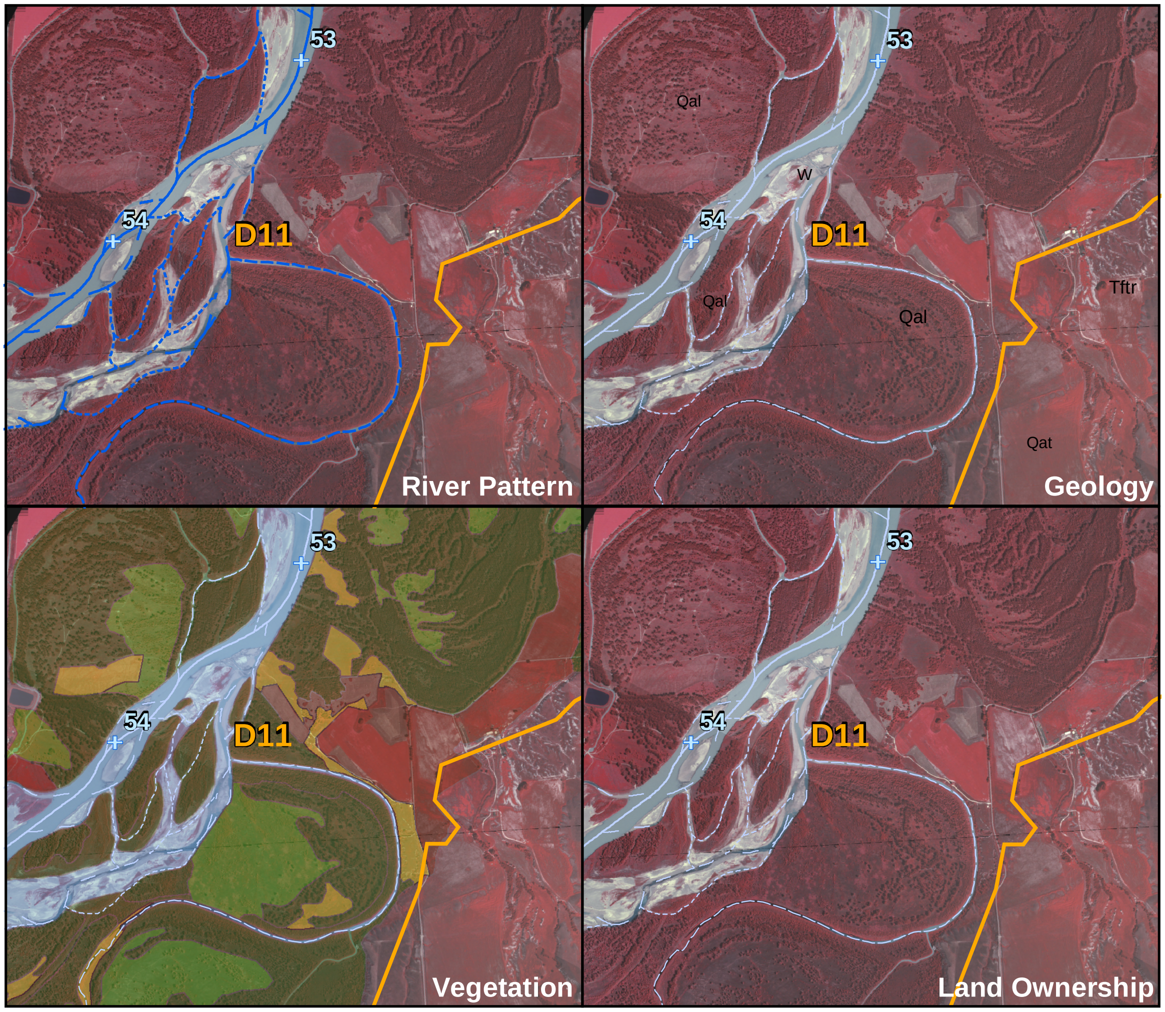
Geomorphic Reconnaissance and GIS Development Yellowstone River, Montana

Springdale to the Missouri River Confluence

FINAL REPORT



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1. Introduction

The Yellowstone River has received increased public attention in recent years due to combined effects of damaging flood events and increased development pressures within the river corridor. Major flood events in 1996 and 1997 resulted in an increased awareness of the potential magnitudes of Yellowstone River flooding and bank erosion, as well as associated threats to infrastructure and land use. In addition, public concern regarding the potential impacts of bank stabilization measures on the biological and physical sustainability of the river corridor has been heightened.

1.1. Yellowstone River Cumulative Effects Investigation

In 1997, the Governor of Montana, Marc Racicot, appointed the Upper Yellowstone River Task Force (UYRTF) to consider issues in Park County along the upper river, including the cumulative effects of bank stabilization. Subsequent to the development of the UYRTF, litigation pursued in 1999 by a coalition of concerned environmental groups resulted in a directive by a Federal District Court for the Army Corps of Engineers (ACOE) to develop a Cumulative Effects Study for the entire mainstem of the Yellowstone River.

In 1999, the Yellowstone River Conservation District Council (YRCDC) was formed to address issues related to conservation and cumulative effects within the Middle and Lower Yellowstone River corridor. The council is comprised of representatives from eleven Montana Conservation Districts (CDs) that are located along the river between Springdale and the Montana/North Dakota state line. The Montana Conservation Districts represented on the YRCDC include: Carbon, Custer, Dawson, Park, Prairie, Richland, Rosebud, Stillwater, Sweet Grass, Treasure, and Yellowstone Counties. Additional YRCDC membership includes one representative each from McKenzie County, North Dakota, and the Montana Association of Conservation Districts (MACD).

The Cumulative Effects Study (CES) of the Yellowstone River Corridor has been under collaborative development by the Corps of Engineers, the YRCDC, a Technical Advisory Committee (TAC), and a Resource Advisory Committee (RAC). The project formulation has included the identification of those disciplines relevant to the CES, and the development of scopes of work for those individual studies. On January 22, 2004 the Feasibility Cost Share Agreement and Project Management Plan were signed, marking the transition from three years of planning and preliminary studies to commencement of the Cumulative Effects Investigation.

1.2. Purpose of the Geomorphic Reconnaissance

The CES plan development efforts have shown that an intensive assessment of the entire 477 mile-long Yellowstone River corridor between Springdale and the Missouri River confluence is an immense undertaking. To maintain the viability of the project, the group developing the CES plan recommended that the corridor be segmented into a series of reaches that could be grouped in terms of basic stream form, allowing the identification of a series of representative reaches for detailed analysis in the CES. In response to this recommendation, a Geomorphic Reconnaissance of the Yellowstone River from

Springdale to the Missouri River Confluence was contracted by the Custer County Conservation District on behalf of the YRCDC.

The following document contains the results of the reconnaissance level geomorphic investigation of the Yellowstone River between Springdale and its confluence with the Missouri River in McKenzie County, North Dakota. This area is defined collectively as the Middle and Lower Yellowstone River corridor. The Middle Yellowstone River extends from near Springdale to the Bighorn River, and the Lower Yellowstone reaches from the Bighorn River to the Missouri River.

The overall goal of the investigation is to identify representative reaches for detailed investigations in succeeding phases of the Yellowstone River Cumulative Effects Investigation. Primary subtasks of the investigation include: 1) compilation of existing appropriate digital information into an ArcView GIS project; 2) subreach classification and representative reach selection; 3) delineation of project area boundaries (corridor margins) to help identify the project area extent; and, 4) inventory and preliminary evaluation of available historic aerial photography.

Throughout this project effort, several progress updates showing results of preliminary findings have been presented to the Yellowstone River Conservation District Council (YRCDC) and associated Technical Advisory Committee (TAC) to promote effective collaboration and continual review. Furthermore, the identification of representative reaches was performed in collaboration with the Montana State University Fisheries Coop Unit, as part of their parallel reconnaissance investigation of Yellowstone River fisheries conditions and research plan development (Probosczc and Guy, 2004).

1.3. Acknowledgements

This effort was performed through a contract between Custer County Conservation District and Confluence Consulting, Inc (CCI). The technical aspects of this project were performed primarily by Applied Geomorphology, Inc. (AGI), and DTM Consulting, Inc. (DTM). Contracting and oversight were provided by CCI. The authors recognize both Custer County and CCI for facilitating project contracting and execution. Additionally, the constant input provided by the YRCDC Technical Advisory Committee (TAC) has proven invaluable in this effort, and is greatly appreciated. TAC members played a critical role in general project oversight and representative reach selection. Beneficial input was also received from members of both the Resource Advisory Committee (RAC) members and YRCDC. The project team extends its gratitude to all involved parties that facilitated this effort.

2. Physical Setting

The following characterization of the Yellowstone River corridor geology and geomorphology is based on available existing documents. This summary is intended to provide a general description of corridor conditions, and to highlight relevant information sources that may be useful in future investigations.

2.1. Regional Geologic History

East of Springdale, Montana, the Yellowstone River flows through the Northern Great Plains physiographic province, an extensive area that slopes gently eastward from the Rocky Mountains toward the Missouri and Mississippi Rivers (Figure 2-1). The bedrock geology of the Northern Great Plains consists primarily of Cretaceous and Tertiary age sedimentary rocks that are over 55 million years old. These units were deposited in response to erosion of the Rocky Mountain uplift. More recently, during the last 10 million years, the Rocky Mountain Front has been further uplifted several thousand feet (Wayne and others, 1991). This uplift resulted in the formation of a broad surface (piedmont) that slopes gently to the east from the Rocky Mountain Front.

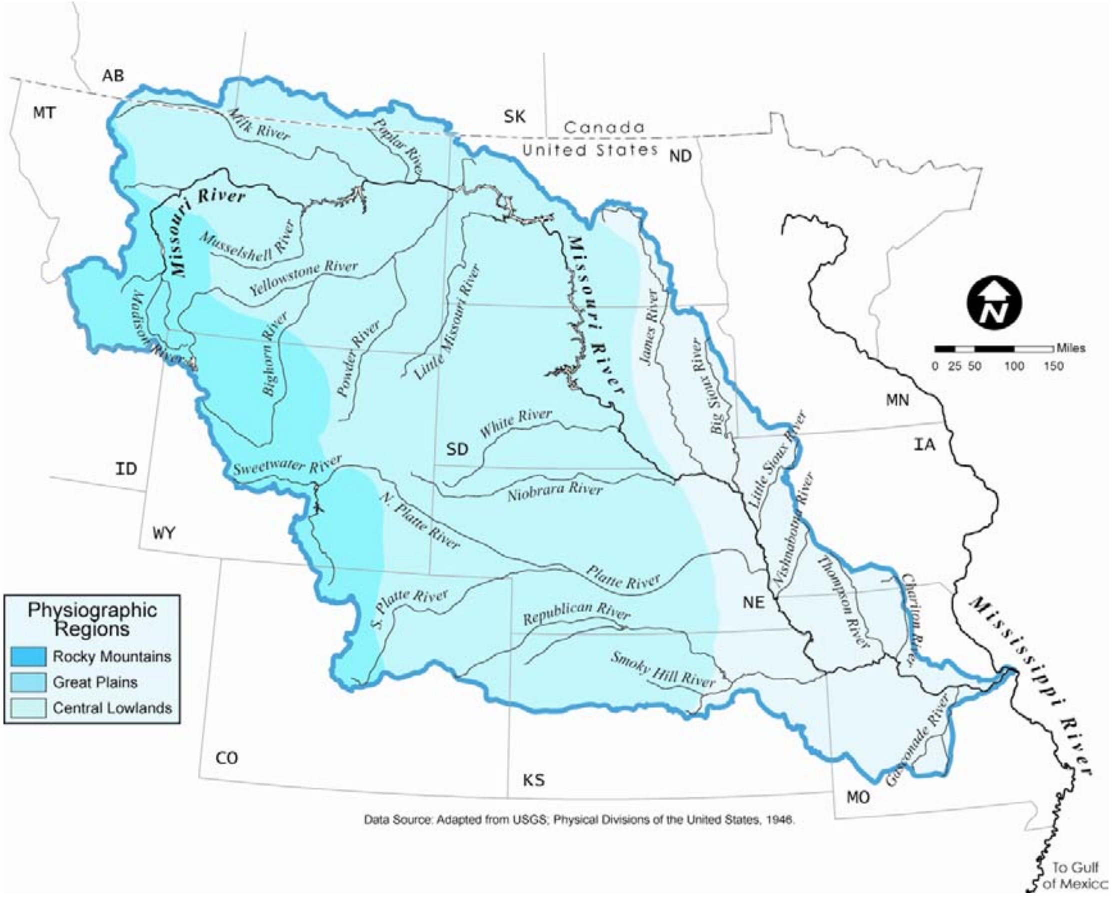

Figure 2-1. Physiographic regions of the Missouri River watershed (Project WET)

During Pliocene time (over 2.5 million years ago), river systems began to dissect the Northern Great Plains, and the ancestral Yellowstone River drained northward to Hudson Bay (Wayne and others, 1991). Significant changes to the system occurred as a consequence of continental glaciation, which began about 2.5 million years ago. The ice repeatedly blocked the easterly flowing rivers, causing them to form lakes, spill across divides, and form new courses. At one point, a lobe of the ice sheet extended as far south as Intake, blocking the course of the Yellowstone River (Howard, 1960). The river was impounded to form Lake Glendive near present-day Glendive. Lake Glendive eventually extended upstream of Miles City to near Hathaway. About 20,000 years ago, the ice sheet retreated to the north, shifting and dropping the river's mouth. This base level lowering caused the river to downcut into its valley fill, resulting in the formation of a series of terraces that bound the river today (Zelt and others, 1999).

Koch (1977) reported that the channel has downcut into stiff lake bed clays upstream of Glendive. On higher surfaces, strand lines from Glacial Lake Glendive are visible on air photos near the I-90 bridge near Fallon (WAI and others, 2001), where the lake bed sediments overlie Fort Union rocks.

2.2. Bedrock Geology

The form of the Yellowstone River is often profoundly affected by bedrock geology (Koch, 1977). Consequently, it is important to consider the character and distribution of the range of rock types that compose the corridor margin. The following is a basic description of the corridor geology. A more detailed assessment of the role of bedrock geology in Yellowstone River Corridor geomorphology is described in Section 4.5.

From Springdale to Columbus, the Yellowstone River flows through the southern part of the Crazy Mountain Basin. In this section, river valley walls typically consist of sandstones and shales of the Hell Creek Formation. Between Columbus and Park City, the Yellowstone River valley walls are comprised of sandstones and shales of the Judith River Formation. At Park City, the valley bottom widens dramatically, where the valley wall geology shifts to fine grained shales and siltstones of the Claggett and Telegraph Creek Formations. At Billings, the steep sandstone valley walls are Cretaceous in age, and include the Eagle Sandstone (Rimrocks at airport), Belle Fourche Shale (southern, or right valley wall between Laurel and Billings), and the Judith River Formation.

Downstream of Billings, the Yellowstone River flows through relatively flat-lying sedimentary rocks of Cretaceous and Tertiary age (Figure 2-2). From Billings to Forsyth, Cretaceous sandstones and shales form the valley perimeter. Between Myers and Forsyth, the Cretaceous-age Bearpaw Shale has been uplifted to the valley floor along the Porcupine Dome. Where the Bearpaw Shale and claystone units of the Fort Union are exposed in the valley walls, landslides are common mechanisms of valley wall failure (WAI, 2001). Downstream of Rosebud, the valley wall geology consists of softer Tertiary-age Fort Union Formation interbedded sandstone, shale, coal, and red clinker beds. The majority of identified coal resources in Montana are within the Fort Union Formation.

Between Miles City and Glendive, the river is entrenched into resistant sandstone of the Fort Union Formation, and there is almost no riparian zone along the active channel margin. Around Miles City, the valley walls are comprised of the Tullock Member of the Fort Union Formation, which consists of interbedded sandstones and shales.

A large geologic structure, the Cedar Creek Anticline, crosses the river at a high angle between Fallon and Glendive. Cretaceous sandstones and shales are exposed on its axis, forming the valley wall for approximately 15 miles in the vicinity of Glendive. Downstream of these sandstone exposures, the Ludlow Member of the Fort Union Formation forms the valley wall. Between Savage and the mouth, the valley wall widens markedly as the Tongue River member of the Fort Union Formation becomes exposed in the valley wall.

2.2.1. Mapped Bedrock Grade Controls

Several outcrops of bedrock have been described as locally steep channel segments in the Lower Yellowstone River (Table 1). These outcrops have the potential to serve as natural grade controls for the system, and if they are eroded out or removed, they have the potential to induce downcutting upstream.

In July, 1806, as William Clark of the Lewis and Clark Expedition traveled down the Yellowstone River, he described a series of anomalously steep sections of river channel. Approximately 12 miles downstream of the Tongue River confluence, the party encountered what has been generally referred to as the Menagerie Rapids. Downstream of that point, at Buffalo Shoals, a three foot drop in the channel bed extended almost the entire width of the river (Silverman and Tomlinson, 1984). Approximately 60 years later, it was reported that the drop on the shoals had been considerably reduced. Approximately 20 miles further downstream, a second series of rapids was named Bear Rapids. The last of the “animal series”, called Wolf Rapids, was located about three miles downstream of the mouth of the Powder River. Wolf Rapids were considered the most difficult navigation challenge of the lower river. The rapids consisted of a vertical drop of 4 feet over approximately 250 feet, where the channel flowed over a “rocky bed” along a 50 foot high riverbank (Confluence, 2003).

All of the grade breaks described above are located between Miles City and Glendive. A few other rapids were described downstream of Glendive by the Maguire Survey of the mid- 1870’s (Table 1). The presence of headcuts, nickpoints, or rapids in the channel bed indicates active downcutting of the river system. For the grade breaks to manifest themselves in the form of rapids or waterfalls, the bed substrate must have sufficient erosion resistance to maintain the steep drop. It is therefore likely that the series of steep drops reflect the response of the river to base level lowering, and the concentration of the features reflects the presence of Ft. Union Formation in the channel bed between Glendive and Miles City. The cause of base level lowering is not clear.

In 1877, efforts were made to remove the grade break at Wolf Rapids to improve navigation. The Buffalo and Bear rapids were also removed as transportation on the river increased in the late 1800’s. It is possible that the removal of these grade controls may have induced some channel response upstream.

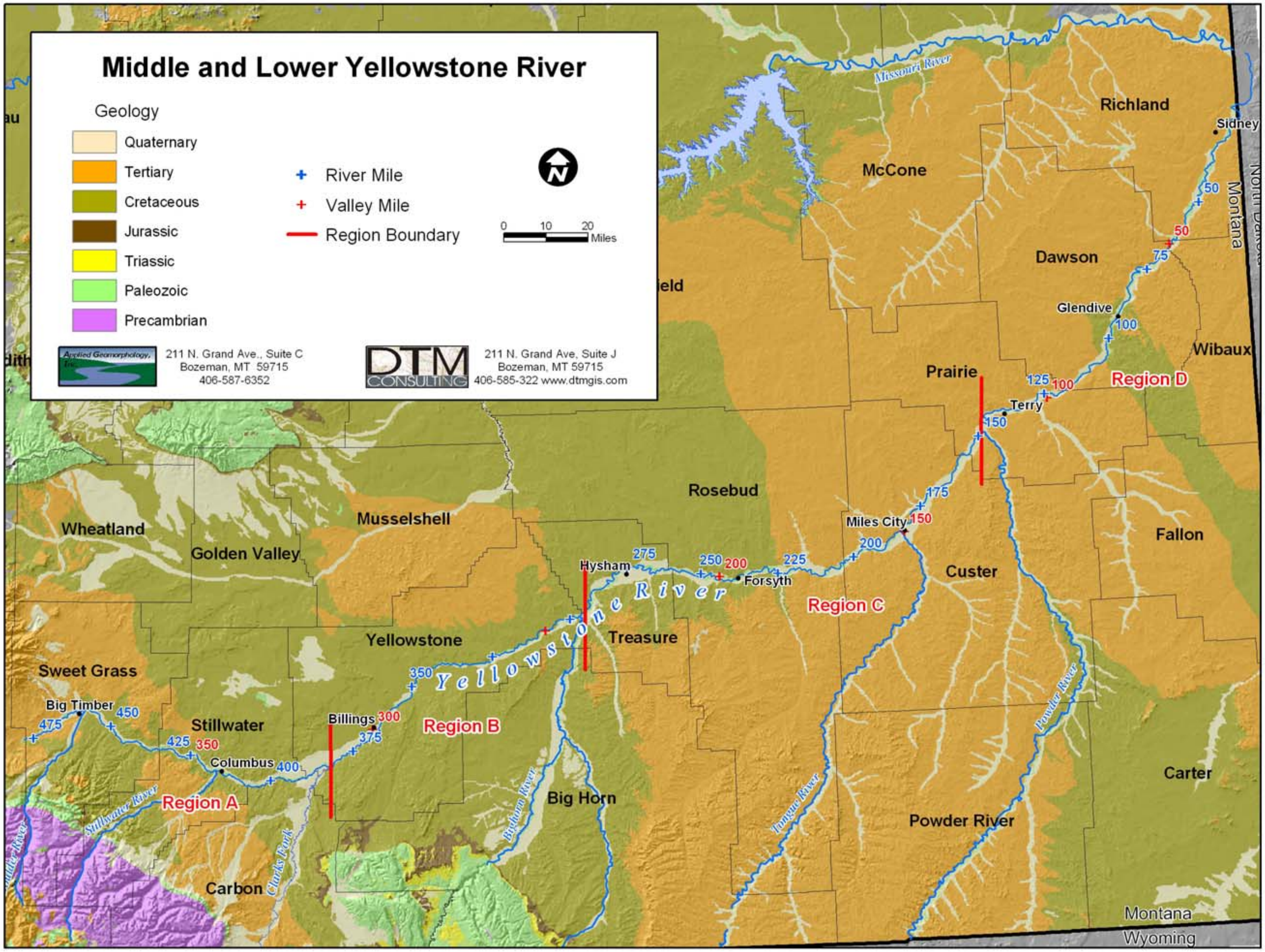

Figure 2-2. Generalized geologic map of the Middle and Lower Yellowstone River Basin

Table 1. Identified natural grade controls, Lower Yellowstone River

Approximate RM	*Year Identified*	*Name*	*Description*
RM 175 (10 miles d/s of Tongue River confluence)	1806 (Lewis and Clark)	Menagerie Rapids	
RM 163	1806 (Lewis and Clark); 1873-1876 (Maguire)	Buffalo Shoals	Approximately 3 ft drop over entire channel width (considerable erosion of scarp by 1866 reported)
RM 157 (?)	1806 (Lewis and Clark)	Bear Rapids	
RM 152	1873-1876 (Maguire)	Bower	Upstream of Powder River
RM 142 (6 miles d/s of Powder River confluence)	1806 (Lewis and Clark)	Wolf Rapids	Fall of 4 ft in 250 yards; Rough rocky bed
RM 145	1878 (Maguire)	Key West, Crosby's, Jacob's, and McLewn's Rapids	Downstream of Powder River, (~Wolf Rapids)
RM 112	2001 (Womack)		Sandstone ledge
RM 109	1878 (Maguire)	Walker's, Murdock's	Cabin Creek Confluence
RM 90	1878 (Maguire)	Glendiver, Monroe	Near Glendive
RM 79	1873-1876 (Maguire)	Unnamed	Upstream of Intake
RM 63	1873-1876 (Maguire)	Unnamed	Downstream of Intake

2.3. Quaternary Terraces

Quaternary-age terraces along the Yellowstone River valley extend from the lower river upstream to the Paradise Valley. The terraces are typically coarse grained sediments that were deposited as outwash deposits during a period of extensive alpine glaciation in the upper watershed (Zelt and others, 1999). Individual terrace surfaces tend to converge in the upstream direction, which reflects the progressive entrenchment of the lower reaches of the river. The same high terrace surface that is approximately 380 feet above the river near Glendive, is only 120 feet above the river near Billings. In the vicinity of Billings, five distinct Pleistocene-age terrace units have been mapped above the elevation of the modern river and its alluvial deposits (Lopez, 2000; Table 2).

2.4. Major Tributaries

Numerous observations of the Yellowstone River indicate that tributary confluences can mark significant change in river conditions due to changes in contributing hydrology and sediment load. The main tributaries to the Yellowstone between Springdale and the Missouri River include the Boulder, Stillwater, Clarks Fork, Bighorn, Tongue, and Powder Rivers. All of these tributaries enter the system from the south. The largest annual flow contribution to the Yellowstone River is derived from the Bighorn River (Table 3), and the water yield from tributaries relative to their size decreases significantly in the downstream direction from 1.1 cfs/sq mile on the Boulder River to 0.04 cfs/sq mile on the Powder River.

Of all of the Yellowstone's tributaries, the Powder River has been described as having the poorest water quality (DNRC, 1977). It has been estimated that the Powder River delivers only 5% of the Yellowstone River's flow and 50% of its sediment load. In 1806, Clark described the Powder River as striking the Yellowstone with a "forceful current", and carrying small red stones (Silverman and Tomlinson, 1984).

Table 2. Descriptions of mapped terraces in the vicinity of Billings (Lopez, 2000)

Unit	*Thickness (ft)*	*Estimated height above river (ft)*	*Description*	*Influence on current Yellowstone River perimeter*
Qat1	20-40	10-20	Cobbles and pebbles; minor sand and silt	Extensive
Qat2	40-60	20-40	Cobbles and pebbles; minor sand and silt	Extensive (Billings and Laurel are situated on this surface)
Qat3	20-30	50-90	Cobbles and pebbles; minor sand and silt	Moderate: At Clark's Fork confluence (White Horse Bench), and TLB valley wall downstream of Billings
Qat4	20	200-300	Multiple coalescing units	None Identified
Qat5	20	400-500	Discontinuous erosional remnants	None Identified

Table 3. Drainage area and flow contributions for major tributaries of the Yellowstone River (modified from Zelt and others, 1999)

Tributary	*Gage Location*	*Drainage Area (sq mi)*	*Mean annual discharge (cfs)*	*Discharge per unit area (cfs/sq mi)*
Boulder	Big Timber	521	575	1.10
Stillwater	Absarokee	975	939	0.96
Clarks Fork	Belfry	1154	934	0.81
Bighorn	Bighorn	22,885	3,810	0.17
Tongue	Miles City	5397	421	0.08
Powder	Locate	13,189	586	0.04

2.5. River Morphology

To date, there has been no comprehensive geomorphic assessment of the entire Yellowstone River corridor. Koch (1977) evaluated the potential effects of altered streamflows on the hydrology and geomorphology of the middle and lower river as part of the Yellowstone Impact Study. The Yellowstone Impact Study, conducted by the Water Resources Division of the Montana Department of Natural Resources and Conservation (DNRC), was intended to evaluate the impacts of water withdrawals and development on physical and biological resources within the middle and lower Yellowstone River basin. Womack and Associates, Inc. (WAI) performed two studies that included geomorphic evaluations of portions of the Yellowstone River (WAI , 2000 and 2001). Koch (1977) characterized five reaches downstream of Billings, and WAI (2001) evaluated six reaches between Billings and Glendive (Table 4).

Recently, a compilation of historic records regarding physical and biological conditions observed within the Yellowstone River corridor prior to 1900 was completed (Confluence, 2003). This document includes a summary of historic records regarding descriptions of channel and riparian conditions, fisheries, wildlife, and climate, and provides a general idea of the condition of the corridor in the 19th century.

Koch (1977) concluded that in the mid-1970's, the general character of the Yellowstone River main stem was very similar to that observed during the William Clark expedition of 1806. This general characterization consisted of anabranching (abundant side channels) and braided reaches with wooded islands and gravel bars, and intervening reaches with very few islands and minimal gravel bars. These split flow channel conditions are best exemplified by stretches above Forsyth and below Glendive (DNRC, 1977). Koch (1977) noted that the form of the Yellowstone River varies as a function of river valley and valley wall configuration. In general, the river tends to closely follow the valley wall until the valley trend changes; at such points, the channel commonly crosses the valley bottom to the opposite valley wall. In areas where the river is not directly against a valley wall, the channel is more dynamic, and assumes a braided or anabranching (multi-channeled) planform.

Womack (2001) suggested that the coarse bed material of the river valley that is derived from glacial outwash material is often more resistant to erosion than the relatively soft bedrock of the valley walls. As a result of this variability in erosion resistance, the river tends to "hug" the valley walls. Where the river migrates across the valley bottom towards the opposite valley wall, it tends to exhibit more braiding and develops a particularly rich and diverse riparian zone.

The Yellowstone River is similar to most large river systems in that its bed sediment tends to fine in the downstream direction. In the mountainous headwater areas, bed material consists of gravels and boulders; intermediate reaches are dominated by gravels, and the lower basin is characterized by a sand and gravel substrate (Zelt and others, 1999). In the upper and transitional river sections, the bed of the Yellowstone River and its bounding terraces contain coarse gravel that was apparently delivered by very high flows during glacial meltout periods. As a result, the channel is naturally armored along much of its extent. Near the Clarks Fork confluence, the median grain size (d_{50}) of the armoring layer is about 200 mm (8 inches), and d_{50} of the underlying sand and gravel alluvium is about 50 mm (2 inches) (WAI and others, 2001). The median diameter of bed material in the river downstream of Billings is on the order of 19 to 38 mm (3/4 to 1.5 inch; Koch, 1977).

Table 4. Summary of reach descriptions provided in geomorphic assessments of Lower Yellowstone River by Koch (1977) and WAI (2001)

Site Name	Length (miles)	Characteristics
Site 1 (Koch) Huntley to Pompey's Pillar *RM 331-350*	19.9	Characteristic of the middle Yellowstone River. The channel follows the valley wall for the majority of the reach, with the exception of a four mile stretch directly downstream of Huntley. The channel is sinuous (single thread with relatively consistent meander attributes such as amplitude and frequency) where it follows the valley wall, and irregular (single thread with highly variable meander attributes) where "uncontrolled". Islands, tributary mouth bars, and mid-channel bars are common. The presence of side channels, chutes, and active backwater areas reflect active channel shifting characteristic of gravel bed streams, which Koch describes as "irregular lateral activity".
Site F (WAI) *RM 321-331*	8.0	At Big Mary's Island, at a point of valley narrowing. Relatively narrow (800 ft) active corridor width. Left valley wall is sandstone cliffs of Hell Creek Fm. Very dynamic reach. Extensive split flow. Floodplain isolation by transportation corridor to south.
Site E (WAI) *RM 294-300*	6.25	Highly dynamic reach, with extensive split flow. Some floodplain isolation to south. Hell Creek Formation exposures on north side of Government Island.
Site 2 (Koch) *Bighorn to Froze-to-Death Creek* *RM 268-293*	24.9	Just downstream of the Bighorn River confluence. Irregular valley trend and width, and a channel pattern ranging from sinuous to irregular meandering. Islands and bars are common.
Site D (WAI) *RM 277-287*	10.0	Myers Bridge. Highly dynamic, extensive split flow. Within a transition zone from entrenched confined channel upstream to wide dynamic corridor downstream. Bars have been extensively colonized by vegetation since 1949. Site is underlain by Bearpaw Shale on western edge of Porcupine Dome. Valley walls consist of Bearpaw Shale overlain by Hell Creek sandstone. At the site, the valley widens from 7000 ft upstream to over 13,000 ft.
Site C (Koch) *RM 220-230*	9.0	Cartersville Bridge near Rosebud. Dynamic reach; bars have been colonized by vegetation since 1949. Valley walls consist of Hell Creek Formation. Some floodplain isolation. Dikes have been built to behead secondary channels.
Site 3(WAI) *Near Hathaway to above Miles City* *RM 186-205*	19.2	Between Hathaway and Miles City, the Yellowstone River valley is relatively narrow and irregular. In this section, the river meander pattern is more regular than is typically seen, although the channel is straight to slightly sinuous where it flows along the valley wall. Islands are less frequent than the other reaches, although lateral bars are present along the sinuous sections, and point bars are found in meandering sections. Lateral channel activity is relatively regular, exhibited by meander migration and cutoff.
Site 4 (Koch) *Buffalo Rapids to below Terry* *RM 136-152*	18.4	This section of the Yellowstone River is incised, and intermittently bounded by bedrock on both the channel bed and banks. Islands are rare, and lateral channel migration is minimal.
Site B (WAI) *RM 125-132*	7.6	Upstream of Fallon; entrenched, with a narrow floodplain area. Minimal lateral migration; valley walls erode via mass failure. The site is underlain by Fort Union Fm, and sandstone outcrops in the channel bed. The channel is trapezoidal and shallow in cross section. Sediment storage is minimal. Multiple terraces bound the active channel. Some terraces are gullied. Terraces indicate systemic downcutting. Widening occurs by mass failure of Fort Union claystone that overlies the sandstone on terrace margins.
Site A(WAI) *RM 108-117*	8.6	Downstream of Fallon, there has been a reduction of unvegetated midchannel bar area since 1949 (attributed to the loss of sediment input from the Bighorn River). Resistant sandstone of the Fort Union Formation is exposed in the bed and banks. Landslides are present. Average slope is 3 ft/mile.
Site 5 (Koch) *Intake to Savage* *RM 49-66*	17.0	Representative of the lower section of the river from near Glendive to the mouth. The predominant river course is along the east side of the valley. Islands and mid-channel bars are common. Numerous chutes and backwater areas indicate active lateral shift.

