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

Part2:
Geomorphic, Hydrologic, and Hydraulic Investigation for Phase 1 Remedial Design/Remedial Action

April 2010

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Powell, Deer Lodge, and Granite Counties, Montana

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Executive Summary

This report presents the results of a geomorphic, hydrologic, and hydraulic investigation conducted as Part 2 of the Draft Final Clark Fork Site Sampling and Analysis Plan (SAP) Addendum, Reach A, Phase 1 (Tetra Tech & CDM, 2009), of the Clark Fork River Operable Unit (CFROU) Remedial Design/Remedial Action by Camp Dresser & McKee Inc. (CDM) and Applied Geomorphology, Inc. The CFROU is part of the Milltown Reservoir/Clark Fork River Superfund Site and includes the Clark Fork River starting at the confluence of Silver Bow Creek with the old Clark Fork River channel and ending at Milltown Reservoir, just east of Missoula. The Operable Unit is divided into three reaches (A, B, and C) and this report focuses on the first 3.5 river miles of Reach A, designated as Phase I, from Warm Springs Ponds to Perkins Lane Bridge.

Heavy metals originating from historic mining activities, milling and smelting processes associated to the Anaconda Company operations in Butte and Anaconda have accumulated in the Clark Fork River bed, banks and floodplain over a period of at least 100 years. The Montana Department of Environmental Quality (DEQ), as lead agency, with additional oversight from the Environmental Protection Agency (EPA) (and the National Park Service (NPS) for remedial activities on the Grant-Kohrs Ranch), will oversee, manage, coordinate, and implement the Remedial Design, Remedial Action(s), and Operation and Maintenance for the Clark Fork Site. DEQ will coordinate with the NRDP in the implementation of the Clark Fork Aquatic and Riparian Resources Restoration Plan and in the integration of the Clark Fork Aquatic and Riparian Restoration Plan components into the Work. DEQ will coordinate with NPS to implement the Federal Restoration Plan at the Grant-Kohrs Ranch and, where appropriate, integrate the Federal Restoration Plan components into the work. NRDP and NPS are included in the Sampling and Analysis (SAP) Planning Team to understand and receive the information to be collected, understand how that information is to be analyzed, provide review and comment, and better coordinate aspects of state and federal restoration with the remedy for the Clark Fork Site.

The overall objective of the investigations described in this report is to support design of reconstructed streambanks and other river channel modifications necessary for the remediation and restoration of Reach A of the Clark Fork River. Specific objectives of the investigations include determining:

- Existing bank condition for the purpose of determining which banks are in need of reconstruction and what level of treatment is needed;
- Existing instream pool habitat units to assess conditions for restoration design;
- Peak flow hydrology for this portion of the Clark Fork River;
- Channel geometry through surveyed cross-sections to allow computation of flow characteristics under design conditions;
- Existing toe of bank material.

This report discusses the geomorphic characteristics of the Clark Fork River in the Phase 1 area, the peak flow hydrology, hydraulic analysis, and toe of bank materials.

Geomorphology

The field data and observations presented in this chapter, in combination with the bank toe investigation and previous reports (e.g., Smith *et al*, 1998), support the conclusion that system aggradation has created an entrenched morphology on the Phase 1 segment of Reach A, where the channel has become dissociated from its adjacent floodplain. Flood events in the late 1800s and early 1900s resulted in the deposition of up to several feet of tailings on the floodplain. Natural-levee type deposition on the tops of banks has created a floodplain surface that slopes away from the channel in many places. The Warm Springs Ponds were constructed as a sediment trap in response to these events. Since the ponds have been operational, the post-mining evolution of the channel appears to have been very slow and aggradation in the reach has been dampened by the reduction of both sediment loading and flood flows due to peak flow attenuation by the ponds.

In an entrenched alluvial system, the channel will attempt to reestablish a floodplain (known as an inset floodplain) at the current channel elevation in an attempt to accommodate low recurrence interval flows, as is the case with the Phase 1 reach. However, low channel lateral migration rates, due to a deficiency of coarse sediment, the presence of cohesive bank material, and reduced energy in flood flows, have constrained this floodplain development process. As a result, comparison of current and 1950's aerial images indicates that the channel planform has changed very little.

From Warm Springs Creek to Perkins Lane Bridge, width to depth ratios increase, and inset floodplain planforms become more common. This trend may be related to increased sourcing of coarse sediment from the banks, or potentially variations in floodplain aggradation thicknesses relative to upstream locations.

Although one direct consequence of relatively slow migration rates in the Phase 1 reach is a commensurately low rate of tailings entrainment, it is clear that bank erosion and entrainment does occur. The most compelling evidence of tailings entrainment is the failure of multiple 1990 bank treatment sites that were designed to stop bank erosion in contaminated areas.

The bank erosion hazard index (BEHI) ratings developed for this reach do not correlate well to migration rate measurements, as the BEHI ratings are highly dependent on vegetation densities on the eroding bankline. In this system, where phytotoxicity resulting from heavy metals contamination results in bare banks, severity ratings can be extreme on banks that are not actively moving. It is expected at most of these locations, if the banks were not phytotoxic, they would be well vegetated and not eroding. The BEHI rating procedure may prove to be very effective in the CFROU, as it identifies both phytotoxic banklines that are relatively stable and rapidly migrating banklines, both of which are important with regard to remedial action.

The erosion inventory performed for this effort represents a summary of conditions observed in the fall of 2009. Many of the actively eroding banks inventoried were previously treated in the 1990 demonstration project (Schafer and Associates, 1991), indicating that some erosion sites have persisted through time. As the system evolves, however, it will be important to continue to monitor bank integrity through the reach. If sediment loads to the reach increase due to the progressive delivery of bedload through the Mill/Willow bypass for example, sediment storage may ensue, and erosion locations and severities may change. Similarly, if a large flood event were to occur in the reach, banks that currently show no evidence of retreat may be destabilized.

Hydrology

The Phase 1 study area includes two primary streams, Silver Bow Creek below the Pond 2 discharge at Warm Springs Ponds, and the Clark Fork River. The Clark Fork River begins at the confluence with Warm Springs Creek, and separate peak flows were determined for these two reaches because of the influence of Warm Springs Creek, which typically contributes about one-third the flow of the Clark Fork River.

Peak flow hydrology has been predicted for the Phase 1 area of the CFROU to provide peak flows for hydraulic analysis of the existing river channel and floodplain. Two analytical methods were pursued:

1. The USGS regression equation method, which uses basin characteristics and regional regressions equations, was used to estimate peak flows for 2-, 5-, 10-, 25-, 50- and 100-year recurrence intervals.

2. The same interval flows were also calculated using USGS gage data and Bulletin 17B methods. The primary gage records analyzed were for the Silver Bow at Warm Springs (USGS No. 12323750) and Clark Fork near Galen (USGS No. 12323800) gages, which bracket the site on the upstream and downstream ends respectively.

Because the gages used in method 2 have relatively short periods of record (25- and 20-years respectively), correlations with longer term gages including the Clark Fork River at Deer Lodge (USGS No. 12324200) and Middle Fork Rock Creek (USGS No. 32000) were used to extend the Clark Fork River near Galen record to about 72 years. This extended record provides better estimates of infrequent peak flows such as the 50- and 100-year recurrence flows. No such extension was attempted for the Silver Bow Creek at Warm Springs and only flows up to the 25-year recurrence interval were calculated for this gage station because of the lack of suitable comparison gages.

The regression equation predicted peak flows are much higher than the peak flows calculated based on gage records. This is because actual flows on the Clark Fork River are heavily impacted by the presence of the Warm Springs Ponds immediately upstream of the site. These ponds reduce flow peaks considerably through the deten-

tion of tributary flow. Therefore, the peak flows based on gage records are considered more representative of the present day hydrology at the Phase 1 site, and are the peak flows chosen for use in the hydraulic analysis. These flows are presented in Table ES-1. Other than Warm Springs Creek, there are no tributaries that contribute significant flow to the Clark Fork River in the Phase 1 area.

Table ES-1. Predicted Flood Flows for CFROU – Phase 1 Area.

Recurrence Interval (yrs)	Clark Fork River near Galen, MT	Silver Bow Creek at Warm Springs, MT
	Bulletin 17B Estimate (20 or 72 yrs) (cfs)	Bulletin 17B Estimate (25-yrs) (cfs)
2	522	396
5	861	694
10	1,094	921
25	1,286	1,235
50	1,415	--
100	1,533	--

This analysis of flood events is based on peak flows during a period when the Warm Springs Ponds were in place, and it reflects the attenuation of the peaks by the ponds. If in the future the ponds are eliminated, the Upper Clark Fork River hydrology would change radically with much larger peak flows occurring along with greater sediment delivery to the system, and the design basis for streambank and floodplain remediation would need to be modified to account for this change.

A related concern with the current management of the ponds is that 100-year or larger events are bypassed around the ponds to prevent potential failure of the ponds. A dike on the west side of Silver Bow Creek just upstream of the ponds is built to erode away at a flow about equal to the entering 100-year peak flow, estimated at 3,300 cfs, and cause the flood to bypass the ponds and discharge directly to the Clark Fork River. Therefore, a flow much larger than the 100-year peak flow calculated in this study could be released to the Clark Fork River, increasing downstream risk beyond the level considered in this analysis.

Hydraulic Analysis of Existing Conditions

A hydraulic model of peak flows was developed for Silver Bow Creek below the Warm Springs Ponds and the Clark Fork River above Perkins Lane Bridge. The purpose of the model is to develop reach-averaged and point estimates of water depths, energy slopes, and velocities on the river for determination of forces on overbanks, banks and bed of the river. This information will be used during remedial design, primarily to develop appropriate bank treatments. A secondary purpose is to map the extent of flooding and magnitude of shear stresses on the floodplain as a basis for development of appropriate floodplain treatment designs. This will be especially important should the design include modifications to floodplain elevations, in which

case the model can be modified to calculate the hydraulic parameters of the redesigned configuration.

For development of the hydraulic model, a field survey of channel cross-sections was conducted using GPS survey grade equipment. This information was combined with LIDAR survey mapping developed for the floodplain to assemble complete model cross-sections. The GPS surveys are capable of a vertical accuracy of 0.2 feet and the topography developed from the LIDAR mapping has an accuracy suitable for one-foot contour mapping.

The Army Corps of Engineers HEC-RAS model was used to analyze the 2-, 5-, 10-, 25-, 50- and 100-year recurrence flows for the Phase 1 area. The model accounts for main channel and overbank flows with appropriate roughness (Manning's "n") values. The main channel roughness was determined through channel inspections and by calibrating the water elevations obtained during the survey with flow obtained from the Galen gage. The overbank roughness was estimated using aerial imagery from the relative proportions of slickens, small trees, shrubs, and grasses on the overbank using typical values for these vegetation types.

Reach-averaged hydraulic parameters were predicted by the model for the range of flows including velocity, hydraulic depth, and energy slope, which can be used to evaluate shear stress and other design values needed for streambank and floodplain design. These reach averaged values are presented in the Section 4 of the report.

Modeling results indicate that the existing channel generally contains the 10-year and at some locations the 100-year flow. Typically, river channels in western Montana have a bankfull flow corresponding to the 1.5 to 2-year recurrence event so this discrepancy suggests that the existing channel was formed when peak flows were significantly higher before the Warm Spring Ponds were constructed. The existing channel banks are higher than the broader floodplain due to the deposition of tailings transported and deposited on the overbanks within a few hundred feet of the channel during the 1908 and other floods prior to construction of the Warm Springs Pond. If these banks are over-topped, some of the flow will not return to the main channel for several miles. However, the amount of flow lost from the channel during the 100-year flood, typically less than 20 cfs at any one location, is small compared to what is transported in the channel, and this effect was not incorporated in the model.

Bank Toe Materials

A bank toe material investigation was conducted to determine if suitable materials exist at locations where they would support upper bank reconstruction in the remedial action. If appropriate material, typically gravels and cobbles, exist at the correct elevation, they will provide a stable base for upper bank construction. If these materials are not present or are too deep, they may need to be supplemented with imported material of an appropriate size to support the reconstructed upper bank. Test pits were excavated along the river during the field investigation conducted by Tetra Tech as part of Part 1 of the contaminant characterization. Test pit logs indicate the

texture of the bank toe materials and laboratory sieve analysis of six bank toe samples indicate the range of materials observed. Groundwater levels were noted and pictures of the test pits were taken. Data was compiled by Tetra Tech, analyzed by CDM, and included in this report.

The vertical location of bank toe materials was plotted on profiles showing the bank elevations, test pit surface elevations, groundwater level, and top surface of potentially suitable toe material. Comparison of the top surface of the toe material elevation with the bank toe elevation as determined by stream surveys shows that the sampled toe material was typically at or somewhat below the measured bank toe elevation. The range of variation in this comparison is significant with a standard deviation typically around one-foot. This indicates that we cannot assume that the potentially suitable toe materials, when present, are located at the bank toe elevation, and toe conditions at each bank will have to be considered individually during construction.

Six toe material samples were submitted to Tetra Tech's materials testing laboratory for particle size analysis. One sample was located on Silver Bow Creek, one was located on Warm Springs Creek, and four were located on the Clark Fork River within the ARCO property. The toe materials are predominantly classified under the Uniform Soil Classification System as gravels with sands and cobbles or sands with gravels and cobbles. Both these materials may serve as bank toes if they are present at appropriate elevations although some other materials encountered at the toe elevations are probably not adequate for toe material. The D_{50} (mean particle size of the distribution) of the bank toe materials along the Clark Fork River ranges from 0.16 to 1.29 inches, a wide range that depends on the relative proportions of sand and gravel. However, the D_{84} (particle size which is greater than 84% of particles in the distribution), which is important in calculating the shear stress that can cause mobilization of bank material, tends to be more consistent with a typical size of 2-inches.

An estimate of the likelihood of encountering suitable toe materials at reconstructed bank locations was made using the results of the field and laboratory analysis of toe materials. Along Silver Bow Creek and the Clark Fork River, sand and gravel materials were encountered in the bank toes at suitable elevations for reconstruction at about 90% of locations. Some of these materials may not be coarse enough to serve as bank toes. In addition, the top of the suitable materials is sometimes below the bank toe with mean depths of 0.7 to 0.8 ft. below the bank toe. This result indicates that the in-place bank toe material may need to be supplemented with imported suitable materials during bank reconstruction.

In this investigation bank toe materials potentially suitable to support bank reconstruction were found at many locations along Silver Bow Creek below the Warm Springs Ponds and along the Clark Fork River on the ARCO property. At a majority of the locations on Silver Bow Creek, the suitable materials were below the bank toe elevation; and on half the locations on the Clark Fork River, the suitable materials were below the bank toe. During construction, it will be necessary to supplement the bank toe material at some locations including locations where suitable materials are

absent. During the design process, the hydraulic model results will be used to develop design criteria for bank toe materials and a comparison with the existing toe materials will be made to determine if these preliminary conclusions on the availability of suitable materials are correct.

Section 1
Introduction

The Clark Fork River Operable Unit (CFROU) is part of the Milltown Reservoir/Clark Fork River Superfund Site and includes the uppermost 120 miles of the Clark Fork River between Warm Springs Ponds and Missoula, Montana. The Operable Unit was divided into three reaches (A, B, and C) as shown on Figure 1-1. This report focuses on the first 3.5 river miles of Reach A, designated as Phase I, from Warm Springs Ponds to Perkins Lane bridge.

1.1 Site Background

Heavy metals originating from historic mining activities, milling and smelting processes associated to the Anaconda Company operations in Butte and Anaconda have accumulated in 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 other surface waters. In addition to erosion, heavy metals are leached from the contaminated sediments and tailing 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).

The Montana Department of Environmental Quality (DEQ), as lead agency for remediation of the CFROU, with additional oversight from the Environmental Protection Agency (EPA) (and the National Park Service (NPS) for remedial activities on the Grant-Kohrs Ranch), will oversee, manage, coordinate, and implement the Remedial Design, Remedial Action(s), and Operation and Maintenance for the CFROU. DEQ will coordinate with the Natural Resource Damage Program (NRDP) at the Montana Department of Justice in the implementation of the Clark Fork Aquatic and Riparian Resources Restoration Plan and in the integration of the Clark Fork Aquatic and Riparian Restoration Plan components into the Work. DEQ will coordinate with NPS to implement the Federal Restoration Plan at the Grant-Kohrs Ranch and, where appropriate, integrate the Federal Restoration Plan components into the work. NRDP and NPS are included in the Sampling and Analysis (SAP) Planning Team to understand and receive the information to be collected, understand how that information is to be analyzed, provide review and comment, and better coordinate aspects of state and federal restoration with the remedy for the Clark Fork Site.

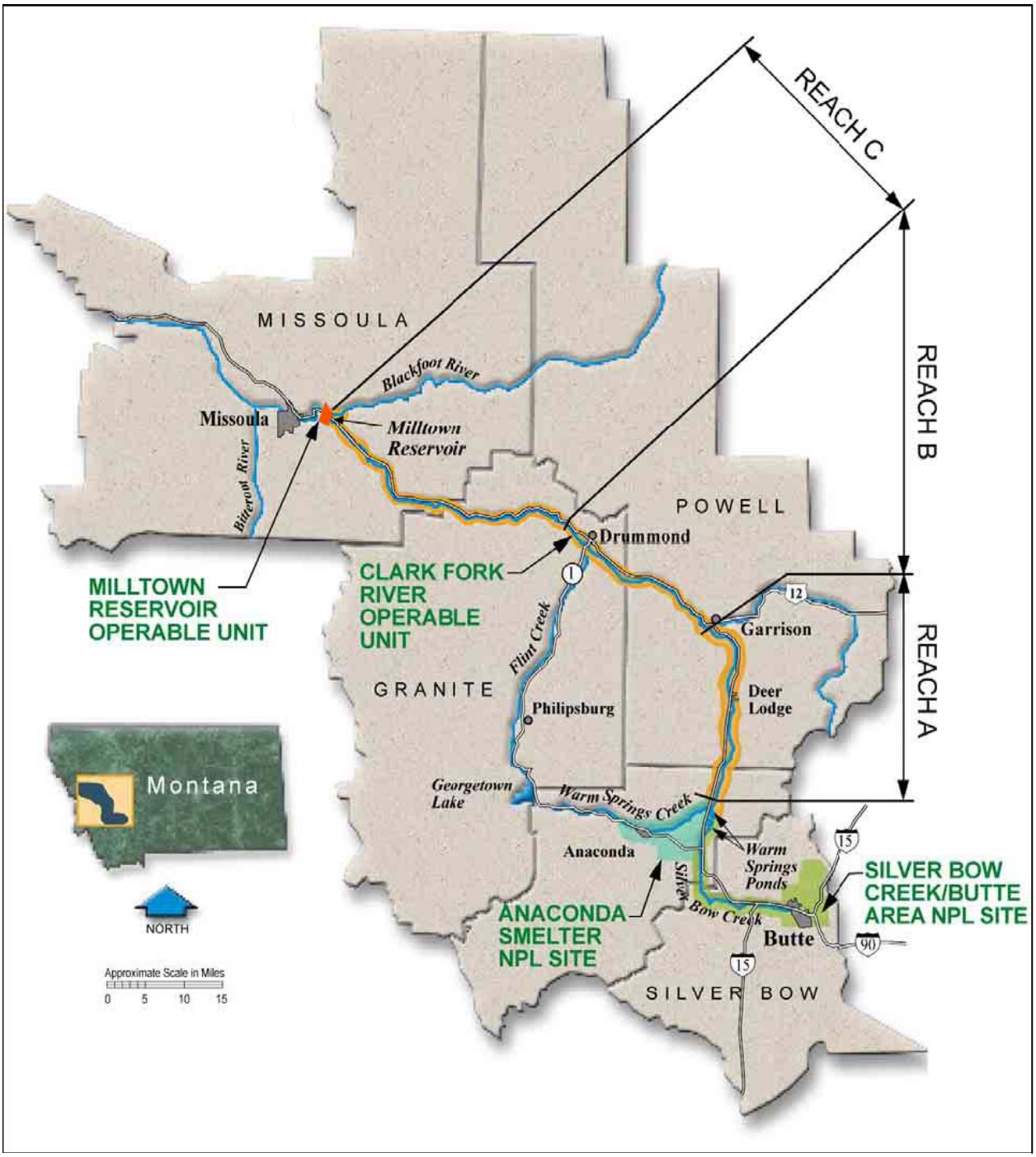

Figure 1-1. Clark Fork River Operable Unit Reaches.

1.2 Purpose and Objective

As part of the remedial design effort, DEQ has retained consultants to develop design data on floodplain materials and streambank conditions in the Phase 1 area. The purpose of this study is to evaluate the existing geomorphic, hydrologic, and hydraulic characteristics of the Clark Fork River in the Phase I area. The overall objective of these investigations is to support the design of reconstructed river banks and channel modifications necessary for the remediation and restoration of Reach A of the Clark Fork River. Specific objectives of the investigations are to determine:

- Bank condition for the purpose of determining which banks are in need of reconstruction and what level of treatment is needed;
- Instream pool habitat units to assess conditions for restoration design;
- Peak flow hydrology for this portion of the Clark Fork River;
- Instream geometry through surveyed cross-sections to allow computation of flow characteristics under design conditions; and
- Bank toe material types under banks that are being investigated.

These work items are described in an Addendum to the Clark Fork River Sampling and Analysis Plan for Geomorphic and Hydraulic Field Investigations, Phase 1 (Tetra Tech and CDM, 2009).

1.3 Site Location and Description

The CFROU is located within three counties, Deer Lodge, Powell, 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. The downstream boundary is the Milltown Reservoir Sediments Operable Unit, just east of Missoula, Montana. The Operable Unit was divided into three main reaches, Reach A, B, and C as shown in Figure 1-1. This report focuses on the first 3.5 river miles of Reach A, between the discharge of Warm Springs Pond and Perkins Lane as shown on Figure 1-2. Although the upstream end of the CFROU is the confluence of Silver Bow Creek and the old Clark Fork River channel, this study includes a portion of Silver Bow Creek upstream of the site to ensure that any upstream unstable banks will not affect mitigation downstream in the CFROU.

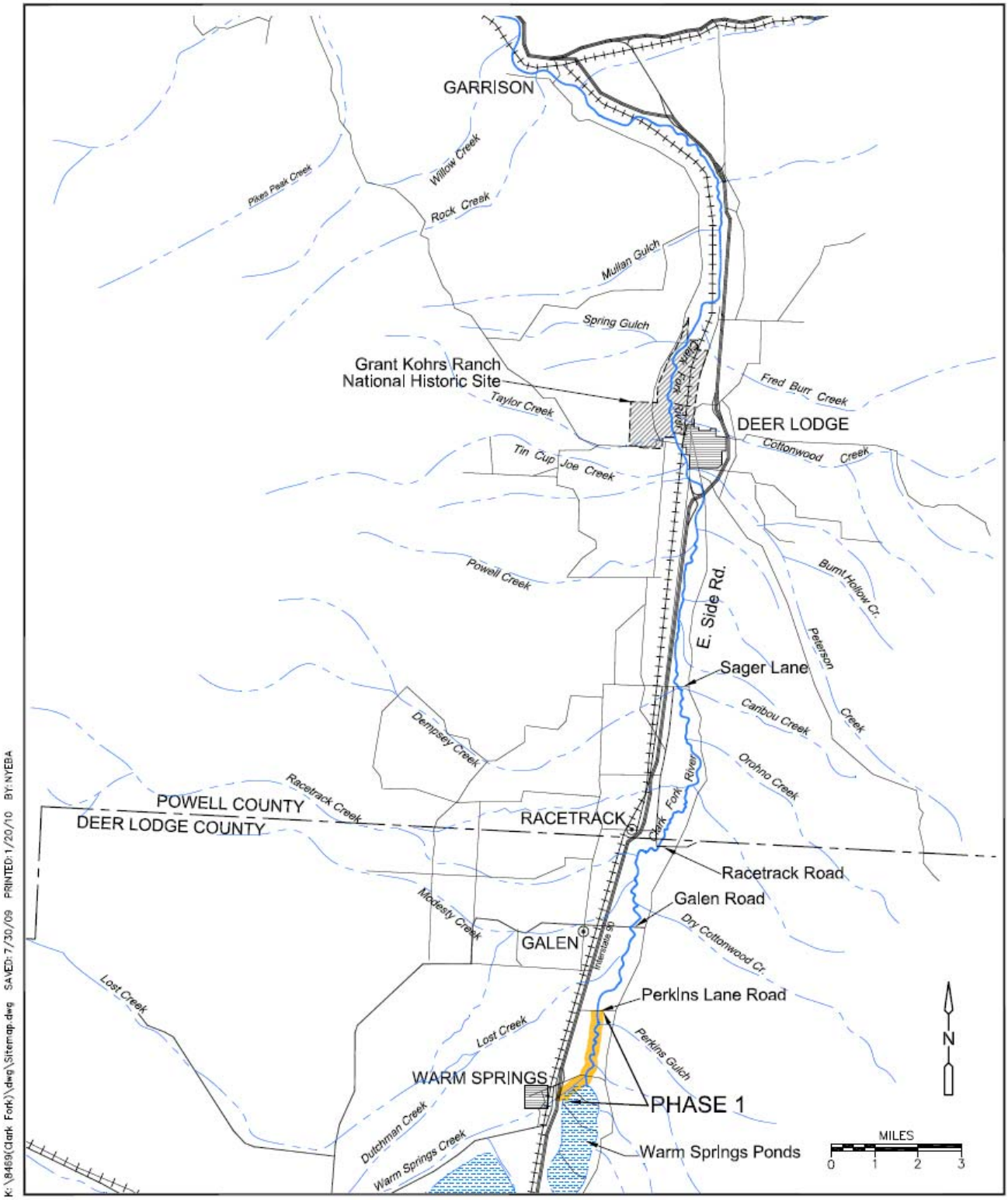

Figure 1-2
Clark Fork River, Reach A
Clark Fork River OU

1.4 Previous Studies

Since the Upper Clark Fork River became part of a National Priorities List (NPL) site in 1982, numerous studies have been conducted on the river some of which address the geomorphology and hydrology of the river or the reconstruction of streambanks. The US Geological Survey (USGS) and others (Smith *et al,* 1998) undertook a study from 1995 to 1998 to quantify metals sources and transport in the Upper Clark Fork River Operable Unit. This report provides a geomorphic background for the upper river including the Phase 1 area, but peak flow hydrology is addressed only downstream of the site, and no hydraulic modeling was developed.. An important conclusion of this report was that 60% of the copper transported in the upper river originates from bank erosion. The USGS also addressed vegetation controls on bank erosion rates in a later report (Griffin and Smith, 2001), and developed criteria for shrub planting density on the floodplain of the Clark Fork River in Smith and Griffen (2002). R2 Resource Consultants developed peak flow hydrology for the USGS gage at Deer Lodge but did not develop hydrology for the Phase 1 area. The Record of Decision (USEPA/MDEQ, 2004) Appendix B presents the peak flows estimated for the Deer Lodge gage along with other relevant criteria for streambank design. This appendix also includes four proposed streambank treatment designs.

In 1990 the Governor's Demonstration Project demonstrated lime amendment and revegetation techniques in the Clark Fork River floodplain and reconstructed some eroding banks. This work occurred in the Phase 1 area and the Final Report for the Clark Fork River Demonstration Project (Schafer, 1991) documents the construction techniques used in the streambank reconstruction. However, the report does not provide a design basis for the bank treatments and there is no reference to geomorphic, hydrologic, or hydraulic studies used to support the designs. More recently, EPA has developed a Clark Fork River Riparian Evaluation System (CFRRipES), which was used to map streambank classes and and stream bank treatment areas (CH2M-Hill, 2008).

1.5 Report Organization

Sections 2 through 5 of this report describe the existing geomorphic, hydrologic, and hydraulic conditions in Phase I of Reach A. Geomorphic aspects and selected habitat features of the river are described in Chapter 2. Chapter 3, Hydrology, presents an analysis of flood hydrology in the Phase I area. The hydrology is integrated with a hydraulic model in Chapter 4 to develop water-surface profiles for different flow levels, to determine the typical channel capacity, and to develop reach-average hydraulic characteristics in Phase I. Chapter 5 presents results of the bank toe material investigation conducted by Tetra Tech in the fall of 2009.

Section 2
Geomorphology

Starting at the confluence of the Mill/Willow Bypass and Pond 2 discharge and ending at the I-90 bridges downstream of Garrison, Reach A of the Clark Fork River Operable Unit (CFROU) consists of 47.5 miles of river channel. The uppermost 3.5 miles of Reach A, which is referred to as Phase 1, extends from the upper limit of the CFROU at the confluence of Silver Bow Creek and its historic channel (RM 0.84) downstream to Perkins Lane Bridge at RM 4.25. In this chapter, the geomorphology of the Reach A, Phase 1 segment of the Clark Fork River is described in support of the development of bank stability treatment designs. This assessment has been extended upstream of the upper Phase 1 boundary for about 0.44 miles to incorporate a section of channel between the Pond 2 discharge and upper end of the CFROU that has currently has locally unstable banks that may require treatment and downstream of the Phase 1 boundary to assess the overall geomorphic conditions of this section of river. As such, the project extent addressed herein extends from RM 0.4 (2,100 feet downstream of the Pond 2 discharge) to RM 4.25 (Perkins Lane Bridge).

Specific objectives of the geomorphic assessment include the following:

- Perform a field investigation to define and characterize geomorphically-based reaches;
- Perform a bankline erosion assessment;
- Describe channel morphology using field survey data;
- Measure bed sediment gradations;
- Describe pool habitat features; and
- Summarize the geomorphology of Phase 1 reach with an emphasis on bank erosion patterns and controls.

2.1 Methods

The information used to describe the existing geomorphic condition of the project reach is derived from a field investigation and channel survey that was performed in October/November 2009. The geomorphic field investigation consisted of walking the entire reach, and collecting the following data:

- Trends in channel morphology, used to develop reach breaks;
- Locations and severity of eroding bank segments;
- Mapped infrastructure elements and areas of engineered channel modifications;

- Pool habitat mapping and measurements of residual depth;
- Pebble counts; and
- Digital photographs of each inventoried bank, each pebble count site, and general reach attributes.

Subsequent to the geomorphic field investigation, air photos from 1950 and 1977 were obtained, georectified and incorporated into an ARCMAP GIS environment. The banklines on this imagery, as well as the 2006 project imagery were digitized to identify bankfull channel margins through time. These digitized banklines were then utilized to approximate 1950-2006 migration rates at banks identified as actively eroding in the field.

2.2 Geologic/Geomorphic Setting

The project reach, which extends from the Pond 2 discharge point to the Perkins Lane Bridge, is located in the Upper Deer Lodge Valley. In this area, the Clark Fork River flows through a north-trending meanderbelt that abuts the eastern margin of the valley. Figure 2-1 is a map of the surface geology of the Upper Clark Fork River (Berg and Hargrave, 2004). The low hills east of the river corridor consist of quartz monzonite of Cretaceous age. Overlying these granitic rocks, the lower hillslopes on the valley's edge consist of Tertiary-age sediments that are comprised of silty to sandy mudstone to conglomerates. Broad, gravel-veneered pediments form prominent landforms over both the Tertiary sediments and older monzonite. These pediment deposits range in thickness from 1 to 20 feet, and contain subrounded cobbles and pebbles in a sandy matrix with some caliche development (Berg and Hargrove, 2004). Wisconsin-age glacial till forms large outwash plains west of the river. These deposits contain well-rounded material that ranges in size from boulders to sand (Berg and Hargrave, 2004).

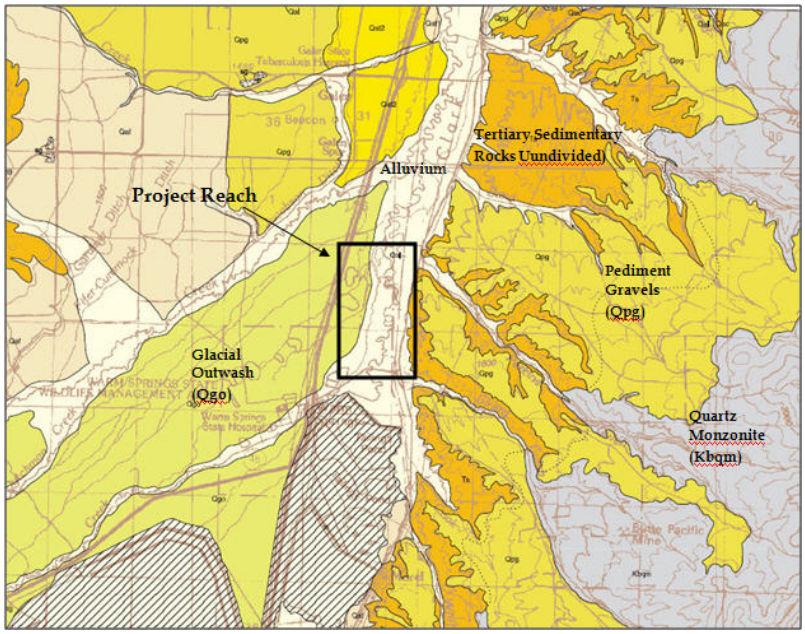

Figure 2-1. Geologic map of upper Clark Fork River (Berg and Hargrave, 2004).

2.3 Geomorphic History

In the Upper Deer Lodge Valley, the Clark Fork River is a highly sinuous, variably entrenched stream that has been strongly influenced by human activities. Smith and others (1998) describe several lines of evidence that support the claim that, prior to settlement, the Upper Deer Lodge Valley supported extensive beaver populations that created a wide river corridor characterized by split flow and extensive dam complexes. These lines of evidence include early descriptions by fur trappers of dense vegetation and clear flowing waters. Field evidence that supports the historic presence of beaver includes peat layers and channel remnants in the riverbanks that are smaller in cross section than the modern channel. The removal of beaver from the Northern Rockies is becoming increasingly recognized as an agent of major geomorphic change in alluvial streams of the region. These changes include conversion of a multi-thread system to a more consolidated flow path, lower water tables, a deeper channel profile, a lower potential for avulsion, and less efficient sediment trapping capabilities (Butler and Malanson, 2005). Beaver populations were likely eradicated in the early 1800s.

Following the beaver trapping era, mining in the upper Clark Fork region began in the 1860s. Floods in the late 1800s and early 1900s resulted in the deposition of tailings on the Clark Fork River floodplain. Smith et al (1998) suggest that the extensive deposition of tailings on the Clark Fork floodplain was in part due to the pre-mining geomorphology of the system. These conditions, which stem in part from the historic presence of beaver, include perched channels, irregular floodplain topography, and dense floodplain vegetation. Smith et al (1998) suggest that dense vegetation on the channel margin slowed overflows and promoted deposition on the channel edges, creating natural levees that slope away from the channel. Conveyance of flood flows over these natural levees and into adjacent floodplain areas then drove deposition of suspended material as flow velocities slowed on the floodplain surface, and variations in floodplain thickness reflect deposition on topographically irregular ground. These authors also note the "the fact that the river channel retained its single-thread integrity despite the intensity of the 1908 flood provides supporting evidence that the floodplain still was sufficiently vegetated to provide ample resistance to bank erosion and overbank flow".

The current geomorphology of the project reach strongly supports the depositional processes postulated by Smith et al (1998). Tailings deposition on the margins of the channel has resulted in cross section entrenchment, high flow capacities, and a sloping surface away from the topbank towards the western floodplain (Chapter 4).

The Warm Springs Ponds were constructed between 1911 and 1959 by the Anaconda Company to trap tailings before they entered the Clark Fork River (www.buttectec.org). The 2,400 acres of ponds contain millions of cubic yards of tailings and contaminated soils, and their storage effects include reduction of downstream sediment loads and flood peaks (See Section 3, Hydrology).

