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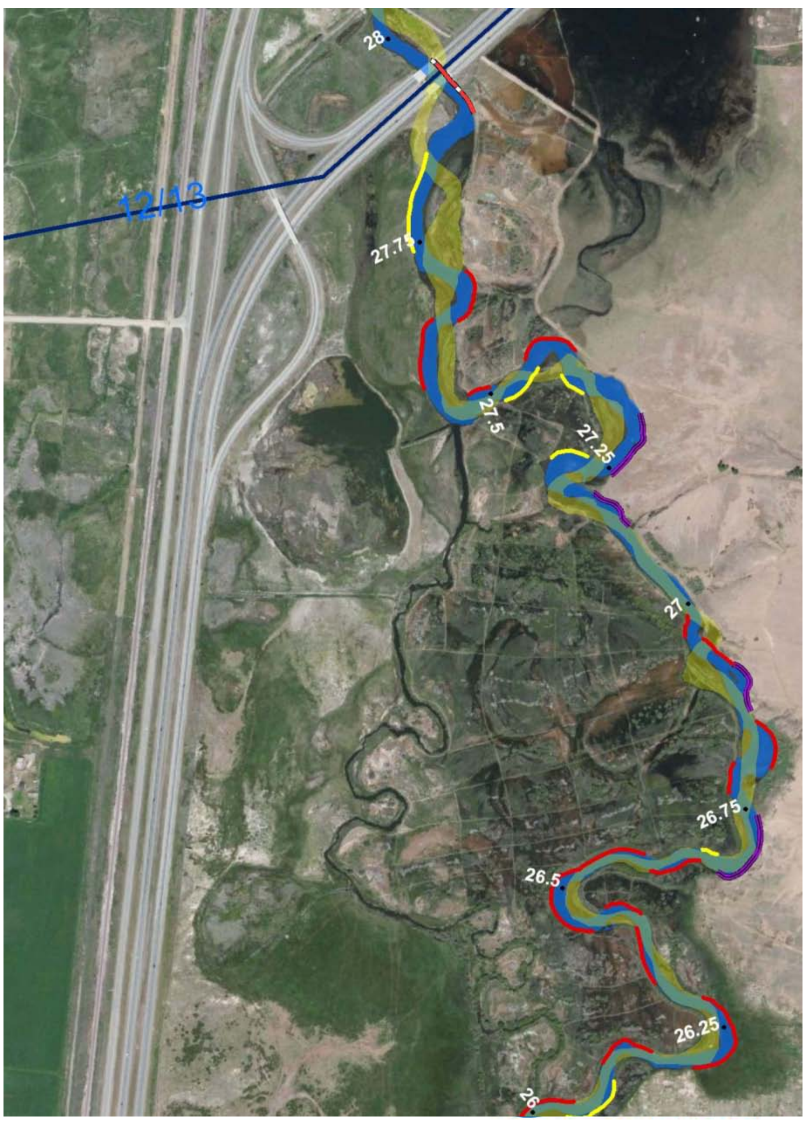
Clark Fork River Operable Unit Milltown Reservoir/Clark Fork River Superfund Site Powell, Deer Lodge, and Granite Counties

Geomorphology and Hydrology of Reach A



Prepared for:

Montana Department of Environmental Quality

September 23, 2013

CDM Smith

Applied Geomorphology, Inc.

Clark Fork River Operable Unit
Milltown Reservoir/Clark Fork River NPL Site
Powell, Deer Lodge, and Granite Counties, Montana

Final Report: Geomorphology and Hydrology of Reach A

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Section 1

Introduction

This site investigation report presents an overview of the geomorphology and surface water hydrology for Reach A of the Clark Fork River Operable Unit (CFROU) of the Milltown Reservoir/Clark Fork River Superfund site. The Clark Fork Site is divided into three reaches (A, B, and C) as shown on Figure 1-1. Reach A is the focus of most of the planned remedial actions in the operable unit. This report for Reach A provides an overview of river characteristics that are important for a geomorphic and hydrologic understanding of this river system. The purpose of these studies is to give DEQ an overview of stream behavior in Reach A that will guide the overall plan for remediation and provide a basis for development of individual Remedial Actions. This report has been prepared for the Montana Department of Environmental Quality (DEQ) by CDM Smith and Applied Geomorphology.

1.1 Site Description

The CFROU is located within four counties, Deer Lodge, Powell, Granite, and Missoula Counties. The upstream boundary at the Operable Unit is located at the confluence of Silver Bow Creek and the original Clark Fork River channel just downstream of the Warm Springs Ponds. The original channel of the river upstream of this point was obliterated when the Warm Springs Ponds were built. In Reach A, the Clark Fork River runs through a broad intermountain valley for 45 miles before being joined by the Little Blackfoot River, which marks the end of Reach A. The Flint Creek Mountains lie to the west and the Continental Divide rises to the east of the valley, usually called the Deer Lodge Valley. Ranches border the river on both sides through most of Reach A, and the valley is used for cattle grazing and hay production. Water is diverted from the Clark Fork and its tributaries for irrigation of fields, and center pivots and other sprinkler systems use groundwater and surface water as well. There is one town along the river, Deer Lodge, and some suburban development in areas south of Deer Lodge. The Grant Kohrs Ranch, a National Historic Site, is located just north of Deer Lodge. Figure 1-2 shows Reach A of the Clark Fork River and surrounding features

Heavy metals originating from historic mining activities, milling and smelting processes associated with the Anaconda Company operations in Butte and Anaconda have accumulated on the Clark Fork River stream banks and floodplain over a period of at least 100 years. The primary sources of contamination are tailings and contaminated sediments mixed with soils in the stream banks and floodplains, which erode during high flow events and enter the river and its tributaries. In addition to erosion, heavy metals are leached from the contaminated sediments and tailings directly into the groundwater and eventually to surface water. These contaminant transport pathways result in impacts to terrestrial and aquatic life along the Clark Fork River as described in the Record of Decision (ROD) for the site (USEPA/MDEQ, 2004).

1.2 Purpose and Scope

The purpose of this investigation is to provide an overview of stream behavior in Reach A that will guide the overall plan for remediation and provide a basis for development of individual remedial actions. This investigation includes a geomorphic analysis of the study reach as well as a hydrologic

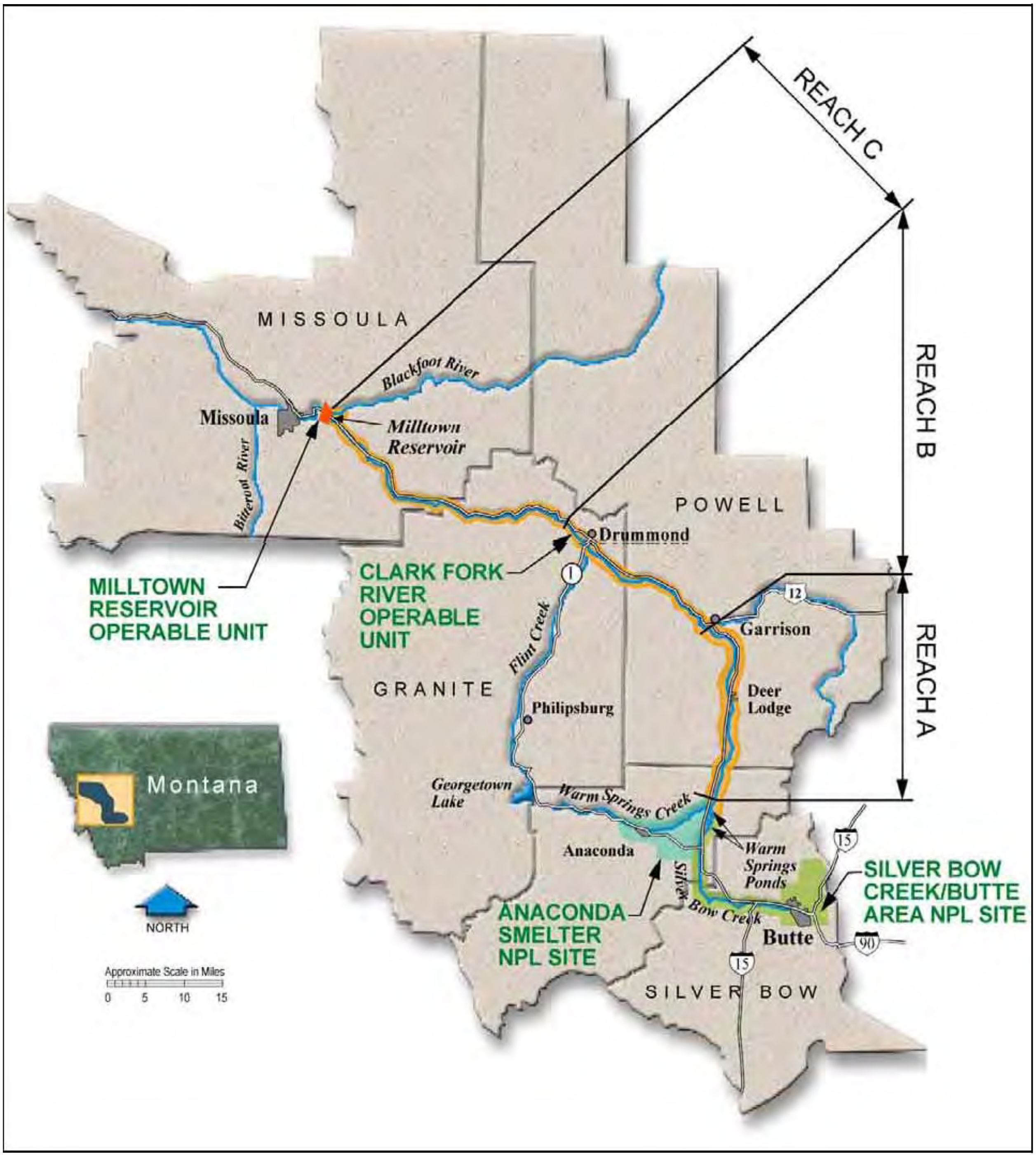
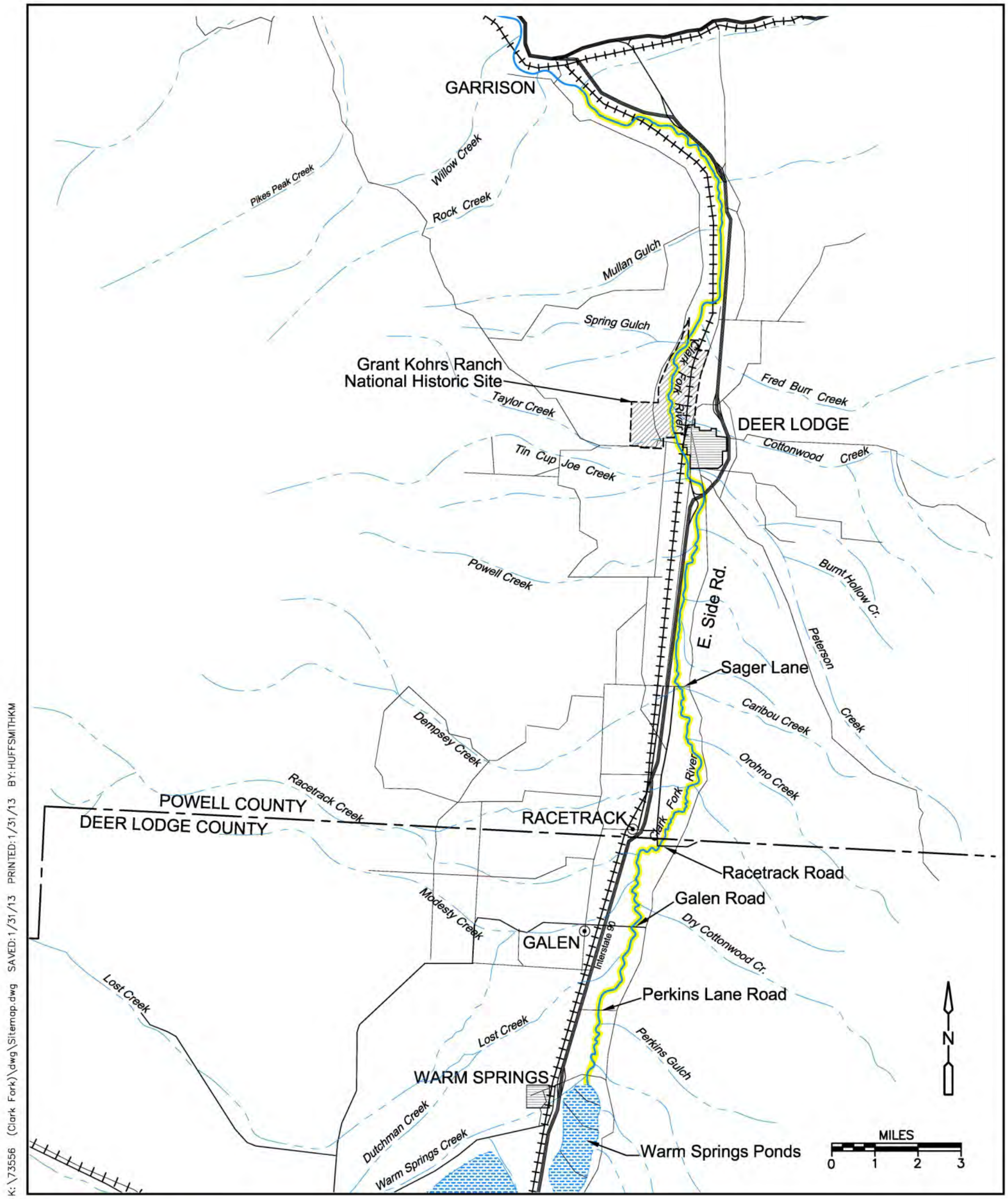


Figure 1-1. Clark Fork River Operable Unit Reaches.



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REACH A

Figure 1-2
Clark Fork River, Reach A
Clark Fork River OU

analysis of peak flows and flow durations. It is important to have an understanding of both these disciplines when considering remedial and restoration approaches to Reach A so that individual remedial designs are consistent with overall river function.

The geomorphic investigation consisted of office assessment work and field work. The office assessment work included:

- Review of historic imagery and General Land Office Survey maps to determine lateral migration;
- Determination of rates of bank movement since 1955; and
- Identification of geomorphic features on the floodplain from LiDAR data.

The field investigation consisted of floating the length of Reach A to map and inventory existing features. Tasks included:

- Mapping geomorphic features, bank armor, and existing infrastructure;
- Classifying and mapping stream banks in a three tier sytem;
- Investigating tributary confluences for geomorphic and erosional stability; and
- Photographing features.

Section 2 of this report presents the results of the geomorphic investigation, which summarizes data related to Reach A geology and geomorphology. Based on topographic and geomorphic trends, Reach A has been subdivided into seven subreaches, and results are summarized by both subreach and phase boundaries to provide context for future design efforts. Reach A has been divided into 22 Phases for purposes of construction. The information has been extracted from a GIS project that contains pre-existing data as well as field data collected as part of this investigation. These data include published geologic mapping (Berg and Hargrave, 2004, Berg, 2005); georeferenced 1869 General Land Office Survey (GLO) maps (GLO, undated); georeferenced 1914 maps of the river downstream of Deer Lodge (USGS, 1914); orthorectified 1955 aerial imagery (USGS, 1955); high resolution 2006 imagery and 2006 LiDAR data (CH2MHill, 2008); high resolution 2011 imagery (Fugro Horizons, 2011); and field data. The 2006 LiDAR data has been converted to a hillshade layer to help assess floodplain features, and it was also used to develop an inundation model to characterize floodplain connectivity in each subreach. A water surface profile has been extracted from the LiDAR data by collecting elevations every 100 ft along the river channel. Banklines have been digitized for the 1955 and 2011 imagery, and 2006 banklines were imported from previous work. Over 1,800 migration vectors have been collected to characterize 1955-2011 rates of lateral channel migration. The banklines from the 2006 and 2011 high resolution imagery have been used to calculate turnover and mapped slickens recruitment during that time frame and to characterize recent changes in light of high runoff events in recent years. Field data that have been summarized include inventoried eroding banks, mapped geologic influences, riffle crest locations, and photographic documentation.

Section 3, hydrology, presents the results of two main tasks: development of peak flow hydrology and development of a flow duration curve for the US Geological Survey (USGS) gage at Deer Lodge (No. 1232420). Peak flow hydrology for the mainstem of the Clark Fork River was developed using gage record and record extension methods. The result of this analysis was a table of estimated peak flows for the 2, 5, 10, 25, 50 and 100 –year recurrence floods for the three Reach A mainstem stations shown on Figure 3-1. Tributary peak flows were developed for 12 tributaries to Reach A of the Clark Fork River using a combination of gage and regression methods. The estimated peak flows were tabulated for the 2, 5 and10-year recurrence events. Less frequent events were not calculated for these tributaries because the short periods of record at the gages did not justify calculation of infrequent events. These peak flows can serve as a basis for design for both tributaries and the mainstem in the various phases of Reach A construction.

A flow-duration curve was developed for the period of record at the USGS gage at Deer Lodge using mean daily flows. This analysis resulted in a curve showing the likelihood that a given flow will be exceeded in any one year. These data are useful for estimating flood durations, performing sediment transport calculations, and supporting development of designs.

Section 2
Geomorphology

As described in Section 1, the following geomorphic summary is intended to provide baseline information to support future design efforts in Reach A. Phase-scale remediation projects in Reach A typically include a baseline assessment of existing geomorphic, hydrologic, and hydraulic conditions that form the context for identifying historic impacts, design approaches, and monitoring criteria. This geomorphic summary will not eliminate the need for additional phase-scale geomorphic investigations, but it will provide data summaries that can be used as a foundation for that work.

Numerous data layers have been compiled and developed in an ArcMAP 10 GIS project to allow continued efficient access to the information as future phases undergo design. It is important to note, however, that design has been ongoing in several phases of Reach A (Phases 1, 2, 5, 6, 7, 15, and 16); as a result, the field data for those areas were collected prior to this effort. Only a portion of the data collected for those phases have been included here. Important datasets compiled and developed for this effort are shown in Table 2-1.

Table 2-1. Summary of GIS Datasets used in assessment

GIS Datasets	Description	Source
Orthorectified imagery	1955 Black and white , 1:37,400	USGS Scanned orthorectified, and mosaicked by MapCon Mapping, Salt Lake City.
	2006 High resolution color	Project dataset
	2011 High resolution color	Project dataset
	2011 Bing Imagery (mid-July, 2011)	ArcGIS.com
LiDAR	2011 topography collected with high resolution imagery	Project dataset
Inundation Mapping	Inundation model layer showing approximate floodplain inundation area at 2-year discharge	Created from LiDAR dataset
Historic Mapping	Digital 1869 GLO maps imported into GIS and georeferenced using section lines (BLM source)	Bureau of Land Management
	Digital 1914 maps from Deer Lodge to Garrison georeferenced using section lines (USGS, 1914)	USGS
Channel Migration Zone Mapping	100-year Channel Migration Zone (CMZ) clipped to exclude geologic units and floodplain areas anticipated to be outside of contaminant removal boundary	Developed as part of project
Banklines	Digitized banklines for 1955, 2006, and 2011 imagery	1955 and 2011 Created; 2006 from CH2MHill (2008)
Geology	Simplified 1:50,000 geologic map units (Berg and Hargrave, 2004; Berg, 2005; Derkey et al., 1993)	Montana Bureau of Mines and Geology
Migration Vectors	1955-2011 measurements snapped to digitized banklines	Developed as part of project
Water Surface Profile	2006 LiDAR extracted water surface profile at 100 ft stations	Developed as part of project
Valley Profile	2006-LiDAR extracted valley profile from digitized meander corridor axis	Developed as part of project
RipES Polygons	RipES mapping	CH2MHill (2008)
Turnover Polygons	Intersected bankline dataset (1950-2011 and 2006-2011)	Developed as part of project
Bank Erosion Inventory	Actively eroding stream banks identified in field inventory	Developed as part of project
Riffle Density	GPS mapped riffle crests	Developed as part of project

A series of map and field note appendices support the geomorphic assessment. These include:

APPENDIX A: Geologic Maps (Published maps with units consolidated in GIS)

APPENDIX B: Historic Maps (1869 and 1914)

APPENDIX C: Erosion Inventory Mapping Results

Appendix D; Channel Migration Zone Maps (100-year Channel Migration Corridor)

APPENDIX E: Inundation Maps (Estimated floodplain connectivity at Q2)

APPENDIX F: Field Data Sheet Summary (Tabulated summary of qualitative field observations)

2.1 Field Investigation

During the fall of 2012, those phases of Reach A that have not yet undergone preliminary design investigations were floated and mapped to collect baseline data in support of future assessment and design efforts. The inventory concentrated on locating and attributing eroding banks, mapping geologic controls and riffle crests, and producing a photographic record. The Reach A phases that are currently undergoing design and hence were ***not*** inventoried for this effort include Phases 1-2 (above Perkins Lane), Phases 5-7 (Dry Cottonwood Creek Ranch and Paracini Pond), and Phases 15-16 (Grant Kohrs Ranch). A summary of basic field observations made in each Phase are tabulated in Appendix F.

2.2 Subreach Delineation

Reach A has been subdivided into 22 "phases", which are essentially implementation segments that reflect geographic features such as road crossings and land ownership boundaries (Figure 2-1). In an effort to better characterize the geomorphology of Reach A, these phases have been grouped into seven geomorphic subreaches (Figure 2-2; Table 2-2). The boundaries of each subreach were forced to match phase boundaries to facilitate summarization of data on both a subreach and phase scale. The subreaches reflect primarily changes in geologic influences and slope. Tributary confluences were not used to define subreach boundaries, so hydrologic parameters such as flood frequency discharges may vary within a given subreach.

Throughout this document, data are compiled both on a subreach scale and a phase scale. The subreach scale summaries allow interpretation of overall geomorphic trends and help to group phases in terms of process and anticipated remediation strategies, while phase summaries provide data specific to implementation segments intended to help characterize baseline conditions prior to phase-scale project design.

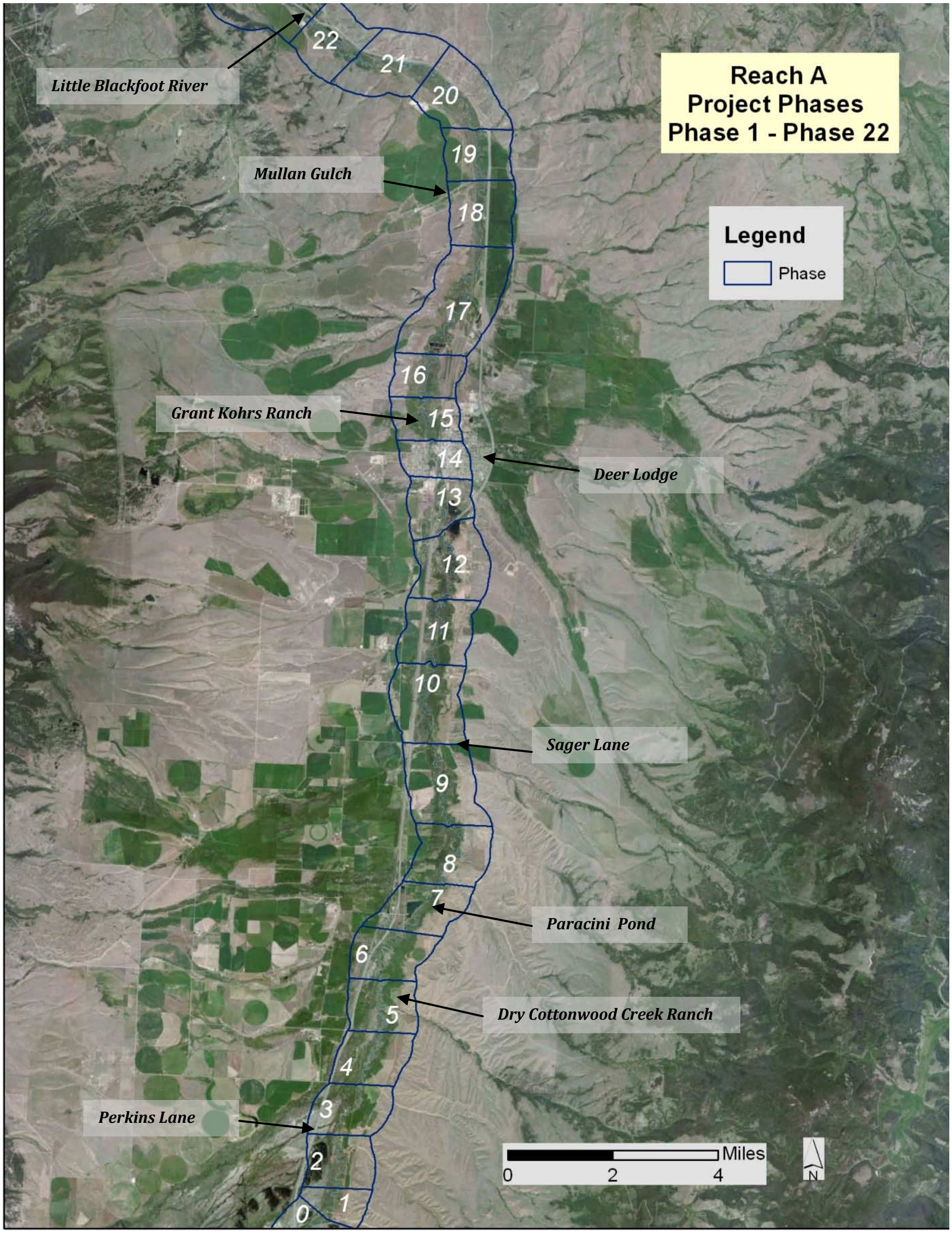

Figure 2-1. Reach A Phase Boundaries.