2.6. Primary Human Influences Affecting Stream Behavior

Although the Yellowstone River has retained much of its primary character since it was described by William Clark in 1805, it has undergone significant change in response to a vast array of human influences that have occurred since that time. The most prominent activities to date with respect to potential geomorphic response include dam construction on the Bighorn River, bank armoring, and flow diversion.

2.6.1. Bighorn River Dams

The geomorphology of the Bighorn River is strongly impacted by dam construction, the largest of which are Boysen Reservoir (1952), and Yellowtail Dam (1966). Prior to the construction of these dams, the Bighorn was a highly braided river (DNRC, 1977). In 1806, Clark described the Bighorn River as being over 600 feet wide, and having a "muddy, yellowish color" (Silverman and Tomlinson, 1984). Prior to Yellowtail Dam 7completion, annual sediment delivery at the mouth of the Bighorn River was estimated at 7.2 million tons. Based on 6 years of data, post-dam sediment production has been estimated at 1.5 million tons per year, which is an 80% decrease (Silverman and Tomlinson, 1984). Average annual peak discharges have dropped from 20,199 cfs to 8,800 cfs (WAI, 2001). Since the completion of Yellowtail Dam, the river has consolidated and eliminated islands, forming more of a single thread system. Koch (1977) used aerial photographs from 1939, 1950, and 1974 to evaluate temporal changes within the Bighorn River corridor downstream of Yellowtail Dam. Koch showed that the spatial extent of gravel bars was reduced by 77 percent following dam completion.

Cold water releases at Yellowtail Dam have resulted in the formation of a cold-water fishery that extends from the afterbay dam downstream to about 10 miles below St. Xavier (DNRC, 1976). Fisheries inventories have recorded in excess of 6,000 trout per mile of river in this section (Schneider, 1985). This fishery transitions to a plains warm-water fishery below that point.

The geomorphic response of the Bighorn River in response to dam construction may have occurred in a similar fashion on the Tongue River although such changes have not been documented (DNRC, 1977). This suggests that the river has evolved from a highly braided, sediment-laden stream to a single thread system that contributes much less sediment to the Yellowstone River since the completion of Tongue River Dam.

2.6.2. River Engineering Works

The natural course of the Yellowstone River has been locally impacted by river training structures, such as dikes, levees, and bank armoring. In some areas, dikes and armoring have led to a reduction in total channel length (WAI, 2000). Flood control measures have included the construction of dikes. In Miles City, flooding was relatively commonplace prior to 1900, but the construction of a system of dikes in the early 1900's have made spring flooding a rarity (Schneider, 1985).

Irrigation development along the Yellowstone River has included the construction of several low-head dams, including Huntley, Waco-Custer, Yellowstone, Cartersville, Rancher, and Intake. The largest diversion structure is at Intake, approximately 15 miles northeast of Glendive. Estimated 1984 irrigation diversion rates at the structure were 1200 cfs (Silverman and Tomlinson, 1984). Irrigation typically occurs between May and September, and federal and state projects downstream of Billings irrigate approximately 111,000 acres.

3. GIS Development

One objective of the Geomorphic Reconnaissance is to construct a robust Geographic Information Systems (GIS) database for use in the geomorphic assessment as well as future Cumulative Effects Investigation efforts. Throughout this project, GIS was utilized for data compilation, analysis, and presentation. The GIS construction and project applications include the following:

- compilation of existing digital data;
- digitization of channel centerline and creation of river mile stationing;
- generation of river corridor maps, including tiled air photo maps;
- support for geomorphic assessment and fisheries reconnaissance through statistical summarization of reach features; and,
- development of an inundation model to define river corridor boundaries.

Throughout the study, the value of the GIS was demonstrated not only through its use in the compilation, analysis, and presentation of large amounts of spatial information, but as a means of allowing constant, efficient review of project progress, and using that information to help guide project execution based on input from the TAC and YRCDC. As the GIS-derived products were reviewed, additional requests were made for information to satisfy specific purposes. For example, the GIS was used to create tiled maps showing parcel boundaries on the CIR aerial photos with a corresponding table to identify the 2400+ individual owners of parcels greater than 10 acres along the Lower Yellowstone. This information will be utilized to address access issues in future project phases. The tiled maps of the entire river corridor that were used throughout this study are included in the back of this report (Map 1 and Map 2).

The GIS was also utilized to support the concurrent fisheries reconnaissance study performed by the MSU Fisheries Coop Unit (Proboszcz and Guy, 2004). Since the fisheries assessment included identifying and analyzing specific reaches for the study and assessing them based on the same parameters as the geomorphic assessment, it was most efficient for the GIS team to collaborate with the fisheries team and perform the analysis in the project GIS.

3.1. Baseline Data Compilation and Documentation

An ArcView GIS database has been developed for use in the Cumulative Effects Investigation, and to serve as a repository of new project information as it becomes available. Included with this report is a CD containing the baseline GIS data, a portable GIS project referencing the data, and Federal Geographic Data Committee (FGDC) compliant metadata for all datasets. Due to the sheer size of some of the imagery, it was impossible to include these data on the CD. These data are scheduled to be archived and available for download from NRIS and/or the Corps of Engineers.

Table 5 lists the GIS data compiled for this project. All data are provided in Montana State Plane NAD83 coordinates. In some cases, data was re-projected from its native coordinate system to provide consistency. The included metadata contain information regarding the source, process steps, and intended use for specific data sets.

Table 5. Datasets incorporated into project GIS

Dataset	*Name*	*Type*	*Description*
Aerial Photography			
CIR	Available from NRIS	TIFF	1:24,000 Color Infra-red aerial photos from August 2001
Digital Orthophoto Quadrangle	Available from NRIS	MrSID	1:12,000 aerial photography 1996-1997
Boundaries			
County Boundaries	County.shp	Shapefile	Contains boundaries of all MT counties
Region Breaks	Region_break_lines.shp	Shapefile	Boundary of the 4 major regions identified for the project
Valley Bottom Boundary	Valley_bottom.shp	Shapefile	Boundary of the valley bottom
Land Ownership/ Management	Land_owner.shp	Shapefile	Boundaries of privately owned and publicly managed lands
Cadastral	Cadastral.shp	Shapefile	Parcel boundaries and land owner's name, address, and acreage
Conservation Districts Priority sites	Cd_priority_reaches.shp	Shapefile	Reaches selected for the geomorphic assessment by conservation district offices along the Yellowstone River
LIDAR Corridor	Lidar_corridor_proposed.shp	Shapefile	Proposed corridor for the LIDAR data acquisition flight.
3-Mile Segment Polygons	3_mile_segment_poly.shp	Shape	3-mile segments used to calculate statistics for the LIDAR corridor
Floodplain Mapping Reaches	Flood_map_reaches.shp	Shapefile	Nominated floodplain mapping reaches
Subreach Line Boundaries	Subreach_line.shp	Shapefile	Linear delineations of subreaches used for geomorphic analysis
Subreach Boundary Polygons	Subreach_poly.shp	Shapefile	Polygon boundaries of subreaches used for geomorphic analysis
Elevation			
30 meter DEM	Dem30m	Grid	30 m resolution digital elevation model
30 meter SRTM elevation data	SRTM	Grid	30 m resolution elevation data from the Shuttle Radar Topography Mission
Geology			
Statewide Geology	Geology_500k.shp	Shapefile	1:500,000 scale statewide geology data
MBMG geology data	Geology_100k.shp	Shapefile	1:100,000 scale geology data by quadrangle (where available)
Hydrology			
NHD Centerline	NHD_centerline.shp	Shapefile	1:100,000 scale hydrology data for the Yellowstone River
NHD Centerline Station Points	NHD_station_pts_1_mi.shp	Shapefile	1 mile station points along the Yellowstone River NHD centerline
Lower Yellowstone Channels	Yell_channels_2001.shp	Shapefile	Primary, secondary, overflow and anabranching channels digitized off from the 2001 1:24,000 CIR aerial photos
Lower Yellowstone Centerline Station Points	Yell_channels_station_pts_1_mi.shp	Shapefile	1 mile station points along the Yellowstone River centerline from the CIR
TIGER hydrology	Tiger_hydro.shp	Shapefile	Streams and rivers from 2000 census data

Dataset	***Name***	***Type***	***Description***
Tributary confluence points	Trib_confluences_pt.shp	Shapefile	Points representing confluences of the major rivers and streams and the Yellowstone River
Miscellaneous			
Floodplains	Femaq3_COE.shp	Shapefile	Floodplain delineations from the Corps of Engineers
Cities	cities.shp	Shapefile	Cities along the Yellowstone River corridor
Geographic Names Information System	gnis.shp	Shapefile	Contains labels of all features on USGS maps of Montana
Physical Features Line data	Phys_feature_ln.shp	Shapefile	Physical features inventory as lines
Physical Features Point data	Phys_feature_pt.shp	Shapefile	Physical features inventory as points
Wells	wells.shp	Shapefile	Well data from the Ground Water Information Center
Valley Bottom Centerline	Valley_centerline.shp	Shapefile	Centerline of the valley bottom
Valley Bottom Centerline Station Points	Valley_centerline_station_pts_1_mi.shp	Shapefile	1 mile station points along the valley centerline
Soils			
Soils	soils.shp	Shapefile	1:24,000 SSURGO soils data (where available)
Vegetation			
GAP Vegetation	Yellveg	Grid	90 meter GAP vegetation
2003 Vegetation Inventory	vegcover.shp	Shapefile	Vegetation inventory from 2003

The Natural Resource Information System (NRIS) of the Montana State Library was the primary source for baseline GIS data. These data include standard GIS layers such as roads, boundaries, ownership, and hydrology, which are generally available statewide. Due to the large spatial extent of the study area, a 5-mile corridor was defined on either side of the river, and many large datasets were clipped to this boundary. If necessary, the original unclipped data can be acquired from NRIS.

Recent project aerial photographs include 106 individual black and white Digital Orthophoto Quadrangles (DOQ) from 1996-1997 and 10 color infrared (CIR) photo mosaics from 2001. The DOQs are provided in MrSID image format with associated georeferencing information. The CIR mosaics were originally created in UTM coordinates and were reprojected to State Plane coordinates for this project by NRIS.

Two Digital Elevation Models (DEMs) are provided for the study area. The standard 30-meter DEM provided by the United States Geological Society provides complete coverage for the project area, however many of the DEMs are level one quality (Fair) and contain a large number of processing artifacts. For this reason, the Shuttle Radar Topographic Mission (SRTM) 30-meter DEMs were also acquired and merged for the project area. The SRTM dataset provides a consistent and current (February 2000) representation of the earth's surface across the entire project area. This dataset was used for all analyses.

Throughout the project, every effort was made to use the most complete and current data available. Unfortunately, some datasets such as geology and soils are not available for the entire study area. Some of these data gaps are scheduled for completion in the near future. Future project work should include acquiring these data and integrating them with existing project data as they become available.

3.2. River Corridor Delineation

The performance of any river corridor study requires a delineation of study area boundaries. The initial placement of such boundaries will determine spatial data needs and associated project costs. Preliminary cost estimates for detailed topographic data necessary for the Cumulative Effects Investigation were based on an estimated extent of 900 square miles, reflecting a corridor length of 450 miles and average assumed width of 2 miles. As the Yellowstone River corridor consists of a relatively narrow migration and inundation zone that is inset within alluvial surfaces and a broad bedrock defined valley, it was recognized that the cost of data acquisition could be significantly reduced if the corridor were better defined. Several approaches were taken to define the river corridor of the lower Yellowstone, including slope-break analysis of DEM data, geologic map compilation, and inundation model development. The process of corridor delineation is outlined in Appendix A. The results of the delineation effort show that a simple GIS-based inundation model, calibrated to mapped floodplain boundaries and extrapolated to unmapped areas, can effectively define corridor boundaries that correlate to terrace margins, valley bottom margins, and isolated mapped floodplain areas. On the Lower Yellowstone, the river corridor as defined by the inundation model is 696 square miles, 23 percent less than the original estimates. Furthermore, as the model is blind to flow obstructions, it is anticipated that the inundation corridor will be useful in identifying potential restoration areas where human influences such as embankments and levees have isolated historic floodplain areas.

3.3. Stream Stationing: River Miles and Valley Miles

The geomorphic assessment of a river corridor typically includes the evaluation of channel length as well as river valley dimensions. As a result, streams are commonly spatially referenced with stationing developed along the channel centerline or valley trend. The most recent comprehensive stationing for the Yellowstone River was published in 1976 by the DNRC, and at that time the agency described river mile stationing as "the most practical method of measurement along waterways for such purposes as water rights descriptions and scientific investigation" (DNRC, 1976). The DNRC stationing was based on combined sources of USGS topographic maps, aerial photos, and county projection sheets, and published as a booklet containing a list of features and associated river mile. For this project, it was not feasible to recreate the centerline that was utilized in the DNRC effort. Even if the 1976 stationing had been adopted, the application of relatively old stationing to a dynamic channel would make channel lengths calculated from the station values inaccurate.

As this evaluation is intended to provide a baseline foundation for future investigations, river mile stationing was re-established based on the 2001 color infrared photography. This allows the use of stationing values to calculate channel length, and provide a snapshot of current conditions that can be utilized in future analyses. The channel centerline was digitized from the 2001 color photography, and one mile station points were created along that line. The valley bottom was also defined and digitized (based on analysis of slope using DEM data), and a valley centerline created with corresponding one mile stationing points.

The resulting river stationing includes both Valley Mile and River Mile (Figure 3-1). Valley miles describe stream corridor distances, and river miles refer to distance along the channel centerline. Since the river course is sinuous, the valley distance is shorter than the channel distance. Between the Missouri River and Springdale, the valley distance of the Yellowstone River corridor is 396 miles, and the channel length is 477 miles. Stationing of major features within the corridor is summarized in Table 6.

Table 6. River and Valley Mile Stationing of major features, Yellowstone River corridor*

Cities		
City	***Valley Mile***	***River Mile***
Sidney	21	28
Savage	41	54
Intake	56	72
Glendive	73	93
Miles City	150	183
Rosebud	183	223
Forsyth	195	237
Hysham	223	275
Bighorn	239	296
Custer	245	302
Huntley	287	352
Billings	300	367
Laurel	315	385
Park City	323	395
Columbus	341	415
Reed Point	358	433
Greycliff	371	448
Big Timber	382	460
Springdale	396	477
County Borders		
County Line	***Valley Mile***	***River Mile***
McKenzie & Richland	12	15
Richland & Dawson/Wibaux	49	64
Dawson/Wibaux & Dawson	52	68
Dawson & Prarie	95	119
Prairie & Custer	125	155
Custer & Rosebud	167	204
Rosebud & Treasure	212	259
Treasure & Yellowstone	240	297
Yellowstone & Stillwater	319	390
Stillwater & Sweetgrass	359	434
Sweetgrass & Park	396	477
Confluences		
Tributary	***Valley Mile***	***River Mile***
Powder	118	148
Tongue	151	184
Bighorn	240	297
Clarks Fork	313	382
Stillwater	342	416
Boulder	380	458

***** Based on 2001 Imagery***

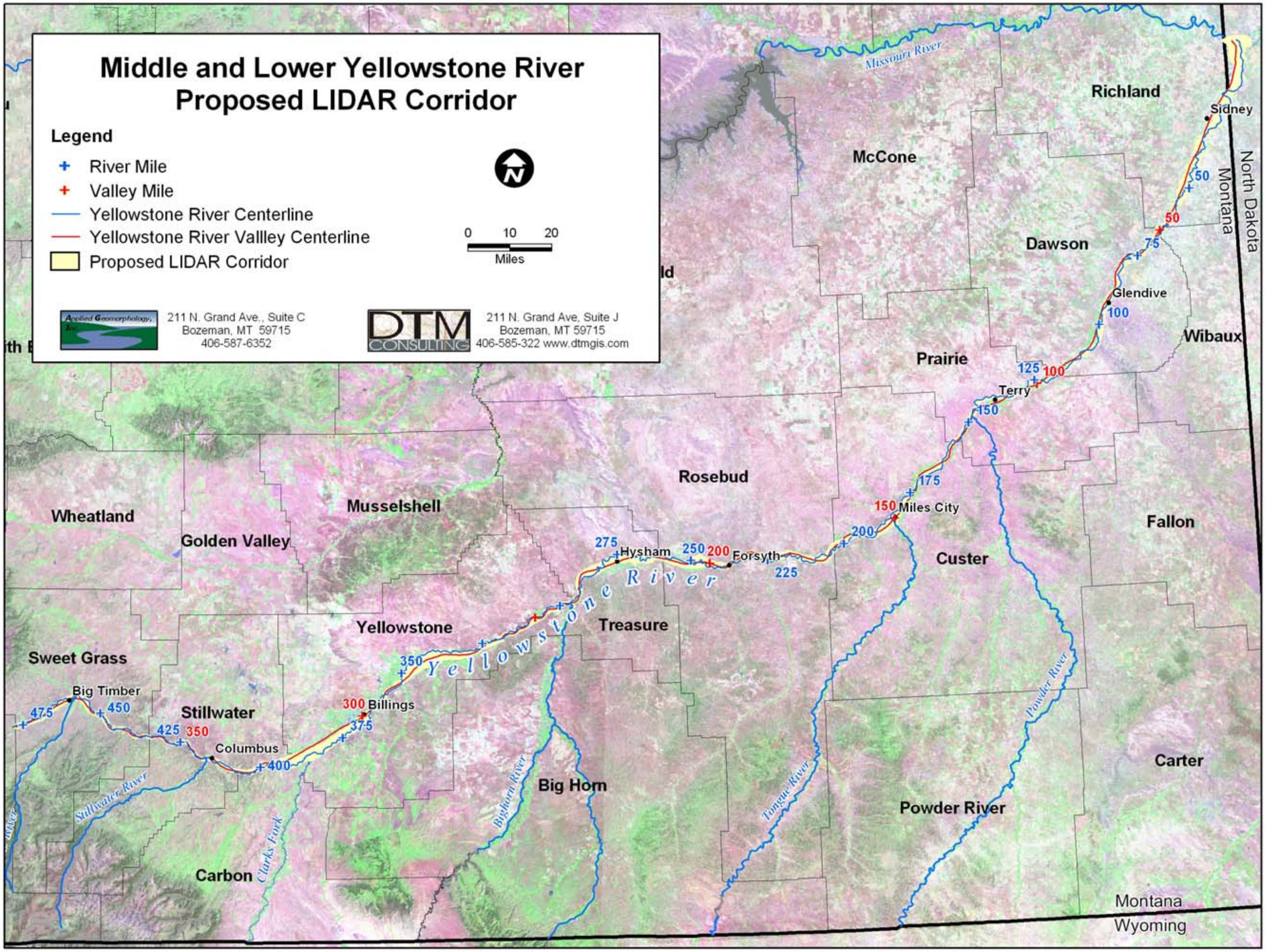

Figure 3-1. Middle and Lower Yellowstone River map showing stationing and LIDAR corridor

3.4. Land Ownership

A useful application of the GIS data is the generation of land ownership maps that identify specific parcel owners in the corridor. A series of land ownership maps have been created as part of this effort and distributed to members of the Yellowstone River Conservation District Council. The information will be readily available to identify property owners during the Cumulative Effects Investigation. A summary of the land ownership patterns for each county shows that in most counties, over 90% of the land within the corridor is privately owned. The exceptions to this trend are Carbon, Custer, Prairie and Wibaux counties, where over 20% of the land that lies within the river corridor is owned by government (Table 7). Tribal land constitutes approximately 1% of the corridor area in Treasure County.

Table 7. Public, private, and tribal land ownership distribution, Yellowstone River corridor

County	***State/ Local Govt (acres)***	***Federal Govt (acres)***	***Private (acres)***	***Tribal (acres)***	***Percent State***	***Percent Federal***	***Percent Private***	***Percent Tribal***
Carbon	168	700	2691	0	5%	20%	76%	0%
Custer	1946	8585	19045	0	7%	29%	64%	0%
Dawson	1116	1782	24718	0	4%	6%	90%	0%
Prairie	528	3430	13997	0	3%	19%	78%	0%
Richland	3632	861	33654	0	10%	2%	88%	0%
Rosebud	1440	275	40934	0	3%	1%	96%	0%
Stillwater	331	94	20724	0	2%	0%	98%	0%
Sweetgrass	768	132	24303	0	3%	1%	96%	0%
Treasure	1714	653	29655	222	5%	2%	92%	1%
Yellowstone	5419	4949	100052	0	5%	4%	91%	0%
Wibaux	256	232	120	0	42%	38%	20%	0%

4. Regional Geomorphic Zones

Between Springdale and the Yellowstone River/Missouri River confluence, the physiography of the Yellowstone River and its tributaries transitions from steep, confined mountainous areas to plains conditions. This physiographic transition correlates to a downstream transition from a salmonid to warm-water fishery. To ensure that the comparison of reaches in the Cumulative Effects Investigation occurs in reaches of similar baseline conditions, the corridor was subdivided into regions.

The regional zones that have been distinguished based on dominant fish species include a headwaters zone, a transition zone, and a plains zone. The downstream end of the headwaters zone has been placed in several places, including Big Timber (DNRC, 1976), Reed Point (Zelt and others, 1999), or Columbus (Silverman and Tomlinson, 1984). The primary change to warm–water species has been identified as at Laurel, which marks the confluence of the Clarks Fork River (DNRC, 1976). The downstream end of the transition zone has been consistently placed at the Bighorn River confluence.

The downstream changes in dominant fish species are reflected in progressive changes in landscape geomorphology. Upper reaches are steeper, and have a coarser bed substrate. Channel slope and substrate size decrease in the downstream direction. For this study, the project length (Springdale to mouth) was divided into four primary geomorphic regions (Figure 4-1; Table 8). The upstream region extends from Springdale to the Clarks Fork confluence at Laurel. The break at Laurel was selected based on changes in dominant fish species, as well as on the reduction in valley confinement and channel slope, and on the hydrologic and sedimentologic influences of the Clarks Fork. From the Clarks Fork, the transition zone extends downstream to the Bighorn River. The warm water section has been divided into two regions, one extending from the Bighorn River to the Powder River, and one from the Powder River to the Missouri. The break at the Powder River is based on the relatively large, fine grained sediment load delivered by the Powder River to the Yellowstone, and the associated probable effects on stream morphology and fisheries habitat.

4.1. Upper Zone: Region A

From Yellowstone National Park to approximately the Clarks Fork confluence near Laurel, the Yellowstone River supports a cold-water salmonid fishery, including cutthroat trout, rainbow trout, brown trout, and mountain whitefish. Eleven species of fish from five families are commonly found in the upper zone (Silverman and Tomlinson, 1984). The channel substrate consists primarily of gravel, cobble and boulders, and the average channel slope is 11 feet per mile (0.2%). These conditions provide high quality habitat and spawning grounds for salmonids. From Gardiner to Big Timber, the system is classified as a “blue ribbon” trout stream (DNRC, 1976).

The upstream limit of this project is Springdale, Montana, which is on the Sweetgrass County/Park County boundary. From Springdale to the Clarks Fork confluence, the Yellowstone River is approximately 95 miles long. Counties included in the Upper Zone include Sweetgrass County and Stillwater County.

4.2. Transition Zone: Region B

Between the Clarks Fork confluence and the Bighorn River confluence, which is approximately 90 river miles, the river is within a biological transition, with both cold and warm water fish species present. Silverman and Tomlinson (1984) identify twenty fish species from eight families that inhabit the Transition Zone. Water temperatures gradually increase in the downstream direction. Within this reach, the average gradient is eight feet per mile (0.15%), and the channel substrate includes more fine sediment. The Transition Zone lies entirely within Yellowstone County.

4.3. Plains Zone: Region C

Downstream of the Bighorn River confluence, a plains warm-water fishery is supported, which is characterized by a diverse variety of non-salmonid, warm-water species. In this section, which is approximately 150 miles long, the Yellowstone is a prairie river. This aquatic ecosystem includes carp, goldeye, burbot, stonecat, sauger, walleye, channel catfish, paddlefish, and shovelnose sturgeon (DNRC, 1976; 1977; Schneider, 1985). The channel slope is relatively consistent in Region C at approximately three feet per mile (0.06%). Backwater areas are heavily silted, even though the channel bed consists of cobble and gravel. The Region C Plains Zone includes Treasure, Rosebud, and Custer County.

4.4. Plains Zone: Region D

Within Region D, the Yellowstone is a prairie river somewhat similar to Region C in terms of fisheries. These two zones collectively support 46 species of fish from 12 families (Silverman and Tomlinson, 1984). However, the river gradient within Region D drops in the downstream direction from three feet per near the Powder River to approximately 1 foot per mile (.02%) downstream of Sydney. In region D, low channel gradients are accompanied by relatively high turbidity and multiple thread channel segments. This change in channel condition is likely in part due to major contributions of sand from the Powder River. The average valley bottom width of Region D is in excess of 3 miles, whereas that of Region C is approximately 2 miles. The geomorphic environments associated with quality fisheries habitat in Region D include side channels, chutes, and backwater areas, in addition to pools, runs, and riffles. Climax riparian plant communities in the Plains Zone typically consist of grassland species including blue gramma and western wheatgrass. Near the mouth of the river, rainfall increases, and forests of green ash and bur oak form the climax community (Silverman and Tomlinson, 1984). Region D includes Prairie, Dawson, Wibaux, Richland and McKenzie Counties.

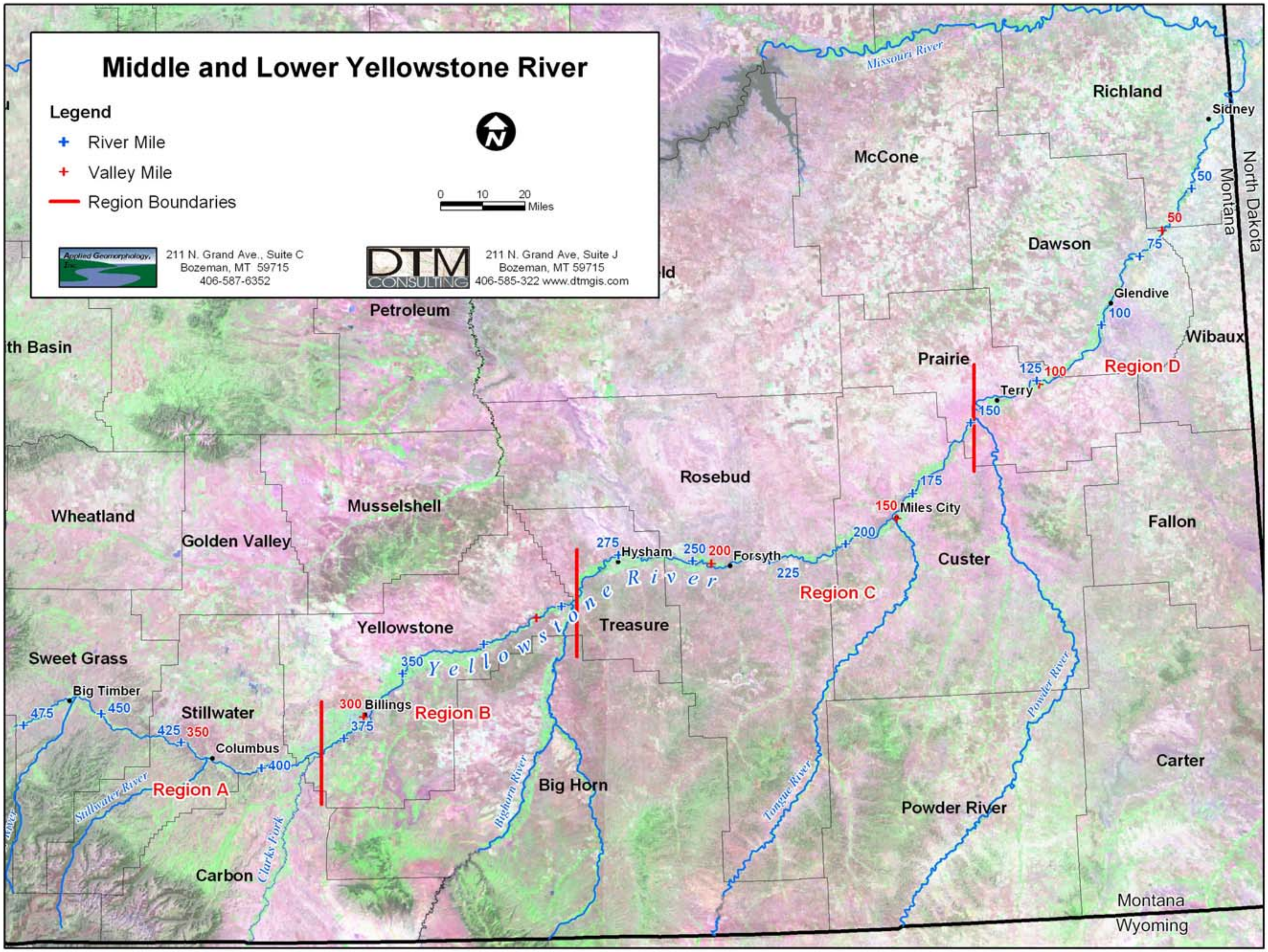

Figure 4-1. Regional geomorphic zones of the Middle and Lower Yellowstone River

Table 8. Major geomorphic regions of Yellowstone River corridor project area

Region	*Valley Miles*	*River Miles*	*River Length (Miles)*	*Landform/Ecoregions**	*Fisheries*
A: Springdale to Clarks Fork	396-313	477-382	95	Northwestern Great Plains: Unglaciated Mountain High Plains, Ponderosa Pine Forest-Savannah Hills. Foothill Grasslands to south. Steep dissected valley margins with alluvial fans extending into river corridor. Coarse grained, relatively steep, commonly braided channel. Cretaceous sandstones (Hell Cr Fm),	Cold water salmonid: cutthroat, rainbow, brown, mtn whitefish
B: Clarks Fork to Bighorn River	313-240	382-297	85	Northwestern Great Plains: Central Grassland, Pryor-Bighorn Foothills to south. Cretaceous sandstone/shale	Cold and warm water species
C: Bighorn River To Powder River	240-118	297-148	149	Northwestern Great Plains: Central Grasslands, Sagebrush Steppe, River Breaks Tertiary Ft Union	non-salmonid, warm-water species: carp, burbot, stonecat, sauger, walleye, channel catfish, pallid sturgeon, paddlefish, shovelnose sturgeon
D: Powder River to Missouri River	118-0	148-0	148	Northwestern Great Plains: Central Grasslands, River Breaks; Tertiary Ft Union Formation. Major contributions of sandy sediment load from Powder River.	Same as above

(Woods and others, 1999)

4.5. Regional trends in river geomorphology

In order to screen geomorphic conditions within each of the four zones, and to assist with further reach delineations, the river was divided into three-mile valley segments. Numerous geomorphic parameters were summarized within the GIS for each segment (Appendix B). The results identify major downstream trends in parameters such as valley width, valley slope, and stream sinuosity. For each of the three-mile valley segments, the primary geologic unit comprising the valley wall was identified, and integrated into the dataset to help discern relationships between geomorphic parameters and geologic setting (Table 9).