Currently, the bed of the Clark Fork River consists of coarse gravel and cobbles. Smith et al (1998) concluded that this bed material represents a largely immobile armor layer that formed as the river incised in response to beaver dam removal and flood events, and that this armor layer is at the same elevation as the pre-mining channel bed. Subsequent test pit information supports this conclusion; excavations on the channel margins consistently encountered a coarse cobble horizon at the same general elevation as the current channel bed (see Section 5, Bank Toe Investigation).

Within the project reach, deposition of up to several feet of tailings on the Clark Fork River floodplain a century ago has resulted in the formation of elevated banks and reduced floodplain access. Whereas stream channel entrenchment is commonly the result of channel incision (downcutting), in this case available data indicate that entrenchment is a direct consequence of rapid floodplain aggradation prior to the activation of Warm Springs Ponds as a sediment trap. The post-aggradational evolution of the channel, which would typically include reductions in entrenchment through channel widening and inset floodplain development, has been hampered by 20th century reductions in flood flow peak volumes and sediment delivery rates resulting from detention of flow in the Warm Springs Ponds.

2.4 Project Reach Delineation

From the Pond 2 discharge outlet to Perkins Lane Bridge, the Clark Fork River has been divided in to five reaches (Figure 2-2). The reach boundaries reflect changes in geomorphic character, including factors such as channel slope, planform, lateral confinement, floodplain access, and pool frequency. As the CFROU begins at RM 0.84, the assessed reach above this point his referred to as the "Upper Reach". From the start of the CFROU downstream, the Phase 1 portion of the Clark Fork River that extends to Perkins Lane Bridge has been divided into four reaches, referred through as Reach 1 through Reach 4 (Table 2-1). Table 2-2 summarizes geomorphic parameters for each reach. A time series of air photos (1950, 1976, and 2006) for each reach is contained in Appendix A.

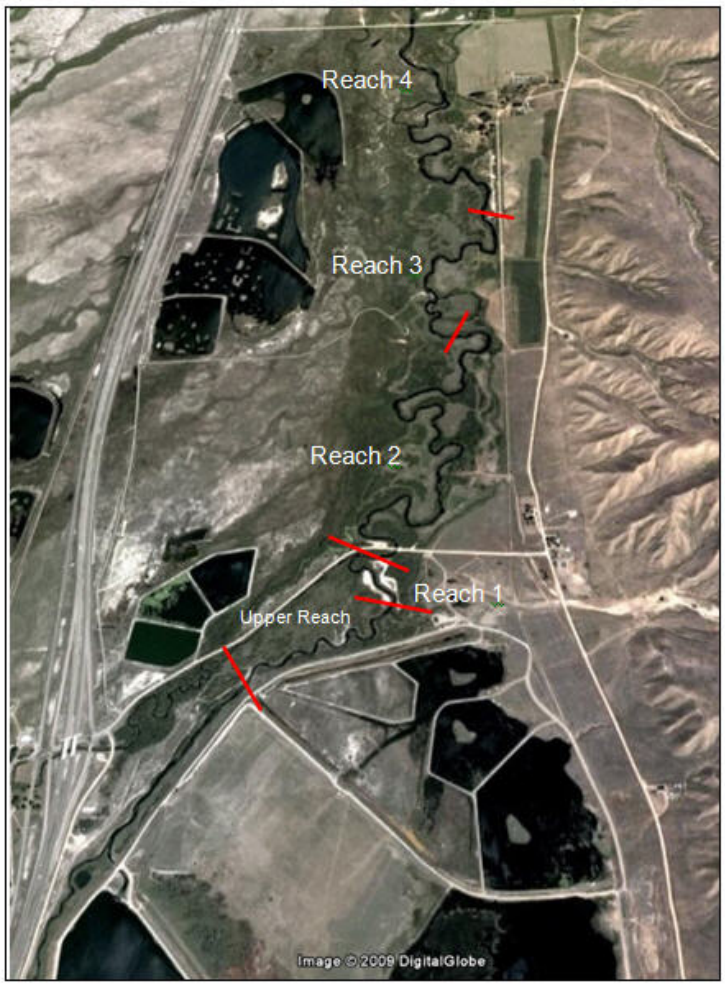

Figure 2-2. Oblique Northward View of Project Reach Showing Geomorphic Reach Delineation.

Table 2-1. General Summary of Reach A-Phase 1 Geomorphic Reaches, Clark Fork River

Reach	River Mile	Cross Sections	Eroding Banks[1]	Comment
Upper	0.4-0.84	1-14	EB 0-1 to EB 0-8	Upstream of Operable Unit; constructed as channelized segment 1950-1977; rebuilt 1977-2006 with meandering planform
1	0.84-1.05	15-21	EB 0-9 to EB 0-17	To Warm Springs Cr confluence; natural channel segment
2	1.05-2.50	22-64	EB 1-01 to EB 2-10	Sinuous, entrenched; fine grained bank stratigraphy; minimal change between 1950 and 2006.
3	2.50-3.15	65-85	EB 2-11 to EB 3-04	Notable widening relative to upstream, increased presence of gravel in bank toes, limited gravel bars; severe erosion through meander cutoff that was initiated by 1950.
4	3.15-4.20	86-125	EB 3-04 to EB 4-02	High width to depth ratio; coarse bed; persistent split flow section since 1950.

Note: [1] See Appendix B for maps of locations of eroding banks.

Table 2-2. Geomorphic Parameter Summary, Clark Fork River - Reach A - Phase 1.

Parameter Type	Parameter	Reach				
		Upper	1	2	3	4
General	RM Start	0.40	0.84	1.05	2.50	3.15
	RM Stop	0.84	1.05	2.50	3.15	4.20
	Length (miles)	0.44	0.21	1.45	0.65	1.05
	Number of Cross Sections	14	7	41	21	51
Slope/ Planform	Water Surface Slope (%)	0.3%	0.1%	0.1%	0.1%	0.2%
	Sinuosity	1.5	1.5	2.1	1.4	1.6
Cross Section Morphology	Mean Depth (median of all surveyed cross sections; ft)	4.5	3.1	3.7	2.7	2.4
	Maximum Depth (median of all surveyed cross sections; ft)	6.3	5.4	5.5	4.5	4.0
	Top Width (median of all surveyed cross sections; ft)	66.9	50.4	51.9	49.6	51.2
	Width to Depth Ratio (median of all surveyed cross sections)	15.3	14.8	14.7	18.5	19.7
Pool Habitat	Pool Frequency (pools/mile)	20.5	23.8	14.5	18.5	14.3
	Median Residual Pool Depth (ft)	3.5	1.6	2.7	2.8	2.4
Substrate	Pebble Count D_{50} (in)	NA	NA	1.2 (PC1) 1.5 (PC2) 2.2 (PC3)	1.7 (PC4)	2.1 (PC5) 2.1 (PC6) 2.0 (PC7)

Note: NA – Not available

2.5 Bank Erosion Inventory

In October 2009, a bank erosion inventory was performed through the Phase 1 project length in support of the location and design of appropriate remedial bank treatments. To that end, each bankline through the project reach has been continuously mapped and segmented according to erosion severity. The segmentation was based on evidence of active erosion, which includes banks that are poorly reinforced by deep binding rootmass, steeply inclined banklines, and evidence of active sediment delivery to the channel.

As prescribed in the Phase 1 Sampling and Analysis Plan (CDM and AGI, 2009), a bank erosion hazard index (BEHI) rating was generated for each mapped segment of actively eroding bank. This streambank erodibility rating procedure is based on five parameters: bank height-bankfull height ratio, rooting depth, rooting density, bank angle, and degree of surface protection (Rosgen, 2001; http://www.epa.gov/warsss). The individual inventoried banks are numbered sequentially and grouped by river

mile (RM). For example, Bank 3-05 is located between RM 3.0 and RM 4.0, and was the fifth bank inventoried downstream of RM 3.0. A tabulated summary of the erosion inventory results is contained within Appendix B.

2.5.1 Erosion Patterns

The types of bank erosion observed in the project reach include long extents of retreating bankline with active topple failure (Figure 2-3), as well as areas of severe discontinuous scalloping (Figure 2-4). Where this type of scalloping was identified, the entire series of scallops were mapped and the erosion severity of the scallops was applied to that bank extent. In some areas, minor erosion features were present on banks that are steep yet support woody vegetation. These banks were typically undercut, and rated low in terms of severity (Figure 2-5). Where there was no clear evidence of active erosion, the banks were not rated.

Figure 2-3. Continuous Left Bank Erosion into In-situ Treated Area, Bank 3-08.

Figure 2-4. Discontinuous Severe Erosion Forming Scalloped Bank, Bank 2-18.

Figure 2-5. Steep Bank with Mild Undercutting and Woody Vegetation Reinforcement.

2.5.2 Bank Materials

The bank stratigraphy in the project reach typically consists of silts and laminated silty sands that extend from the toe to top of bank. The lower bank is most commonly comprised of organic rich, moderately cohesive fine sediment (Figure 2-6). This unit supports variably dense root systems, and some willows. In places, tailings deposits conformably overlie this unit, suggesting that it represents the pre-mining Clark Fork River floodplain surface.

Figure 2-6. Eroding Bank 0-8 Showing Cohesive Lower Bank Unit; Note Root Density and Exposed Erosion Control Fabric.

From the Upper Reach through Reach 2, gravel was rarely observed in the bank. The frequency of observed exposed of gravel in the bank toe increases in the downstream direction, and this trend is accompanied by increases in width to depth ratio (Section 2.6.7). In several locations, banks are undercut where gravels are exposed (Figure 2-7). The results of the bank toe investigation (Chapter 5) indicate that although gravels were not commonly observed in the bank stratigraphy, a coarse gravel layer persistently underlies the moderately cohesive lower bank unit.

A cohesive blue clay was noted in the bank toe at two sites in the project reach. There has been some discussion of the potential association with this clay with Glacial Lake Missoula. However, the maximum elevation of Glacial Lake Missoula was approximately 4,150 feet, which indicates that the lake extended to just beyond Garrison, but not into the project reach (Alt, 2001). The origin or spatial extent of this clay is unknown.

Figure 2-7. Bank Undercutting at Gravel Horizon, Bank 1-17.

Tailings deposits are commonly exposed in the upper bank stratigraphy (Figure 2-8). These exposures are typically planar, indicating sheetflow deposition on gently sloping surfaces; however, in some locations, a concave lower contact indicates the burial of historic channels or other irregular pre-mining topography.

Figure 2-8. Tailings Exposure in Bank 1-12.

2.5.3 Erosion Inventory Results

A total of 13,353 feet of bankline was mapped as eroding in the 3.7-mile long project reach, which reflects approximately 33% of the entire bank length (Table 2-3). This includes a total of 86 individually rated bank segments. Reach 2 has the greatest length of BEHI-rated bankline, although approximately one-half of that erosion has a moderate or low rating (Figure 2-9). When normalized to the total bankline in a given reach, results show that the percent of bankline mapped as actively eroding decreases in the downstream direction. Although total erosion decreases downstream, the extent of banklines rated as having either, an extreme or very high BEHI rating increases downstream (Figure 2-10).

Table 2-3. Extent of Mapped Eroding Bankline, Clark Fork River Phase 1.

Severity	Total Length in Feet						Percent of Bankline					
	Upper	Reach 1	Reach 2	Reach 3	Reach 4	Total	Upper	Reach 1	Reach 2	Reach 3	Reach 4	Total
Extreme	252	199	660	1100	440	2651	4%	9%	4%	16%	4%	7%
Very High	0	0	739	233	1142	2114	0%	0%	5%	3%	10%	5%
High	554	117	1297	327	959	3254	8%	5%	8%	5%	9%	8%
Moderate	970	614	2360	468	201	4913	14%	28%	15%	7%	2%	11%
Low	0	276	378	67		721	0%	12%	2%	1%	0%	2%
Total	**1776**	**1206**	**5434**	**2195**	**2742**	**13353**	**38%**	**54%**	**35%**	**32%**	**25%**	**33%**

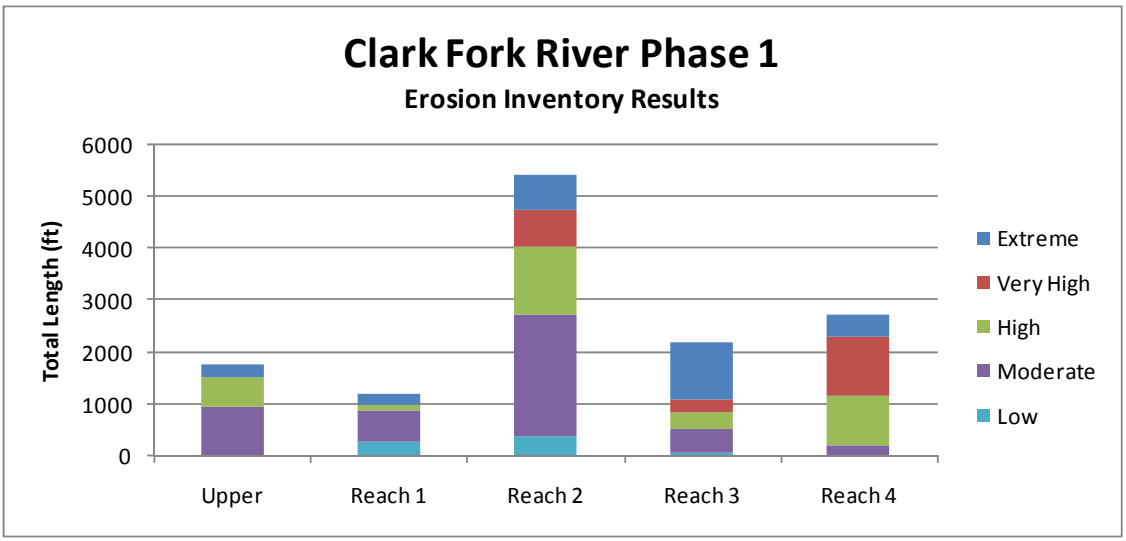

Figure 2-9. Total Length of Mapped Eroding Bankline, Reaches Upper, 1 through 4.

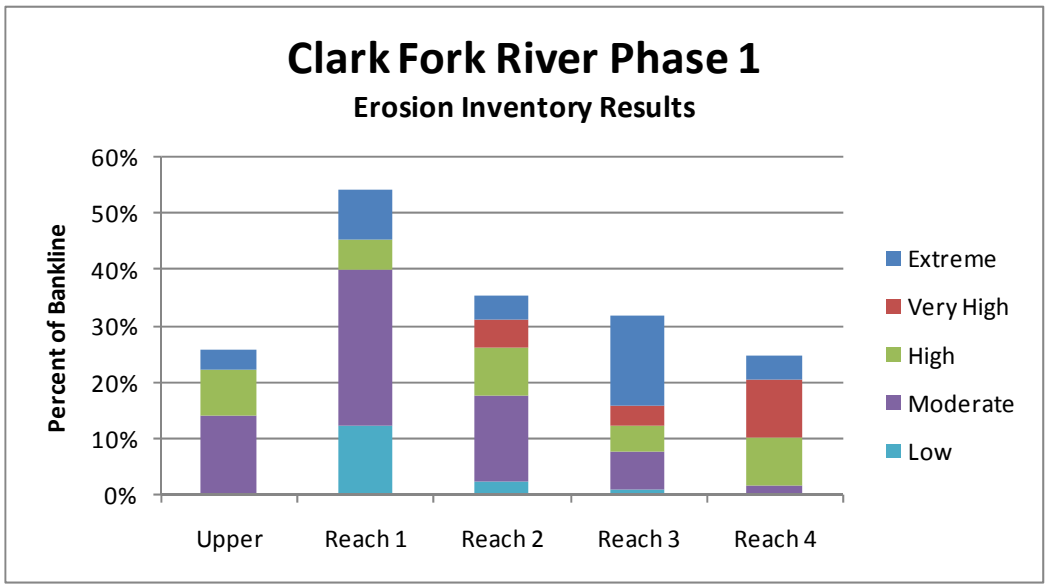

Figure 2-10. BEHI Ratings as a Percent of Total Bankline, Reaches Upper, 1 through 4.

Upstream of the Operable Unit boundary, bank erosion in the Upper Reach consists primarily of outside bank erosion on a channel segment that was constructed in 1990 (Appendix A; Figure 2-11). The BEHI rating of these banks is typically moderate, with a single bankline (Bank 0-7) mapped as extreme. This extreme-rated bank is 252 feet long, and consists of eroding white/gray fine sediment with minimal vegetation. Just downstream, a bank segment with a high severity rating (Bank 0-8) contains exposed and undermined coir fabric remnants, reflecting erosion into a previous bank treatment (Figure 2-6). Older erosion control efforts are also evident at Bank 0-2, where riprap has been flanked. Bank erosion into previously treated banks is discussed in Section 2.5.6. In the Upper Reach, which was constructed as a meandering channel since 1976, 38% of the bankline was mapped as eroding, although much of that erosion is of moderate severity (Figure 2-10).

In Reach 1, which marks the beginning of the Operable Unit, bank erosion is fairly continuous on the left bank. The BEHI ratings for Reach 1 are typically low to moderate, however two bank segments were rated as extreme. In total, 54% of the bankline within Reach 1 was mapped as eroding (Figure 2-10 and Figure 2-11).

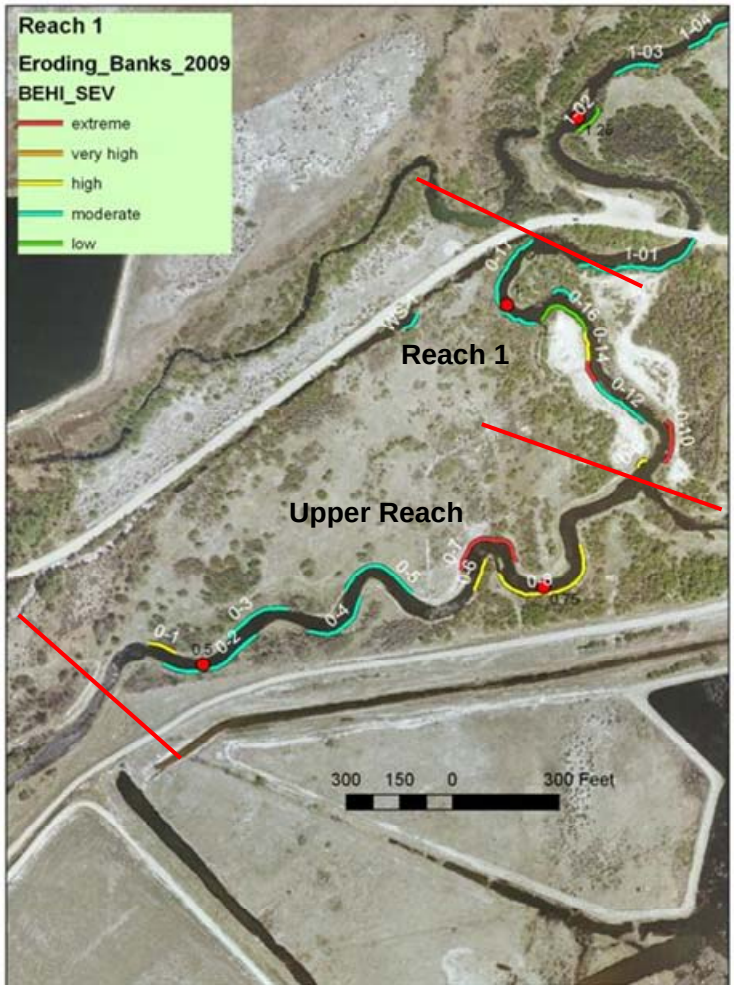

Figure 2-11. Map of Upper Reach and Reach 1 Showing Results of Bank Erosion Inventory.

Reach 2 is characterized by relatively extensive bank erosion; however, in a fashion similar to Reach 1, the BEHI ratings for much of the mapped erosion are of moderate to low severity. A total bank length of 5,434 feet, or 35% of the bank length, was mapped as eroding in Reach 2. Almost 2,700 feet of bank was BEHI- rated as high to extreme, and 2,740 feet was rated as moderate to low. One site, Bank 1-12 at RM 1.72, is over 500 feet long and its BEHI rating is extreme. This bankline is characterized by visible tailings, a deep hole at the bank toe, and an inset floodplain surface on the opposite bank. The bank erosion severity increases in the downstream direction through the mapped bankline extent; the highest ratings occur on the apex and downstream limb of the bend.

Figure 2-12. Map of Reach 2 Showing Results of Bank Erosion Inventory.

A total bank length of 2,195 feet, or 32% of the entire bankline was mapped as eroding in Reach 3 (Figure 2-13). Reach 3 has the greatest extent of bankline mapped as having an extreme BEHI rating, with a total of 1,100 feet of bank, or 16% of the entire bankline categorized as extreme. Approximately 800 feet of additional bank was rated with a high to very high bank erosion hazard index.

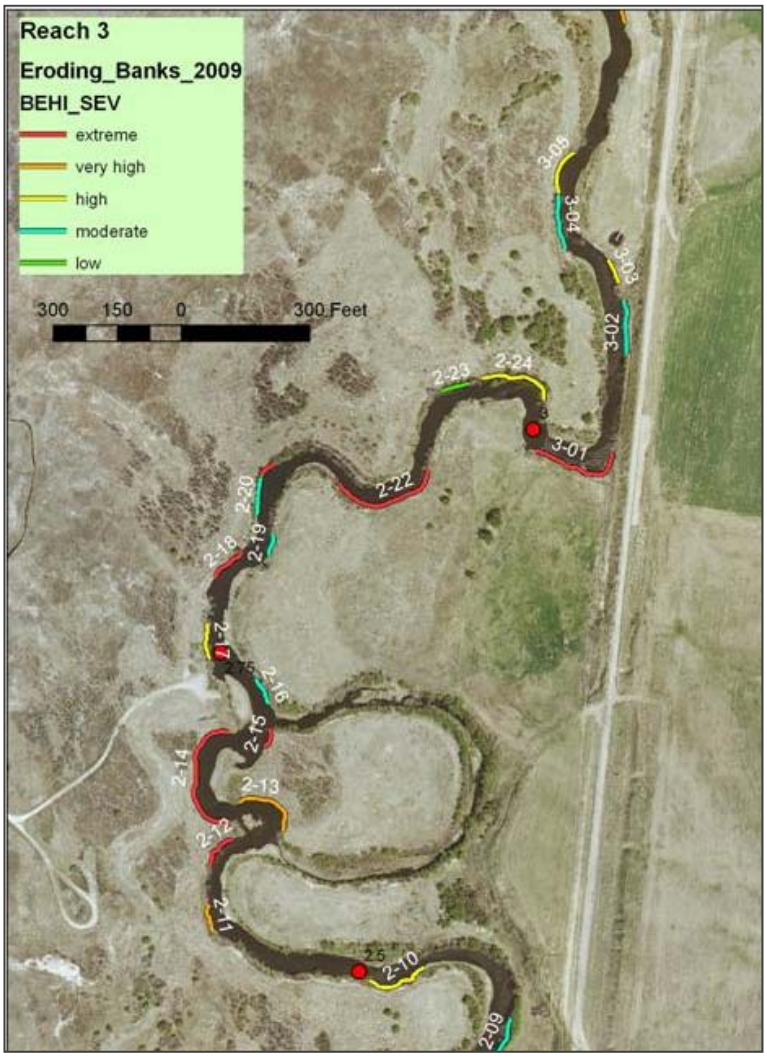

Figure 2-13. Map of Reach 3 Showing Results of Bank Erosion Inventory.

Reach 3 contains the single most dynamic channel segment between Warm Springs Creek and Perkins Lane Bridge. At River Mile 2.65, a bendway cutoff occurred sometime prior to 1950 (Figure 2-14). In 1950, the cutoff channel appears relatively new, as both the old meander bend and the cutoff channel are actively conveying flow. Near Missoula, long-term gage records on the Clark Fork River show flood events in both 1947 and 1948. If these floods occurred in the Upper Clark Fork, the cutoff may have been triggered by those events. By 2009, the meander has been abandoned, and the cutoff channel has developed point bars and cutbanks (Figure 2-14). These changes are accompanied by several sites of extreme BEHI ratings, which is an indication that the adjustment process remains active. The coarse gravel deposits within the cutoff area and downstream indicate that the erosion has produced gravel bedload and associated bar forms (Figure 2-15). Upstream of this cutoff, coarse bar features are notably lacking.

Figure 2-14. Reach 3 Cutoff in 1950 (left) and 2006 (right) Showing 2009 Bank Erosion Locations.

Figure 2-15. View of Gravel Bar and Extreme Right Bank Erosion in Reach 3 Cutoff, Bank 2-15.

One concern with the Reach 3 cutoff is potential upstream bed instability due to channel shortening. To assess this potential, bed profile through the cutoff reach was

created using the minimum elevations from each surveyed cross section (Figure 2-16). Linear best lines for the profiles, which extend approximately one mile upstream and one mile downstream of the cutoff, show a discontinuity above and below the cutoff point of approximately one vertical foot.

The Reach 3 cutoff reduced the length of the Clark Fork River channel from approximately 1,253 feet through the meander to approximately 265 feet through the cutoff, reflecting a reduction in total channel length of approximately 988 feet. At an average reach slope of 0.001, this would cause a discontinuity of 0.98 feet, which is similar to that shown in Figure 2-16. This suggests that the grade discontinuity generated by the cutoff has not substantially migrated upstream. Bank erosion and channel lengthening have absorbed some of the original steepened grade through the cutoff. If the continued lengthening of this cutoff channel is arrested by remedial action, it is important to consider the future of the grade discontinuity, in that profile data indicate that there is some potential for downcutting of up to a foot upstream of RM 2.6.

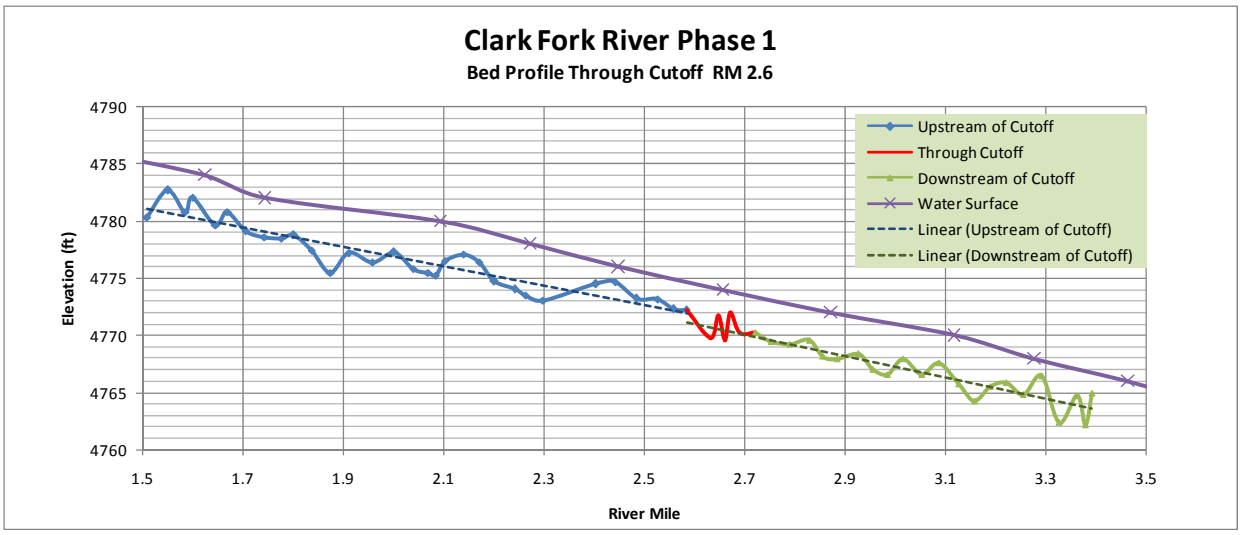

Figure 2-16. Bed and Water Surface Profiles through Channel Cutoff Area, Reach 3, Showing Discontinuity in Best-fit Lines.

A total of 2,742 feet, or 25% of the entire bankline in Reach 4 was mapped as eroding (Figure 2-10, Figure 2-17. The majority of this bankline (2,541 feet) was rated as having a high, very high, or extreme erosion severity rating. At Bank 3-06, the channel has migrated into an area that was previously treated in-situ; existing bank stratigraphy consists of tilled upper bank materials and underlying untilled tailings (Figure 2-18).

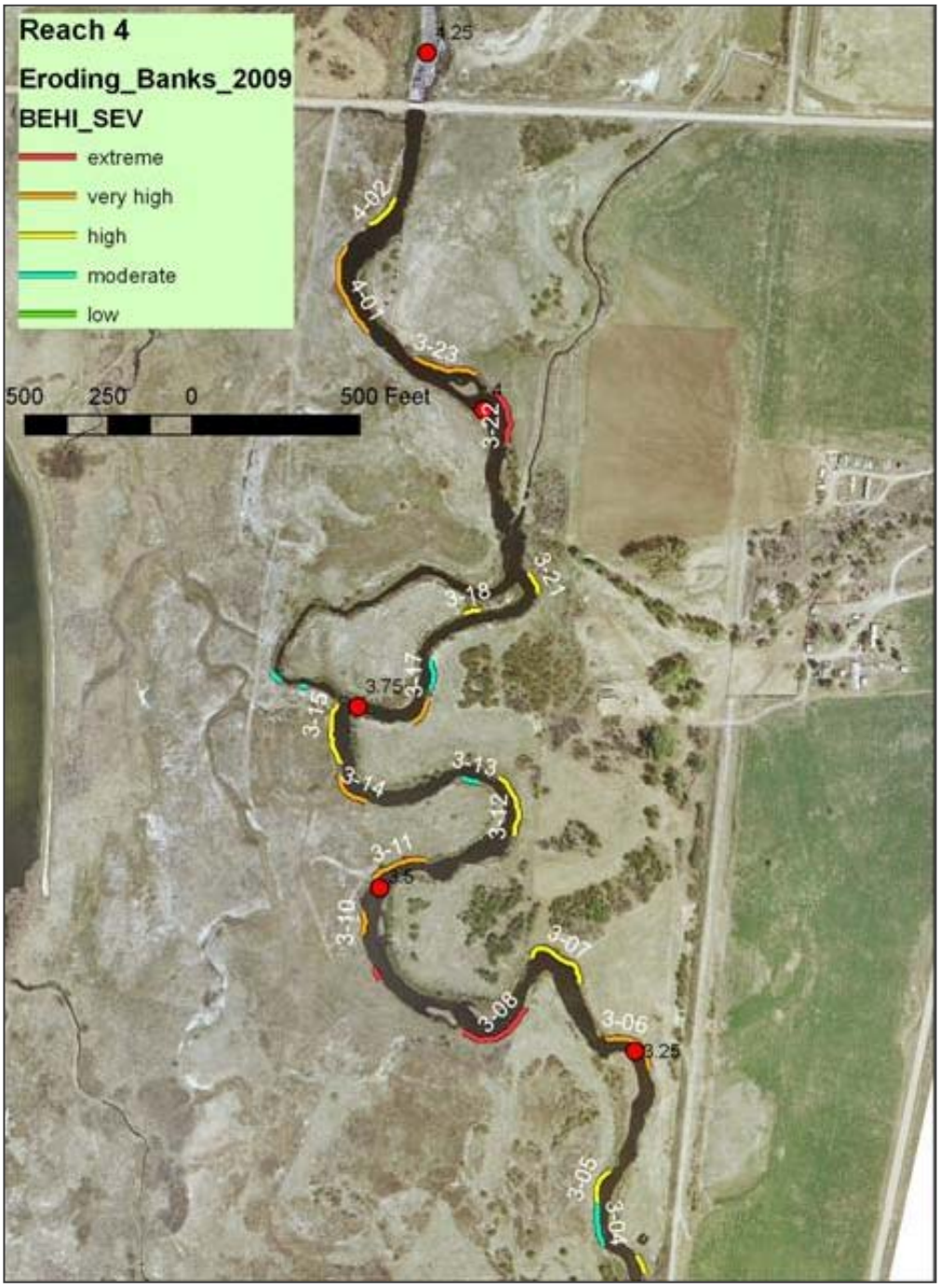

Figure 2-17. Map of Reach 4 Showing Results of Bank Erosion Inventory.

Figure 2-18. Tilled Upper Bank and Underlying Tailings, Bank 3-06.

At RM 3.75, the Clark Fork River enters a split flow segment that is approximately 700 feet long. This site marks the only perennial split flow condition in the Phase 1 project reach. A comparison of the 1950 and 2006 imagery indicates very little change with this configuration over the past 60 years (Figure 2-19). When the bank segments identified as eroding in 2009 are plotted on the 1950 imagery, it is clear that channel movement has been minimal since 1950, and BEHI ratings are low around the island.

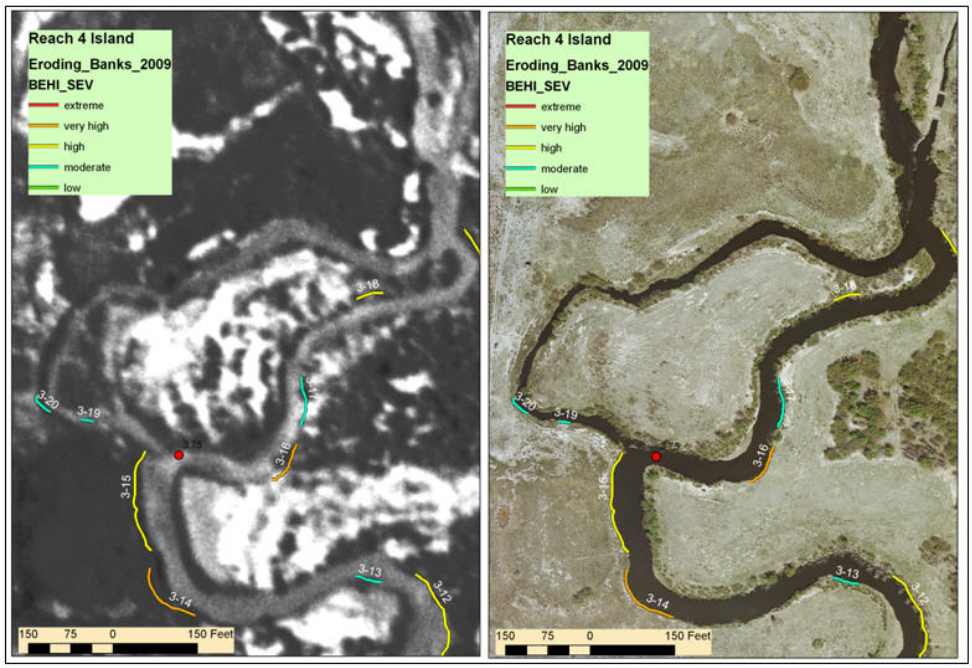

Figure 2-19. Reach 4 Island in 1950 (left) and 2006 (right) Showing 2009 Bank Erosion Locations.

2.5.4 Bank Erosion and Migration Rates

Air photos from 1950, 1977, and 2006 were incorporated in the GIS project to assess migration rates through the Phase 1 reach. Banklines were digitized in the GIS and shifts in those banklines were measured at each bank that received a severity rating. The banklines were then attributed with this retreat rate, based on the 56-year timeframe. Rates of bank movement were not measured in the Upper Reach, as this segment of the channel was constructed since 1977.

The accuracy of migration distance measurement is limited by several factors, including the resolution of the imagery, quality of rectification, and extent of bankline obscurity due to overhanging vegetation. Griffin and Smith (2001) performed a migration rate assessment in the project reach and identified a measurement accuracy limit of approximately 0.33 ft/yr. The Griffin and Smith (2001) effort documented migration over a nine-year timeframe, whereas this effort reflects 56 years of channel movement. In this effort, the accuracy of measurements made on the 1950s imagery is on the order of 5 feet, which translates to a minimum measurement accuracy of 0.1 ft/yr. Because of the limited resolution of the older photography, the migration rates are considered approximate, and interpreted in relative terms.

