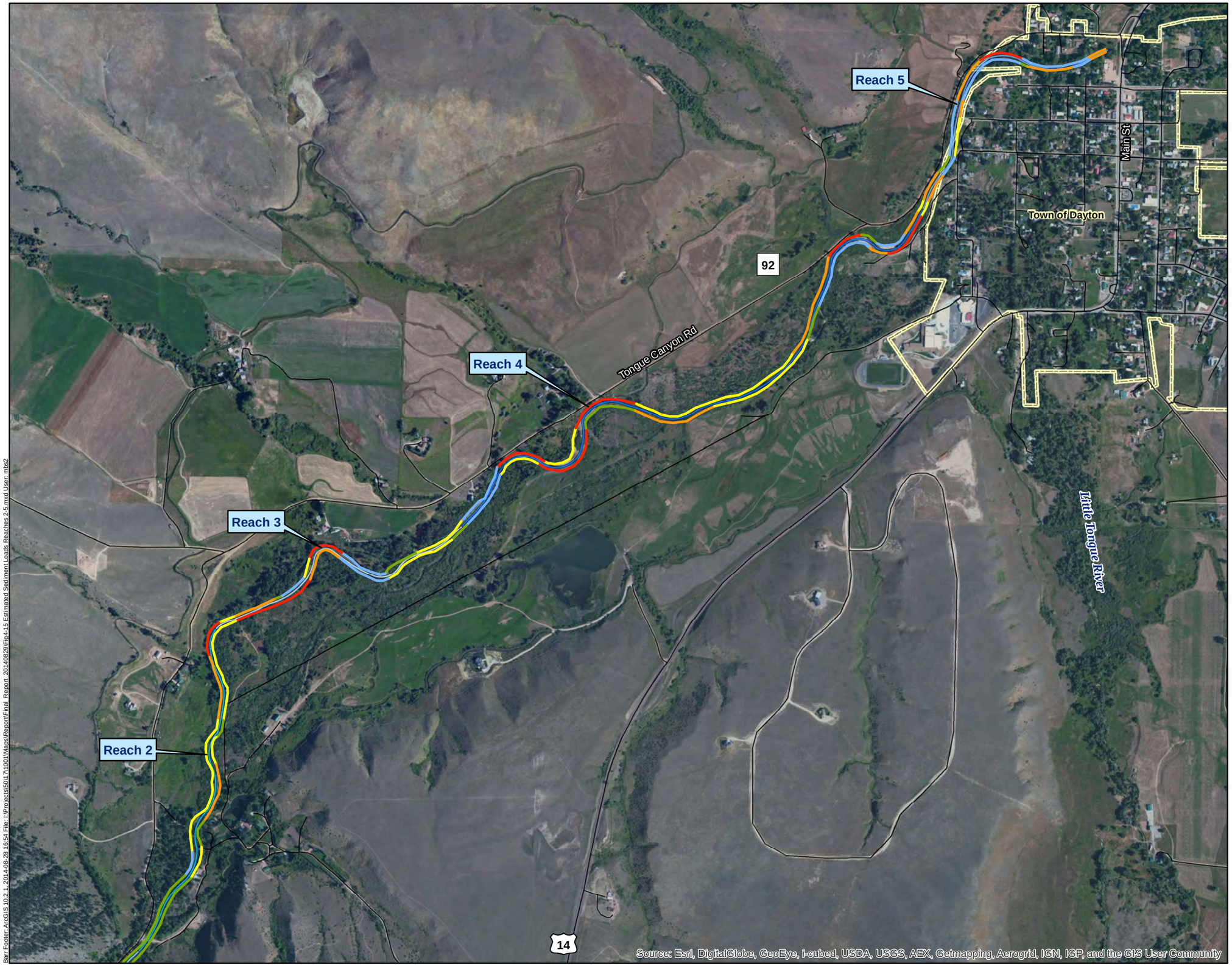
Feet
1,000 0 1,000

Figure 4-14

LATERAL EROSION RATES, REACHES 2-5
Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT
BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:51 File: I:\Projects\5017\10001\Mxds\Report\Final_Report_20140829\Fig4-14 Lateral Erosion Rates Reaches 2-5.mxd User: mbs2



Estimated Erosion Rate

- 0.005 - 0.02 tons/ft/year
- 0.02 - 0.06 tons/ft/year
- 0.06 - 0.10 tons/ft/year
- 0.10 - 0.14 tons/ft/year
- 0.14 - 0.30 tons/ft/year