4.5.1. Valley Width

The valley width of the corridor as defined by the topographic definition of the valley walls ranges from less than one to over six miles (Figure 4-2). The widest valley areas are located in the upper end of Region B, between the Clarks Fork confluence and Billings, where the valley bottom is typically over four miles wide. In general, the width of the valley bottom increases in the downstream direction, from a minimum average width of approximately 1.3 miles in upper areas of Sweetgrass County to over four miles near the river mouth.

Geologic mapping extending from Springdale to the North Dakota border was obtained to assess potential relationships between geology and valley configuration. For each 3-mile segment, the dominant valley wall geology was identified and compared to the valley dimension. The results show a striking relationship between geology and valley configuration. The presence of shale, rather than sandstone, in the valley wall correlates to an abrupt widening of the valley bottom (Figure 4-3). For example, the widest section of valley floor is between Billings and Park City (VM 294-327), and this reach is bound by a series of predominantly shale units, including the Telegraph Creek, Claggett, Niobrara, and Bell Fourche units (identified as "Miscellaneous Shale" on Figure 4-3). The Bearpaw shale similarly can be correlated to valley floor widening, as it comprises the valley wall from Huntley to Pompey's Pillar (VM 261-288), in Mission Valley (VM 212-230), and in Hammond Valley (VM 199-206) (Plate 1 and Plate 2). Towards the river mouth, the Tongue River member of the Fort Union Formation is similarly associated with a relatively wide valley bottom. Whereas shales are typically associated with valley bottom widening, the narrowest valley bottom in the study reach occurs between Springdale and Park City, where the valley walls are comprised of resistant sandstone of the Hell Creek Formation.

The valley bottom width measurements reflect the distance between identified valley wall slope breaks, which are marked by abrupt changes in slope at the base of the steep bedrock valley walls. As such, these measured widths typically include the terrace surfaces that are inset within the valley. The inundation model (Section 3.2) was utilized to delineate the active river corridor, and thus it excludes high terraces. The results of the model show that the active river corridor is typically on the order of one to two miles wide, with local areas in which the floodplain widens to over two miles (Figure 4-4). Similar to total valley bottom width, the relatively wide areas of the modeled inundation corridor can be correlated to the presence of shales in the valley margin, (Figure 4-5, Plate 1, Plate 2).

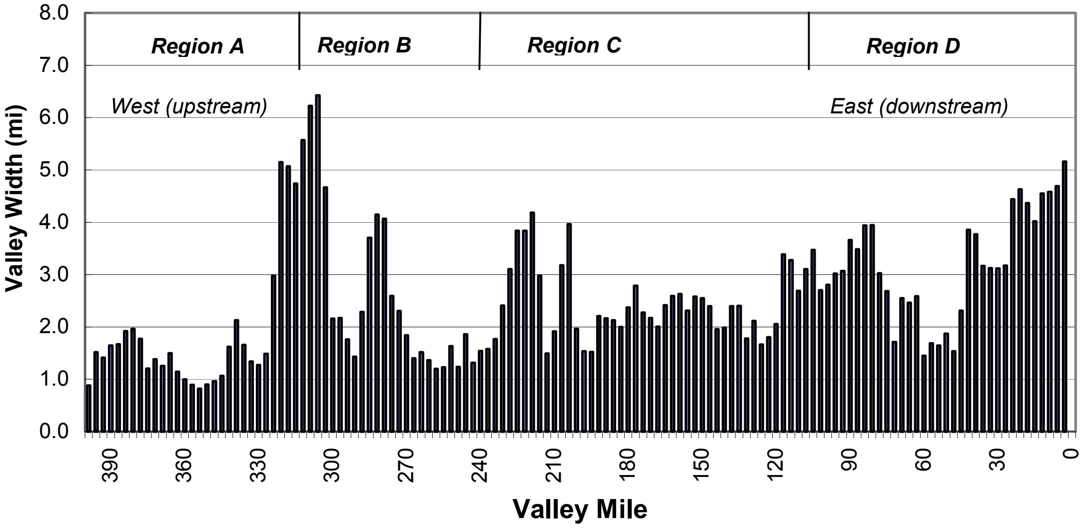

Figure 4-2. Valley bottom width estimates based on valley wall slope break

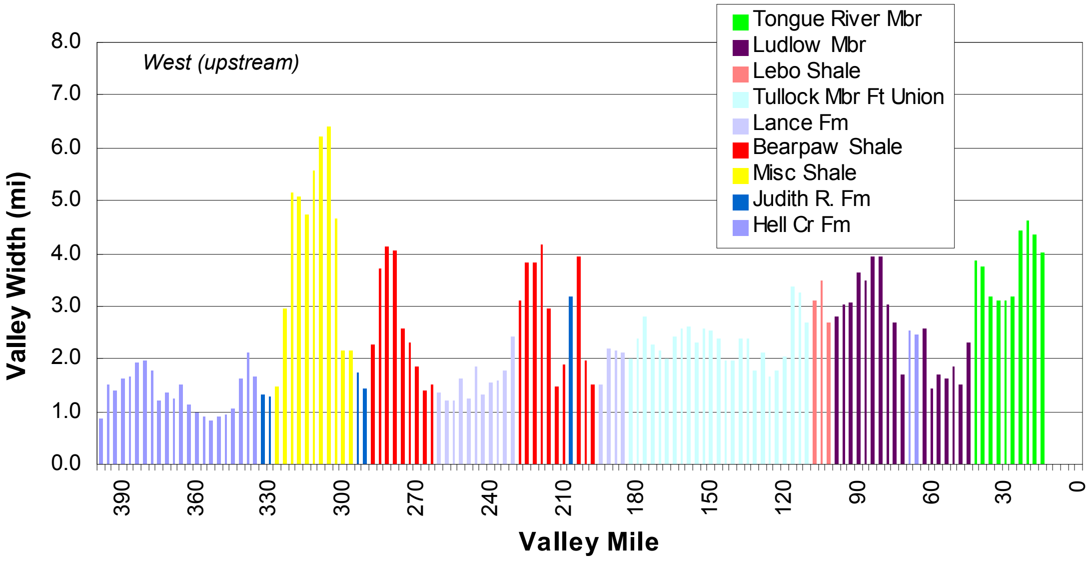

Figure 4-3. Valley bottom width and associated valley wall geology

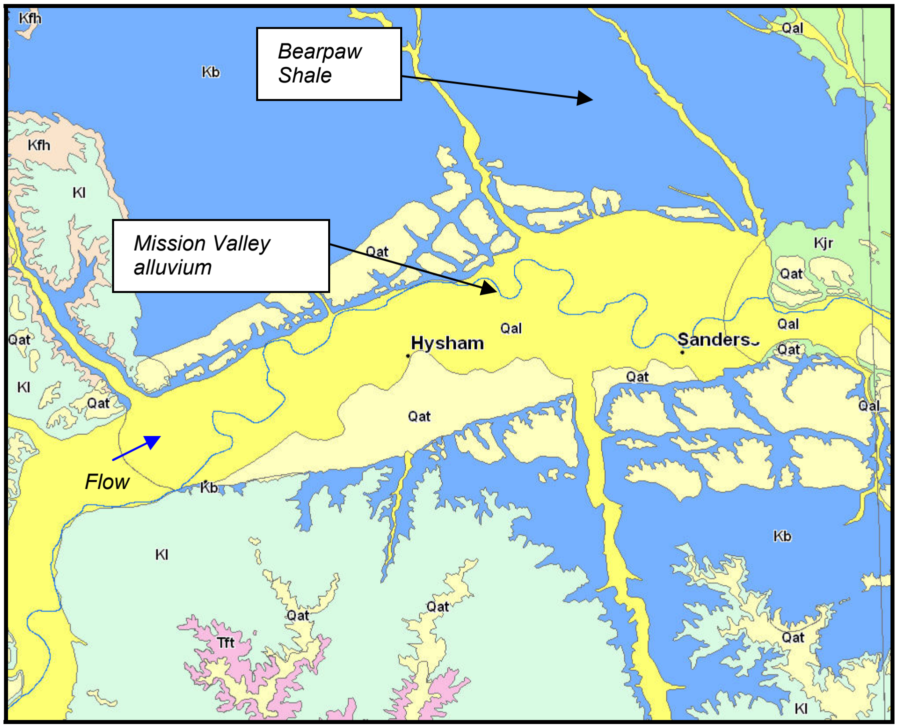

Plate 1. Geologic map of Yellowstone River corridor at Mission Valley (Qal) showing valley bottom widening within Bearpaw Shale (Kb).

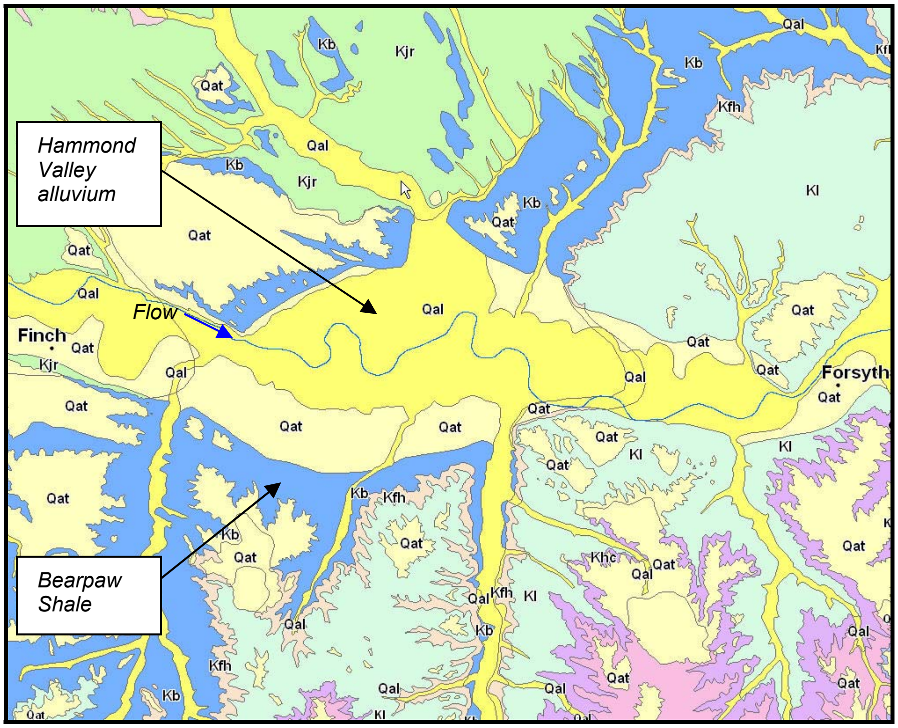

Plate 2. Geologic map of Yellowstone River corridor at Hammond Valley (Qal) showing valley bottom widening within Bearpaw Shale (Kb)

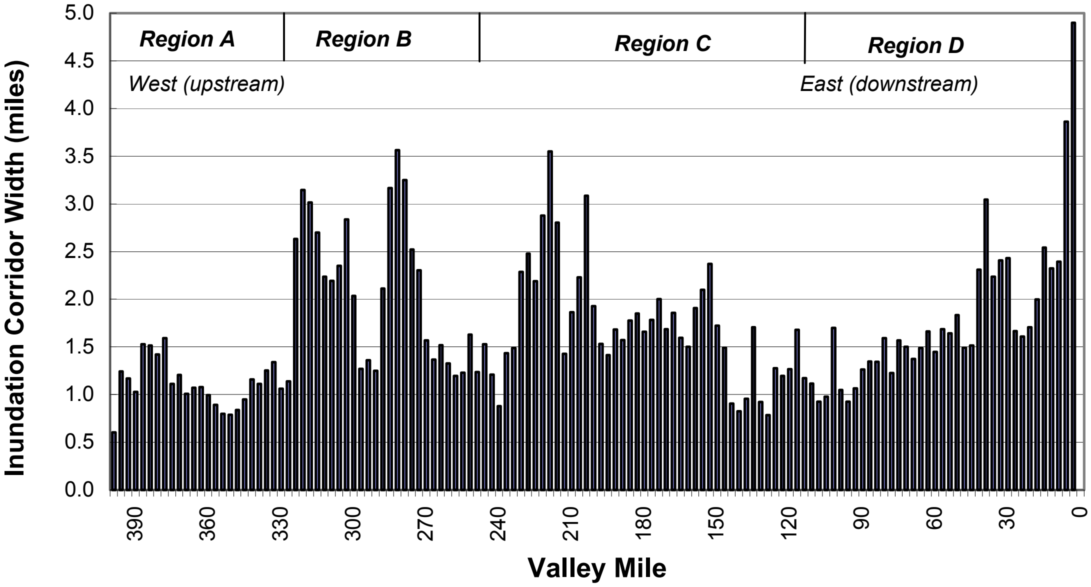

Figure 4-4. Estimated width of valley bottom prone to inundation, Yellowstone River corridor

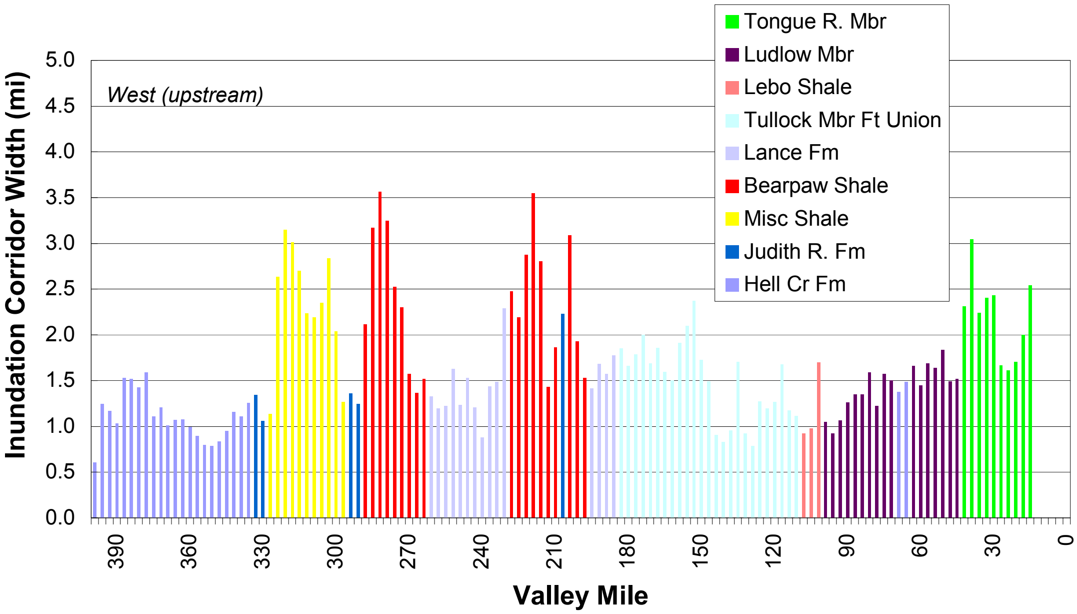

Figure 4-5. Inundation corridor width and associated valley wall geology

4.5.2. Channel Slope

Channel slope was measured in the GIS environment using DEM topographic data to estimate water surface elevations on 3-mile increments (Figure 4-6). The slope values should therefore be considered approximate. In general, however, slope trends show a reduction in slope in the downstream direction, from approximately 0.2% in Region A to less than 0.05% in Region D. The relatively steep slopes in Region A correlate to exposures of Hell Creek Fm sandstone in the valley walls Figure 4-7. The slope reduction at the downstream end of Region B marks the Bighorn River confluence.

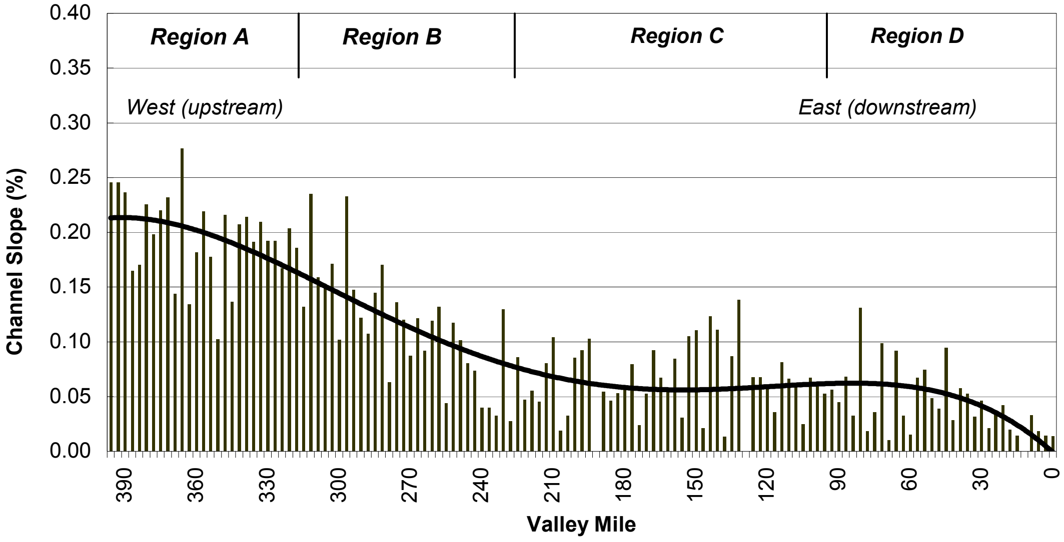

Figure 4-6. Channel slope measured with DEM data on 3-mile increments, Yellowstone River

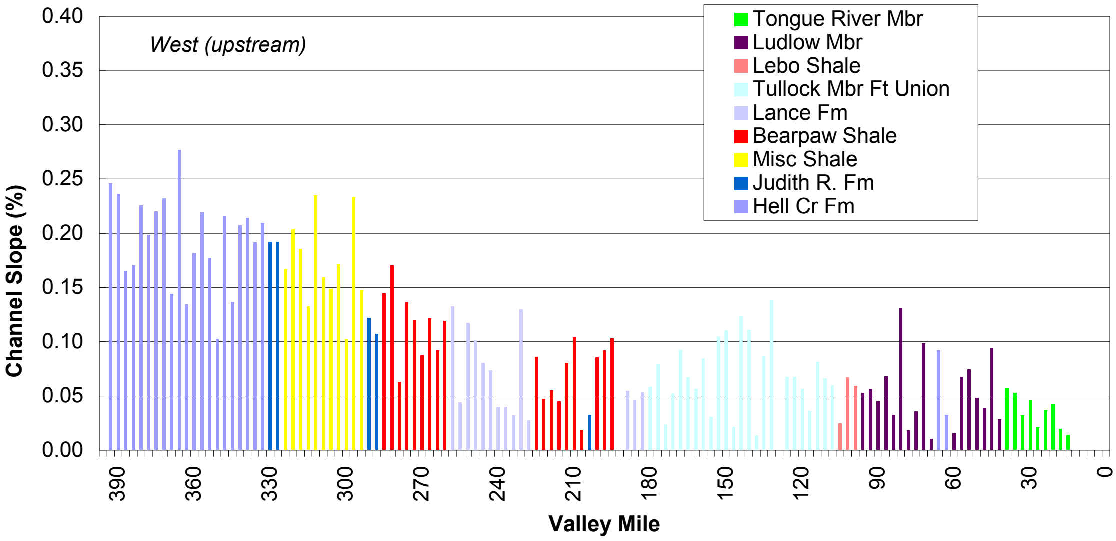

Figure 4-7. Estimated channel slope and associated valley wall geology

Valley slope trends are similar to those of channel slope. The general trend is a gradual downstream reduction in gradient. Between Valley Mile 135 and 150, where the river flows through the Tullock Member of the Fort Union Formation, the channel is relatively steep. This area is located downstream of Miles City is in the vicinity of mapped rapids (Table 1). The anomalously steep channel slope in this area may reflect erosional variability in the Tullock units; in addition, the presence of headcuts or rapids may be reflected in the high slope values.

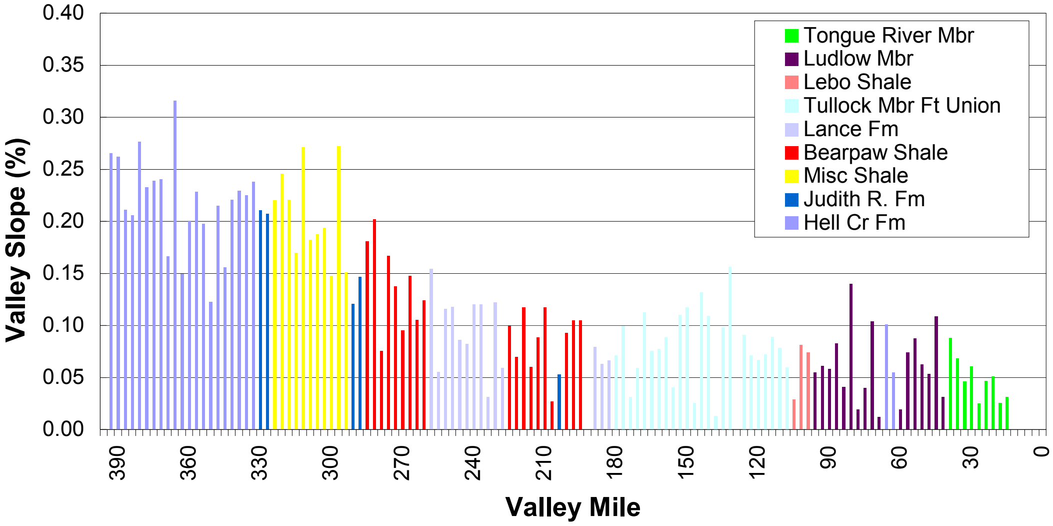

Figure 4-8. Estimated valley slope and associated valley wall geology

4.5.3. Sinuosity

River sinuosity is a measure of the length of channel relative to the valley distance, and reflects how convoluted or tortuous a river segment is. The sinuosity of the Yellowstone River, as defined by 3-mile long corridor segments, ranges from near-straight channels (sinuosity = 1), to very sinuous segments (sinuosity >2; Figure 4-9). In Regions A and B, which extend from Springdale (VM 396) to the Bighorn River confluence (VM 240), the sinuosity is relatively low, averaging less than 1.2. For several miles downstream of the Bighorn River confluence (VM 240), the sinuosity is much higher, exceeding 2 in areas such as the Mission Valley and Hammond Valley. Between the Tongue River confluence (VM 151) and Intake (VM 56) sinuosity is relatively low, where the stream is geologically confined.

4.5.4. Bank Protection Extent

The NRCS Physical Features Inventory (Table 5) was utilized to summarize the extent of bank protection mapped on the riverbanks. The percent bank protection was calculated as a summation of mapped rock riprap, concrete, flow deflectors, and "other" armor, with respect to the total length of the main channel. If bank protection is located on secondary channels, then the estimates will overestimate the total percent of armored bank. The estimates of bankline protection show that in general, bank armoring is highest in the

Billings area (VM 300), where over 30 percent of the banks are armored (Figure 4-10). Bank armoring extents exceed 20 percent in Region C between Miles City and Forsyth.

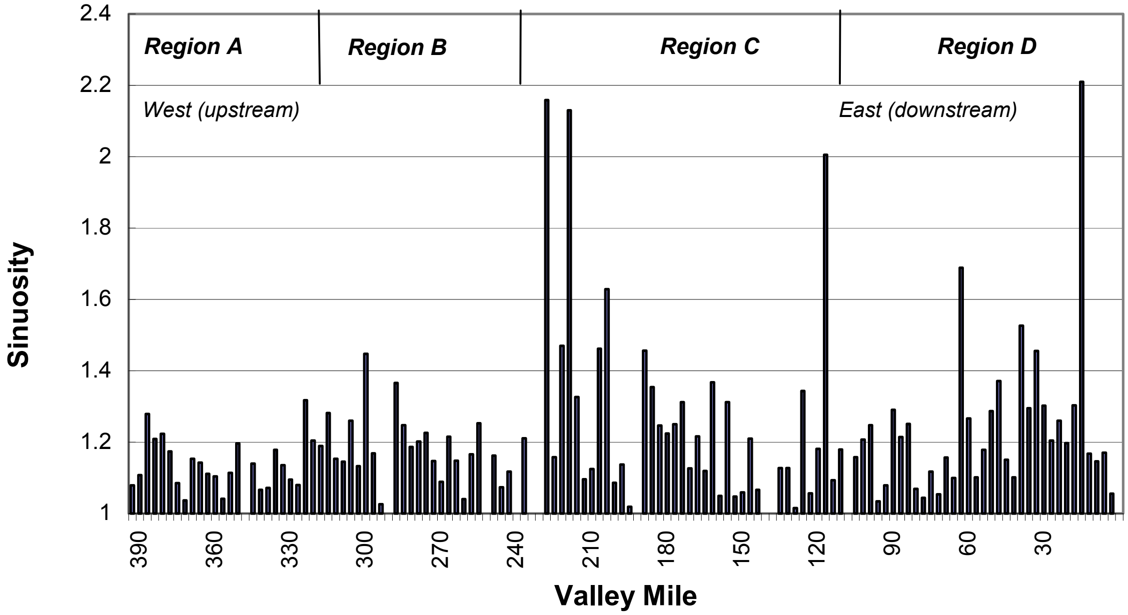

Figure 4-9. Primary channel sinuosity (channel length/valley length) Yellowstone River

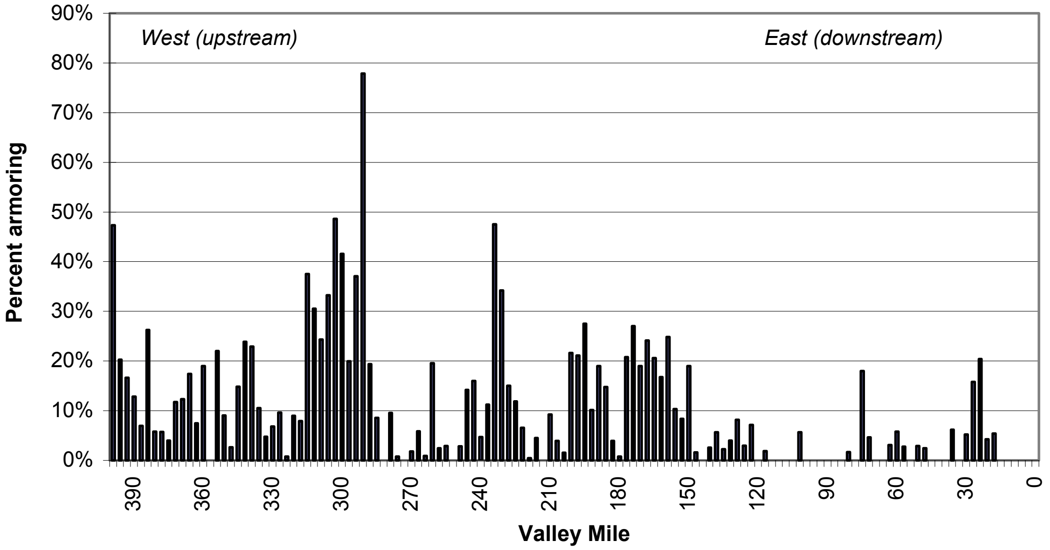

Figure 4-10. Estimated bank armoring extent based on Physical Features Inventory, Yellowstone River

Table 9. Spatial trends in geology and associated valley features

Valley Mile	*River Mile*	*Reach*	*Formation: Lithology*	*Influence/Comments*
396-380	477-458	A1-A4	Hell Creek (Khc): sandstone	Narrow corridor; Extensive Qat 2 ~20-40 ft above river steep slope (>.2%), low sinuosity, low braiding parameter
380-333	458-416	A5-A12	Hell Creek (Khc): sandstone	Narrow corridor, Qat; steep slope (>2%), low braiding parameter, low sinuosity
333-327	416-400	A13-A15	Judith River (Kjr): shale/sandstone	Narrow corridor, low terrace (Qat1) common
327-294	400-360	A16-B2	Telegraph Creek (Ktc), Claggett (Kcl), Niobrara (Kn), Belle Fourche (Kbf): shale	Wide corridor, steep slope
294-288	360-353	B3-B4	Judith River (Kjr): shale/sandstone	Narrow corridor, reducing slope
288-261	350-321	B5-B8	Bearpaw (Kb): shale	Wide corridor, low slope
261-230	321-287	B9-C2	Lance (Kl): sandstone/shale/coal	Narrow corridor, low slope
230-212	287-259	C3-C7	Bearpaw (Kb): shale	**Mission Valley** Wide corridor, low slope (<.1%), high sinuosity
212-206	259-252	C8	Judith River (Kjr): shale/sandstone	Narrow corridor, low slope (<.1%)
206-199	252-242	C9	Bearpaw (Kb): shale	**Hammond Valley** Wide corridor, low slope, high sinuosity
199-184	242-224	C10-C11	Lance (Kl): sandstone/shale/coal	Narrow corridor
184-110	224-176	C12-D1	Tullock Mbr Ft Union Fm: sandstone/shale/coal	At Miles City (Tongue R), width drops due to increased terrace encroachment downstream. Narrow corridor. Rapids: Menagerie, Buffalo, Bear, Bower, Wolf
110-100	136-125	D2	Lebo Mbr Ft Union Fm shale	Moderate corridor width; highly confined
100-69	125-89	D3-D4	Ludlow Mbr Ft Union Fm: sandstone/shale/coal	Wide corridor, Rapids: Walker, Murdoch, Glendiver, Monroe
69-64	89-84	D5-D7	Hell Cr. Fm (Khc): sandstone/shale	Moderate corridor width
64-43	84-56	D8-D10	Ludlow Mbr Ft Union Fm: sandstone/shale/coal	Moderate corridor width
43-12	56-15	D11-D14	Tongue River Mbr Ft Union Fm: sandstone/shale/coal	Downstream of Savage; wide corridor, low slope

5. Reach Delineation and Classification

The ultimate goal of the geomorphic assessment of the Middle and Lower Yellowstone River is to identify representative reaches that, upon detailed scientific investigation, can be used to develop Best Management Practices (BMPs) and management strategies that can be appropriately applied to the entire corridor length. More specifically, the objectives of this assessment include the following:

1. Segmentation of the project area into manageable lengths (reaches) for future efforts related to research, recommendation development, restoration implementation, and monitoring;

2. Characterization of each reach in terms of its fundamental physical condition;

3. Identification of similarities between reaches, by assigning "reach types";

4. Identification of a series of reaches that effectively reflect the range of corridor conditions; and,

5. Selection of a series of "representative" reaches for intensive study.

5.1. Established Stream Classification Systems

River systems occupy a broad range of forms and dominant processes that can be difficult to sort into discrete categories. In order to impose some degree of order to the spectrum of stream form and behavior, stream classification systems have been developed to categorize rivers based on various criteria. Because rivers are so variable, it is not surprising that numerous classification systems have been developed and applied over the last century. Typically, stream classifications are based on the following types of information:

- Stream pattern (braided, meandering, etc…)
- Sinuosity (ratio of channel length to valley length)
- Channel size
- Substrate size (e.g. sand or gravel)
- Channel slope
- Channel perimeter materials (alluvial or bedrock)
- Channel confinement (extent of floodplain access)
- Bedforms (e.g. planar bed and pool-riffle environments)

The resulting classifications can be grouped in terms of their focus on channel form, such as shape, size, and slope, or channel process, such as rate of change.