Figure 2-20 shows the inventoried bank conditions plotted by river mile and approximate migration rate. Migration rates at the inventoried banklines range from 0 ft/yr to approximately 1.5 ft/yr. The site with the most rapid migration rate is located in Reach 3 (Bank 2-14) where the left bank is eroding through the cutoff channel shown

in Figure 2-14. Sites rated as low to moderate BEHI severity generally have migration rages less than 0.5 ft/yr.

Numerous sites rated as having a severe erodibility index have relatively low migration rates. This is because the BEHI rating is strongly influenced by the presence and density of reinforcing vegetation, such that banks that do not support vegetation due to the presence of tailings receive a high severity rating, regardless of the rate of bank movement. This lack of correlation between BEHI rating and rate of bank migration is shown in Figure 2-21. In general, the increasing BEHI severity classes have a progressively higher maximum migration rate; however, all severity classes have sites with fairly low migration rates as well (Figure 2-21). The sites that were noted in the field as containing orange/yellow stratified tailings in the bank are concentrated in the more severe BEHI categories; however, this high erodibility index does not necessarily correlate to a rapid rate of bank migration.

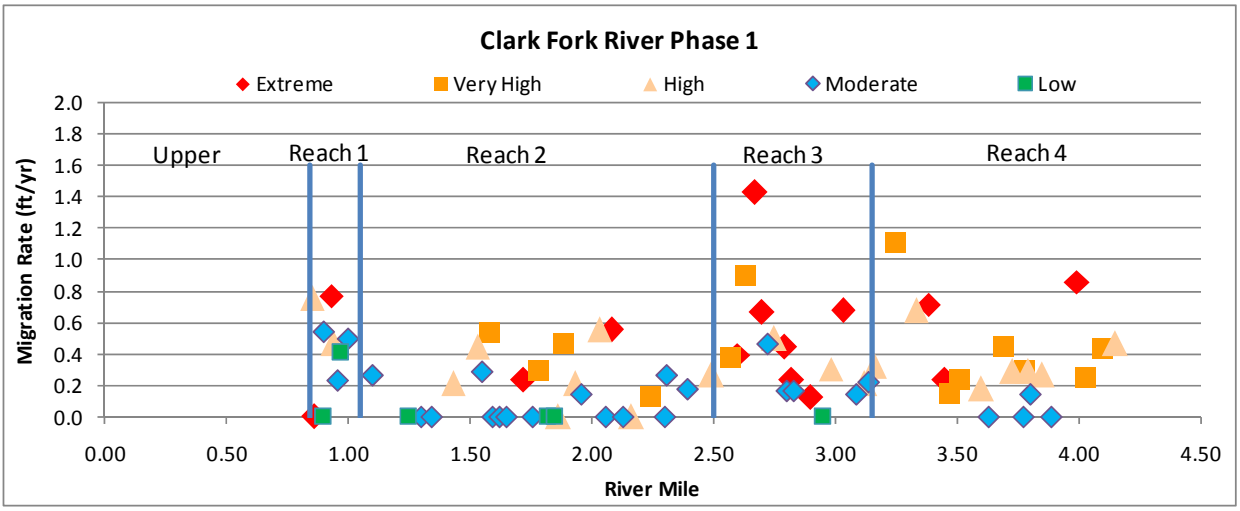

Figure 2-20. Estimated Migration Rate for Eroding Banks Showing Location and BEHI Severity Rating.

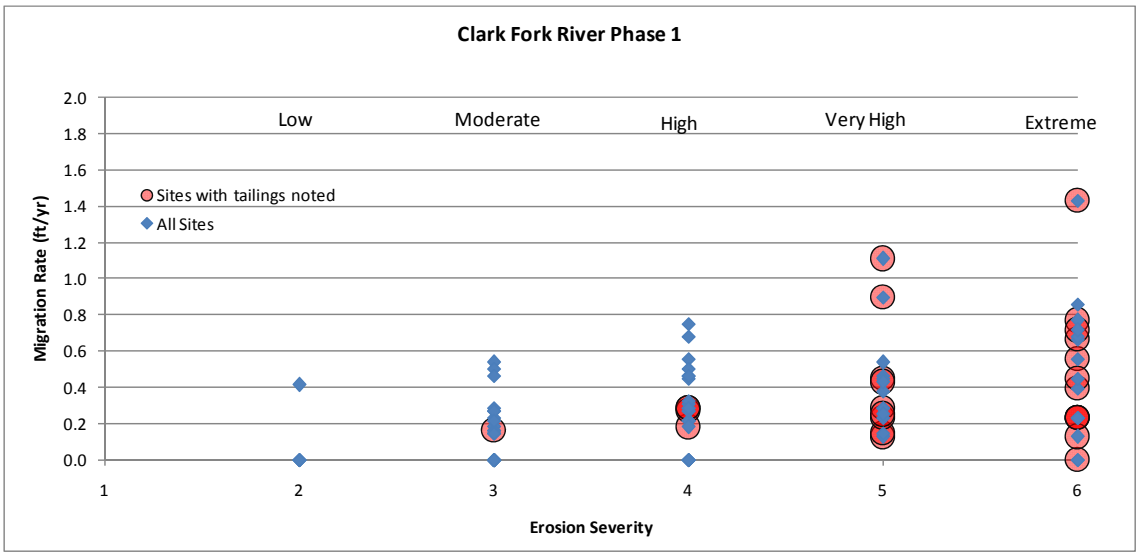

Figure 2-21. Erosion Severity of Rated Banklines Plotted against Migration Rate with Sites Noted in Field as Tailings-dominated Highlighted.

Griffin and Smith (2001) evaluated centerline migration rates for 276 bendways on the Clark Fork River through the Deer Lodge Valley. Their results show that the lowest rates of lateral movement occur in the first eight river miles, which includes the Phase 1 reach described herein. These authors measured typical migration rates of 0-1 ft per year from the Warm Springs Creek confluence to Perkins Lane Bridge, noting that that the most rapidly eroding banks typically had a thick (~1 ft) layer of well-sorted pebbles at their base. They also showed that erosion rates calculated for the 1989-1997 time frame decrease from 1.27 feet per year for slickens, to 0.27 ft per year for cut-banks with dense vegetation. The results of this analysis are similar; field estimates of woody vegetation cover on the eroding banklines show an overall reduction in migration rate with increasing woody vegetation density, although the overall correlation is poor (R2 = 0.077).

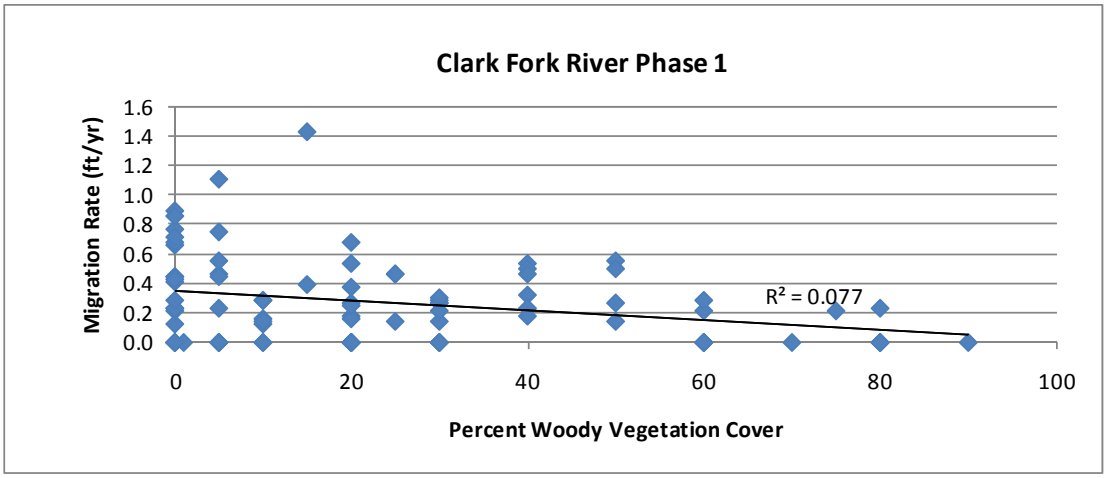

Figure 2-22. Migration Rate (ft/yr) Plotted against Field Estimates of Woody Vegetation Cover on Bank.

2.5.5 Bank Erosion and Radius of Curvature (Rc)

The BEHI erodibility index, in conjunction with a near-bank shear stress value, can be used to approximate streambank erosion rate and sediment yield (Rosgen, 2001). In order to assess this potential predictive relationship for the project reach, a near-bank shear stress (NBS) was estimated at each inventoried bank. Due to a lack of hydraulic data at the time of analysis, radius of curvature-based NBS categories were used (www.epa.gov/warsss). This stream pattern-based approach to estimating NBS is considered a general prediction of NBS, versus other methods that provide either a detailed prediction or validation. The NBS categories, which range from extreme NBS to very low NBS, show increasing shear stress with decreasing Rc/W values (Figure 2-23). That is, as a bendway tightens through time (Rc/W decreases), the NBS is predicted to become continually more severe until an extreme NBS category is reached at Rc/W values less than 1.5.

For the Clark Fork River data, a plot of migration rate versus Rc/W values shows a poor linear correlation between migration rate and Rc/W values (Figure 2-23). Stratification between erosion severity ratings is also poor. R-squared values for best-fit linear relationships are 0.031 and 0.079 for the extreme and very high erosion severity ratings, respectively.

Also plotted on Figure 2-23 is an upper envelope for the maximum values in each NBS category. This envelope shows that the two highest migration rates occur at sites where the Rc/W ratio is between 1.5 and 3. Other studies that have empirically correlated Rc/W values to migration rates show that the relationship is non-linear in that migration rates are highly variable, yet reach a maximum value at Rc/W values of approximately 2, and as Rc/W values further decrease, migration rates drop (Hooke, 1997; Figure 2-24). This "upper envelope" relationship may be more applicable to the Clark Fork River Phase 1 project reach data.

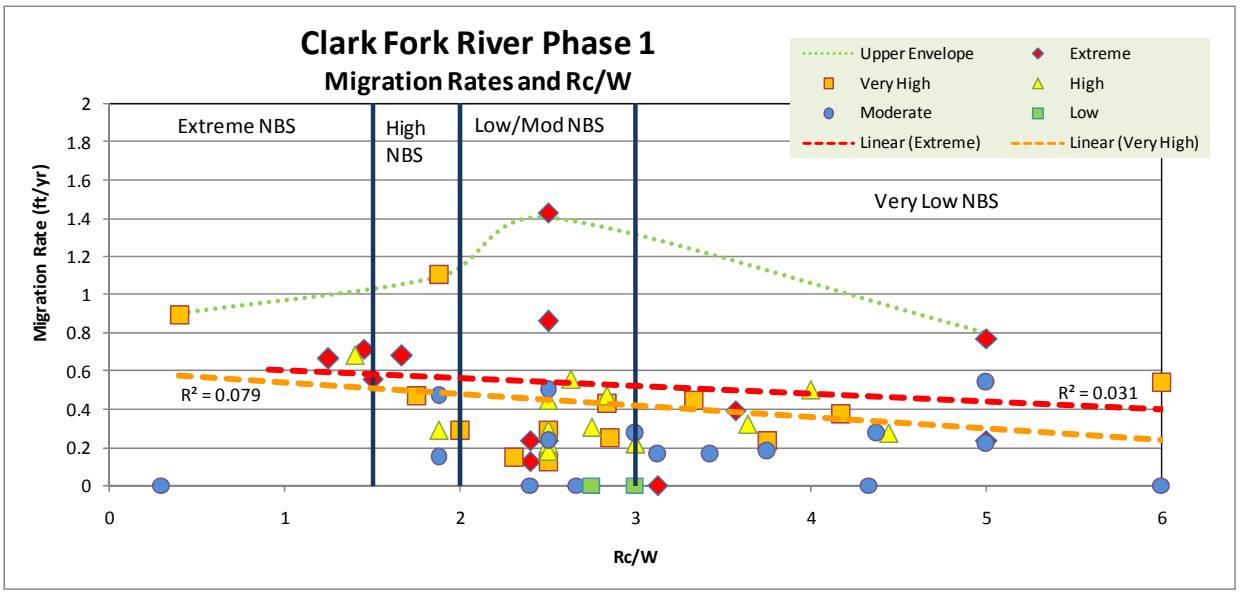

Figure 2-23. Radius of Curvature to Width Ratios (Rc/W) Plotted Against Migration Rate for Inventoried Banks, Showing Near Bank Shear (NBS) Categories and Erosion Severity Site Ratings.

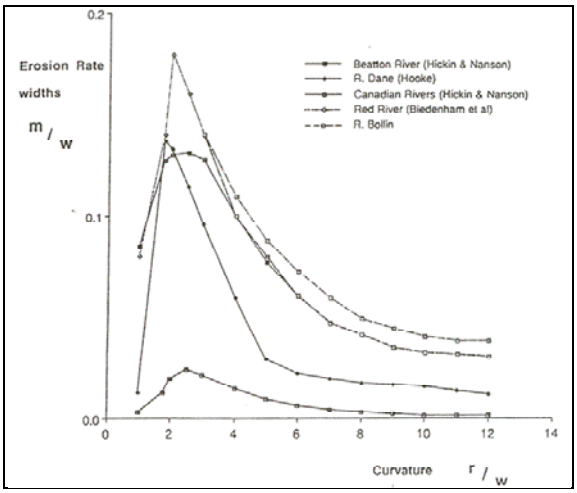

Figure 2-24. Relationship between Migration Rate and Bend Curvature (Hooke, 1997).

A comparison of BEHI rating, migration rate, and Rc/W values again demonstrate that BEHI ratings, due to their reflection of phytotoxicity at some sites, do not closely correlate to either migration rate or estimated near bank shear. It will therefore be critically important to apply site-specific calculations of shear stress derived from the hydraulic model to each site and not to infer either shear stress or migration rate from erosion hazard index.

2.5.6 Erosion into Previously Treated Areas

During the field investigation, it was apparent that numerous eroding banks had been previously reconstructed. Treatment remnants such as fabric and metal staples are

commonly exposed in the banks (Figure 2-25). Furthermore, these banks were typically adjacent to floodplain areas that showed evidence of in-situ treatment, such as flat topography, moderately dense rye grass, and constructed drainage swales.

Figure 2-25. Exposed Mesh and Metal Staples, Bank 3-08.

In order to consider the relationship between historic bank protection efforts and current bank condition, the types and locations of treatments associated with the Clark Fork River Demonstration Project (Schafer and Associates, 1991) were reviewed.

The Clark Fork River Demonstration Project, completed in 1990, focused primarily on tilled lime treatment of floodplain areas (Schafer and Associates, 1991). This floodplain work included the construction of erosion/sediment control structures where surface waters re-entered the Clark Fork River. Also included in the demonstration project was the "restoration and stabilization" of approximately 3,200 lineal feet of streambank between Warm Springs Creek and Perkins Lane Bridge. During the stream survey associated with this demonstration project effort, approximately 20 locations were identified for the following bank treatment steps:

1) Removal of tailings and dead vegetation from the streambank area;
2) Reconstruction of the streambank using clean material;
3) Construction of a temporary dike between the tailings and the regraded bank;
4) Lime application; and,
5) Seeding and placement of erosion control fabric (coir).

On reconstructed banks, live willow clumps were incorporated into the re-graded streambank where feasible (Schafer and Associates, 1991). In some areas, portions of the re-graded streambanks were armored with gravels excavated from the riverbed.

Shafer and Associates (1991) noted that although tailings were anticipated to be about 20 to 30 inches in depth where re-grading was to occur, they were in excess of five feet deep at several locations, which required over-excavation of the banks. These areas were excavated, rebuilt, compacted, and covered with erosion control fabric. Local cobbles and gravels were used to protect the toe, and willow clumps were transplanted where feasible.

During the field investigation, it became apparent that several of the 1990 Demonstration Project sites are currently experiencing active erosion. Fabric and mesh is exposed in actively eroding banks, and channel migration appears to have progressed into areas that were tilled. In order to assess which banks were treated previously, as-built drawings from the Demonstration Project Report were reviewed to compare 1990 treatment sites to 2009 erosion sites (Schafer and Associates, 1991). A total of 14 sites that were treated in 1990 were mapped as eroding in 2009 (Table 2-4). All of the sites had been re-graded and three of the sites included relocation of mid-channel bars to the adjacent bankline. The 2009 BEHI ratings of these previously treated banks range from low to extreme (Figure 2-26), and eleven of the sites currently have a high to extreme rating. The reconstructed banks that are currently eroding are contributing tailings to the stream.

2.6 Channel Morphology

This section contains a summary of the morphologic characteristics of the Clark Fork River channel in the Phase 1 project reach including a summary of general field observations, as well as a statistical summary of morphologic parameters derived from cross sections surveyed in support of hydraulic modeling.

Table 2-4. Inventoried streambanks treated as part of 1990 demonstration project showing current erosion severity rating.

Site	*BEHI Rating (2009)*	*Demonstration Project Activities (1990)*	*Field Comments*
1-02	Low	Regrade, relocate mid-channel bar	Short right bank segment with clay toe; opposite small island; woody vegetation density low, but no evidence of active retreat
1-06	High	Regrade	Collapsed blocks provide some surface protection; wide cross section may limit shear
1-13	Moderate	Regrade	Steep, fine grained bank with mature willows on topbank.
2-14	Extreme	Regrade	Core of new channel formed via neck cutoff; severe erosion; some gravel in toe
2-15	Extreme	Regrade	Severely eroding right bank section in avulsion zone; tailings, failed blocks at toe indicate active retreat, ongoing planform adjustment
2-18	Extreme	Regrade	Severe erosion with tailings; two primary scallops showing active failure
2-19	Moderate	Regrade	Moderate erosion with minor gravel; narrow cross section; high angle of thalweg to bank
3-05	High	Regrade	Active retreat with failed blocks at toe
3-06	Very High	Regrade	Failed graded bank; erosion control fabric evident; erosion severity increases downstream
3-08	Extreme	Regrade streambank, relocate mid-channel bar	Left bank just on FWP land; previously treated segment with failed blocks; fence eroding out; metal staples; block failure indicates active retreat; fabric exposed in bank
3-14	Very High	Regrade streambank	Severe erosion; fairly low bank elevation; thin tailings undercut and block failing; irregular outer bankline/channel width in bend apex
3-16	Very High	Regrade streambank	Failed blocks at toe; rye grass on top of bank; in-situ treated, tilled, with fabric; uppermost section of bank treated
3-22	Extreme	Regrade streambank	High fine bank with riprapped toe, against valley wall; blue clay in toe (soft); no tailings evident; bank swallows, poorly functioning riprap
4-01	Very High	Regrade streambank, relocate mid-channel bar	Coarse toe; mid-channel bar downstream; open floodplain, heavily grazed; unvegetated, outside bend; discontinuous erosion

Figure 2-26. Bank 2-15 that was Treated in 1990 as Part of Clark Fork River Demonstration Project.

2.6.1 Inset Floodplain Development

Although much of the Phase 1 reach is fairly entrenched with limited floodplain access, a low bankfull bench commonly forms an inset floodplain within the entrenched cross section. The elevation of this surface appears to approximate that of the historic floodplain elevation, and as such may represent the re-exposure of a pre-mining floodplain surface. Where willows have colonized this surface, it is relevant to consider their origin, as they may be sprouted from seed, or perhaps may reflect the regrowth of pre-mining willow stock that has been exhumed (Figure 2-27). If willows are re-sprouting from the historic floodplain, this may facilitate vegetative recovery in the event that exhumation of the historic floodplain occurs as part of remedial activities. At Milltown Dam near Missoula, excavation of impounded sediment has exposed the historic floodplain upstream of the old dam site. After two full growing seasons, native vegetation that may be derived from a pre-dam residual seed bank is colonizing the surface (Parker, 2009). The native species include several species of willow, dogwood, cattail, aspen, sedges, and rushes.

Figure 2-27. View of Willow Growth on Right Bank Inset Floodplain, RM 2.38.

2.6.2 Observed Influence of Decadent Willows and Beaver Activity on Channel Morphology

Within the project reach, large decadent willows line much of the bankline. These willows are commonly rooted in the cohesive bank toe, but partially buried by tailings. Because of the brittle nature of these shrubs, and their ubiquity, the project reach has a notably large supply of small woody debris. This small woody debris has facilitated inset floodplain development within the entrenched channel. At several locations, inset floodplain development has occurred via trapping of fine sediment on thick woody debris platforms. These woody debris accumulations may be related to beaver activity, as evidence of foraging was present in the reach. However, only one beaver dam was mapped, in the split flow section of Reach 4 where a small dam was present in the smaller side channel.

Figure 2-28. Thick Woody Debris Accumulation and Fine Sediment Trapping

2.6.3 Channel Slope

A water surface profile of the project reach shows that the channel is relatively steep (0.3%) in the Upper Reach, which was constructed in 1990. Below the mouth of Warm Springs Creek, the channel slope is 0.1% in Reach 1 through Reach 3. The river steepens slightly into Reach 4, to a slope of 0.2%.

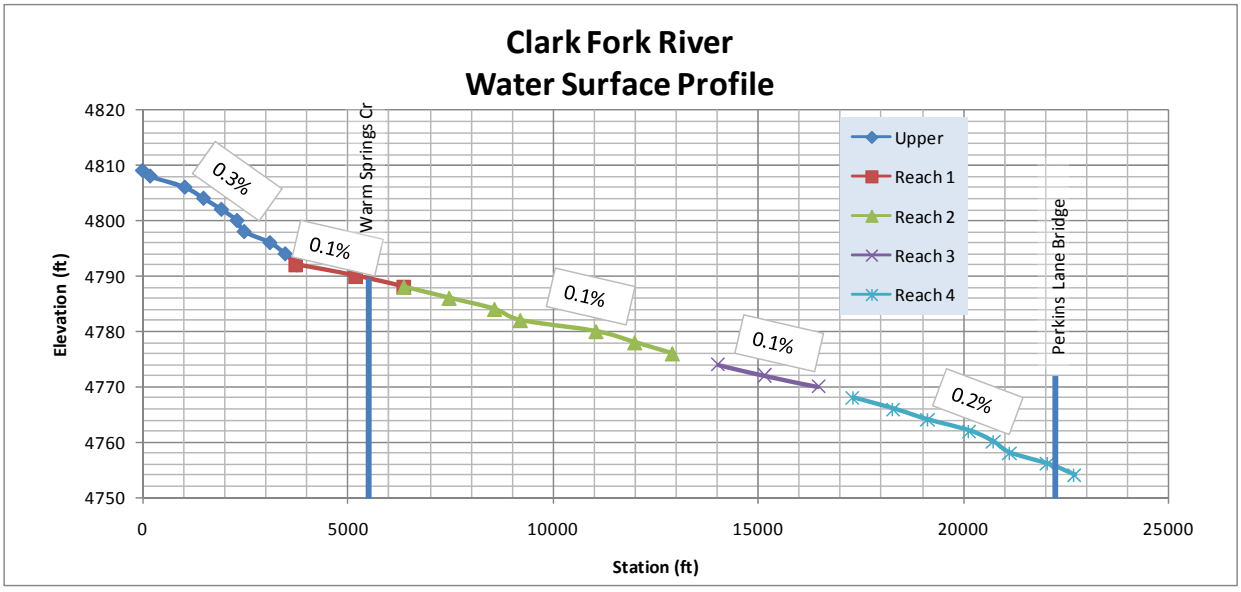

Figure 2-29. Water Surface Profile of Clark Fork River, Reach A Phase 1.

2.6.4 Channel Cross Section

An assessment of surveyed cross sections allows a statistical summarization of the morphology of each reach. The morphologic parameters of mean depth, maximum depth, topwidth, and width to depth ratio have been derived from the cross section survey (Table 2-2). The statistics developed include maximum, minimum, median, 25th percentile, and 75th percentile values for each parameter. These statistics are intended to provide insight into downstream trends in channel form, as well as the variability associated with each parameter.

It should be noted that the survey point descriptions do not explicitly define bankfull channel elevations. As such, the bank elevation references utilized for this analysis are the survey points referred to as "top bank" in the survey dataset. For each cross section, the lowest "top bank" elevation was utilized to define the top of bank.

2.6.5 Channel Depth

The mean and maximum channel depth measurements (calculated as the difference between the top of bank and the average or minimum channel bed elevation, respectively) show a consistent reduction in bank heights in the downstream direction (Figure 2-30). A similar trend is seen in the maximum cross section depth values (Figure 2-31).

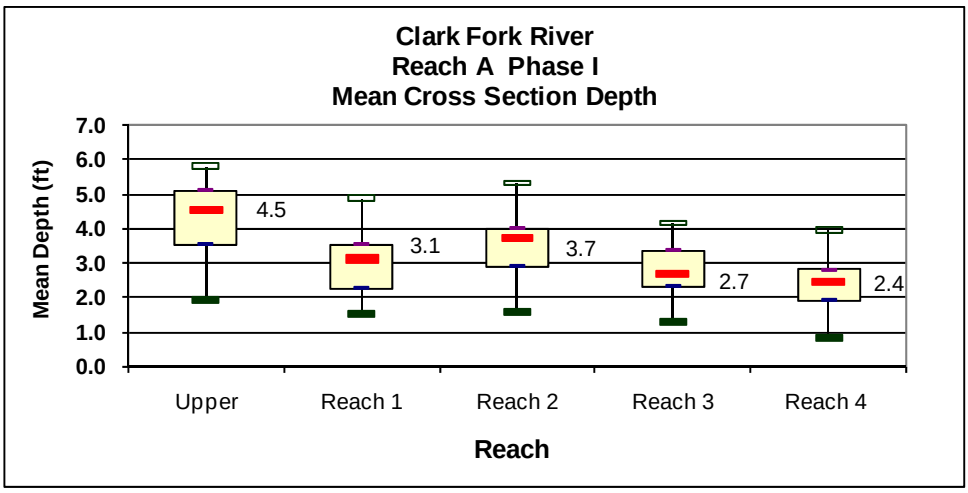

Figure 2-30. Summary Statistics for Mean Cross Section Depth; Median Values are Labeled.

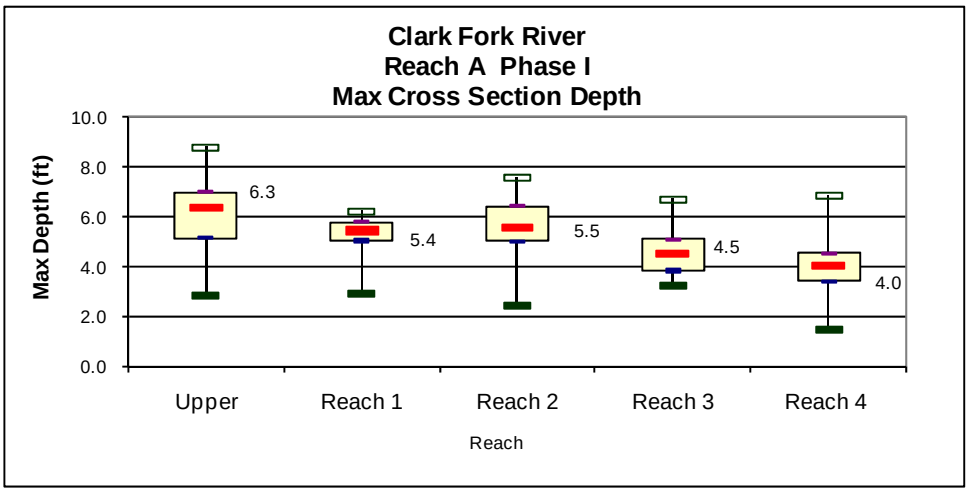

Figure 2-31. Summary Statistics for Maximum Cross Section Depth; Median Values are Labeled.

2.6.6 Top Width

Summary statistics for crown top width for the surveyed cross sections indicate that in channel widths are typically on the order of 50-70 feet in the Upper Reach, which is a constructed channel segment. Below the Warm Springs Creek confluence, median topwidths are consistently on the order of 50 feet (Figure 2-32 and Figure 2-33). This topwidth is consistent with that measured by General Land Office surveyors in 1868; in surveying the area just south, surveyors described the channel as 75 links wide, which is 49.5 feet (http://glo.mt.gov, T5N R9W 1868 Rectangular Notes, p. 285).

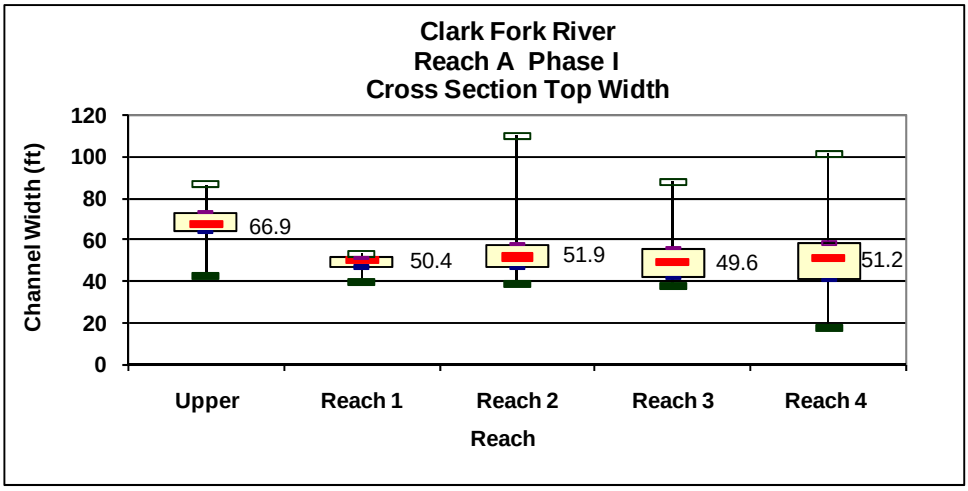

Figure 2-32. Summary Statistics for Cross Section Width; Median Values are Labeled.

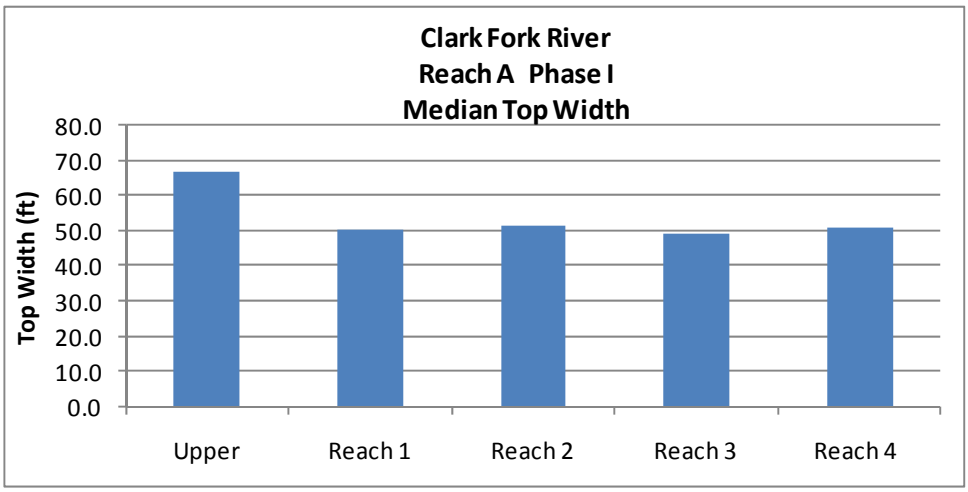

Figure 2-33. Median Surveyed Top Width Values for each Geomorphic Reach, Clark Fork River Reach A-Phase 1.

2.6.7 Width to Depth Ratio

The median width to depth ratio for each project reach is less than 20, increasing from 14.8 in Reach 1 to 19.6 in Reach 4 (Figure 2-34 and Figure 2-35). The range of measured width to depth ratios tends to increase in the downstream direction. This increasing variability in width to depth ratio in the downstream direction is accompanied by an increase in the 75th percentile value from 20.8 in Reach 1 to 29.8 in Reach 4.

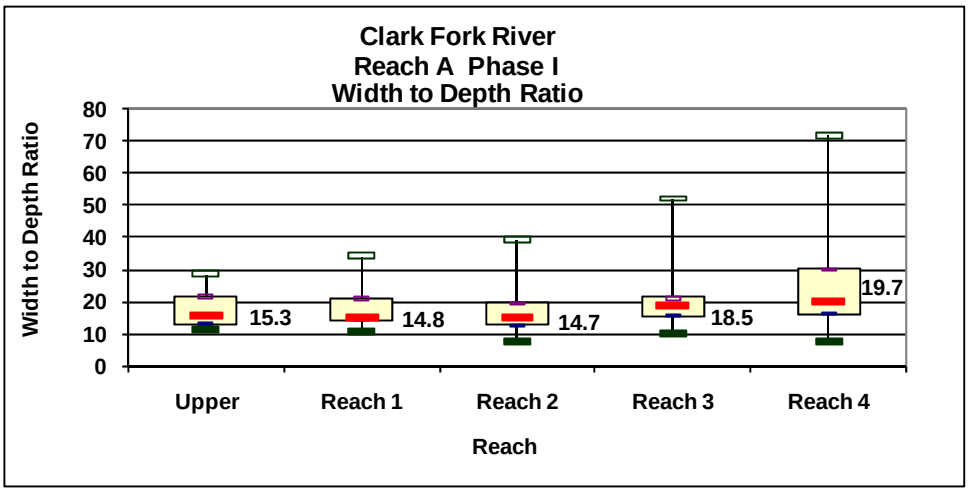

Figure 2-34. Summary Statistics for Width to Depth Ratio, Phase 1 of Clark Fork River; Median Values are Labeled.

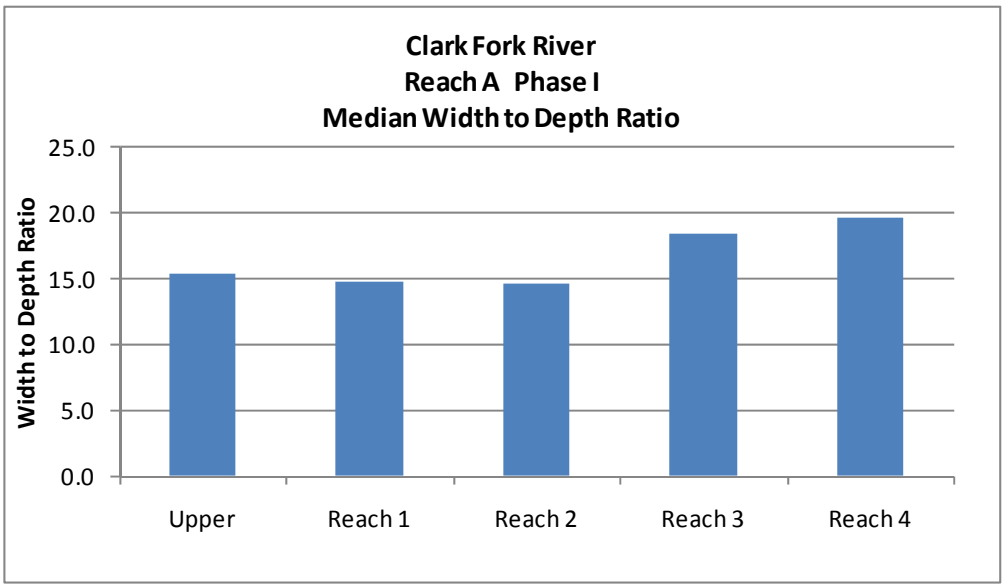

Figure 2-35. Median Surveyed Width to Depth Ratio for Geomorphic Reaches, Clark Fork River -Phase 1.