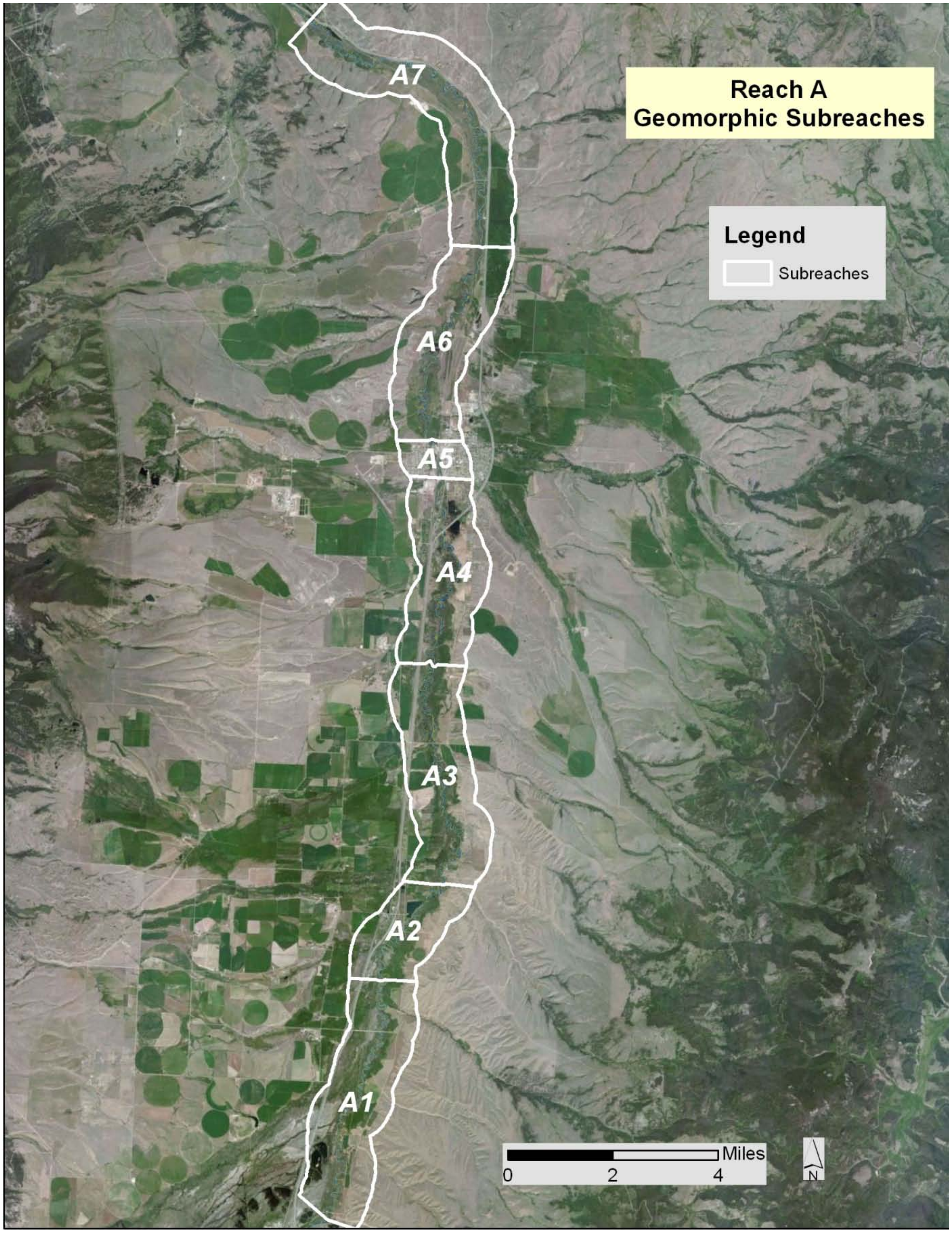

Figure 2-2. Reach A Subreach delineation.

Table 2-2. Subreach and Phase Stationing, Reach A.

Subreach	General Location	RM	Length (mi)	Phase	Station Start (ft)	Station Stop (ft)	Channel Length (ft)	Channel Length (mi)
A1	Warm Springs to Dry Cottonwood Creek Ranch	0.8-10.9	10.1	1	4400	12300	7900	1.5
				2	12300	22300	10000	1.9
				3	22300	33000	10700	2.0
				4	33000	45950	12950	2.5
				5	45950	57800	11850	2.2
A2	Lower Dry Cottonwood Creek Ranch, Paracini Pond	10.9-14.9	3.9	6	57800	68700	10900	2.1
				7	68700	78500	9800	1.9
A3	Racetrack Cr to ~3 miles below Sager Lane, Dempsey Cr	14.9-23.2	8.4	8	78500	90850	12350	2.3
				9	90850	105900	15050	2.9
				10	105900	122700	16800	3.2
A4	To Deer Lodge	23.2-29.1	5.9	11	122700	134500	11800	2.2
				12	134500	147500	13000	2.5
				13	147500	153900	6400	1.2
A5	Deer Lodge	29.1-30.0	0.9	14	153900	158500	4600	0.9
A6	Grant Kohrs Ranch to below Water Treatment Plant	30.0-36.3	6.3	15	158500	165675	7175	1.4
				16	165675	172800	7125	1.3
				17	172800	191700	18900	3.6
A7	To Garrison	36.3-56.6	9.3	18	191700	200800	9100	1.7
				19	200800	208500	7700	1.5
				20	208500	219500	11000	2.1
				21	219500	231200	11700	2.2
				22	231200	240850	9650	1.8

2.3 Geologic Setting

The Deer Lodge Valley is a north-south trending half-graben with front range faults on its west side, and no major faults on its east side (Berg and Hargrave, 2004). On the west side of the valley, the Flint Creek Range forms a distinct series of high peaks and glaciated valleys. This range is part of the Sapphire Block, a large mass of sedimentary rock that was thrust eastward from Idaho about 70 million years ago. Granites have intruded into the sedimentary rocks, forming the high peaks of the Flint Creek Range such as Mount Powell. Gold Creek, on the northern end of the Flint Creek Range, was the site of the first gold discovery in Montana in 1852. The eastern side of the valley consists of granites of the Boulder Batholith that are overlain by volcanic rocks. Dissected Pleistocene-age pediments overlie the volcanics, and typically sit hundreds of feet above the river corridor.

The sedimentary fill of the Deer Lodge Valley consists of an extremely thick sequence of Tertiary basin fill that is overlain by a thin veneer of Quaternary alluvium. The depth of the basin fill was recorded a few miles south of Deer Lodge, where a well drilled through 10,052 feet of Tertiary sediments before reaching Eocene volcanic rocks (Berg and Hargrave, 2004).

Approximately 10,000 years ago, alpine glaciers scoured the high valleys of the Flint Creek Range and extended down into the Deer Lodge Valley. Large glacial outwash deposits, which consist of coarse braided stream gravels, extend into the core of the Deer Lodge Valley, and can be found on both the east and west sides of the Clark Fork River. In the upper part of the valley, prominent outwash deposits have been mapped at the mouths of Lost Creek, Warm Springs Creek, and Mill Creek on the west side of the valley. These deposits have been described by Berg and Hargrave (2004) as forming "easily recognizable plains visible from the air or air photos with abandoned braided stream channels and large flat plains with a consistent trend to the north and northeast toward the Clark Fork River". Further north, till distributions indicate that alpine glaciers were present in the drainages of Cottonwood Creek and Baggs Creek east of Deer Lodge, and Rock Creek north of Deer Lodge (Derkey et al., 1993).

Reworking of the outwash gravels by the Clark Fork River has created a series of terraces that border the river bottom; these terraces range in height from 3 to 30 feet above the modern floodplain. Derkey et al. (1993) suggest that the Holocene terraces that bound the Clark Fork River corridor record a continual narrowing of the Clark Fork River floodplain as the river reworked and downcut into the glacial outwash. This was driven by a dramatic reduction in sediment loading and streamflow from the mountains as the alpine glaciers receded, and conversion of the Clark Fork River from a broad, glacially fed braided stream system to the single-thread meandering condition of today.

One of the most interesting aspect of the terraces is that those on the east side tend to be fine sands and silts derived from reworked Tertiary volcanics and Cretaceous granites, whereas those on the west side are much coarser grained outwash and reworked outwash gravels. The east side terraces, alluvial fans, and colluvial deposits tend to be more erodible than those to the west.

Appendix A contains a series of geologic maps for Reach A (Berg and Hargrave, 2004; Berg, 2005, Derkey et al., 1993). These maps are modified digital datasets that have been downloaded from the Montana Bureau of Mines and Geology website (www.**mbmg**.mtech.edu/). To simplify the maps, multiple units have been consolidated to highlight those that affect the river corridor. Those units, which typically consist of terraces, alluvial fans, and outwash gravels, affect the river corridor as laterally confining landforms, floodplain constrictions, potential major sediment sources, and modifiers of valley slope and river channel geomorphology.

A summary of the geologic influences in each subreach and project phase is contained in Table 2-3. In Subreach A1, which extends from Warm Springs to just below Dry Cottonwood Creek, the floodplain is largely geologically unconfined, although there is some terrace and alluvial fan influence in the lower portion of the subreach. The influence of geologic units increases in Subreach A2, where the river has eroded into high coarse grained terraces on the east side of the corridor through the lower portion of Dry Cottonwood Creek Ranch and below Paracini Pond. Valley margin influences increase significantly again in Subreach A3, where a broad outwash fan drapes the Racetrack Creek and Dempsey Creek corridors, impinging on the Clark Fork River meanderbelt. Several alluvial fans encroach into the valley from the east. The influence of these geologic controls is evidenced by an abrupt channel steepening for several miles below Racetrack Creek. The floodplain confinement is reduced in Subreach A4 as the river approaches Deer Lodge, where a broad low gradient valley has some alluvial fan influence from the east side, but remains largely a broad floodplain with extensive mapped tailings deposits.

The city of Deer Lodge is built largely on terraces that confine the river corridor through town in Subreach A5. Downstream of town through the Grant Kohrs Ranch and Subreach 6, a large outwash deposit has been mapped in the lower Cottonwood Creek drainage; however, the river currently flows to the west of this deposit, and there is no direct evidence of its influence on the corridor. Below the Deer Lodge wastewater treatment ponds in Subreach 7, the river is confined between the rail grade and Interstate such that the corridor boundary is primarily transportation infrastructure. The railroad was built on the edge of the stream corridor, effectively isolating the river from the bluffs of the large outwash deposit at the mouth of Mullan Gulch (Rock Creek Cattle Rd) to the west. In one location near the Phase 21/22 boundary, the river abuts colluvial deposits on the south side of the valley while the rail grade is on the north side of the river.

Table 2-3. Summary of geologic influences on river geomorphology, Reach A.

Subreach	Phases	Confining Units	Comments
A1	1-5	Low terraces, alluvial fans	Largely unconfined, with well-developed river corridor floodplain east of upper valley outwash deposits. Intermediate terrace encroaches into river corridor in lower portion of Phase 4, and river intersects Dry Cottonwood Creek alluvial fan in middle portion of Phase 5.
A2	6-7	High terrace	Strong influence of high terrace and glacial outwash on west side of river corridor; several large meanders in Phase 6 have eroded into the high terrace where diversion ditches and abandoned Milwaukee line parallel meanderbelt.
A3	8-10	Glacial outwash, low terrace, Tertiary sediments on east side	At the mouth of Racetrack Creek, the channel steepens as it abuts glacial outwash and terrace deposits to the west. On the east side of the valley in Phase 8, the river has eroded into fine- grained colluvial sediments and Tertiary units (Ts). Valley wall influences continue downstream in Phase 9 with low terraces on the east and alluvial fan confinement at mouth of Orofino Creek. The river follows a terrace along the west edge of the river corridor through Phase 10.
A4	11-13	None	Some localized terrace and alluvial fan influences as channel slope decreases relative to upstream. Several alluvial fans extend into the corridor in Phase 12, forming high, fine grained banks.
A5	14	None	Confined through Deer Lodge with terraces on both sides of channel.
A6	15-17	None	Minimal geologic influences through Grant Kohrs Ranch and for several miles below. Confinement in lower part of Phase 17 due to transportation infrastructure (abandoned Milwaukee line and I-90).
A7	18-22	Glacial outwash at Rock Creek	Glacial outwash fan at, and downstream of, Mullan Gulch (Rock Cr. Cattle Rd); otherwise, confinement caused by railroad grade and I-90.

2.4 Historic Mapping

Historic mapping is a potentially useful tool for identifying historic channel locations that may have been active during upstream mining activities of the late 19th and early 20th centuries. These channels may host contaminated floodplain deposits that are displaced from the modern channel. The challenge in using these maps, however, is that the level of mapping detail varies between survey crews, and the only locations where the historic channel can be located with some certainty is by evaluating field notes at section line crossings. To that end, the historic maps should be used as a coarse screening tool to identify potential major changes in channel location over the past 140 years.

Historic mapping of Reach A was available from two sources, including General Land Office Survey Maps (www.glorecords.blm.gov) and a series of 1914 plan and profile sheets from the river downstream of Deer Lodge (USGS, 1914). These georeferenced maps are compiled in Appendix B, with areas of potentially significant shifts in channel location highlighted (green ovals). These areas indicate deviations between the historic and modern channel course at surveyed section lines, other areas of major deviation, and areas where the mapped historic channel correlates to modern floodplain swales. As further phases are evaluated, areas of substantial shift in channel location may warrant review of the survey notes that accompany the maps to specifically locate the channel on section lines. The maps in Appendix B show that the 1914 Marshall maps (USGS, 1914), which were developed specifically for the river channel, have much higher level of detail and accuracy than the GLO maps. However, these maps were made following the construction of the railroad grade between Deer Lodge and Garrison, so any changes prior to that time are unmapped. Township-scale GLO maps were not available for the lowermost portions of Reach A (downstream of Phase 19).

The GLO maps of the Deer Lodge Valley have relatively poor river course mapping detail relative to other areas in Montana. For example, Figure 2-3 shows a major difference between the 2011 channel course and that of the 1869 GLO survey in Phase 11. In this figure the dark blue is the modern channel; the swale to the west is an abandoned channel, indicating that the deviation may be real. However, the historic survey notes for this area (Figure 2-4) indicate that the left bank of the river was 1876 ft east of the section corner (28.43 chains) in 1869. Currently, the river is approximately 1869 ft from the section corner, essentially in the same location. The mapping, however, shows the 1869 river to be several hundred feet west of the modern location, indicating that the river location was mapped poorly on the GLO maps, and that the deviation is actually mis-mapping of the channel on the section line. Approximately 1,000 feet south of the section line, the floodplain swale suggests that in this specific area, the river may have been west of its modern course in 1869.

In other areas, the deviations on the map correlate much better to the values in the field notes. Significant shifts have been verified in Phase 2 (Perkins Lane Bridge), Phase 6 (Dry Cottonwood Creek Ranch), and Phase 15 (Grant Kohrs Ranch). These documented shifts from the latter part of the 19th century have helped shed light on test pitting results that sometimes show tailings accumulations in these historic channels, and with respect to hydraulic modeling results that sometimes show flood flow conveyance through these relic features. Ultimately, however, the use of GLO mapping requires more detailed assessment of the mapped deviations (evaluation of the notes) to identify areas of major historic shift.

Channel widths can also be derived from the survey notes; the 1869 notes describe the river at this location as 86 ft wide and single thread (1.3 chains; Figure 2-4), which is consistent with modern conditions. The notes also describe passing through an 83-ft wide (1.25 chains) thicket of willows. At the end of the notes section for each township, surveyors wrote a general description of the area that can shed light on overall conditions observed by the surveyor. Figure 2-5 shows a portion of the summary description for T7N R9W, which includes Phases 10-14. The notes describe cottonwood groves along the river, willow thickets, alder, and birch.

The GLO maps from the Deer Lodge valley are all from 1869. During this time, agricultural activities were commonly recorded in the notes, including hay production, grazing, and plowing of fields. Not a single reference to beaver has been identified thus far in the notes, suggesting a lack of beaver prevalence in the main channel of the Clark Fork River at that time.

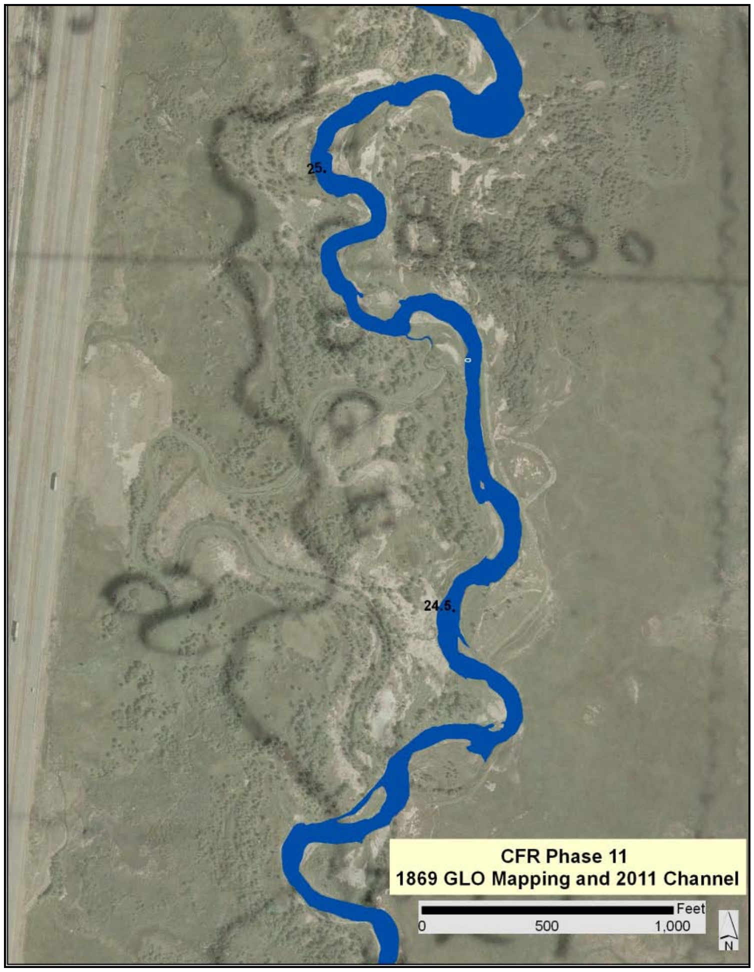

Figure 2-3. Example of deviation between 1869 GLO map and modern channel (blue), including a section line crossing, Phase 11.


East on a random line between
Sec. 16 and 21
Va 20° 15' E
1.30 Road N and S
13.00 Flat of Deer Lodge River
28.43 Deer Lodge River left bank runs N.
Ran North 50 lks for base. thence
a flag on line on right bank bears
S 69° E gives angle opposite base =
21° Nat. cotan 21° = 2.60 × .50 = 1.30 =
distance across the river
29.73 Enter thicket of willows
31.00 leave thicket

Figure 2-4. 1869 GLO survey notes for east-west section line in Figure 2-3; left column tracks distance in chains from section corner (1 chain = 66 ft).

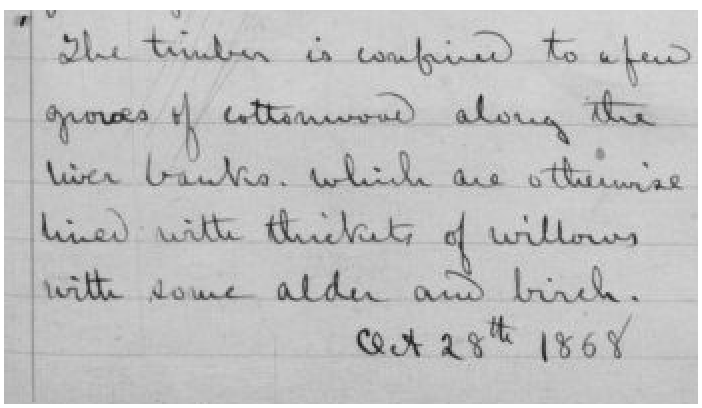
The timber is confined to a few
groves of cottonwood along the
river banks. which are otherwise
lined with thickets of willows
with some alder and birch.
Oct 28th 1868

Figure 2-5. Summary notes for T7N, R9W describing vegetation conditions in 1868.

Figure 2-6 shows an example overlay of the 1914 Marshall maps with the 2011 stream channel. As these maps were made specifically to document the plan and profile of the Clark Fork River, they are much more detailed and accurate than the GLO maps. In Phase 20, for example, the 1914 maps show two major cutoffs at RM 40 (Figure 2-6).

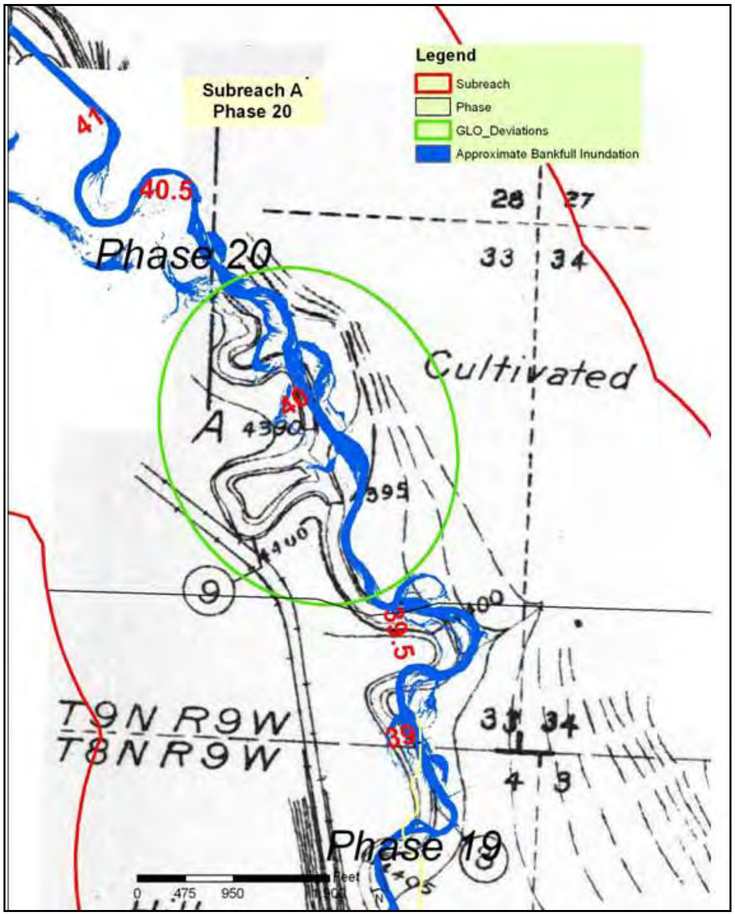

Figure 2-6. Example of deviation between 1914 channel (Marshall, 1914) and modern channel, Phase 20.

2.5 Downstream Trends in Geomorphic Parameters

The following section presents data for the entirety of Reach A to show downstream trends and patterns in slope, planform, bank erosion, channel migration rates, sediment, floodplain turnover rates, and riffle crest densities.

2.5.1 Slope and Sinuosity

As described in Section 2.2, channel and valley slope were used to help delineate project subreaches. These gradients appear to be affected by local geologic influences (Section 2.3).

The 2006 LiDAR data were used to generate water surface and valley profiles at 100 ft stations between Warm Springs and Garrison (Table 2-4; Figure 2-7). The application of phase-scale best-fit lines on these profiles show that channel slope typically ranges from 0.15% to 0.21%, with an especially steep section in Subreach A5 (Phase 14) through Deer Lodge (0.25%). Valley slope ranges from 0.28% to 0.38%, demonstrating a higher range of overall variability relative to channel slope. This indicates that the river has in part adjusted to valley slope by modifying its length, lengthening in steep valley segments and straightening in areas of relatively low valley slope. This is a typical response of alluvial rivers to maintain relatively constant channel slopes, as described by Schumm

(1977): "within a valley there are reaches of valley floor that are steeper and gentler than the average gradient. To maintain a relatively constant gradient, the river lengthens its course by meandering on the steeper reaches. Thus, if other causes are eliminated, high sinuosity reaches of a channel should reflect a steeper valley slope and vice versa."

Figure 2-7 shows an abrupt reduction in channel slope between Subreach A3 and A4 (Phases 10 and 11). This subreach boundary marks the downstream end of a large glacial outwash fan and low terraces that confine the river corridor and potentially contribute coarse sediment through Phases 8-10. In subreach A4 (Phases 11-13) the river corridor widens with reduced confinement, valley and channel slopes are lower, and tailings deposition appears to have been relatively extensive.

A plot of channel sinuosity shows a continued reduction in the downstream direction from Phase 1 to Phase 22 (Figure 2-8). This is likely in due to lower valley slopes below Deer Lodge, as well as increasing river corridor confinement by transportation infrastructure.

Table 2-4. Slope and sinuosity derived from 2006 LiDAR data, Reach A.

Subreach	Water Surface Slope	Valley Slope	Sinuosity	Phase	Water Surface Slope	Valley Slope	Sinuosity
A1	0.18%	0.35%	2.03	1	0.17%	0.42%	2.19
				2	0.22%	0.37%	1.79
				3	0.17%	0.34%	1.81
				4	0.15%	0.40%	2.23
				5	0.16%	0.34%	2.20
A2	0.19%	0.31%	1.76	6	0.16%	0.31%	1.84
				7	0.24%	0.31%	1.68
A3	0.21%	0.37%	1.84	8	0.23%	0.39%	1.66
				9	0.23%	0.39%	1.81
				10	0.17%	0.37%	2.02
A4	0.15%	0.24%	1.58	11	0.18%	0.30%	1.72
				12	0.14%	0.22%	1.77
				13	0.13%	0.21%	1.16
A5	0.25%	0.39%	1.18	14	0.25%	0.33%	1.18
A6	0.19%	0.30%	1.54	15	0.21%	0.33%	1.63
				16	0.18%	0.28%	1.59
				17	0.19%	0.31%	1.50
A7	0.21%	0.29%	1.47	18	0.18%	0.25%	1.38
				19	0.20%	0.34%	1.45
				20	0.21%	0.33%	1.47
				21	0.21%	0.30%	1.44
				22	0.25%	0.29%	1.61

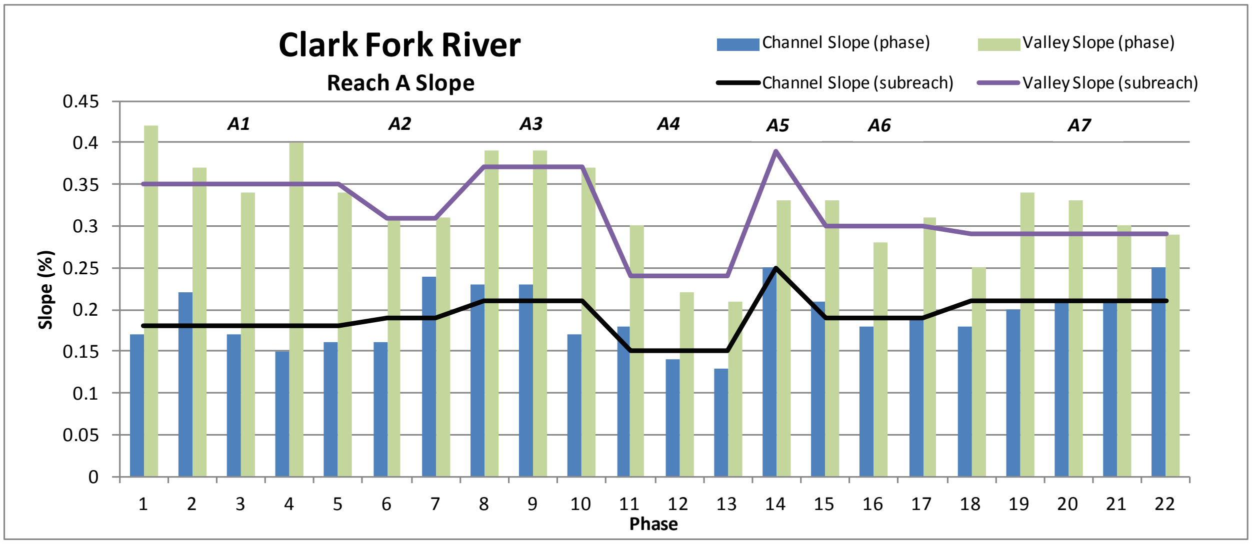

Figure 2-7. Channel and valley slope for Reach A Phases (bars) and Subreaches (lines).