5.1.1. Form-Based Channel Classification

All river systems can be described in terms of their basic form. The use of form-based stream classification systems to communicate basic channel form is an accepted practice among river scientists. Several classifications, such as the Rosgen (1994) classification, have become established as common vocabulary within the discipline. The classification vocabulary allows people to quickly create a common vision of the stream condition (e.g. meandering gravel bed stream versus a bedrock canyon stream). Examples of established classifications that are based on stream form include the following:

- Channel patterns, such as braided, meandering, and straight (Figure 5-1; Leopold and Wolman 1957; Brice, 1975; Schumm, 1977);
- Sediment load, such as bed load, mixed load, and suspended load (Schumm, 1977);
- Boundary material, such as alluvial, colluvial, or bedrock (Gilbert, 1914; Schumm, 1977; Montgomery and Buffington, 1998);
- Combined morphologic parameters such as gradient, entrenchment, sinuosity, and pattern (Rosgen, 1994);
- Stream order (Horton, 1945; Strahler, 1964); and
- Drainage pattern, such as dendritic or radial (Howard, 1967).

Form-based classifications have been utilized to infer channel processes such as relative channel stability (Schumm, 1977). However, their use as an actual design tool or in the assessment of channel change through time has been criticized, as they do not necessarily identify specific processes, such as human impacts or climate trends that have affected the channel condition (Miller and Ritter, 1996).

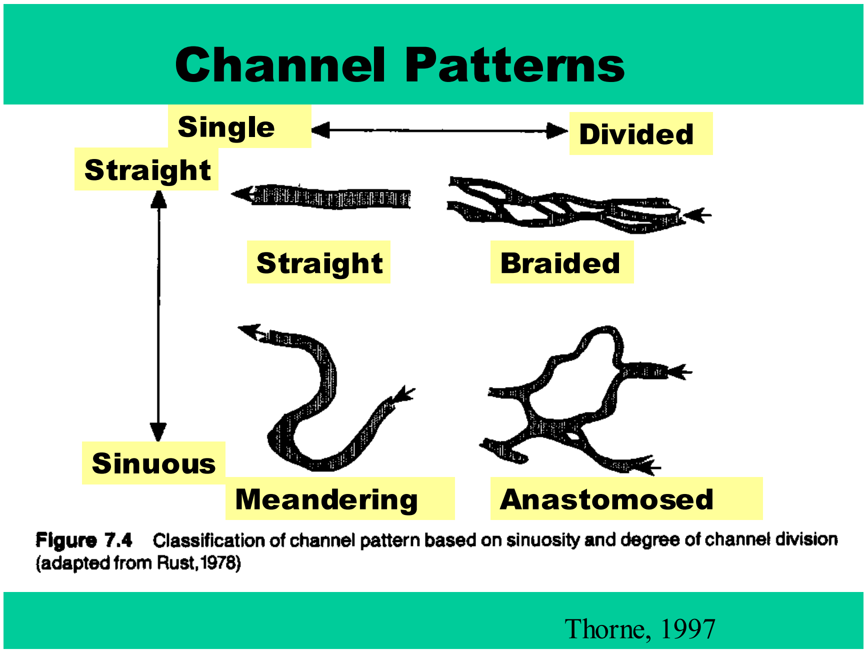

Figure 7.4 Classification of channel pattern based on sinuosity and degree of channel division (adapted from Rust, 1978)

Thorne, 1997

Figure 5-1. Stream patterns commonly used in classifications (Thorne, 1977)

5.1.2. Process-Based Channel Classification

Form-based classifications are limited due to their failure to account for trends of channel adjustment (Thorne, 1997). As a result, efforts have been made to develop stream categorizations based on adjustment processes and channel evolution (Montgomery and Buffington, 1998). Such process-based classifications require an assessment of the ongoing nature of channel adjustment. This typically requires an inference of channel adjustments via channel form, which in turn requires careful observation and a high level of understanding of the linkages between river form and process (Thorne, 1997).

Published process-based classifications include those based on:

- Morphologic indicators of aggradational/degradational conditions (Brice, 1981; Brookes, 1988; Downs, 1995);
- Channel pattern-derived stability indicators (Figure 5-2; Schumm and Meyer, 1979);
- Relationship of transport capacity to sediment supply (Montgomery and Buffington, 1998);
- Incised channel evolution (Schumm and others, 1984, Simon, 1994); and,
- Stability assessment ratings (Pfankuch, 1978; Johnson and others, 1999; Simon and Downs, 1995).

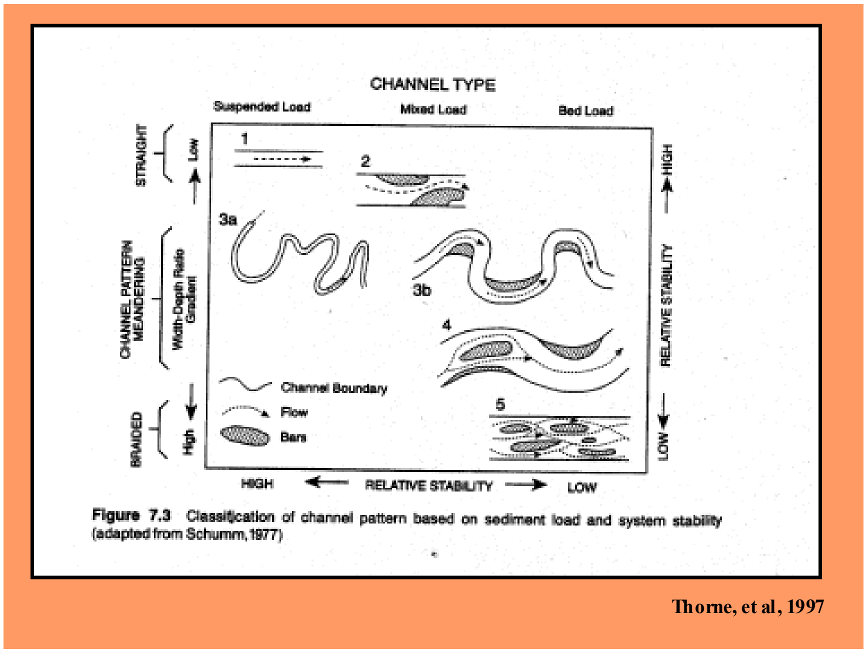

Figure 7.3 Classification of channel pattern based on sediment load and system stability (adapted from Schumm, 1977)

Thorne, et al, 1997

Figure 5-2. Relative channel stability as inferred from channel pattern (Schumm, 1977)

5.2. Previous Approaches to Yellowstone River Classification

The Yellowstone River is characterized by a wide array of channel patterns, including straight, sinuous, meandering, and braided. Silverman and Tomlinson (1984) used the channel classification system of Schumm and Meyer (1979) to generally describe the lower Yellowstone River, although their work did not include specific reach segmentation and classification (Table 10). This classification system is based primarily on sediment load type, and associated channel pattern. In general, channel pattern is related to the proportion of the total sediment load that is suspended load (silt and clay) and bedload (sand and gravel). Schumm and Meyer (1979) describe five channel patterns and their relative scale of dynamic change.

Table 10. Channel descriptions applied to Lower Yellowstone (Silverman and Tomlinson, 1984)

Pattern	*Planform*	*Sediment Load*	*Form*	*Process*	*Relative Rate of Change*
1	Straight	Suspended Load	Straight thalweg	Transport	Low
2	Straight	Mixed Load	Straight channel/ sinuous thalweg; alternate bars	Thalweg shift/ bar migration	Low
3a	Meandering	Suspended Load	Uniform width; small point bars	Neck cutoffs	Low
3b	Meandering	Mixed Load	Wider at bends; large point bars	Chute and neck cutoffs, migration	Medium
4	Meandering /Braided	Bed Load	Large point bars	Frequent chute cutoffs	Medium/High
5	Braided	Bed Load	Multiple thalweg; numerous bars and islands	Active sediment reworking, channel shift	High

On the lower Yellowstone River, it is clear that channel pattern is an important component of channel form, and as such, should be used in classification. However, it is also important on the lower river to describe the types of materials forming the channel perimeter, such as bedrock versus alluvial reaches. The classification system of Montgomery and Buffington (1997) describes channel perimeter materials, as well as channel bedform configurations that allow the classification to fundamentally characterize channel processes that are characteristic of each classification type. Furthermore, the Montgomery/Buffington classification system includes "forced" channel types, in which an on-site external influence has modified the original channel type. For instance, a braided channel that has been channelized into a single thread meandering stream would be termed a "forced pool riffle/braided" channel type.

On the upper Yellowstone River, as part of the efforts associated with the Governor's Task Force (DNRC, 2002), the river classification applied between Gardiner and Springdale is based on a customized classification system that contains elements derived from a pattern-based classification (Schumm and Meyer, 1979), as well as a process-based classification (Montgomery and Buffington, 1997). The basic components of the classification are shown in Table 11.

Table 11. Geomorphic classification scheme applied to Upper Yellowstone River (Dalby and Robinson, 2003)

Channel Type	*Natural Confinement*	*Channel Slope*	*Sinuosity*	*Sediment sources/ availability*	*Gravel Bar Frequency*	*Side Channel Frequency*	*Channel Modification*	*Channel Stability*	
								Vertical	*Horizontal*
Bedrock	High	>.003	<1.5	Low	Low	Low	Low	High	High
Cascade	High	>.003	<1.5	Low	Low	Low	Low	High	High
Plane Bed	Med High	.001-.003	1.1-2	Low	Low	Low	Low	High	High
Pool-Riffle	Low Med High	.001-.003	1.5-2.5 (?)	Moderate	Low, Medium, High	Low, Medium	Low, Medium, High	Varies	Varies
Anabranching	Low	<.002	Multiple channel	High	High	High	High	Varies	Varies
Anabranching/ Braided	Low	<.002	Multiple channel/ braided	High	High	High	High	Low	Low
Forced (Human)	Varies								
Forced (Natural/ Human)	Varies								

5.3. Classification Basis for the Middle and Lower Yellowstone River

The classification of a river system requires the determination as to whether or not an existing broad classification system can be directly applied, or whether a more project specific classification should be developed and applied. The selection of a classification approach is based largely on the project objectives, as well as on the type of information available to describe channel conditions. The stream classifications previously developed for the Upper (Dalby and Robinson, 2003) and Lower (Silverman and Tomlinson, 1984) Yellowstone River were very different due to the inherent differences between the two regions (Section 5.2).

For this effort, the reach delineation and classification were performed remotely, using information derived from existing reports and the project GIS. The primary information utilized from the GIS includes Color-Infrared Aerial Photography (2001), and geologic mapping. Because of the scale of the project, the aerial photographs served as the primary information source for the reach delineation and classification. The evaluation of the photos in the GIS environment allowed rapid scanning of stream conditions at various scales. Additional useful information in the GIS included geologic maps, the physical features inventory, soils maps, floodplain delineations, and vegetation mapping.

The previous classification schemes developed for the Yellowstone River included information that was unavailable for this study, such as dominant substrate, bedforms, and sediment load. The direct application of an approach developed for other river segments was therefore not feasible. Classifications are limited by the available information (Kondolf and others, 2003). Based on the available information and the overall project goals, a relatively general, broad classification system was developed based upon dominant channel pattern and bedrock influence. It is anticipated that with further study, these classifications will be modified with additional information derived during field investigations, so that the classification can better reflect channel process.

5.3.1. Stream Pattern (Planform)

Stream pattern is a major component of remote channel classification, because stream sinuosity and channel density are readily discernible on aerial photographs and maps. Also, stream pattern provides a good indicator of the relative dynamics of a stream; that is, whether the stream is prone to rapid change (braided stream), or slow change (straight channel; Figure 5-2). In order to assess stream pattern for this effort, the four following types of channel segments were digitized in the GIS:

- *Primary:* the main thread of the active channel.
- *Secondary:* well-developed side channels that are separated from the main channel by mostly open bar areas.
- *Overflow:* distinguishable flow paths within the river corridor that convey water during relatively high flow events.

- *Anabranching:* Relatively long stream segments that are separated from the main channel by vegetated islands. Anabranching has been defined as "the division of a river by islands whose width is greater than three times water width at average discharge" (Brice and others, 1978; Schumm 1985).

The relative lengths of each channel type were used to help identify overall stream pattern classification. The following pattern categories were utilized in the classification (Brice, 1975):

1. *Meandering:* A dominant single thread channel, with a sinuosity typically in excess of 1.2

2. *Braiding:* Extensive unvegetated bars that are typically less than 3 times wider than the active channel

3. *Anabranching:* Well vegetated islands that are typically over 3 times wider than the active channel

4. *Islands:* Reaches with numerous meander cutoffs in a vegetated river corridor, and with numerous vegetated bars that are less than 3 times the active channel width

5.3.2. Confinement

The physical boundary of a stream channel profoundly influences its form and behavior (Kondolf and others, 2003). Streams bounded by alluvium (stream sediment) are generally adjustable in nature, although the relative ability of a stream to transport that material may control the level of channel response to natural or human impacts. In contrast, streams bounded by bedrock are more resilient with regard to physical stressors such as floods or human disturbance. Even relatively limited bedrock influences can affect stream behavior on largely alluvial streams, such as on the Yellowstone River, where the channel flows through an alluvial valley, but intermittently abuts bedrock valley walls. In these areas, the presence of bedrock has the potential to affect channel migration rates and patterns, riparian conditions, and in-stream habitat. From a multidisciplinary standpoint, and in considering the potential effects of human disturbance on river behavior, it is therefore important to include bedrock influences within the classification scheme. The following descriptors have been applied to each reach, based on a qualitative assessment of aerial photographs:

1. *Unconfined:* Channel segments that do not abut the bedrock valley margin through the entire reach. These segments are prone to rapid lateral migration and sediment reworking.

2. *Partially Confined:* Partially unconfined reaches are those in which the channel intermittently abuts the valley wall. As such, part of the channel cross section is made of bedrock. This commonly occurs where the channel flows straight along the valley wall, or where a bendway impinges onto the bedrock margin. These stream types are prone to relatively low migration rates.

3. *Confined:* Confined reaches are those in which both channel margins are dominated by bedrock. Within the project reach, this occurs between Miles City and Fallon (RM 176-125), where the Yellowstone River flows through a confined bedrock valley of Fort Union Formation.

5.4. Reach Delineation Results

Reach delineation is a commonly applied technique in geomorphic assessment. The basic intent of reach delineation is to identify river segments that exhibit similar geomorphic conditions, which may relate to stream pattern, slope, hydrology, valley configuration, or perimeter materials. In the process of doing that, a long river can be broken up into workable lengths. It is important to avoid creating reaches that are too short to allow the evaluation of whole river features, such as a meander bend. In general, reach lengths of at least 10 to 20 times the average channel width provide enough length to capture channel conditions and habitat characteristics (Montgomery and Buffington, 1997). On the Yellowstone River, this translates to minimum reach lengths on the order of several miles.

The reach delineation consisted of a visual assessment of the 2001 CIR photography, and segmentation of the river corridor based on significant changes in stream pattern and valley wall influence. The original reach delineations were then modified based on subsequent GIS analysis and Technical Advisory Committee (TAC) review. The resulting delineation consists of a total of 67 reaches, averaging approximately 7 miles in length (Figure 5-3). The reach distribution by county is shown in Table 12. The reaches are referenced with respect to their geomorphic region, and thus are numbered A1 though A18, B1 through B12, C1 through C21, and D1 through D16 (Table 13).

In general, reach lengths increase in the downstream direction as the Yellowstone River channel enlarges. Reaches in Region A average 5.3 miles in length, and reaches in Region D average 9.3 miles in length (Table 13). For each reach, however, the minimum reach lengths identified should be sufficient for comprehensive geomorphic analysis.

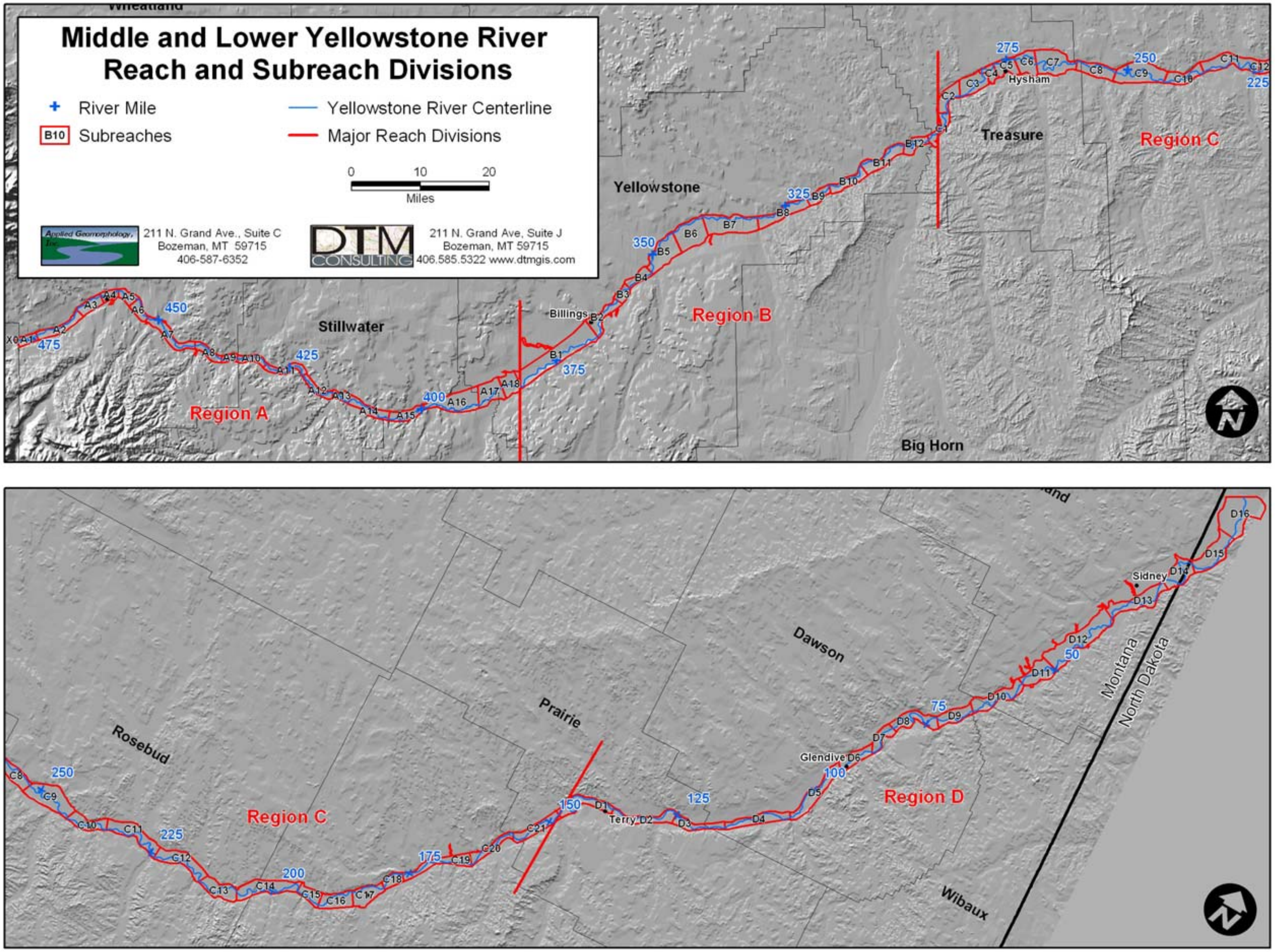

Figure 5-3. Delineated reaches, Yellowstone River

Table 12. Number and average length of reaches by county

County	*Number of Reaches*	*Average Reach Length (mi)*
Custer	5	6.0
Custer/Prairie	2	8.5
Dawson	6	8.3
Dawson/Wibaux/Richland	1	10.7
McKenzie	2	7.5
Prairie	2	11.4
Prairie/Dawson	1	8.3
Richland	3	10.8
Richland/McKenzie	1	8.8
Rosebud	5	9.1
Rosebud/Custer	1	12.1
Stillwater	5	5.7
Stillwater/Carbon	2	7.8
Sweetgrass	8	5.0
Sweetgrass/Stillwater	1	2.5
Treasure	7	5.4
Treasure/Rosebud	1	6.5
Yellowstone	13	6.8
Yellowstone/Carbon	1	4.6
Total	***67***	***7.1***

Table 13. Reach distribution by geomorphic region

Region	*Reach Reference*	*Number of Reaches*	*Average Length (mi)*	*Maximum Length (mi)*	*Minimum Length (mi)*
A Springdale to Clarks Fork	A1-A18	18	5.3	9.7	2.5
B Clarks Fork to Bighorn	B1-B12	12	7.1	15.4	3.0
C Bighorn to Powder	C1-C21	21	7.1	12.1	2.9
D Powder to Missouri	D1-D16	16	9.3	15	5.4

5.5. Reach Classification Results

The classification system applied to the project reach consists of a total of 10 categories based on channel planform and degree of confinement (Table 14, Table 15). Using this classification, the total number of reaches falling into each category ranges from 1 to 11. Of the total 67 reaches, 62 of them fall into seven categories. A summary of the individual reach delineations and classifications is shown in Table 16 through Table 19. The reaches are delineated in terms of River Mile, to allow easy reference to the channel length. Additional information for each individual reach, including parameters regarding geomorphology, vegetation, and physical features are included in Appendix B and Appendix C.

Table 14. Summary parameters for geomorphic classification

Type Abbrev.	*Classification*	*Number of Reaches*	*Slope (ft/ft)*	*Planform/ Sinuosity*	*Natural Confinement*	*Gravel Bar Frequency*	*Side Channel Frequency*
UA	Unconfined anabranching	11	<.0022	Mult. Channels	Low	Moderate	High
PCA	Partially confined anabranching	11	<.0023	Mult. Channels	Moderate	Moderate	High
UB	Unconfined braided	6	<.0024	Mult. Channels	Low	High	High
PCB	Partially confined braided	11	<.0022	Mult. Channels	Moderate	High	High
PCM	Partially confined meandering	2	<.0014	>1.2	Moderate	Low/Moderate	Moderate
PCS	Partially confined straight	9	<.0020	<1.3	Moderate	Low/Moderate	Low
PCM/I	Partially confined meandering/islands	11	<.0007	Mult. Channels	Moderate	Low/Moderate	Moderate
CS	Confined straight	1	<.0001	<1.2	High	Low	Low
CM	Confined meandering	3	<.0008	<1.5	High	Low	Low
US/I	Unconfined straight/islands	1	<.0003	<1.2	Low	Low/Moderate	Moderate

The application of multiple classification schemes within a given river system can cause difficulty in long-term river management due to disagreement between terminology and delineation criteria. On the Yellowstone, however, the application of an existing classification system is difficult at this time due to limitations in data. The Upper Yellowstone classification system developed by Dalby and Robinson (2003) could potentially be applied to the project reach with additional field information (Table 15).

Table 15. Relationships between various classifications

Type Abbrev.	*Channel Classification*	*Silverman/ Tomlinson (1984), Schumm/ Meyer (1979) Type*	*Dalby/ Robinson (2003), Montgomery /Buffington (1997) Type*	*Major Elements of Channel Form*	*Relative Rate of Change*
UA	Unconfined anabranching	Meandering/braided bedload; meandering mixed load	Anabranching	Primary thread with islands that exceed 3X average channel width	High
PCA	Partially confined anabranching	Meandering/braided bedload; meandering mixed load	(Forced) Anabranching	Partial bedrock control; Primary thread with islands that exceed 3X average channel width	Moderate
UB	Unconfined braided	Meandering/braided bedload	Braided	Primary thread with gravel bars; Average braiding parameter generally >2 for entire reach	High
PCB	Partially confined braided	Meandering/braided bedload	(Forced) Braided	Partial bedrock control; primary thread with gravel bars; Average braiding parameter generally >2	Moderate
PCM	Partially confined meandering	Meandering mixed load;	(Forced) pool/riffle or Plane Bed	Partial bedrock control; main channel thread with minimal bar area; average braiding parameter <2	Moderate
PCS	Partially confined straight	Straight/Meandering mixed load	(Forced) pool/riffle or plane bed	Partial bedrock control; low sinuosity channel along valley wall	Low
PCM/I	Partially confined meandering/islands	Meandering mixed load	(Forced) pool riffle	Partial bedrock control; sinuous main thread with stable, vegetated bars	Moderate
CS	Confined straight	Straight/meandering mixed load	Forced pool/riffle or plane bed; Bedrock	Bedrock confinement; low sinuosity	Very Low
CM	Confined meandering	Meandering mixed load	Forced pool/riffle or plane bed; Bedrock	Bedrock confinement; sinuous; uniform width; small point bars	Very Low
US/I	Unconfined straight/islands	Straight mixed load	N/A	Low sinuosity with vegetated bars	

Table 16. Region A reach breakdown and geomorphic classification

Reach Identification	*Length (mi)*	*Downstream River Mile*	*Upstream River Mile*	*County*	*Classification*	*Comments*
A1	3.00	474.0	477.0	Sweetgrass	PCB: Partially confined braided	***Springdale*** : Low primary sinuosity; large open bar area; extensive armoring
A2	7.70	466.3	474.0	Sweetgrass	UB: Unconfined braided	***Grey Bear*** fishing access
A3	4.80	461.5	466.3	Sweetgrass	PCB: Partially confined braided	Upstream of ***Big Timber*** ; Hell Creek Formation valley wall
A4	3.00	458.5	461.5	Sweetgrass	UB: Unconfined braided	To ***Boulder River*** confluence; encroachment at Big Timber; extensive armor
A5	3.50	455.0	458.5	Sweetgrass	UB: Unconfined braided	Low Qat1 terrace on right bank
A6	3.30	451.7	455.0	Sweetgrass	PCS: Partially confined straight	Channel closely follows left valley wall
A7	9.70	442.0	451.7	Sweetgrass	PCB: Partially confined braided	***Greycliff*** : Narrow valley bottom with alluvial fan margins
A8	5.00	437.0	442.0	Sweetgrass	PCB: Partially confined braided	Floodplain isolation behind interstate and R/R
A9	2.50	434.5	437.0	Sweetgrass Stillwater	UA: Unconfined anabranching	To ***Reed Pt*** ; extensive secondary channels in corridor
A10	5.00	429.5	434.5	Stillwater	PCS: Partially confined straight	Channel closely follows left valley wall
A11	7.50	422.0	429.5	Stillwater	PCB: Partially confined braided	High right bank terrace with bedrock toe; ***I-90 bridge*** crossing
A12	6.00	416.0	422.0	Stillwater	PCB: Partially confined braided	To ***Stillwater*** confluence
A13	3.00	413.0	416.0	Stillwater	PCA: Partlialy confined anabranching	***Columbus*** ; extensive armoring, broad islands
A14	7.00	406.0	413.0	Stillwater	PCA: Partially confined anabranching	Valley bottom crossover
A15	6.50	399.5	406.0	Stillwater, Carbon	PCB: Partially confined braided	Follows Stillwater/Carbon County line
A16	9.20	390.3	399.5	Stillwater, Carbon	PCA: Partially confined anabranching	***Park City*** : Major shift in land use, and increase in valley bottom width
A17	4.60	385.7	390.3	Yellowstone Carbon	UA: Unconfined anabranching	To ***Laurel;*** WAI Reach A
A18	3.30	382.4	385.7	Yellowstone	UA: Unconfined anabranching	To Clark Fork; land use change to row crops; WAI Reach A

Table 17. Region B reach breakdown and geomorphic classification

Reach Identification	Length (mi)	Downstream River Mile	Upstream River Mile	County	Classification	Comments
B1	15.40	367.0	382.4	Yellowstone	UB: Unconfined braided	Extensive armoring ***u/s Billings*** ; WAI Reaches B,C,D
B2	7.00	360.0	367.0	Yellowstone	PCB: Partially confined braided	***Billlings*** ; WAI Reach E
B3	3.00	357.0	360.0	Yellowstone	UB: Unconfined braided	Wide corridor d/s ***Billings*** ; WAI Reach F
B4	4.10	352.9	357.0	Yellowstone	PCS: Partially confined straight	Channel closely follows right valey wall; extensive bank armor
B5	7.90	345.0	352.9	Yellowstone	UA: Unconfined anabranching	***Huntley:*** includes ***Spraklin Island***
B6	5.30	339.7	345.0	Yellowstone	PCB: Partially confined braided	Channel closely follows left valley wall
B7	9.20	330.5	339.7	Yellowstone	UB: Unconfined braided	Unconfined reach
B8	9.00	321.5	330.5	Yellowstone	PCA: Partially confined anabranching	***Pompey's Pillar***
B9	4.70	316.8	321.5	Yellowstone	UA: Unconfined anabranching	Meander cutoff isolated by railroad
B10	7.00	309.8	316.8	Yellowstone	PCM: Partially confined meandering	Encroached
B11	8.30	301.5	309.8	Yellowstone	PCA: Partially confined anabranching	To ***Custer Bridge***
B12	4.50	297	301.5	Yellowstone	UA: Unconfined anabranching	to ***Bighorn River*** confluence

Table 18. Region C reach breakdown and geomorphic classification

Reach Identification	*Length (mi)*	*Downstream River Mile*	*Upstream River Mile*	*County*	*Classification*	*Comments*
C1	6.00	291.0	297.0	Treasure	UA: Unconfined anabranching	From ***Bighorn*** confluence: Includes 1 mile of left bank valley wall control; Extensive bank prot.
C2	4.00	287.0	291.0	Treasure	PCB: Partially confined braided	To ***Myers Br*** (RM 285.5); Railroad adjacent to channel on valley wall; low sinuosity
C3	7.00	280.0	287.0	Treasure	UA: Unconfined anabranching	To ***Yellowstone Diversion*** : very sinuous; large meanders, extensive bars; historic avulsion
C4	2.90	277.1	280.0	Treasure	PCB: Partially confined braided	Below ***Yellowstone Diversion***
C5	3.30	273.8	277.1	Treasure	PCS: Partially confined straight	***Hysham***
C6	5.80	268.0	273.8	Treasure	UA: Unconfined anabranching	***Mission Valley***
C7	9.00	259.0	268.0	Treasure	UA: Unconfined anabranching	***Mission Valley***
C8	6.50	252.5	259.0	Treasure Rosebud	PCS: Partially confined straight	Rosebud/Treasure County Line
C9	10.60	241.9	252.5	Rosebud	UA: Unconfined anabranching	***Hammond Valley***
C10	6.90	235.0	241.9	Rosebud	PCM: Partially confined meandering	***Forsyth***
C11	11.00	224.0	235.0	Rosebud	PCM/I: Partially confined meandering/islands	to ***Cartersville Bridge***
C12	10.00	214.0	224.0	Rosebud	PCM/I: Partially confined meandering/islands	***Rosebud*** ; numerous meander cutoffs
C13	7.00	207.0	214.0	Rosebud	PCM/I: Partially confined meandering/islands	Valley bottom crossover
C14	12.10	194.9	207.0	Rosebud Custer	PCM/I: Partially confined meandering/islands	Series of meander bends
C15	3.90	191.0	194.9	Custer	PCS: Partially confined straight	Very low riparian vegetation
C16	6.00	185.0	191.0	Custer	PCM/I: Partially confined meandering/islands	to ***Miles City***
C17	5.00	180.0	185.0	Custer	PCS: Partially confined straight	***Miles City; Tongue River***
C18	4.00	176.0	180.0	Custer	PCS: Partially confined straight	Channel follows left valley wall
C19	11.00	165.0	176.0	Custer	CM/S: Confined straight	Confined
C20	8.20	156.8	165.0	Custer Prarie	CM/S: Confined straight	Confined
C21	8.80	148.0	156.8	Custer Prairie	CM: Confined meandering	To ***Powder River;*** confined

Table 19. Region D reach breakdown and geomorphic classification

Reach Identification	*Length (mi)*	*Downstream River Mile*	*Upstream River Mile*	*County*	*Classification*	*Comments*
D1	12.20	135.8	148.0	Prairie	CM: Confined meandering	To ***Terry Bridge*** ; confined
D2	10.50	125.3	135.8	Prairie	CM: Confined meandering	To ***Fallon, I-90 Bridge*** ; confined
D3	8.30	117.0	125.3	Prairie Dawson	PCS: Partially confined straight	Hugs right bank wall; into ***Dawson County***
D4	11.10	105.9	117.0	Dawson	PCM/I: Partially confined meandering/islands	
D5	11.20	94.7	105.9	Dawson	PCA: Partially confined anabranching	Long secondary channels; to ***Glendive***
D6	5.70	89.0	94.7	Dawson	PCM/I: Partially confined meandering/islands	***Glendive***
D7	5.40	83.6	89.0	Dawson	PCA: Partially confined anabranching	
D8	10.60	73.0	83.6	Dawson	PCA: Partially confined anabranching	To ***Intake***
D9	6.00	67.0	73.0	Dawson	PCM/I: Partially confined meandering/islands	Downstream of ***Intake***
D10	10.70	56.3	67.0	Dawson Wibaux Richland	PCA: Partially confined anabranching	Vegatated islands
D11	6.30	50.0	56.3	Richland	PCA: Partially confined anabranching	***Elk Island*** : Very wide riparian; marked change in channel course since 1981 geologic map base
D12	15.0	35.0	50.0	Richland	PCA: Partially confined anabranching	Secondary channel on valley wall; Sinuous; long abandoned secondary channel
D13	11.20	23.8	35.0	Richland	PCM/I: Partially confined meandering/islands	
D14	8.80	15.0	23.8	Richland, McKenzie	PCM/I: Partially confined meandering/islands	Into ***McKenzie County*** , North Dakota: High sinuosity
D15	8.30	6.7	15.0	McKenzie	PCM/I: Partially confined meandering/islands	
D16	6.70	0.0	6.7	McKenzie	US/I: Unconfined straight/islands	***To Misouri River confluence*** : low sinuosity; alternate bars; vegetated islands

5.6. Reach Type Examples

The following series of example reach types is intended to provide a visual reference for the classification results. The images reflect the 2001 Color Infrared photography that was utilized in the reach delineation and classification.