The increase in width to depth ratio in the downstream direction through the Phase 1 reach was evident in the field. In the upper reaches, bank heights are consistently over four feet, and inset floodplain surfaces tend to be sloping and relatively narrow (Figure 2-36) Point bars are rare, and bank stratigraphy is fine grained and moderately cohesive. In contrast, lower reaches tend to have less confinement, greater extents of inset floodplain areas, more frequent gravel bars, and less cohesive toe materials (Figure 2-37).

Figure 2-36. View Downstream from RM 0.95 Showing Channel Entrenchment, Reach 1.

Figure 2-37. View Downstream from RM 3.35 Showing Inset Low Confinement, and Well-developed Inset Floodplain Surfaces in Reach 4.

2.7 Substrate

A total of seven pebble counts (Wolman, 1954) were collected within Reach A Phase 1 in October 2009 (Table 2-5 and Figure 2-38). The pebble counts were collected in riffle environments to assess the coarser fraction of bed material in the system. The gradations developed for the pebble counts show that the samples are dominated by coarse gravel, with lesser fractions of fine gravel and cobble (Figure 2-39). When plotted spatially, the pebble counts show a coarsening trend in the downstream direction (Figure 2-40). This coarsening trend may relate to the increased local sediment sourcing of gravels in the downstream direction. These sediment sources include the recently excavated cutoff channel in Reach 3, as well as an increased frequency of gravel exposures in the bank (Figure 2-41).

Table 2-5. Pebble Count Gradation Values, Clark Fork River-Phase 1

Sample	Reach	River Mile	Gradation (inches)		
			D16	D50	D84
PC1	2	1.10	0.55	1.18	2.52
PC2	2	1.65	0.63	1.54	2.52
PC3	2	2.25	0.94	2.17	3.35
PC4	3	2.80	0.98	1.65	2.36
PC5	4	3.25	1.26	2.05	3.23
PC6	4	3.50	1.34	2.05	2.95
PC7	4	4.15	1.38	2.01	3.07

Figure 2-38. Example Pebble Count Data Collection Site (PC#3).

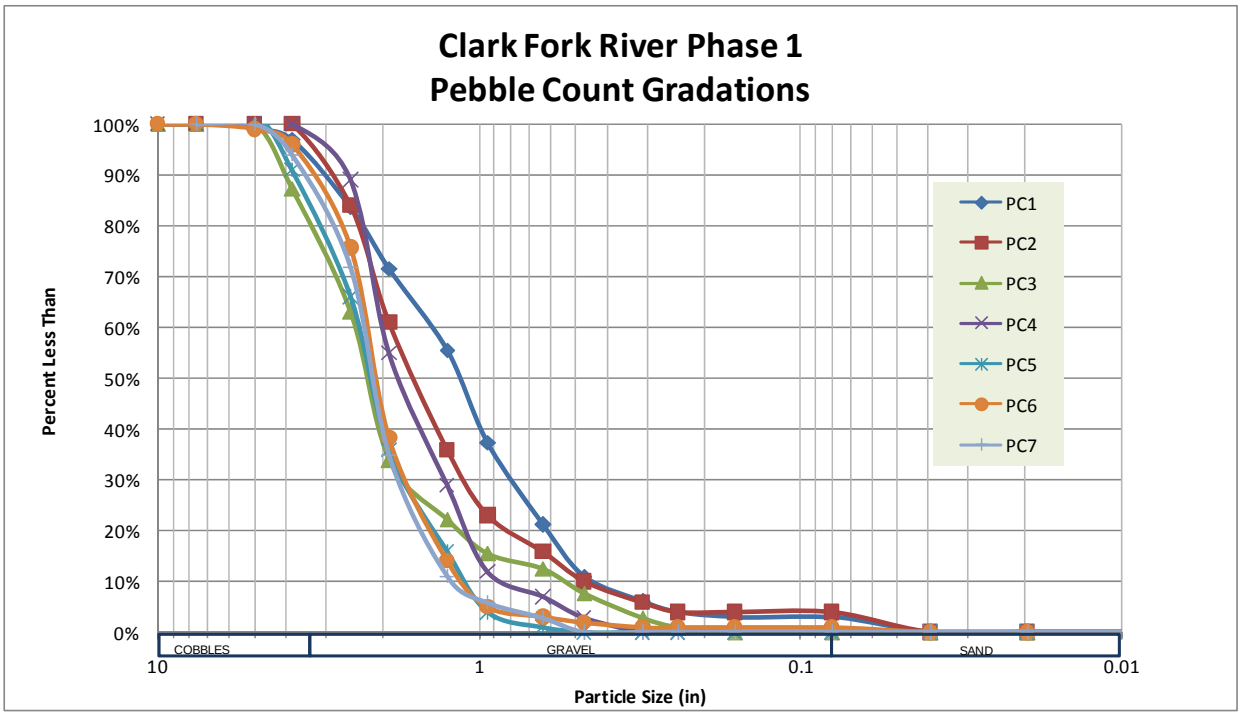

Figure 2-39. Particle Size Distributions for Pebble Counts, Clark Fork River-Phase 1.

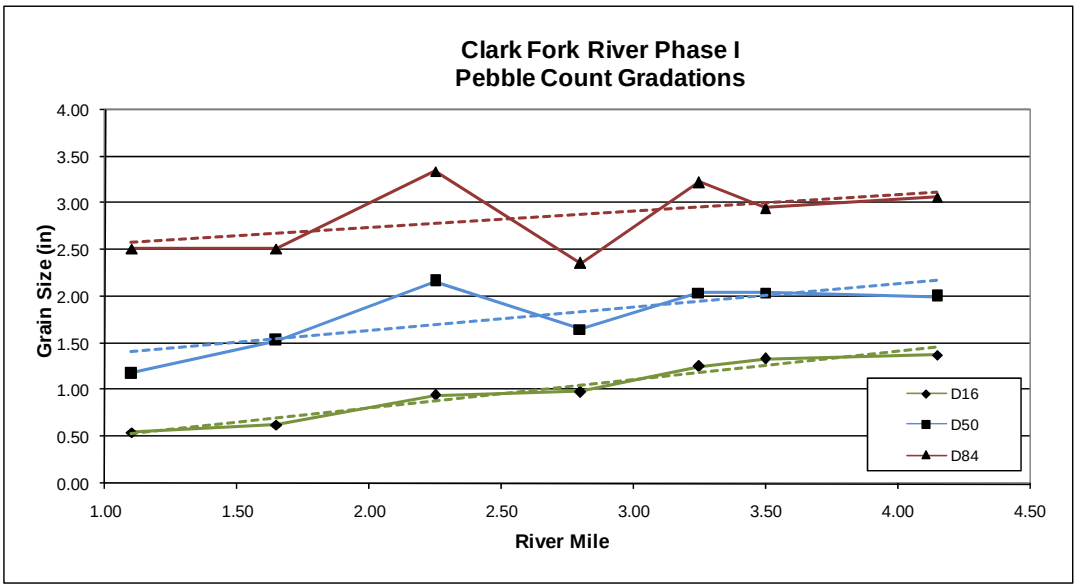

Figure 2-40. Downstream Trend in Pebble Count Gradations, Clark Fork River-Phase 1.

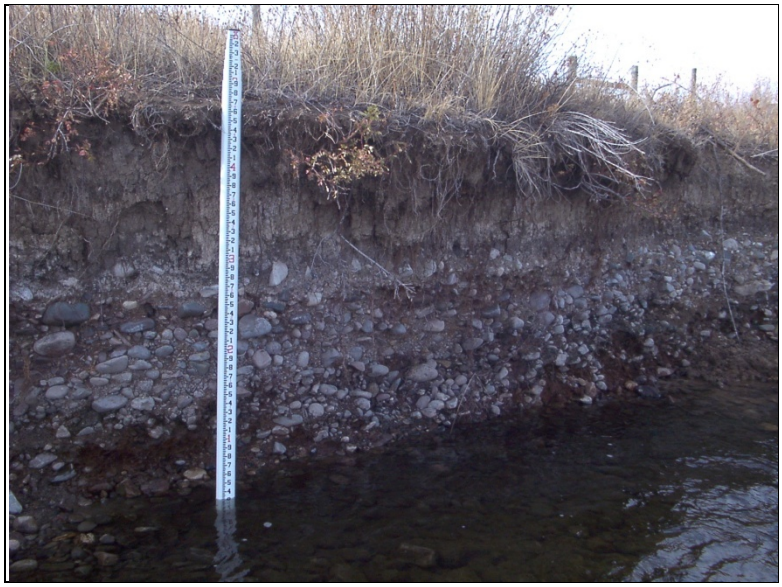

Figure 2-41. Coarse Sediment Exposed in Bank 3-01, Reach 3.

2.8 Pool Habitat Parameters

During the field investigation, the following pool parameters were measured:

- Pool location (mapped on air photo and referenced to closest cross section);
- Maximum water depth;
- Tailout crest depth; and
- Pool type.

Coarse pool data were collected with a measuring staff to approximate residual pool depths through the project reach. Residual pool parameters describe the condition of the pool when the tailout crest (typically the crest of a riffle) is dry. As such, it describes the depth and area of a pool that would exist if the pool were simply ponded and there was no through-flowing water. Residual pool depth was calculated as the difference between the maximum water depth in the pool and the tailout crest water depth. These methods are intended to provide a general summary of pool conditions within the reach, and do not provide a level of precision necessary for monitoring.

A total of 62 pools were measured in the project reach. Resulting pool frequencies are highest in Reach 1, with a total of 24 pools per mile (Figure 2-42). For general comparison, the measured pool frequencies in Subarea 3 on Silver Bow Creek (pre-remediation) ranged from zero to 23 pools per mile (Tetra Tech and AGI, 2007). Many of these Subarea 3 pools were formed against bedrock exposures in Durant Canyon. Downstream in Subarea 4 on Silver Bow Creek, below the mouth of Durant Canyon, pool frequencies ranged from 0 to 30 pools per mile (Boyd and Kauffman, 2009). Pool types in this area included convergent scour pools on the downstream ends of islands, and ponding behind beaver dams. In both Subarea 3 and Subarea 4 on Silver Bow Creek, most pools were formed as lateral scour features on bendways. In the Phase 1 section of the Clark Fork River, all pools were identified as lateral scour features. No bedrock exposures were mapped in the reach, and although there was evidence of beavers foraging willows no beaver dam-related pool features were identified.

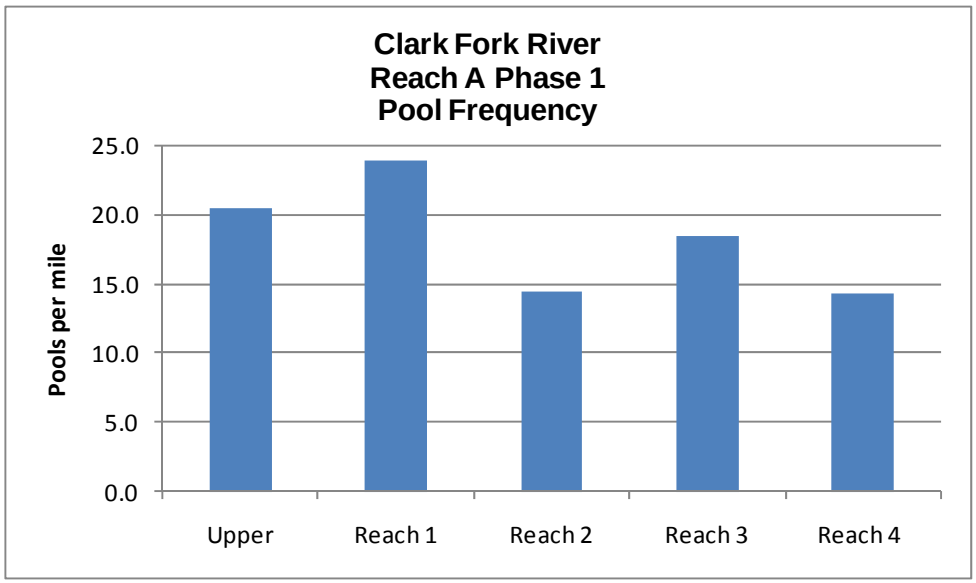

Figure 2-42. Measured Pool Frequency by Reach, Clark Fork River-Phase 1.

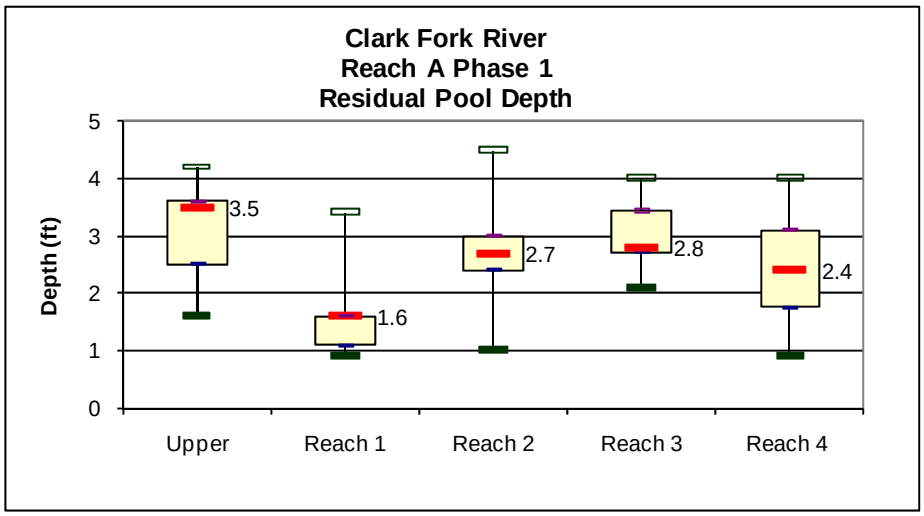

Figure 2-43. Residual Pool Depth Statistics (Median Values Labeled); Clark Fork River-Phase 1.

Median residual pool depths in the four reaches range from 1.6 feet to 3.5 feet. There is no clear residual depth trend in the downstream direction. The median residual pool depth value is highest in the constructed channel segment of the Upper Reach. Pool depths are fairly consistent in Reaches 2 through 4.

2.9 Summary

The field data and observations presented in this chapter, in combination with the bank toe investigation, hydrologic investigation, hydraulic investigation, and previous reports (e.g. Smith and others, 1988), support the conclusion that system aggradation has created an entrenched morphology on the Phase 1 segment of Reach A of the Clark Fork River. Flood events in the late 1800s and early 1900s deposited up to several feet of tailings on the channel margins and floodplain. Natural-levee type deposition on the tops of banks has created a floodplain surface that slopes away from the channel in many places. Warm Springs Ponds were constructed as a sediment trap in response to these events. Since the ponds have been operational, the post-mining evolution of the channel appears to have been very slow and aggradation in the reach has been dampened by the reduction of both sediment loading and flood flows due to peak flow attenuation by the ponds (Appendix A).

In an alluvial system, channel entrenchment is commonly associated with the continued development of an inset floodplain surface within the entrenched cross section. In the Phase 1 reach, an incipient inset floodplain has begun to form; however, low migration rates have constrained this process. These low migration rates are due to a deficiency of coarse sediment to drive lateral migration, the presence of cohesive banks, and reduced flood energy. As a result, the current channel planform shows very little change since the 1950's imagery (Appendix A). Only in Reach 3, where a cutoff event has produced gravel bedload, has significant change in channel planform occurred.

From Warm Springs Creek to Perkins Lane Bridge, width to depth ratios increase, and inset floodplain platforms become more common. This trend may be related to increased sourcing of coarse sediment from the banks, or potentially due to variations in floodplain aggradation thicknesses relative to upstream.

Although one direct consequence of relatively slow migration rates in the Phase 1 reach is a commensurately low rate of tailings entrainment, it is clear that bank erosion and entrainment does occur. The most compelling evidence of tailings entrainment is the failure of multiple 1990 bank treatment sites that were designed to stop bank erosion in contaminated areas.

The erosion hazard index ratings developed for this reach do not correlate well to migration rate measurements, as the BEHI ratings are highly dependent on vegetation densities on the eroding bankline. In this system, where phytotoxicity results in bare banks, severity ratings can be extreme on banks that are not actively moving. The BEHI rating procedure may prove to be very effective in the CFROU, as it identifies both phytotoxic banklines that are relatively stable, and rapidly migrating banklines, both of which are important with regard to remedial action.

The erosion inventory performed for this effort represents a summary of conditions observed in the fall of 2009. Many of the actively eroding banks inventoried were previously treated in the 1990 demonstration project (Schafer and Associates, 1991), indicating that some erosion sites have persisted through time. As the system evolves, however, it will be important to continue to monitor bank integrity through the reach. If sediment loads to the reach increase due to the progressive delivery of bedload through the Mill/Willow bypass for example, sediment storage may ensue, and erosion locations and severities may change. Similarly, if a large flood event were to occur in the reach, banks that currently show no evidence of retreat may destabilize.

Hydraulic modeling results indicate that under current hydrologic conditions, a 10-year flood event is largely contained within the active channel through the project reach. Flooding extents associated with a 100-year event are broader, yet remain largely contained within the active meanderbelt. Although flooding extents for a 100-year event or less are largely limited to the immediate river corridor, it is important to note that, due to the aggraded bank condition in the project reach, the floodplain surface commonly slopes away from the channel, especially to the west of the current river course. An increase in flood magnitudes and associated overtopping to the west may result in extensive flooding in these topographically low areas, potentially causing floodplain erosion and instability.

Section 3
Hydrology

The purpose of this chapter is to provide peak flood flow predictions for various recurrence intervals for the Clark Fork River Operable Unit (CFROU). The peak flood flows will be used as a basis for design of stream bank and adjacent floodplain improvements at different locations within the Phase 1 area. Peak flows are also used to design erosion control Best Management Practices (BMPs) to be implemented during construction. Most BMPs are expected to be constructed in the floodplain and will depend on analysis of localized precipitation for their design. This hydrologic analysis only addresses flows in rivers and streams for purpose of the streambank design. Overland runoff will be addressed during the design phase of this project.

This peak flood flow analysis is based on existing U.S. Geological Survey (USGS) stream flow records from gages located within the CFROU and surrounding areas. Published USGS methods for estimating flow frequency were used in the analysis including regression analysis (Parrett and Johnson, 2004) and annual flood-frequency analysis using Bulletin 17B guidelines (Flynn, Kirby, and Hummel, 2006). Records were extended for some stations using standard regression techniques.

3.1 Description of Site Hydrology

Figure 1-1 shows the three reaches of the CFROU. Reach A refers to the first 47.5 river miles of the Clark Fork River. The reach starts at the confluence of the Mill/Willow bypass and the outlet channel of Warm Spring Pond 2 and ends at the I-90 bridges downstream of Garrison, Montana.

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. A weir outlet structure regulates the discharge into Silver Bow Creek. The ponds' normal elevation is approximately 4,835 ft (Atlantic Richfield Company, 2007). The structure is currently operated by ARCO whose operator regulates the outlet discharge to adjust for temperature fluctuation mainly during the summer months in the Clark Fork River. These adjustments can have an impact on the flows downstream of the outlet structure adding uncertainties to the flows of all downstream stations. The ponds' discharge joins with the Willow Creek/Mill Creek bypass and become the lower part of Silver Bow Creek. The drainage area contributing from the Willow Creek and Mill Creek is approximately 74 square miles. The original Clark Fork riverbed, which was obliterated by the Warm Springs Ponds and is located approximately 0.8 river miles downgradient of Pond 2 outlet channel, is the beginning of the CFROU. Just downstream, Warm Springs Creek joins with Silver Bow Creek and becomes the Upper Clark Fork River before it crosses the Warm Springs Road. Perkins Gulch, which generally has a small flow, drains into the river approximately half a mile upgradient of the end of Phase I (at Perkins Lane). Several irrigation diversion structures are located along this river stretch.

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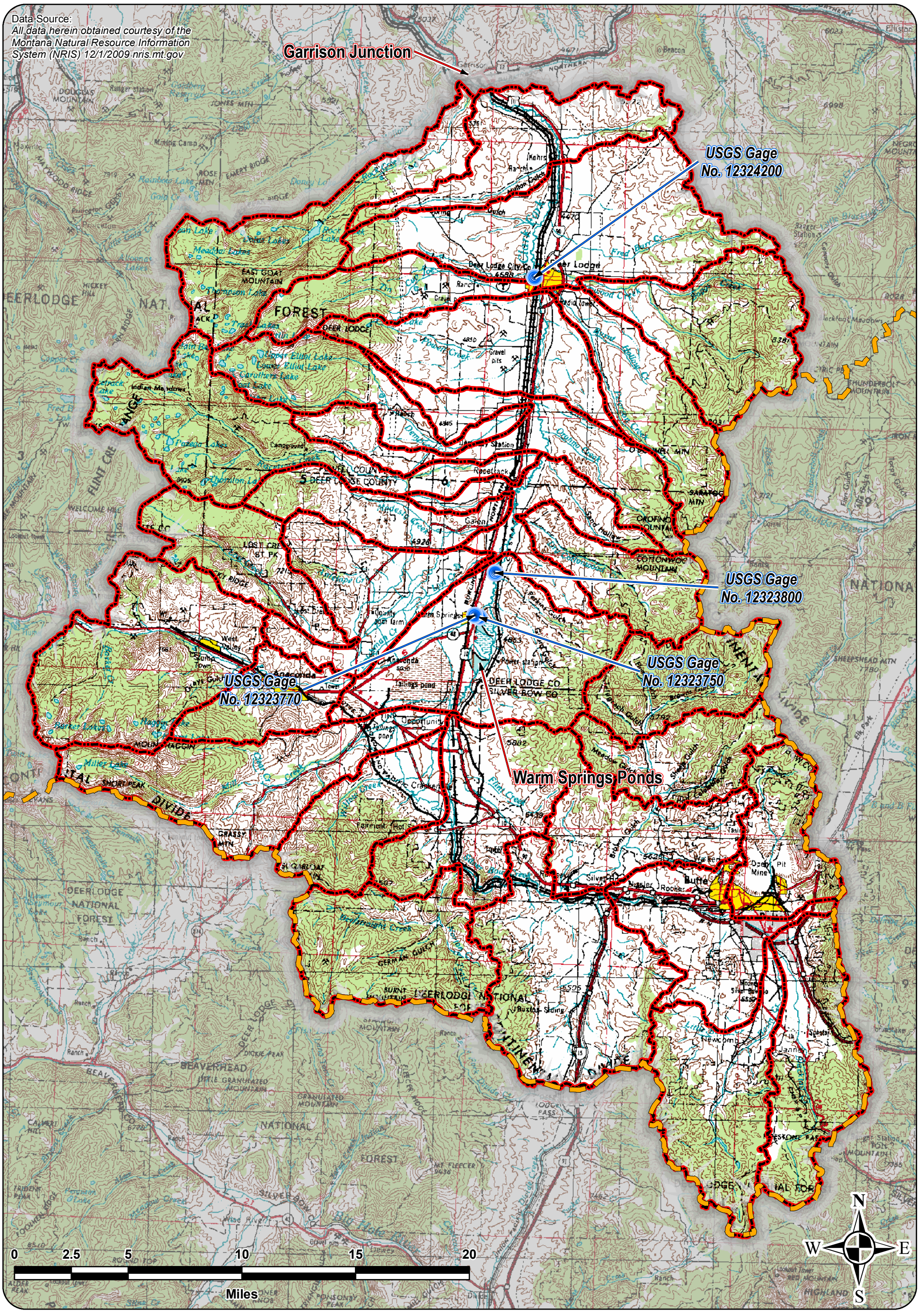

Figure 3-1
Reach A
Upper Clark Fork Drainage Basins
Powell, Deerlodge, Silverbow Counties, Montana

Drainage Boundary
Clark Fork Gage Station
Continental Divide

CDM

Downstream of Perkins Lane Bridge the Clark Fork River is crossed by several other bridges before reaching the town of Deer Lodge as well as numerous bridges in and downstream of Deer Lodge. In addition, numerous tributaries drain into the river. Several irrigation intakes are located in Reach A as well as irrigation returns, which are often combined with natural drainages. The river bisects the community of Deer Lodge and crosses the Powell and Deer Lodge county line.

For the purpose of this hydrologic analysis, emphasis will be given to the stretch of river starting at the beginning of CFROU and ending at Perkins Lane Bridge at approximately river mile 4.25 (Phase 1 area). Because of the potential impacts of the upstream conditions, the reach of Silver Bow Creek immediately above the beginning of CFROU will also be analyzed.

The gaging stations important for analysis of Reach A flows, their corresponding drainage areas, and years of record are summarized in Table 3-1.

Table 3-1. Clark Fork River Headwaters and Reach A Gages.

USGS Station Number	Station Name	Years of Record	Drainage Area (acre)
12323750	Silver Bow Creek at Warm Springs	25	394
12324200	Clark Fork at Deer Lodge	30	916
12323800	Clark Fork near Galen, MT	20	561
12323770	Warm Springs Creek at Warm Springs	25	163

3.2 Data Analysis Methods

The Upper Clark Fork River starts at the confluence of Silver Bow Creek and Warm Springs Creek downstream of Warm Springs Ponds. Several tributaries and irrigation intakes are located in this reach of stream. Two reaches of the Clark Fork River are of interest in the analysis of peak flows, the reach above the Warm Springs Creek confluence and the reach downstream of the Warm Springs Creek confluence to Perkins Lane Bridge. The Silver Bow Creek at Warm Springs Creek gage is representative of the reach above Warm Springs Creek, and the Clark Fork near Galen, MT gage is representative of the reach below the Warm Springs Creek confluence. These gage locations are therefore the focus of this analysis although other gages in the area provide useful information as well. For this analysis, the USGS gaging stations listed in Table 3.2 were analyzed.

Table 3.2 – USGS Gaging Station Used in the Peak Flow Analysis.

USGS Station Number	Name	Location	Years of Record
12323750	Silver Bow Creek at Warm Springs	Upstream of the confluence of Warm Springs Creek and Silver Bow Creek	25
12323770	Warm Springs Creek at Warm	On Warm Springs Creek at the town of Warm Springs	25
12323800	Clark Fork near Galen, MT	Next to the Perkins Lane Bridge approximately 3.25 river miles	20
12324200	Clark Fork at Deer Lodge	At the town of Deer Lodge, MT	30
12332000	Middle Rock Creek near Phi-	On the Middle Fork of Rock Creek near the town of Philipsburg, MT	71
06033000	Boulder River at Boulder, MT	On the Boulder River at the town of Boulder, MT	69

Gaging stations located above the Warm Springs Ponds on Silver Bow Creek were not included in the analysis because Silver Bow Creek is diverted into the Warm Springs Ponds and the ponds' outfall is regulated by an outlet structure in Pond 2. The ponds are extensive and greatly diminish peak flows on Silver Bow Creek. Therefore, gages on Silver Bow Creek upstream of the ponds are not useful in peak flow analysis. Mill Creek and Willow Creek are bypassed around Warm Springs Ponds and combined with Pond 2 discharge above Silver Bow Creek at Warm Springs gaging station. Although data is available for the Pond 2 outfall and the Mill/Willow Creeks bypass, this data does not add additional information to this analysis and it is not useful for expanding the record at the Silver Bow Creek at Warm Springs gage. Therefore, only the Silver Bow Creek at Warm Springs gage is used for estimating the peak flows on this stream above its confluence with Warm Springs Creek. Estimates of the flood hydrology on Warm Springs Creek are included in this section for completeness although at present design work is not planned for this stream since it is outside the CFROU.

Regional regression equations were used with variables appropriate for CFROU to estimate the 2-, 5-, 10-, 25-, 50-, and 100-year peak flows. 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 four gaging stations. The program calculates and reports three discharge values that are based on the bulletin 17B estimate, the systematic record, and "expected probability" estimate (Flynn, 2006).

To achieve a higher level of confidence for less frequent peak flows, particularly the 50- and 100-year events, the Clark Fork at Galen, MT station data, which only includes 20 years of record, was extended with regressed data from nearby stations within the region to increase the record length to 72 years. Several stations were considered for

record extension with the most promising being No. 12324200, Clark Fork at Deer Lodge, No. 06033000, Boulder River at Boulder, and No. 12332000, Middle Fork Rock Creek near Philipsburg. The gage on the Clark Fork at Deer Lodge provides 10 more years of record than the Galen gage and the other two stations provide about 50 more years of record. Record extension was not performed at the Silver Bow Creek gage because suitable nearby gages are not available and those segments of the river will only require smaller storm intervals for design purposes. Therefore, the smaller set of data at Silver Bow Creek near Warm Springs gage is expected to be adequate for present purposes.

3.3 Flood Hydrology Analysis

The purpose of this section is to estimate peak discharges in the Clark Fork River for various recurrence interval floods for the CFROU Reach A, Phase 1 area. A recurrence interval, which is the reciprocal of annual exceedance frequency, represents the average length of time between exceedances of a particular annual peak discharge. For example, an annual peak discharge with a recurrence interval of 2 years has a 0.5 chance of exceedance in any year. In this section, the analysis of peak discharge estimates by various methods is presented.

3.3.1 Regression Equation Method

One frequently used method to determine flood peak flows at ungaged sites or sites with limited records is through a series of regression equations relating flood peak flows to drainage basin and climatic characteristics. In 2004, USGS published an updated report for using regression equations to estimate ungaged flood frequency peak discharges in eight regions in Montana (Parrett and Johnson, 2004). The regression equations were applied to the Silver Bow Creek, Warm Springs Creek, Clark Fork near Galen, and Clark Fork at Deer Lodge stations listed in Table 3-1.

Because the Clark Fork River Reach A – Phase I area is located near the boundary of the west and southwest regions, regression equations for both regions were used. The west region regression equations rely on drainage area (square miles), mean annual precipitation (inches), and percent of drainage basin covered by forest to estimate peak flood flows for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events. The southwest region relies on the area (square miles) and the percent of the basin above 6,000 feet to estimate the storm events. All the variables required to calculate the flows are included in the report except for the station No. 12323800 (Clark Fork near Galen, MT). At this site, the values used for station No. 12324200 (Clark Fork at Deer Lodge) were used except for the basin area in the calculations because the drainage basin and climatic characteristics are similar. Table 3-3 lists the applicable regression equations, variables used and corresponding results for all four gage stations.

The accuracy of the regression equations can be expressed as the standard error of prediction or as equivalent years of record. The average standard error of prediction is defined as an average measure of the accuracy of the regression equation when estimating peak flows for ungaged watersheds similar to those that were used to

derive the regression equation. The true value of the flood peak flow predicted by the regression equations will be within plus or minus one standard error of prediction about two out of three times. The average standard error of prediction for the west region regression equations in Table 3-3 ranges from a high of 58.5 percent for the 100-year flood event to a low of 54.3 percent for the 10-year flood event.

Another method of measuring accuracy of the regression equations is through the equivalent years of record. The equivalent years of record is the number of years of recorded flow data needed at the site to achieve the same accuracy as the regression equation. The equivalent years of record for the regression equations are also listed in Table 3-3.

A third method of measuring accuracy is through confidence limits. Confidence limits define a range both above and below the regression equation results. Within the range, it is known with a certain probability that the true value of the N-year peak flood flow lies within the confidence limits. Figure 3-2 illustrates 95 percent confidence limits for the regression equation results presented in Table 3-3. The confidence limits are also compared to confidence limits of other methods described in the subsequent sections of this report.

3.3.2 Gage Records

Another method used to estimate flood peaks within Phase I was to rely on measured flood peaks at the selected gaging stations. This method is sometimes referred to as Bulletin 17B analyses (U.S. Department of Interior and U.S. Geological Survey, 2006). Bulletin 17B provides methods to eliminate high and low outliers and for estimating statistics of the log-Pearson Type III distribution, which include a mean, standard deviation, and weighted skew of the data.

The following stations were used in the analysis and are described below.

Silver Bow Creek at Warm Springs (USGS station #12323750) is located after the discharge of Warm Springs Ponds and has a drainage area of approximately 394 square miles. It includes contributions from the Mill/Willow Bypass. This USGS gaging station has 25 years of peak streamflow records from 1972 to 1979, 1989, and from 1993 to 2008.

Warm Springs Creek at Warm Springs (USGS station #12323770) is located on Warm Springs Creek above the confluence with Silver Bow Creek and has a drainage area of approximately 163 square miles. This USGS gaging station has 25 years of record between 1984 and 2008.

Clark Fork near Galen, Montana (USGS station #12323800) is located on the Clark Fork River just above the Perkins Lane Bridge and has a drainage area of approximately 651 square miles. This USGS gaging station has 20 years of record between 1989 and 2008.

Table 3-3. Estimated Peak Flood Flows Derived from Regression Equations and Variables.

		Average Standard Error of Protection, in percent	Equivalent Years of Record	**Silver Bow Creek at Warm Springs**	**Clark Fork at Deer Lodge**	**Clark Fork near Galen, MT[1]**	**Warm Springs Creek at Warm Springs**
	A, Drainage Area (sq miles)			394	916	561	163
	P, Mean Annual Precipitation (inches)			17	22	22	35
	F, Percentage of Basin Covered by Forest			41	46	46	94.7
	E_{6000}, Percent of Area above 6,000 ft			66	62	62	66
West Region Regression Equation							
Q_2 =	$0.268*A^{0.927}*P^{1.60}(F+1)^{-0.508}$	60.5	0.9	951	2,967	1,883	877
Q_5 =	$1.54*A^{0.884}*P^{1.36}(F+1)^{-0.577}$	55.4	1.4	1,655	4,642	3,010	1,259
Q_{10} =	$3.63*A^{0.86}*P^{1.25}(F+1)^{-0.605}$	54.3	1.9	2,229	5,937	3,894	1,563
Q_{25} =	$8.5*A^{0.835}*P^{1.14}(F+1)^{-0.639}$	54.6	2.7	2,898	7,320	4,861	1,867
Q_{50} =	$13.2*A^{0.823}*P^{1.09}(F+1)^{-0.652}$	56	3.1	3,463	8,536	5,702	2,151
Q_{100} =	$18.7*A^{0.812}*P^{1.06}(F+1)^{-0.664}$	58.5	3.4	4,035	9,763	6,557	2,452
Southwest Region Regression Equation							
Q_2 =	$3.02*A^{0.881}*(E_{6000}+1)^{0.0981}$	94.4	0.9	883	1,845	1,198	406
Q_5 =	$17.1*A^{0.80}*(E_{6000}+1)^{-0.104}$	79	1.7	1,317	2,602	1,758	650
Q_{10} =	$41.9*A^{0.765}*(E_{6000}+1)^{-0.214}$	75.9	24	1,648	3,184	2,188	839
Q_{25} =	$109*A^{0.728}*(E_{6000}+1)^{-0.332}$	75.6	3.4	2,093	3,947	2,762	1,101
Q_{50} =	$201*A^{0.704}*(E_{6000}+1)^{-0.408}$	77.4	4	2,429	4,511	3,194	1,305
Q_{100} =	$351*A^{0.682}*(E_{6000}+1)^{-0.476}$	80.3	4.5	2,794	5,115	3,661	1,530

Notes:
Qn= Peak flow with recurrence interval of n years.
1- Evaluated with Clark Fork at Deer Lodge variables.