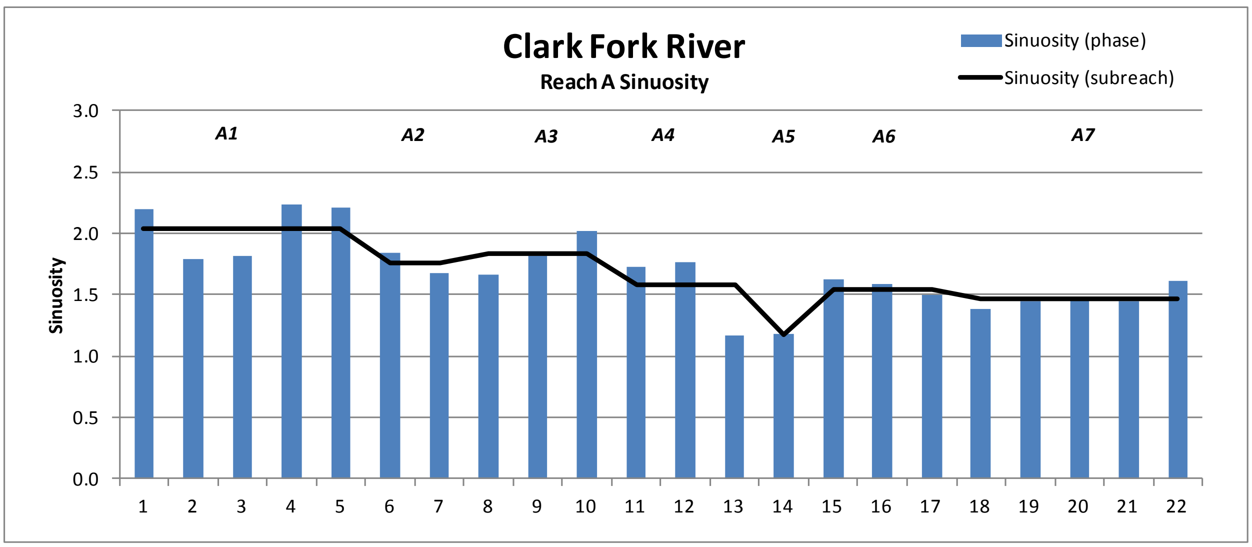

Figure 2-8. Reach A sinuosity for Phases (bars) and Subreaches (line).

2.5.2 Bank Erosion

During the fall 2012 field assessment, handheld GPS units were used to record locations of eroding banks. Bank erosion sites were mapped as upstream and downstream point features, and these were converted to digitized bankline segments in the GIS project. Each mapped eroding bank was attributed by severity, observable presence of tailings, bank height, and vegetation characteristics. This rapid inventory of bank conditions has been performed for all Reach A phases. Bank erosion inventory data are summarized in Table 2-5, and a series of maps showing the mapped banklines from the 2012 field inventory are compiled in Appendix C. These maps also show the 1955 and 2011 channel footprints, so that eroded banks can be linked to mapped migration sites. In some cases, migration rates have slowed such that areas of significant historic movement are not actively eroding.

Bank inventory data are plotted in Figure 2-9 to graphically show downstream trends in erosion and bank armor extents. The plot shows that, upstream of Deer Lodge (Phase 14), severe bank erosion is fairly consistently on the order of 20% of total bankline when compiled on a subreach scale. Deer Lodge shows very little severely eroding bank due to the extent of bank armor through town (22% of total bank armored). Downstream of Deer Lodge, the extent of severely eroding bank is lower than upstream, especially in Reach A6 (Phases 15-17), where less than 15% of the bankline was mapped as severely eroding.

Phase 10 has the most extensive severe erosion, with 29% of the bankline inventoried as severe (Appendix C, Figure C-5).

Bank armor is relatively rare upstream of the Interstate Bridge in Deer Lodge (Phase 13); however, through Deer Lodge armor is extensive due to floodplain development, and, further downstream, the river is extensively armored where it flows along the toe of the Interstate road prism.

The most extensive influence of terraces and alluvial fans is in Phase 8, where 12% of the bankline is comprised of something other than modern valley bottom alluvium (Appendix C, Figure C-3).

Table 2-5. Bank erosion inventory results, Reach A.

Phase	Moderate	Severe	Armor	Terrace Edge	Reach Length (ft)	Bank Length (ft)	Moderately Eroding (ft)	Severely Eroding (ft)	Armor (ft)	Terrace Edge (ft)
1*	2974	3012	0	307	7900	15800	18.8%	19.1%	0.0%	1.9%
2*	669	4201	0	233	10000	20000	3.3%	21.0%	0.0%	1.2%
3	531	4004	118	426	10700	21400	2.5%	18.7%	0.6%	2.0%
4	976	4417	0	0	12925	25850	3.8%	17.1%	0.0%	0.0%
5*	73	3951	N/A	N/A	11850	23700	0.3%	16.7%	N/A	N/A
6*	120	4055	N/A	N/A	10900	21800	0.6%	18.6%	N/A	N/A
7*	3634	1537	590	642	9800	19600	18.5%	7.8%	3.0%	3.3%
8	1309	2699	979	2869	12350	24700	5.3%	10.9%	4.0%	11.6%
9	3434	5110	0	1385	15050	30100	11.4%	17.0%	0.0%	4.6%
10	1670	9711	0	201	16800	33600	5.0%	28.9%	0.0%	0.6%
11	2470	5752	0	327	11800	23600	10.5%	24.4%	0.0%	1.4%
12	3243	5895	357	1642	13000	26000	12.5%	22.7%	1.4%	6.3%
13	0	1900	1500	0	6400	12800	0.0%	14.8%	11.7%	0.0%
14	653	184	2014	0	4600	9200	7.1%	2.0%	21.9%	0.0%
15*	1876	2328	0	0	7175	14350	13.1%	16.2%	0.0%	0.0%
16*	3432	1731	685	307	7125	14250	24.1%	12.1%	4.8%	2.2%
17	2002	4980	1076	2162	18900	37800	5.3%	13.2%	2.8%	5.7%
18	1168	2873	0	0	9100	18200	6.4%	15.8%	0.0%	0.0%
19	302	3054	372	482	7700	15400	2.0%	19.8%	2.4%	3.1%
20	1824	4000	742	0	11000	22000	8.3%	18.2%	3.4%	0.0%
21	3303	3816	1528	0	11700	23400	14.1%	16.3%	6.5%	0.0%
22	1045	3934	0	668	9650	19300	5.4%	20.4%	0.0%	3.5%

* Data from Preliminary Design Investigations.

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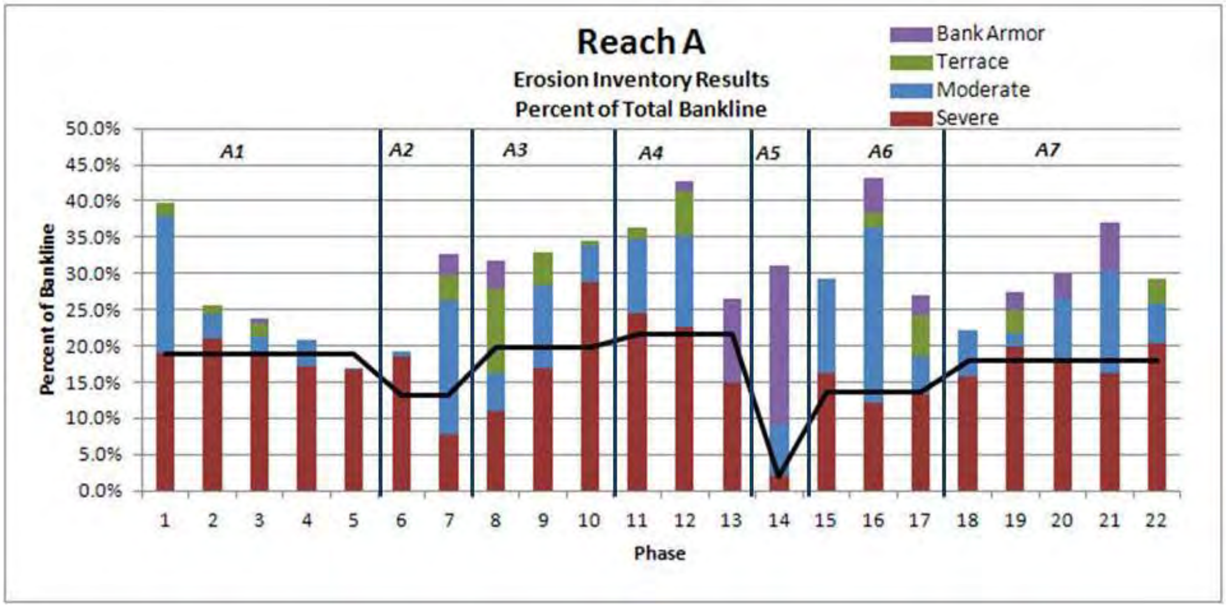

Figure 2-9. Rapid erosion inventory results, Reach A; black line is severe erosion by Subreach.

2.5.3 Floodplain Turnover

Floodplain turnover, defined as the rate at which the channel consumes floodplain and creates channel, has been quantified using bankline polygons developed from 1955, 2009, and 2011 banklines. An intersection of these polygons allows the calculation of acreage that has changed from one condition to another, such as from floodplain to channel, which reflects erosion. Areas converted from channel to floodplain reflect deposition to floodplain elevations. These turnover acreages can help define the quantity of material recruited by the river through time, as well as the rates and locations of floodplain growth. Since recent depositional areas such as point bars that vegetate and become floodplain are commonly contaminated, this assessment may shed some light on extents and types of recent depositional areas that may contain reworked tailings.

Floodplain Turnover from 1955 to 2011

The intersection of the 1955 and 2011 bankfull polygons allows quantification of area that has been eroded (floodplain to channel) or aggraded (channel to floodplain) since 1955. In some cases, this turnover reflects meander migration and point bar growth, such as in Figure 2-10 where the blue areas reflect cut bank migration and sediment recruitment, whereas maroon areas depict 1950s channel that is now vegetated floodplain. In contrast, patterns in Figure 2-11 show net gain in floodplain area (maroon) versus loss (blue), indicating channel narrowing. Any contaminants in areas mapped as maroon will be reworked in-stream depositional features versus original early-20th century fluvial tailings flood deposits.

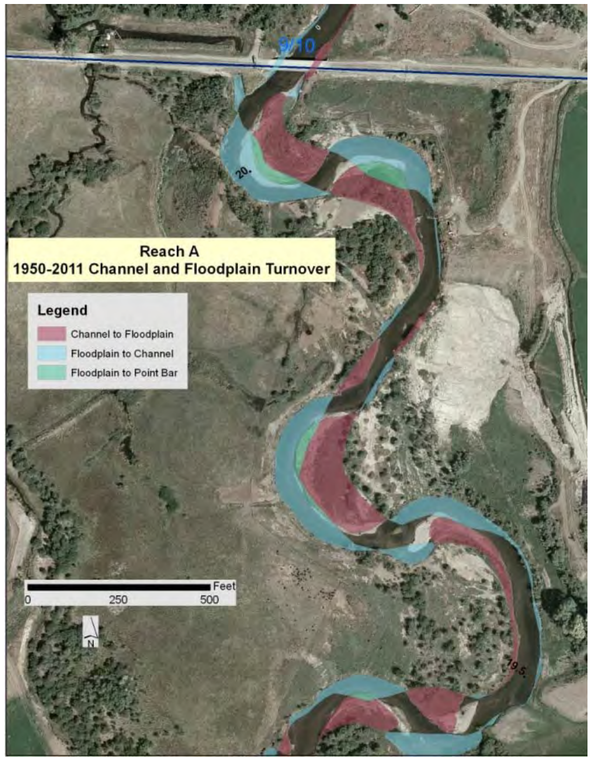

Figure 2-10. 1955-2011 turnover showing meander migration, Phase 9.

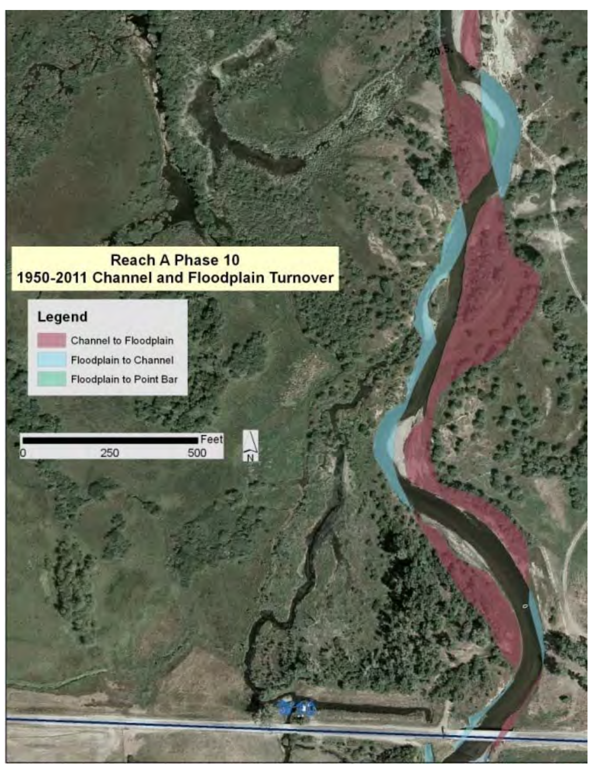

Figure 2-11. 1955-2011 turnover showing channel narrowing, Phase 10.

Figure 2-12 shows the acreage of polygon conversions by phase. Between 1955 and 2011, the greatest amount of sediment recruitment from the floodplain ("floodplain to channel") occurred in Phase 12, where 12.8 acres of floodplain area was eroded into the channel. In most subreaches, there has been a net gain of floodplain area since 1955, indicating channel narrowing and vegetation encroachment into the channel and cutoff areas. This is most pronounced in Phases 6 and 7 where meander cutoffs at River Mile (RM) 11 (Dry Cottonwood Creek Ranch) and RM 14 (Paracini Pond) have been colonized by vegetation. In Reach A, a total of 131.2 mapped acres of floodplain were converted to channel between 1955 and 2011, and 171.4 acres of channel were converted to floodplain.

The shape files for these turnover polygons can be made available to project designers if they are of interest, as they may help inform test pitting strategies, and provide context in terms of historic floodplain deposition of tailings versus in-channel reworking and deposition as point bars.

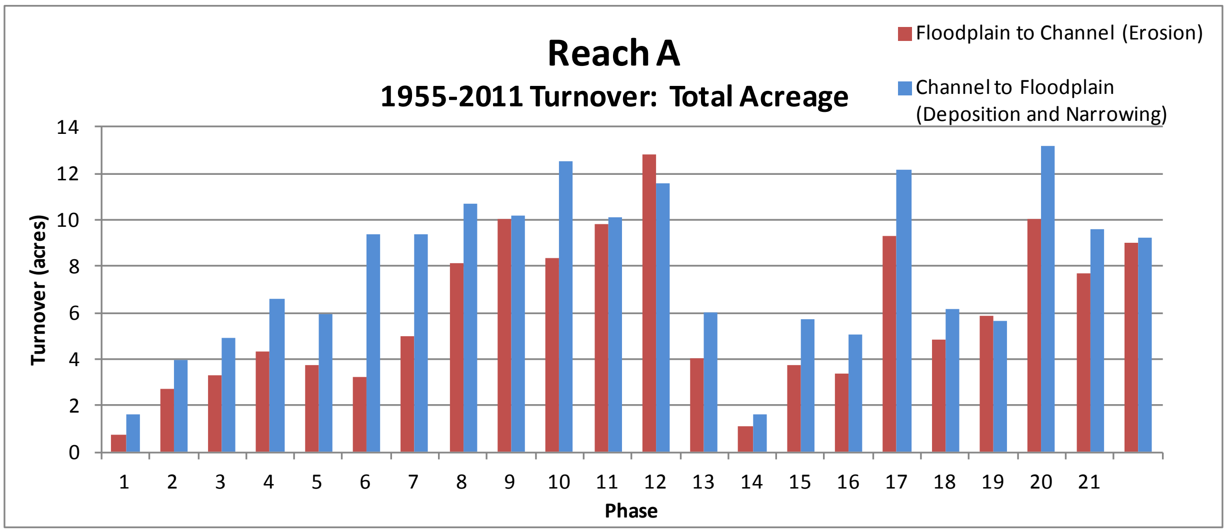

Figure 2-12. Total acreage converted between 1955 floodplain and 2011 channel, Reach A.

Floodplain Turnover from 2006-2011

High resolution imagery from both 2006 and 2011 allows the quantification of turnover during those five years, which included several above-average runoff events. In addition, RipES mapping data allows quantification of the acreage of eroded slickens (unvegetated tailings) (CH2MHill, 2008). Figure 2-13 shows the total acreage of sediment recruited from 2006 to 2011. In general, recruitment areas were relatively small in Phases 1-6, and then eroded acreage increases markedly between Paracini Pond (Phase 7) and Deer Lodge (Phase 14). Below Deer Lodge, spikes in total acreage of eroded area occur in Phase 17 and Phase 22. With the exception of Phase 22, the amount of eroded ground is fairly consistent at just under one acre per river mile

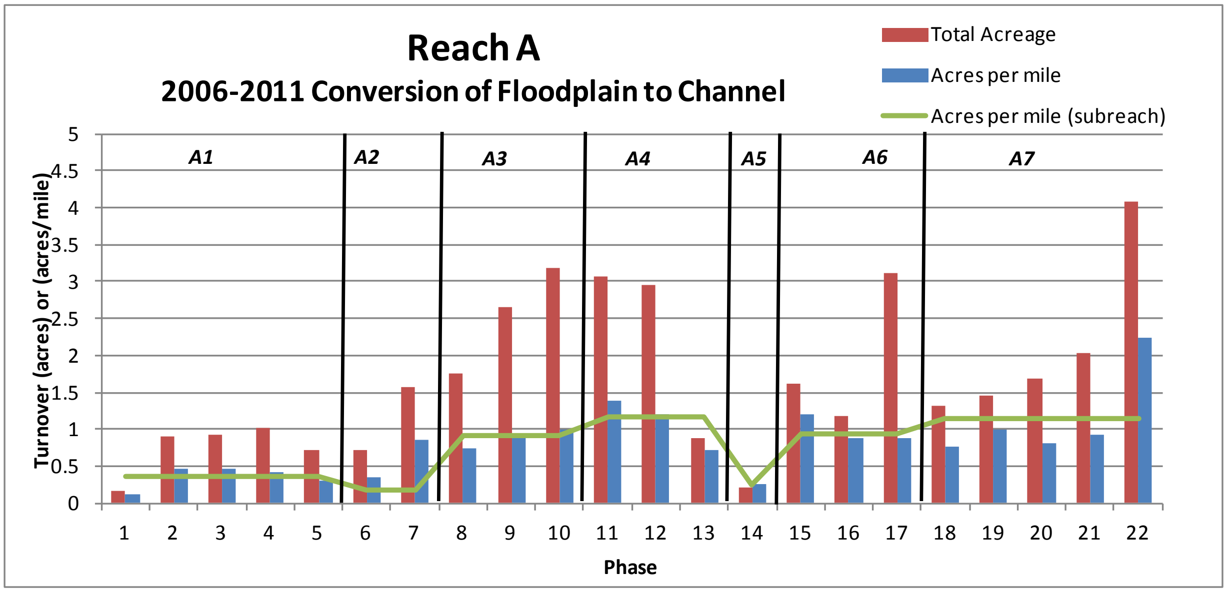

Figure 2-13. Bank erosion acreage (conversion of floodplain to channel), 2006-2011.

When integrated with the RipES mapping (CH2MHill, 2008), the turnover analysis shows that between 2006 and 2011, at total of 32.9 acres of area mapped as tailings impacted soils, and 0.71 acres of area mapped as slickens were recruited through bank erosion in Reach A (Figure 2-14). As defined in CH2MHill (2008), impacted soils are contaminated but partially vegetated whereas slickens are un-vegetated tailings deposits. The most severe slickens recruitment occurred in Phase 22 at the mouth of the Little Blackfoot River, where over 14,000 square feet (0.32 acres) of slickens were eroded (Figure 2-15). A comparison of the 2006 and 2011 imagery shows how a meander migrated northward extended into a tailings deposit that completely modified the channel configuration at the confluence (Figure 2-16).

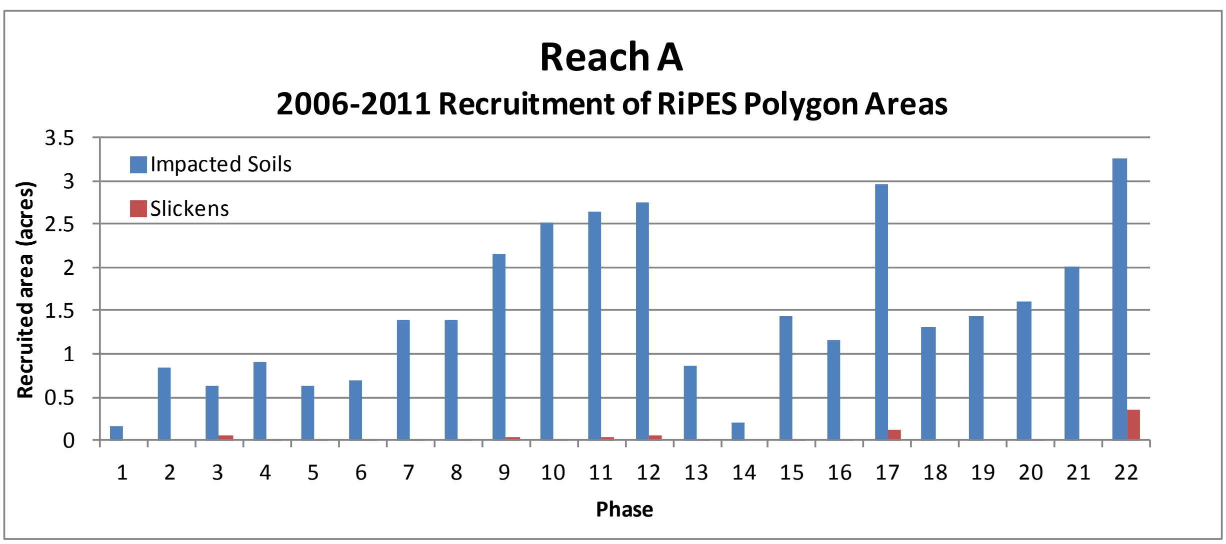

Figure 2-14. Acreage of mapped impacted soils and slickens recruitment, 2006-2011.

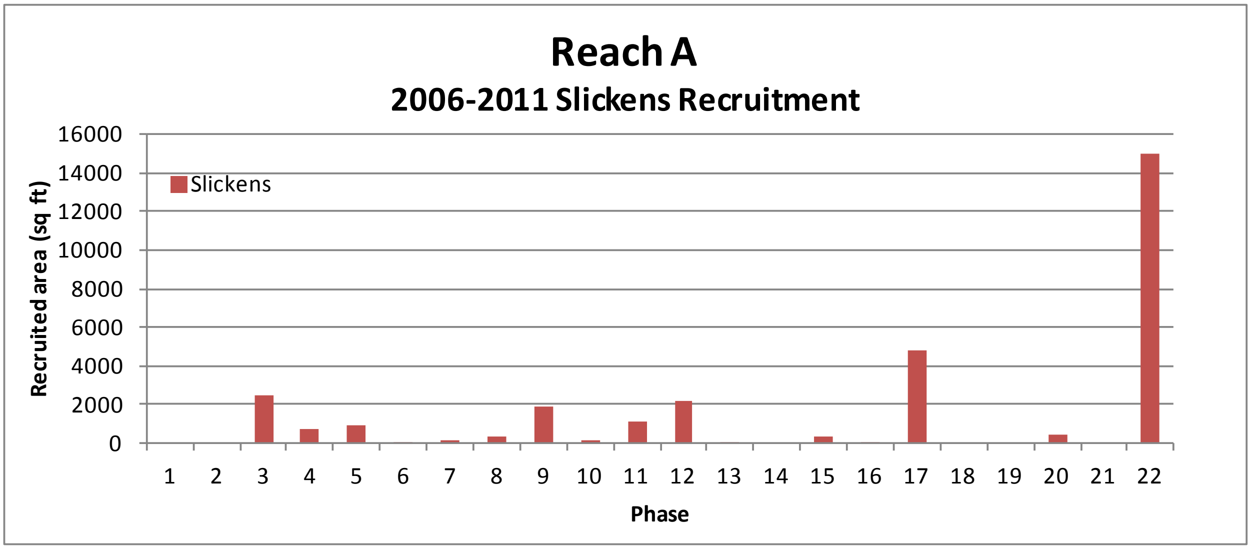

Figure 2-15. Total square footage of 2006-2011 slickens recruitment by phase.