5.6.1. Reach A9: Unconfined Anabranching

Reach A9, which is located upstream of Reed Point, is an Unconfined Anabranching reach type. The reach has extensive split flow, and the side channels flow around vegetated islands that are over three times the channel width (Plate 3). The primary thread of the river is largely unconfined by bedrock valley walls, although there are bounding terraces in the valley, as well as some encroachment by the highway and rail line. The channel slope is 0.2%, which is typical of Region A, and the braiding parameter is 2.9, which is relatively high. The mapped bank armoring is derived from the NRCS Physical Features Inventory dataset. The river corridor as defined for the topographic data collection defines the lateral corridor margin that was utilized in the GIS-based summarization of reach characteristics (Appendices B, C, and D). This reach should be considered as having a relatively high rate of change due to its lack of bedrock confinement, limited length of bank armor, and high concentration of side channels.

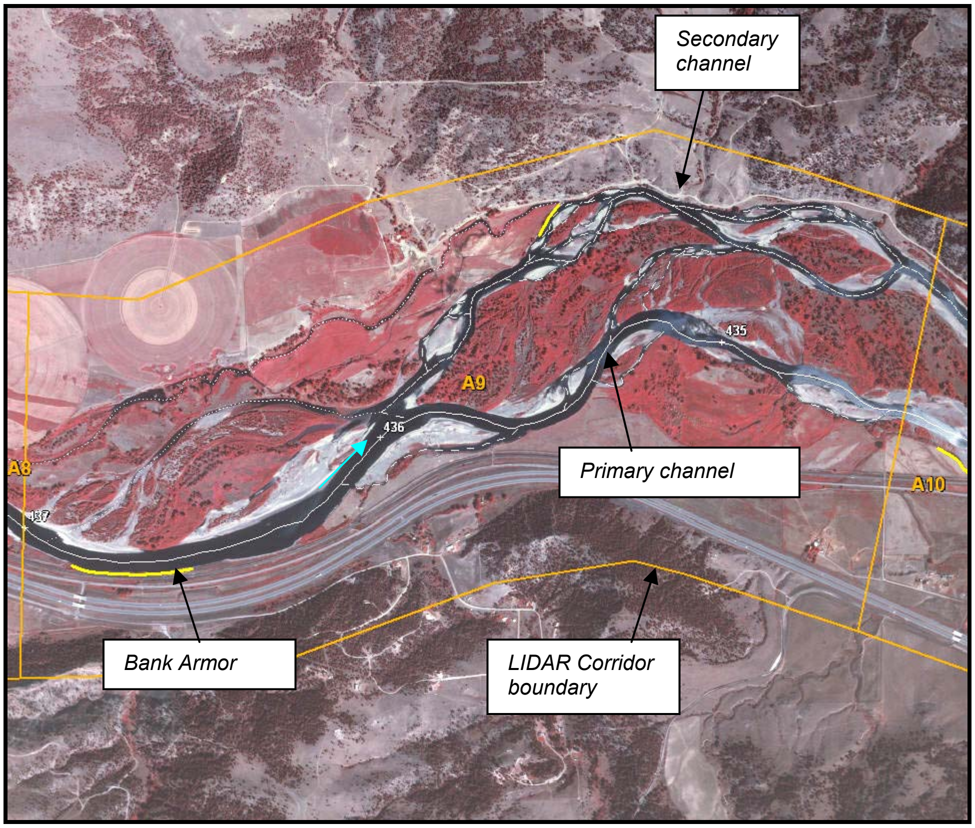

Plate 3. Reach A9, just upstream of Reed Pt, showing Unconfined Anabranching reach type. Note numerous side channels, and wide vegetated islands

5.6.2. Reach A12: Partially Confined Braided

Reach A12, located upstream of the Stillwater confluence, is a Partially Confined Braided reach type (Plate 4). This reach has side channels that flow around open gravel bars that are characteristic of braided reaches. The braiding parameter is 2.3, and the slope is 0.2%. The river flows along the right (south) valley wall margin which consists of Hell Creek Formation sandstone. In areas, the left (north) side of the river valley consists of a low terrace (Qat1). Approximately 10% of the main channel bankline within Reach A12 is armored. Due to the course of the main channel thread along the south valley wall geologic control, the reach is classified as partially confined, and overall rate of change is likely moderate.

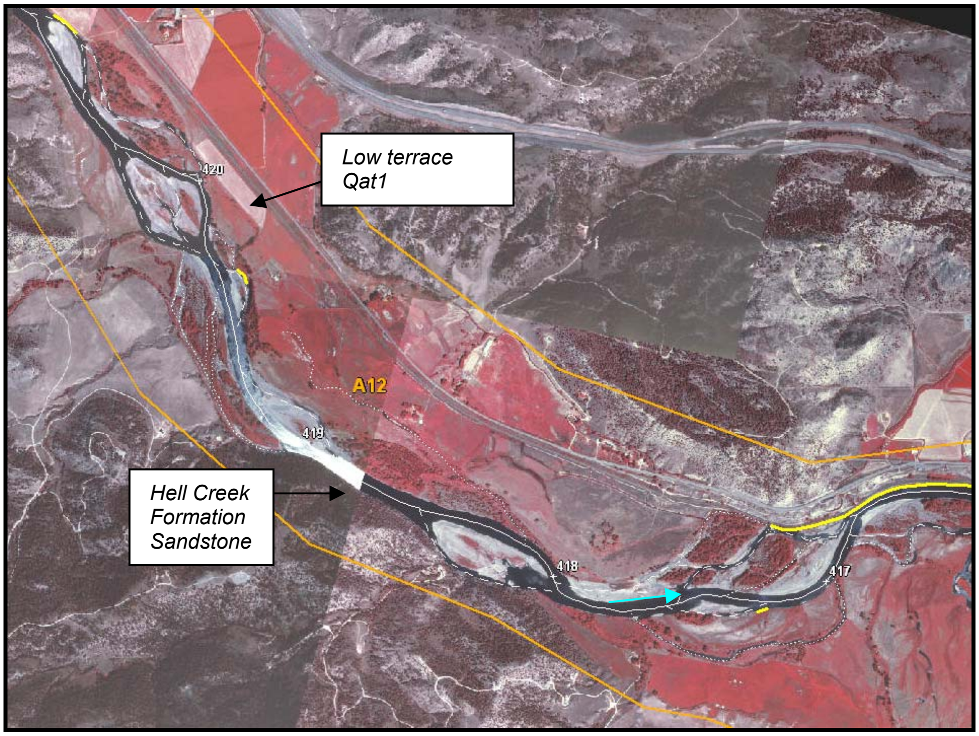

Plate 4. Reach A12, located upstream of the Stillwater River confluence. Note unvegetated gravel bars and split flow characteristic of a braided reach type

5.6.3. Reach B4: Partially Confined Straight

Downstream of Billings, Reach B4 is a Partially Confined Straight channel type (Plate 5). This channel closely follows the south valley wall which is comprised of Judith River Formation sandstone and shale. The sinuosity of the reach is 1.02, and the braiding parameter is 1.2, which indicates that the channel is very straight (sinuosity close to 1), and that it does not have extensive side channels (braiding parameter close to 1). The Physical Features Inventory data indicate that approximately 71 percent of the main channel bankline is armored, and dikes and levees collectively reach 41% of the channel length. The slope of the reach is 0.14 %, which reflects the downstream reduction of slope from Region A (0.2%) to Region C (0.1%). Based on the confinement, sinuosity, and extent of armoring and diking, Reach B4 would be considered to have relatively low rates of change through time, although the presence of a meander cutoff north of the channel indicates that there has been some planform adjustment within the reach.

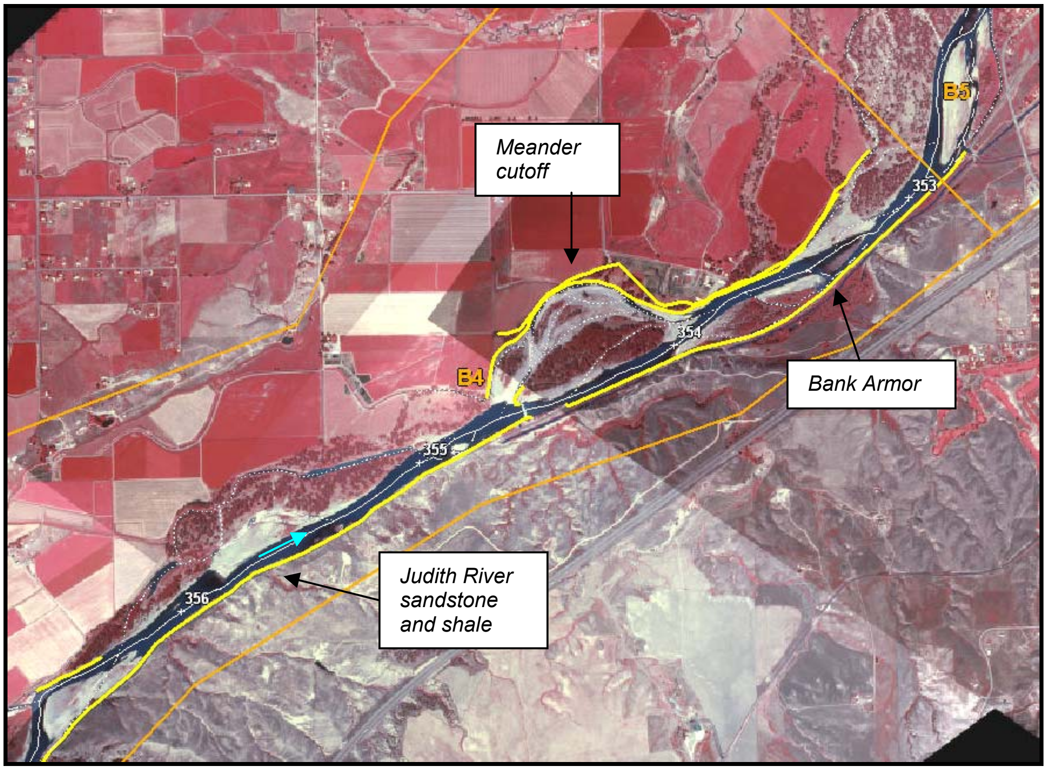

Plate 5. Reach B4 downstream of Billings. Note straight channel and valley wall control of Partially Confined Straight channel type

5.6.4. Reach B7: Unconfined Braided

Where the Bearpaw shale comprises the margins of the Yellowstone River valley, the river corridor and valley bottom tend to widen. An example of this occurs between Huntley and Pompey's Pillar, in Reaches B5-B8. This reach was also described by Koch (1977) as Site 1. Within this area, the channel intermittently abuts the valley wall, but in some areas, such as in Reach B7, the channel is unconfined (Plate 6). Reach B7 is an example of an Unconfined Braided channel segment, in which split flow is common (braiding parameter = 2.17). The channel slope is 0.11 %, which is relatively low, and typical of wide, shale-controlled valley bottoms. The agricultural development on the south side of the river in this reach occurs on a low terrace surface (Qat1). The open bar surfaces in Reach B7 show evidence of new riparian plant growth, which suggests that the reach is relatively dynamic. No bank armoring was mapped in this reach as part of the Physical Features Inventory.

5.6.5. Reach B10: Partially Confined Meandering

Upstream of the Bighorn River confluence, near Waco and Sevenmile Flat, the Yellowstone River flows along the northern valley margin, against sandstones and shales of the Lance Formation. In this area, the river corridor is relatively narrow, and the channel slope is moderate (0.14%). In Reach B10, the river occupies a single, meandering thread, and the extent of split flow around active gravel bars is relatively low

Plate 7). The reach is partly confined to the north by the valley wall, which will affect river geomorphology and associated habitat. Overflow channels are common through the forested river corridor to the south. The rate of change in the reach, based on geomorphic indicators, is expectedly moderate.

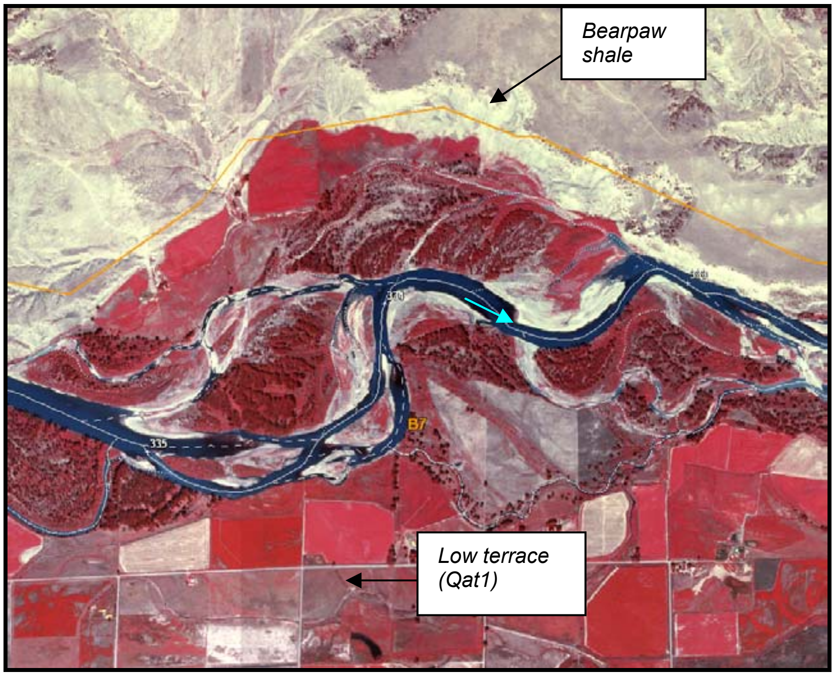

Plate 6. Reach B7 downstream of Huntley, showing a wide valley bottom with Bearpaw shale margins and associated wide river corridor

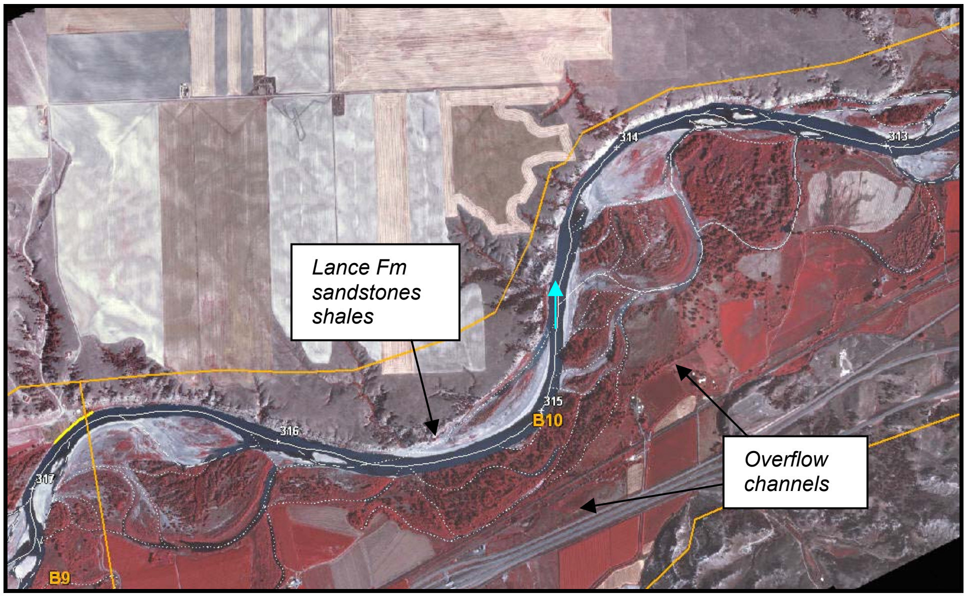

Plate 7. Reach B10 near Waco, a Partially Confined Meandering reach type

5.6.6. Reach C12: Partially Confined Meandering/Islands

From Forsyth to just below Hathaway, the Yellowstone River is relatively sinuous, flowing through a long series of open bendways. In one portion of this area, near Rosebud, several of these open bends have chute channels flowing across their cores, forming large, densely vegetated islands at meander bends (Plate 8). Although the primary planform characteristic of Reach C12 as a whole is a sinuous meandering channel, the localized bendway cutoff/island development is distinct, and thus incorporated into the classification category. The reach is partly confined due to the local controls provided by the Tullock Member of the Fort Union Formation.

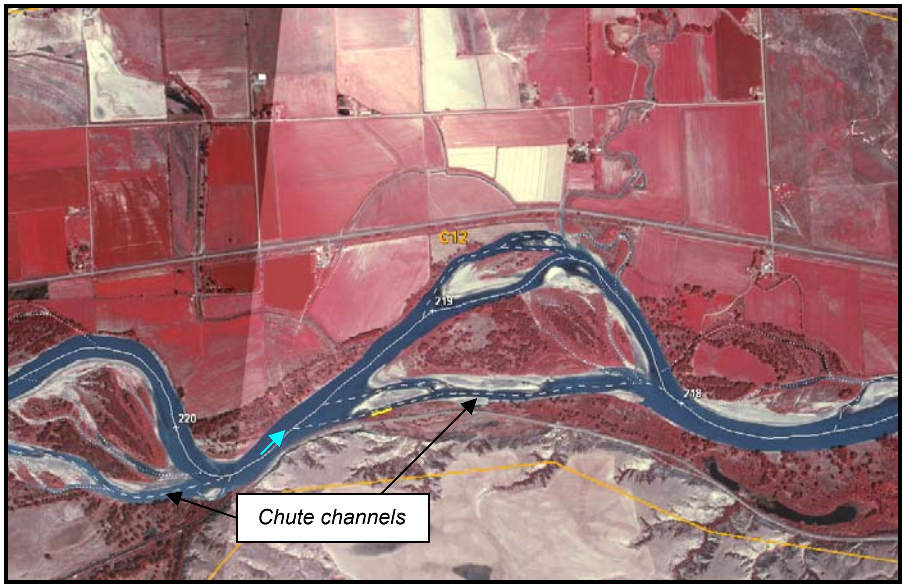

Plate 8. Reach C12 downstream of Rosebud, with sinuous main channel and active chute channels

5.6.7. Reach D1: Confined Meandering

From Miles City to Fallon, the Yellowstone River corridor narrows due to the encroachment of Tertiary-age Fort Union Formation rocks and inset alluvial terraces into the valley bottom. From the Powder River downstream to Fallon, the riparian corridor is very narrow, and the channel is confined within bedrock units. The presence of rock units in the bed within this reach is evidenced by the historic reporting of multiple rapids between Miles City and Fallon, including Menagerie, Buffalo, Bear, Bower, and Wolf rapids. Just downstream of the Powder River confluence, Reach D1 is an example of a confined meandering channel that has limited riparian corridor and little evidence of active channel migration Plate 9. On the Order of 1% of the channel length is armored in this reach, although dikes and levees occupy approximately 7% of the channel length. The slope of the reach is a relatively low 0.05%.

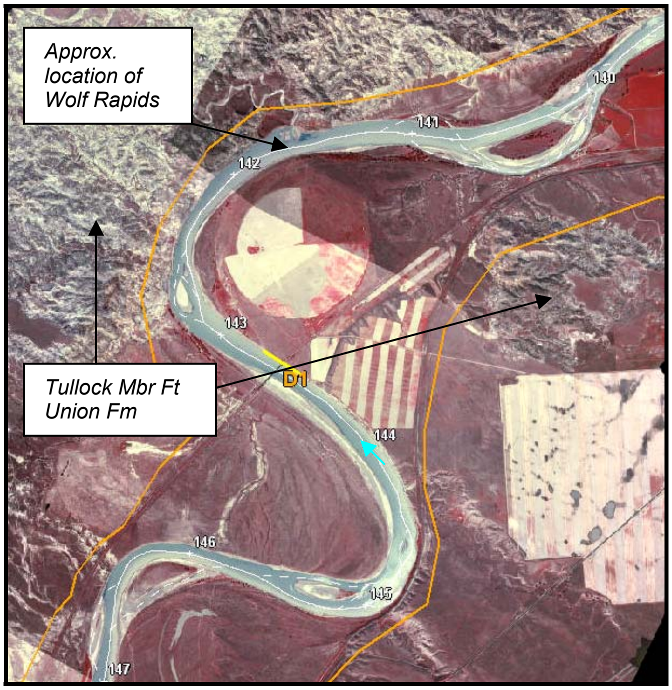

Plate 9. Reach D1, just downstream of the Powder River confluence, a Confined Meandering reach type

5.6.8. Reach D12: Partially Confined Anabranching

In Region D, which extends from the Powder River confluence to the confluence with the Missouri River, the geomorphology of the Yellowstone River is distinctly different from upstream areas. The river slope is low, the valley bottom tends to be wide, and densely forested islands are common. Reach D12 is located 45 miles upstream of the river mouth, just downstream of Elk Island (Plate 10). The reach shows a wide riparian corridor, with several active side channels. The river continues to occupy a primary thread, however, and that channel commonly abuts the southern valley wall. The multi-channeled areas typically are localized, and joined by single thread channel segments. The low slope and multiple channel configuration within these reaches potentially supports a description of these channel segments as anastomosing. As these multichanneled segments tend to be relatively localized, such that there is no extensive network of distributary channels, however, these reach segments have been incorporated into the anabranching classification for the purpose of this reconnaissance-level effort. It is important to note, however that anabranching reaches in the lower river will have a lower relative rate of dynamic change than those identified in upstream regions due to their lower slope and finer grained sediment load.

5.6.9. Reach D16: Unconfined Straight/Islands

The mouth of the Yellowstone River consists of a unique reach type, which is a relatively straight channel with numerous forested islands (Plate 11). This reach is affected by the Missouri River, as it flows onto the Missouri River floodplain. The slope of Reach D16 is 0.3% (1.6 ft per mile), which is very low, such that the channel is prone to sediment deposition and bar formation. Additionally, depositional features at the confluence indicate that reach is backwatered by the Missouri River, which will exacerbate depositional trends through the reach.

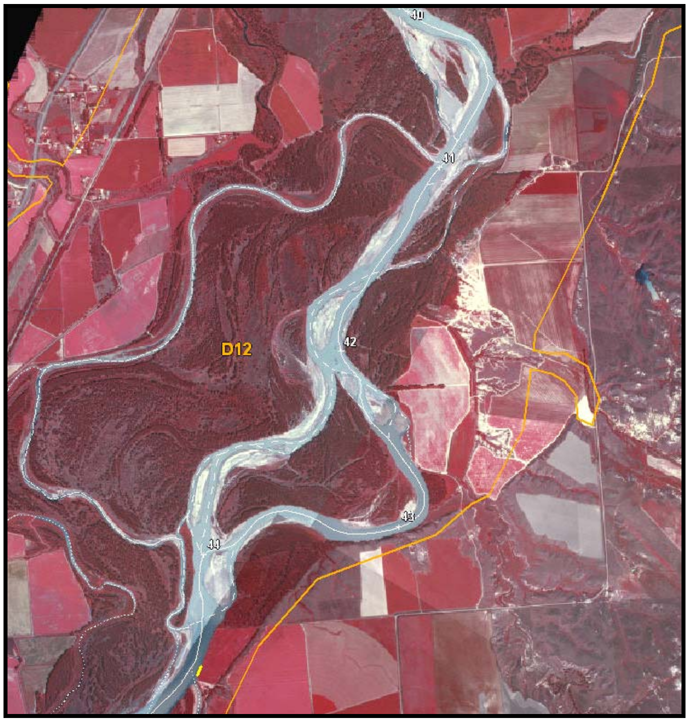

Plate 10. Reach D12, showing low broad riparian corridor and multiple channel threads common in lower river.

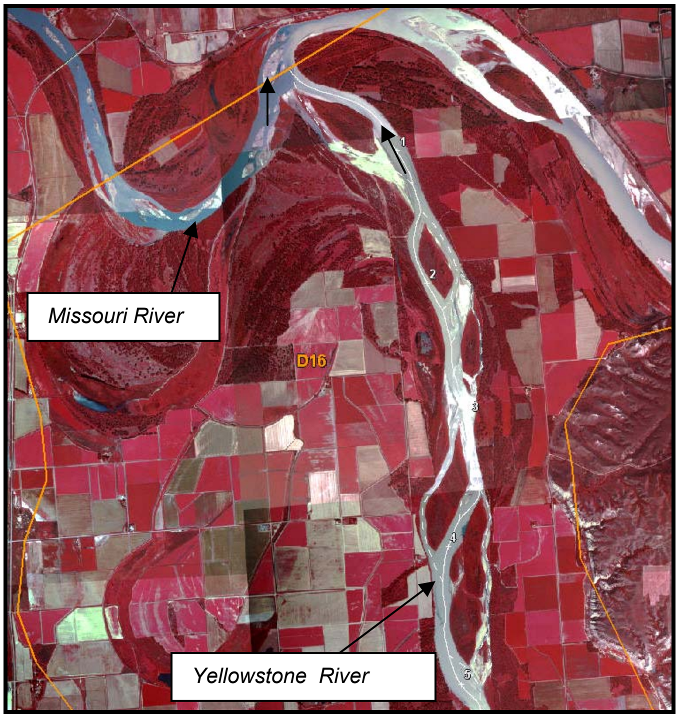

Plate 11. Reach D16, the mouth of the Yellowstone River

5.7. Priority Reach Selection

The selection of priority reaches for detailed study in the Cumulative Effects Investigation was a collaborative effort that included a series of revisions based on input from the Technical Advisory Committee (TAC). Reach selection was ultimately based on the following combined factors:

- results of the site selection process performed by the MSU fisheries COOP unit to satisfy requirements of the fisheries component of the Cumulative Effects Investigation;
- site distributions that represent both geomorphic regions as well as reach types;
- within given regions and reach types, the selection of paired reaches to reflect high and low extents of erosion control as quantified by the physical features inventory;
- areas slated for FEMA floodplain studies, to optimize data acquisition and analysis efforts; and,
- areas identified as having special management concerns by individual Conservation Districts.

The results of the priority reach selection are shown in Table 21 through Table 24. A total of 33 reaches were selected for further study, which represents almost 50% of the total corridor length between Springdale and the Missouri River (Table 20). The reaches that contain fisheries study sites represent 30 percent of the river length, and those areas are most extensive downstream of the Bighorn River confluence. Reaches that include specific areas slated for floodplain mapping are concentrated in Region B, in the vicinity of Billings, as well as around the communities of Reed Point, Columbus, Park City, and Glendive. These reaches collectively represent approximately 22 percent of the river length. Supplemental reaches selected on the basis of ensuring effective geomorphic representation incorporate approximately 42 percent of the river, and reaches that include Conservation District interest represent 22 percent of the entire project extent.