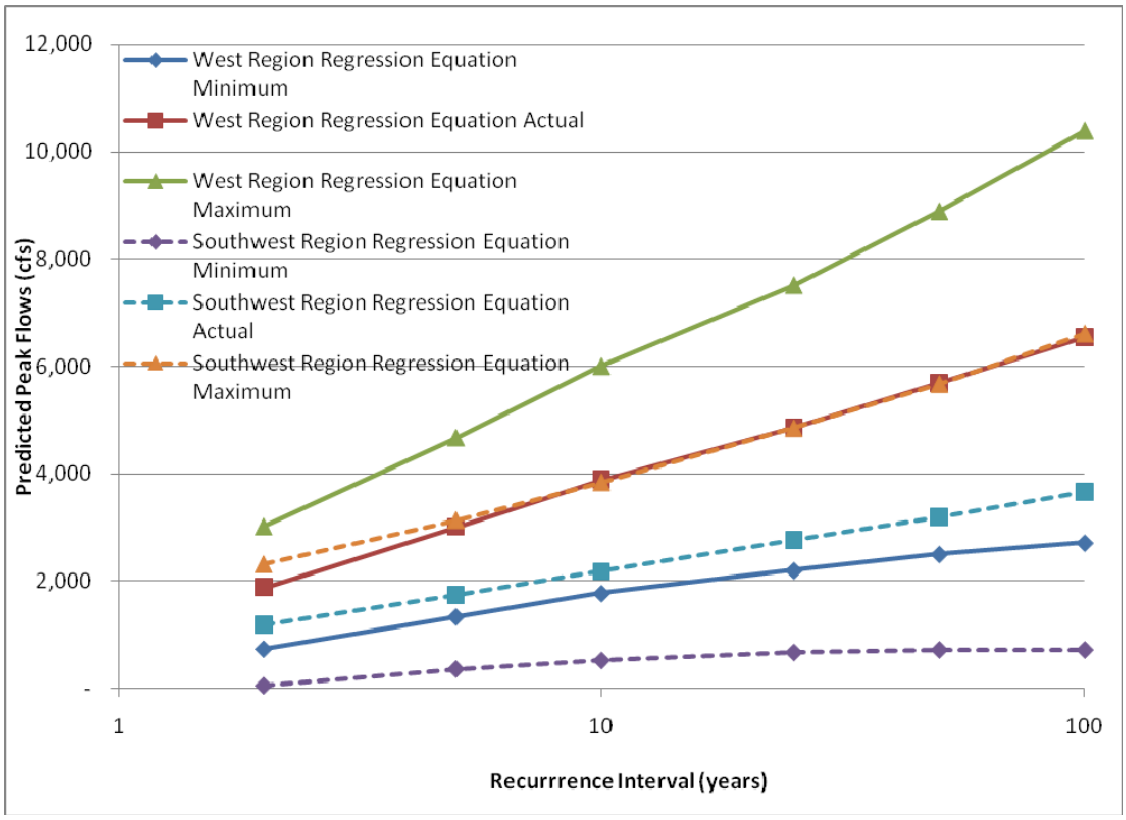

Figure 3-2. Predicted Regression Equation Values Comparison.

Clark Fork at Deer Lodge, Montana (USGS station #12324200) is located on the Clark Fork River in Deer Lodge, Montana and has a drainage area of approximately 995 square miles. This USGS gaging station has 30 years of record between 1979 and 2008.

Table 3-4 tabulates the peak stream flows for each of the stations. The data was downloaded from the USGS website (http://waterdata.usgs.gov).

For the purpose of the Phase I analysis, the gaging station Clark Fork near Galen, MT is the most representative to predict the peak flows between the Warm Springs Creek confluence and Perkins Lane Bridge. Because the gaging station only has 20 years of record (1989 to 2008), the data set was extended using similar gage stations' records as described below.

The available data, between 1989 and 2008, for the Clark Fork near Galen, MT was plotted against the data for the Boulder River at Boulder, Middle Fork Rock Creek and the Clark Fork at Deer Lodge gage stations for the same years. Those data points that occurred in different seasons were removed from the data set. The Deer Lodge gage correlated well ($R^2 = 0.75$) with the Galen gage and was used to extend the

Table 3-4. Peak Stream Flow Data for Analyzed USGS Gaging Stations.

	USGS 12323750 Silver Bow Creek at Warm Springs MT	USGS 12323770 Warm Springs Creek at Warm Springs MT	USGS 12323800 Clark Fork near Galen MT	USGS 12324200 Clark Fork at Deer Lodge MT
Year	Stream-flow (cfs)			
1972	586	--	--	--
1973	324	--	--	--
1974	1,000	--	--	--
1975	1,320	--	--	--
1976	1,210	--	--	--
1977	226	--	--	--
1978	637	--	--	--
1979	460	--	--	697
1980	--	--	--	1,710
1981	--	--	--	2,500
1982	--	--	--	1,450
1983	--	--	--	1,190
1984	--	462	--	1,730
1985	--	165	--	492
1986	--	397	--	2,090
1987	--	108	--	463
1988	--	146	--	409
1989	5502	208	737	1,430
1990	--	183	374	507
1991	--	339	795	1,020
1992	--	57	150	367
1993	407	274	581	613
1994	217	228	428	462
1995	709	373	1,120	1,240
1996	471	442	926	1,400
1997	784	494	1,240	2,020
1998	296	292	545	1,200
1999	359	252	610	819
2000	103	70	145	263
2001	125	109	224	310
2002	207	133	324	461
2003	457	399	912	1,060
2004	114	121	213	286
2005	330	321	571	848
2006	274	253	528	654
2007	330	274	605	1,130
2008	516	385	787	1,020

record at the Galen gage for the period 1979 to 1988. The Middle Fork Rock Creek gage had a better correlation coefficient (R^2=0.74) than the Boulder River gage

(R^2=0.56) when compared with the Clark Fork near Galen gage. The Boulder River data also has gaps in the period of record. Therefore, the Middle Fork Rock Creek gage was preferred for extension of the Galen gage record in the period 1938 to 1978. With the additional values, the peak stream flow data set for the Clark Fork at Galen gage was increased to 72 years. The values calculated from the 20 year and 72 years data sets are summarized in Table 3-5 and compared to each other. Appendix C includes figures showing these relations with their corresponding regression equations.

The four gaging station data sets and the extended data set for the Clark Fork near Galen, MT gaging station were entered in the PeakFQ program. This program uses the Pearson Type III frequency distribution to the logarithms of instantaneous annual peak flows following Bulletin 17B guidelines of the Interagency Advisory Committee on Water Data. The guidelines can be found at the following web site http://water.usgs.gov/osw/bulletin17b/bulletin_17B.html. The program predictions are included in Table 3-5. For comparison, the USGS Regression equation analysis results were included in the table. The program's output files can be found in Appendix C.

Table 3-5. Peak Flow Summary.

Stations Number	Station Name	Method	Q_2 (cfs)	Q_5 (cfs)	Q_{10} (cfs)	Q_{25} (cfs)	Q_{50} (cfs)	Q_{100} (cfs)
12323750	Silver Bow Creek at Warm Springs	Regression Equation (West Region)	951	1,655	2,229	2,898	3,463	4,035
		Regression Equation (Southwest Region)	883	1,317	1,648	2,093	2,429	2,794
	(25 Year Record)	Bulletin 17B Estimate	**396**	**694**	**921**	**1,235**	1,488	1,755
12324200	Clark Fork at Deer Lodge	Regression Equation (West Region)	2,967	4,642	5,937	7,320	8,536	9,763
		Regression Equation (Southwest Region)	1,845	2,602	3,184	3,947	4,511	5,115
	(30 Year Record)	Bulletin 17B Estimate	835	1,418	1,859	2,472	2,965	3,486
12323800	Clark Fork near Galen, MT	Regression Equation (West Region)	1,883	3,010	3,894	4,861	5,702	6,557
		Regression Equation (Southwest Region)	1,198	1,758	2,188	2,762	3,194	3,661
	(20 Year Record)	Bulletin 17B Estimate	**522**	**861**	**1,094**	1,390	1,610	1,827
	(Extended 72 Year Record)	Bulletin 17B Estimate	649	929	1,096	**1,286**	**1,415**	**1,533**
12323770	Warm Springs Creek at Warm Springs	Regression Equation (West Region)	877	1,259	1,563	1,867	2,151	2,452
		Regression Equation (Southwest Region)	406	650	839	1,101	1,305	1,530
	(25 Year Record)	Bulletin 17B Estimate	**233**	**373**	**465**	**581**	**665**	**746**

Note: Bold values are preferred estimates for design purposes.

3.3.3 Other Predictive Flow Methods

A flood insurance study of the Clark Fork River in Deer Lodge County was completed for the federal flood insurance program in 1980 (FEMA, 1980). The entire study area was downstream of Phase 1, and it only developed peak flows for the Clark Fork River at Deer Lodge. The flood peaks were developed using regression equations available at that time and are comparable to the peaks determined using the current West Region regression equations. At the time of that study, the Deer Lodge gage had just started operation and the Galen gage was not yet in operation. These two gages provide site specific data that provide more accurate estimates of peak flows than the previous or current regression equations for this area. Therefore, we find that the information developed in this report is a better representation of the current Upper Clark Fork River peak flow hydrology.

3.4 Summary of Peak Flow Calculations

Published flood frequency studies are not available other than the Flood Insurance Studies conducted in 1980 for the Federal Emergency Management Agency (FEMA) for Anaconda –Deer Lodge County. This study used regression equation methods to predict a 10-year flood of 6,340 cfs and a 100-year flood of 9,410 cfs. For this report, the two methods that were discussed in the previous sections, the USGS regional regression equations and the Bulletin 17B analyses of gage records, were employed. The results of the USGS regional regression equations are considerably higher than the gage records due to the fact that the regression equations do not take into account the storage available in the Warm Springs Ponds, and therefore overestimate the probable peak flows in the river. For flows up to the 25-year event, gage records analysis results in peak flows that are consistent with observed conditions on this river system. For the 50- and 100-year events, the periods of record are too short to verify the results provided by either method. However, because the gage record is established from measured conditions on the Upper Clark Fork River, it is likely that the extended gage records developed in this study are the best estimates for the less frequent events as well.

For design purposes, the Silver Bow Creek at Warm Springs gage records should be used for the analysis upstream of the confluence of Silver Bow Creek and Warm Springs Creek. However, less frequent return intervals (50- and 100-year flows) are suspect due to the short period of record and should not be used for design. For the designs below the confluence, gage records for the Clark Fork near Galen, MT station should be used due to its location at the downstream end of the Phase 1 area. The flows calculated with only 20 years of record are slightly lower and reflect the drier period of the past 20 years. These flows are considered representative for near term, more frequent flood events and will be used for the 2-, 5-, and 10-year recurrence intervals. The 72-year record calculations include somewhat wetter years and therefore produce slightly higher flows. Because these estimates include a much longer period of record, they will be used for the 25-, 50- and 100-year recurrence intervals. Note that the 100-year flood is estimated from an extended 72-year period of record

and is an extrapolated value. Table 3.6 summarizes the recommended flood flows for both locations.

Table 3-6. Recommended Flood Flows for Design for the Clark Fork River–Phase 1.

Recurrence Interval (yrs)	Clark Fork River near Galen, MT	Silver Bow Creek at Warm Springs, MT
	Bulletin 17B Estimate (20 or 72 yrs) (cfs)	Bulletin 17B Estimate (25-yrs) (cfs)
2	522	396
5	861	694
10	1,094	921
25	1,286	1,235
50	1,415	--
100	1,533	--

Note: For the Clark Fork River near Galen, the 2, 5 and 10- year floods are predicted directly from the 20 years of record; the remaining floods are predicted from the 72 year extended record.

3.5 Role of Warms Springs Ponds

In 1908 a large flood in the Upper Clark Fork River Basin swept mine waste, deposited in near-stream locations in Butte and Anaconda, downstream, some of which was deposited in the Phase 1 area. This flood in conjunction with previous and succeeding smaller floods transported enough contaminated material into the Clark Fork River floodplain to disrupt its agricultural use. Complaints from farmers and ranchers caused the Anaconda Company to construct two sediment detention ponds (Ponds 1 and 2) on the lower portion of Silver Bow Creek in 1918 to protect the Clark Fork River valley from mine wastes transported by Silver Bow Creek. A larger third pond was built between 1954 and 1959 (USEPA, 2000). Only Ponds 2 and 3 are currently in use but their combined area of 2,400 acres results in significant modification of flood flows on Silver Bow Creek. Ponds 2 and 3 are not operated for storage purposes, but their large surface area allows sufficient short-term detention to reduce flood peaks. For example, USGS gage records show an estimated daily average flow of 1,300 cfs at the gage on Silver Bow Creek at Opportunity (above the ponds) on February 11, 1996 that resulted in a discharge of only 217 cfs at the gage below the ponds.

This analysis of flood events is based on peak flows during a period when Ponds 2 and 3 were in place, and it reflects the attenuation of the peaks by the ponds. If in the future the water quality improves on Silver Bow Creek to the point that the ponds are no longer needed, ARCO may want to divert Silver Bow Creek around the ponds to lessen its operation and maintenance costs. In this case, the flood hydrology of the Upper Clark Fork River would change radically and much larger peak flows could occur along with greater sediment delivery to the downstream system. The design basis for streambank and floodplain remediation would need to be revised if bypass of the ponds is implemented.

Another important consideration with the current pond operation is the management of large floods. To prevent potential failure of the ponds, 100-year recurrence or larger events are bypassed around the ponds. A dike on the west side of Silver Bow Creek just upstream of Pond 3 is built to erode away at a flow about equal to the 100-year peak flow, which was calculated to be 3,300 cfs at the pond inlet (USEPA, 2000). This will cause the flood to bypass the ponds through the Mill/Willow bypass and discharge directly to the Clark Fork River. Depending on the magnitude of the flood and the actual behavior of the sand plug in the dike, a flow much larger than the 100-year peak flow calculated in this study could be released to the Clark Fork River. Therefore, under current operation of the ponds, there is a large increase in flood magnitude and associated downstream risk in the region of the 100-year event, and this risk has not been considered in this analysis.

Section 4
Hydraulic Modeling of Existing Conditions

This section describes the development and results of the hydraulic analysis of peak flows on Silver Bow Creek below the Warm Springs Ponds and the Clark Fork River above Perkins Lane Bridge. The purpose of the analysis is to develop reach-averaged and point predictions of water depths, energy slopes, and velocities on the river for determination of the forces impacting the floodplain, the banks and the bed of the river. These predictions will be used during design to develop appropriate bank stabilization treatments. A secondary purpose is to map the extent of flooding and magnitude of shear stresses on the riverine system to develop appropriate floodplain treatment designs. This will be especially important should the design include modifications to the elevation of the floodplain, in which case the model can be modified to predict the hydraulic parameters of the proposed configuration.

The methods used to develop the hydraulic model are described in this section, predictions of hydraulic parameters are presented, and the results are interpreted. Design criteria and riverine improvement designs will be developed in the next stage of the remedial design process.

4.1 Model Development

The model employed to predict hydraulic characteristics of the Clark Fork River under peak flow conditions is the U.S. Army Corps of Engineers HEC-RAS model (USACE, 2008) version 4.0. This model uses representative cross-sections along the stream reach as the basis for a one-dimensional flow model. For a steady-state application such as this, the input data includes the roughness coefficients (Manning's "n"), distance between sections, and peak flows. Numerous output parameters are available but for this application, the most important ones are water elevation, depth, velocity, and energy slope.

4.1.1 Cross-Section Development

A major component of the work in constructing the model is cross section geometry. The general procedure used for this project involved obtaining channel cross sections at a maximum interval of 200-feet using GPS technology. Sections were generally placed at riffles and pools, especially pools formed in bendways. Additional channel sections were surveyed near bridge structures and at other points where differences in channel and floodplain conditions could result in changes in hydraulic characteristics. Additional cross sections were located about 600 feet downstream of Perkins Lane Bridge to facilitate determination of the model's initial condition, which is based on normal flow characteristics. At bridges, the surveyors measured cross sections immediately upstream and downstream of the bridge as well as the bridge openings. Bridge geometry (i.e., hydraulic opening), including skew, was also determined.

The floodplain/overbank portions of the cross sections were developed from LIDAR (light distance and ranging) mapping developed specifically for Phase 1. The aerial data collection was conducted by Montana LIDAR of Kalispell, Montana, and the map

was produced by Spencer B. Gross of Reno, Nevada. The mapping was of sufficient accuracy to define the smaller drainageways in the floodplain that could transport significant overbank flows. At the top of bank on each side of the surveyed cross section, each section was extended across the floodplain in a direction perpendicular to the anticipated direction of flow. Because the river channel is highly sinuous in many areas, the sections were convoluted on some of the overbanks. Sections were extended to the expected high water mark of the 100-year recurrence flood. The GPS surveys are capable of a vertical accuracy of 0.2 feet and the topography developed from the LIDAR mapping has an accuracy suitable for one-foot contour mapping.

The geospatial data from the LIDAR mapping and cross section locations were imported from ArcGIS into HEC-RAS using the HEC-GeoRAS interface (USACE, 2009). The cross-section survey points were inserted manually into the program. The HEC-Geo-RAS interface also allowed importing the main channel and secondary channel centerlines, and right and left bank stations and lengths. The locations of the cross-section are found on maps in Appendix D.

4.1.2 Roughness Coefficient Determination

HEC-RAS uses Manning's "n" as a roughness coefficient, a number whose value increases as the local channel or bank increases in roughness. For purposes of accurate flow computation, the model divides the floodplain into three segments in the cross-sectional direction, the left and right overbanks and the main channel.

The main channel of Silver Bow Creek and the Clark Fork River in the project area is a gravel bed stream with some bank roughness and little observed variation in this condition. Roughness coefficient for the main channel was calculated by adjusting the value until the modeled water surface elevation matched the surveyed water level for a reach about 1,000 feet upstream of the USGS Clark Fork River near Galen gage at Perkins Lane Bridge. The calibration was performed at some distance upstream of the bridge to avoid the difficulty of accurately modeling the complex flow in the vicinity of the bridge. The roughness coefficient was varied and, using a least–squares fit to the survey data about five stations, the optimal fit was obtained with n = 0.036 for the channel. This value is consistent with a gravel bed stream with irregular side slopes (see for example Chow, 1959, Figure 5-5).

Overbank roughness is complex because the floodplain is a mosaic of grasslands and wooded areas that include small trees such as willow and birch. A roughness coefficient of 0.035 was chosen for tall grasslands, a coefficient of 0.1 was assigned to areas of trees, 0.02 for slicken, and 0.15 for tall, dense shrubs such as birch and willow. These values are consistent with values found in Table 5-6 of *Open-Channel Hydraulics* (Chow, 1959). Based on aerial photography, roughness coefficients were assigned for each cross section and entered into the model.

4.1.3 Structures

Phase 1 of the Clark Fork River includes two bridges, the first bridge is located below the confluence of Silver Bow Creek and Warm Springs Creek at river station 74+72 at Warm Springs Road. The second is located at the most downstream section of Phase 1 at Perkins Lane Road. Both bridges were modeled using the survey information provided by Brown and Associates, following procedures in the *2008 USACE HEC-RAS River Analysis System User's Manual*.

4.1.4 Split Flow

Because of the sinuosity of the river, several oxbows that provide alternative flow paths are present in Phase 1, but only one appears to flow during low flow conditions. This oxbow is located below cross-section 105 at station 197+50. To model the split low condition, a separate reach was created in the model with two junctions connecting to the main channel. The flow of the modeled flood events was split according to the hydraulic characteristics of the channels, and the model uses the energy equation to match the energy grade at the upstream end of the upper stream junction.

Several islands exist within the river, and, depending on the flow event, some islands are overtopped at higher flows. At some locations, once the water level reaches a specific elevation, the channel flow may split and create an island within the channel. Each of these areas was carefully evaluated to make sure that the split flow condition actually existed.

4.1.5 Levees

Because HEC-RAS is a one-dimensional model, it is unable to directly predict if overbank flow is able to access lower areas within the floodplain without additional analysis of site topography and multiple split flow scenarios. To ensure that water is contained within the main channel and any accessible drainage ways in the floodplain, levees are inserted into the model. These levees do not represent physical structures but determine how the model distributes flow across the floodplain. The topographic map and each cross section are evaluated to predict where water can overtop and where the water returns to the main channel. The flow of water overtopping the banks was calculated at these locations and a determination was made if the amount of water is significant to warrant a split flow analysis and a change in the main channel flow. At all the cross sections where overflow was possible, the amount of water calculated to be lost at any one location was less than 20 cfs, which is negligible in comparison to the main channel flow. Therefore, levees were inserted to maintain the flows in-channel or within the adjacent floodplain drainage ways.

4.1.6 Model Calibration

During the field investigation and cross section survey, the river was running at approximately 150 cfs based on gage information at the near Galen station, which is located at Perkins Lane Bridge. The model was initially run at a flow of 150 cfs and calculated water levels were compared to the stage recorded at the Perkins Lane Bridge. The two elevations compared well indicating that the model predicted the

water surface accurately at this location and additional adjustments to the model were not needed before evaluating peak flows.

4.1.7 Peak Flow Events

To model the hydraulic conditions of the 2-, 5-, 10-, 25-, 50- and 100-year events, several models had to be developed. Normally, a single model is used to evaluate the behavior of a range of flows. However, the unusual configuration of the floodplain required individual evaluation of each flow to determine where flow was most likely occupying side channels. Then the model levees were adjusted to reflect this determination. Each different levee configuration needed to be represented in a separate model.

The model was initially run to determine the channel capacity and at which flood event the banks would overtop. The results indicated that for most of the cross sections in Phase 1 the main channel could convey the 10-year flood event. Based on this determination, one model was developed to simulate the 2-, 5- and 10-year flood events, which were generally in-channel flows. A second model was developed to evaluate the 25-year flood event and a third one was created to evaluate the 50- and the 100-year events.

The predicted flood flows presented in Section 3, Table 3-6 were used in the evaluation. The flood flows for Silver Bow Creek differed from the ones for the Clark Fork River due to the flow contributions of Warm Springs Creek. Because flows for the 50- and 100-year flow events were not estimated for Silver Bow Creek, model results for these flows are not presented for this portion of the project.

4.1.8 Reach Definition

The models were divided into different geomorphic reaches as described in Section 2. For consistency, the same reaches were used for the hydraulic evaluation and are described in the table below. Reach 4 was divided into several sections to account for the split flow at the modeled oxbow. Table 4-1 presents a summary of the hydraulic reaches.

4.2 Model Results and Discussion

As described above, several models were developed to evaluate different peak flow events. Table 4-2 summarizes the peak flow discharges used in the model for the different reaches.

4.2.1 Water Surface Profiles

The thalweg and the water-surface profiles for the modeled floods are shown in Figure 4-1. The profiles show a significant drop in water elevation at the two bridges. During all the modeled flood events (2- through 100-year), the water surface at Warm Spring Road Bridge reaches the lower cord of the bridge but does not overtop the road. A backwater condition is created during these events. At the Perkins Lane

Table 4-1. Phase 1 Hydraulic Reach Summary.

Reach	River Mile	River Station	Cross Sections	Description
Upper Reach	0.4 to 0.84	25+88 to 43+43	1-14	Start of the project and the confluence with the historic Silver Bow Creek channel
Reach 1	0.84 to 1.05	43+43 to 52+52	15-20	Historic Silver Bow Creek channel to upstream of confluence with Warm Springs Creek
Reach 2	1.05 to 2.50	52+52 to 129+00	21-63	Confluence of Warm Springs Creek , low width to depth ratio, low channel slope, contains ARCO property
Reach 3	2.5 to 3.15	129+00 to 163+00	64-84	Greater width to depth ratio, contains gravel in many banks
Reach 4A	3.15	163+00 to 197+50	85-105	Upstream of oxbow –Higher width to depth ratio, gravel in banks
Reach 4B		197+50 to 205+70	106-111	During oxbow – split flow, main channel east of oxbow
Reach 4C	End 4.20	205+70 to 221+00	112-122	Below oxbow – Main channel below oxbow
Reach 4-Oxbow			106A-116A	Oxbow reach – minor channel at split flow

Table 4-2. Peak Discharges in cfs Evaluated in the Hydraulic Models.

	Hydraulic Reaches							
Flood Event	Upper Reach	Reach 1	Reach 2	Reach 3	Reach 4A	Reach 4B	Reach 4C	Reach 4-Oxbow
2-year	396	522	522	522	522	435	522	87
5-year	694	861	861	861	861	678	861	183
10-year	921	1,094	1,094	1,094	1,094	842	1,094	252
25-year	1,235	1,286	1,286	1,286	1,286	947	1,286	338
50-year	1,415	1,415	1,415	1,415	1,415	1,017	1,415	398
100-year	1,533	1,533	1,533	1,533	1,533	1,088	1,533	445

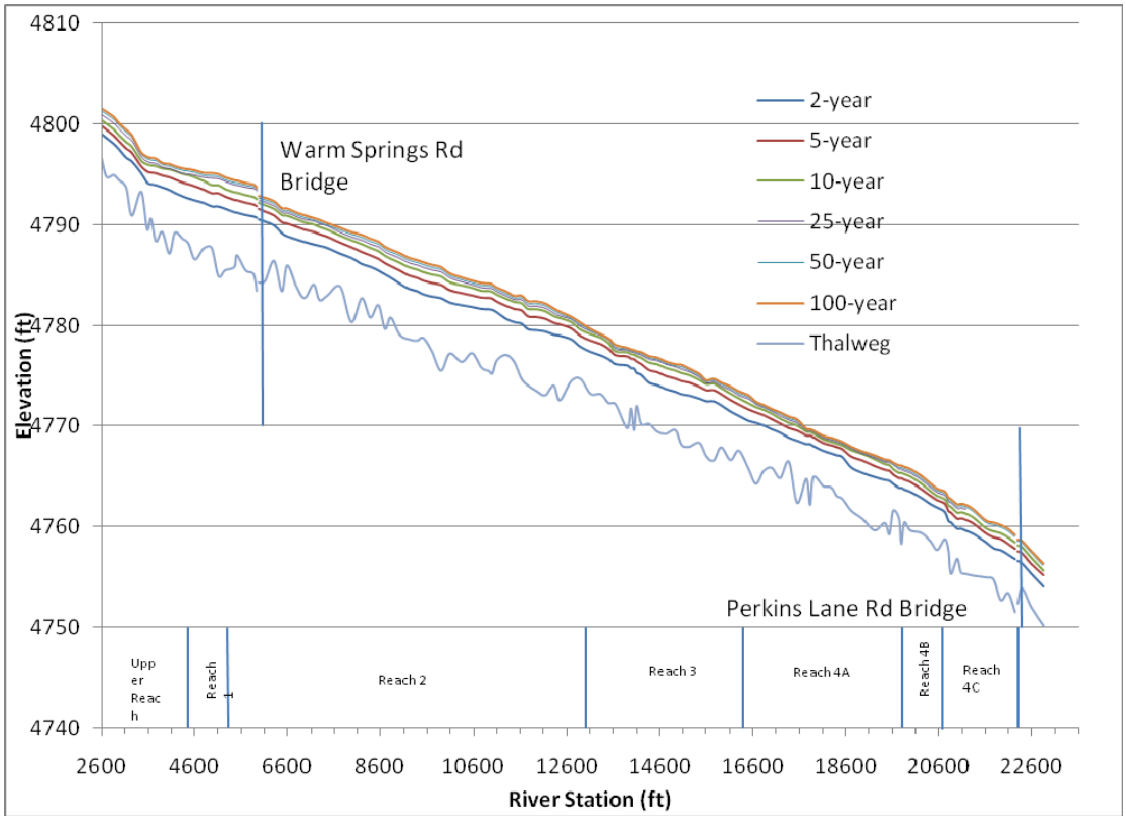

Figure 4-1. Computed Surface Water Profiles for the Clark Fork River-Phase 1.

Bridge, during the 100-year flow approximately 0.7 feet of clearance is still available between the bridge's lower cord and the water surface and the water does not overtop the road at any of the flood events.

4.2.2 Reach-Averaged Hydraulics

Hydraulic conditions in the channel at the modeled range of discharges determine the shear stress on the bed and banks of the channel. The reach-averaged hydraulic conditions important for calculation of shear stress and other relevant design criteria, e.g., discharge, hydraulic depth, channel velocity and energy slope, are summarized in Table 4-3. The values were calculated by averaging the models' output values for each of the reach cross-sections. Parameters for Silver Bow Creek (Upper Reach and Reach 1) for the 50- and 100-year floods were not calculated because these events were not estimated for Silver Bow Creek.

Peak flows for Phase 1 were presented in Section 3. Modeled flows increase at the confluence of Silver Bow Creek and Warm Springs Creek and decrease at station 198+00 where the river splits at the oxbow. Discharges for the split flow condition at the oxbow were first calculated using Manning's equation and then refined using the HEC-RAS program. The peak flow discharges are included in Table 4-3. The flows in the main channel range between 85% for the 2-year event to 71% for the 100-year

Table 4-3. Reach-averaged Hydraulic Conditions in the Clark Fork River, Phase 1.

Hydraulic Reach	Flow Event					
	2-year	5-year	10-year	25-year	50-year	100 -year
	Discharge (cfs)					
Upper Reach	396	694	921	1,235	-	-
Reach 1	396	694	921	1,235	-	-
Reach 2	522	857	1094	1,285	1,415	1,533
Reach 3	522	861	1094	1,286	1,415	1,533
Reach 4A	522	861	1094	1,286	1,415	1,533
Reach 4B	435	678	842	947	1,017	1,088
Reach 4C	522	861	1094	1,286	1,415	1,533
Reach 4 Oxbow	87	183	252	338	398	445
	Hydraulic Depth (ft)					
Upper Reach	2.18	2.48	2.78	2.85	-	-
Reach 1	3.41	4.09	3.93	1.65	-	-
Reach 2	3.40	3.91	3.60	2.45	2.34	2.43
Reach 3	2.86	3.07	2.87	1.52	1.43	1.45
Reach 4A	2.74	2.68	2.64	1.37	1.51	1.54
Reach 4B	2.81	3.15	3.36	2.98	3.03	3.07
Reach 4C	2.40	2.73	2.75	2.92	2.87	2.98
Reach 4 Oxbow	2.02	2.51	2.33	1.70	1.69	1.77
	Main Channel Velocity (ft/s)					
Upper Reach	3.58	4.12	4.43	5.06	-	-
Reach 1	2.11	2.57	2.85	2.33	-	-
Reach 2	3.25	3.87	4.19	4.35	4.54	4.68
Reach 3	3.48	3.93	4.16	4.29	4.39	4.47
Reach 4A	3.20	3.82	4.14	4.05	4.15	4.25
Reach 4B	3.45	4.07	4.39	4.46	4.49	4.54
Reach 4C	3.56	4.08	4.30	4.45	4.52	4.59
Reach 4 Oxbow	1.93	2.65	2.90	3.05	3.26	3.33
	Energy Slope (ft/ft)					
Upper Reach	0.00376	0.00337	0.00316	0.00338	-	-
Reach 1	0.00060	0.00062	0.00068	0.00040	-	-
Reach 2	0.00158	0.00159	0.00164	0.00162	0.00168	0.00170
Reach 3	0.00217	0.00194	0.00193	0.00189	0.00190	0.00189
Reach 4A	0.00175	0.00190	0.00204	0.00185	0.00188	0.00190
Reach 4B	0.00201	0.00214	0.00231	0.00227	0.00225	0.00223
Reach 4C	0.00287	0.00257	0.00267	0.00265	0.00255	0.00252
Reach 4 Oxbow	0.00138	0.00187	0.00212	0.00193	0.00202	0.00197

Note: Dash indicates not calculated.

event of the total flow. Results indicate that during the 2- and the 5- year flows, the water stays within the channel, except immediately upstream of the bridges, where the channel narrows. During the 10-year event, flow overtops the banks at several locations into adjacent channels before it returns to the main channel. During the 25-, 50- and 100-year events, the floodplain is inundated in several locations, mainly at floodplain tabs and upstream of bridges. The inundation maps included in Appendix D show the extent of inundation for the 10- and 100-year events.

The hydraulic depth is calculated by dividing the cross-sectional flow area by the top width. The model's predictions range from 4.09 feet to 1.43 feet in the main channel and 2.51 feet to 1.69 feet in the oxbow channel. Velocities in the channel range from 2.11 feet per second (ft/s) to 5.06 ft/s in the main channel and from 1.93 ft/s to 3.33 ft/s in the oxbow channel. Higher velocities occur in Silver Bow Creek where the slopes are steeper. The velocities increase can be expected with higher flows.

The energy slope ranges from 0.158 percent to 0.338 percent in the main channel and from 0.138 to 0.197 percent in the oxbow channel. Again, the energy slope is highest in the Upper Reach and increases with higher flows in each reach.

4.2.3 Channel Capacity and Floodplain Configuration

The models predict that the channel capacity is close to the 10-year event in the Clark Fork River reaches and close to the 100-year event in Silver Bow Creek. Inundation maps showing the extent of out of bank flow for the 10- and 100-year floods are presented in Appendix D. It appears that the channel that exists today is the same as the channel that predates the construction of the Warm Spring Ponds, which began in 1911. Silver Bow Creek is currently diverted through the Warm Spring Ponds and the discharge is regulated by the outlet structure in Pond 2. As discussed in Section 3, the ponds greatly reduce the peak flows on the Clark Fork River in the immediate downstream reaches. Table 3-5 shows the expected regression equation peak flow for the Clark Fork River in Phase 1, which may represent typical flows without the ponds. The 2-year flood event (1,198 cfs) from the southwest region regression equation is similar to the 10-year flood based on the Bulletin 17B estimates (1,094 cfs) that are calculated from current gage records. Normally, the expectation in western Montana is that the channel capacity of a river is approximately that of a 1.5 to 2-year flood event. The existing channel size is consistent with the expected hydrology of the river before the Warm Springs Ponds were constructed.

Figure 4-2 shows a typical cross section (cross-section 30) occurring a short distance downstream (north) of Warm Springs Road and the predicted water levels of the 2- and 10-year flows at this location. In this figure with a highly exaggerated vertical scale, it is evident that an event slightly higher than the 10-year flow would overtop the banks at this location and flow into side channels that are at some distance from the main channel especially on the left bank. In fact, the left bank flow would probably not return entirely to the main channel until forced in at the Perkins Lane Bridge, several miles downstream. As discussed previously in this section, the non-returning

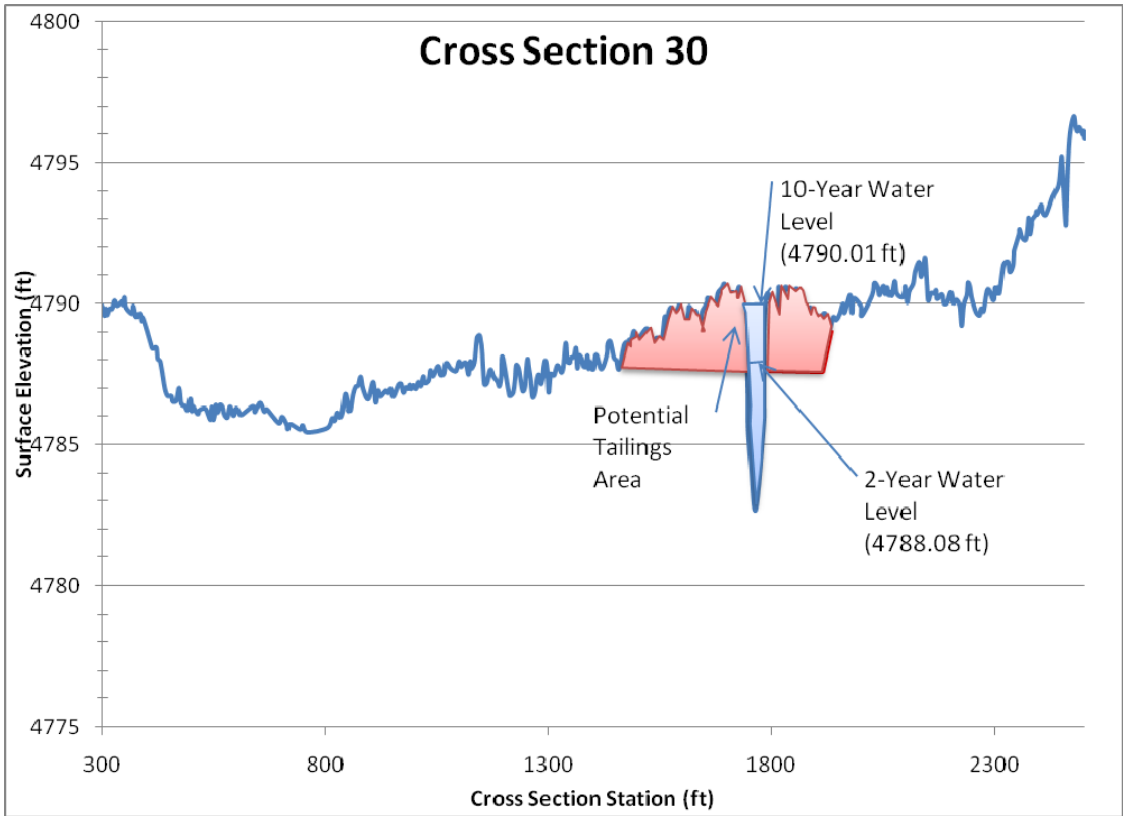

Figure 4-2. Cross-section 30 Showing Raised Channel Banks and Probable Tailings Locations.

flows are not expected to be significant at even the estimated 100-year event, but it is noteworthy that the channel has an apparent perched configuration along the eastern side of the floodplain, a configuration that is not commonly observed in natural channels.