Project River Reaches

- Reach 1
- Reach 2
- Reach 3
- Reach 4
- Reach 5
- Municipal Boundary

Feet

1,000 0 1,000

Figure 4-15

ESTIMATED SEDIMENT LOADS, REACHES 2-5

Tongue River Stream Improvement Plan
Sheridan County Conservation District
Dayton, Wyoming

SHERIDAN COUNTY CONSERVATION DISTRICT

BARR

Barr Footer: ArcGIS 10.2.1, 2014-08-28 16:54 File: I:\Projects\5017\1001\Maps\Report\Final Report_20140829\Fig4-15 Estimated Sediment Loads Reaches 2-5.mxd User: mbs2

5.0 Assessment Results and Recommendations

SVAP meetings and discussions provided the team with locations and landowner-specific topics of concern to focus their survey efforts within each reach. SVAP assessment results—combined with the bank erosion potential maps and pattern analysis—allowed priorities for future work to be more clearly identified.

Data from each reach and profile survey was used to compare existing channel conditions to those found in other studies of the Tongue River in the immediate area or expected conditions for similar stream classifications. Departure from expected conditions gives perspective on the extent of potential measures to construct or move the channel towards a more stable configuration and/or dimension. A range of dimensionless ratios was developed to guide channel modifications and provide general guidance in developing projects to address bank erosion, over-widened conditions, and the desire for fish habitat diversity improvements. Aerial pattern evaluation using historic aerial imagery provided insight into the nature of channel meander migration and interruptions caused by past channelization. Aerial images also confirmed observations of high erosion in specific areas related to the river's tendency to seek a more stable planform via increased sinuosity.

Additional guidance using a hydraulic model such as the Hydraulic Engineering Centers River Analysis System, HEC-RAS (http://www.hec.usace.army.mil/software/hec-ras/features.aspx), or Adaptive Hydraulics, ADH (http://chl.erdc.usace.army.mil/adh), will be required for specific design in Reach 5 and portions of Reach 4 due to existing infrastructure and floodplain ordinances. A hydraulic model allows modeling of a selected range of flows and associated velocities and shear stress to guide channel sizing, material size selection, and local hydraulics associated with the placement of new elements in the channel to improve in-stream habitat diversity.

Table 5-1 Comparison of channel classification values

Location	W_{bkf}, ft	D_{bkf},ft	A_{bkf}, ft^2	W/D Ratio	Ent. Ratio	Sinuosity	D_{50}, mm	Class.	Q_{bkf} cfs
Reach 1 and 2	56	3.4	192	16	1.3	1.10	n/a	B-2	1,360
Reach 3	80	2.0	160	40	1.1	1.10	101	F-3	
Reach 4	64	2.7	171	24	4.7	1.25	56.9	C-4	
Reach 5	78	2.6	200	31	4.5	1.05	56.2	C-4	
SCCD Regional Curve Development	75	3.0	226.2	25	1.8	1.0	240	B-3c	1,310
Padlock Ranch*	79	3	237	26	6.3	1.10	71.4	C-3	1,114
USGS Regional Curves**	86.4	2.8	238	--	==	--	--	--	1,364
Scott Park	93	2.8	258	33	>2.2	1.16	82.2	C-3	1,361

* Reference reach data

** From Figure 4, USGS 2012, basins with >25 inches mean annual precipitation and drainage area estimated at 200 square miles

5.1 Reach 1

Reach 1 is a stable stream reach and was not included in the effort to develop a stream improvement concept plan.

5.2 Reach 2

Reach 2 is a stable reach of stream with minor local bank erosion issues that should be addressed with the specifically affected landowners. Removal of deep-rooted woody cover to enhance river views in some areas may contribute to localized reductions in bank stability.

5.3 Reach 3

Considering adjacent land use, two primary landowners, and the generally lower slope of Reach 3 (particularly between Station 158+00 and 125+00), re-meander of the river could be considered. Re-meander of the river would primarily be focused on speeding the river's trend towards increased sinuosity. This would improve habitat diversity through installation of in-stream and bank structures. The river in this area may provide adequate floodplain space to pursue measures to increase sinuosity, depending on landowner objectives and desired conditions

Now classified as an F channel, the evolution of Reach 3 is towards a C channel, with corresponding increases in sinuosity and floodplain access for flows in excess of bankfull. Bank grading, with wood vane and root wad placements to allow more frequent access to the floodplain—coupled with narrowing of the active channel and an increase in sinuosity—would help achieve an increase in diversity of in-stream features and subsequent improvements in fish habitat.