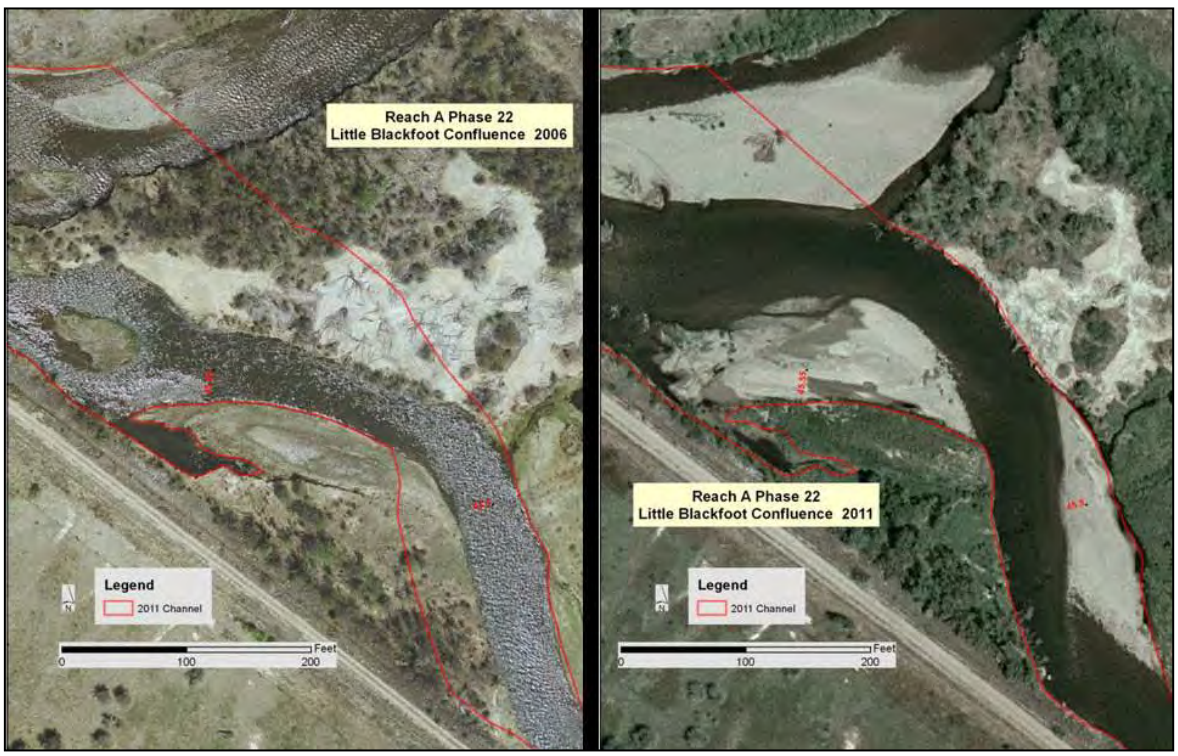

Figure 2-16. Little Blackfoot River confluence in 2006 (left) and 2011 (right).

2.5.4 Channel Migration Rates and Channel Migration Zone Mapping

Channel migration rates are an important component of the geomorphic assessment of Reach A as they can be used to help determine the potential for tailings entrainment through bank erosion. To quantify these rates, over 1800 migration vectors were collected in the GIS that record migration distances between the 1950s air photos and the 2011 imagery. These vectors were collected where active bank movement exceeding 20 feet had occurred, and the vectors were collected at approximately 20 ft. intervals along any given eroding bankline. In some phases that are currently under design, different sets of imagery and associated banklines were used; these timeframes were taken into consideration in the rate analysis (e.g., Phases 5 and 6 rates are based on imagery from 1949 and 2006).

Measured migration distances and rates from approximately 1950 to 2011 are compiled in Table 2-6. The total number of migration vectors range from a low of 3 in Phase 1 to a maximum of 199 in Phase 10 (Figure 2-17). Statistics were collected for each suite of measurements to determine the minimum, mean, maximum, and various quartile values for each phase (Figure 2-18 and Figure 2-19).

To characterize the risk of tailings entrainment via bank erosion, these statistics have been used to develop Channel Migration Zone (CMZ) maps for those phases that are not yet in design (Appendix D). CMZ boundaries for Phases in design have been developed separately using the same basic criteria. On these maps, measured migration rates have been used to define a 100-year erosion buffer that has been added to the 2011 banklines. This buffer width reflects the 90th percentile migration rate extrapolated to a 100-year migration distance. Based on available data, it is impossible to determine if the measured ~60 year rate measurements are sustainable over 100 years; typically migration rates vary as bendways mature. As a result, the 90th percentile, 100-year migration distance reflects a buffer that, if the eroding banklines were to continue eroding at the same rate for 100 years, 90% of those eroding sites would not exceed the buffer. This provides an empirical, relatively conservative assessment of entrainment risk, and by applying the buffer to all banks, it allows for the onset of erosion in currently stable areas over the next century. The resulting buffers, which were added to the 2011 banklines in the GIS, range in width from 61 feet in Phase 1 to 219 feet in Phase 19 (Figure 2-20).

As tailings entrainment could occur both through bank migration and channel avulsion (rapid shifting to a new channel), avulsion hazards were also mapped as part of the CMZ (Figure 2-21). These areas typically reflect bendway cores that are prone to cutoff, but also include floodplain channels that may be prone to reactivation. These channels were identified by both visual mapping on the air photos, and using inundation mapping to assess their hydrologic connectivity to the main channel (Section 2.5.5).

Islands have been mapped separately to allow their consideration with respect to the feasibility of test pitting and tailings removal. These islands can be several acres in size, and will require specific strategies for contaminant characterization and remediation.

Table 2-6. Summary of channel migration measurements, Reach A.

Phase	Number of Measurements	Mean Migration Distance (ft)	Mean Migration Rate (ft/yr)	Maximum Migration Distance (ft)	Maximum Migration Rate (ft/yr)	90th Percentile Migration Rate (ft/yr)	90th Percentile 100-yr Migration Distance (ft)
1	3	31.4	0.6	35.6	0.6	0.6	61
2	58	40.0	0.7	107.0	1.9	1.2	117
3	59	41.6	0.7	97.5	1.7	1.3	131
4	100	39.1	0.7	83.9	1.5	1.1	107
5	57	32.9	0.5	64.3	1.0	0.8	81
6	42	35.2	0.6	74.2	1.2	0.9	87
7	34	42.3	0.7	94.5	1.7	1.1	115
8	99	55.5	1.0	147.5	2.6	1.6	158
9	177	50.1	0.9	139.6	2.4	1.4	139
10	199	41.7	0.7	112.5	2.0	1.1	113
11	135	58.8	1.0	149.8	2.6	1.6	165
12	133	60.0	1.1	162.9	2.9	1.8	179
13	60	52.9	0.9	162.7	2.9	1.5	149
14	16	32.8	0.6	60.8	1.1	0.8	75
15	43	68.2	1.2	161.5	2.8	1.8	178
16	36	50.2	0.9	121.0	2.1	1.5	155
17	110	56.4	1.0	168.9	3.0	1.7	170
18	82	48.6	0.9	200.2	3.5	1.4	142
19	66	75.4	1.3	234.0	4.1	2.2	219
20	114	60.2	1.1	134.3	2.4	1.9	193
21	131	49.2	0.9	166.9	2.9	1.6	156
22	114	55.6	1.0	134.1	2.4	1.7	165

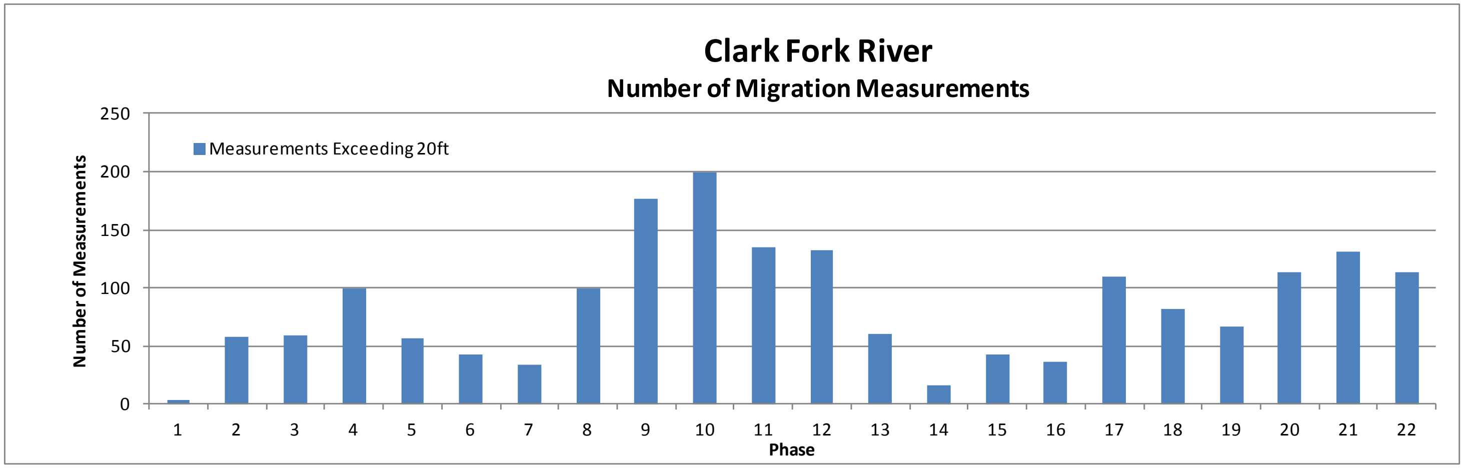

Figure 2-17. Total number of ~1950-2011 migration measurements collected over 20 ft. long, Reach A.

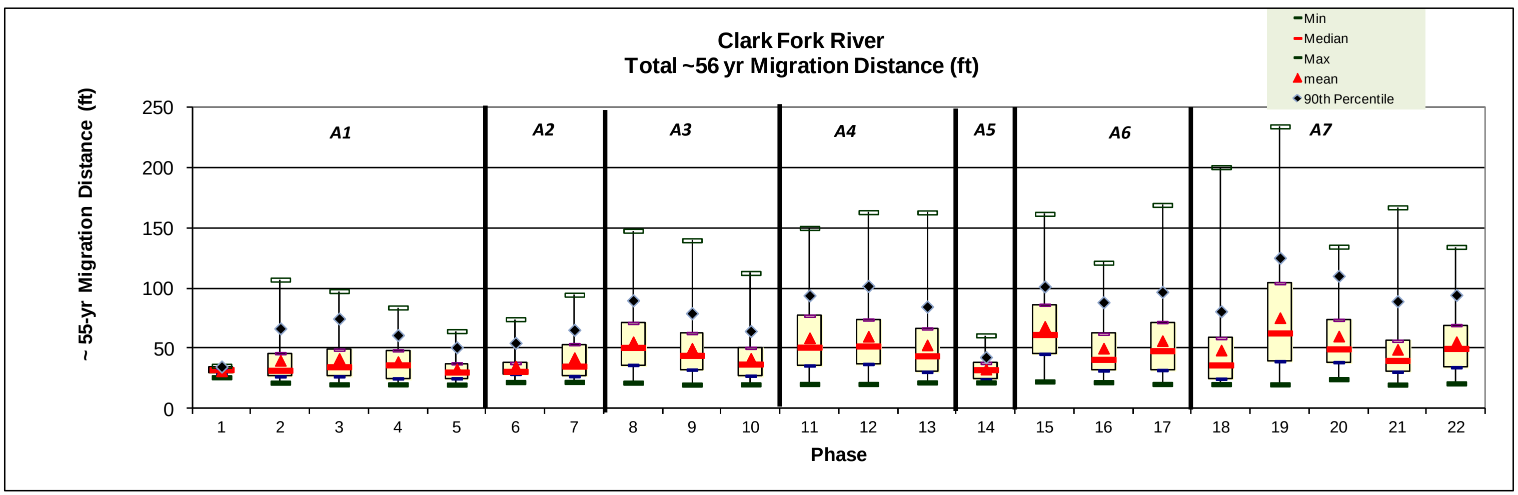

Figure 2-18. Box-and-whisker plots showing range of migration distance measurements by Phase.

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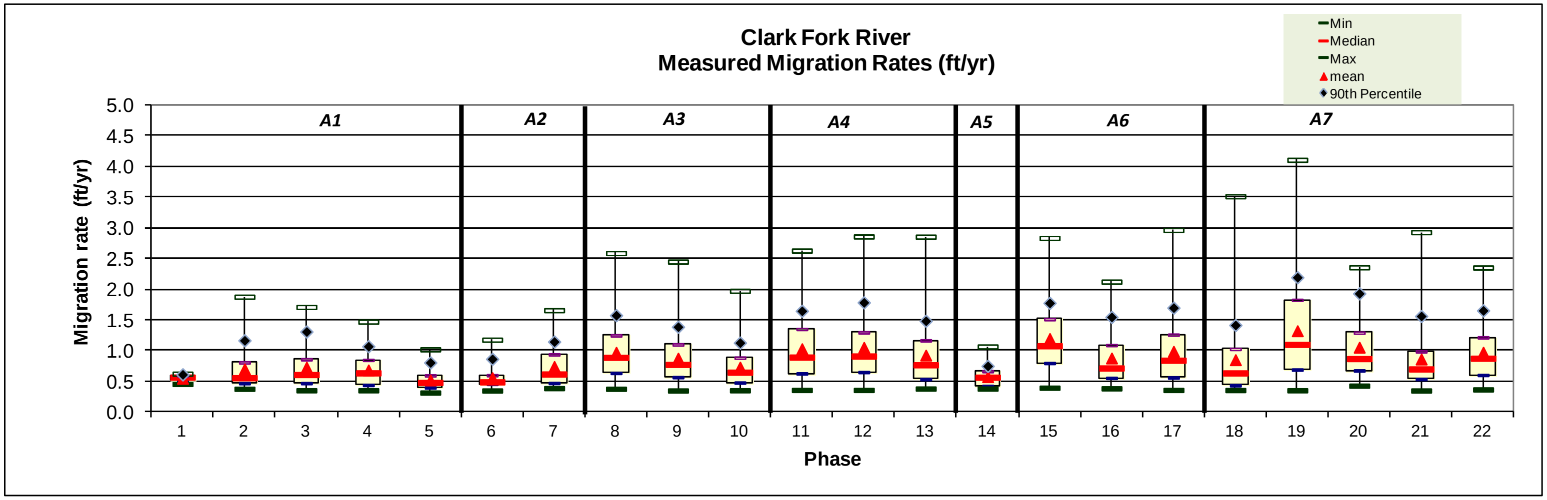

Figure 2-19. Box-and-whisker plots showing range of migration rate measurements by Phase.

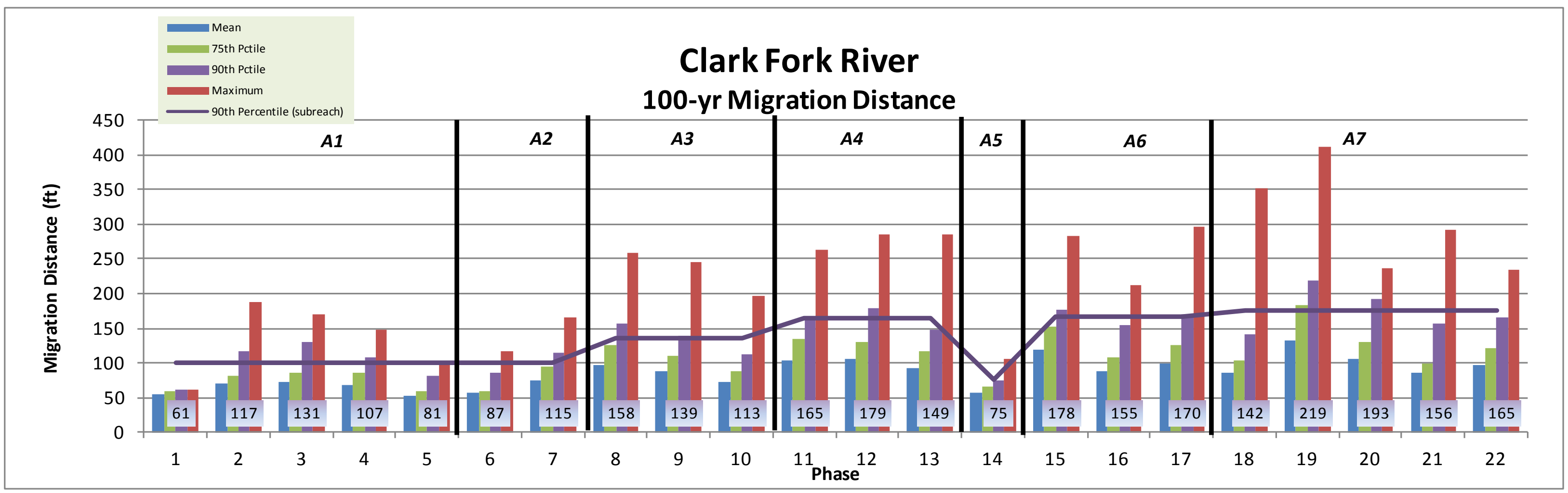

Figure 2-20. 100-year migration distance buffers used to define CMZ erosion hazard area; buffer values (90th percentile) labeled.

Field observations and pit data from other phases indicate that terrace deposits and other surfaces that are perched above the active river corridor are too high to have been flooded and draped by tailings deposits. As a result, these areas were clipped out of the CMZ using geologic mapping and a LiDAR hillshade layer, so that the CMZ boundary can serve as a preliminary screening tool for likely removals. Clipped areas can be seen in the lower portion of Figure 2-21, where the channel flows against terraces and hillslope colluvium. Table 2-7 lists the main confining units in the river corridor, their height above the river corridor (Berg and Hargrave, 2004), and the observed presence of a tailings cap on the unit. Based on the height of the feature and the presence of tailings, certain units were excluded from the Channel Migration Zone-based removal corridor boundary.

Table 2-7. Summary of prominent river corridor geologic units and tailings presence.

Unit	Height above river corridor	Presence of observable tailings	Inclusion in anticipated removal corridor
Qal (alluvium)	0	Common	Included
Qat1 (low terrace)	3-6	Variable	Included
Qat2 *(intermediate terrace)*	6-16	None	Excluded
Qat3 (high terrace)	20-30	None	Excluded
Glacial Outwash	Variable	None	Excluded
Alluvial Fan	Variable	Variable	Variable

Buffers were also adjusted where relatively long channel segments (thousands of feet) within a given phase show minimal historic movement. This also can be seen in Figure 2-21, which shows a change in the buffer width in the middle of Phase 17. In this area, rapid migration was measured upstream of the railroad grade, but downstream, migration was minimal. To account for this, the segment with minimal migration was assigned a nominal 50 ft buffer, which accommodates removals to support bankline riparian integrity.

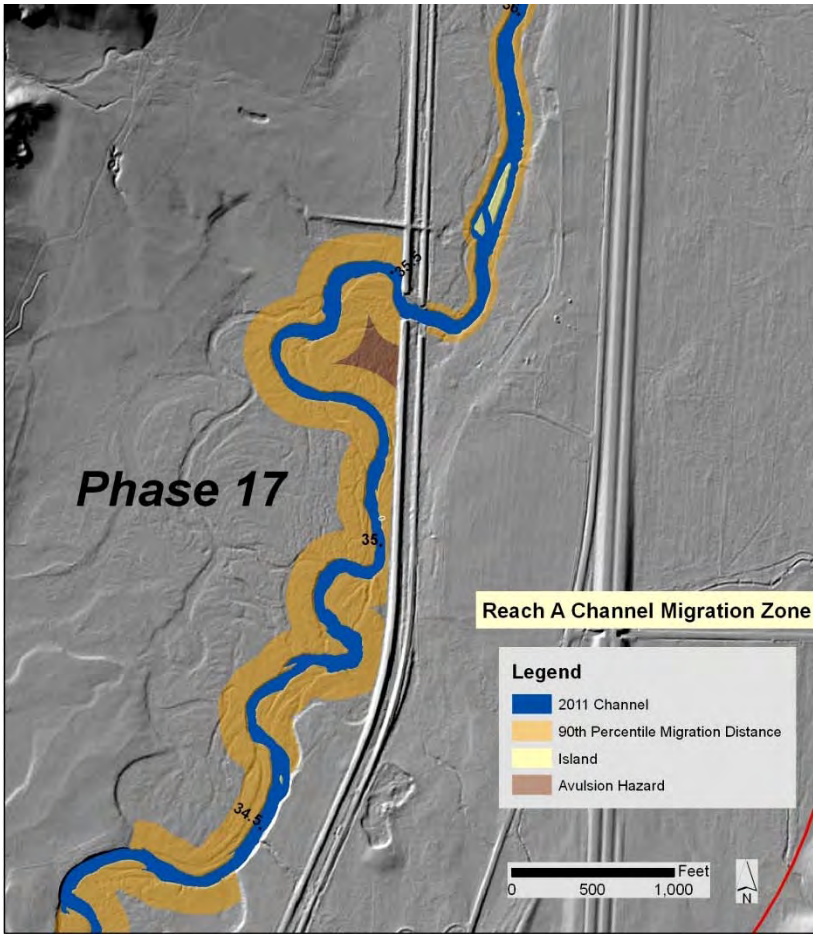

Figure 2-21. Example CMZ map, Phase 17.

Although these maps provide a basic framework for future removal corridor delineations, it is critical to note that prior to being adopted as a removal boundary, the CMZ will be modified based on test pitting and contaminant distribution mapping. This mapping will allow expansion or contraction of the removal corridor based on site specific-data and contaminant removal criteria. Thus, the boundaries will change with future phase-scale investigations. That said, a summary of the acreages included within each phase does provide some sense of potential removal footprints related to the CMZ. These acreages are totaled in Table 2-8 and Figure 2-22. The total CMZ area, which approximates a maximum removal corridor based on entrainment risk, is 1127 total acres for phases not yet in design, or approximately 25 acres per river mile. Of that total, 48 acres are islands. Figure 2-23 shows the total CMZ acreage by river mile.

Table 2-8. CMZ acreages, Reach A.

Phase*	Island Area (acres)	Buffer Area (acres)	Avulsion Hazard Area (acres)	Total CMZ Area (acres)	Acres per River Mile
3	0.7	60.2	2.2	63.0	31.1
4	8.0	57.8	2.3	68.2	27.8
8	0.5	59.1	4.2	63.8	27.3
9	1.3	85.5	7.8	94.7	33.2
10	1.2	79.6	7.9	88.7	27.9
11	0.2	84.0	6.1	90.3	40.4
12	11.3	84.9	17.9	114.2	46.4
13	1.0	40.4	0.0	41.4	34.2
14	0.0	11.9	0.0	12.0	13.7
17	1.1	97.4	2.3	100.8	28.2
18	5.2	58.0	8.1	71.3	41.4
19	10.0	67.1	0.8	77.9	53.4
20	0.6	87.9	8.2	96.6	46.4
21	0.6	64.1	6.9	71.6	32.3
22	0.5	63.4	3.3	67.3	36.8
Total	47.8	1001.2	78.1	1127.2	25.2

*Does not include phases currently in design.

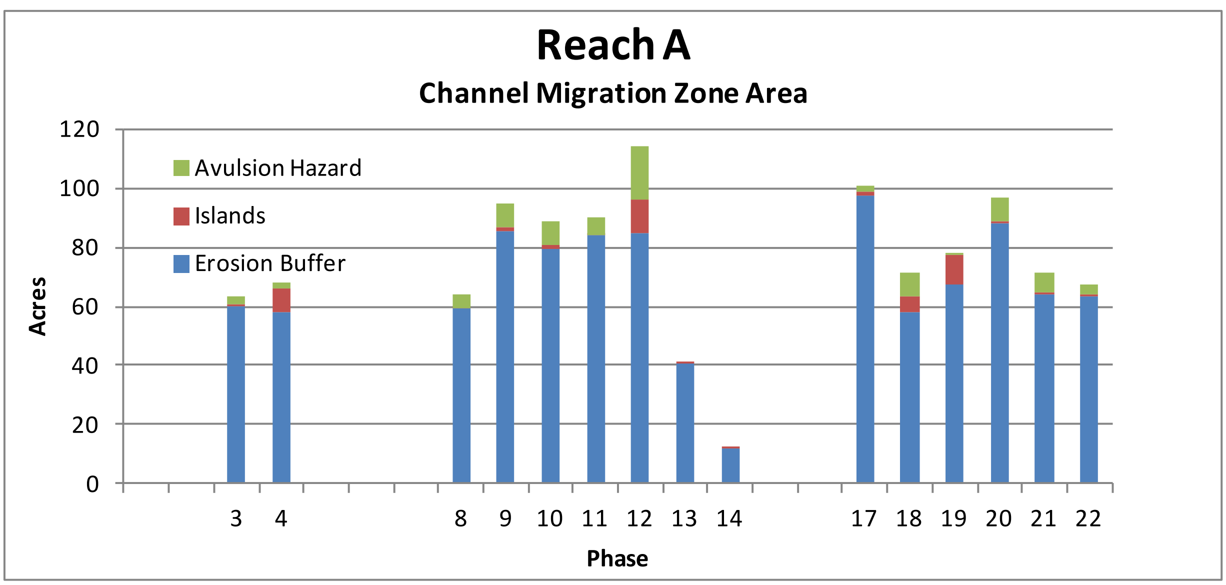

Figure 2-22. Total CMZ acreage by Phase.

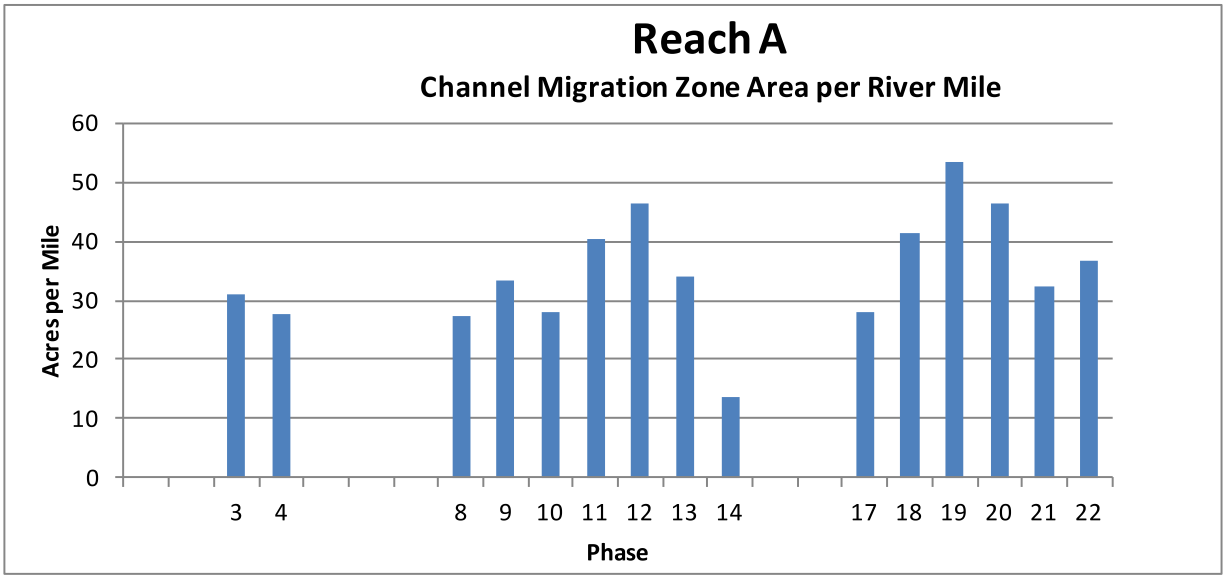

Figure 2-23. Acres of CMZ per River Mile, Reach A.

2.5.5 Floodplain Access

Floodplain access is an important component of remediation design in Reach A because hydrologic connectivity between the river and floodplain shapes riparian recovery and long-term geomorphic stability in the reach. Previous evaluations have shown the river to be locally detached from the floodplain, primarily due to aggradation on the floodplain surface that has increased bank heights and channel capacity. As a result, the frequency of overbank flooding has been reduced and the depth to groundwater increased, both of which adversely impact overall river health and riparian corridor sustainability.