The mounding of the right and left banks above the typical floodplain is probably related to tailings deposition that occurred in the flood of 1908 and other floods that occurred prior to construction of the Warm Springs Ponds. Based on metal concentrations found in soil, it appears that the deposition resulted from deposition of tailings carried downstream from Butte during these floods. Contamination found during Phase 1 investigations in 2009 was reported to extend 2 to 4 feet below ground surface within several hundred feet of the banks. This contamination is illustrated conceptually in Figure 4-2. Mechanisms for advective transport and deposition of fine-grained tailings in the Upper Clark Fork River are discussed in the geomorphic history section of Smith *et al* (1998).

Section 5
Bank Toe Investigation

Stability of banks is dependent upon having an suitable bank toe material, particularly at banks in high shear stress locations such as outer bends. The bank toe is the grade break at the base of the bank slope where it meets the streambed. In this section the term "bank toe material" means the material that extends beneath the bank at an elevation below the bank toe elevation and supports the upper bank. The toe material is especially critical because shear stresses increase with depth and are highest at the toe of the bank. Therefore, the bank toe is the most likely portion of a bank to fail under high flow conditions if it is not designed to withstand the shear stress anticipated at this depth. Generally in natural alluvial river systems, the bank toe material consists of gravels and cobbles that provide resistance to high shear stresses and slowly erode or deform under high flows. If less resistant material are present at the bank toe elevation, a streams tends to migrate rapidly and bank collapse commonly occurs. Another consideration to weigh in bank design is whether the toe should be designed to be rigid under all expected flow conditions or begin to erode and deform at a certain flow.

Design criteria for bank toe strength will be set for Phase I of the Clark Fork River Remedial Design during the design phase that follows this investigation. At this time, it is not known if bank toe materials encountered in this investigation will meet these criteria. However, existing alluvial cobbles and gravels in the Clark Fork River floodplain have been sorted through natural processes to produce resistant alluvial beds that currently serve as bank toes in many locations. The ability of these alluvial deposits to withstand predicted shear stresses will be investigated during the design of Phase 1.

To determine the availability of suitable materials for bank toes in the existing CFROU channel and floodplain, Tetra Tech and CDM undertook an investigation in the fall of 2009. Test pits were excavated along the stream as part of a larger contaminant investigation conducted by Tetra Tech that is described in the *Addendum to the Clark Fork River Sampling and Analysis Plan for Geomorphic and Hydraulic Field Investigations* (Tetra Tech and CDM, 2009). This section of the report presents the methods and results of this investigation. The expectation is that the data presented here can serve as a basis for determining the strength of existing bank toes and the potential need for construction of new bank toes in some locations during the remedial design and action. Contaminant information collected from these test pits is discussed in a separate report to be prepared by Tetra Tech.

5.1 Bank Toe Investigation Methods

Test pit for identification of bank toe materials were located near CFROU banks and its immediate upstream tributaries during Phase 1 investigations. The locations emphasized outer bends and areas identified for stream bank construction (Treatment Levels 2, 3 and 4) in the CFRRipES analysis (http://www.cfrripes.com/). The Riparian Evaluation system (RipES) was developed by EPA to provide a method for quan-

tifying the floodplain and streambank impacts on the Clark Fork River. The results of application of this system to the Clark Fork River are presented on the above cited website.

In the current investigation, all stream bank test pits were evaluated for contamination, but only a subset included bank toe material investigation. A small track excavator was used to open test pits about 5 feet behind the river bank at these locations and the test pits were excavated about 5 to 8 feet deep. Materials were logged and groundwater levels noted. The bank toe material was expected to be encountered near the streambed toe elevation. Because the bank toe material was usually under water, it was sampled by bucket and viewed at the surface. The Unified Soil Classification System (USCS) was used to classify the material. Six samples were placed in sample bags, labeled, and delivered to Tetra Tech's materials testing laboratory to determine the gradation under ASTM C136/C117 standards. These samples served to calibrate the field observations and were selected predominately to include gravel sizes and larger materials. Photographs of typical toe material types were taken and described. Locations and elevations of the test pit were surveyed with an accuracy of at least 0.2 feet by Dan Brown and Associates.

Locations of test pits are included in Appendix E. The appendix also contains the raw data file and the gradations of the laboratory samples. Test pit logs can be found in the supporting document for this investigation prepared by Tetra Tech. Figure 5-1 shows a typical streambank test pit no. 01540. The gravel layer, although present at this location, is below the groundwater level and not visible in the photograph. Figure 5-2 shows the bucket sample of toe material from streambank test pit no. 01541. The cobbles present in most samples are visible in this photograph.

5.2 Data Analysis

During the investigation, 42 test pits were opened of which 34 were subject to bank toe investigation. Nine of the test pits were located along Silver Bow Creek above the Warm Springs Creek confluence, one was located on Warm Springs Creek, and 24 were located on the Clark Fork River below the confluence with Warm Springs Creek and above the north boundary of the ARCO property. Data are presented in Appendix E.

The objectives of this analysis of the bank toe material are:

- Determine the vertical position of the suitable bank materials to the bank toe elevations,
- Analyze the gradations of the bank toe materials, and
- Estimate the frequency of occurrence and approximate locations of suitable bank toe materials where bank toes may be needed during bank reconstruction.

Figure 5-1. Typical Streambank Test Pit (No. 01540).

Figure 5-2. Typical Bank Toe Material, Test Pit No. 01541.

5.2.1 Vertical Position of Bank Toe Materials

The top layer of the left and right bank toe materials are plotted relative to the bank toe elevation in Figures 5-3 and 5-4. These figures also show test pit surface elevation, bank elevation, and groundwater levels. The left bank toe data, which is shown in Figure 5-3, was collected on Silver Bow Creek above the operable unit, on the Clark Fork River down to the Warm Springs Road Bridge, and then downstream of station 81+00 to the north boundary of the ARCO property. No data was collected on the left bank on the downstream side of the Warm Springs Road Bridge (station 58+00) for almost one-half mile because this bank appeared to have no bank erosion severe enough to require bank reconstruction as judged by previous inspections and CFRRipES data.

Right bank toe data was collected from the beginning of the operable unit (station 44+50) more or less continuously to the north boundary of the ARCO property. Data was not collected upstream of the operable unit on the right bank of Silver Bow Creek because of difficult access to this side of the stream.

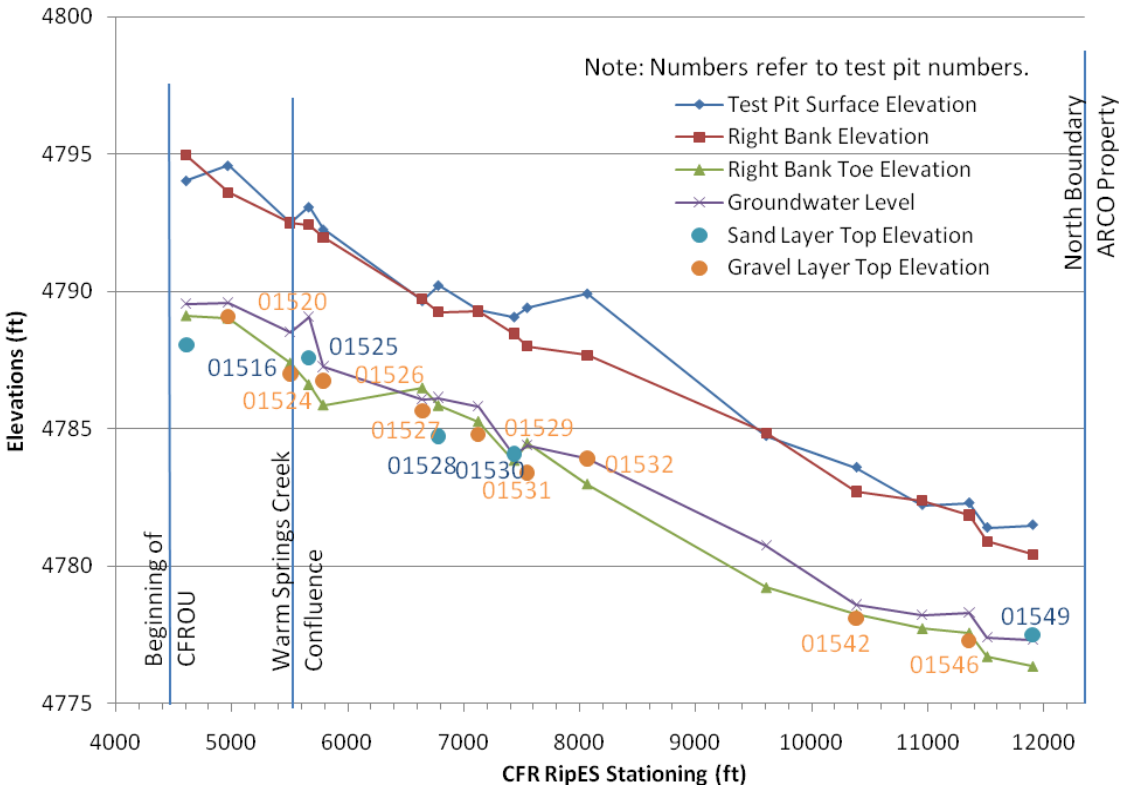

Figure 5-3. Left Bank Toe Elevations.

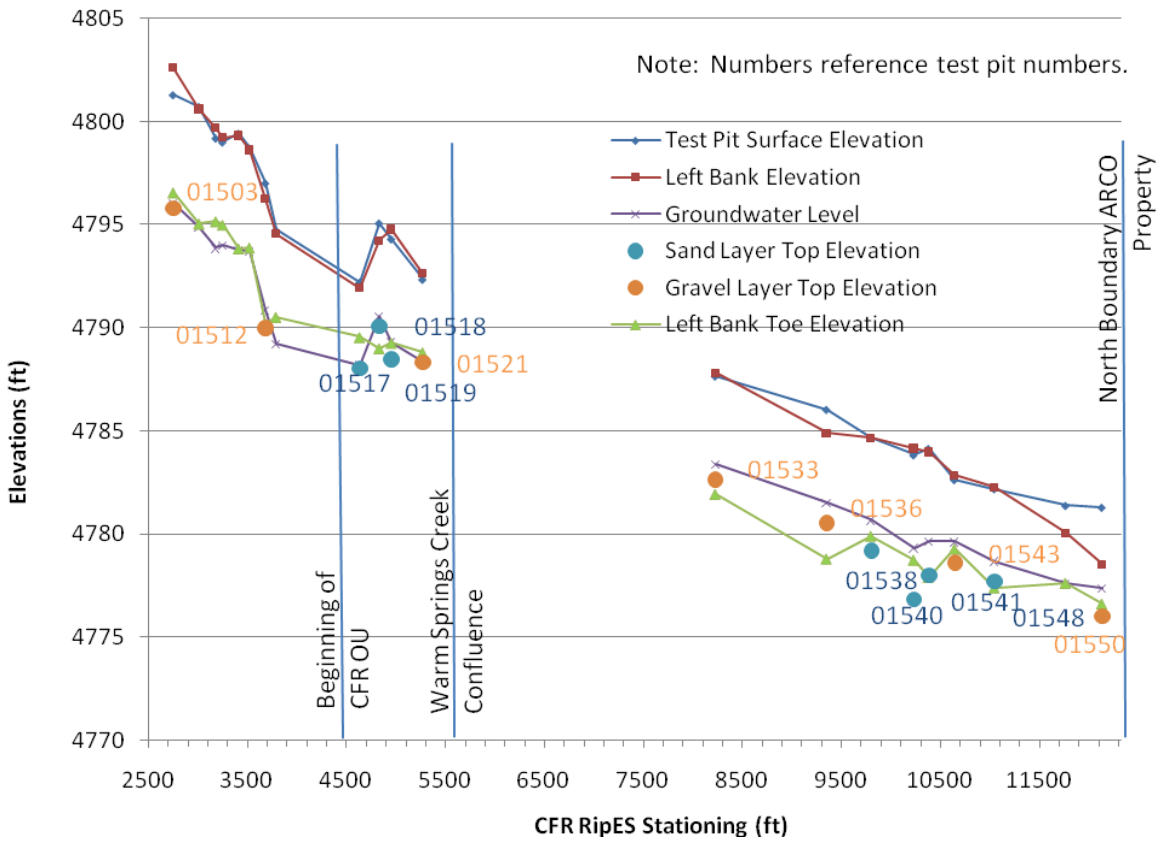

Figure 5-4. Right Bank Toe Elevations.

As shown for left bank data in Figure 5-3, the top of the sand and gravel deposits are generally near the bank toe elevation. Statistics performed on the difference between the top of the sand and gravel deposits and the bank toe elevations in the reach above Warm Springs Creek confluence show the average elevation for sand and gravel being 0.5 ft below the bank toe. In the lower reach of the Clark Fork River on ARCO property, the top of the sand and gravel deposits averages 0.1 ft below the bank toe elevation. However, the standard deviation for both the reaches is relatively large being about one foot. This suggests that there is enough variability of the sand and gravel elevations that we cannot assume that the toe materials, when present, are located at the bank toe elevation, and toe conditions at each bank will have to be considered individually during construction. Note that on the lower portions of the river within the ARCO property the groundwater level is consistently above the top of the sand and gravel deposits suggesting that dewatering may be needed to construct bank toes in this reach.

The data for the right bank are shown in Figure 5-4. The top of the sand and gravel deposits tend to be very close to the bank toe elevations with the mean elevation for sand being at the bank toe elevations and the mean elevation for gravel being 0.1 ft lower. Again, the standard deviations of these measurements are approximately one foot, suggesting that site-specific conditions dictate the presumed construction needs

for bank toes. Also, note that top elevations of toe materials are consistently lower than groundwater elevations indicating a probable need for some dewatering during construction.

5.2.2 Bank Toe Material Gradations

Six bank toe materials were analyzed for particle size distribution using ASTM Methods C136/C117 standards. Data sheets are found in Appendix E and Table 5-1 summarizes key information on the particle size analyses. Figure 5-5 plots the cumulative distribution of the particles from cobbles through sands. No analysis of the fine fraction (less than 200 sieve) was conducted.

Table 5-1. Summary of Particle Size Analysis of Bank Toe Material.

	Station & Bank[1]	Depth[2] (in)	USCS[3]	D_{50} (in)	D_{84} (in)
TP 01513	37+94 L	72-96	Silty sand with gravel	0.07	1.06
TP 01522	Warm Springs Creek, R	48-60	Silty gravel with sand and cobbles	0.40	1.86
TP 01526	57+89 R	66-90	Well graded gravel with sand and cobbles	0.55	2.00
TP 01531	75+47 R	72-96	Poorly graded gravel with sand and cobbles	1.29	3.11
TP 01533	82+32 L	60-72	Well graded gravel with sand and cobbles	0.78	1.96
TP 01549	119+05 R	48-72	Poorly graded sand with silt, gravel and cobbles	0.16	2.00

Note: (1) Station in feet from CFR RipES database; L – Left bank, R - Right bank
(2) Bottom of sample interval indicated; total thickness unknown.
(3) Unified Soil Classification System

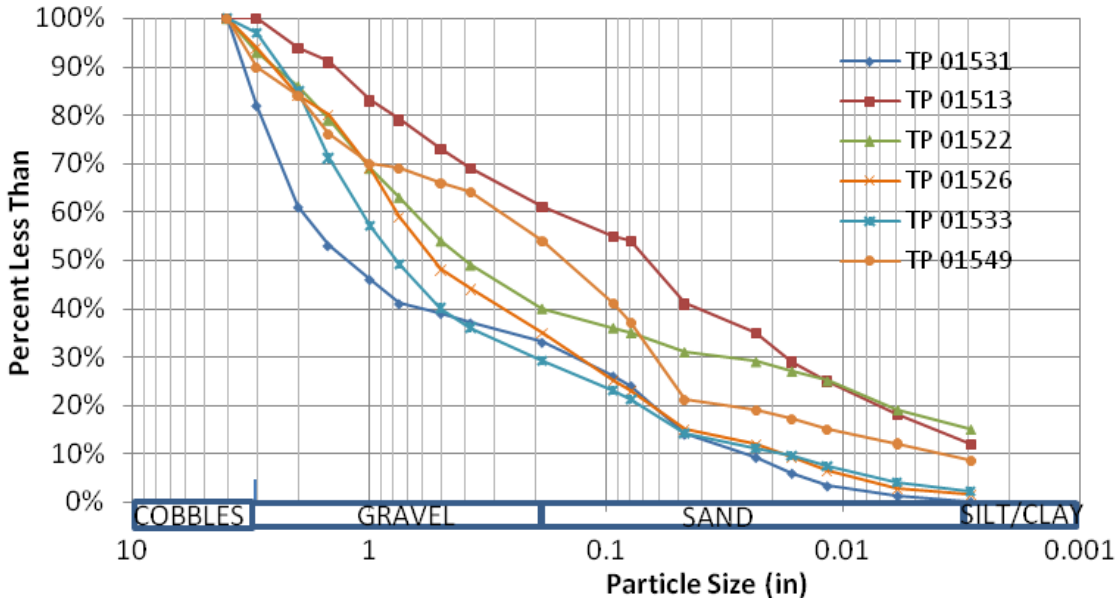

Figure 5-5. Toe Material Particle Size Gradations, Clark Fork River, Phase 1.

Most particle size analyses of the bank toe materials include material from fines (silts and clays) to cobbles with the predominant size classes being sands and gravels. There is a rather wide range of size distributions as shown in Figure 5-5 and wide range in D_{50} particle sizes (0.07 to 1.29 inches) shown in Table 5-1. All of the samples except the one from test pit 01513 include significant gravel fractions (greater than 30%) and some cobble. Test pit 01513 is located on the outside bank of a bend in Silver Bow Creek that is showing significant erosion. If this bank is reconstructed, consideration should be given during design to the relatively small particle sizes in the existing bank toe.

Test pit 01522 is located on a bank of Warm Springs Creek that has been identified as potentially requiring reconstruction. The other four test pits are located on the Clark Fork River between the confluence with Warm Springs Creek and the north boundary of the ARCO property. Three of these test pits have bank toe materials that classify as gravel but one, test pit 01549, classifies as sand although it contains a large gravel fraction as well. Table 5-1 presents the D_{50} and D_{84} particle sizes, which are useful in hydraulic design of bank toes and bed material. D_{50} is used in Shield's equation for predicting incipient motion of particles, and D_{84} is used in equations for calculation of the fraction of total shear stress on particles (as opposed to bed form). The mean value of D_{50} for the four Clark Fork River test pits is 0.70 inches, and the mean value of D_{84} is 2.27 inches. Note that the D_{50} values are quite variable, while the D_{84} values are considerably less variable.

5.2.3 Expected Occurrence of Suitable Bank Toe Materials

The location of banks to be reconstructed during remedial action will be identified during the design process. Therefore, the locations of the streambank test pits for this investigation were selected based on areas where bank reconstruction might be expected and are assumed to offer a representative sample of toe materials that will be encountered during bank reconstruction. Suitable bank toe materials were not found at all test pit locations although when present they were frequently found at an elevation that will enable them to protect the reconstructed bank. The particle size distribution required for a bank toe to be stable is dependent on the selected design flow and the shear stress calculated for a particular location or reach of stream. These design criteria and calculation of the required particle distribution will be part of the design process so the appropriate size distribution for toe materials is not known at this time. However, based on the lateral stability of most stream banks in Phase 1 and our current knowledge of river hydraulics, we assume that toe materials that classify as gravel and those that classify as sand with gravel and cobbles are suitable materials for bank toes. Silty sands are most likely not suitable materials for stable bank toes.

Fourteen test pits were excavated along Silver Bow Creek upstream of the Warm Springs Creek confluence during the streambank investigations. Nine of these test pits were selected for bank toe investigation and encountered sand or gravel layers at

depths suitable for bank toe material. Test pit no. 01513 has a USCS classification of silty sand, which is not considered suitable bank toe material. This suggests that suitable materials may generally be found in 89% of locations along the banks of Silver Bow Creek. Two additional test pits (nos. 01505 and 01507) encountered a caliche (a calcium carbonate cemented soil) layer that could potentially serve as a bank toe if it is at the right elevation and sufficiently thick. Although this material could potentially be suitable, it was not included in this calculation. Table 5-2 summarizes the suitable bank toe material findings from this analysis.

Table 5-2. Summary of Suitable Bank Toe Occurrences.

	Silver Bow Creek	Clark Fork River River
Suitable Materials Analysis: Analy-		
Total Bank Toe Material Pits	9	24
Suitable Materials	8	22
Percentage	89%	92%
Materials Below Bank Toe Elev.:		
No. with Materials below	6	11
Mean Depth below	0.8 ft.	0.7 ft.
Maximum Depth below	1.5 ft.	1.9 ft.

On the Clark Fork River below the Warm Springs Creek confluence, 24 streambank test pits were excavated of which 22 encountered suitable bank toe materials. This suggests that 81% of bank reconstruction locations on the Clark Fork River will have suitable materials. In this group of test pits, two locations (nos. 01534 and 01539) were estimated in the field to be silty sands and therefore not be suitable bank toe material.

Although suitable bank materials are found at a high percentage of locations, some of the materials are deeper than the bank toe elevations. In this case, if a bank is reconstructed, it may be necessary to place additional material to bring the rock protection up to the design elevation. At six of the eight locations on Silver Bow Creek toe material is estimated to be lower than the bank toe. The average depth that might require additional suitable material is 0.8 feet and the maximum depth is 1.5 feet. On the Clark Fork River, toe material is estimated to be lower than the bank toe at 11 locations with a mean depth of 0.7 feet below the bank toe and a maximum depth of 1.9 feet.

In this investigation bank toe materials potentially suitable to support bank reconstruction were found at many locations along Silver Bow Creek below the Warm Springs Ponds and along the Clark Fork River on the ARCO property. At a majority of the locations on Silver Bow Creek, the potentially suitable materials were below the bank toe elevation; and on half the locations on the Clark Fork River, the potentially suitable materials were below the bank toe. During construction, it will be necessary to supplement the bank toe material at some locations including locations where suitable materials are absent. During the design process, the hydraulic model results will

be used to develop design criteria for bank toe materials and a comparison with the existing bank toe materials will be made to determine if these preliminary conclusions on the availability of suitable materials are correct.

Section 6
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Appendix A - Aerial Photograph Time Series

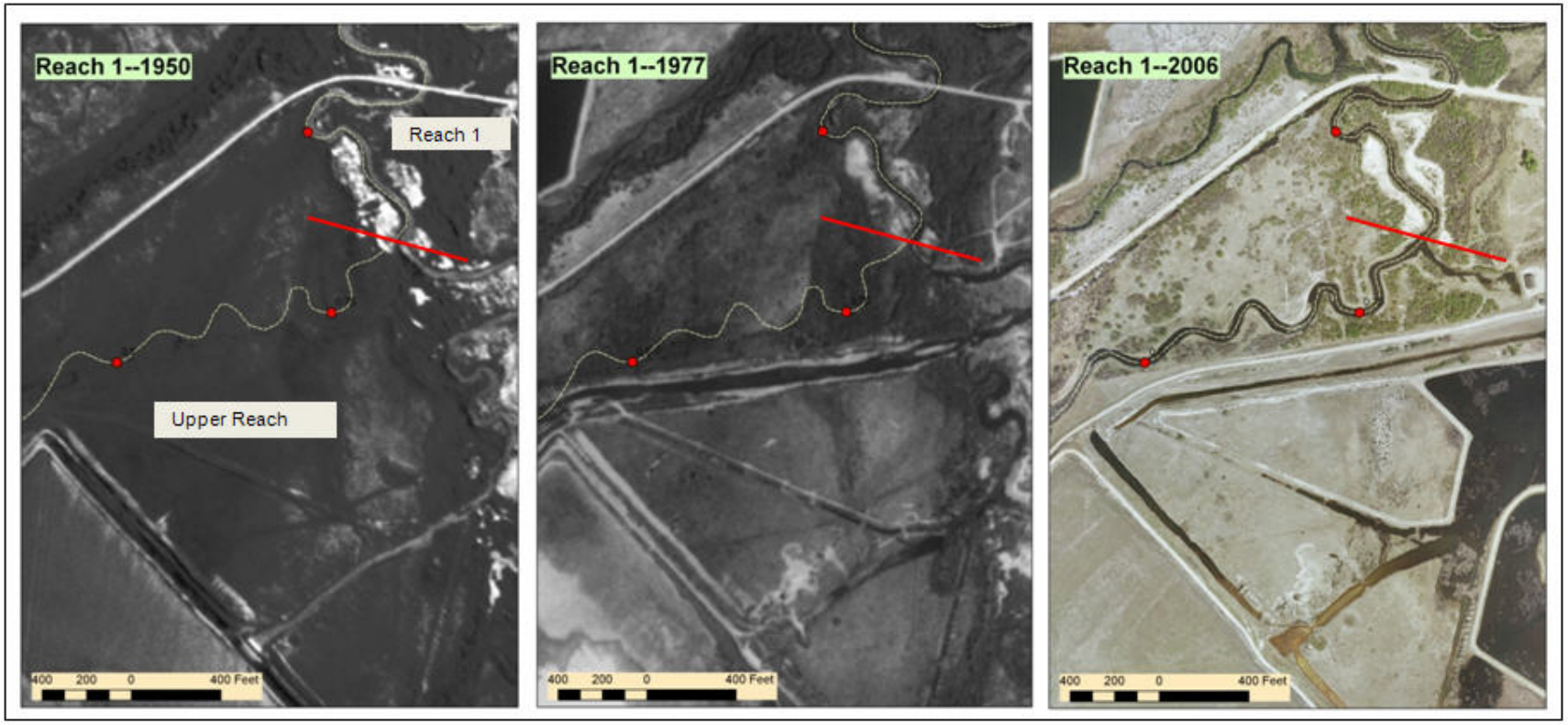


Figure B- 1. Air photo time series showing 1950, 1977, and 2006 conditions, Upper Reach and Reach 1.

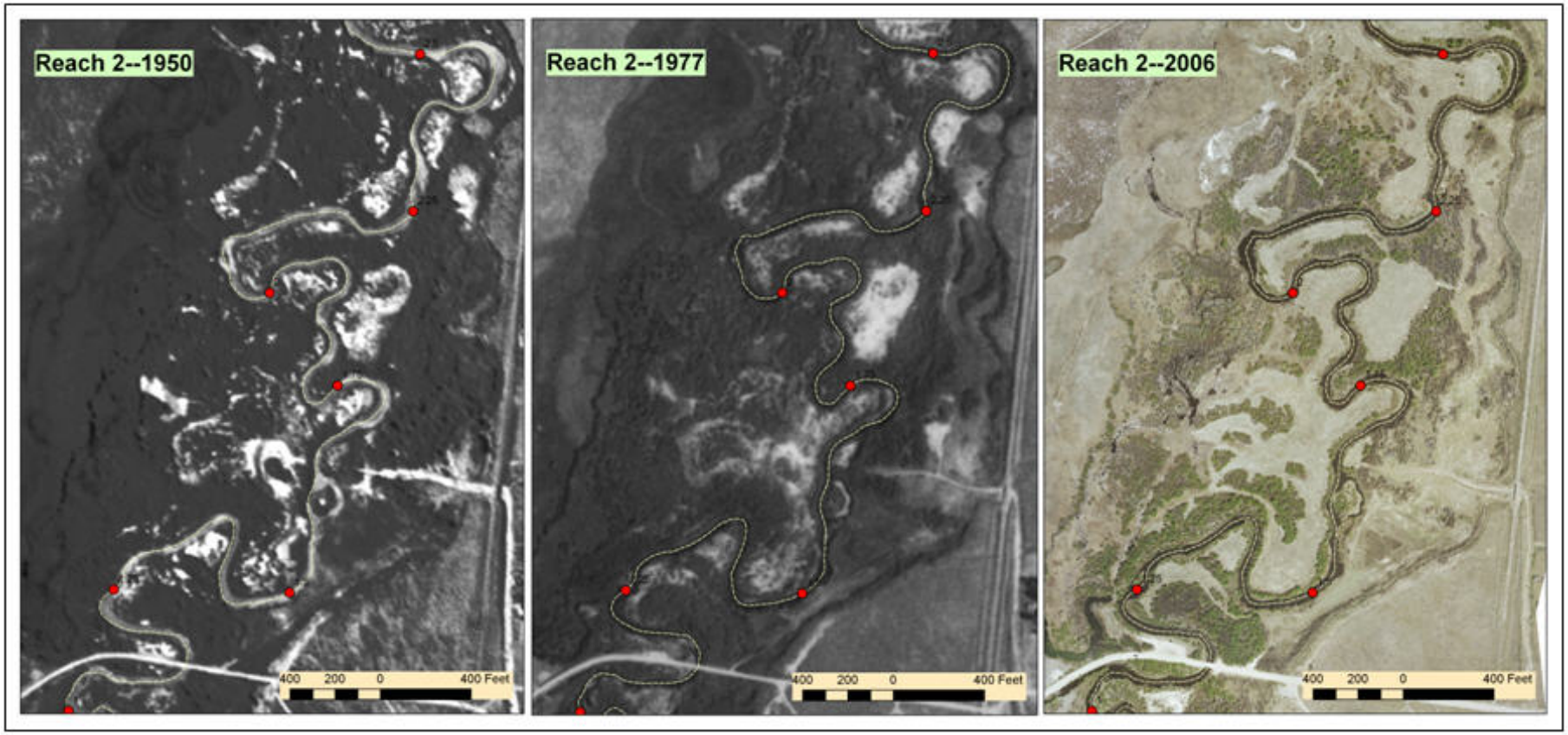


Figure A- 1. Air photo time series showing 1950, 1977, and 2006 conditions, Reach 2.

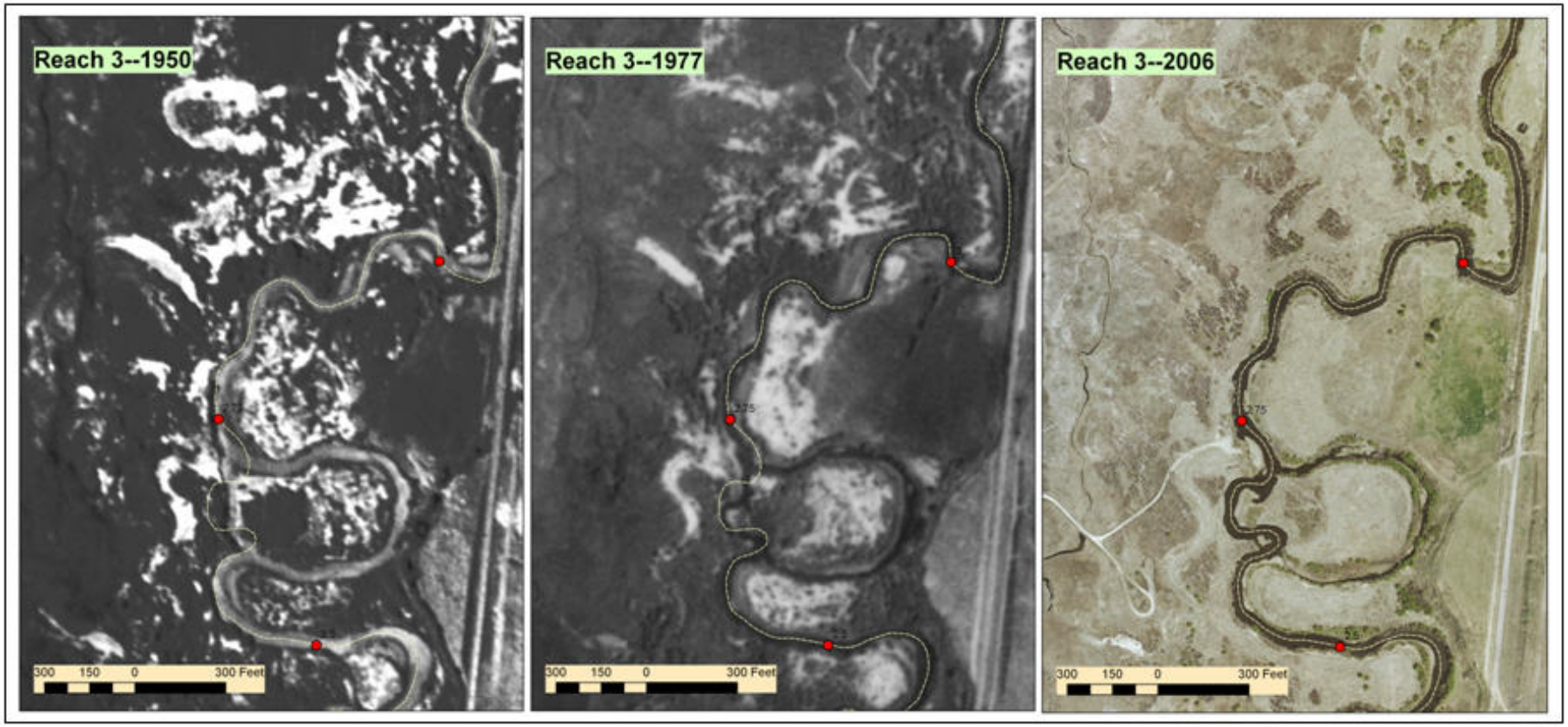


Figure A- 2. Air photo time series showing 1950, 1977, and 2006 conditions, Reach 3.