Table 20. Summary of selected reach distribution and length

Region	*Number of Reaches Selected*	*Miles Selected*	*Percent Total Length Selected*	*Reaches Including Fisheries (mi)*	*Reaches Including Flood Study (mi)*	*Reaches Adding Geomorphic Representation (mi)*	*Reaches Including CD Interest*
A: Springdale to Clarks Fork	10	58.6	62%	33.4	25.1	49.6	44.0
B: Clarks Fork to Bighorn	8	60.9	71%	17.1	60.9	44.8	25.4
C: Bighorn to Powder	8	69.1	46%	41.7	0	55.6	26.1
D: Powder to Missouri	7	68.4	46%	50.9	16.9	51.5	11.2
Percent of Total	49%	54%		30%	22%	42%	22%

Table 21. Selected Reaches, Region A

Selected Study Reaches	*Floodplain Proposals*	*Geomorph*	*Fisheries Site*	*CD Interest*	*Length (mi)*	*Classification*	*Percent Armoring*	*Basis for selection as Study Reach*	*Location*
A6		**X**		**X**	3.30	PCS: Partially confined straight	6%	Compare with A10 as low modification PCS type (6% armor); CD interest	***Springdale***
A7		**X**	12	**X**	9.70	PCB: Partially confined braided	12%	Fisheries; High modification PCB type (12% armor); CD interest	***Greycliff***
A10	**X**	**X**		**X**	5.00	PCS: Partially confined straight	12%	Compare with A6 as high modification PCS type (12% armor); Reed Pt floodplain mapping	
A11		**X**	11	**X**	7.50	PCB: Partially confined braided	14%	Fisheries; High modification PCB type (14% armor); CD interest	***I-90*** crossing
A12				**X**	6.00	PCB: Partially confined braided	10%	High modification PCB type (10% armor) CD interest; continuity, Stillwater confluence	To ***Stillwater*** confluence
A13	**X**				3.00	PCA: Partially confined anabranching	25%	High modifcation PCA reach type (25% armor); Columbus floodplain mapping	***Columbus***
A14		**X**	10		7.00	PCA: Partially confined anabranching	16%	Fisheries; Compare with A16 as high modification PCA type (16% armor)	
A16	**X**	**X**	9	**X**	9.20	PCA: Partially confined anabranching	6%	Fisheries; Compare with A14 as moderate modification PCA type (6% armor)	***Park City***
A17	**X**	**X**			4.60	UA: Unconfined anabranching	8%	Moderate modification UA type (8% armor) compare to A18	To ***Laurel***
A18	**X**	**X**		**X**	3.30	UA: Unconfined anabranching	38%	High modification UA type (38% armor); compare to A17; Laurel floodplain mapping, CD interest	To Clark Fork

Table 22. Selected Reaches, Region B

Selected Study Reaches	*Floodplain Proposals*	*Geomorph*	*Fisheries Site*	*CD Interest*	*Length (mi)*	*Classification*	*Percent Erosion Control**	*Basis for selection as Study Reach*	*Location*
B1	**X**	**X**		**X**	15.40	UB: Unconfined braided	34%	High modification UB type (34% armor); Compare to B7; Billings floodplain mapping; CD interest	***u/s Billings***
B2	**X**	**X**		**X**	7.00	PCB: Partially confined braided	34%	High modification PCB type (34% armor); Billings floodplain mapping; CD interest; Compare to B6	***Billlings***
B3	**X**			**X**	3.00	UB: Unconfined braided	24%	Floodplain Proposal	d/s ***Billings***
B4	**X**				4.10	PCS: Partially confined straight	72%	Floodplain Proposal	
B5	**X**	**X**	ALT16		7.90	UA: Unconfined anabranching	12%	Fisheries; moderate modification UA type (12% armor); floodplain mapping	***Huntley, Spraklin Island***
B6	**X**	**X**			5.30	PCB: Partially confined braided	6%	Low modification PCB type (6% armor); compare to B2	
B7	**X**	**X**	ALT15		9.20	UB: Unconfined braided	0%	Low modification UB type; Compare to B1	
B8	**X**				9.00	PCA: Partially confined anabranching	3%	Floodplain mapping	***Pompey's Pillar***

Table 23. Selected Reaches, Region C

Selected Study Reaches	*Floodplain Proposals*	*Geomorph*	*Fisheries Site #*	*CD Interest*	*Length (mi)*	*Classification*	*Percent Erosion Control**	*Basis for selection as Study Reach*	*Location*
C3		**X**		**X**	7.00	UA: Unconfined anabranching	25%	High modification UA type (25% armor); compare with C7, C9; CD interest	To ***Yellowstone Diversion***
C7		**X**	8		9.00	UA: Unconfined anabranching	2%	Fisheries; Low modification UA type (2% armor)	***Mission Valley***
C8					6.50	PCS: Partially confined straight	5%	Continuity	***Rosebud/Treasure County Line***
C9		**X**	7		10.60	UA: Unconfined anabranching	6%	Fisheries; moderate modification UA type (6% armor); compare with C3, C7	***Hammond Valley***
C10		**X**			6.90	PCM: Partially confined meandering	22%	High modification PCM type (22% armor)	***Forsyth***
C12		**X**	6		10.00	PCM/I: Partially confined meandering/islands	3%	Fisheries; low modification PCM/I (3% armor); compare with C14	***Rosebud***
C13				**X**	7.00	PCM/I: Partially confined meandering/islands	33%	Continuity	
C14		**X**	5	**X**	12.10	PCM/I: Partially confined meandering/islands	17%	Fisheries; high modification PCM/I (17% armor); compare with C12; CD interest	

Table 24. Selected Reaches, Region D

Selected Study Reaches	*Floodplain Proposals*	*Geomorph*	*Fisheries Site #*	*CD Interest*	*Length (mi)*	*Classification*	*Percent Erosion Control**	*Basis for selection as Study Reach*	*Location*
D5	X				11.20	PCA: Partially confined anabranching	4%	Low modification PCA u/s Glendive (4% armor); floodplaiin mapping	To ***Glendive***
D6	X		ALT13		5.70	PCM/I: Partially confined meandering/islands	6%	Mod modification PCM/I at Glendive (6% armor); floodplain mapping	***Glendive***
D10		X	4		10.70	PCA: Partially confined anabranching	2%	Fisheries; Low modification PCA (2% armor)	
D11		X			6.30	PCA: Partially confined anabranching	0%	Low modification PCA (0% armor)	***Elk Island***
D12		X	3		15.00	PCA: Partially confined anabranching	3%	Fisheries; low modification PCA (3% armor)	
D13		X	2	X	11.20	PCM/I: Partially confined meandering/islands	13%	Fisheries; High modification PCM/I (13% armor); compare with D15	
D15		X	1		8.30	PCM/I: Partially confined meandering/islands	0%	Fisheries; low modification PCS/I (0% armor); compare with D13	

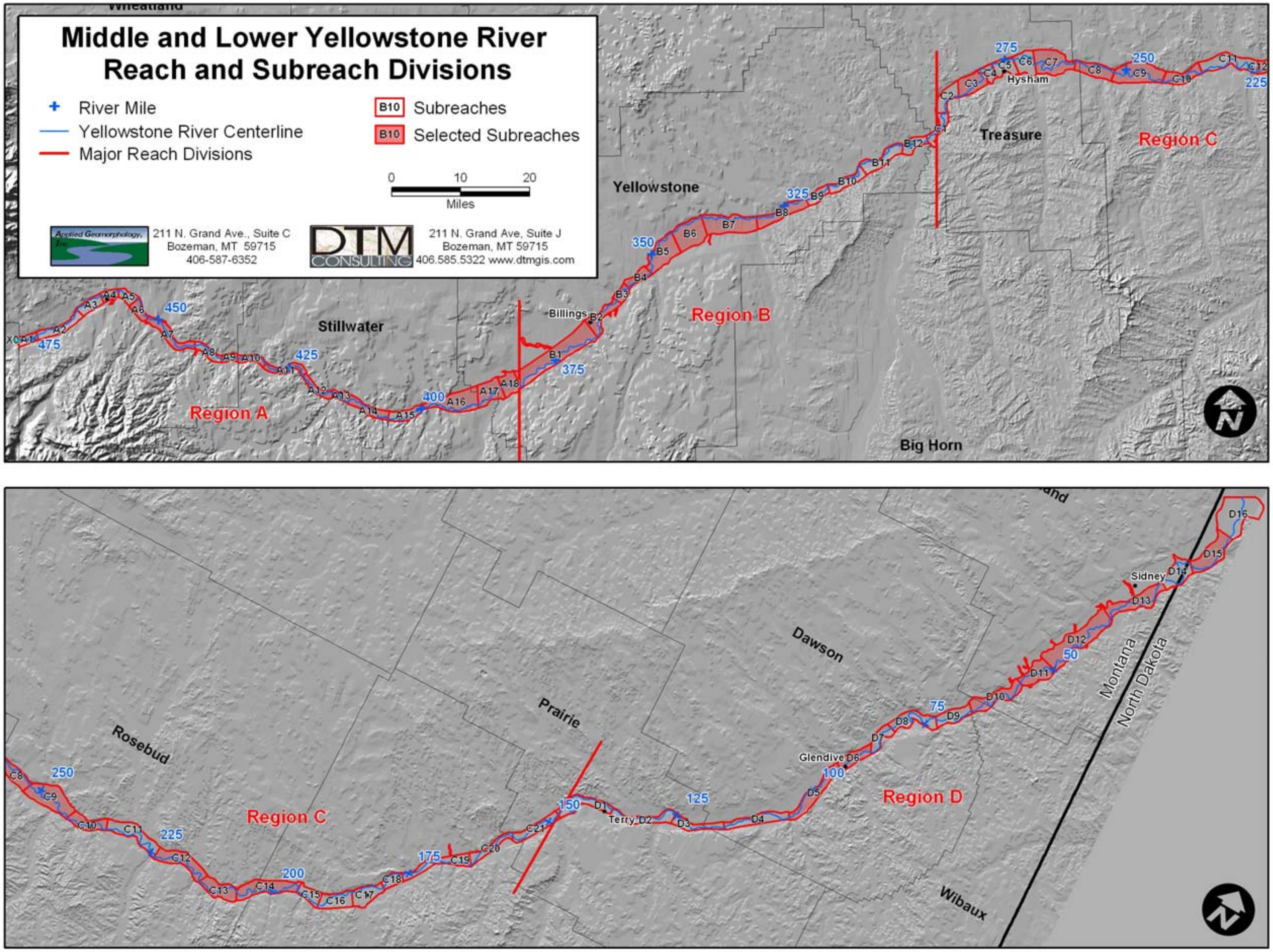

Figure 5-4. Map of selected reaches, Yellowstone River

6. Aerial Imagery Assessment

Aerial imagery will play an important role across many disciplines when developing the Cumulative Effects Investigation. As such, a thorough review and assessment of available imagery sources for the study area was completed. The ultimate goal of this process was to identify the sources, availability and condition of all current and historic aerial photography sources. This inventory will likely be used to select two image sets that will be scanned and georeferenced for use in the GIS. A variety of agencies, universities, and private entities were identified as possible sources for aerial photography and were contacted in an effort to identify all historic aerial photography. The results of this search are summarized below. Detailed information on availability of photos, photo dates, river corridor coverage, acquisition costs and some photo/index numbers are included in Appendix E.

6.1. Imagery Sources

The following sources were contacted while researching available imagery for the Lower Yellowstone River corridor.

- USDA Aerial Photography Field Office (APFO) Salt Lake City, UT Archives
- USGS EROS Data Center, SD
- National Archives and Records Administration (NARA) in Washington, DC
- Conservation District offices along the Lower Yellowstone River, MT and ND
- Fairchild Collection at Whittier College, CA
- Montana Department of Transportation, Helena
- Fairchild and Teledyne Collections at UC Santa Barbara, CA
- Montana Bureau of Mines and Geology, Butte
- US Bureau of Reclamation, Billings, MT

6.2. Availability

Table 25 summarizes the results of the data search by year and by county. Because the aerial photography missions are generally flown by county, a single series is likely to span two or more years in order to cover the entire study area. As such, it may be necessary to acquire images from more than one source to ensure complete coverage. This is especially true for older photography where an individual source may have incomplete coverage. Most archives require the purchase of index maps to determine the specific photos to order. For newer flights, these indexes are either on-line, or have been provided by the archiving agency.

Table 25. Summary of available aerial photography

	Sweet-grass	*Still-water*	*Yellow-stone*	*Treasure*	*Rosebud*	*Custer*	*Prairie*	*Dawson*	*Richland*	*McKenzie*
1937			NARA							
1938								NARA	NARA	
1939										NARA, CD[2]
1940			NARA							
1941		NARA								
1942			CD[1]							
1946			EE[1]			EE[2]				
1948	EE[2]									
1949			CD	EE	EE	EE	EE	EE, NARA	EE, NARA	EE, NARA, CD[2]
1950			APFO, NARA, CD[1]	APFO, NARA	APFO, NARA	APFO, NARA, CD	APFO, NARA	APFO	APFO	
1951	EE[1]	EE	EE[1]				EE[1]			EE[1]
1952										EE[1]
1953	EE[1]	EE	EE[1]	EE[1]	EE					EE
1954		NARA, CD								
1955	NARA									
1956			EE[2]	EE[2]					APFO	
1957-58	CD	CD	CD, APFO	CD[1], APFO	CD, APFO	CD, APFO	CD, APFO	CD, APFO	CD[1]	CD[2]
1962		APFO, CD								
1965	APFO, CD[1]						EE[2]	EE	EE	
1966			APFO, EE[1], CD		EE	EE[1]				
1967							APFO	APFO, CD	CD	EE[1]
1968				APFO, CD[2]	APFO	APFO, CD	EE[2], CD			
1962-68	APFO	APFO	APFO	APFO	APFO	APFO	APFO	CD, APFO	CD	
1969			EE[1]			EE[1]				
1970	CD	APFO			EE[2]					
1971							EE[1]		EE[2]	EE[2]
1972			CD[1]							
1973			EE[2]							

	Sweetgrass	***Stillwater***	***Yellowstone***	***Treasure***	***Rosebud***	***Custer***	***Prairie***	***Dawson***	***Richland***	***McKenzie***
1974		CD						EE^{1}	EE^{2}	CD^{2}
1975	EE^{2}	EE	EE^{2}				CD	EE^{2}	EE^{1}	EE^{2}
1974-75			CD			CD				
1976										EE^{2}
1978			EE^{2}		EE^{2}	APFO, EE^{1}, CD^{1}	APFO			
1979	CD^{1}	APFO, CD	APFO	APFO, CD^{1}	APFO				EE^{2}	EE
1978, 79, 80	APFO	APFO	CD, APFO	APFO	CD^{1}, APFO	CD, APFO	CD, APFO	APFO		
1980	EE^{1}	EE^{1}	EE^{1}	EE	EE	EE	EE^{2}	EE, CD	EE, CD	EE, CD^{2}
1981	EE	CD, EE^{1}	EE^{1}	EE^{1}	EE^{2}	EE	EE	EE	EE	EE
1983						EE^{1}	EE^{2}		EE^{2}	
1984						EE^{1}	EE^{2}			
1986	EE	EE^{1}								
1988	EE^{2}									
1991	EE, APFO	CD, EE, APFO	CD, EE, APFO	CD^{1}, EE, APFO	CD, EE, APFO	EE, APFO	EE, APFO	CD, EE, APFO	EE^{1}, APFO	CD, EE^{1}, APFO
1992	EE^{1}	EE^{1}	EE^{2}	EE^{2}	EE^{2}	EE^{2}	EE^{2}	EE^{2}	EE^{1}	EE
1991-92									CD	
1995	EE	EE^{1}		EE^{2}	EE^{2}				EE^{2}	EE^{2}
1996	APFO	EE^{1}, APFO	EE, APFO	APFO, EE^{1}	APFO, EE^{2}	EE, APFO	EE, APFO	EE, APFO	EE, APFO	EE, APFO
1995-96									CD	
1997	EE^{2}, CD^{1}	EE^{2}	EE^{2}	EE^{1}	EE^{1}	EE^{1}	EE^{1}	EE^{1}	EE^{2}	EE^{2}
1998				EE^{2}	EE^{2}	EE^{2}	EE^{2}			

EE = NHAP, NAPP, or Survey photography available through USGS Earth Explorer.
CD = Photography available from the local Conservation District offices.
APFO* = Photography available from the USDA Aerial Photography Field Office (Salt Lake City Archives).
NARA* = Photography available from the National Archives and Records Administration.

No Superscript = Complete coverage for the county.
1 = Most of the county has coverage. Only a couple of photos are missing.
2 = Some of the county has coverage. Coverage includes scattered individual photos.
*APFO and NARA search results were returned as lists of indexes that are necessary to order to determine photos needed. Therefore, it is not possible to determine whether the coverage is complete for each county.

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Appendix A: Delineation of Yellowstone River Corridor Boundaries

The Yellowstone River corridor delineation reflects an initial integration of available digital information including floodplain mapping, topography, and geology. Because there are spatial gaps in that information, an inundation model was developed, using existing data for calibration, to develop a comprehensive delineation of the entire corridor. The resulting corridor was evaluated with respect to inclusiveness of several relevant parameters, including hydric soils, wetland plants, flood frequency, 100-year flood zone, 500-year flood zone, linear physical features, point physical features, and riparian vegetation, to determine its comprehensiveness.

A.1. Corridor Delineation Based on Geologic Mapping and Topography

Initially, geologic mapping and topography were utilized to define preliminary corridor boundaries. A series of four initial corridor configurations were developed using this information, including three terrace configurations and the entire topographic valley bottom (Table A1). Mapping units were not always consistent between quadrangles, and so units were combined where necessary to provide continuity. Additional data, including mapped floodplain area, soils, inventoried physical features, and GAP vegetation data were then assessed with respect to their inclusion in the various corridor configurations. A major limitation in the mapping data is that the coverage was incomplete at the time of this evaluation. The geology dataset contains spatial gaps between RM 0-47, RM 118-174, and RM 257-328. This includes 330 square miles of estimated corridor area.

A.2. Corridor Delineation Based on Inundation Model

In order to effectively bridge the gaps in the geologic dataset, and provide a consistent methodology for defining the LIDAR data collection corridor across the entire project area, a general inundation model based on topography and stream profile was developed for the entire project reach (Table A1). The model was designed to roughly define a consistent inundation surface for the entire study area. The general steps for developing this surface are described below.

The initial step was to define a valley centerline that follows the general trend of the valley. Cross sections were then developed at three mile intervals along this line. The minimum elevation for each cross section was extracted using the 30 meter SRTM (Shuttle Radar Topographic Mission) DEM. Working from the downstream end, the model then creates a series of inclined planes between the cross section lines by calculating the elevation difference between each line and the next line upstream. This elevation difference was then scaled using a formula developed during the calibration process and added to the base elevation of the downstream cross section line. Thus, as the model works upstream, it is constantly adjusting the slope of each inclined plane according to the elevation differences between adjacent cross sections. The final step was to extract all areas where the elevation of the model plane was greater than or equal to the DEM surface elevation.

Table A1: Corridors evaluated for LIDAR data acquisition

Corridor	*Map Units*	*Description*
Qal	Qal + Qat1+Water	Corridor Qal includes mapped Quaternary alluvium, and the lowermost mapped terrace unit. In places, this unit was not differentiated from the other terraces, and mapped as undifferentiated Qat. As such, the lowest terrace is under-represented in this corridor.
Qal (b)	Qal w/100m buffer +Qat1+water	Corridor Qal (b) includes a 100m buffer added to either side of the Qal corridor.
Qat	Qal + Qat + Qat1 + Qat2 + Water	Corridor Qat includes relatively extensive terraces surfaces, mapped as Qat2 in some areas, and Qat in others. These terraces extend well above the floodplain surface.
VB	Valley bottom units	The delineation of a broad corridor boundary that includes the entire valley bottom of the Yellowstone River valley was based on an assessment of topography, geology, and CIR imagery. Initial boundaries were determined based on slope-of-slope data derived from the DEM. This parameter depicts abrupt changes in ground surface slope, and as such, effectively delineates the transition from valley floor to valley wall. The preliminary corridor was then modified to include the confluence areas of major tributaries, to refine the boundary where the valley wall was poorly depicted by the slope data, and to include areas identified by the inundation model described below.
IM	Inundation Model	The Inundation Model corridor includes all areas defined by the DTM model. This model was roughly calibrated to match the available 500 year floodplain mapping and to bridge the gaps between incomplete geologic and floodplain mapping. In some areas, the extents of the modeled corridor were expanded to include adjacent transportation infrastructure that may be influencing corridor hydrodynamics.

The model was calibrated by comparing the resulting model extents to the existing 500-year floodplain mapping. Several model runs were used to adjust the scaling formula before the final inundation model was produced. The resulting corridor was then modified to include adjacent transportation infrastructure that may influence corridor hydrodynamics.

A.3. Corridor Assessment Methods

For each reach, each corridor alternative was assessed in terms of its inclusion of a series of mapping units that are relevant to geomorphic floodplain delineation. These map units include:

- Mapped 100-year Floodplain (COE)
- Mapped 500-year Floodplain (COE)
- Suitability for Wetland Plants (soils mapping: “good” or “fair” soil types)
- Hydric Soils (soils mapping)
- Flood Frequency (soils mapping: “frequent”, “occasional”, or “rare” soil types)
- GAP riparian mapping data

- Physical features inventory

A.4. Corridor Estimation/Calibration in Mapped Areas

For each corridor, a reach-based query was performed for the mapping units described above. It is important to note that the data gaps prevent the assessment of the entire river length, and as such, percentages are tallied with respect to "mapped" corridors (Table A2).

Table A2: Percent coverage of mapping units within four (mapped) corridor alternatives

Corridor	*Mapped 100-Yr Floodplain*	*Mapped 500-Yr Floodplain*	*Hydric Soils*	*Inventoried Physical Features (Points)*	*Inventoried Physical Features (Lengths)*	*Gap Count*	*Flood Frequency (Freq., Occas. or Rare from Soils)*
Qal	94	89	62	87	98	80	78
Qal (b)	96	91	65	98	99	84	80
Qat	98	97	87	97	99	92	92
VB	100	100	100	100	100	100	100
Inundation Model	97	97	85	100	100	90	89

The valley bottom corridor (Corridor VB) is one hundred percent inclusive of all of the mapping attributes (Table A2). This is by definition the case, as the map units beyond the valley bottom corridor boundary were clipped from the dataset to preclude inclusion of tributary map units.

Table A3 contains a breakdown of the total area associated with each corridor, and the relative percent of each corridor area to the original area estimate.

Table A3: Summary of evaluated corridor aerial extents, and anticipated savings relative to original estimate

	Orig Estimate	*New Estimate: Corridor Areas (square miles)*				
	(sq mi)	*Qal*	*Qal (b)*	*Qat*	*VB*	*IM*
Total	570	270	296	459	619	430
Savings (sq mi)	570	300	274	111	-49	140
Percent		53%	48%	20%	-9%	25%

Corridor Qal encompasses 53% less aerial coverage than the original estimate, however it excludes significant areal extents of mapped floodplain and floodplain-related soils attributes. Corridor Qal (b) represents a 48% reduction in aerial coverage required from original estimates, although map unit coverage for floodplain-related soils units is limited. Corridor Qat is largely inclusive of most floodplain-related map units. The only map units that are not at least 90% included are hydric soils and suitability for wetland plants. Approximately 20% less area is included in Qat than original corridor estimates.

The Inundation Model corridor boundary is inclusive of over 95% of mapped physical features and floodplain area. The lack of 100% coverage of floodplain area is primary due to the exclusion of mapped floodplain at tributary confluences. Soils and gap count data range from 82% to 90% coverage.

A.5. Extension of Inundation Models to Unmapped Areas

The comprehensive inclusion of floodplain related features within the inundation corridor in areas with relevant mapping indicates that the model effectively defines the active river corridor. The inundation corridor has thus been utilized to define the project area boundaries. When extended to the entire project reach, the inundation corridor coverage is on the order of 700 square miles, which, relative to the 900 mile estimate, represents a 23% reduction in project area and associated topographic data requirements.

Appendix B: GIS-Derived Summaries for 3 Mile Valley Segments

GIS Statistics, 3 Mile Valley Lengths: Valley Dimensions and Braiding Parameter

Segment Number	***Valley Mile***	***Valley Length (mi)***	***Inundation Corridor Area (sq mi)***	***Inundation Corridor Average Width (mi)***	***Valley Bottom Average Width (mi)***	***Total Channel Length (ft)***	***Main Channel Length (ft)***	***Braiding Parameter***
0	0	0.1	7.2			2211	1445	1.5
1	3	2.9	14.4	4.9	5.2	38608	16359	2.4
2	6	3.0	11.6	3.9	4.7	58130	18549	3.1
3	9	3.0	7.2	2.4	4.6	52721	18160	2.9
4	12	3.0	7.0	2.3	4.5	56837	18512	3.1
5	15	3.0	7.6	2.5	4.0	101206	34960	2.9
6	18	3.0	6.0	2.0	4.4	56414	20633	2.7
7	21	3.0	5.1	1.7	4.6	34261	18960	1.8
8	24	3.0	4.8	1.6	4.4	55593	19953	2.8
9	27	3.0	5.0	1.7	3.2	76295	19079	4.0
10	30	3.0	7.3	2.4	3.1	75236	20622	3.6
11	33	3.0	7.2	2.4	3.1	86669	23028	3.8
12	36	3.1	6.9	2.2	3.2	85343	21192	4.0
13	39	2.9	8.9	3.0	3.8	117528	23430	5.0
14	42	3.0	6.9	2.3	3.9	105753	17412	6.1
15	45	3.0	4.5	1.5	2.3	61222	18224	3.4
16	48	3.0	4.5	1.5	1.5	69661	21713	3.2
17	51	3.0	5.5	1.8	1.9	90403	20393	4.4
18	54	3.0	4.9	1.6	1.6	62943	18662	3.4
19	57	3.0	5.1	1.7	1.7	60278	17450	3.5
20	60	3.0	4.3	1.4	1.4	66744	20051	3.3
21	63	3.0	5.0	1.7	2.6	79945	26709	3.0
22	66	3.0	4.4	1.5	2.5	71292	17282	4.1
23	69	3.0	4.1	1.4	2.6	77985	18454	4.2
24	72	3.0	4.5	1.5	1.7	49119	16701	2.9
25	75	3.0	4.7	1.6	2.7	40699	17687	2.3
26	78	3.0	3.7	1.2	3.0	80599	16538	4.9
27	81	3.0	4.8	1.6	3.9	56820	16917	3.4

GIS Statistics, 3 Mile Valley Lengths: Valley Dimensions and Braiding Parameter

Segment Number	*Valley Mile*	*Valley Length (mi)*	*Inundation Corridor Area (sq mi)*	*Inundation Corridor Average Width (mi)*	*Valley Bottom Average Width (mi)*	*Total Channel Length (ft)*	*Main Channel Length (ft)*	*Braiding Parameter*
28	84	3.0	4.0	1.3	3.9	96895	19825	4.9
29	87	3.0	4.0	1.3	3.5	47982	19226	2.5
30	90	3.0	3.8	1.3	3.7	57983	20414	2.8
31	93	3.0	3.2	1.1	3.1	57555	17092	3.4
32	96	3.0	2.8	0.9	3.0	29133	16370	1.8
33	99	3.0	3.1	1.0	2.8	42505	19755	2.2
34	102	3.0	5.1	1.7	2.7	26743	19144	1.4
35	105	3.0	2.9	1.0	3.5	19682	18328	1.1
36	108	3.0	2.8	0.9	3.1	22007	15977	1.4
37	111	3.0	3.3	1.1	2.7	20281	18490	1.1
38	114	3.0	3.5	1.2	3.3	35525	17318	2.1
39	117	3.0	5.0	1.7	3.4	54394	31756	1.7
40	120	3.0	3.8	1.3	2.1	39712	18702	2.1
41	123	3.0	3.6	1.2	1.8	36208	16735	2.2
42	126	3.0	3.8	1.3	1.7	48485	21272	2.3
43	129	3.0	2.4	0.8	2.1	26834	16072	1.7
44	132	3.0	2.8	0.9	1.8	40836	17852	2.3
45	135	3.0	5.1	1.7	2.4	23309	17860	1.3
46	138	3.0	2.9	1.0	2.4	17624	15624	1.1
47	141	3.0	2.5	0.8	2.0	15525	15525	1.0
48	144	3.0	2.7	0.9	2.0	41776	16884	2.5
49	147	3.0	4.5	1.5	2.4	38573	19180	2.0
50	150	3.0	5.2	1.7	2.5	42084	16776	2.5
51	153	3.0	7.1	2.4	2.6	36077	16593	2.2
52	156	3.0	6.3	2.1	2.3	71639	20792	3.4
53	159	3.0	5.7	1.9	2.6	47006	16564	2.8
54	162	3.0	4.5	1.5	2.6	59371	21701	2.7
55	165	3.0	4.8	1.6	2.4	54339	17766	3.1

GIS Statistics, 3 Mile Valley Lengths: Valley Dimensions and Braiding Parameter

Segment Number	Valley Mile	Valley Length (mi)	Inundation Corridor Area (sq mi)	Inundation Corridor Average Width (mi)	Valley Bottom Average Width (mi)	Total Channel Length (ft)	Main Channel Length (ft)	Braiding Parameter
56	168	3.0	5.6	1.9	2.0	50780	19240	2.6
57	171	3.0	5.1	1.7	2.2	47796	17823	2.7
58	174	3.0	6.0	2.0	2.3	72161	20772	3.5
59	177	3.0	5.4	1.8	2.8	65974	19818	3.3
60	180	3.0	5.0	1.7	2.4	51963	19380	2.7
61	183	3.0	5.6	1.9	2.0	59371	19745	3.0
62	186	3.0	5.3	1.8	2.1	65207	21479	3.0
63	189	3.0	4.7	1.6	2.2	69078	23026	3.0
64	192	3.0	5.0	1.7	2.2	46711	14920	3.1
65	195	3.0	4.2	1.4	1.5	34238	16137	2.1
66	198	3.0	4.6	1.5	1.5	42526	18015	2.4
67	201	3.0	5.8	1.9	2.0	73158	17189	4.3
68	204	3.0	9.3	3.1	4.0	116828	25794	4.5
69	207	3.0	6.7	2.2	3.2	88531	23136	3.8
70	210	3.0	5.6	1.9	1.9	60419	17807	3.4
71	213	3.0	4.3	1.4	1.5	49136	17361	2.8
72	216	3.0	8.4	2.8	3.0	115098	20986	5.5
73	219	3.0	10.6	3.5	4.2	107954	33735	3.2
74	222	3.0	8.6	2.9	3.8	67964	23270	2.9
75	225	3.0	6.6	2.2	3.8	51242	18339	2.8
76	228	3.0	7.4	2.5	3.1	125370	34183	3.7
77	231	3.0	6.9	2.3	2.4	44974	14875	3.0
78	234	3.0	4.5	1.5	1.8	51327	15235	3.4
79	237	3.0	4.3	1.4	1.6	58190	19160	3.0
80	240	3.0	2.6	0.9	1.5	67161	15521	4.3
81	243	3.0	3.6	1.2	1.3	90360	17730	5.1
82	246	3.0	4.6	1.5	1.9	67682	16942	4.0
83	249	3.0	3.7	1.2	1.2	115705	18506	6.3

GIS Statistics, 3 Mile Valley Lengths: Valley Dimensions and Braiding Parameter

Segment Number	Valley Mile	Valley Length (mi)	Inundation Corridor Area (sq mi)	Inundation Corridor Average Width (mi)	Valley Bottom Average Width (mi)	Total Channel Length (ft)	Main Channel Length (ft)	Braiding Parameter
84	252	3.0	4.9	1.6	1.6	94221	15581	6.0
85	255	3.0	3.7	1.2	1.2	94062	19834	4.7
86	258	3.0	3.6	1.2	1.2	95714	18484	5.2
87	261	3.0	4.0	1.3	1.4	110589	16451	6.7
88	264	3.0	4.6	1.5	1.5	118967	18185	6.5
89	267	3.0	4.1	1.4	1.4	105521	19237	5.5
90	270	3.0	4.7	1.6	1.8	98268	17251	5.7
91	273	3.0	6.9	2.3	2.3	101978	18153	5.6
92	276	3.0	7.6	2.5	2.6	105370	19413	5.4
93	279	3.0	9.7	3.3	4.1	89090	19026	4.7
94	282	3.0	10.7	3.6	4.1	65118	18781	3.5
95	285	3.0	9.5	3.2	3.7	106525	19755	5.4
96	288	3.0	6.3	2.1	2.3	143406	21623	6.6
97	291	3.0	3.7	1.2	1.4	57350	15713	3.6
98	294	3.0	4.1	1.4	1.8	81941	16299	5.0
99	297	3.0	3.8	1.3	2.2	85801	18438	4.7
100	300	3.0	6.1	2.0	2.2	65020	22925	2.8
101	303	3.0	8.5	2.8	4.7	84291	17954	4.7
102	306	3.0	7.0	2.3	6.4	79818	19927	4.0
103	309	3.0	6.6	2.2	6.2	92126	18134	5.1
104	312	3.0	6.7	2.2	5.6	82435	18267	4.5
105	315	3.0	8.1	2.7	4.7	121368	20290	6.0
106	318	3.0	9.0	3.0	5.1	78879	18834	4.2
107	321	3.0	9.4	3.1	5.1	106257	19077	5.6
108	324	3.0	7.9	2.6	3.0	107197	20868	5.1
109	327	3.0	3.4	1.1	1.5	52819	17054	3.1
110	330	3.0	3.2	1.1	1.3	56698	17388	3.3
111	333	3.0	4.0	1.3	1.3	57945	17974	3.2