One technique that has been employed thus far in support of remediation design is inundation modeling. With this technique, the high resolution LiDAR data is overlain with a simulated water surface plane that is roughly calibrated to the 2-year water surface. All pixels below that plane are then identified as wet during the 2-year event, and areas above remain dry. To date, the 2-year water surface plane has been calibrated using hydraulic modeling results from phases under design.

For this effort, the modeled 2-year water surface was not available, so calibration of the inundation model was done qualitatively by matching inundation modeling completed in Phases 15 and 16 (Tetra Tech, 2012). The water surface plane was then established as an elevation above the water surface at the time of the LiDAR data collection. The calibration showed a good match of the modeled 2-year water surface elevation with a water surface plane located 2.44 feet above the water surface elevation at the time of the mapping (2006). Because this calibration technique is coarse and site-specific variations in stage/discharge are expected, the results presented here are approximate and are intended to broadly characterize relative levels of entrenchment in Reach A.

An interesting aspect of the inundation modeling calibration is the close correlation between the modeling results and the most active Bing Imagery (© 2013 Microsoft). The Bing Imagery in this area was collected between July 9th and 17th, 2011, when flows were still well above average following the 2011 runoff peak (dates of the Bing Imagery were obtained using an online Bing Metadata App). The mean daily flows during that time frame ranged from 550 to 800cfs. As described in Section 3 of this report, the estimated 2-year discharge for the Clark Fork River near Galen is 584cfs. So, during the time of imagery collection, the river was flowing close to or just above a 2-year discharge.

Figure 2-24 and Figure 2-25 show the inundation modeling layer superimposed on the Bing imagery. The modeled inundation extent visually correlates well to the inundated areas seen on the imagery suggesting that the model is a fairly good representation of floodplain connectivity during an approximate2yr flow event.

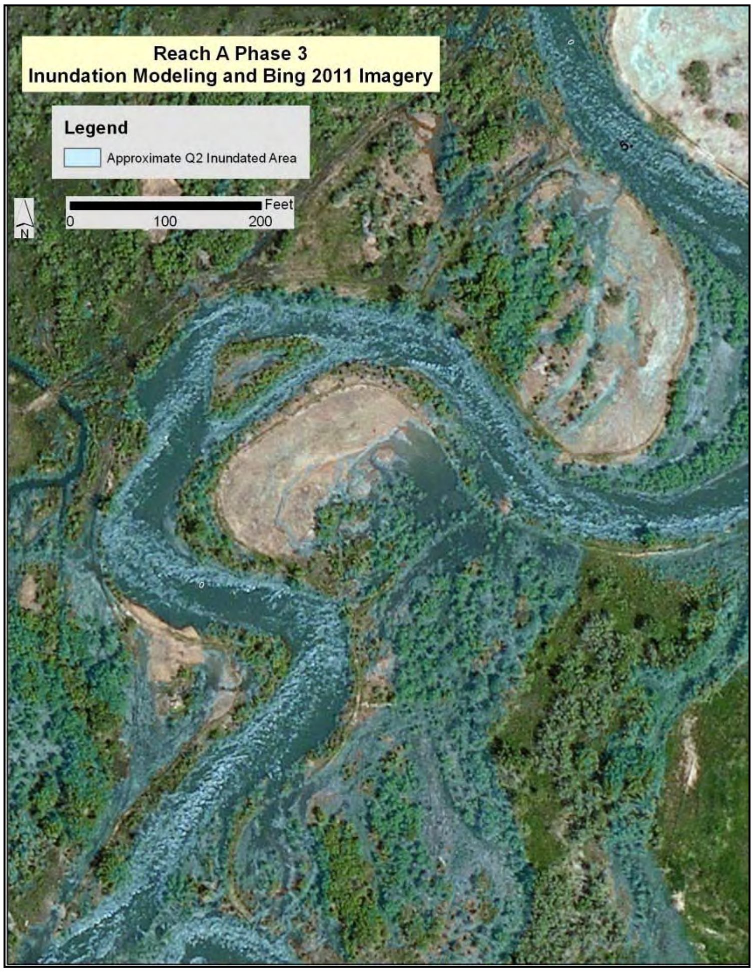

Figure 2-24. Inundation modeling layer (blue) overlain on Bing Imagery, Phase 3.

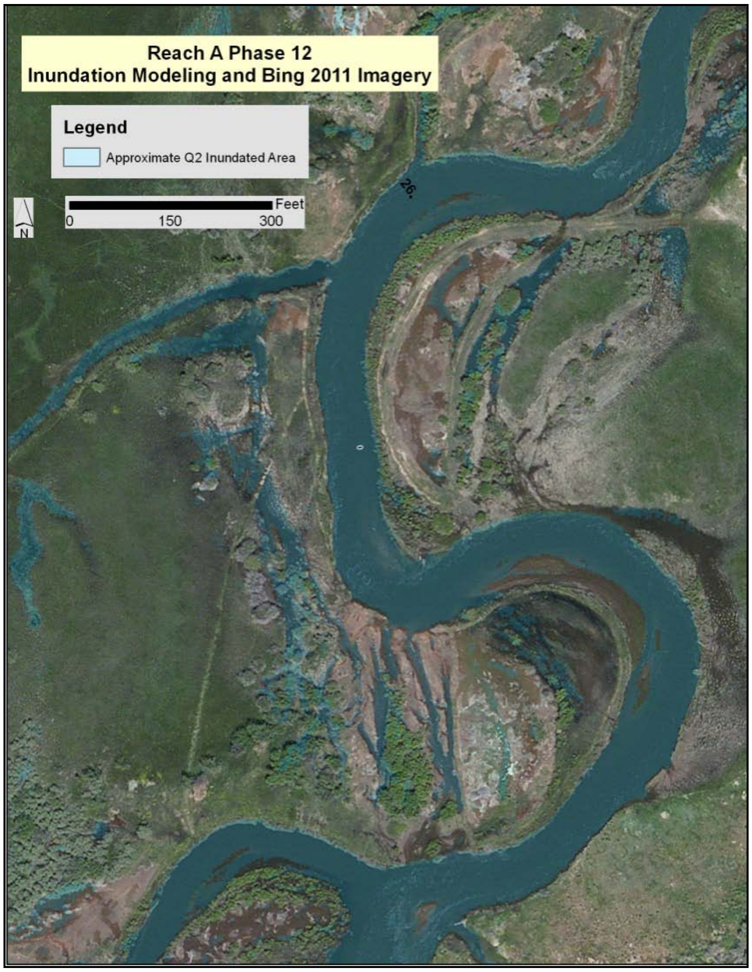

Figure 2-25. Inundation modeling layer (blue) overlain on Bing imagery, Phase 12.

Inundation maps for the entirety of all phases of Reach A are compiled in Appendix E. These maps highlight areas of inundation within the active river corridor, as well as floodplain depressions and swales that may reflect historic channel courses or potential avulsion pathways.

Figure 2-26 presents the inundated floodplain area within the active meanderbelt of each Phase of Reach A. Only the meanderbelt inundation area was quantified to highlight areas of channel entrenchment. As the acreage of inundation has been normalized to valley mile, the results provide a good depiction of entrenchment and floodplain isolation. The results show that entrenchment varies substantially between subreaches, and that there are no clear downstream trends in entrenchment. This correlates well with field observations that recorded discontinuous entrenched channel segments throughout Reach A. On an acres per valley mile basis, Phases 3, 8, and 11 show the most floodplain access, whereas the most limited floodplain access is in Phase 10 and Phase 14.

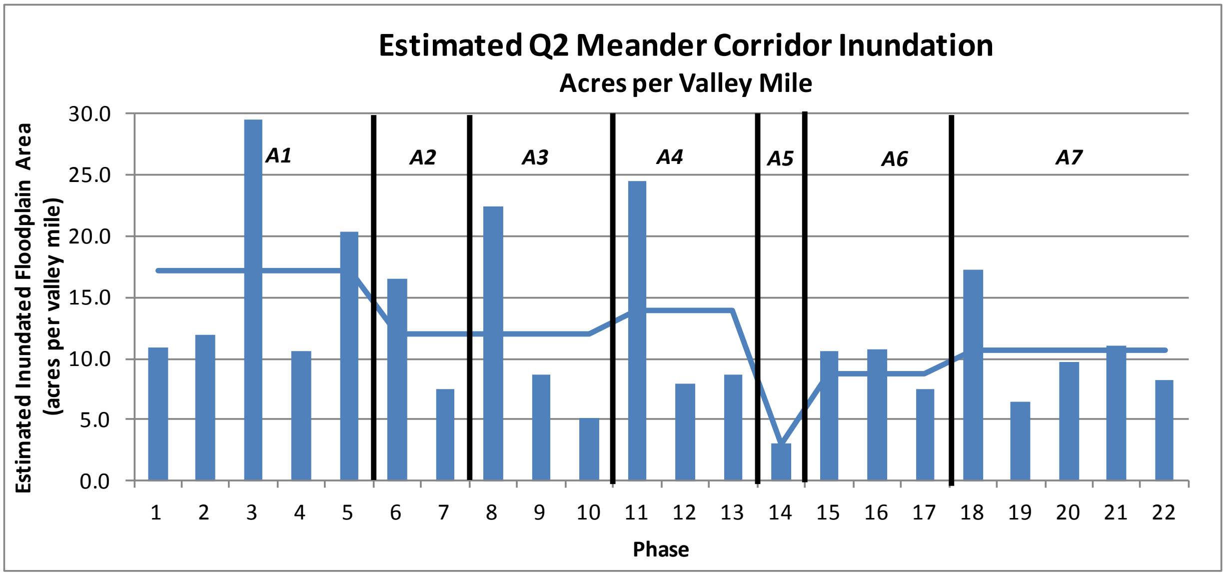

Figure 2-26. Estimated inundated floodplain area within the Clark Fork River meanderbelt, Reach A.

2.5.6 Riffle Density

High riffle densities can highlight areas of channel oversteepening, and have been evaluated on Grant Kohrs Ranch (Phases 15 and 16) to assess potential nickpoint formation and movement (Swanson, 2002). During the field investigation, riffle crests were mapped using a handheld GPS. A total of 217 riffle crests were mapped through the subreaches floated (all Reach A subreaches except Phases 1, 2, 5, 6, 7, 15, 16).

Results show the riffle densities tend to decrease in the downstream direction between Phases 3 and 19, with an abrupt increase in lowermost Phases 20-22 (Figure 2-27). Typically, gravel bed streams have riffle densities on the order of every 5-7 channel widths. Through Reach A, that riffle frequency is only approached in uppermost Phases 3 and 4, and lowermost Phases 20-22 (Figure 2-28). By and large, riffle densities in Phase 7-19 are low, which may reflect lack of overall bedform complexity and habitat quality in these areas.

At this scale, there is no evidence of concentrated riffle features in Reach A that may indicate active downcutting. Any grade discontinuities are likely at a smaller scale, and thus should be considered during individual phase investigations.

CDM Smith

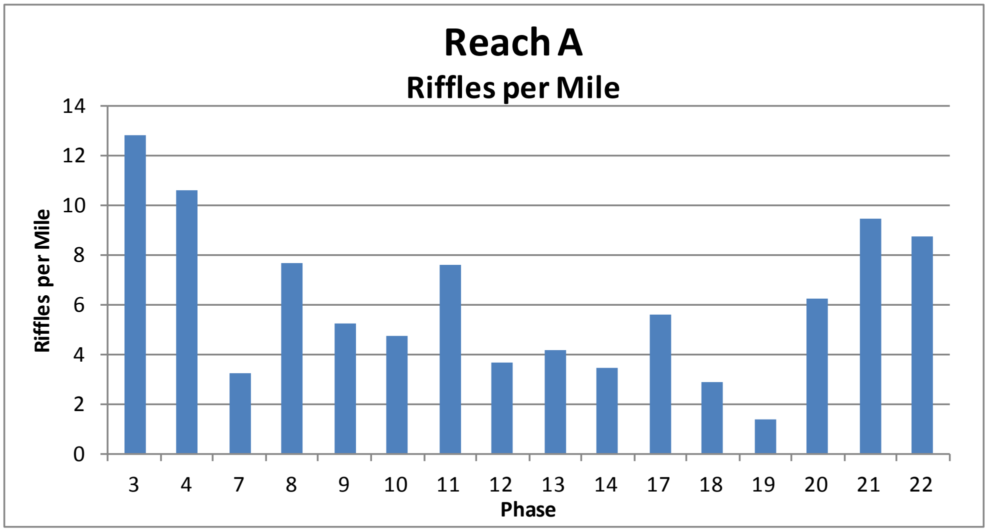

Figure 2-27. Inventoried riffle density (riffles per mile), Reach A.

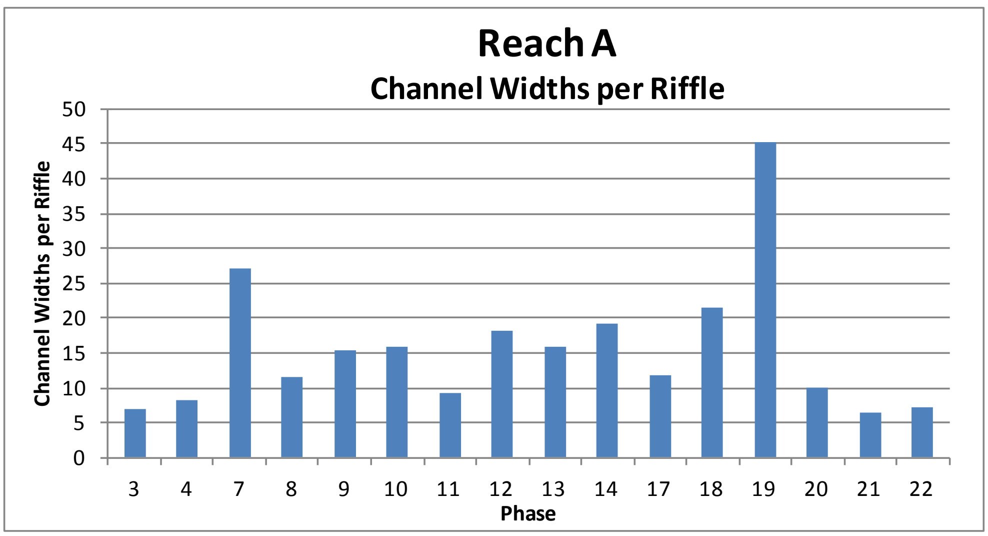

Figure 2-28. Number of channel widths per riffle, Reach A field inventory.

2.6 Subreach Characterization

The following section contains summary descriptions of each Subreach drawing from both quantitative analyses and qualitative field observations.

2.6.1 Subreach A1 (RM 0.8-10.9; Phases 1-5)

Subreach A1 consists of the first 10.1 miles of Reach A, extending from just above Warm Springs Creek to near Dry Cottonwood Creek Ranch. The geomorphology of the upper 3.4 miles of this subreach, Phase 1 and Phase 2, has been previously described (CDM and AGI, 2010) as has Phase 5, which is the lowermost 2.2 miles of Subreach A1(Terragraphics, 2012).

This subreach is geologically unconfined, with a well-developed river corridor at the eastern margin of upper valley glacial outwash deposits. A low terrace abuts the river corridor in the lower end of Phase 4, and Phase 5 flows against the toe of the Dry Cottonwood Creek alluvial fan.

GLO maps show a large shift in channel location at the boundary between Phase 2 and 3, where the channel was relocated to site the Perkins Lane bridge (Appendix B, Figure B-1).

The highest migration rates measured in Subreach A1 is in Phase 3, where the 100-year erosion buffer is 131 feet wide. Although migration rates are relatively high, the extent of severely eroding bankline in this phase is typical of the subreach. Phase 3 is also marked by significantly more floodplain connectivity than any other, potentially reflecting new floodplain development and floodplain connectivity via meander migration.

Extensive tailings deposits were observed in the upper banks in Phase 3. Coarse toe material in the banks increases in the downstream direction, and although floodplain connectivity is good, there are isolated areas of high banks and entrenchment (Figure 2-29). This likely reflects areas where especially thick tailings deposits (such as natural levees) now comprise the active bank. Figure 2-30 shows variable bank heights and tailings thicknesses that demonstrate that variability. The historic floodplain below tailings deposits commonly supports mid-bank woody vegetation, or lower bank root remnants (Figure 2-30). Mid-bank woody vegetation tends to be of moderate density. Bank trampling by cattle was noted as extensive in Phase 3, and this trampling locally occurs where tailings comprise the bank. Gravel riffle crests are common; riffle crest density was also noted as high—the riffle crest density of almost 13 riffles per mile is the highest of all of the inventoried phase segments. Gravel/cobble toes are commonly discontinuous and upwardly convex, indicating exposure of buried gravel bars (Figure 2-31).

Figure 2-29. View downstream of locally entrenched channel segment, Subreach A1, Phase 3, RM 5.5.

Figure 2-30. Right bank tailings deposit, Subreach A1, Phase 3, RM 6.15.

Figure 2-31. Coarse cobble bank toe with convex surface, Subreach A1, Phase 3, RM 6.0.

Figure 2-32 shows the abandoned Milwaukee Rail grade bisecting the Clark Fork River floodplain as it trends northward along the stream corridor. In the upstream portion of Phase 3, the river flows on the west side of the railroad grade, which forms a distinct linear embankment on the floodplain. At RM 5.25, the river crosses the grade under an old railroad bridge, which marks the original river location during the early 1900s when the Milwaukee Line was built. There two primary channel stability concerns associated with this crossing. First, a large bendway upstream of the bridge is migrating downvalley, such that it is effectively migrating northward past the bridge, creating a situation where the river will have to flow up-valley to get to the bridge (Figure 2-32). Secondly, Clark Fork River overflows on the west side of the embankment either have to pass through the bridge opening or continue northward on the west side of the railroad grade which acts as a levee, preventing water from returning to the river. As floodwaters flow north, they enter Lost Creek, which then can convey flow under the railroad grade and back to the river. This poses an avulsion risk to the Clark Fork River; in the event that the alignment to the bridge continues to decay, more floodwater will flow northward on the west side of the rail line and into Lost Creek. This may result in Lost Creek capturing this segment of the Clark Fork River. Remediation design in Phase 3 should thus carefully consider the role of the railroad embankment in terms of the bridge approach, overflow patterns, the stability of lower Lost Creek, and the conveyance capacity of Lost Creek through the embankment in Phase 4. The river avulsion hazard in Phase 3 was not mapped in the CMZ removal corridor boundary because of its extent and complexity. However, the RIPES data do show some slickens in the area, and as such Phase 3 sampling will need to extend north of RM 5.25 on the west side of the abandoned railroad grade.

Phase 4 is very sinuous, which has allowed the channel to maintain a low slope (0.15%) even though the valley slope is relatively steep (0.40%). Inundation modeling indicates very limited floodplain access and Figure 2-33 shows the typical high banks that limit floodplain access. Two bendways have cut off in Phase 4 since 1950; one relatively old cutoff occurred at RM 8.4, and another occurred since 2006 at RM 7.6. There are eight acres of islands in Phase 4. The bank inventory recorded massive and extensive exposures of tailings. Locally, dense willows and water birch reinforce the mid-bank; the highest concentrations of these vegetation-reinforced banks tend to be on the downstream limbs of meander bends (Figure 2-34). The effectiveness of mid-bank vegetation is demonstrated in Figure 2-35 where banks with mid-bank vegetation are stable, whereas those without are more prone to undercutting and collapse of upper bank tailings. Bank trampling by cattle is common, which has locally destabilized banks and exposed tailings (Figure 2-36). Phase 4 provides excellent opportunities for the preservation of extensive lengths of vegetated mid-bank, to capitalize on existing bank stability and toe material complexity.

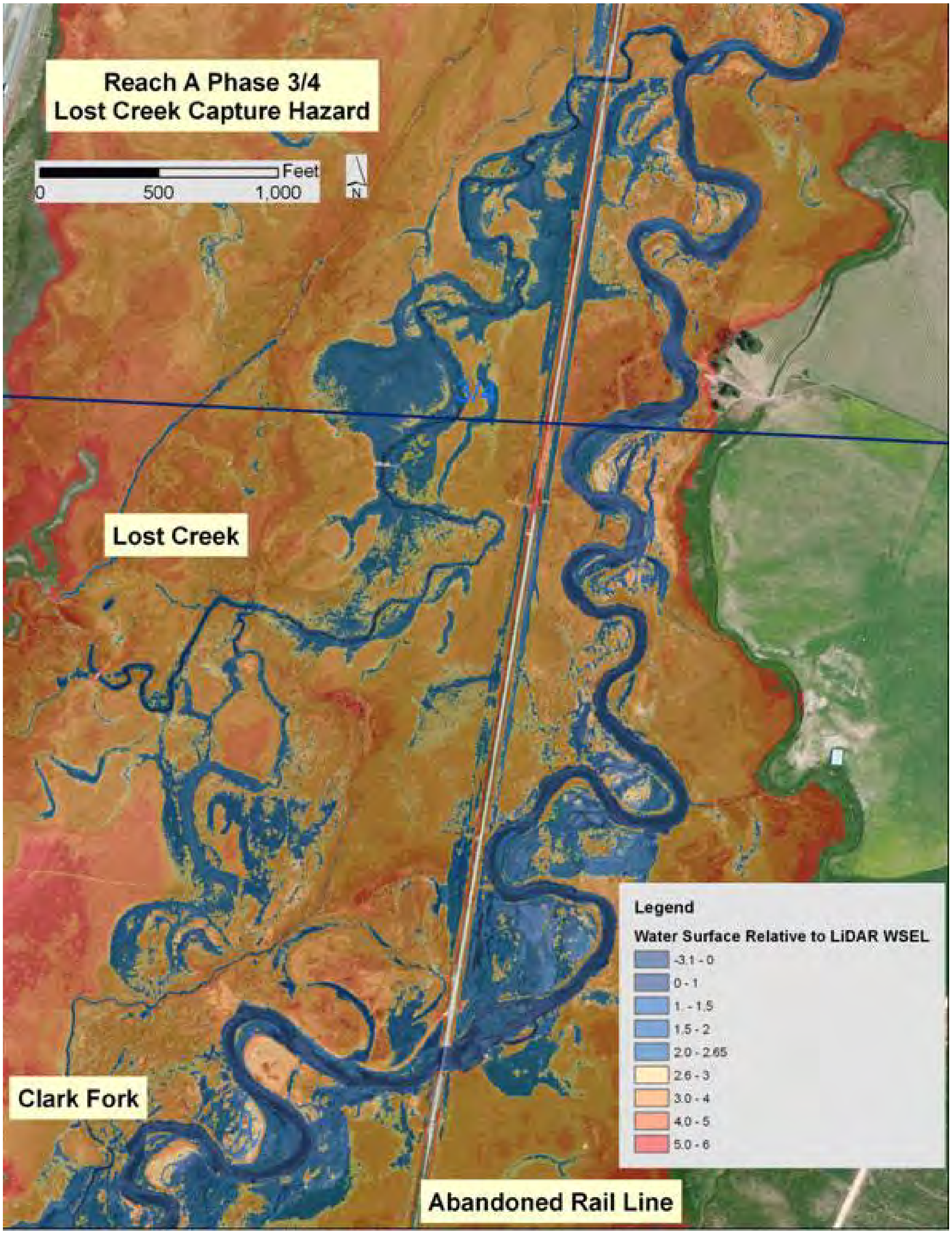

Figure 2-32. Inundation mapping showing avulsion hazard at Lost Creek, Phases 3 and 4.

Figure 2-33. High right bank showing coarse bar deposit in toe with overlying historic floodplain deposits and tailings cap; inundation modeling indicates lack of floodplain connectivity at this location, Subreach A1, Phase 4, RM 7.1.

Figure 2-34. View downstream of dense woody vegetation on downstream limb of meander band, Subreach A1, Phase 4, RM 6.9.

Figure 2-35. Panorama showing role of mid-bank woody vegetation in providing bank stability (left), versus low stability (right); Subreach A1, Phase 4, RM 7.6.

Figure 2-36. Cattle grazing in river corridor, Subreach A1, Phase 4, RM 6.4.

Lost Creek enters Phase 4 at RM 6.75. On the day of the field inventory (11/1/12), Lost Creek was contributing 65 cfs (Figure 2-37). The mouth and lower end of Lost Creek were stable and effectively reinforced by floodplain vegetation. A breached beaver dam was present at the mouth of the creek.

Figure 2-37. Mouth of Lost Creek, Subreach A1, Phase 4, RM 6.75.

2.6.2 Subreach A2 (RM 10.9-14.9; Phases 6-7)

Subreach A2 is 3.9 miles long, extending from near Dry Cottonwood Creek at Galen Road down to below Paracini Pond. This subreach is currently under design and the upper 2.1 miles (Phase 6) has been described in previous documents (Terragraphics, 2012). Phase 7 is in the preliminary stages of design, hence data have been collected but a Preliminary Design Plan has not been developed. In Phase 7, the river is strongly influence by a high terrace and glacial outwash terrace on the west side of the river, and several alluvial fans enter the corridor from the east (Appendix A, Figure A-2).

The GLO maps suggest that both Phases 6 and 7 have approximately 1mile long channel segments that are hundreds of feet west of the 1869 channel location. In Phase 6, this correlates to a large floodplain swale that is now a hayfield. In Phase 7, this correlates to a broad low floodplain area northeast of Paracini Pond (Appendix E, Figure E-7).

Tailings exposures in Phase 7 banklines were noted in the field as sporadic in location and variable in thickness; locally visible tailings thicknesses in the banks reach 24 inches, and the deposits are commonly overlain by a few inches of soil. Terrace exposures on the west side of the corridor are erosion resistant, supported by coarse toe material and indurated mid-bank deposits (Figure 2-38). The terrace on the right bank in Phase 7 was described as 30 ft tall, with erodible sand/silt stratifications that support dense numbers of bank swallow nests. This terrace is also exposed downstream in Phase 8 (Figure 2-44).

Figure 2-38. View downstream of left bank terrace exposure, Subreach A2, Phase 7, RM 14.25.

2.6.3 Subreach A3 (RM 14.9-23.2; Phases 8-10)

Subreach A3 is 8.4 miles long, extending from just above Racetrack Creek to approximately 3 river miles below Sager Lane and Dempsey Creek.