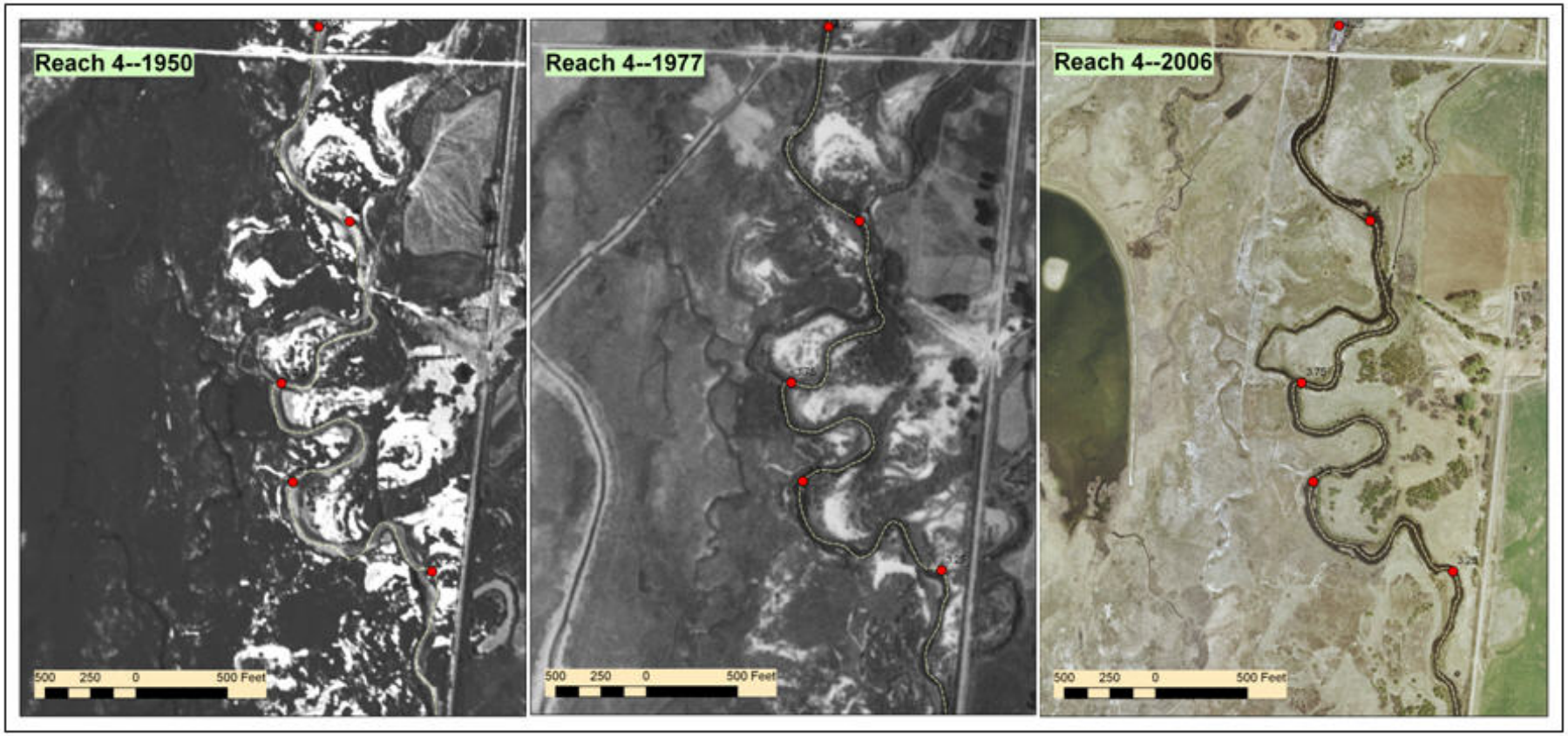


Figure A- 3. Air photo time series showing 1950, 1977, and 2006 conditions, Reach 4.

Appendix B - Erosion Inventory Results

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
0-1	L	85	6	35.5	High	60	N/A	314	Locally severe erosion downstream of left bank rock riprap; Pool #1	Class 2	Treatment 2
0-2	R	305	5	22.0	Moderate	5	N/A	315	Flanked riprap with minor scallops; line of large rock in middle of channel	Class 2	Treatment 3/4
0-3	L	201	4	23.0	Moderate	5	N/A	316	Lateral Scour against constructed bank; Pool #3	Class 2	Treatment 3/4
0-4	R	208	5	21.0	Moderate	10	N/A	317	Lateral Scour against constructed bank; Pool #4	Class 3	Treatment 4
0-5	L	256	4	28.5	Moderate	5	N/A	318	Lateral Scour against constructed bank; good surface protection; Pool #5	Class 2 .	Treatment 3/4
0-6	R	98	5	30.5	High	80	N/A	319	Coarse material; short segment of severe right bank erosion downstream of riprap and coarse constructed rock grade control; locally dense vegetation	Class 2	Treatment 3
0-7	L	252	5	47.0	Extreme	5	N/A	320	Severe left bank erosion into fines; very tight bend; eroding white/gray fines; extent matches RIPES; Pool #7	Class 2	Treatment 4
0-8	R	371	4	34.5	High	30	N/A	321 322	Failed fabric in bank; retreat over cohesive, organic rich toe; Pool #8, Pool#9	Class 2/ Class 3	Treatment 4 (small section Treatment 1 in core of bend)
0-9	L	36	6	37.0	High	5	0.8	323	Short bank section downstream of exposed fabric; Immediately opposite Pond #2 Discharge	Class 1	Treatment 1
0-10	R	131	6	49.0	Extreme	20	0.0	324	Severity increases downstream	Class 1	Treatment 4: (small section Class 1 in core of bend)
0-11	L	96	3	17.0	Low	0.0	0	325	Impacted soils behind	Class 1	Treatment 2
0-12	L	186	5	23.0	Moderate	40	0.5	326	Moderate TLB erosion; mature willows mid-bank	Class 1	Treatment 3
0-13	L	68	7	47.0	Extreme	0	0.8	327	Thick tailings exposed in bank	Class 1	Treatment 4

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
0-14	L	81	6	35.0	High	5	0.5		Moderate TLB erosion	Class 1	Treatment 3
0-15	R	74	6	28.0	Moderate	80	0.2		Moderate erosion; decadent willows	Class 2	Treatment 4
0-16	L	180	3	11.0	Low	0	0.4	328	Low inset surface; passsive edge with active deposition	Class 1	Treatment 2
0-17	L	354	6	29.0	Moderate	40	0.5	329 330	Some undercutting; mature willows mid-bank (at Qbf); no evidence of active retreat	Class 3	Upper portion Treatment 4; remainder Treatment 1:
1-01	R	376	5	26.0	Moderate	50	0.3	331 332	Few short scallops just downstream of Warm Springs Confluence	Class 3	Treatment 1
1-02	R	96	2	13.0	Low	10	0.0	334	Short right bank segment with clay toe; opposite small island; woody vegetation density low, but no evidence of active retreat	Class 2	Treatment 4
1-03	R	131	4	23.0	Moderate	70	0.0	335	Fairly dense willows, willows in mid-bank and at toe; local failure but no evidence of rapid retreat	Class 2	Treatment 2
1-04	R	158	4	21.5	Moderate	80	0.0	336	Straight segment with fairly dense willow line on topbank; steep, fine grained banks but no evidence of active retreat; slickens behind in core of tight bend	Class 3	Treatment 2
1-05	R	463	6	32.0	High	60	0.2	337 338	Fairly dense willow line; vertical banks with some undercutting; severity increases downstream	Class 3	Upper portion Treatment 2 ; middle Treatment 1; lower Treatment 4
1-06	R	127	6	38.5	High	5	0.4	340	Collapsed blocks provide some toe stability; wide cross section may limit shear	Class 1	Treatment 4
1-07	L	69	5	26.0	Moderate	60	0.3	341	Thalweg abuts left bank with island on right; irregular width; fast current, but mature willows provide surface protection	Class 1	Treatment 4

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
1-08	R	184	6	43.0	Very High	20	0.5	CDM 740 741 724	Thick taillings beneath mature willows; edge of island against main channel; variable width-- consider scalping island to bankful elevation	Class 3 .	Primarily Treatment 2 with short section Treatment 4
1-09	R	182	6	27.5	Moderate	80	0.0	343	Landward side of island; consider scalping of and proactive treatment of banks behind; standing water in back channel teal-colored	Class 3 .	Treatment 1
1-10	R	69	4	28.5	Moderate	60	0.0	344	Minor scalloping below moderately dense willows that extend to mid-bankretreat	Class 3	Treatment 2
1-11	R	154	5	29.5	Moderate	60	0.0	345	Moderately dense willows; mild erosion	Class 3	Treatment 1 with short segments Treatment 2
1-12	R	549	6	50.5	Extreme	5	0.2	346	Severe erosion of talings; minimal woody vegetation; deep pool on bend; low inset floodplain surface on opposite bank.	Class 1/ Class 3	Upper Portion Treatment 4, severity decreases downstream
1-13	L	117	6	30.0	Moderate	20	0.0	347	Steep, fine grained bank with mature willows on topbank. Minor left bank erosion; short section of moderate severity	Class 1	Upper portion treatment 2 with Treatment 4 on d/s end
1-14	L	78	6	40.5	Very High	30	0.3	348	Outside bend; locally severe; backwatered; slow current	Class 1	Small section Treatment 4; remainder Treatment 2
1-15	R	100	2	14.0	Low	20	0.0	349	Passive margin against Qbf bench; woody debris platform with young willows behind	Class 1	Treatment 2
1-16	L	182	2	19.5	Low	0	0.0	350	Passive margin against Qbf bench; dense Hb-vegetation with some undercutting	Class 1	Treatment 2

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
1-17	R	74	5	35.0	High	30	0.0	351 352	Upstream passive limb of small bendway; erosion severity due to undercutting of gravel toe	Class 2	Treatment 2
1-18	L	227	6	44.0	Very High	25	0.5	353 354	Locally severe scalloping on bendway apex; meander tab behind is good candidate for inset floodplain	Class 2	Treatment 1
1-19	R	211	6	36.0	High	75	0.2	355	Gravel toe; decadent willows provide some protection; mature willows at mid-bank	Class 3	Treatment 1
1-20	L	251	3	26.5	Moderate	30	0.1	356	Local scalloping against low Qbf bench	Class 2	Mid-portion Treatment 3; remainder Treatment 1
2-01	L	198	6	39.0	High	50	0.6	357	Discontinuously severe cutbank on composite bendway; wetland areas draining in from west. Local scalloping with active retreat	Class 3	Small section Treatment 4; remainder Treatment 2
2-02	R	103	5	29.0	Moderate	20	0.0	358?	Moderate severity on right bank; inside bank on composite bendway; some undercutting, but no evidence of active retreat	Class 3	Treatment 2
2-03	L	111	5	47.5	Extreme	5	0.6	359	Locally severely eroding tailings on bendway apex	Class 3	Mostly treatment 1 with short segment Treatment 4
2-04	R	263	3	26.0	Moderate	60	0.0	360 361	Moderate right bank erosion; dense decadent willows; undercut, largely stable bank	Class 3	Treatment 3
2-05	R	72	5	38.5	High	20	0.0	362	Inside bend; steep fine grained banks with some undercutting; limited mature willows. Thalweg appears to clip bank. Impacted soils behind.	Class 2	Treatment 3
2-06	R	250	5	42.5	Very High	10	0.1	363	Severe local scalloping on outside bend; undercutting; severity increases downstream	Class 3/ Class 2	Upper Treatment 1 Lower Treatment 4

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
2-07	R	107	5	29.5	Moderate	30	0.0	364	Some gravel; mature/decadent willows at toe and mid-bank	Class 2	Treatment 1
2-08	L	73	3	29.0	Moderate	30	0.3		Low surface	Class 1	Treatment 4
2-09	R	307	4	28.5	Moderate	20	0.2	365	Against berm/old embankment approaching east valley wall; mature birch at toe	Class 2	Treatment 1
2-10	R	152	5	39.5	High	30	0.3	367 368	Discontinuous scalloping; most severe retreat on downstream end of segment; impacted soils behind	Class 1	Treatment 2
2-11	L	70	7	41.0	Very High	20	0.4	370	Severe left bank erosion; short section of severe undercutting; may be incised due to d/s cutoff	Class 2	Treatment 4
2-12	L	95	6	50.5	Extreme	15	0.4	371 372	Fine grained toe with thick upper bank tailings; may be downcut due to downstream cutoff	Class 2	Treatment 4
2-13	R	163	6	44.0	Very High	0	0.9	373	New channel/avulsed. Severe erosion at upper end of neck cutoff	Class 2	Treatment 4
2-14	L	317	6	50.5	Extreme	15	1.4	376 377	Core of new channel formed via neck cutoff; severe erosion; some gravel in toe	Class 1	Treatment 4
2-15	R	48	6	47.5	Extreme	0	0.7	378 379	Short severely eroding right bank section in avulsion zone; tailings, failed blocks at toe indicate active retreat, ongoing planform adjustment	Class 2	Treatment 4
2-16	R	67	3	25.0	Moderate	40	0.5	380	Some gravel, moderate erosion downstream of avulsion	Class 2	Treatment 4
2-17	L	88	6	32.0	High	50	0.5	381	Locally severe, just downstream of avulsed segment; numerous decadent willows at toe; local scalloping	Class 1	Treatment 4
2-18	L	94	6	50.5	Extreme	0	0.4	382	Severe erosion with tailings; two primary scallops showing active failure	Class 1	Treatment 4
2-19	R	55	4	28.0	Moderate	20	0.2	383	Moderate erosion with minor gravel; narrow cross section with fast current; high angle of thalweg to bank	Class 2	Treatment 4

Bank ID	Bank	Length (ft)	Approx Bank Height (ft)	BEHI Rating	BEHI Severity	Percent Woody Vegetation Cover	Estimated Migration Rate (ft/yr)	Photo #	Comments	RIPES Buffer Class*	RIPES Treatment**
2-20	L	89	5	30.0	Moderate	10	0.2	384 385	Blue clay in toe---Glacial Lake Missoula? Moderately eroding with 1 ft undercut banks; fairly stable with good undercut habitat	Class 1	Treatment 2
2-21	L	40	6	49.0	Extreme	0	0.2	386, 387	Locally severe erosion at scallops with tailings exposed; local scour	Class 1	Very short segment Treatment 4 remainder Treatment 1
2-22	R	273	4	50.5	Extreme	0	0.1	389 390	Block failure on bendway; severe bendway erosion with severity increasing downstream; organic-rich clay toe; failed blocks at toe	Class 1	Treatment 4
2-23	L	67	5	18.0	Low	90	0.0	391	Smooth bank with decadent willows; outer bank of upstream limb of bend; thick willows, good habitat; no evidence of retreat	Class 2	Treatment 4
2-24	L	178	4	33.5	High	30	0.3	393	Steep point bar edge of low inset surface on opposite bank; deep hole with discontinuous erosion; erosion severity increases downstream through bend	Class 2	Core of bend Treatment 1 lower portion Treatment 4
3-01	R	233	7	52.0	Extreme	0	0.7	394 395 396 397	Cobbles in bank, fines in downstream direction; red oxidized, friable sand at toe; extends from water gap downstream; unusually high, coarse bank adjacent to eastern valley margin; depositional sufaces slope valleyward (west)	Class 2/ Class 1	Upper portion Treatment 2; lower segment Treatment 4
3-02	R	128	4	21.5	Moderate	50	0.1	399	Downstream of rock riprap; straight reach with minor erosion	Class 1	Treatment 2
3-03	R	61	4	37.0	High	0	0.2	400	On broad bend just upstream of vortex weir; short bank segment	Class 2	Treatment 4
3-04	L	129	4	29.5	Moderate	30	0.2	404	Downstream of vortex weir; some undercutting and scalloping; minor gravel; moderately dense willows	Class 3	Treatment 1
3-05	L	111	5	39.5	High	40	0.3	405	Active retreat with failed blocks at toe	Class 1	Treatment 4

Bank ID	*Bank*	*Length (ft)*	*Approx Bank Height (ft)*	*BEHI Rating*	*BEHI Severity*	*Percent Woody Vegetation Cover*	*Estimated Migration Rate (ft/yr)*	*Photo #*	*Comments*	*RIPES Buffer Class**	*RIPES Treatment***
3-06	R	191	3	46.0	Very High	5	1.1	408 409 410 469-475	Failed graded bank; erosion control fabric evident; erosion severity increases downstream	Class 1	Treatment 4
3-07	R	219	3	39.5	High	20	0.7	412	Severe bendway erosion at fenceline; discontinuous with a deep pool	Class 1/ Class 2	Treatment 4
3-08	L	237	3	47.5	Extreme	0	0.7	413 414 415 416 417	Left bank just on FWP land; previously treated segment with failed blocks; fence eroding out; metal staples; block failure indicates active retreat; fabric exposed in bank	Class 2	Treatment 4
3-09	L	35	5	49.0	Extreme	0	0.2	420	Unconsolidated, iron-rich gravel at toe; short segment of severe erosion; sparse woody floodplain vegetation	Class 2	Treatment 1
3-10	L	74	3	46.0	Very High	10	0.1	421 422	Actively block failing, up to 1' undercutting; short severely eroding segment opposite depositional bar	Class 2	Treatment 4
3-11	L	174	3	44.0	Very High	40	0.2	423 424	Locally severe erosion; gravel toe;	Class 2	Upper portion Treatment 1; lowermost portion has very short Treatment 4 segment
3-12	R	200	4	39.0	High	40	0.2	427	Locally severe erosion in bendway; point bar on opposite bank; potentially deposition from u/s avulsion	Class 2	Primarily Treatment 1 with very short section Treatment 5 (high shear)
3-13	L	48	3	28.0	Moderate	20	0.0	428	Passive margin on downstream limb of bend; moderate erosion with gravel toe	Class 2	Treatment 2

Bank ID	*Bank*	*Length (ft)*	*Approx Bank Height (ft)*	*BEHI Rating*	*BEHI Severity*	*Percent Woody Vegetation Cover*	*Estimated Migration Rate (ft/yr)*	*Photo #*	*Comments*	*RIPES Buffer Class**	*RIPES Treatment***
3-14	L	132	3	40.5	Very High	0	0.4	429	Severe erosion; fairly low bank elevation; thin tailings undercut and block failing; irregular outer bankline/channel width in bend apex	Class 2	Treatment 4
3-15	L	192	4	38.5	High	10	0.3	430	Upper portion looks limed; sandy toe; erosion discontinuous with scallops; irregular outer bankline (same bend as 3-14)	Class 2	Alternating Treatment 1 and Treatment 2
3-16	R	84	4	42.5	Very High	0	0.3	431 432	Failed blocks at toe; rye grass on top of bank; in-situ treated, tilled, with fabric; uppermost section of bank treated	Class 2	Treatment 4
3-17	R	91	3	28.5	Moderate	25	0.1	433	Moderate erosion in split flow reach; low bank, irregular edge on downstream limb of bend; area behind appears in-situ treated	Class 1	Treatment 3
3-18	L	49	4	34.0	High	20	0.3	435 436	Left bank on downstream end of long island; dense decadent willows; thin sliver of island with high tailings pile behind eroding bank; short segment of high severity	Class 2	Treatment 4
3-19	L	22	2	21.0	Moderate	0	0.0	442	Side channel in upper end of split flow reach; road crossing (access to in-situ treatments); low severity	Class 2	Treatment 3
3-20	L	40	3	29.0	Moderate	1	0.0	443	Short section on side channel on apex of small bend; minor erosion	Class 3	Treatment 1
3-21	R	71	3	34.0	High	10	0.3	445	Locally severe with scallops; right bank just above flow convergence	Class 2	Treatment 1
3-22	R	168	8	50.0	Extreme	0	0.9	450 451 452	High fine bank with riprapped toe, against valley wall; blue clay in toe (soft); no tailings evident; bank swallows, poorly functioning riprap	Class 1	Treatment 4
3-23	R	195	5	42.5	Very High	20	0.3	453	Right bank erosion opposite mid-channel bar; large bank scallop; some decadent willows at toe; locally severe erosion	Class 3	Treatment 3

Bank ID	*Bank*	*Length (ft)*	*Approx Bank Height (ft)*	*BEHI Rating*	*BEHI Severity*	*Percent Woody Vegetation Cover*	*Estimated Migration Rate (ft/yr)*	*Photo #*	*Comments*	*RIPES Buffer Class**	*RIPES Treatment***
4-01	L	292	5	40.7	Very High	0	0.4	459 460 461	Coarse toe; mid-channel bar downstream; open floodplain, heavily grazed; unvegetated, outside bend; discontinuous erosion	Class 1	Treatment 4
4-02	L	117	4	33.5	High	25	0.5	462 463	Locally severe with scallops; birch root masses provide lower bank stability; some undercutting at scallops	Class 1	Treatment 4
WS-1	R	62	4	25.5	Moderate	0	0.0	483 484	50-60 ft above pourover; right bank erosion into low bank of light bray silt/clay with minor sand. Erosion resistant. D/S end (~15 ft) most severe erosion. Pourover is ferricrete grade control; may cause downcutting u/s. Hb vegetation; no floodplain	Class 2	Treatment 2

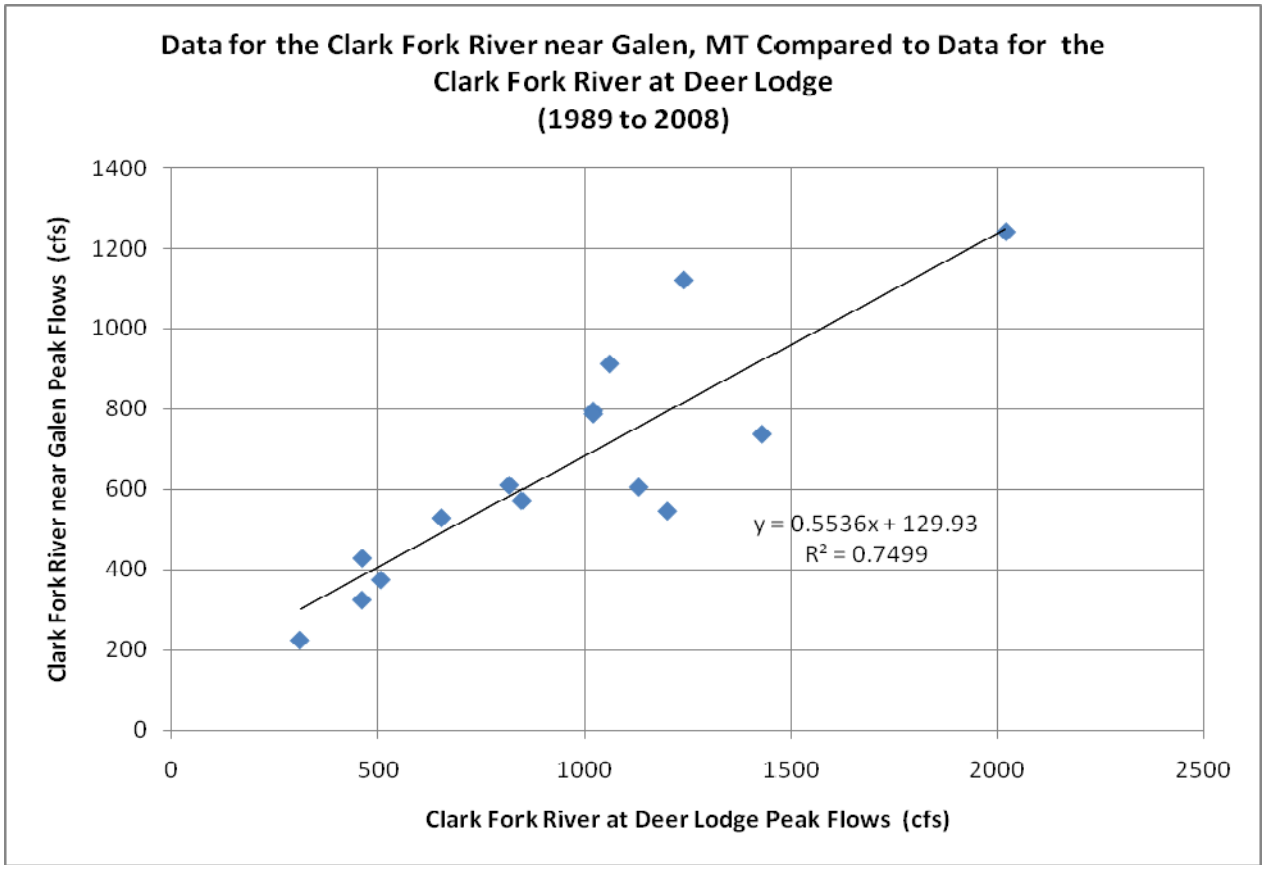
*RIPES Buffer Class descriptions (http://www.cfrripes.com)

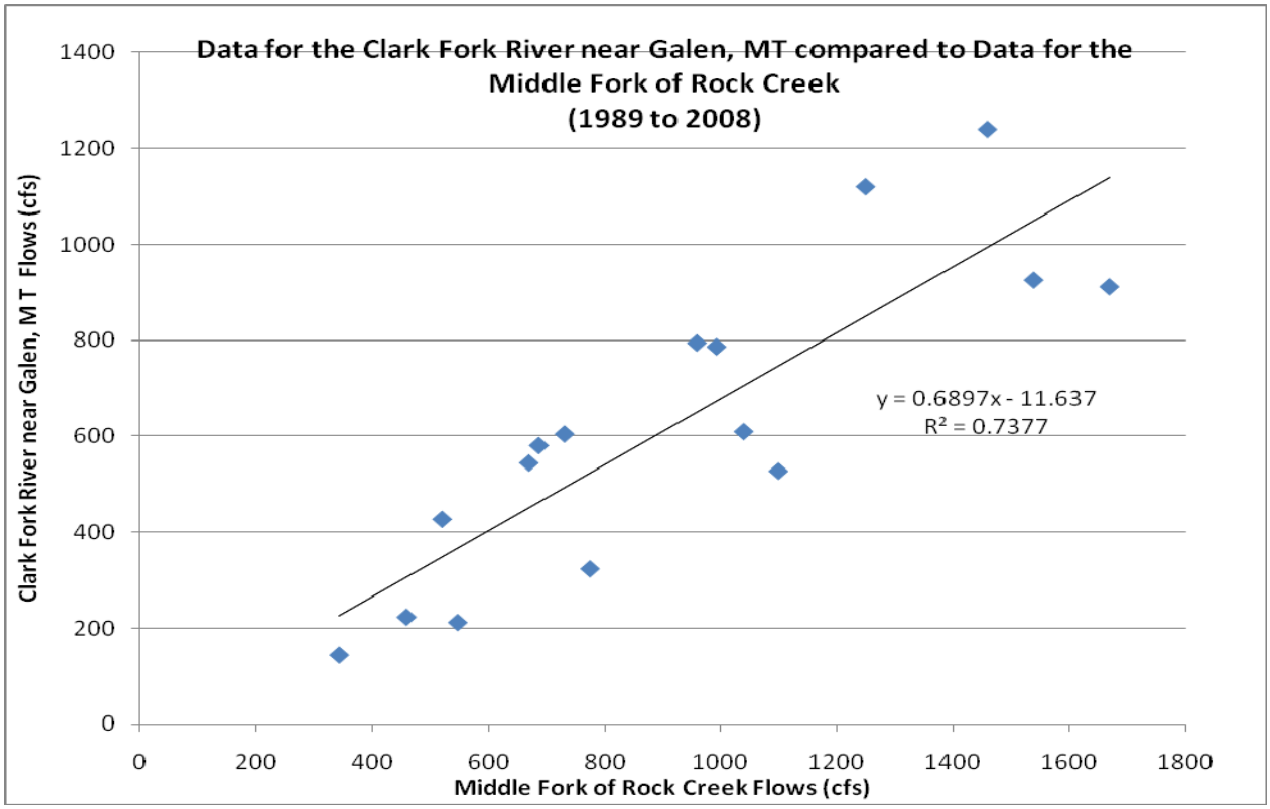
Buffer Class	Description
1	Class 1: Phytotoxic; streambanks are actively eroding and are significant contributors of contaminant release to the river.
2	Non-phytotoxic, but streambanks are contaminated, unstable, and eroding.
3	Banks are contaminated but have deep, binding woody vegetation holding the streambank in place.

**RIPES Treatment descriptions (http://www.cfrripes.com)

Treatment	Description
1	Vegetation Augmentation
2	Low Shear Stresses/Flow Velocities
3	Moderate shear stresses acting on immediate streambank
4	High critical shear stresses acting on streambank

Appendix C - Peak Flow Correlations and Method 17B Peak Flow Calculations


Data for the Clark Fork River near Galen, MT Compared to Data for the Clark Fork River at Deer Lodge (1989 to 2008)
Clark Fork River near Galen Peak Flows (cfs)
Clark Fork River at Deer Lodge Peak Flows (cfs)
y = 0.5536x + 129.93
R² = 0.7499
0
200
400
600
800
1000
1200
1400
0
500
1000
1500
2000
2500


Data for the Clark Fork River near Galen, MT compared to Data for the Middle Fork of Rock Creek (1989 to 2008)
Clark Fork River near Galen, M T Flows (cfs)
Middle Fork of Rock Creek Flows (cfs)
y = 0.6897x - 11.637
R² = 0.7377
0
200
400
600
800
1000
1200
1400
0
200
400
600
800
1000
1200
1400
1600
1800

```
                         SILVER BOW CREEK AT WARM SPRING.PRT
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.000.000
  Ver. 5.2            Annual peak flow frequency analysis     Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines      11/04/2009 10:52

                         --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\SILVER BOW
                         specifications - PKFQWPSF.TMP

                      Output file(s):
                         main - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\SILVER BOW

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.001.001
  Ver. 5.2            Annual peak flow frequency analysis     Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines      11/04/2009 10:52

           Station - 12323750  Silver Bow Creek at Warm Springs MT


                     I N P U T   D A T A   S U M M A R Y

                Number of peaks in record            =       25
                Peaks not used in analysis           =        0
                Systematic peaks in analysis         =       25
                Historic peaks in analysis           =        0
                Years of historic record             =        0
                Generalized skew                     =   -0.083
                     Standard error                  =    0.550
                     Mean Square error               =    0.303
                Skew option                          =   WEIGHTED
                Gage base discharge                  =      0.0
                User supplied high outlier threshold =   --
                User supplied low outlier criterion  =   --
                Plotting position parameter          =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********

    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                   0.0
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.             71.8
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.      2114.6
1


  Program PeakFq           U. S. GEOLOGICAL SURVEY            Seq.001.002
  Ver. 5.2            Annual peak flow frequency analysis     Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines      11/04/2009 10:52
```

SILVER BOW CREEK AT WARM SPRING.PRT

Station - 12323750 Silver Bow Creek at Warm Springs MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	2.5905	0.2955	-0.207
BULL.17B ESTIMATE	0.0	1.0000	2.5905	0.2955	-0.155

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

	ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
	0.9950	61.1	59.2	49.3	32.5	92.1
	0.9900	74.1	72.2	62.8	41.6	108.1
	0.9500	123.5	122.4	114.7	79.7	166.9
	0.9000	161.2	160.6	154.0	111.0	210.5
	0.8000	221.0	221.4	216.0	162.9	280.1
	0.6667	294.8	296.3	292.1	227.9	369.0
2yr -	0.5000	396.4	398.8	396.4	315.1	499.8
	0.4292	447.3	449.8	448.8	357.2	569.4
5yr	0.2000	693.8	694.6	708.4	546.9	943.1
10-yr.	0.1000	920.5	916.5	957.8	706.4	1329.0
25-yr	0.0400	1235.0	1220.0	1326.0	913.5	1918.0
50yr	0.0200	1488.0	1460.0	1641.0	1072.0	2426.0
100-yr	0.0100	1755.0	1710.0	1995.0	1232.0	2991.0
200-yr	0.0050	2036.0	1970.0	2395.0	1397.0	3616.0
500 yr	0.0020	2431.0	2331.0	3005.0	1620.0	4539.0

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.003
Run Date / Time
11/04/2009 10:52

Station - 12323750 Silver Bow Creek at Warm Springs MT

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1972	586.0		1997	784.0	
1973	324.0		1998	296.0	
1974	1000.0		1999	359.0	
1975	1320.0		2000	103.0	
1976	1210.0		2001	125.0	
1977	226.0		2002	207.0	
1978	637.0		2003	457.0	
1979	460.0		2004	114.0	
1989	550.0		2005	330.0	
1993	407.0		2006	274.0	
1994	217.0		2007	330.0	

1995	709.0	2008	516.0
1996	471.0		

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.004
Run Date / Time
11/04/2009 10:52

Station - 12323750 Silver Bow Creek at Warm Springs MT

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1975	1320.0	0.0385	0.0385
1976	1210.0	0.0769	0.0769
1974	1000.0	0.1154	0.1154
1997	784.0	0.1538	0.1538
1995	709.0	0.1923	0.1923
1978	637.0	0.2308	0.2308
1972	586.0	0.2692	0.2692
1989	550.0	0.3077	0.3077
2008	516.0	0.3462	0.3462
1996	471.0	0.3846	0.3846
1979	460.0	0.4231	0.4231
2003	457.0	0.4615	0.4615
1993	407.0	0.5000	0.5000
1999	359.0	0.5385	0.5385
2005	330.0	0.5769	0.5769
2007	330.0	0.6154	0.6154
1973	324.0	0.6538	0.6538
1998	296.0	0.6923	0.6923
2006	274.0	0.7308	0.7308
1977	226.0	0.7692	0.7692
1994	217.0	0.8077	0.8077
2002	207.0	0.8462	0.8462
2001	125.0	0.8846	0.8846
2004	114.0	0.9231	0.9231
2000	103.0	0.9615	0.9615

1

```
 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      25

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  12323750       USGS Silver Bow Creek at Warm Spri


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
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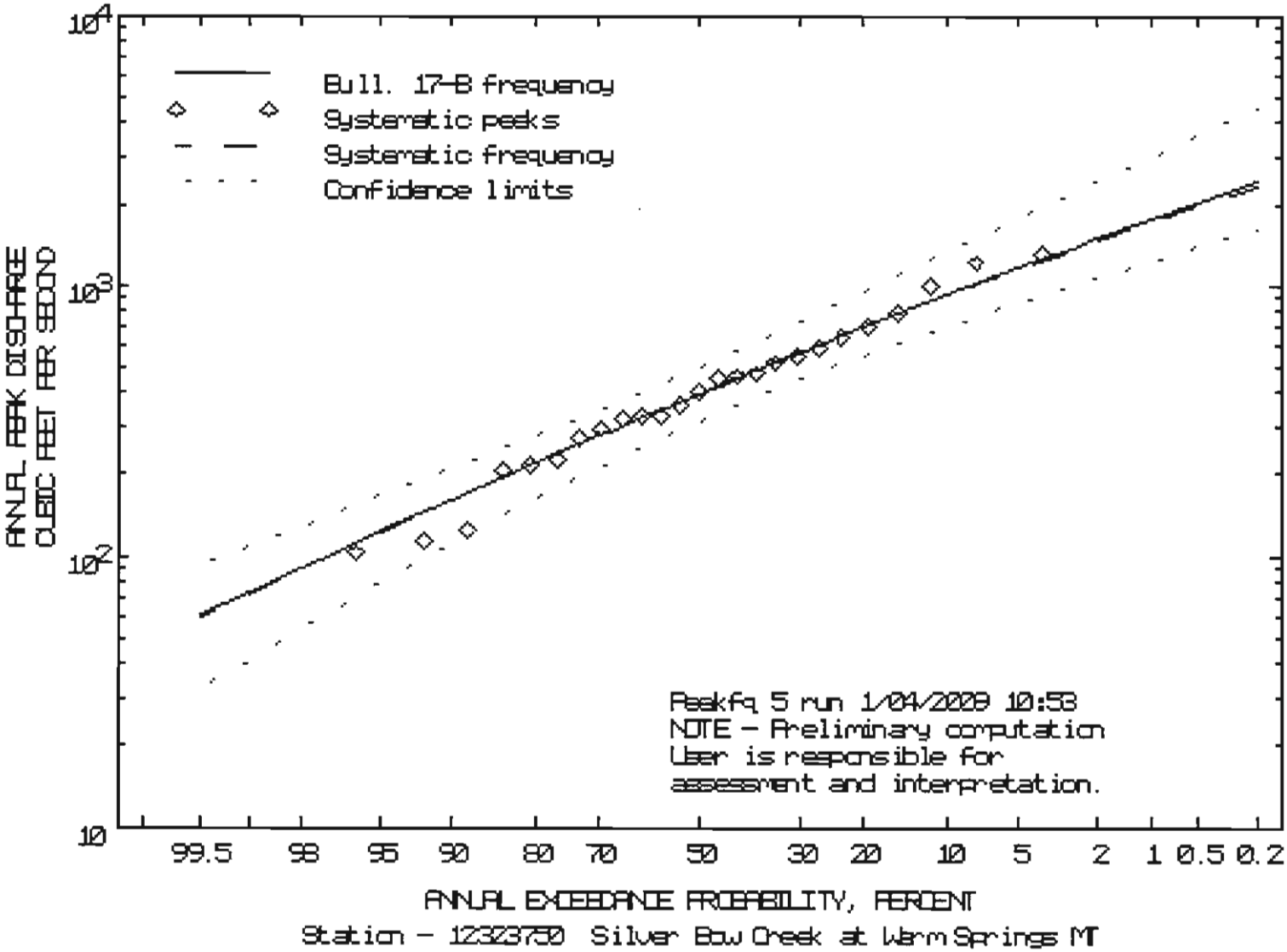
Bull. 17-B frequency
Systematic peaks
Systematic frequency
Confidence limits
Peakfq 5 run 1/04/2009 10:53
NOTE - Preliminary computation
User is responsible for
assessment and interpretation.
ANNUAL PEAK DISCHARGE
CUBIC FEET PER SECOND
10
10^2
10^3
10^4
99.5
98
95
90
80
70
50
30
20
10
5
2
1
0.5
0.2
ANNUAL EXCEEDANCE PROBABILITY, PERCENT
Station - 12323750 Silver Bow Creek at Warm Springs MT