GIS Statistics, 3 Mile Valley Lengths: Valley Dimensions and Braiding Parameter

Segment Number	Valley Mile	Valley Length (mi)	Inundation Corridor Area (sq mi)	Inundation Corridor Average Width (mi)	Valley Bottom Average Width (mi)	Total Channel Length (ft)	Main Channel Length (ft)	Braiding Parameter
112	336	3.0	3.8	1.3	1.7	96300	18633	5.2
113	339	3.0	3.3	1.1	2.1	58833	17003	3.5
114	342	3.0	3.5	1.2	1.6	70462	16906	4.2
115	345	3.0	2.8	0.9	1.1	58841	18010	3.3
116	348	3.0	2.5	0.8	1.0	57492	15819	3.6
117	351	3.0	2.4	0.8	0.9	75673	18827	4.0
118	354	3.0	2.4	0.8	0.8	56859	17766	3.2
119	357	3.0	2.7	0.9	0.9	34725	16432	2.1
120	360	3.0	3.0	1.0	1.0	65313	17484	3.7
121	363	3.0	3.2	1.1	1.1	54742	17638	3.1
122	366	3.0	3.2	1.1	1.5	61088	18050	3.4
123	369	3.0	3.0	1.0	1.3	52752	18269	2.9
124	372	3.0	3.6	1.2	1.4	39041	16419	2.4
125	375	3.0	3.3	1.1	1.2	35502	17169	2.1
126	378	3.0	4.8	1.6	1.8	40666	18562	2.2
127	381	3.0	4.3	1.4	2.0	38290	19419	2.0
128	384	3.0	4.5	1.5	1.9	62237	19142	3.3
129	387	3.0	4.6	1.5	1.7	74067	20244	3.7
130	390	3.0	3.1	1.0	1.6	47988	17552	2.7
131	393	3.0	3.5	1.2	1.4	43494	17084	2.5
132	396	3.0	3.7	1.2	1.5	52448	17263	3.0
133	399	0.7	0.4	0.6	0.9	4231	2066	2.0

GIS Statistics, 3 Mile Valley Lengths: Bank Protection Extents from Physical Features Inventory

SEGMENT ID	*Valley Mile*	*Main Channel Length (mi)*	*Main Channel Bankline Length (mi)*	*Length Riprap (ft)*	*Length Ccrete (ft)*	*Length Other (ft)*	*Length Flow Dflctrs (ft)*	*Total Length Mapped Bank Prot*	*Pct Riprap*	*Pct Concrete*	*Pct Other*	*Percent Flow Dflctrs*	*Percent Total Bank Prot*
0	0	0.3	0.5	0	0	0	0	0	0%	0%	0%	0%	0%
1	3	3.1	6.2	0	0	0	0	0	0%	0%	0%	0%	0%
2	6	3.5	7.0	0	0	0	0	0	0%	0%	0%	0%	0%
3	9	3.4	6.9	0	0	0	0	0	0%	0%	0%	0%	0%
4	12	3.5	7.0	0	0	0	0	0	0%	0%	0%	0%	0%
5	15	6.6	13.2	0	0	0	0	0	0%	0%	0%	0%	0%
6	18	3.9	7.8	0	0	0	2230	2230	0%	0%	0%	5%	5%
7	21	3.6	7.2	1612	0	0	0	1612	4%	0%	0%	0%	4%
8	24	3.8	7.6	3975	1788	1006	1359	8128	10%	4%	3%	3%	20%
9	27	3.6	7.2	0	1540	1949	2532	6020	0%	4%	5%	7%	16%
10	30	3.9	7.8	171	0	286	1683	2140	0%	0%	1%	4%	5%
11	33	4.4	8.7	0	0	0	0	0	0%	0%	0%	0%	0%
12	36	4.0	8.0	424	1944	245	0	2613	1%	5%	1%	0%	6%
13	39	4.4	8.9	0	0	0	0	0	0%	0%	0%	0%	0%
14	42	3.3	6.6	0	0	0	0	0	0%	0%	0%	0%	0%
15	45	3.5	6.9	0	0	0	0	0	0%	0%	0%	0%	0%
16	48	4.1	8.2	0	1051	0	0	1051	0%	2%	0%	0%	2%
17	51	3.9	7.7	1174	0	0	0	1174	3%	0%	0%	0%	3%
18	54	3.5	7.1	0	0	0	0	0	0%	0%	0%	0%	0%
19	57	3.3	6.6	961	0	0	0	961	3%	0%	0%	0%	3%
20	60	3.8	7.6	2307	0	0	0	2307	6%	0%	0%	0%	6%
21	63	5.1	10.1	871	0	0	763	1634	2%	0%	0%	1%	3%
22	66	3.3	6.5	0	0	0	0	0	0%	0%	0%	0%	0%
23	69	3.5	7.0	0	0	0	0	0	0%	0%	0%	0%	0%
24	72	3.2	6.3	0	1532	0	0	1532	0%	5%	0%	0%	5%
25	75	3.3	6.7	4868	1049	0	431	6348	14%	3%	0%	1%	18%
26	78	3.1	6.3	0	0	0	0	0	0%	0%	0%	0%	0%

GIS Statistics, 3 Mile Valley Lengths: Bank Protection Extents from Physical Features Inventory

SEGMENT ID	*Valley Mile*	*Main Channel Length (mi)*	*Main Channel Bankline Length (mi)*	*Length Riprap (ft)*	*Length Ccrete (ft)*	*Length Other (ft)*	*Length Flow Dflctrs (ft)*	*Total Length Mapped Bank Prot*	*Pct Riprap*	*Pct Concrete*	*Pct Other*	*Percent Flow Dflctrs*	*Percent Total Bank Prot*
27	81	3.2	6.4	556	0	0	0	556	2%	0%	0%	0%	2%
28	84	3.8	7.5	0	0	0	0	0	0%	0%	0%	0%	0%
29	87	3.6	7.3	0	0	0	0	0	0%	0%	0%	0%	0%
30	90	3.9	7.7	0	0	0	0	0	0%	0%	0%	0%	0%
31	93	3.2	6.5	0	0	0	0	0	0%	0%	0%	0%	0%
32	96	3.1	6.2	0	0	0	0	0	0%	0%	0%	0%	0%
33	99	3.7	7.5	0	0	0	0	0	0%	0%	0%	0%	0%
34	102	3.6	7.3	2171	0	0	0	2171	6%	0%	0%	0%	6%
35	105	3.5	6.9	0	0	0	0	0	0%	0%	0%	0%	0%
36	108	3.0	6.1	0	0	0	0	0	0%	0%	0%	0%	0%
37	111	3.5	7.0	0	0	0	0	0	0%	0%	0%	0%	0%
38	114	3.3	6.6	0	0	0	0	0	0%	0%	0%	0%	0%
39	117	6.0	12.0	1196	0	0	0	1196	2%	0%	0%	0%	2%
40	120	3.5	7.1	0	0	0	0	0	0%	0%	0%	0%	0%
41	123	3.2	6.3	2379	0	0	0	2379	7%	0%	0%	0%	7%
42	126	4.0	8.1	1260	0	0	0	1260	3%	0%	0%	0%	3%
43	129	3.0	6.1	2620	0	0	0	2620	8%	0%	0%	0%	8%
44	132	3.4	6.8	1414	0	0	0	1414	4%	0%	0%	0%	4%
45	135	3.4	6.8	800	0	0	0	800	2%	0%	0%	0%	2%
46	138	3.0	5.9	1771	0	0	0	1771	6%	0%	0%	0%	6%
47	141	2.9	5.9	797	0	0	0	797	3%	0%	0%	0%	3%
48	144	3.2	6.4	0	0	0	0	0	0%	0%	0%	0%	0%
49	147	3.6	7.3	0	611	0	0	611	0%	2%	0%	0%	2%
50	150	3.2	6.4	4579	1789	0	0	6368	14%	5%	0%	0%	19%
51	153	3.1	6.3	296	2191	0	276	2763	1%	7%	0%	1%	8%
52	156	3.9	7.9	2954	0	0	1334	4288	7%	0%	0%	3%	10%
53	159	3.1	6.3	8072	0	151	0	8223	24%	0%	0%	0%	25%
54	162	4.1	8.2	5500	0	0	1762	7262	13%	0%	0%	4%	17%

GIS Statistics, 3 Mile Valley Lengths: Bank Protection Extents from Physical Features Inventory

SEGMENT ID	***Valley Mile***	***Main Channel Length (mi)***	***Main Channel Bankline Length (mi)***	***Length Riprap (ft)***	***Length Ccrete (ft)***	***Length Other (ft)***	***Length Flow Dflctrs (ft)***	***Total Length Mapped Bank Prot***	***Pct Riprap***	***Pct Concrete***	***Pct Other***	***Percent Flow Dflctrs***	***Percent Total Bank Prot***
55	165	3.4	6.7	4888	0	0	2424	7312	14%	0%	0%	7%	21%
56	168	3.6	7.3	4748	0	0	4537	9285	12%	0%	0%	12%	24%
57	171	3.4	6.8	6015	743	0	0	6759	17%	2%	0%	0%	19%
58	174	3.9	7.9	1451	0	1354	8421	11226	3%	0%	3%	20%	27%
59	177	3.8	7.5	8226	0	0	0	8226	21%	0%	0%	0%	21%
60	180	3.7	7.3	304	0	0	0	304	1%	0%	0%	0%	1%
61	183	3.7	7.5	1510	0	46	0	1556	4%	0%	0%	0%	4%
62	186	4.1	8.1	6352	0	0	0	6352	15%	0%	0%	0%	15%
63	189	4.4	8.7	8231	0	504	0	8736	18%	0%	1%	0%	19%
64	192	2.8	5.7	3027	0	0	0	3027	10%	0%	0%	0%	10%
65	195	3.1	6.1	8874	0	0	0	8874	27%	0%	0%	0%	27%
66	198	3.4	6.8	5881	0	0	1726	7607	16%	0%	0%	5%	21%
67	201	3.3	6.5	6474	0	0	953	7427	19%	0%	0%	3%	22%
68	204	4.9	9.8	804	0	0	0	804	2%	0%	0%	0%	2%
69	207	4.4	8.8	1805	0	0	0	1805	4%	0%	0%	0%	4%
70	210	3.4	6.7	3285	0	0	0	3285	9%	0%	0%	0%	9%
71	213	3.3	6.6	0	0	0	0	0	0%	0%	0%	0%	0%
72	216	4.0	7.9	1884	0	0	0	1884	4%	0%	0%	0%	4%
73	219	6.4	12.8	288	0	0	0	288	0%	0%	0%	0%	0%
74	222	4.4	8.8	2477	574	0	0	3051	5%	1%	0%	0%	7%
75	225	3.5	6.9	4345	0	0	0	4345	12%	0%	0%	0%	12%
76	228	6.5	12.9	10274	0	0	0	10274	15%	0%	0%	0%	15%
77	231	2.8	5.6	10179	0	0	0	10179	34%	0%	0%	0%	34%
78	234	2.9	5.8	14489	0	0	0	14489	48%	0%	0%	0%	48%
79	237	3.6	7.3	3601	0	702	0	4303	9%	0%	2%	0%	11%
80	240	2.9	5.9	1458	0	0	0	1458	5%	0%	0%	0%	5%
81	243	3.4	6.7	5666	0	0	0	5666	16%	0%	0%	0%	16%
82	246	3.2	6.4	3635	0	0	1169	4804	11%	0%	0%	3%	14%

GIS Statistics, 3 Mile Valley Lengths: Bank Protection Extents from Physical Features Inventory

SEGMENT ID	***Valley Mile***	***Main Channel Length (mi)***	***Main Channel Bankline Length (mi)***	***Length Riprap (ft)***	***Length Ccrete (ft)***	***Length Other (ft)***	***Length Flow Dflctrs (ft)***	***Total Length Mapped Bank Prot***	***Pct Riprap***	***Pct Concrete***	***Pct Other***	***Percent Flow Dflctrs***	***Percent Total Bank Prot***
83	249	3.5	7.0	1045	0	0	0	1045	3%	0%	0%	0%	3%
84	252	3.0	5.9	0	0	0	0	0	0%	0%	0%	0%	0%
85	255	3.8	7.5	1153	0	0	0	1153	3%	0%	0%	0%	3%
86	258	3.5	7.0	0	0	0	896	896	0%	0%	0%	2%	2%
87	261	3.1	6.2	6446	0	0	0	6446	20%	0%	0%	0%	20%
88	264	3.4	6.9	338	0	0	0	338	1%	0%	0%	0%	1%
89	267	3.6	7.3	2254	0	0	0	2254	6%	0%	0%	0%	6%
90	270	3.3	6.5	616	0	0	0	616	2%	0%	0%	0%	2%
91	273	3.4	6.9	0	0	0	0	0	0%	0%	0%	0%	0%
92	276	3.7	7.4	0	289	0	0	289	0%	1%	0%	0%	1%
93	279	3.6	7.2	0	2168	1465	0	3633	0%	6%	4%	0%	10%
94	282	3.6	7.1	0	0	0	0	0	0%	0%	0%	0%	0%
95	285	3.7	7.5	0	2754	0	609	3363	0%	7%	0%	2%	9%
96	288	4.1	8.2	2459	3823	0	2093	8374	6%	9%	0%	5%	19%
97	291	3.0	6.0	15642	8831	0	0	24472	50%	28%	0%	0%	78%
98	294	3.1	6.2	9241	0	0	2845	12086	28%	0%	0%	9%	37%
99	297	3.5	7.0	5026	592	192	1536	7347	14%	2%	1%	4%	20%
100	300	4.3	8.7	1499	17558	0	0	19057	3%	38%	0%	0%	42%
101	303	3.4	6.8	6389	11061	0	0	17450	18%	31%	0%	0%	49%
102	306	3.8	7.5	3145	8086	125	1885	13241	8%	20%	0%	5%	33%
103	309	3.4	6.9	3657	4941	212	0	8810	10%	14%	1%	0%	24%
104	312	3.5	6.9	2447	5278	418	3008	11150	7%	14%	1%	8%	31%
105	315	3.8	7.7	6590	6800	376	1466	15232	16%	17%	1%	4%	38%
106	318	3.6	7.1	1508	625	0	848	2980	4%	2%	0%	2%	8%
107	321	3.6	7.2	2154	1262	0	0	3416	6%	3%	0%	0%	9%
108	324	4.0	7.9	296	0	38	0	334	1%	0%	0%	0%	1%
109	327	3.2	6.5	2553	650	79	0	3282	7%	2%	0%	0%	10%
110	330	3.3	6.6	2369	0	0	0	2369	7%	0%	0%	0%	7%

GIS Statistics, 3 Mile Valley Lengths: Bank Protection Extents from Physical Features Inventory

SEGMENT ID	Valley Mile	Main Channel Length (mi)	Main Channel Bankline Length (mi)	Length Riprap (ft)	Length Ccrete (ft)	Length Other (ft)	Length Flow Dflctrs (ft)	Total Length Mapped Bank Prot	Pct Riprap	Pct Concrete	Pct Other	Percent Flow Dflctrs	Percent Total Bank Prot
111	333	3.4	6.8	1697	0	0	0	1697	5%	0%	0%	0%	5%
112	336	3.5	7.1	3927	0	0	0	3927	11%	0%	0%	0%	11%
113	339	3.2	6.4	7720	0	0	64	7783	23%	0%	0%	0%	23%
114	342	3.2	6.4	5233	2836	0	0	8069	15%	8%	0%	0%	24%
115	345	3.4	6.8	5161	0	0	178	5339	14%	0%	0%	0%	15%
116	348	3.0	6.0	828	0	0	0	828	3%	0%	0%	0%	3%
117	351	3.6	7.1	2835	0	0	575	3410	8%	0%	0%	2%	9%
118	354	3.4	6.7	7818	0	0	0	7818	22%	0%	0%	0%	22%
119	357	3.1	6.2	0	0	0	0	0	0%	0%	0%	0%	0%
120	360	3.3	6.6	6494	0	136	0	6630	19%	0%	0%	0%	19%
121	363	3.3	6.7	2620	0	0	0	2620	7%	0%	0%	0%	7%
122	366	3.4	6.8	2651	0	791	2837	6279	7%	0%	2%	8%	17%
123	369	3.5	6.9	3695	0	797	7	4498	10%	0%	2%	0%	12%
124	372	3.1	6.2	3860	0	0	0	3860	12%	0%	0%	0%	12%
125	375	3.3	6.5	1359	0	0	0	1359	4%	0%	0%	0%	4%
126	378	3.5	7.0	0	0	0	2123	2123	0%	0%	0%	6%	6%
127	381	3.7	7.4	1995	0	248	0	2243	5%	0%	1%	0%	6%
128	384	3.6	7.3	8257	0	0	1786	10043	22%	0%	0%	5%	26%
129	387	3.8	7.7	2796	0	0	0	2796	7%	0%	0%	0%	7%
130	390	3.3	6.6	3551	0	945	0	4496	10%	0%	3%	0%	13%
131	393	3.2	6.5	5687	0	0	0	5687	17%	0%	0%	0%	17%
132	396	3.3	6.5	5627	0	0	1367	6994	16%	0%	0%	4%	20%
133	399	0.4	0.8	923	0	0	1033	1957	22%	0%	0%	25%	47%

GIS Statistics, 3 Mile Valley Lengths: Channel Slope and Sinuosity

Segment ID	Valley Mile	Elevation Difference (ft)	Main Channel Length (ft)	Channel Slope (%)	Valley Length (ft)	Valley Slope (%)	Sinuosity
1	3	2.33	16359	0.01%	15495	0.02%	1.06
2	6	3.41	18549	0.02%	15843	0.02%	1.17
3	9	5.97	18160	0.03%	15845	0.04%	1.15
4	12	-0.03	18512	0.00%	15849	0.00%	1.17
5	15	4.99	34960	0.01%	15820	0.03%	2.21
6	18	4.07	20633	0.02%	15835	0.03%	1.30
7	21	8.04	18960	0.04%	15835	0.05%	1.20
8	24	7.38	19953	0.04%	15835	0.05%	1.26
9	27	4.00	19079	0.02%	15835	0.03%	1.20
10	30	9.58	20622	0.05%	15835	0.06%	1.30
11	33	7.31	23028	0.03%	15818	0.05%	1.46
12	36	11.18	21192	0.05%	16361	0.07%	1.30
13	39	13.51	23430	0.06%	15349	0.09%	1.53
14	42	4.92	17412	0.03%	15813	0.03%	1.10
15	45	17.22	18224	0.09%	15835	0.11%	1.15
16	48	8.43	21713	0.04%	15831	0.05%	1.37
17	51	9.87	20393	0.05%	15844	0.06%	1.29
18	54	13.87	18662	0.07%	15833	0.09%	1.18
19	57	11.78	17450	0.07%	15849	0.07%	1.10
20	60	3.08	20051	0.02%	15836	0.02%	1.27
21	63	8.66	26709	0.03%	15815	0.05%	1.69
22	66	15.88	17282	0.09%	15723	0.10%	1.10
23	69	1.90	18454	0.01%	15951	0.01%	1.16
24	72	16.47	16701	0.10%	15842	0.10%	1.05
25	75	6.30	17687	0.04%	15828	0.04%	1.12
26	78	3.05	16538	0.02%	15844	0.02%	1.04
27	81	22.17	16917	0.13%	15827	0.14%	1.07

GIS Statistics, 3 Mile Valley Lengths: Channel Slope and Sinuosity

Segment ID	Valley Mile	Elevation Difference (ft)	Main Channel Length (ft)	Channel Slope (%)	Valley Length (ft)	Valley Slope (%)	Sinuosity
28	84	6.46	19825	0.03%	15846	0.04%	1.25
29	87	13.09	19226	0.07%	15838	0.08%	1.21
30	90	9.18	20414	0.04%	15821	0.06%	1.29
31	93	9.64	17092	0.06%	15835	0.06%	1.08
32	96	8.66	16370	0.05%	15835	0.05%	1.03
33	99	11.74	19755	0.06%	15835	0.07%	1.25
34	102	12.86	19144	0.07%	15854	0.08%	1.21
35	105	4.56	18328	0.02%	15826	0.03%	1.16
36	108	9.54	15977	0.06%	15981	0.06%	1.00
37	111	12.27	18490	0.07%	15682	0.08%	1.18
38	114	14.10	17318	0.08%	15836	0.09%	1.09
39	117	11.45	31756	0.04%	15833	0.07%	2.01
40	120	10.59	18702	0.06%	15831	0.07%	1.18
41	123	11.32	16735	0.07%	15839	0.07%	1.06
42	126	14.40	21272	0.07%	15835	0.09%	1.34
43	129	-1.08	16072	-0.01%	15835	-0.01%	1.01
44	132	24.73	17852	0.14%	15835	0.16%	1.13
45	135	15.55	17860	0.09%	15849	0.10%	1.13
46	138	2.10	15624	0.01%	15821	0.01%	0.99
47	141	17.25	15525	0.11%	15824	0.11%	0.98
48	144	20.86	16884	0.12%	15831	0.13%	1.07
49	147	4.07	19180	0.02%	15850	0.03%	1.21
50	150	18.56	16776	0.11%	15835	0.12%	1.06
51	153	17.45	16593	0.11%	15838	0.11%	1.05
52	156	6.40	20792	0.03%	15851	0.04%	1.31
53	159	14.01	16564	0.08%	15781	0.09%	1.05
54	162	12.27	21701	0.06%	15871	0.08%	1.37
55	165	11.94	17766	0.07%	15866	0.08%	1.12

GIS Statistics, 3 Mile Valley Lengths: Channel Slope and Sinuosity

Segment ID	Valley Mile	Elevation Difference (ft)	Main Channel Length (ft)	Channel Slope (%)	Valley Length (ft)	Valley Slope (%)	Sinuosity
56	168	17.81	19240	0.09%	15822	0.11%	1.22
57	171	9.35	17823	0.05%	15817	0.06%	1.13
58	174	4.95	20772	0.02%	15834	0.03%	1.31
59	177	15.78	19818	0.08%	15849	0.10%	1.25
60	180	11.28	19380	0.06%	15828	0.07%	1.22
61	183	10.50	19745	0.05%	15836	0.07%	1.25
62	186	9.94	21479	0.05%	15857	0.06%	1.35
63	189	12.56	23026	0.05%	15807	0.08%	1.46
64	192	-1.97	14920	-0.01%	15831	-0.01%	0.94
65	195	16.63	16137	0.10%	15839	0.10%	1.02
66	198	16.60	18015	0.09%	15843	0.10%	1.14
67	201	14.69	17189	0.09%	15827	0.09%	1.09
68	204	8.40	25794	0.03%	15840	0.05%	1.63
69	207	4.30	23136	0.02%	15830	0.03%	1.46
70	210	18.56	17807	0.10%	15835	0.12%	1.12
71	213	13.97	17361	0.08%	15844	0.09%	1.10
72	216	9.48	20986	0.05%	15826	0.06%	1.33
73	219	18.63	33735	0.06%	15835	0.12%	2.13
74	222	10.99	23270	0.05%	15835	0.07%	1.47
75	225	15.78	18339	0.09%	15836	0.10%	1.16
76	228	9.35	34183	0.03%	15835	0.06%	2.16
77	231	19.32	14875	0.13%	15835	0.12%	0.94
78	234	4.92	15235	0.03%	15849	0.03%	0.96
79	237	-2.62	19160	-0.01%	15822	-0.02%	1.21
80	240	42.74	15521	0.28%	15850	0.27%	0.98
81	243	13.05	17730	0.07%	15869	0.08%	1.12
82	246	13.58	16942	0.08%	15787	0.09%	1.07
83	249	18.76	18506	0.10%	15923	0.12%	1.16

GIS Statistics, 3 Mile Valley Lengths: Channel Slope and Sinuosity

Segment ID	Valley Mile	Elevation Difference (ft)	Main Channel Length (ft)	Channel Slope (%)	Valley Length (ft)	Valley Slope (%)	Sinuosity
84	252	18.27	15581	0.12%	15748	0.12%	0.99
85	255	8.76	19834	0.04%	15835	0.06%	1.25
86	258	24.44	18484	0.13%	15851	0.15%	1.17
87	261	19.61	16451	0.12%	15810	0.12%	1.04
88	264	16.73	18185	0.09%	15844	0.11%	1.15
89	267	23.39	19237	0.12%	15835	0.15%	1.21
90	270	15.06	17251	0.09%	15849	0.09%	1.09
91	273	21.78	18153	0.12%	15822	0.14%	1.15
92	276	26.40	19413	0.14%	15837	0.17%	1.23
93	279	11.97	19026	0.06%	15834	0.08%	1.20
94	282	31.98	18781	0.17%	15833	0.20%	1.19
95	285	28.60	19755	0.14%	15836	0.18%	1.25
96	288	23.22	21623	0.11%	15835	0.15%	1.37
97	291	19.16	15713	0.12%	15843	0.12%	0.99
98	294	24.01	16299	0.15%	15885	0.15%	1.03
99	297	42.97	18438	0.23%	15777	0.27%	1.17
100	300	23.39	22925	0.10%	15835	0.15%	1.45
101	303	30.73	17954	0.17%	15852	0.19%	1.13
102	306	29.65	19927	0.15%	15818	0.19%	1.26
103	309	28.86	18134	0.16%	15835	0.18%	1.15
104	312	42.94	18267	0.24%	15835	0.27%	1.15
105	315	26.86	20290	0.13%	15832	0.17%	1.28
106	318	34.96	18834	0.19%	15835	0.22%	1.19
107	321	38.87	19077	0.20%	15838	0.25%	1.20
108	324	34.83	20868	0.17%	15835	0.22%	1.32
109	327	32.77	17054	0.19%	15795	0.21%	1.08
110	330	33.39	17388	0.19%	15876	0.21%	1.10
111	333	37.69	17974	0.21%	15834	0.24%	1.14

GIS Statistics, 3 Mile Valley Lengths: Channel Slope and Sinuosity

Segment ID	Valley Mile	Elevation Difference (ft)	Main Channel Length (ft)	Channel Slope (%)	Valley Length (ft)	Valley Slope (%)	Sinuosity
112	336	35.62	18633	0.19%	15816	0.23%	1.18
113	339	36.44	17003	0.21%	15866	0.23%	1.07
114	342	35.03	16906	0.21%	15848	0.22%	1.07
115	345	24.63	18010	0.14%	15798	0.16%	1.14
116	348	34.14	15819	0.22%	15879	0.22%	1.00
117	351	19.29	18827	0.10%	15736	0.12%	1.20
118	354	31.52	17766	0.18%	15949	0.20%	1.11
119	357	36.05	16432	0.22%	15787	0.23%	1.04
120	360	31.75	17484	0.18%	15837	0.20%	1.10
121	363	23.71	17638	0.13%	15869	0.15%	1.11
122	366	49.92	18050	0.28%	15802	0.32%	1.14
123	369	26.31	18269	0.14%	15834	0.17%	1.15
124	372	38.08	16419	0.23%	15835	0.24%	1.04
125	375	37.82	17169	0.22%	15823	0.24%	1.09
126	378	36.80	18562	0.20%	15808	0.23%	1.17
127	381	43.85	19419	0.23%	15875	0.28%	1.22
128	384	32.60	19142	0.17%	15834	0.21%	1.21
129	387	33.39	20244	0.16%	15829	0.21%	1.28
130	390	41.52	17552	0.24%	15841	0.26%	1.11
131	393	42.02	17084	0.25%	15837	0.27%	1.08

Appendix C: GIS-Derived Summaries of Geomorphic Parameters by Reach

Reach ID (Selected Highlighted)	Length (mi)	Downstream River Mile	Upstream River Mile	County	Corridor Area (sq miles)	Corridor Width (miles)	Classification	All Channels Length (ft)	Primary Channel Length (ft)	Secondary Channels Length (ft)	Overflow Channels Length (ft)	Anabr Channels Length (ft)	Approx Channel Slope	Braiding Parameter	Woody Veg (acres per mile)
A1	3.0	474.0	477.0	Sweetgrass	3.8	1.2	PCB: Partially confined braided	53143	17606	14985	20552	0		1.85	na
A2	7.7	466.3	474.0	Sweetgrass	8.1	1.1	UB: Unconfined braided	108739	40772	42705	19872	4195	0.22%	2.05	na
A3	4.8	461.5	466.3	Sweetgrass	5.9	1.6	PCB: Partially confined braided	90471	24373	27741	29426	8932	0.22%	2.14	na
A4	3.0	458.5	461.5	Sweetgrass	3.6	1.5	UB: Unconfined braided	40219	16898	10731	12590	0	0.14%	1.64	na
A5	3.5	455.0	458.5	Sweetgrass	4.1	1.6	UB: Unconfined braided	37247	17873	17488	1886	0	0.24%	1.98	na
A6	3.3	451.7	455.0	Sweetgrass	4.4	1.4	PCS: Partially confined straight	40213	17773	15926	6514	0	0.20%	1.90	na
A7	9.7	442.0	451.7	Sweetgrass	9.8	1.1	PCB: Partially confined braided	130820	51142	42303	37375	0	0.20%	1.83	na
A8	5.0	437.0	442.0	Sweetgrass	5.0	1.1	PCB: Partially confined braided	82406	26452	38696	17258	0	0.19%	2.46	na
A9	2.5	434.5	437.0	Sweetgrass Stillwater	2.2	1.0	UA: Unconfined anabranching	64137	13169	24627	13964	12378	0.20%	2.87	na
A10	5.0	429.5	434.5	Stillwater	4.2	0.9	PCS: Partially confined straight	54737	26173	15488	10524	2552	0.20%	1.59	na
A11	7.5	422.0	429.5	Stillwater	5.6	1.1	PCB: Partially confined braided	151297	39612	53710	52965	5010	0.14%	2.36	na
A12	6.0	416.0	422.0	Stillwater	5.0	1.1	PCB: Partially confined braided	100783	31762	39832	29189	0	0.18%	2.25	na
A13	3.0	413.0	416.0	Stillwater	3.1	1.2	PCA: Partly confined anabranching	67093	15712	27950	17791	5641	0.23%	2.78	na
A14	7.0	406.0	413.0	Stillwater	7.5	1.4	PCA: Partly confined anabranching	161725	37572	55429	64376	4349	0.21%	2.48	na
A15	6.5	399.5	406.0	Stillwater, Carbon	6.8	1.3	PCB: Partially confined braided	108637	33839	32620	30529	11649	0.21%	1.96	na
A16	9.2	390.3	399.5	Stillwater, Carbon	17.7	2.1	PCA: Partly confined anabranching	231784	48923	76137	84683	22041	0.16%	2.56	na
A17	4.6	385.7	390.3	Yellowstone Carbon	11.0	1.7	UA: Unconfined anabranching	105070	25300	26234	37185	16351	0.22%	2.04	112.57
A18	3.3	382.4	385.7	Yellowstone	7.9	3.2	UA: Unconfined anabranching	101615	16446	15407	59592	10170	0.16%	1.94	211.16