The upper end of Subreach A3 near Racetrack Creek is marked by an abrupt channel and valley steepening as the river flows against glacial outwash and terrace deposits. In Phase 8, the river flows along the east valley wall that consists of fine-grained colluvial deposits and Tertiary-age units. Almost 3,000 feet of bankline in Phase 8 consists of these deposits, which are high in elevation and therefore clipped from the CMZ removal corridor boundary. Much of this bankline is armored as well; Phase 8 has almost 1,000 feet of mapped bank armor, much of which is on right bank, where homes have been built on the high surfaces that are actively eroding (Figure 2-39). In the active stream corridor, bank structure commonly consists of overhanging upper bank vegetative mats that effectively conceal tailings. When the overhanging bank fails, tailings deposits become exposed (Figure 2-40). These overhanging vegetative mats may be a short-term consequence of 2011 flooding. With time, these draping features may very well be stripped away by water, ice, and cattle trampling. Mid-bank woody vegetation, although sporadic, locally significantly contributes to bank stability (Figure 2-41).

Figure 2-39. View downstream of active terrace erosion on right bank, Subreach A3, Phase 8, RM 15.0.

Figure 2-40. Left bank exposure of tailings where overhanging material has failed, Subreach A3, Phase 8, RM 15.1.

Figure 2-41. View upstream of left bank vegetation reinforcement, Subreach A3, Phase 8, RM 16.85.

Racetrack Creek enters Phase 8 at RM 15.7. During the field inventory on 10/17/2012, the creek was contributing approximately 15-20cfs. As it approaches the Clark Fork River, Racetrack Creek is a stable channel with abundant mobile spawning gravels (approximately 16-24mm), vegetated banks, and good bedform complexity (Figure 2-42 and Figure 2-43).

Figure 2-42. View upstream of lowermost Racetrack Creek, Subreach A3, Phase 8, RM 15.7.

Figure 2-43. Racetrack Creek bed substrate, Subreach A3, Phase 8, RM 15.7.

Just below the Racetrack Creek confluence in Phase 8, there is an approximate 1,500 ft.-long abandoned channel to the west of the modern channel at RM 16.2 that forms a prominent, sinuous wetland feature. The channel has slickens on its margins; remediation in this area may provide excellent opportunities for integrated side channel restoration. Based on the size and planform of this abandoned channel, it represents an abandoned Clark Fork channel versus an avulsed section of lower Racetrack Creek.

Subreach 8 has almost 1,000 feet of bank armor most of which is on the right bank. Bank migration rates in Phase 8 average 1.0 ft/year with a maximum measured rate of 2.6 ft/year since 1950.

On the east side of the valley in Phase 8, terraces and colluvial deposits tend to be very fine-grained and erodible relative to exposures on the west side of the corridor. These units are actively contributing sand and finer material to the river (Figure 2-44). These high surfaces are draped by younger, similarly fine-grained terrace and colluvial units (Figure 2-45).

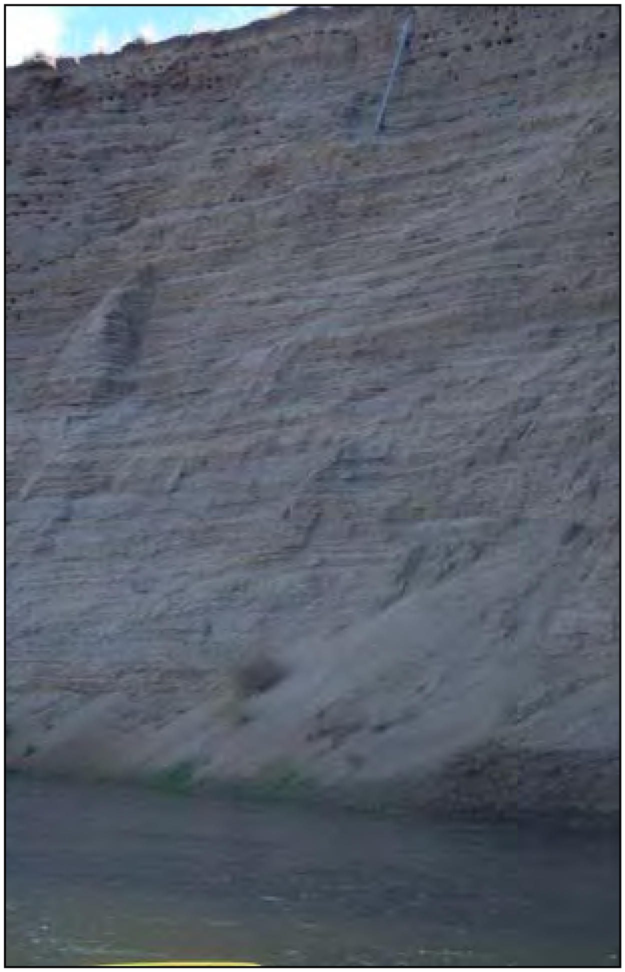

Figure 2-44. High sandy terrace deposits on right valley wall, Subreach A3, Phase 8, RM 16.

Figure 2-45. View downstream showing intersection of high valley wall sediments (mapped as Tertiary) and younger draping terrace (left), Subreach A3, Phase 8, RM 16.1.

At the Phase 8/9 boundary, the river crosses to the west side of the valley, where it flows against coarse glacial outwash deposits (Figure 2-46). These units are derived primarily from Flint Creek Range glacial outwash, and are distinctively coarse grained and more stable than the high exposures on the east side of the valley, which are derived from Tertiary volcanics, coarse granites, and associated alluvial fans. These stable terrace margins also support deep pools, in contrast to those on the east valley wall. Downstream of the Orofino Creek alluvial fan at RM 17.75, the high left bank terrace is irrigated, and significant seepage was noted at the toe (Figure 2-47).

Figure 2-46. View downstream of left bank glacial outwash exposure, Subreach A3, Phase 9, RM 17.9.

Figure 2-47. Outwash terrace, Subreach A3, Phase 9, RM 17.9.

Where not against the high terrace, bank heights in Phase 9 were noted as consistently low, with laminated tailings ranging from less than a foot to over 2 feet thick. Migration rates in Phase 9 are relatively high, with an average rate of 0.9 ft/yr for all banks that show in excess of 20 ft of movement since 1950. One bioengineered bank treatment was mapped in Phase 9 at RM 19.7 (Figure 2-48 through 2-50).

Figure 2-48. Topple failure of overhanging tailings horizon, Subreach A3, Phase 9, RM 17.4.

Figure 2-49. View downstream of right bank showing low bank height and tailings cap, Subreach A3, Phase 9, RM 19.05.

Figure 2-50. Typical bank stratigraphy showing historic floodplain unit (gray) and overlying tailings, Subreach A3, Phase 9, RM 19.5.

GLO maps show a major deviation between the 1869 and 2011 channel course in the middle of Phase 10 at RM 21.5 (Appendix B, Figure B-3). Although there are no sections lines in this area to verify the GLO mapping, inundation modeling shows an abandoned channel over 1,000 feet east of the modern channel that coarsely correlates to the GLO mapping (Appendix E, Figure E-10). Although this area of distant floodplain is low in elevation, floodplain connectivity with the active meander corridor itself is low.

A total of 9,711 feet of bankline in Phase 10 was mapped as severely eroding, which at almost 30% of the bankline is the highest percentage of any inventoried subreach. Migration rates in Phase 10 are moderate, although a total of 199 migration vectors were collected in the subreach, indicating extensive, although not particularly rapid bank erosion. On an acres per mile basis, Phase 10 has the most extensive floodplain turnover rates, with over 3 acres per mile of floodplain eroded since the 1950s (Section 2.5.3). Grazing pressure and bank trampling by cattle is common, which may contribute to the bank instability. Tailings exposed in the banks commonly exceed 24 inches in thickness. Phase 10 demonstrates the potential for the channel to exhibit high floodplain turnover rates due to moderate rates of movement over extensive bank lengths.

Dempsey Creek enters Phase 10 approximately 1,000 feet downstream of Sager Lane at RM 20.35. On the day of the field inventory (10/18/12), Dempsey Creek was contributing on the order of 5 cfs. The lower end of the creek has stable banks with dense vegetation, much of the creek was backwatered due to a beaver dam at the mouth (Figure 2-51).

Figure 2-51. Dempsey Creek near mouth, Subreach A3, Phase 10, RM 20.35.

2.6.4 Subreach A4 (RM 23.2-29.1; Phases 11-13)

Subreach A4 extends from approximately 3 miles below Dempsey Creek to Deer Lodge. The slope of the river and valley is markedly lower in this subreach relative to upstream, and extensive slickens deposits have been mapped on the floodplains of Phase 11 and Phase 12 (Figure 2-52).

Phase 11 has fairly extensive floodplain connectivity, with low floodplain areas both in abandoned channel swales and in broader areas of flow spreading (Appendix E, Figure E-11). Tailings exposed in the banks are relatively thick and commonly massive (poorly laminated), suggesting historic infilling of floodplain swales by contaminants. Test pitting in Phase 11 should help identify tailings accumulations in accessible floodplain swales that could be prone to recruitment. Woody vegetation both in the streambanks and the adjacent floodplain are highly decadent (lacking vigor;Figure 2-53) and include both willow and water birch. Phase 11 is also characterized by long eroding cutbanks, with recent movement evidenced by undermined fences and broad, gently sloping point bars that are indicative of high migration rates. Bank trampling is common, and cutbanks commonly exceed 5 ft in height. Locally, clay lenses support the bank toe. A distinct, white, 1 inch thick ashy horizon exposed terrace margins may represent the Mazama Ash, a 6,800 year old deposit that records the eruption and collapse of Mt. Mazama at what is now Crater Lake in south-central Oregon.

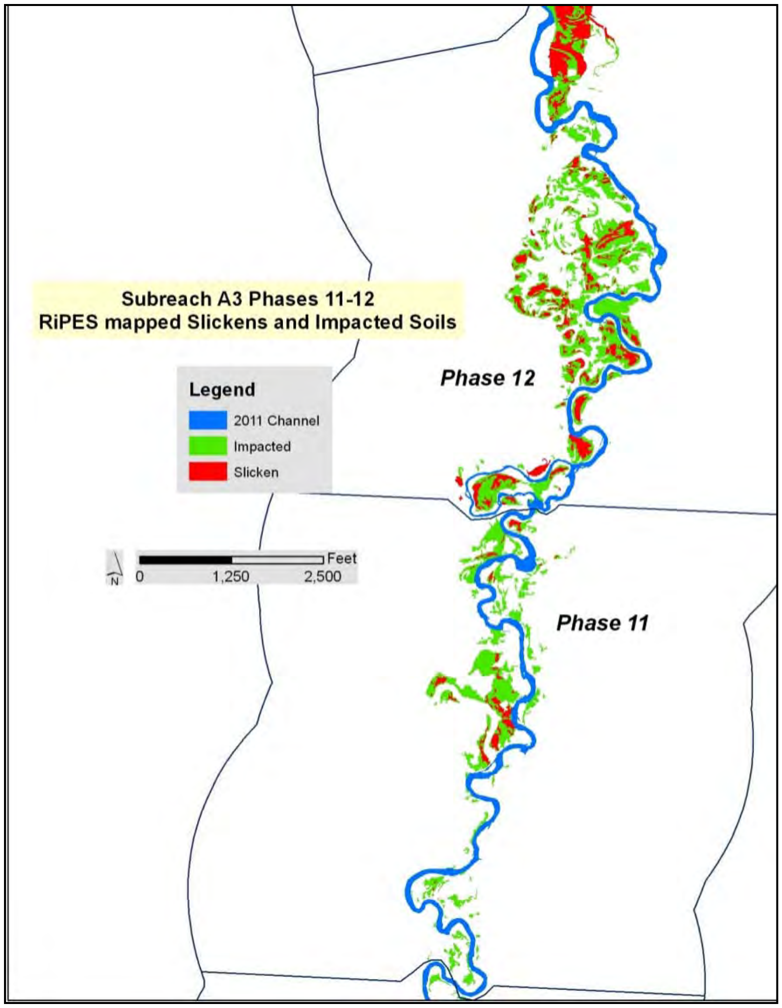

Figure 2-52. Mapped Slickens and Impacted Soils Polygons, Phase 11 and 12 (CH2MHill, 2008).

Figure 2-53. Decadent willows on bankline.

Bank erosion commonly consists of toe undercutting and progressive collapse of overhanging, typically contaminated upper banks (Figure 2-54 through Figure 2-56). From 2006 to 2011, over 2.5 acres of Phase 11 floodplain area mapped by RiPES as impacted soils were recruited to the channel by bank erosion. Approximately 1,100 square feet of slickens were eroded during that same timeframe.

Figure 2-54. Coarse toe material, Subreach A4, Phase 11, RM 23.5.

Figure 2-55. Bank undercutting and upper bank topple failure, Subreach A4, Phase 11, RM 24.15.

Figure 2-56. View downstream of typical cutbank erosion, Subreach A4, Phase 11, RM 24.8.

The uppermost portion of Phase 12 (RM 25.6) hosts a major avulsion that occurred sometime since 1950 (Figure 2-57). This avulsion cut off approximately ½ mile of channel that is now a continuous thread of low energy slackwater habitat. The abandoned channel is actively narrowing as the channel is progressively isolated from the main river. The avulsion has created an approximate 9 acre island that will require access considerations during remediation design.

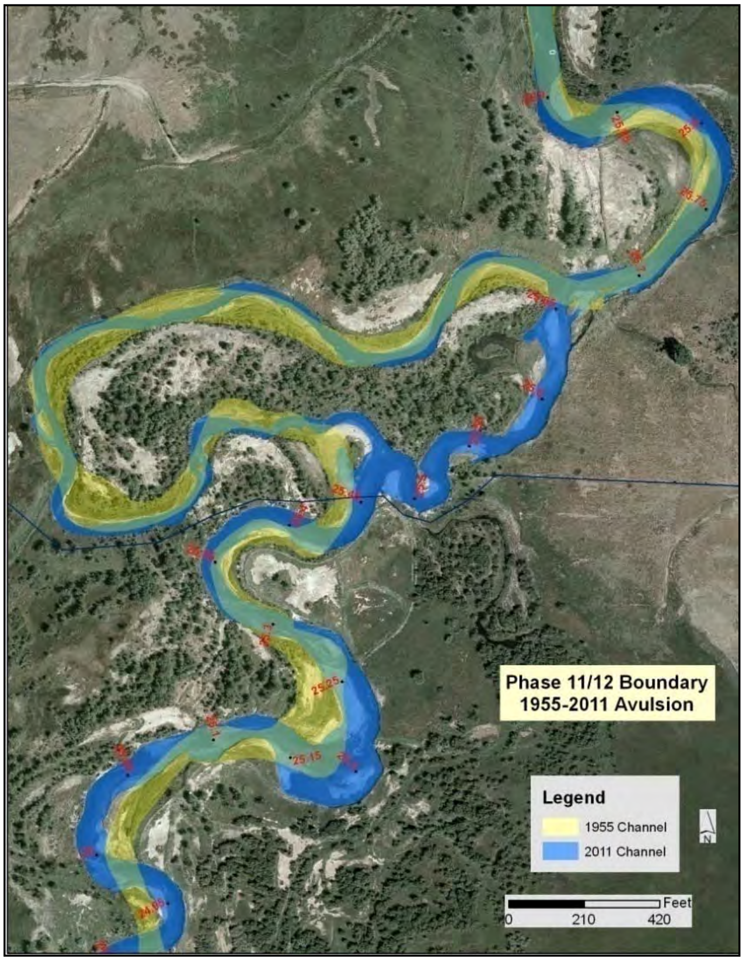

Figure 2-57. 1955-2011 avulsion, Phase 11/12 boundary.

One prominent alluvial fan and several terrace surfaces extend into the river corridor in Phase 12, forming high fine grained banks that are most prominent on the east side of the river corridor (Appendix A, Figure A-3). These high banks are clearly visible in the CMZ maps (Appendix D, Figure D-7).

In the middle portion of Phase 12, the river flows along the east side of the river corridor, flowing along high banks and cliffs along the channel formed by alluvial fans and terraces (Appendix A, Figure A-3). West of the channel, a broad floodplain area has extensive bermed slickens deposits that were inundated in 2011 (Figure 2-58). In several locations the river has migrated into these berms, which has created artificially high banklines. The bed substrate in Phase 12 is increasingly dominated by sand, with broad, highly mobile sand waves visible on the streambed.

Figure 2-58. July 2011 inundation, Reach 12; note secondary channel west of main thread.

On the far west side of the valley, a secondary channel is a prominent, low elevation feature that has been mapped as an avulsion hazard (Figure 2-58; Appendix D, Figure D-7). This channel was mapped as a 40-ft wide slough in 1869. This channel has a meandering planform with tailings in several meander cores. The channel does not currently flow as a perennial side channel; the upper end is dry under baseflow conditions, along its course which is over a mile long, it gains flow from the west, likely including groundwater seepage and irrigation return flows, to create a persistently wetted channel on the lower several thousand feet of channel (Figure 2-58). This prominent feature in Phase 12 should be carefully considered in terms of both contaminant characterization and potential side channel/wetland restoration.

As the river approaches Deer Lodge, bank armoring becomes more common; approximately 12% of the bankline in Phase 13 is currently armored. Although the Subreach is relatively urbanized, it does exhibit active migration relative to the downstream section through town (Phase 14). A total of 60 migration vectors were collected in Phase 13, with an average migration rate of 0.9 ft per year. Floodplain access in Phase 13 is relatively poor.

2.6.5 Subreach A5 (RM 29.1-30.0; Phase 14)

Subreach A5 consists of the town of Deer Lodge. This Subreach is highly confined by terraces on both sides of the channel, and bank armoring is extensive (Figure 2-59 and Figure 2-60; Appendix A, Figure A-3). There are three road bridges and one railroad bridge in Phase 14.

Figure 2-59. Left bank cribwall bank protection Subreach A5, Phase 14, RM 29.4.

Figure 2-60. Rock riprap bank armor, Subreach A5, Phase 14, RM 29.4.

2.6.6 Subreach A6 (RM 30.0-36.3; Phases 15-17)

Subreach A6 extends from the upper end of Grant Kohrs ranch to below the Deer Lodge Water Treatment Plant. The upper 2.7 miles of this subreach (Phases 15 and 16) are currently in design phase and the geomorphology of this section of river has been described in previous documents (Tetra Tech, 2012).

In Phase 17, the river enters a corridor that is confined largely by transportation infrastructure including a railroad grade and I-90. Tailings thicknesses are variable, and distinct buff-colored tailings are commonly capped by up to several inches of darker material (Figure 2-61 through Figure 2-63). Tailings exposed in the bank are noticeably thicker upstream of the railroad bridge in Phase 17 (Figure 2-63) indicating that the embankment has backwatered flood flows and promoted floodplain deposition of the contaminants. As described in Section 2.5.4, migration rates in Phase 17 are markedly higher upstream of the railroad line crossing at RM 35.5. Approximately one mile downstream of the Deer Lodge wastewater treatment lagoons, a high left bank terrace intersects the stream corridor, contributing coarse gravels to the stream channel (Figure 2-64).

Figure 2-61. Relatively thin tailings cap, Subreach A6, Phase 17, RM 35.4.

Figure 2-62. High left bank with decadent willows, Subreach A6, Phase 17, RM 33.1.

Figure 2-63. Eroding right bank, Subreach A6, Phase 17, RM 35.2.

Figure 2-64. Left bank terrace mapped as Q2, Subreach A6, Phase 17, RM 34.2.

2.6.7 Subreach A7 (RM 36.3-56.6; Phases 18-22)

Subreach A7 extends from below the Deer Lodge Wastewater Treatment Lagoons to the end of Reach A at the Little Blackfoot River confluence near Garrison. Confinement in this Subreach is caused by sub parallel lines of I-90 and the railroad grade. One glacial outwash fan extends into the corridor in Phase 19 at the mouth of Mullan Gulch, at the Rock Creek Cattle Road (Appendix A, Figure A-5). Also at the mouth of Mullan Gulch there is an approximate 14 acre island that is crossed by the Rock Creek Cattle Road.

In Phases 18 through 20, exposed tailings thicknesses continue to be highly variable although distinct tailings layers are still distinguishable this far down the corridor (Figure 2-65and Figure 2-66). Bank failures tend to be topple collapses of upper bank fine sediment over a retreating toe (Figure 2-67 through Figure 2-69). There are long stretches in Phase 18 with minimal erosion, and entrenchment varies through the subreach. Bedform complexity is minimal; bed material is coarse and supports long, largely embedded run habitats.

Figure 2-65. Typical bank stratigraphy, Subreach A7, Phase 19, RM 38.6.

Figure 2-66. Bank stratigraphy, Subreach A7, Phase 19, RM 39.1.

Figure 2-67. View downstream of overhanging banks and common erosion pattern, Subreach A7, Phase 20, RM 40.15.

Figure 2-68. Left bank erosion, Subreach A7, Phase 20, RM 40.9.

Figure 2-69. Right bank erosion showing deposition over tailings, Subreach A7, Phase 20, RM 40.95.

The Marshall Maps of 1914 show several cutoffs in Phase 20 (RM 40; Appendix B, Figure B-6). These meander scars are evident on the LiDAR hillshade layer; however, inundation modeling suggests that these oxbows have become relatively perched suggesting downcutting in the subreach (Appendix E, Figure E-20). One of these perched meanders at RM 40 hosts exposed tailings. Bank trampling by livestock is common in Phase 20, which exposes tailings in the bank. Banklines at both riffles and on cutbanks are actively eroding. Streambanks are locally reinforced by a very coarse cobble toe (Figure 2-70).

In Phase 21, one meander at RM 42 appears to have been cut off as part of I-90 development. A total of 1,528 feet of bankline was mapped as armored in Phase 21, and most of that armor is right bank riprap against Interstate-90. In some areas, actively eroding banks against the I-90 embankment are not armored (Figure 2-71).

Similar to upstream areas, tailings in Subreach A7 are commonly obscured by overhanging grassed topbank layers that drape into the channel (Figure 2-72). These overhanging upper bank features commonly form notably symmetrical failure patterns (Figure 2-73).

Figure 2-70. Cobble toe in left bank, Subreach A7, Phase 20, RM 41.5.

Figure 2-71. Right bank erosion adjacent to I-90, Subreach A7, Phase 21, RM 41.75.

Figure 2-72. Left bank upper collapse exposing tailings, Subreach A7, Phase 21, RM 42.9.

Figure 2-73. Symmetrical topbank overhang and collapse, Subreach A7, Phase 21, RM 43.65.

In Phase 22, tailings exposures in the banks increase significantly (Figure 2-74). There is almost no upper bank woody vegetation reinforcement, and most erosion sites are long eroding cutbanks. At the lowermost end of Reach A at the Little Blackfoot confluence, the Marshall maps of 1914 show that the configuration of the confluence was different than today, likely reconfigured by the I-90 corridor (Appendix B, Figure B-6). In 1914, the river formed a major meander at the confluence, the core of which contains the massive slickens deposit that has been significantly eroded since 2006 (Section 2.5.3).

Figure 2-75 shows the relationship between floodplain surface height and tailings accumulations in Phase 22, with thick tailings accumulating in low areas which may represent old channels. Erosion into the I-90 embankment continues to be a problem in this reach as evidenced by an undermined fence line at the toe of the embankment RM 42.25 (Figure 2-76).   As the embankment likely doesn't have tailings, this erosion is more of an infrastructure concern than a remediation concern.   At the lowermost end of Reach A at the Blackfoot River confluence, the slickens recruitment described in Section 2.5.2 is demonstrated in right bank exposures of very thick tailings, some of which show green staining (Figure 2-77).

Figure 2-74. Slickens in old meander cutoff, Subreach A7, Phase 22, RM 43.9.

Figure 2-75. Right bank erosion showing topographic control on tailings deposition, Subreach A7, Phase 22, RM 45.0.

Figure 2-76. View downstream of erosion into I-90 embankment, Subreach A7, Phase 22, RM 42.25.

Figure 2-77. Slickens deposit at mouth of Little Blackfoot River, Subreach A7, Phase 33, RM 45.5; note green staining in middle of photo (arrows).

2.7 Summary and Discussion

Within Reach A, the Clark Fork River can be summarized by an implementation phase scale, geomorphic subreach scale, or valley scale. The data provided in this chapter are intended to provide some context on all of those levels to support future baseline geomorphic investigations in phase-scale remediation design.

On all scales, Reach A is affected by the geology of the valley. Alluvial fans, outwash fans and young terraces frequently impinge into the river corridor, creating high banklines that do not host recent tailings-laden flood deposits. Upstream of Deer Lodge, the high banks on the east side of the corridor (right bank) tend to be relatively fine grained alluvial fans, terraces, and colluvial deposits that are erodible and thus fine sediment sources to the river. On the opposite side of the valley, the terraces and outwash deposits are coarse, reworked glacial outwash materials that include coarse gravels and cobbles. In general, these units are less erodible; however, they do show some retreat and associated coarse sediment recruitment to the river. These coarse units are also prone to seepage with topbank irrigation that may contribute to slope instability.

Downstream of Deer Lodge, the river is less directly affected by these geologic units. The corridor is primarily confined by the railroad grade and I-90, both of which parallel the river between Deer Lodge and the Little Blackfoot River at Garrison.

Historic maps of the river allow some consideration of pre-mining conditions of the Clark Fork River. Major changes in river course since the 1860-1880 period of General Land Office Survey mapping may shed light on floodplain tailings accumulations, in that tailings may be concentrated in previously active channel threads that are now distanced from the river. If the GLO maps are to be used to assess historic channel locations, they should be scrutinized carefully, as in some cases the mapped location of the river on the maps does not correlate with the surveyed location of the river in the accompanying notes. Whenever possible, GLO survey notes should be used to bolster or validate interpretations made using the maps.

The slope of the river in Reach A typically ranges from 0.15% to 0.21%, with a short section of steeper slope (0.25%) through Deer Lodge. Valley slope tends to flatten in the downstream direction, and the river becomes straighter (lower sinuosity) in the downstream direction, indicating that the river has adjusted its length to accommodate changes in valley slope and thus maintain a relatively consistent channel slope.

Bank erosion inventory data have been summarized to show the total amount of severely eroding bankline that is prone to contributing tailings to the river. As test pit data have indicated that terraces and alluvial fans are free of tailings contamination, these banklines are summarized separately. With regard to alluvial banks that are likely to contain tailings, a total of 83,144 feet of bank has been inventoried as severely eroding. On a subreach scale, this reflects a relatively consistent erosion extent of 30% of the total bankline. The most extensive severe erosion is in Phase 10, where 29% of the total bankline was inventoried as severely eroding.

In terms of acreage of area recruited by the river, a turnover analysis indicates that, between 1955 and 2011, a total of 131.2 acres of floodplain was eroded by the river. This material has in part been re-deposited; during that same timeframe, a total of 171 acres has been converted from 1955 channel area to modern vegetated floodplain. Contamination in these areas would reflect reworked recruited tailings rather than original contaminated flood deposits from the early 20th century.