Some areas of localized heavy streamside use by cattle may contribute to bank instability; however, seasonal-use management with temporary fencing would likely allow vegetation density to increase.

Use of woody elements for in-stream cover and/or bank treatments would be preferable to rock use in Reach 3. Woody cover can provide similar potential for development of deeper pools associated with large in-stream objects and, in general, provides better overhead cover for fish habitat than rock features. Pool and in-stream habitat for fish is limited in the reach and would be improved with additional local scour pool development and subsequent bed material diversity.

The floodplain forest would have naturally supplied these elements to the river during high flows and, following the 2003 fire, there is a ready source of logs and root wads. Large rock does not appear to be a naturally occurring in-stream feature in this reach, as the river has been unable to transport large boulders downstream of Reach 2 on a regular basis. Appendix K includes general design details for wood-based bank and in-stream cover features.

The land use and lack of infrastructure that dominates the river corridor in this reach makes it possible to use the appropriate dimensionless ratios, coupled with detailed site survey, to develop designs for in-stream habitat diversity improvement or bank treatments. Detailed hydraulic models, as required in Reaches 4 and 5, would not be necessary, provided that adjacent landowners do not require a more rigorous quantification of the potential effects of habitat improvement efforts.

Landowner-desired conditions and receptiveness to a planned effort to increase river sinuosity will be the most important factor in developing a plan of action in Reach 3.

Non-structural options to improve bank stability, riparian habitat, and in-stream habitat include the establishment of wider riparian buffer strips, fenced cattle watering lanes, and/or grazing management systems that do not allow for unrestricted livestock access to the river banks. Grazing management systems have been successful in establishing riparian buffers in northeast Wyoming (Jellison et. al 2007). Woody plantings or woody plants within a new buffer area may require early protection from domestic and wild grazing (Cundy 2014).

5.4 Reach 4

The local hydraulics in this reach—associated with the existing infrastructure in Dayton, proximity to County Highway 14, and Tongue River Diversion No. 1—would be better understood with the use of a hydraulic model. A hydraulic model would also increase understanding of the reach and quantify risks associated with high flows for the county and landowners. A model boundary should extend upstream to at least Station 165+00. Without the information provided by a hydraulic model, design parameters would be compromised.

Two sub-reaches in Reach 4 (164+00 to 180+00 and 220+00 to 227+00) exhibit planform, channel shape, and slope features developed during the high-flow events in 2011 and 2014. These provide guidance for the channel shape and spacing in other river reaches with locally higher slopes. The overall diversity and local features of these sub-reaches (deeper outside bend pools, scour pools, in-stream object cover) provide some of the better fish habitat in the study reach. Although not currently viewed as stable, these

areas provide insight into the dynamic equilibrium and channel forms developed following two recent high-flow events.

Existing bank erosion protection measures found upstream of Station 220+00 on the left bank should be examined more closely to ascertain whether they are configured to be most effective. A hydraulic model extending upstream to Station 165+00 would aid in quantifying the impact of the gabion baskets placed on the left bank upstream of the Tongue River No. 1 Diversion.

The maintenance activity associated with the Tongue River No. 1 Diversion from near Station 183+00 to 184+00 should be examined to determine if a vane-type structure would be a less maintenance-intensive approach to water diversion than a push-up diversion dam, which creates more in-stream disturbance. Bank erosion issues could be more appropriately addressed with a more permanent in-stream diversion structure.

Historic map imagery suggests that sinuosity was once greater between Station 195+00 and 210+00, an area where there is now relatively low sinuosity. There may be opportunity to increase the river sinuosity in this area depending on private landowner perspectives. An incremental increase in sinuosity would add diversity and improve associated fish habitat. Sinuosity could be increased by construction of a new river centerline and channel or by strategic placement of in-stream and bank features that would encourage migration of the river centerline over time.

Intermittent erosion protection measures in Reach 4 should be re-examined and checked against the SVAP-noted areas of concern to determine whether other measures such as placement of toe-wood, engineered root wads, log vanes, or rock and log vanes (Appendix K) would more effectively address the need to reduce the width/depth ratio, improve fish habitat, and handle bank erosion. Woody cover will provide more benefit to fish habitat than features comprised of rock alone.