Reach ID (Selected Highlighted)	Length (mi)	Downstream River Mile	Upstream River Mile	County	Corridor Area (sq miles)	Corridor Width (miles)	Classification	*All Channels Length (ft)*	*Primary Channel Length (ft)*	*Secondary Channels Length (ft)*	*Overflow Channels Length (ft)*	*Anabr Channels Length (ft)*	*Approx Channel Slope*	*Braiding Parameter*	*Woody Veg (acres per mile)*
B1	15.4	367.0	382.4	Yellowstone	32.4	9.6	UB: Unconfined braided	370267	81213	67391	207594	14069	0.22%	1.83	146.08
B2	7.0	360.0	367.0	Yellowstone	9.3	1.7	PCB: Partially confined braided	128102	36854	47759	43489	0	0.16%	2.30	81.71
B3	3.0	357.0	360.0	Yellowstone	3.8	1.4	UB: Unconfined braided	89776	15783	15108	58886	0	0.15%	1.96	216.43
B4	4.1	352.9	357.0	Yellowstone	5.1	1.3	PCS: Partially confined straight	76666	21729	5211	49726	0	0.14%	1.24	95.64
B5	7.9	345.0	352.9	Yellowstone	15.3	2.7	UA: Unconfined anabranching	248406	41695	53123	135744	17844	0.12%	2.27	169.49
B6	5.3	339.7	345.0	Yellowstone	16.6	3.2	PCB: Partially confined braided	116166	27958	13015	65934	9259	0.14%	1.47	104.04
B7	9.2	330.5	339.7	Yellowstone	19.2	2.5	UB: Unconfined braided	248377	48258	56624	107691	35803	0.11%	2.17	125.15
B8	9.0	321.5	330.5	Yellowstone	11.8	1.6	PCA: Partly confined anabranching	282380	48087	42513	142862	48918	0.10%	1.88	144.26
B9	4.7	316.8	321.5	Yellowstone	5.2	1.4	UA: Unconfined anabranching	155243	24901	41253	66530	22559	0.11%	2.66	141.36
B10	7.0	309.8	316.8	Yellowstone	7.6	1.2	PCM: Partially confined meandering	185369	36988	33677	104845	9859	0.14%	1.91	142.01
B11	8.3	301.5	309.8	Yellowstone	10.3	1.4	PCA: Partly confined anabranching	242295	43279	59896	108433	30688	0.05%	2.38	135.13
B12	4.5	297	301.5	Yellowstone	5.6	1.4	UA: Unconfined anabranching	118006	23484	28528	45685	20310	0.11%	2.21	157.09

Reach ID (Selected Highlighted)	Length (mi)	Downstream River Mile	Upstream River Mile	County	Corridor Area (sq miles)	Corridor Width (miles)	Classification	All Channels Length (ft)	Primary Channel Length (ft)	Secondary Channels Length (ft)	Overflow Channels Length (ft)	Anabr Channels Length (ft)	Approx Channel Slope	Braiding Parameter	Woody Veg (acres per mile)
C1	6.0	291.0	297.0	Treasure	6.1	1.4	UA: Unconfined anabranching	107460	32131	15835	33215	26278	0.09%	1.49	139.36
C2	4.0	287.0	291.0	Treasure	8.0	1.8	PCB: Partially confined braided	75160	20783	26655	27722	0	0.11%	2.28	157.81
C3	7.0	280.0	287.0	Treasure	10.4	2.0	UA: Unconfined anabranching	144795	37017	32501	47844	27433	0.05%	1.88	222.52
C4	2.9	277.1	280.0	Treasure	4.0	2.5	PCB: Partially confined braided	42975	15395	6724	14891	5965	0.04%	1.44	160.16
C5	3.3	273.8	277.1	Treasure	7.1	3.6	PCS: Partially confined straight	43978	17661	19791	6526	0	0.06%	2.12	111.53
C6	5.8	268.0	273.8	Treasure	9.4	2.9	UA: Unconfined anabranching	90244	30666	19630	18664	21283	0.03%	1.64	235.77
C7	9.0	259.0	268.0	Treasure	16.8	2.9	UA: Unconfined anabranching	201025	47346	69277	20788	63614	0.07%	2.46	325.15
C8	6.5	252.5	259.0	Treasure Rosebud	9.8	1.7	PCS: Partially confined straight	104648	33791	34638	21877	14343	0.05%	2.03	121.67
C9	10.6	241.9	252.5	Rosebud	19.4	2.6	UA: Unconfined anabranching	258469	56195	31676	68535	102063	0.05%	1.56	326.66
C10	6.9	235.0	241.9	Rosebud	8.9	1.5	PCM: Partially confined meandering	78951	36466	28057	14428	0	0.05%	1.77	209.89
C11	11.0	224.0	235.0	Rosebud	14.8	1.6	PCM/I: Partly confined meandering/islands	173210	58056	66074	28034	21045	0.06%	2.14	177.59
C12	10.0	214.0	224.0	Rosebud	14.1	1.8	PCM/I: Partly confined meandering/islands	155645	52868	49377	53400	0	0.06%	1.93	129.98
C13	7.0	207.0	214.0	Rosebud	11.0	2.1	PCM/I: Partly confined meandering/islands	119844	37103	42199	40541	0	0.05%	2.14	185.79
C14	12.1	194.9	207.0	Rosebud Custer	16.1	1.7	PCM/I: Partly confined meandering/islands	178432	63978	67714	36895	9845	0.07%	2.06	141.80
C15	3.9	191.0	194.9	Custer	6.3	2.0	PCS: Partially confined straight	43641	20200	20545	2896	0	0.06%	2.02	73.30
C16	6.0	185.0	191.0	Custer	10.3	2.1	PCM/I: Partly confined meandering/islands	110507	31739	70229	8539	0	0.06%	3.21	153.34
C17	5.0	180.0	185.0	Custer	10.0	2.3	PCS: Partially confined straight	62155	26645	21576	6903	7032	0.06%	1.81	79.38
C18	4.0	176.0	180.0	Custer	4.8	1.5	PCS: Partially confined straight	44835	21026	16901	4661	2247	0.11%	1.80	77.77
C19	11.0	165.0	176.0	Custer	12.0	1.5	CM/S: Confined straight	86881	58045	28836	0	0	0.10%	1.50	68.62
C20	8.2	156.8	165.0	Custer Prairie	7.1	3.2	CM/S: Confined straight	81711	43544	34511	3657	0	0.04%	1.79	49.35
C21	8.8	148.0	156.8	Custer Prairie	9.3	1.2	CM: Confined meandering	104188	46362	50126	7701	0	0.08%	2.08	39.40

Reach ID (Selected Highlighted)	Length (mi)	Downstream River Mile	Upstream River Mile	County	Corridor Area (sq miles)	Corridor Width (miles)	Classification	All Channels Length (ft)	Primary Channel Length (ft)	Secondary Channels Length (ft)	Overflow Channels Length (ft)	Anabr Channels Length (ft)	Approx Channel Slope	Braiding Parameter	Woody Veg (acres per mile)
D1	12.2	135.8	148.0	Prairie	11.4	3.8	CM: Confined meandering	113319	63897	49422	0	0	0.05%	1.77	18.26
D2	10.5	125.3	135.8	Prairie	10.4	3.2	CM: Confined meandering	66383	55903	10479	0	0	0.05%	1.19	18.34
D3	8.3	117.0	125.3	Prairie Dawson	8.2	2.4	PCS: Partially confined straight	82643	43732	26787	4910	7213	0.04%	1.61	73.71
D4	11.1	105.9	117.0	Dawson	11.5	2.4	PCM/I: Partly confined meandering/islands	158454	58311	72100	13321	14721	0.06%	2.24	73.54
D5	11.2	94.7	105.9	Dawson	13.8	3.9	PCA: Partly confined anabranching	238331	60057	65789	34126	78358	0.06%	2.10	208.63
D6	5.7	89.0	94.7	Dawson	8.3	1.6	PCM/I: Partly confined meandering/islands	72211	29188	38150	4874	0	0.04%	2.31	124.38
D7	5.4	83.6	89.0	Dawson	6.5	1.5	PCA: Partly confined anabranching	117770	28909	49360	30573	8928	0.06%	2.71	138.46
D8	10.6	73.0	83.6	Dawson	11.7	1.7	PCA: Partly confined anabranching	184819	55299	69492	33424	26603	0.05%	2.26	228.28
D9	6.0	67.0	73.0	Dawson	8.9	1.7	PCM/I: Partly confined meandering/islands	103610	32207	29644	30752	11007	0.05%	1.92	239.99
D10	10.7	56.3	67.0	Dawson Wibaux Richland	13.6	1.7	PCA: Partly confined anabranching	202830	56403	92458	26912	27057	0.04%	2.64	228.05
D11	6.3	50.0	56.3	Richland	12.0	2.5	PCA: Partly confined anabranching	173793	33260	43185	49323	48025	0.06%	2.30	531.39
D12	15.0	35.0	50.0	Richland	28.6	2.5	PCA: Partly confined anabranching	274224	78808	88635	42464	64317	0.04%	2.12	299.33
D13	11.2	23.8	35.0	Richland	16.8	2.5	PCM/I: Partly confined meandering/islands	141381	59121	66221	11032	5006	0.03%	2.12	173.06
D14	8.8	15.0	23.8	Richland, Mckenzie	12.3	4.3	PCM/I: Partly confined meandering/islands	123247	46129	64955	0	12164	0.01%	2.41	45.54
D15	8.3	6.7	15.0	Mckenzie	15.7	5.1	PCM/I: Partly confined meandering/islands	123270	44230	79040	0	0	0.04%	2.79	na
D16	6.7	0.0	6.7	Mckenzie	26.8	6.4	US/I: Unconfined straight/islands	91847	35393	56454	0	0	0.03%	2.60	1.20

Appendix D: GIS-Derived Summaries of Physical Features by Reach

Reach	Length (mi)	Downstream River Mile	Upstream River Mile	Intakes	Headgates	Irrig Pumps	Disch Pts	Dike/ Levee (ft)	Rock Rip-rap (ft)	Flow Dflctrs (ft)	Concrete Rip-rap (ft)	Other Erosion Control (ft)	Transp Encroach (ft)	Irrigation Point Features per Mile	Percent Diked/ Leveed	Percent Erosion Control	Percent Transp Encroach
A1	3.00	474.0	477.0	0	1	1	3	331	5159	2400	0	0	6843	1.5	2%	21%	19%
A2	7.70	466.3	474.0	0	0	1	15	1169	10630	0	0	945	12331	2.1	3%	14%	15%
A3	4.80	461.5	466.3	0	0	2	3	1948	5487	0	0	0	0	1.1	8%	11%	0%
A4	3.00	458.5	461.5	0	0	1	4	986	6294	1786	0	0	429	1.6	6%	24%	1%
A5	3.50	455.0	458.5	0	0	2	5	0	1266	0	0	248	0	2.1	0%	4%	0%
A6	3.30	451.7	455.0	0	0	1	4	0	0	2123	0	0	9653	1.5	0%	6%	27%
A7	9.70	442.0	451.7	0	1	4	12	0	8914	1294	0	1588	8232	1.8	0%	12%	8%
A8	5.00	437.0	442.0	0	1	2	2	1852	3695	1549	0	0	15627	1.0	7%	10%	30%
A9	2.50	434.5	437.0	0	1	0	1	0	2042	0	0	0	1835	0.8	0%	8%	7%
A10	5.00	429.5	434.5	0	1	3	2	0	6029	0	0	136	5171	1.2	0%	12%	10%
A11	7.50	422.0	429.5	0	1	1	2	2718	10654	575	0	0	16957	0.5	7%	14%	21%
A12	6.00	416.0	422.0	0	0	0	4	0	6131	178	0	0	10427	0.7	0%	10%	16%
A13	3.00	413.0	416.0	0	0	1	4	0	5090	0	2836	0	0	1.7	0%	25%	0%
A14	7.00	406.0	413.0	0	1	0	6	230	11647	64	0	0	1605	1.0	1%	16%	2%
A15	6.50	399.5	406.0	0	1	1	7	1552	4066	0	0	0	0	1.4	5%	6%	0%
A16	9.20	390.3	399.5	0	1	2	4	0	5003	0	650	117	0	0.8	0%	6%	0%
A17	4.60	385.7	390.3	0	1	3	4	1433	1133	848	1887	0	0	1.7	6%	8%	0%
A18	3.30	382.4	385.7	1	1	0	5	0	6131	1466	4834	190	0	2.2	0%	38%	0%

Reach	Length (mi)	Downstream River Mile	Upstream River Mile	*Intakes*	*Head-gates*	*Irrig Pumps*	*Disch Pts*	*Dike/ Levee (ft)*	*Rock Rip-rap (ft)*	*Flow Dflctrs (ft)*	*Concrete Rip-rap (ft)*	*Other Erosion Control (ft)*	*Transp Encroach (ft)*	*Irrigation Point Features per Mile*	*Percent Diked/ Leveed*	*Percent Erosion Control*	*Percent Transp Encroach*
B1	15.40	367.0	382.4	2	2	4	18	24508	16977	4893	31611	942	3900	1.7	30%	34%	2%
B2	7.00	360.0	367.0	6	0	0	3	8210	6020	1536	17278	192	0	1.3	22%	34%	0%
B3	3.00	357.0	360.0	0	1	1	5	4059	5344	1493	592	0	5173	2.3	26%	24%	16%
B4	4.10	352.9	357.0	0	2	0	5	8974	21125	1352	8831	0	4143	1.7	41%	72%	10%
B5	7.90	345.0	352.9	0	0	0	17	2054	872	2702	6577	0	3013	2.2	5%	12%	4%
B6	5.30	339.7	345.0	0	0	1	7	0	0	0	2168	1465	0	1.5	0%	6%	0%
B7	9.20	330.5	339.7	0	0	1	12	0	0	0	289	0	0	1.4	0%	0%	0%
B8	9.00	321.5	330.5	0	0	1	15	0	3208	0	0	0	13953	1.8	0%	3%	15%
B9	4.70	316.8	321.5	0	1	2	5	0	6446	750	0	0	1747	1.7	0%	14%	4%
B10	7.00	309.8	316.8	0	0	0	6	0	1153	145	0	0	6437	0.9	0%	2%	9%
B11	8.30	301.5	309.8	0	0	4	9	0	2570	1169	0	0	0	1.6	0%	4%	0%
B12	4.50	297	301.5	0	0	1	3	0	7312	0	0	0	15220	0.9	0%	16%	32%

Reach	Length (mi)	Downstream River Mile	Upstream River Mile	Intakes	Head-gates	Irrig Pumps	Disch Pts	Dike/ Levee (ft)	Rock Rip-rap (ft)	Flow Dflctrs (ft)	Concrete Rip-rap (ft)	Other Erosion Control (ft)	Transp Encroach (ft)	Irrigation Point Features per Mile	Percent Diked/ Leveed	Percent Erosion Control	Percent Transp Encroach
C1	6.00	291.0	297.0	0	2	1	4	9035	2696	0	0	0	416	1.2	28%	4%	1%
C2	4.00	287.0	291.0	0	0	1	2	1370	19629	0	0	702	0	0.8	7%	49%	0%
C3	7.00	280.0	287.0	0	2	3	8	17570	18140	0	0	0	13215	1.9	47%	25%	18%
C4	2.90	277.1	280.0	0	0	1	4	0	4345	0	0	0	0	1.7	0%	14%	0%
C5	3.30	273.8	277.1	1	0	0	3	138	0	0	0	0	0	1.2	1%	0%	0%
C6	5.80	268.0	273.8	0	1	4	4	3983	2477	0	574	0	0	1.5	13%	5%	0%
C7	9.00	259.0	268.0	0	0	2	5	429	2172	0	0	0	0	0.8	1%	2%	0%
C8	6.50	252.5	259.0	0	0	3	5	1447	3285	0	0	0	0	1.3	4%	5%	0%
C9	10.60	241.9	252.5	0	0	5	13	3363	5854	953	0	0	0	1.7	6%	6%	0%
C10	6.90	235.0	241.9	0	1	2	5	4859	14234	1726	0	0	0	1.2	13%	22%	0%
C11	11.00	224.0	235.0	0	0	3	8	2699	20499	0	0	504	9832	1.0	5%	18%	8%
C12	10.00	214.0	224.0	0	0	3	10	0	2676	0	0	46	20669	1.3	0%	3%	20%
C13	7.00	207.0	214.0	0	0	3	8	0	13920	8421	743	1354	669	1.6	0%	33%	1%
C14	12.10	194.9	207.0	0	1	8	11	14804	13180	8724	0	0	4432	1.7	23%	17%	3%
C15	3.90	191.0	194.9	0	0	2	2	0	8265	0	0	151	20484	1.0	0%	21%	51%
C16	6.00	185.0	191.0	0	0	1	2	0	6785	1609	0	0	9296	0.5	0%	13%	15%
C17	5.00	180.0	185.0	1	0	3	3	24053	4579	0	3980	0	1754	1.4	90%	16%	3%
C18	4.00	176.0	180.0	0	0	0	4	0	0	0	611	0	0	1.0	0%	1%	0%
C19	11.00	165.0	176.0	0	0	3	14	0	2568	0	0	0	0	1.5	0%	2%	0%
C20	8.20	156.8	165.0	0	0	3	10	0	6094	0	0	0	0	1.6	0%	7%	0%
C21	8.80	148.0	156.8	0	0	3	8	0	2379	0	0	0	0	1.3	0%	3%	0%

Reach	Length (mi)	Downstream River Mile	Upstream River Mile	Intakes	Head-gates	Irrig Pumps	Disch Pts	Dike/ Levee (ft)	Rock Rip-rap (ft)	Flow Dflctrs (ft)	Concrete Rip-rap (ft)	Other Erosion Control (ft)	Transp Encroach (ft)	Irrigation Point Features per Mile	Percent Diked/ Leveed	Percent Erosion Control	Percent Transp Encroach
D1	12.20	135.8	148.0	0	0	3	3	4288	1196	0	0	0	0	0.5	7%	1%	0%
D2	10.50	125.3	135.8	0	0	6	4	1278	889	0	0	0	0	0.9	2%	1%	0%
D3	8.30	117.0	125.3	0	0	1	7	0	1282	0	0	0	0	1.0	0%	1%	0%
D4	11.10	105.9	117.0	0	0	5	5	0	0	0	0	0	0	0.9	0%	0%	0%
D5	11.20	94.7	105.9	0	0	8	11	3545	3770	0	1049	0	2814	1.7	6%	4%	2%
D6	5.70	89.0	94.7	0	0	7	1	7740	1654	431	1532	0	0	1.4	27%	6%	0%
D7	5.40	83.6	89.0	0	0	9	1	0	0	0	0	0	0	1.8	0%	0%	0%
D8	10.60	73.0	83.6	0	0	7	0	519	3178	763	0	0	0	0.7	1%	4%	0%
D9	6.00	67.0	73.0	0	1	2	1	0	961	0	0	0	0	0.7	0%	1%	0%
D10	10.70	56.3	67.0	0	0	4	4	0	1174	0	1051	0	0	0.7	0%	2%	0%
D11	6.30	50.0	56.3	0	0	2	7	0	0	0	0	0	0	1.4	0%	0%	0%
D12	15.00	35.0	50.0	0	0	6	11	350	595	1683	1944	531	0	1.1	0%	3%	0%
D13	11.20	23.8	35.0	2	0	5	12	0	5588	3890	3328	2956	0	1.7	0%	13%	0%
D14	8.80	15.0	23.8	0	0	4	7	0	0	2230	0	0	0	1.3	0%	2%	0%
D15	8.30	6.7	15.0	0	0	0	0	0	0	0	0	0	0	0.0	0%	0%	0%
D16	6.70	0.0	6.7	0	0	1	0	0	0	0	0	0	0	0.1	0%	0%	0%

Appendix E: Aerial Imagery Inventory

Aerial imagery will play an important role across many disciplines when developing the Cumulative Effects Investigation. As such, a thorough review and assessment of available imagery sources for the study area was completed. The ultimate goal of this process was to identify the sources, availability and condition of all current and historic aerial photography sources. This inventory will likely be used to select two image sets that will be scanned and georeferenced for use in the GIS.

A variety of agencies, universities, and private entities were identified as possible sources for aerial photography and were contacted in an effort to identify all historic aerial photography. The result of this search includes information on availability of photos, photo dates, river corridor coverage, and acquisition costs as of the study completion date of February 2004.

In order to identify typical channel features such as bank armoring on aerial photography, imagery at a scale of close to 1:20,000 is required. Regardless of the original acquisition scale, each photograph can generally be enlarged to represent a scale of 1:20,000, or scanned at a higher resolution in order to capture greater detail in the image. As such, it would be more cost-effective to acquire, handle, scan, and store 9"x9" black and white prints at a scale of 1:40,000 and scan them at high resolution, rather than the 18x18 1:20,000 scale images. The loss of detail in the resulting scans should be negligible.

E.1. Imagery Sources

The following sources were contacted while researching available imagery for the Lower Yellowstone River corridor.

- USDA Aerial Photography Field Office (APFO) Salt Lake City, UT Archives
- USGS EROS Data Center, SD
- National Archives and Records Administration (NARA) in Washington, DC
- Conservation District offices along the Lower Yellowstone River, MT and ND
- Fairchild Collection at Whittier College, CA
- Montana Department of Transportation, Helena
- Fairchild and Teledyne Collections at UC Santa Barbara, CA
- Montana Bureau of Mines and Geology, Butte
- US Bureau of Reclamation, Billings, MT

E.2. Availability

Table 1 represents the results of the data search by year and by county. Because the aerial photography missions are generally flown by county, a single series is likely to span two or more years in order to cover the entire study area. As such, it may be necessary to acquire images from more than one source to ensure complete coverage. This is especially true for older photography where an individual source may have incomplete coverage. Most archives require that you purchase index maps to determine the specific photos to order. For newer flights, these indexes are either on-line, or have been provided by the archiving agency.

A general description of each agency's holdings is provided below. Costs for the various indexes and products are provided in the following section.

The **USDA Aerial Photography Field Office (APFO) Salt Lake City Archives** provided hard copy indexes for the years 1980, 1991 and 1996 for the Lower Yellowstone River corridor. These are available at DTM. Indexes for datasets from 1957-58, 1962, 1967-68, and 1978-80 have been identified and can be purchased. Specific photo numbers must be identified from the index and ordered individually.

The **USGS EROS Data Center** houses data from the National Aerial Photography Program (NAPP), National High Altitude Photography (NHAP), Survey Photography, and Index Mapping. The NAPP photography dates from 1987 to the present, the NHAP photography covers 1980-1989, the survey photography dates from 1952-1988, and the index mapping spans the years 1946-1979. The survey photography is the most incomplete as it includes photography acquired by various agencies as needed for specific projects. The index mapping includes photographs that must first be identified from a photo-mosaic index. The most recent NAPP photography (around 1995) was used to create the current Montana DOQQ's. Individual photos from any of these programs can be searched on-line at the USGS EROS Earth Explorer web site. Additionally, DTM has created a GIS Shapefile indicating the extents of each index map for the Survey Photography, as well as individual photo extents for the NAPP and NHAP series.

The **National Archives and Records Administration (NARA) in Washington, DC** is the primary source for aerial photography for the Lower Yellowstone River corridor dating from 1937-1945. However, coverage for this time period appears to be incomplete. Indexes must be ordered from one of several private vendors prior to determining the number of photos required. While this is a fairly expensive source, it is the only source for the earliest photography.

Completing an inventory of local imagery sources involved visiting each of the **Conservation District offices** along the Lower Yellowstone River and physically inventorying the aerial photographs each office has in-house. To maximize efficiency, each office was notified prior to the visit and requested to gather any datasets that had been loaned or distributed to other agencies. In general, each Conservation District (CD) maintains a complete set of most current imagery in 24"x24" format, along with a digital set of DOQQ's. Some CD's, or the co-located FSA offices, archive earlier sets of imagery, though this is variable. As a general rule, the available photography contains extensive marking and writing. While these marks tend not to interfere with viewing the river corridor, the size of the images make scanning more costly and cumbersome. Information for the CD collections is compiled in a Microsoft Access database.

The **Fairchild Collection at Whittier College** houses a few photos from the mid-1940s of the Clarks Fork of the Yellowstone.

Montana Department of Transportation (MDOT) provided an inventory of photos within the Lower Yellowstone River corridor. MDOT employees indicate that they have photos along the Yellowstone River dating back to 1965, including 1,400 non-flood photos and 588 flood photos. These photos are available on Microfilm at the MDOT office in Helena.

The **Fairchild and Teledyne Collections at UC Santa Barbara** have one set of 1973 photos of a flight of the Billings transmission line.

Montana Bureau of Mines and Geology in Butte archives a number of aerial photographs in their basement dating from 1949 through the 1970's. They estimate that it would require "dozens of hours" to identify and do a thorough inventory of aerial photographs along the Lower Yellowstone River corridor.

US Bureau of Reclamation in Billings has photography covering various localized stretches of river, mostly from the 1960s, including some from 1948-49. However, their photo collection is not complete for the entire corridor.

E.3. Costs

Most archiving agencies require that index maps be purchased first to identify specific photos prior to ordering. These are organized by county. Most counties require multiple indexes to cover the river corridor. Certain agencies provided the coverage extent of the available index maps and in some cases the extents of the individual photographs. These extents have been converted into GIS Shapefiles and will be provided along with the project GIS data. Table E1 below lists the approximate number of index maps required for each year and county (in cases where an index must be ordered first).

Once the indexes are ordered and received, the necessary photographs can be identified and ordered. Most flights used the same specifications for acquiring the imagery and thus will result in similar numbers of photographs in order to cover the corridor. Approximately 400 photographs will need to be ordered for each date in order to provide complete coverage of the corridor. Estimated costs associated with imagery acquisition from several agencies are provided below.

USDA/APFO Salt Lake City Archives charges $20 per index sheet. Each data set requires several sheets for complete coverage of the river corridor within each county (Table E1). These indexes will need to be purchased in order to identify the exact photos covering the river corridor and the availability of these photos from the archives. Once identified, each 10"x10" black and white photo costs $5.

USGS EROS Data Center has a variety of products available. The tables below provide details for each product and their associated costs. This archive can be searched on-line to identify the required photos or DTM has created GIS Shapefiles showing the spatial extents of each available photograph and/or the necessary index. Individual indexes cost either $6 or $8 each, depending on the index type.

Table E1. Approximate number of index maps required for each year and county.

	Sweet Grass	Still-water	Yellow-stone	Treasure	Rose-bud	Custer	Prairie	Dawson	Rich-land	McKenzie
1937			7							
1938								4	3	
1939										1
1940			5							
1941		2								
1946		1	2			2	1			
1948	3									
1949			1	2	6	4	3	4, 2	3, 4	2, 2
1950			7	2	2	2	2			
1951	9	14	10				1		1	1
1953	1	1	2	3		1				
1954		2								
1955	2									
1956			2	2					3	
1957			5					5		
1958				2	3	4	2			
1962		2								
1965	2						3	16	13	1
1966			6, 9		14	8				
1967							3	4	2	4
1968				2	3, 1	3, 4	3			1
1969		1	6			8	1			
1970		2		1	6			2		
1971				1	1	1	3		3	5
1973			2							
1974							1	3	2	
1975	4	7	3					1	1	1
1976										2
1978		1	3		2	3, 6	4		1	
1979		2	6	2	3					1
1980	5							4		

Red indicates NARA data (Cost = $35 each).
Blue indicates USDA/APFO data (Cost = $20 each).
Green indicates USGS/ EROS data (Cost = $6 or $8 depending on type of index).

The **National Archives and Records Administration (NARA) in Washington, DC** houses aerial photography for the Lower Yellowstone River corridor dating from 1937-1955. Indexes must be ordered prior to determining the number of photographs required. Indexes are available through a variety of private vendors at a cost of $26 per copy plus a $9 pull fee for each index from NARA. Shipping fees vary, but may be as high as 15% of the total purchase. Aerial photos can be purchased for $15-$16 each depending on the vendor, plus an additional $9 pull fee per photo imposed by NARA. (This pull fee may refer to each 'can' holding negatives and not to each image.)

Table E2. NAPP photography details.

NAPP Photography

Print Size	*Enlargement*	*Scale*	*1" equals*	*B/W*	*CIR*
9 x 9 in	1x	1:40,000	3,333 ft	$10.00	$16.00
15 x 15 in	1.67x	1:24,000	2,000 ft	$25.00	$50.00
18 x 18 in	2x	1:20,000	1,666 ft	$18.00	$45.00
36 x 36 in	4x	1:10,000	833 ft	$33.00	$75.00

Table E3. NHAP photography details.

NHAP Photography

Film Type	*Print Size*	*Enlargement*	*Scale*	*1" equals*	*Cost*
Black & white	9 x 9 in	1x	1:80,000	6,666 ft	$16.00
	18 x 18 in	2x	1:40,000	3,333 ft	$50.00
	30 x 30 in	3.33x	1:24,000	2,000 ft	$45.00
	36 x 36 in	4x	1:20,000	1,666 ft	$75.00

The image sets housed at the **Conservation District offices** may be accessed to fill in holes created by incomplete image sets at the federal archiving agencies. Costs associated with acquiring these images are minimal.

The **Fairchild Collection at Whittier College** images do not cover the study area and no costs were obtained for acquiring these images.

At this time, no costs have been determined for acquiring images from the **Montana Department of Transportation** (MDOT).

No costs are available for imagery from the **Fairchild and Teledyne Collections at UC Santa Barbara**.

Due to the difficulty in searching the **Montana Bureau of Mines and Geology** collection, no costs were determined.

US Bureau of Reclamation in Billings has a limited collection and no costs were determined.

E.4. Results and Recommendations

While we can not guarantee that the USDA/APFO Archives will have all of the older images without ordering the indexes and requesting the actual photos, we are fairly certain that the following photo series are available:

- 1995 – NAPP. Complete coverage available as DOQQ.
- 1996 - USDA/APFO. Index Sheets at DTM.
- 1991 - USDA/APFO. Index Sheets at DTM.
- 1980 - USDA/APFO. Index Sheets at DTM.

- 1978-80 - USDA/APFO. Need to order 11* index sheets at a cost of $20 each for a total of $220.
- 1962-68 - USDA/APFO. Need to order 10* index sheets at a cost of $20 each for a total of $200.
- 1956-58 – USDA/APFO. Need to order 14* index sheets at a cost of $20 each for a total of $280.
- 1946-1953 – Complete USGS photo coverage available but requires ordering indexes first to identify individual photos. Indexes cost $6-8 each. Approximately 41 indexes will be necessary for coverage of the Lower Yellowstone River corridor for these dates for a total of $246- $328 for the indexes alone. Individual photo prices are listed in the tables above.

*The numbers of required indexes stated above are approximate. The results of the data request received from USDA/APFO lumped the results of all years for each county and, in some cases, it is not possible to determine which indexes refer to which year.

E.5. Recommended Steps

At this point, the priority image sets should be identified and steps should be taken to acquire the necessary indexes and photography. 9”x 9” contact prints should then be ordered for the identified images. As a general rule, it will be necessary to order approximately 1 photo per corridor-mile to cover the entire river corridor. This results in approximately 400 images, or around $2,000 to acquire aerial photo coverage from the USDA/APFO archives.

In addition to photo acquisition, the photos will need to be scanned and georeferenced to add to the GIS. Following are a variety of options for scanning aerial photos.

Table E4. Scanning costs.

Scanner	Location	Size	Unit Cost
Selby’s	Bozeman, MT	10x10	$3.00
Mountain CAD	Missoula, MT	10x10	$11.50
USGS	Reston, VA	10x10	$11.75
Carolina Map Distributors	Waynesville, NC	10x10	$11.50

If photos are ordered from the National Archives, there are a number of private vendors housed at the National Archives who make reproductions of aerial photography for researchers in traditional photography formats (negatives and prints) and possibly digital formats.

The scanned photos will need to be georeferenced in order to display them in the GIS. Costs for georeferencing the imagery will vary depending on the accuracy of the required scan referencing and the age of the imagery. Older photos will lack many obvious physical and man-made features that are generally used as reference points.