Some of the material recently eroded into the river was mapped as slickens (CH2MHill, 2008). Since 2006, approximately 33 acres of tailings impacted soils and 0.71 acres of slickens have been eroded into the river. The vast majority of slickens recruitment occurred at the mouth of the Little Blackfoot River, at the very downstream end of Reach A.

The collection of a large array of channel migration measurements provides a framework for assessing the risk of future tailings entrainment via bank erosion by phase. Some phases are notably more dynamic than others and hence have a higher likelihood of entraining tailings via bank erosion. Some phases show avulsion hazards that create additional entrainment risk. These risks have been captured via channel migration zone mapping for each phase that delineates erosion hazard areas based on historic rates of movement, as well as avulsion hazards based on planform, slope, and floodplain erosion features. Based on this analysis, approximately 1,130 acres of floodplain area has been identified as susceptible to erosion over the next century in those phases that are not currently in design. This translates to approximately 25 acres per river mile. Of that total, 48 acres are islands.

Floodplain access is an important component of riparian floodplain sustainability and associated long-term floodplain stability. Since the mid-1850s, the geomorphology of Reach A has been impacted by tailings aggradation on the floodplain, attenuation of flows in Warm Springs Ponds, land use practices, and a likely reduction in beaver populations. Local entrenchment is also due to downcutting caused by meander cutoffs. As a result of these influences, the channel is variably entrenched, resulting in a reduced frequency of floodplain inundation, increased mortality and stress to existing vegetation, conversion of riparian vegetation to upland species, and increased in-channel flow and associated erosive stress. In an effort to characterize relative amounts of floodplain access, a series of inundation maps have been created to graphically depict floodplain connectivity. On a phase-scale, inundated floodplain area in the immediate meander corridor ranges from less than 5 acres per valley mile in Deer Lodge (Phase 14) to over 25 acres per valley mile below Perkins Lane (Phase 3).

2.8 Recent Geomorphic Evolution of Reach A

The geomorphic evolution of Reach A includes the post-glacial conversion of the ancestral Clark Fork River from a wide braided glacially-fed stream system in Pleistocene time to a single thread meandering river. As the alpine glaciers retreated, the river incised through valley bottom glacial outwash deposits, leaving terraces on the river corridor margin that occasionally form high banklines on either side of the river. Currently, coarse bed and lower bank material that is prevalent throughout the system likely represents in part a lag deposit from that process of glacial outwash reworking.

Early descriptions of the Deer Lodge Valley and the Grant Kohrs Ranch area in particular describe dense woody vegetation including birch, willows, and alder on the stream banks and floodplain. In the early 1800s, beaver were present and aggressively trapped from tributary streams in the valley, and, although beaver have been suggested to have been active on the main stem Clark Fork River (Smith et al., 1988), their historic presence on the Clark Fork River in Reach A is poorly documented (Swanson, 2002). To date, no mention of beaver on the main stem Clark Fork River through the Deer Lodge Valley has been identified in the General Land Office Survey notes of the late 1800s although beaver may have been fully trapped out by then. As the beaver trapping in this area was plummeting by the late 1830s, documentation would expectedly be scant. The common exposure of small channel fill deposits in the modern streambanks of the river support the concept of historic sloughs and split flow conditions that would support the notion of historic beaver activity, and there have been evidently been accounts of buried dams being encountered in floodplain sediment (Swanson, 2002).

Large-scale cattle operations were introduced into the Deer Lodge Valley in the 1850s, which would have impacted the previously dense woody riparian corridor. This land use change, along with potential eradication of beaver, would have degraded the riparian corridor, and potentially caused some downcutting, widening, and consolidation of channels. Agricultural land uses in Phase 15 and 16 included draining of fields in the 1880s, indicating that the floodplain was wetter than today (Swanson, 2002).

Sediment loading from upstream mining operations apparently affected this area starting in the late 1860s due to hydraulic mining for gold in Silver Bow Creek (Swanson, 2002). This sediment, loading continued through the late 1800s as smelters and concentrators in Anaconda and Butte produced a combined total of 1400 tons of tailings per day. Tailings were deposited in Ramsay Flats as early as the late 1880s, and landowners in the Deer Lodge valley were building dikes to keep tailings within the channel in the 1890s (Quivik, 1998). Even before the great flood of 1908, agriculturalists were seeing the accumulation of tailings in their fields from flooding and/or irrigation practices. Charles Williams, who owned a farm six miles north of Deer Lodge, believed by 1898 that irrigation water was damaging his crops, and by the early 20th Century had many spots in his fields "where nothing grew". Hugh Magone ranched in the Race Track area and noticed that by the early 1900s tailings had settled over all of the low-lying areas of his bottom land; some areas were white, some green, some "slate gray", and many of these areas no longer supported vegetation (Quivik, 1998). The 1908 flood then caused massive additional deposition of tailings on the Clark Fork River floodplain.

Warm Springs Ponds were built in 1911 to trap mine tailings before they entered the Clark Fork River, cutting off the supply of these materials shortly after the 1908 flood. The modern geomorphology of the system currently reflects that rapid reduction in sediment loading. In the uppermost phases of Reach A, tailings that had accumulated in the channel appear to have been rapidly flushed out, leaving dense woody vegetation on the banks and a high perched floodplain with up to several feet of tailings contamination. Further downstream, sediment loading of contaminated material continued due to upstream bank erosion and tailings entrainment. That sediment loading resulted in continued floodplain deposition of contaminants, as well as in-channel deposition of tailings as observed in modern point bars and abandoned floodplain channels.

Section 3
Hydrology

This section describes the hydrology of Reach A of the Clark Fork River Operable Unit (CFROU) with regard to annual peak flows and flow duration.   Annual peak flood flows will be used as a basis for design of stream bank and adjacent floodplain improvements at different locations within Reach A. An understanding of the peak flow hydrology is also important to understand stream geomorphology because sediment transport on sand and gravel-bed rivers is strongly affected by the peak flow regime of the stream. Although the main focus of this remedial effort and this report is the mainstem of the Clark Fork River, peak flows on tributary streams are also developed because they directly affect the hydrology of the mainstem at intermediate points along the river. There are also portions of these tributaries for which hydrologic information is needed for remedial design as they pass through areas before reaching the main stem.

This peak flow analysis is based largely on existing U.S. Geological Survey (USGS) stream flow records from gages located within the CFROU and surrounding areas. Annual flood-frequency analysis was conducted using Bulletin 17B guidelines and the USGS program PeakFQ (Flynn *et al*., 2006). The USGS regression equation method (Parrett and Johnson, 2004) is also included but it is not relied upon for the main stem for reasons that will be described in Section 3.2. Records were extended for some stations using standard regression techniques.

3.1 Description of Site Hydrology

Figure 3-1 shows the drainage basins contributing runoff to Reach A of the Clark Fork River. Runoff from drainage areas discharging into Silver Bow Creek above the inflow into Warm Springs Ponds passes though the ponds. Near the northwest corner of the ponds, a weir outlet structure regulates discharge into Silver Bow Creek. The ponds' normal elevation is approximately 4,835 ft. (USEPA, 2005). The structure is currently operated by ARCO which regulates the outlet discharge to adjust for summer temperature fluctuations in the Clark Fork River and for other operational purposes. These adjustments can impact river flows downstream of the outlet structure adding uncertainties about how peak flows will actually be managed, and, therefore uncertainties in their magnitudes.   However, since the ponds are not operated as storage reservoirs, there are limits to the amount of regulation that can occur during peak flows. The ponds' discharge joins with the Willow Creek/Mill Creek bypass and become the lower part of Silver Bow Creek. The original Silver Bow Creek streambed was obliterated by the Warm Springs Ponds and reappears approximately 0.8 river miles downgradient of the Pond 2 outlet. Just downstream of this junction, which is the beginning of Reach A, Warm Springs Creek joins with Silver Bow Creek and becomes the Upper Clark Fork River.

Reach A of the Clark Fork River is located in Powell and Deer Lodge counties and traverses a broad, agricultural valley about 25 miles long and about 7 miles wide. The elevation of the valley bottom ranges from about 4,300 to 4,800 feet, and the mountains that flank the valley range up to 10,000 feet to the west and over 8,000 feet on the east. The Clark Fork River is crossed by numerous bridges in Reach A. Tributaries that join the Clark Fork River from the west originate in the Flint Creek Mountains and Anaconda-Pintler Range and tributaries that join from the east originate on the west slope of the Continental Divide. These tributaries have minimal on-stream storage and contribute significantly to the peak flow hydrology of the Clark Fork River. Several irrigation intakes are located

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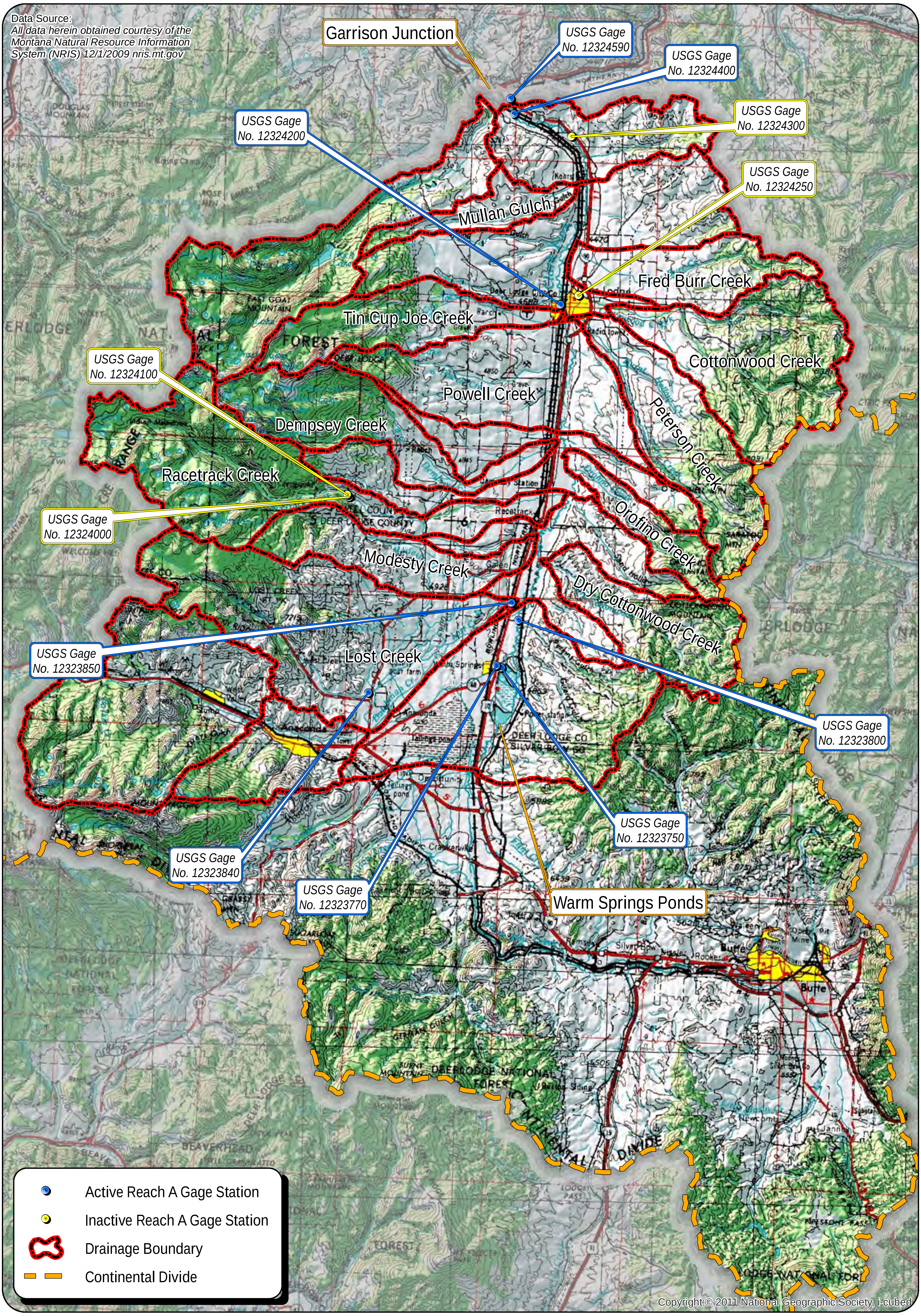


Figure 3-1
Reach A
Upper Clark Fork Gages and Major Tributaries
Powell, Deerlodge, Silverbow Counties, Montana

0 1 2 4 6 8
Miles

CDM Smith

in Reach A as well as irrigation returns, which are often combined with natural drainages. The river bisects the community of Deer Lodge.

The three active USGS gages on Reach A of the Clark Fork River are listed in Table 3-1. It is noteworthy that the drainage area approximately doubles from the upstream gage near Galen to the downstream gage above the Little Blackfoot River. This doubling of drainage area results in significant hydrologic change through Reach A.

Table 3-1 Clark Fork River Mainstem USGS Gages in Reach A.

USGS Station Number	Station Name	Years of Record	Drainage Area (square miles)
12323800	Clark Fork near Galen, MT	24	561
12324200	Clark Fork at Deer Lodge, MT	34	916
12324400	Clark Fork above Little Blackfoot River near Garrison, MT	4	1,140

The only active USGS gages on tributaries to Reach A of the Clark Fork River are on Lost Creek, but gages were previously operated on Cottonwood Creek and Racetrack Creek. Information on these tributary gages is presented in Table 3-2.

Table 3-2 Reach A Tributary USGS Gages.

USGS Station Number	Station Name	Years of Record	Drainage Area (square miles)
12323840	Lost Creek near Anaconda, MT	8	26.4
12323850	Lost Creek near Galen, MT	10	60.5
12324100	Racetrack Creek below Granite Creek near Anaconda, MT	17	39.5
12324250	Cottonwood Creek at Deer Lodge, MT	18	45.4

3.2 Main Stem Data Analysis

The mainstem of the Clark Fork experiences the typical flow regime of the northern Rocky Mountains with a spring high flow period resulting from snowmelt and spring rain storms. Flows decrease rapidly in summer with hotter weather and significant irrigation depletions. Figure 3-2 shows the average annual hydrograph for the Clark Fork near Galen (USGS gage 12323800). This flow regime is typical of the other mainstem stations although the magnitude of flow increases in the downstream direction.

3.2.1 Comparison of Regression Analysis and Gage Record Analysis

Both USGS regional regression equations and gage records were used to predict the 2-, 5-, 10-, 25-, 50- and 100-year peak flows on the mainstem of the Clark Fork River. Because the Upper Clark Fork River is located close to the boundary between the west and southwest regions, regression equations for both regions were evaluated. In addition, the USGS program PeakFQ was used to estimate the flows for the Galen and Deer Lodge gaging stations based on their peak flow records. The PeakFQ program calculates and reports three discharge values that are based on the Bulletin 17B method (Flynn, 2006). Table 3-3 compares the results of the regression analyses with the analysis of the gage record at Deer Lodge.

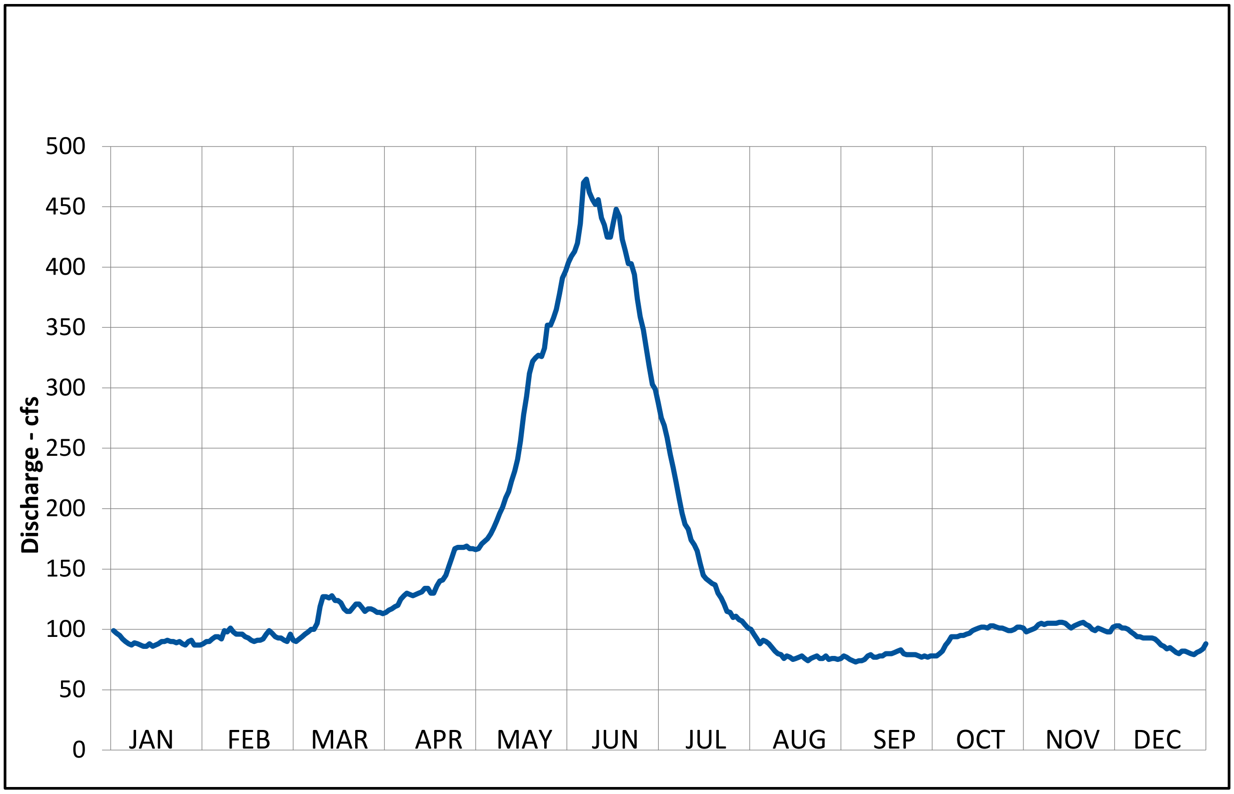


Figure 3-2. Annual Hydrograph for Clark Fork near Galen, MT, USGS Station 12323800.

Table 3-3 also shows that the West Region regression equations consistently overpredict the peak flows (for intervals other than the 2-year) by about a factor of two. The Southwest Region regression equations do somewhat better but still overpredict the peak flows by 49% to 107%. Clearly the USGS regression equations overpredict the peak flows for this reach of the Clark Fork River. In part, this overprediction results from storage effects in the Warm Springs Ponds. However, downstream stations on the Clark Fork River as it nears Missoula, which should be largely free of effects from the ponds, also show this tendency for the regression equations to overpredict peak flows (Bucher, 2010). It appear that the unit runoff values for these two regions are greater than the unit runoff for the upper Clark Fork River. Therefore, the PeakFQ values are preferred at least for more frequent events (up to 25-year recurrence interval).

Table 3-3 Comparison of Regression Analyses and Gage Record Analysis for Clark Fork at Deer Lodge, MT, (Station No. 12324200).

		West Regression Equation		Southwest Regression Equation	
Return Interval	Gage Records PeakFQ (cfs)	Peak Flow (cfs)	Percent Difference with PeakFQ	Peak Flow (cfs)	Percent Difference with PeakFQ
2-year	893	743	-17%	1845	107%
5-year	1490	4642	212%	2602	75%
10-year	1925	5937	208%	3184	65%
25-year	2510	7320	192%	3947	57%
50-year	2966	8536	188%	4511	52%
100-year	3436	9763	184%	5115	49%

3.2.2 Record Extension by Correlation

Less frequent events such as the 50- and 100-year recurrence events may not be predicted well by gage records because of the relatively short period of record (34 years for the Deer Lodge Gage and 24 years for the gage near Galen). Therefore, an attempt was made to correlate these gage records with longer period gages in the region. If a reasonable correlation was found, the regression equation was used to estimate additional flows for corresponding years not in the record for the Clark Fork Reach A gages. Then PeakFQ was run on the extended record and these recurrence frequency values compared to the original record. When the dates of the instantaneous peaks in the two records did not correspond within 30 days, that year of data was not used in the regression calculation because the peak flow hydrology was clearly not similar between the two basins that year. The extension was attempted for all three gages on Reach A of the Clark Fork River. Table 3-4 presents information on the USGS stations that were investigated for use in this analysis.

Table 3-4 USGS Gages Investigated to Extend Clark Fork Gage Records.

USGS Station Number	Station Name	Years of Record	Drainage Area (square miles)
06033000	Boulder River near Boulder		381
12324590	Little Blackfoot River near Garrison	40	407
12331600	Clark Fork at Drummond	31	2378
12332000	Middle Fork Rock Creek near Philipsburg	75	123
12340000	Blackfoot River near Bonner	73	2290
12340500	Clark Fork above Missoula	78	5999

The record for the Clark Fork River near Galen was successfully extended in the 2010 *Geomorphic, Hydrologic, and Hydraulic Investigations for Phase 1* (CDM and AGI, 2010) using the Middle Fork Rock Creek record. This analysis was rerun with three years of additional record at each gage and the correlation noted in Table 3-5.

Table 3-5 USGS Gages Investigated to Extend Clark Fork Gage Records.

Stations Correlated	Correlation (R^2)	Extended Record Used
Clark Fork near Galen with Middle Fork Rock Creek near Philipsburg	70%	Yes
Clark Fork at Deer Lodge with Middle Fork Rock Creek near Phillipsburg	43%	No
Clark Fork at Deer Lodge with Boulder River at Boulder	55%	No
Clark Fork at Deer Lodge with Little Blackfoot River near Garrison	58%	No
Clark Fork at Deer Lodge with Clark Fork at Drummond	67%	No
Clark Fork at Deer Lodge with Clark Fork above Missoula minus Blackfoot River near Bonner	72%	Yes
Clark Fork above Little Blackfoot River with Clark Fork at Deer Lodge	99.8%	Yes

A similar correlation was attempted between the Clark Fork at Deer Lodge and Middle Fork Rock Creek near Philipsburg , but these stations did not correlate well. The correlation with the Little Blackfoot River was somewhat better (R^2 = 55%) but only added six years of record. The correlation with the Clark Fork at Drummond was still better (R^2 = 58%) but only added six years of record. To obtain a longer record with a reasonable correlation, it was necessary to estimate the peak flows for the Clark Fork above its confluence with the Blackfoot River by subtracting the flow on the Blackfoot

River at Bonner from the flow of the Clark Fork above Missoula. This should give a valid result for flows on the Clark Fork River above the confluence when the instantaneous peaks occur within a short duration of each other because there are no significant tributaries between the two gages. When the instantaneous peaks on the Blackfoot River and Clark Fork did not correspond within a few days, the mean daily flow for the Blackfoot River on the date of the Clark Fork peak was used instead of the annual peak for the Blackfoot River. As with other correlations, when the annual peaks at Deer Lodge and above Missoula did not correspond well, these data points were not used in the correlation. The correlation of these two records was R^2 = 72%, and, using this favorable correlation, the Clark Fork at Deer Lodge record was extended from 34 to 73 years.

Only four years of peak flow data are available at this time for the station at the Clark Fork above the Little Blackfoot River. These four data points correlated very well (R^2 = 99.8%) with the Clark Fork at Deer Lodge and were used to extend the record for the station above the Little Blackfoot River.

3.2.3 Estimated Peak Flows for Mainstem Stations

Using the USGS gage records and the extended records derived through regression, mainstem peak flow magnitudes have been estimated for the three USGS stations in Reach A. The program PeakFQ was used to estimate the 1.5-, 2-, 5-, 10-, 25-, 50- and 100-year peak floods. Table 3-6 presents the results of the analysis for the three stations for the station records and the extended records. No gage record analysis is presented for the Clark Fork above the Little Blackfoot River because this station only has four years of record.

Table 3-6 Summary of Peak Flow Analysis using PeakFQ.

	12323800 Clark Fork near Galen		12324200 Clark Fork at Deer Lodge		12324200 Clark Fork above Little Blackfoot River	
Return Frequency	Gage Record (cfs)	Extended Record (cfs)	Gage Record (cfs)	Extended Record (cfs)	Extended Record (cfs)	Extended Record (cfs)
Years of Record	24	75	34	73	34[1]	73[2]
1.5-year[3]	441	-	679	-	-	-
2-year	584	827	893	1,090	923	1,249
5-year	961	1,177	1,490	1,604	1,571	2,218
10-year	1,216	1,380	1,925	1,929	2,047	2,842
25-year	1,535	1,608	2,510	2,319	2,687	3,568
50-year	1,767	1,757	2,966	2,594	3,186	4,056
100-year	1,993	1,893	3,436	2,857	3,700	4,497

[1] Clark Fork above Little Blackfoot River record was extended using Clark Fork at Deer Lodge for 1979-2008.

[2] Clark Fork above Little Blackfoot River record was extended using Clark Fork above Missoula minus Blackfoot River near Bonner for 1940-1978.

[3] 1.5-year event calculated only for existing gage record

Note: Blue shading indicates preferred values for this peak flow study.