In general, considering the surrounding floodplain forest, Reach 4 appears to have a low number of woody debris elements in-stream or in the immediate bank area. The fire in 2003 may have contributed to this, along with removal of larger woody debris to address localized bank erosion. The floodplain forest will provide a readily available source of material for toe-wood and/or other woody items needed for new habitat and bank protection features. As in Reach 3, riparian buffers are applicable for adjacent pastures.

5.5 Reach 5

The existing bank protection features found in Reach 5 (Station 247+00 to Station 257+00) should be evaluated in more detail to determine whether they should remain in place or be modified to avoid unintended bank erosion, bed degradation, or bank overtopping during high-flow events. Anecdotal information from landowners suggests the current structures were put in place some time ago and have changed in form and size since construction. These hard structures force the main current immediately downstream and to the opposite downstream bank, contributing to erosion in these areas.

Transverse bar formation between Station 255+00 and 250+00 indicates a depositional zone and corresponding lack of bedload transport capacity due, in part, to the wider-than-expected width/depth ratio.

A lack of pool habitat is a consequence of compromised bedload transport capacity, lower-than-expected sinuosity, and lack of large in-stream objects such as boulders or log/root wads. Pools are typically found on the outside bends of meanders and associated with local scour around large objects.

The active lateral erosion on the high north banks between Station 248+00 and 257+00 (just downstream from the rubber tire and rock wings) is likely due to the river seeking a more stable sinuosity. This notion is supported by the series of figures shown in the historic channel evaluation (Appendix C). These clearly show channel sinuosity increasing following channelization work conducted in the early 1950s from the Highway 14 Bridge to an area near Station 248+00 (landowner personal communication).

Using information collected in Reach 4, particularly between Station 220+00 and 225+00, an appropriately sequenced and dimensioned series of rock and/or rock/wood J-hooks (similar to the one found between 238+00 and 241+00) would aid in bank protection, fish habitat development, and shifting the river's main flow towards the center of the channel. Appropriate placement of structures will also aid bedload transport and decrease the likelihood for transverse bar formation. J-hooks or cross-vanes (see Appendix K for a typical design) can also enhance pool habitat as scour holes develop immediately downstream. Pool habitat is currently limited to Reach 1.

Bank protection using toe-wood, VRSS/rock, or wood vanes in conjunction with J-hooks and/or cross vanes (see Appendix K for a typical design) may be necessary due to the height of the existing banks. Infrastructure located very close to the river banks will preclude any major grading to re-shape the high banks. Toe-wood placement would allow the bankfull channel width to narrow and more closely match an expected width/depth ratio. Areas from Station 248+00 to 257+00—as noted in SVAP meetings and on erosion potential maps—are a high priority for immediate attention.

An increase in fish habitat diversity in Reach 5 will be achieved by using any or all of the suggested treatments to address the higher-than-expected width/depth ratio and bank erosion.

All recommendations for construction of structures or bank treatments in Reach 5 need to be vetted by use of a hydraulic model such as HEC-RAS. This will provide an estimate of hydraulic parameters such as velocity and shear stress for a range of modeled flows under both existing and proposed channel conditions. Hydraulic modeling using specifically located and dimensioned design features is also necessary to demonstrate compliance with floodplain requirements.

5.6 Priority Reaches and Locations

Priority sites/reaches identified through the assessment and SVAP are noted in Table 5-2. Representative photos or critical locations of site conditions found in the reach are shown. Table 5-2 can be used as a rapid reference guide for the more detailed reach-based discussions found in Section 5. Appendix L identifies a variety of potential bank and/or fish habitat treatments applicable to the priority locations/reaches based on Rosgen classification and the best professional judgment of the team. Each reach and potential treatment will require specific design efforts based on exact location and project length. Appendix K has general design details for the treatments shown in Appendix L.

The priorities for action are within reaches and at sites where bank erosion or regularly occurring in-stream maintenance takes place. Adjacent private infrastructure, Tongue Canyon Road, or the functionality of Tongue River Diversion #1 may be at risk. Practices that reduce bank erosion can improve fish habitat at reaches/sites not specifically identified in Table 5-2; however, these sites do not generally pose immediate risk to high-value private or public infrastructure.

Table 5-2 Priority sites/reaches

Reach and Stationing	Rationale
Reach 5 Station 246+00 to 258+00	Proximity to private infrastructure
Reach 4 Station 217+00 to 220+00	Proximity to Tongue Canyon Road
Reach 4 Station 181+00 to 185+00	Annual maintenance required with in-stream disturbances/erosion

6.0 References

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Appendices