The more frequent peak flow events (1.5-year through 25-year) are best represented by analysis of the gage records without extension because the data are specific to that station. However, these shorter periods of record are less adequate for estimating peak flows longer than the period of the gage records. Therefore, the extended records are used for the less frequent peak flows (50-year and 100-year). Figure 3-3 displays the estimated peak flows at the three USGS gage stations in Reach A. The stations near Galen and at Deer Lodge show a relatively small range of peak flows with changing recurrence interval; that is, the ratio of the 100-year peak to the 2-year peak is slightly over 3. This is believed to be due the effects of peak flow attenuation in the Warm Springs Ponds. However, above the confluence with the Little Blackfoot River, the ratio of the 100-year peak to the 2-year peak is close

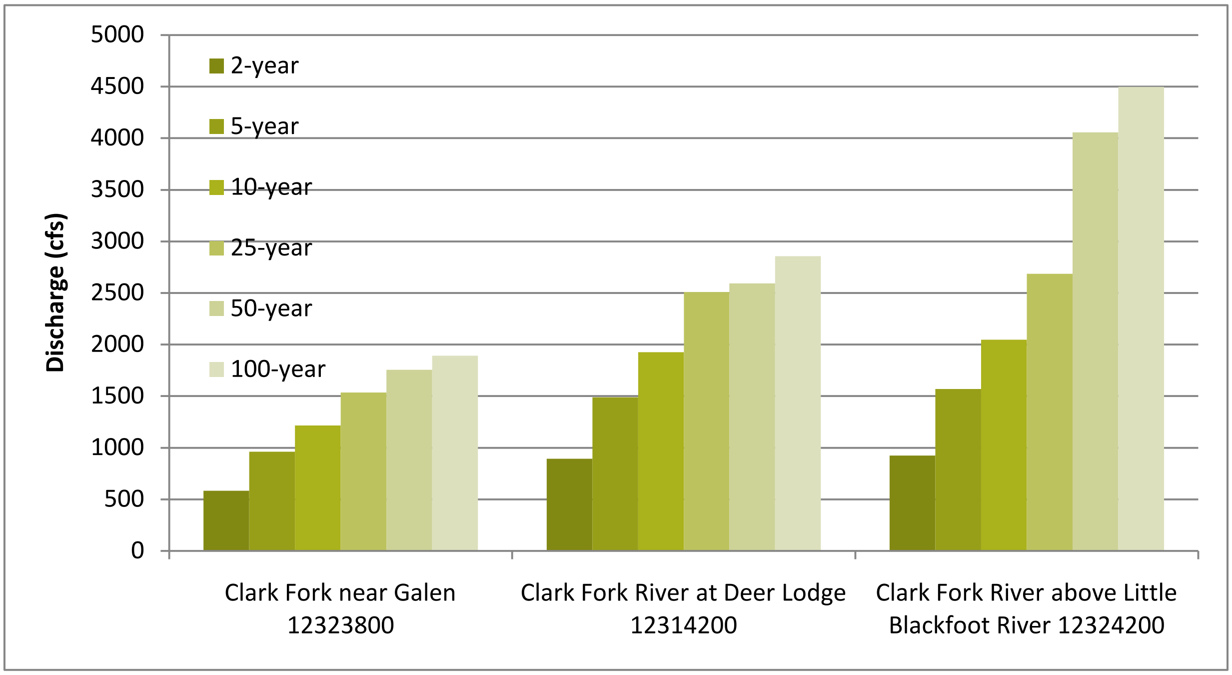


Figure 3-3. Estimated peak flows at USGS gage stations on Reach A of the Clark Fork River.

to 5, which is indicative of an unregulated river in this region of the Rocky Mountains. The effects of the Warm Springs Ponds at this location are reduced by the addition of considerable unregulated flows.

For mainstem locations located between the mainstem stations, it is recommended that the peak flow be proportioned by drainage area as described in Parrett and Johnson (2004). This method recommends use of the regression coefficient for the appropriate return interval when proportioning by drainage area. At each major tributary junction, the peak flows should be calculated to account for the tributary inflow as represented by the increased drainage area of the tributary stream.

3.3 Tributary Stream Peak Flow Analysis

Tributaries to the Clark Fork River in Reach A were also analyzed using USGS regression equations and gage data. As mentioned previously (Table 3-2), there are only three streams that have USGS gage records in this reach: Cottonwood Creek, Racetrack Creek, and Lost Creek. Table 3-7 summarizes the PeakFQ and regression equation analysis of these three streams . As in the main stem analysis, the regression equation predictions differ greatly from the flood frequency analyses. The regression equations consistently underpredict the flood magnitudes for Cottonwood Creek and Racetrack Creek. For Cottonwood Creek, in most cases, both the West Region and Southwest Region regression equations predict almost half the peak flow values that the analysis from gage records calculates. On Racetrack Creek the regression equations also underpredict the peak flows compared to the flood frequency analysis although the West Region equations appear to improve with less frequent flood events. However, given the short periods of record at these stations, the less frequent events (25-, 50-, and 100-year) should not be given much weight.

Table 3-7 Comparison of Regression Analyses and Gage Record Analysis for Tributary Streams in Reach A.

		West Regression Equation		Southwest Regression Equation	
Return Interval	Gage Records PeakFQ (cfs)	Peak Flow (cfs)	Percent Difference with PeakFQ	Peak Flow (cfs)	Percent Difference with PeakFQ
Cottonwood Creek at Deer Lodge, MT, Station No. 12324250					
2-year	243	37.1	-85%	132.1	-46%
5-year	518	251.2	-52%	232.7	-55%
10-year	745	346.7	-53%	312.6	-58%
25-year	1070	462.0	-57%	427.8	-60%
50-year	1340	559.6	-58%	521.2	-61%
100-year	1630	661.6	-59%	626.8	-62%
Racetrack Creek below Granite Creek near Anaconda, MT, Station No. 1234100					
2-year	366	44.7	-88%	120.3	-67%
5-year	485	359.6	-26%	201.9	-58%
10-year	556	462.0	-17%	263.9	-53%
25-year	637	571.5	-10%	350.5	-45%
50-year	693	670.0	-3%	419.0	-40%
100-year	745	775.6	4%	495.4	-34%
Lost Creek near Galen, MT, Station No. 12323850					
2-year	82.4	62.6	-24%	163.2	98%
5-year	103.2	422.6	310%	305.8	196%
10-year	115.8	597.8	416%	426.0	268%
25-year	130.5	819.8	528%	606.1	364%
50-year	140.8	1004.0	613%	757.1	438%
100-year	150.7	1197.2	694%	931.1	518%

Of the two gages on Lost Creek, Lost Creek near Galen (USGS 12323850), located near the mouth of the stream, is most relevant to this project because it represents flows that could be expected in the reconstructed floodplain. Analysis of this 10-year record indicates that regression equations almost always overpredict the flows compared to the PeakFQ analysis by factors of 2 to 7 times. This is the opposite situation that was observed on Racetrack and Cottonwood Creeks. Given that Lost Creek has by far the largest drainage area of any of the Reach A tributaries, it is curious that the highest flow observed at this gage is 117 cfs, well less than the peaks of record for Cottonwood Creek (1830 cfs) and Racetrack Creek (580 cfs). Although the period of record on Lost Creek does not overlap those of the other two tributaries making comparisons difficult, it does contain known wet years and four years of the ten-year record exceed 100 cfs. This notable consistency of peak flows above 100 cfs suggests that the large irrigation diversions just upstream of the gage are significantly reducing the peak flows at this station. Another contributing factor may be that Lost Creek is a losing stream on the broad alluvial fan on the lower portion of its course. Because Lost Creek appears to be greatly affected by these factors and is so dissimilar from the other two tributaries, it is not used in the prediction of peak flows on tributaries of Reach A.

To estimate peak flows on ungaged tributaries along Reach A of the Clark Fork River, the regression equation values for the ungaged tributaries should be increased to reflect the ratios calculated in Table 3-7. The Southwest Region regression values are preferred for this calculation because they are consistent between Racetrack Creek and Cottonwood Creek and they do not have the uncertainty of estimating mean annual precipitation of the West Region regression equations. Mean annual precipitation estimates are based on the Soil Conservation Service (SCS) mapping of the 1941 to 1970 database developed by the SCS (USDA, 1977), which has poor spatial resolution at the scale of these small tributary streams. Table 3-8 presents the multipliers to be used for the 2-, 5- and 10 year peak flows derived for the Southwest Region regression equations. Using this method, peak flows for prominent tributaries at their confluence with the Clark Fork River in Reach A were estimated and are summarized in Table 3-9 for all streams except Cottonwood Creek and Lost Creek. The values based on gage records (PeakFQ) in Table 3-7 should be used for these two tributaries.

Table 3-8 Percent Increase for Southwest Regression Equations for Tributaries to Reach A.

Return Interval	Percent Increase
2-year	244%
5-year	231%
10-year	225%

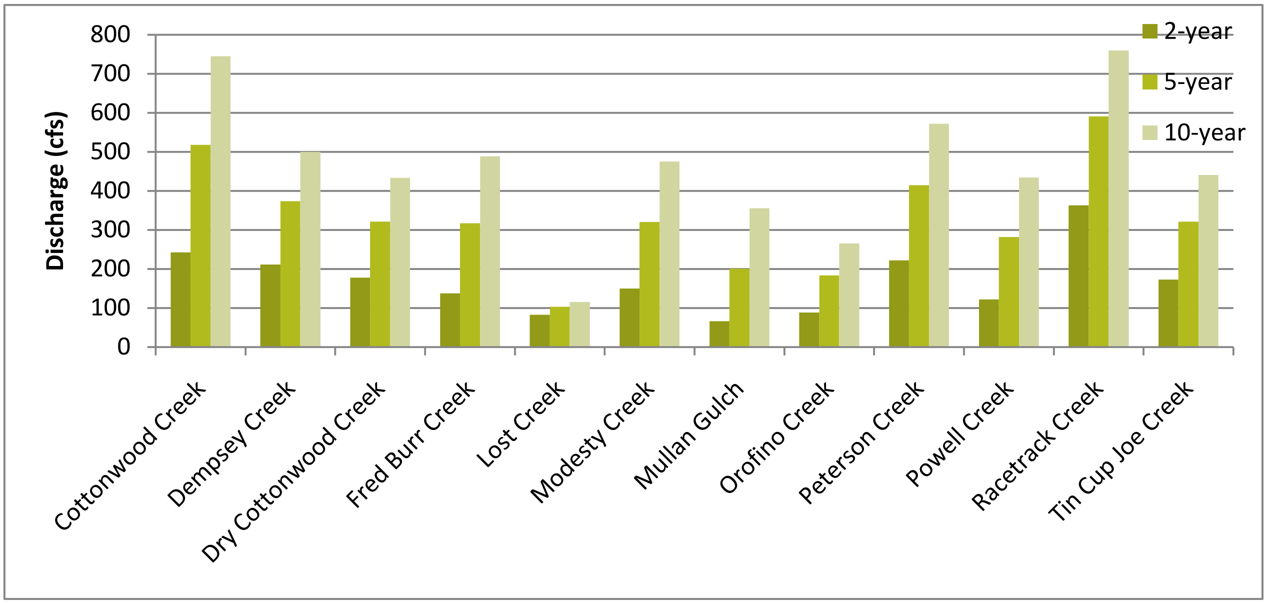
Table 3-9 Estimated Peak Flows for 2, 5, and 10-Year Recurrence Intervals, Reach A Tributaries.

	Area (sq mi)	Percent above 6000 feet	Southwest Regression Eq. - CFS	Percent Increase (Table 3-8)	Estimated CFS
Dempsey Creek (L)	28.4	63			
2-year			86.6	244%	211
5-year			161.4	231%	373
10-year			222.6	225%	500
Dry Cottonwood Creek (R)	23.4	61			
2-year			72.8	244%	178
5-year			138.7	231%	321
10-year			193.2	225%	434
Fred Burr Creek (R)	19.9	19			
2-year			56.5	244%	138
5-year			137.0	231%	317
10-year			217.5	225%	488
Modesty Creek (L)	21.1	27			

	Area (sq mi)	Percent above 6000 feet	Southwest Regression Eq. - CFS	Percent Increase (Table 3-8)	Estimated CFS
2-year			61.5	244%	150
5-year			138.6	231%	321
10-year			211.6	225%	475
Mullan Gulch (L)	9.8	6			
2-year			27.3	244%	67
5-year			86.7	231%	201
10-year			158.4	225%	356
Orofino Creek (R)	11.1	42			
2-year			36.4	244%	89
5-year			79.3	231%	184
10-year			118.1	225%	265
Peterson Creek (R)	31.1	46			
2-year			91.0	244%	222
5-year			179.2	231%	415
10-year			254.9	225%	572
Powell Creek (L)	17.3	20			
2-year			50.2	244%	122
5-year			121.9	231%	282
10-year			193.4	225%	434
Racetrack Creek (L)	51.5	75			
2-year			148.8	244%	363
5-year			255.2	231%	591
10-year			338.3	225%	759
Tin Cup Joe Creek (L)	23	53			
2-year			70.7	244%	173
5-year			138.7	231%	321
10-year			196.4	225%	441

Note: L – left bank tributary; R – Right bank tributary.

Figure 3-4 displays graphically the major tributaries in Reach A of the Clark Fork River with their estimated 2-year, 5-year, and 10-year recurrence interval flows. It is apparent that the major tributaries, as evaluated using peak flows, are Racetrack Creek and Cottonwood Creek. Lost Creek, which has the largest drainage area of any tributary in Reach A, has the lowest peak flows of any in the reach based on its 10-year period of record, a period which included high flows elsewhere in Reach A. It is probable that sizable diversions upstream of the USGS gage on Lost Creek capture much of the spring runoff. During periods when there are no diversions operating on Lost Creek, it often has higher flows than any other gaged tributary to Reach A.



Note: Cottonwood Creek and Lost Creek data are based on gaged flows in Table 3-7. All other tributary data are based on methods of Table 3-9.

Figure 3-4. Major Tributaries of Reach A of the Clark Fork River with their estimated peak flood flows.

3.4 Flow Duration

Although peak flow hydrology is important for understanding river morphology, flow duration also significantly affects river morphology. Flow duration is a measure of the length of time various flows occur on a river averaged over an extended period of time. It is important for calculating sediment transport on a stream but is also important for an understanding of the relative effects of low-frequency recurrence floods. For example, a flood that has a long duration will impart more geomorphic work on a stream than a flood of equal peak that is relatively short. This section discusses some aspects of flow duration on Reach A of the Clark Fork River using the gage that has the longest period of record, the Clark Fork at Deer Lodge, the central of the three Reach A mainstem gages (Figure 3-1).

3.4.1 Flow-Duration at Clark Fork at Deer Lodge

A flow duration curve was constructed for the USGS gage No. 12324200, Clark Fork at Deer Lodge, MT. The 35 year record at this site is the longest of the river gages in Reach A. Using the methods of USGS Water Supply Paper 1542-A (USGS, No date), the mean daily flows were ranked and a curve of probability of exceedence of flow was constructed. Very low flows have a high probability of being exceeded whereas very high flows have a low probability of being exceeded. Figure 3-5 presents the flow-duration curve for the Clark Fork River at Deer Lodge. For each flow a probability of exceedence can be read from the graph. This can be converted to a duration by multiplying the percentage by a length of time, for example, 365 days, for an average annual duration.

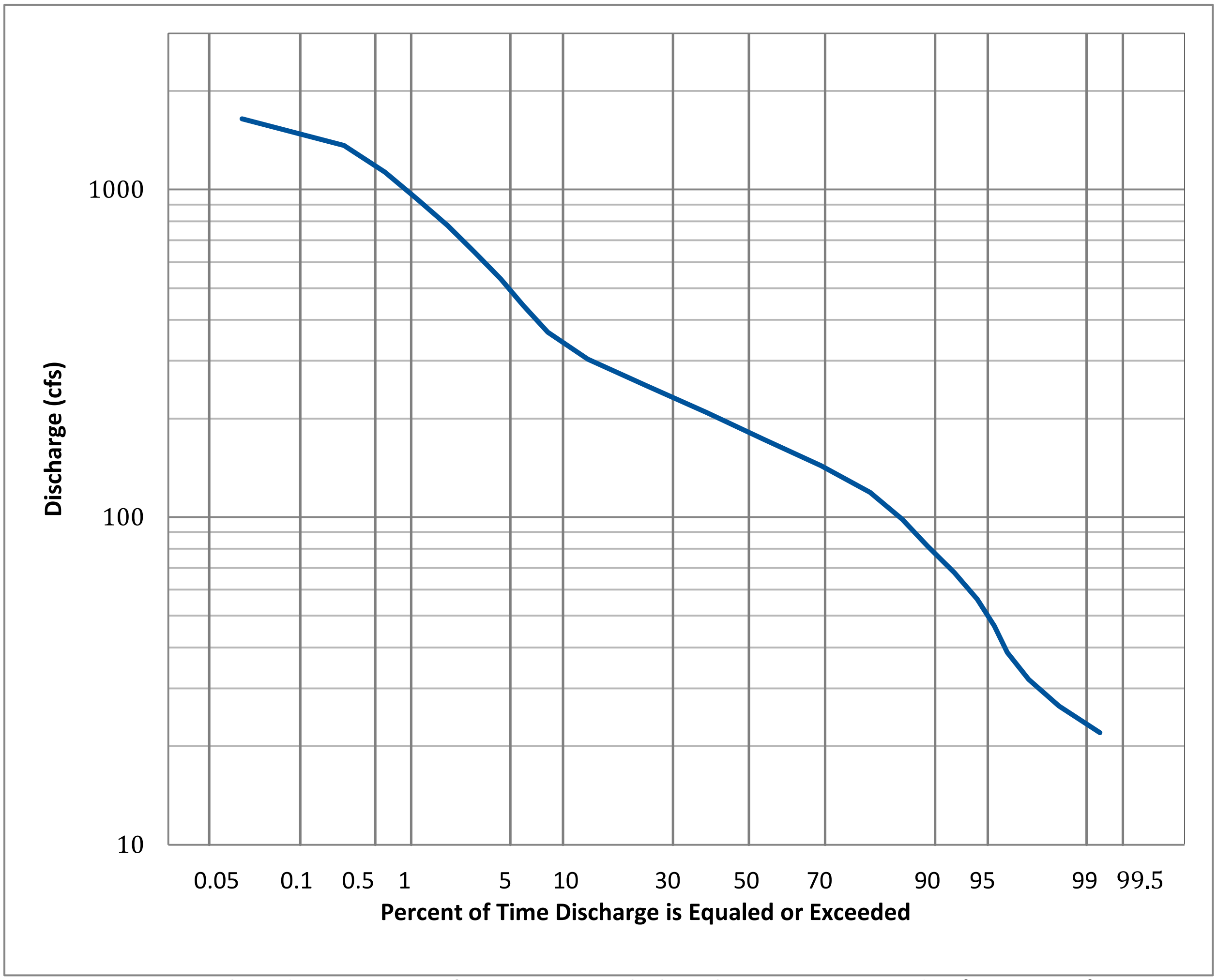


Figure 3-5. Flow-duration curve for USGS gage Clark Fork River at Deer Lodge (1978-2012).

As an example, a 2-year recurrence event on the Clark Fork River at Deer Lodge is predicted to be 893 cfs in Section 3.2.3. According to Figure 3-5 this magnitude of flow is exceeded 2.1% of the time. In an average year, the 2-year recurrence flow is exceeded for 0.021 x 365 days or almost 8 days. However, we should consider that in half the years of record the 2-year recurrence flow does not occur, suggesting that the average duration during years when the 2-year recurrence flow is exceeded is actually about 16 days, a fairly extended high flow period. These statements are predicated on the assumption that there is only one peak flow in a year that exceeds a given recurrence interval. Although this is not strictly true, the typical annual hydrograph shown in Figure 3-2 indicates that floods on this river tend to peak over a fairly short period in the late spring and early summer. Therefore, in most years, the days that exceed a given recurrence interval tend to occur consecutively. More discussion of this issue follows in the presentation of individual storms in the next section.

3.4.2 Flow-Duration during Typical Floods

Useful as a flow-duration curve is, there are several problems interpreting this information. An example was just given of an underestimate of the duration of a flood that exceeds the 2-year recurrence event because this event only occurs in half the years of record. An additional distortion is that the duration of high flows may not be continuous but may consist of two or more high-flow periods. It is therefore useful to look at individual storms of record to understand the duration of actual high-flow events.

One duration of interest in stream restoration design is the period that a single flood is out of bank. This is because longer duration high flow events will perform more channel-forming work as well as increase erosion on the flood plain. Designers should therefore take the duration of bankfull and out of bank flows into consideration when developing channel and floodplain designs. A typical bank full elevation used in the Clark Fork River stream designs is the 2-year recurrence flood. When an annual event equals or exceeds the 2-year recurrence flood, the duration of flooding is likely to be 16 days. What would the probable duration of out-of-bank flow be for a 10-year event or a 25-year event? By selecting some floods of record corresponding roughly to the 10-year and 25-year events, these continuous durations can be estimated using USGS mean daily flow records.

The peak flood in 2011 was 1,970 cfs at the Deer Lodge gage, slightly higher than the 10-year recurrence event, which is predicted to be 1,925 cfs (Table 3-6). This flood flow was continuously above the 2-year recurrence flow of 893 cfs for 43 days from June 6th to July 18th. However, previous to this period, flows also exceeded 893 cfs for 11 days beginning on May 24th, before dropping below 893 cfs for four days before the main flood period began. Combining these two periods results in almost 60 days of continuous flooding in excess of the 2-year event in 2011.

The peak flood of record at the Deer Lodge gage occurred in 1981 and reached a flow of 2,500 cfs, a little less than the calculated 25-year recurrence event of 2,510 cfs. This flood was continuously above the 2-year recurrence flow of 893 cfs for 24 days from May 22nd to June 14th. Although the peak flow of this flood was much higher than the 2011 event, the duration of high water was not nearly as long. Figure 3-6 compares the hydrographs of these two floods.

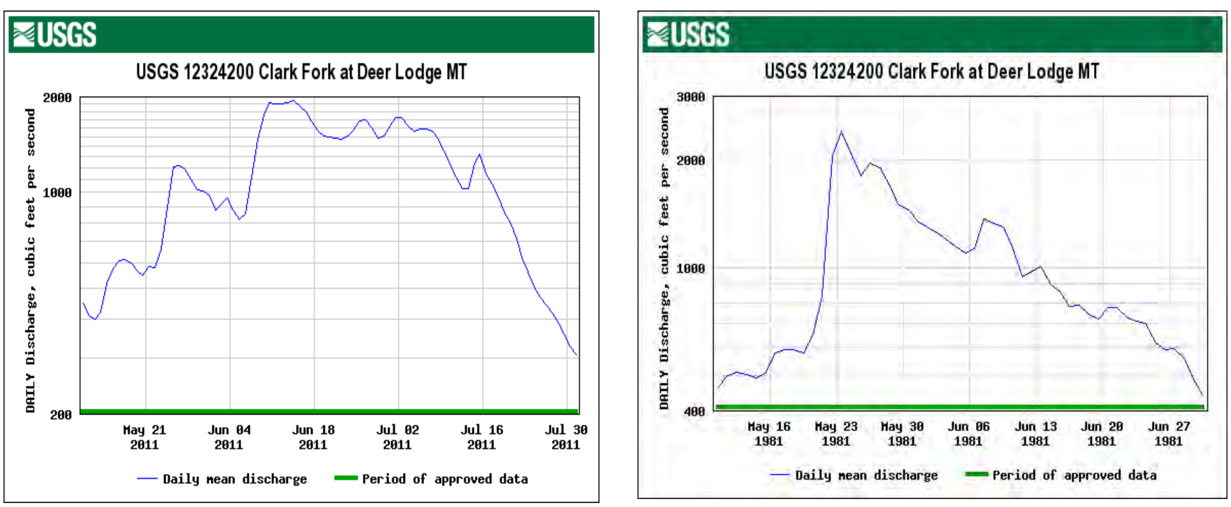


Figure 3-6. Comparison of flood hydrographs from 2011 (left) and 1981 (right).

3.5 Summary and Discussion

This study of the hydrology of Reach A of the Clark Fork River was undertaken to provide an overall understanding of peak flow hydrology of this reach and to provide a basis for design of streambanks and adjacent floodplains throughout Reach A. It addresses both mainstem and tributary hydrology and focuses on peak flow hydrology with some attention to flow duration.

There are three mainstem gages operating on Reach A of the Clark Fork with periods of record ranging from 4 to 34 years, and these gages form the basis of the mainstem analysis with additional regional gage data used to extend records of the existing stations. Peak flows estimated from gage records at the three stations were compared to flows derived from the USGS Regression equations for the West and Southwest Regions (Parrett and Johnson, 2004), and the regression equations were found generally to overestimate peak flows at the gages. The reasons for the inadequacy of the regression equations are two-fold. First, the storage effects of the Warm Springs Ponds just upstream of Reach A reduce the peak flows measured at the gages. In addition, analysis previously conducted for DEQ (Bucher, 2010) showed that unit runoff rates were lower in this area than in the USGS West and Southwest Regions leading to a further reduction in peak flows in this area. As a result, gage records only are used to estimate the 1.5, 2, 5, 10 and 25-year recurrence events for the mainstem stations.

Because the periods of record for the mainstem stations are inadequate for predicting 50- and 100-year recurrence events, the method of correlation with long-term gages was used to extend the records for these stations and estimate these infrequent events. If correlations of about 70% or higher were found between mainstem stations and long-period regional stations, the regression equations derived from these stations were used to predict annual peak flows at the mainstem station during these additional years of record. Using the gages at Middle Fork Rock Creek near Philipsburg, Clark Fork above Missoula, and Blackfoot River near Bonner, records were extended up to 73 or 75 years for all three mainstem gages. These extended records were used to estimate the 50- and 100-year recurrence events.

The estimated peak flows for the upstream (near Galen) station show storage effects of the Warm Springs Ponds but these effects become less apparent towards the downstream end of Reach A. In general, peak flows almost double over the 45 mile reach, indicating that streambank designs may need to be more robust in the downstream portions of Reach A than they are in the upstream areas.

Peak flows were also estimated on 12 of the larger tributaries to the Clark Fork River in Reach A. There are three tributaries with gage records but only Lost Creek is currently being measured; the gages on Cottonwood Creek and Racetrack Creek are not currently operating. Periods of record are short, 8 to 18 years, so only the 2, 5 and 10- year flows were estimated for these sites. Both the West and Southwest Region USGS regression equations were compared to the gage records and found to underestimate measured flows derived from the Racetrack Creek and Cottonwood Creek gages. However, because so few tributaries have records, regression equations were selected as a basis for predicting peak flows on the tributaries with an adjustment factor introduced to bring them in line with the gaged flows. The Southwest Region regression equations were used in this analysis because they presented a more consistent underestimate of measured flows than the West Region equations. These Southwest Region flows for the ungaged tributaries were multiplied by a factor of 225% to 244% to estimate the 2, 5 and 10-year recurrence flows for the ungaged tributaries.

The gage near the mouth of Lost Creek was not used in the estimation of peak flows on ungaged drainages because it presents a different flow regime than Racetrack Creek or Cottonwood Creek.

Although it has the largest drainage basin of all the tributaries, Lost Creek has the lowest peak flows. This is due to the large diversions that are active right above the gage during the high flow period which capture much of the peak flow.

A flow duration curve was developed based on the mean daily flow record of the gage Clark Fork at Deer Lodge. Duration of floods is important because longer duration high flow events will perform more channel-forming work as well as increase erosion on the flood plain. Designers should therefore take the duration of bankfull and out of bank flows into consideration when developing channel and floodplain designs. Investigation of the flow duration curve indicates that, in an average year, flows exceeding the 2-year event extend over almost 8 days. However, considering that in half the years of record the 2-year recurrence flow does not occur, the average duration during years when the 2-year recurrence flow is exceeded is actually about 16 days, a fairly extended high flow period.

Flow durations of individual events were also investigated to give insights into the nature of the duration of high flows. The 2011 high flow, which approximated the 10-year recurrence flow at Deer Lodge, exceeded the 2-year recurrence flow for about 60 days although there was a gap of four days when flows went below the 2-year level. This was a very broad flood peak even for the Clark Fork River. The 1981 high flow, which approximated a 25-year recurrence event at Deer Lodge, exceeded the 2-year flow for 24 days. Although the peak of this event was significantly higher than the 2011 flood, the duration of flooding was shorter. These two examples give some measure of the duration and the variability in duration of floods in this river system.

Section 4

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