```
1
  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.000.000
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/04/2009 08:23

                         --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\CLARK FORK
                         specifications - PKFQWPSF.TMP

                      Output file(s):
                         main - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\CLARK FORK

1


  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.001.001
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/04/2009 08:23

                 Station - 12323800  Clark Fork near Galen MT


                     I N P U T   D A T A   S U M M A R Y

               Number of peaks in record            =       20
               Peaks not used in analysis           =        0
               Systematic peaks in analysis         =       20
               Historic peaks in analysis           =        0
               Years of historic record             =        0
               Generalized skew                     =   -0.070
                    Standard error                  =    0.550
                    Mean Square error               =    0.303
               Skew option                          =   WEIGHTED
               Gage base discharge                  =      0.0
               User supplied high outlier threshold =   --
               User supplied low outlier criterion  =   --
               Plotting position parameter          =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********

    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                   0.0
    WCF195I-NO LOW OUTLIERS WERE DETECTED BELOW CRITERION.            111.4
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.      2260.2
1


  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.001.002
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/04/2009 08:23
```

Station - 12323800 Clark Fork near Galen MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	2.7005	0.2740	-0.693
BULL.17B ESTIMATE	0.0	1.0000	2.7005	0.2740	-0.375

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	79.2	65.9	58.3	38.4	123.1
0.9900	97.4	84.7	77.4	50.6	145.8
0.9500	166.9	159.4	151.4	103.1	228.3
0.9000	218.9	216.4	206.5	146.3	288.2
0.8000	299.4	304.7	291.1	216.9	381.9
0.6667	395.6	408.1	391.1	302.4	498.9
0.5000	522.0	539.4	522.0	411.4	666.3
0.4292	583.0	600.7	585.3	461.7	753.2
0.2000	860.5	861.8	880.2	673.5	1194.0
0.1000	1094.0	1060.0	1140.0	835.7	1613.0
0.0400	1390.0	1286.0	1493.0	1029.0	2197.0
0.0200	1610.0	1437.0	1772.0	1165.0	2660.0
0.0100	1827.0	1574.0	2066.0	1296.0	3140.0
0.0050	2042.0	1699.0	2375.0	1421.0	3637.0
0.0020	2323.0	1847.0	2812.0	1582.0	4315.0

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.003
Run Date / Time
11/04/2009 08:23

Station - 12323800 Clark Fork near Galen MT

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1989	737.0		1999	610.0	
1990	374.0		2000	145.0	
1991	795.0		2001	224.0	
1992	150.0		2002	324.0	
1993	581.0		2003	912.0	
1994	428.0		2004	213.0	
1995	1120.0		2005	571.0	
1996	926.0		2006	528.0	
1997	1240.0		2007	605.0	
1998	545.0		2008	787.0	

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.004
Run Date / Time
11/04/2009 08:23

Station - 12323800 Clark Fork near Galen MT

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1997	1240.0	0.0476	0.0476
1995	1120.0	0.0952	0.0952
1996	926.0	0.1429	0.1429
2003	912.0	0.1905	0.1905
1991	795.0	0.2381	0.2381
2008	787.0	0.2857	0.2857
1989	737.0	0.3333	0.3333
1999	610.0	0.3810	0.3810
2007	605.0	0.4286	0.4286
1993	581.0	0.4762	0.4762
2005	571.0	0.5238	0.5238
1998	545.0	0.5714	0.5714
2006	528.0	0.6190	0.6190
1994	428.0	0.6667	0.6667
1990	374.0	0.7143	0.7143
2002	324.0	0.7619	0.7619
2001	224.0	0.8095	0.8095
2004	213.0	0.8571	0.8571
1992	150.0	0.9048	0.9048
2000	145.0	0.9524	0.9524

1

End PeakFQ analysis.
Stations processed : 1
Number of errors : 0
Stations skipped : 0
Station years : 20

```
Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  12323800       USGS Clark Fork near Galen MT


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
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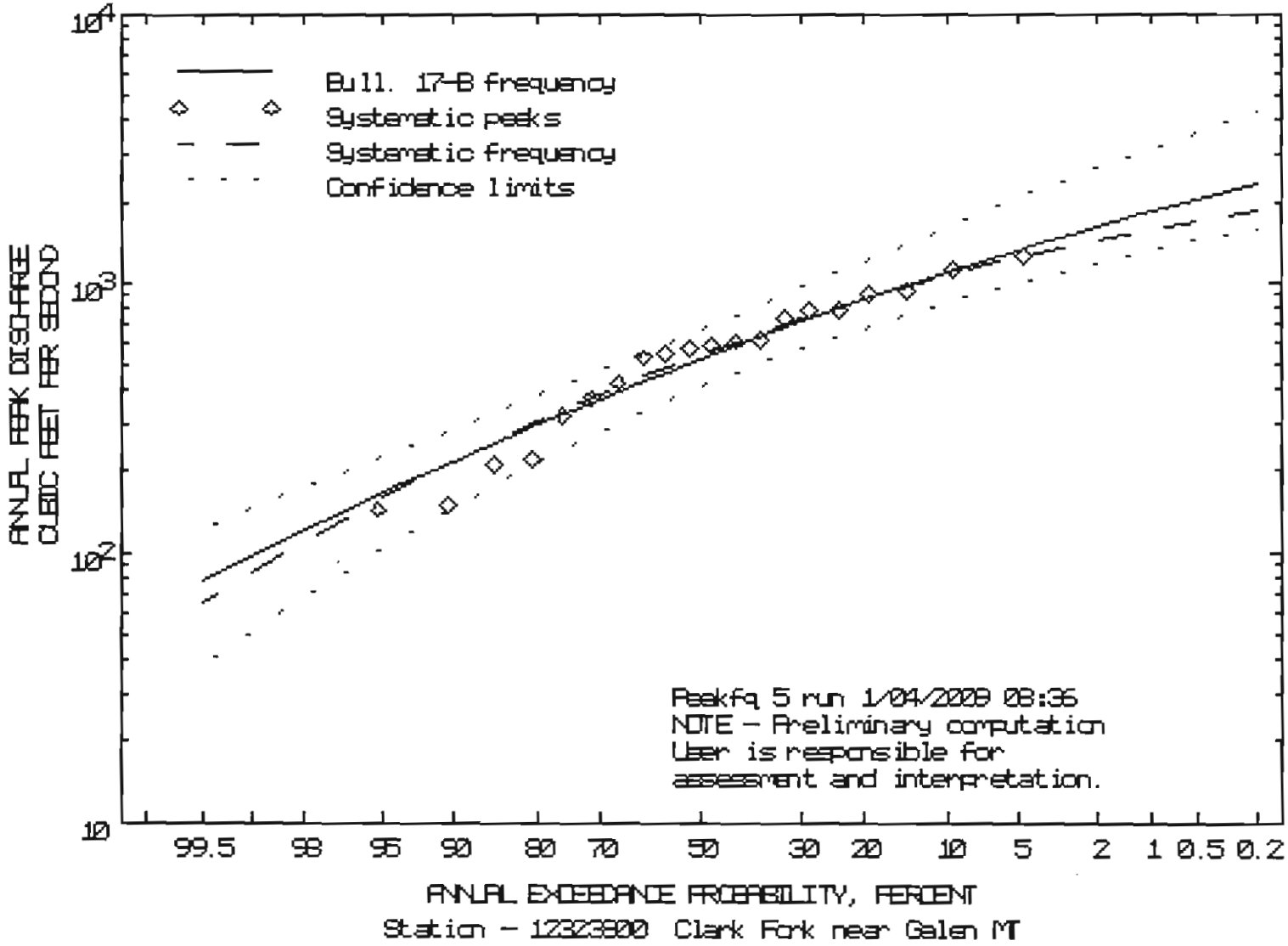

Bull. 17-B frequency
Systematic peaks
Systematic frequency
Confidence limits
Peakfq 5 run 1/04/2009 08:36
NOTE - Preliminary computation
User is responsible for
assessment and interpretation.
ANNUAL PEAK DISCHARGE
CUBIC FEET PER SECOND
10
10^2
10^3
10^4
99.5
98
95
90
80
70
50
30
20
10
5
2
1
0.5
0.2
ANNUAL EXCEEDANCE PROBABILITY, PERCENT
Station - 12323800 Clark Fork near Galen MT

```
1
  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.000.000
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/09/2009 16:05

                         --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\CLARK FORK
                         specifications - PKFQWPSF.TMP

                      Output file(s):
                         main - C:\DOCUMENTS AND SETTINGS\MAINZHAUSENK\MY
DOCUMENTS\CLARK FORK\PEAKFG\CLARK FORK

1


  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.001.001
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/09/2009 16:05

                 Station - 12323800  Clark Fork near Galen MT


                     I N P U T   D A T A   S U M M A R Y

               Number of peaks in record           =       72
               Peaks not used in analysis          =        0
               Systematic peaks in analysis        =       72
               Historic peaks in analysis          =        0
               Years of historic record            =        0
               Generalized skew                    =   -0.070
                    Standard error                 =    0.550
                    Mean Square error              =    0.303
               Skew option                         =   WEIGHTED
               Gage base discharge                 =      0.0
               User supplied high outlier threshold =   --
               User supplied low outlier criterion  =   --
               Plotting position parameter         =     0.00


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********

    WCF134I-NO SYSTEMATIC PEAKS WERE BELOW GAGE BASE.                  0.0
    WCF198I-LOW OUTLIERS BELOW FLOOD BASE WERE DROPPED.       1      149.1
    WCF163I-NO HIGH OUTLIERS OR HISTORIC PEAKS EXCEEDED HHBASE.     2386.6
1


  Program PeakFq          U. S. GEOLOGICAL SURVEY            Seq.001.002
  Ver. 5.2            Annual peak flow frequency analysis    Run Date / Time
  11/01/2007          following Bulletin 17-B Guidelines     11/09/2009 16:05
```

CLARK FORK NEAR GALEN EXTENDED REVISED.PRT

Station - 12323800 Clark Fork near Galen MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	FLOOD BASE		LOGARITHMIC		
	DISCHARGE	EXCEEDANCE PROBABILITY	MEAN	STANDARD DEVIATION	SKEW
SYSTEMATIC RECORD	0.0	1.0000	2.7897	0.2123	-0.845
BULL.17B ESTIMATE	149.1	0.9861	2.7945	0.2024	-0.531

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	'EXPECTED PROBABILITY' ESTIMATE	95-PCT CONFIDENCE LIMITS FOR BULL. 17B ESTIMATES LOWER	UPPER
0.9950	--	119.7	--	--	--
0.9900	--	147.8	--	--	--
0.9500	271.6	249.7	266.2	230.5	310.0
0.9000	336.0	320.4	332.0	292.7	376.6
0.8000	428.0	421.9	425.6	382.4	472.2
0.6667	528.5	531.4	527.3	479.5	578.8
0.5000	649.2	659.5	649.2	592.9	711.9
0.4292	703.7	715.9	704.2	642.9	774.0
0.2000	928.8	935.9	932.8	841.0	1042.0
0.1000	1096.0	1085.0	1104.0	981.5	1250.0
0.0400	1286.0	1239.0	1302.0	1138.0	1496.0
0.0200	1415.0	1334.0	1438.0	1241.0	1665.0
0.0100	1533.0	1414.0	1564.0	1334.0	1823.0
0.0050	1642.0	1483.0	1682.0	1420.0	1972.0
0.0020	1776.0	1559.0	1828.0	1524.0	2155.0

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.003
Run Date / Time
11/09/2009 16:05

Station - 12323800 Clark Fork near Galen MT

I N P U T D A T A L I S T I N G

WATER YEAR	DISCHARGE	CODES	WATER YEAR	DISCHARGE	CODES
1989	737.0		1954	700.0	
1990	374.0		1955	578.0	
1991	795.0		1956	853.0	
1992	150.0		1957	701.0	
1993	581.0		1958	853.0	
1994	428.0		1959	612.0	
1995	1120.0		1960	588.0	
1996	926.0		1961	605.0	
1997	1240.0		1962	543.0	
1998	545.0		1963	642.0	
1999	610.0		1964	805.0	

2000	145.0	1965	963.0
2001	224.0	1966	367.0
2002	324.0	1967	680.0
2003	912.0	1968	530.0
2004	213.0	1969	572.0
2005	571.0	1970	846.0
2006	528.0	1971	666.0
2007	605.0	1972	1108.0
2008	787.0	1973	391.0
1938	696.0	1974	1170.0
1939	433.0	1975	819.0
1940	284.0	1976	653.0
1941	344.0	1977	354.0
1942	874.0	1978	881.0
1943	853.0	1979	516.0
1944	401.0	1980	1077.0
1945	391.0	1981	1514.0
1946	333.0	1982	933.0
1947	915.0	1983	789.0
1948	950.0	1984	1088.0
1949	701.0	1985	402.0
1950	936.0	1986	1287.0
1951	826.0	1987	386.0
1952	621.0	1988	356.0
1953	998.0	2009	1000.0

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq
Ver. 5.2
11/01/2007

U. S. GEOLOGICAL SURVEY
Annual peak flow frequency analysis
following Bulletin 17-B Guidelines

Seq.001.004
Run Date / Time
11/09/2009 16:05

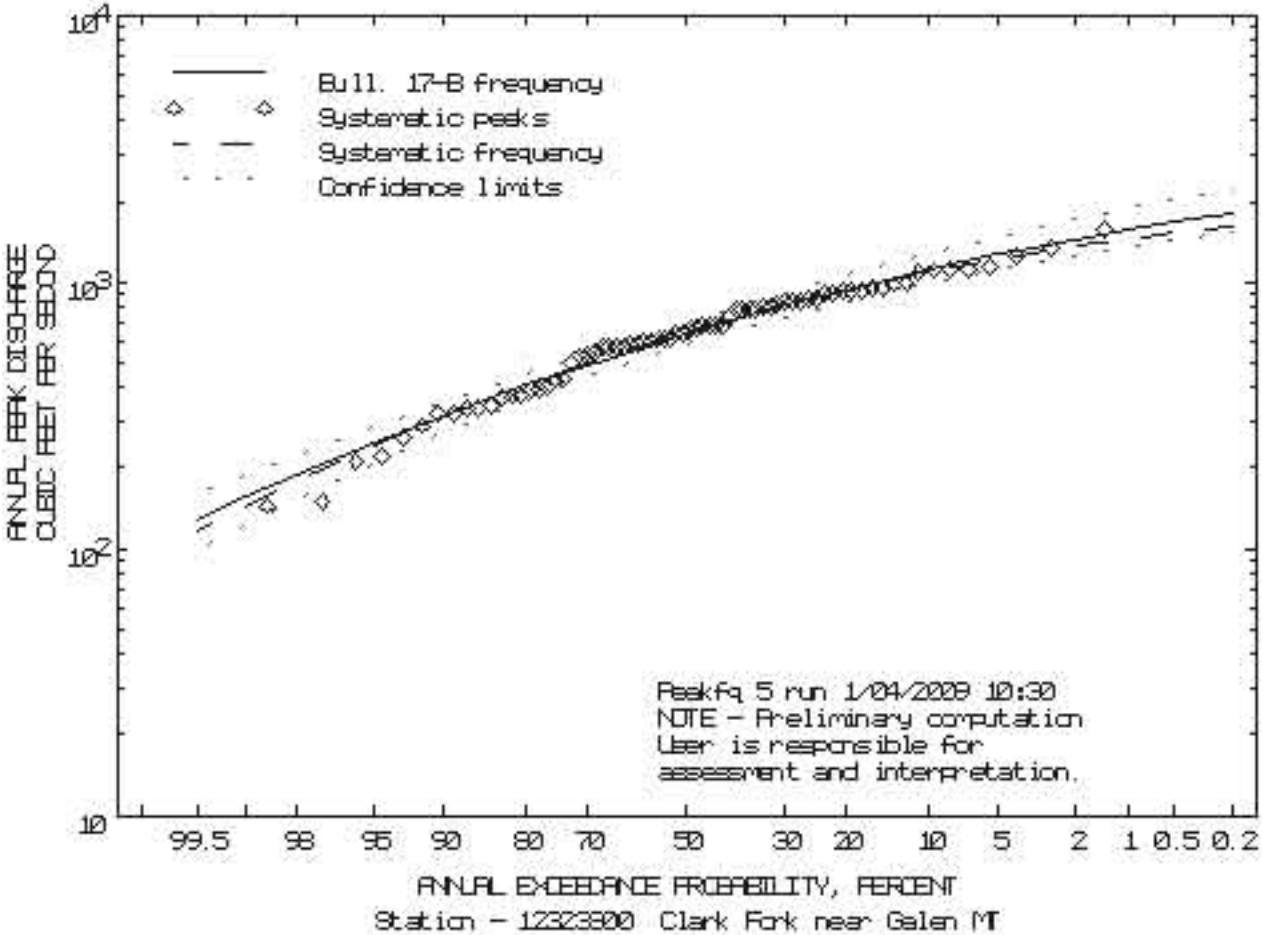
Station - 12323800 Clark Fork near Galen MT

EMPIRICAL FREQUENCY CURVES -- WEIBULL PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	SYSTEMATIC RECORD	BULL.17B ESTIMATE
1981	1514.0	0.0137	0.0137
1986	1287.0	0.0274	0.0274
1997	1240.0	0.0411	0.0411

1974	1170.0	0.0548	0.0548
1995	1120.0	0.0685	0.0685
1972	1108.0	0.0822	0.0822
1984	1088.0	0.0959	0.0959
1980	1077.0	0.1096	0.1096
2009	1000.0	0.1233	0.1233
1953	998.0	0.1370	0.1370
1965	963.0	0.1507	0.1507
1948	950.0	0.1644	0.1644
1950	936.0	0.1781	0.1781
1982	933.0	0.1918	0.1918
1996	926.0	0.2055	0.2055
1947	915.0	0.2192	0.2192
2003	912.0	0.2329	0.2329
1978	881.0	0.2466	0.2466
1942	874.0	0.2603	0.2603
1943	853.0	0.2740	0.2740
1956	853.0	0.2877	0.2877
1958	853.0	0.3014	0.3014
1970	846.0	0.3151	0.3151
1951	826.0	0.3288	0.3288
1975	819.0	0.3425	0.3425
1964	805.0	0.3562	0.3562
1991	795.0	0.3699	0.3699
1983	789.0	0.3836	0.3836
2008	787.0	0.3973	0.3973
1989	737.0	0.4110	0.4110
1949	701.0	0.4247	0.4247
1957	701.0	0.4384	0.4384
1954	700.0	0.4521	0.4521
1938	696.0	0.4658	0.4658
1967	680.0	0.4795	0.4795
1971	666.0	0.4932	0.4932
1976	653.0	0.5068	0.5068
1963	642.0	0.5205	0.5205
1952	621.0	0.5342	0.5342
1959	612.0	0.5479	0.5479
1999	610.0	0.5616	0.5616
2007	605.0	0.5753	0.5753
1961	605.0	0.5890	0.5890
1960	588.0	0.6027	0.6027
1993	581.0	0.6164	0.6164
1955	578.0	0.6301	0.6301
1969	572.0	0.6438	0.6438
2005	571.0	0.6575	0.6575
1998	545.0	0.6712	0.6712
1962	543.0	0.6849	0.6849
1968	530.0	0.6986	0.6986
2006	528.0	0.7123	0.7123
1979	516.0	0.7260	0.7260
1939	433.0	0.7397	0.7397
1994	428.0	0.7534	0.7534
1985	402.0	0.7671	0.7671
1944	401.0	0.7808	0.7808
1945	391.0	0.7945	0.7945
1973	391.0	0.8082	0.8082
1987	386.0	0.8219	0.8219
1990	374.0	0.8356	0.8356
1966	367.0	0.8493	0.8493
1988	356.0	0.8630	0.8630
1977	354.0	0.8767	0.8767
1941	344.0	0.8904	0.8904
1946	333.0	0.9041	0.9041

```
      2002          324.0         0.9178         0.9178
      1940          284.0         0.9315         0.9315
      2001          224.0         0.9452         0.9452
      2004          213.0         0.9589         0.9589
      1992          150.0         0.9726         0.9726
      2000          145.0         0.9863         0.9863
1


 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      72


Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  12323800       USGS Clark Fork near Galen MT


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```


Bull. 17-B frequency
Systematic peaks
Systematic frequency
Confidence limits
ANNUAL PEAK DISCHARGE
CUBIC FEET PER SECOND
10^4
10^3
10^2
10
99.5 98 95 90 80 70 50 30 20 10 5 2 1 0.5 0.2
ANNUAL EXCEEDANCE PROBABILITY, PERCENT
Peakfq 5 run 1/04/2009 10:30
NOTE - Preliminary computation
User is responsible for
assessment and interpretation.
Station - 12323800 Clark Fork near Galen MT

Appendix D - Cross-section Locations and Inundation Mapping

Clark Fork River
10-year Flood Inundation Map
Phase 1 Investigation
South Portion

Figure D-1
Plate 1

Scale of Feet
0 187.5375 750 1,125 1,500
1 in = 400 feet

N

CDM

Z:\gis\Public\Clark Fork\MXD\Phase1_10yr_results_pt1.mxd

Clark Fork River
10-year Flood Inundation Map
Phase 1 Investigation
North Portion

Figure D-1
Plate 2

Scale of Feet
0 187.5 375 750 1,125 1,500
1 in = 400 feet

N

CDM

Z:\gis\Public\Clark Fork\MXD\Phase1_10yr_results_pt2.mxd

Clark Fork River
100-year Flood Inundation Map
Phase 1 Investigation
South Portion

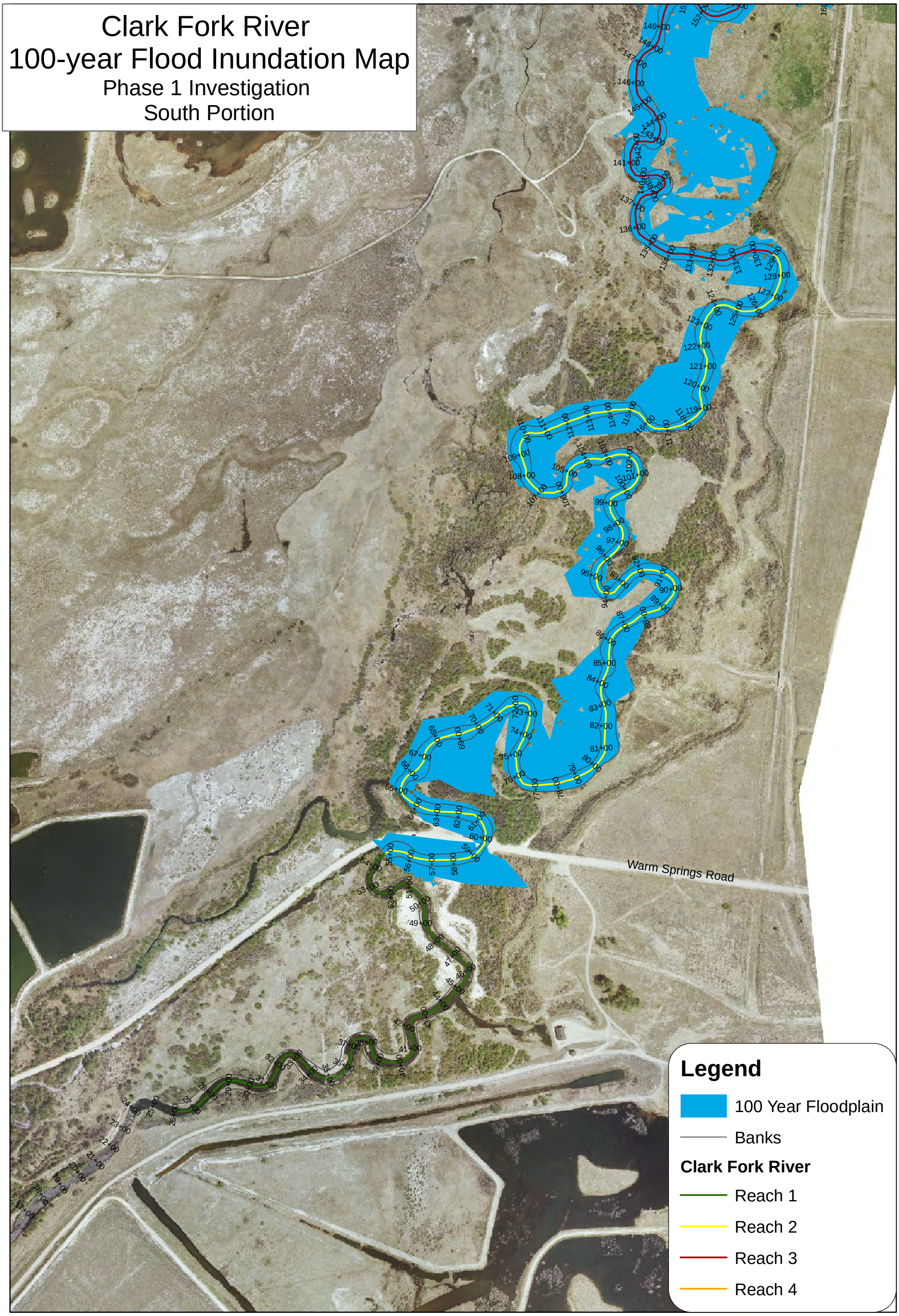


Figure D-2
Plate 1

Scale of Feet
0 187.5 375 750 1,125 1,500
1 in = 400 feet

N

CDM

Z:\gis\Public\Clark Fork\MXD\Phase1_100yr_results_pt1.mxd

Clark Fork River
100-year Flood Inundation Map
Phase 1 Investigation
North Portion

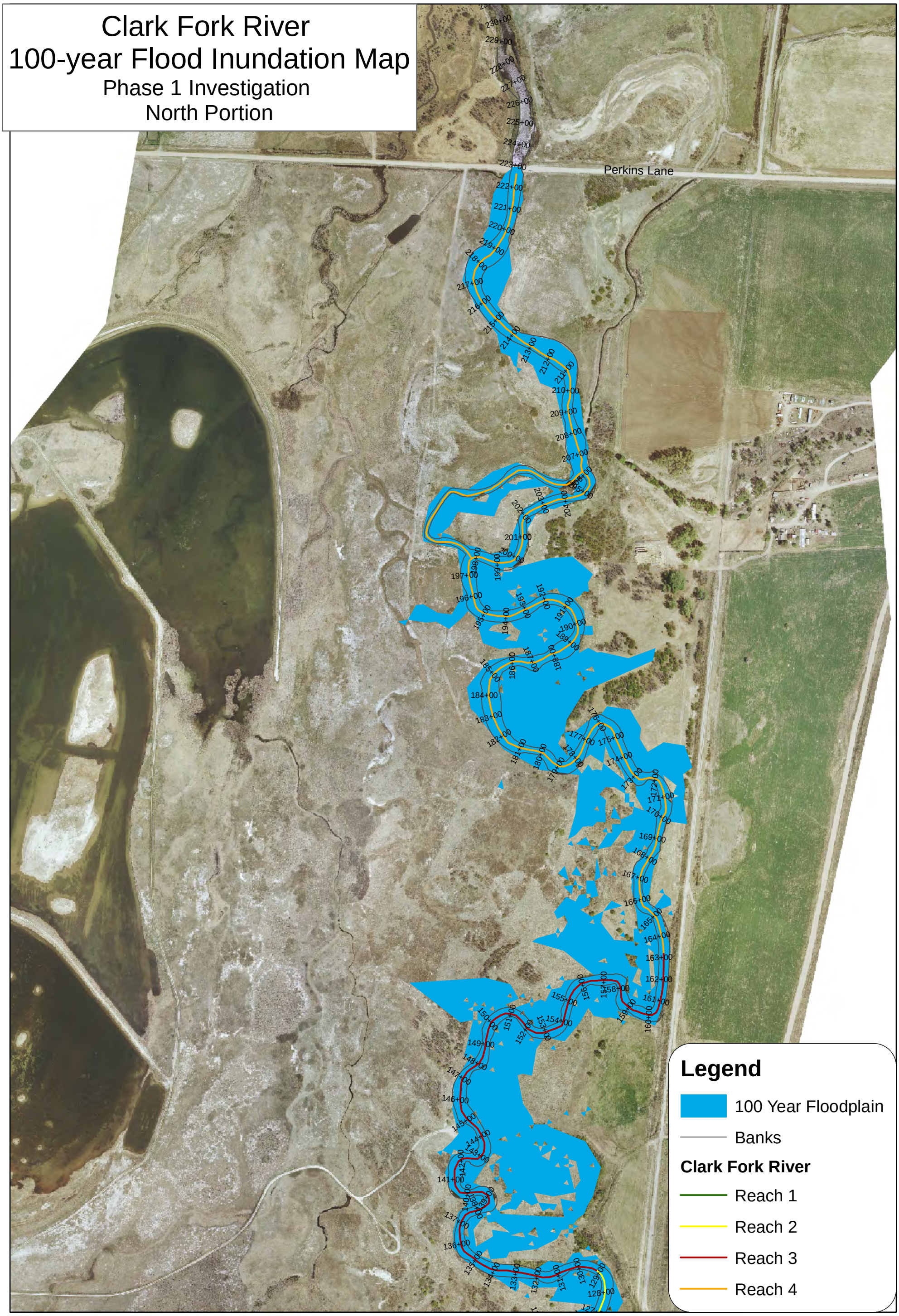


Figure D-2
Plate 2

Scale of Feet
0 187.5 375 750 1,125 1,500

1 in = 400 feet

N

CDM

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Clark Fork River
HEC-RAS Cross-sections
Phase 1 Investigation
South Portion

Figure D-3
Plate 1

Scale of Feet
0 187.5 375 750 1,125 1,500

1 in = 400 feet

N

CDM

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Clark Fork River
HEC-RAS Cross-sections
Phase 1 Investigation
North Portion

Figure D-3
Plate 2

Scale of Feet
0 187.5 375 750 1,125 1,500
1 in = 400 feet

N

CDM

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Appendix E - Test Pit Locations, Test Pit Data File, Toe Material Gradations

Clark Fork River
Streambank Test Pit Locations
Phase 1 Investigation

Sources: Land ownership information from the Montana Cadastral database, January 2009.
Downloaded from the Montana State Library, Natural Resource Information System, http://nris.mt.gov/.
Aerial Photography, Streambank Treatments and 2' contours from CH2MHill, 2008.

0 250 500 1,000
Scale of Feet

1 inch = 400 feet

N

CDM

Z:\gis\Public\Milltown\MXD\Mile_1_4_pt_testpits_11x17.mxd

Clark Fork River, Reach A, Phase 1
Streambank Test Pits

PointID	Easting	Northing	Elevation	Pit	DTW	DTWFlag	USCS Class	Bank Toe Interval
2070	1139598.75	722399.62	4801.29	503	63		GP	66-90
2071	1139854.58	722461.25	4800.72	505		Estimated 70	Not Observed	caliche at 67
2072	1139930.11	722545.91	4799.19	507		Estimated 64	Not Observed	caliche at 60
2073	1140010.71	722603.31	4799.00	508	60		Not Observed	
2074	1140144.51	722507.68	4799.42	510	68		Not Observed	
2075	1140217.22	722511.33	4798.71	511	60		Not Observed	
2076	1140254.91	722626.16	4797.01	512	74		GP	84-108
2077	1140417.44	722622.23	4794.73	513	66		GP	
3014	1140855.3	723001.77	4794.04	516	54		SP	72-96
2000	1140786.37	722989.11	4792.19	517	48		SP	50-66
2002	1140628.26	723117.68	4795.07	518	54		SW	60-72
2004	1140594.46	723244.73	4794.30	519	60		SP	72-84
3018	1140667.84	723264.26	4794.59	520	60		GW	66-90
2083	1140364.58	723314.34	4792.34	521	48		GP	48-66
3044	1140128.41	723277.78	4795.21	522	50		GP	
2085	1140260.87	723391.52	4792.14	523	52		GP	50-60
3023	1140484.01	723464.46	4792.51	524	48		GW	66-90
3019	1140634.28	723426.39	4793.08	525	48		SP	66-90
3021	1140763.45	723433.63	4792.26	526	60		GW	66-90
4015	1140650.32	723879.03	4789.66	527	43		GP	48-72
4014	1140704.06	723988.94	4790.22	528	49		SW	66-72
4011	1141012.83	724125.73	4789.31	529	42		GP	54-72
4009	1141039.02	724013.24	4789.07	530	60		SW	60-84
4007	1141016.83	723882.67	4789.41	531	60		GP	72-76
2066	1141511.37	723964.93	4789.92	532	72		GW	72-96
2236	1141425.59	724128.61	4787.65	533	51		GP	60-72
2091	1141819.5	724740.58	4786.50	534	58		SM	66-80
2246	1141506.64	724653.31	4786.03	536	54		GP	66-90
2115	1141501.71	724846.04	4784.74	537	48		Not Observed	Hand Excavated
2189	1141485.41	725012.95	4784.67	538	48		SP	66-84 (GP at 80)
2110	1141561.79	725130.31	4784.53	539	54		SM	60-80
2186	1141520.65	725299.55	4783.82	540	54		Not Observed	
2184	1141378.1	725267.56	4784.13	541	54		Not Observed	
2126	1141356.61	725336.87	4783.59	542	60		GW	66-90
2182	1141193.93	725119.95	4782.62	543	36		GP	48-72
2127	1141124.09	725364.11	4782.22	544	48		Not Observed	
2178	1141152.37	725472.59	4782.18	545	42		SP	54-78
2121	1141452.46	725485.45	4782.29	546	48		GW	60-72
2118	1141586.37	725492.53	4781.39	547	48		Not Observed	
2205	1141808.83	725497.35	4781.37	548	45		GP	>36
2137	1141945.67	725570.37	4781.49	549	50		SW	48-72
2110	1141561.79	725130.31	4784.53	550	69		GP	63-72

Notes: Data Provided by Tetra Tech, December 2009.
DTW- Depth to Water
Northing Easting and Elevation are State Plane Coordinates, NAD 83, NAVD 1988 in feet.
Depth to water and bank toe interval are in inches.

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE 1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	1
SAMPLE SOURCE:	TEST PIT 015224860	**DATE SAMPLED:**	8/27/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	93
2 in / 50mm	86
1 1/2 in / 37.5mm	79
1 in / 25 mm	69
3/4 in / 19 mm	63
1/2 in / 12.5 mm	54
3/8 in / 9.5 mm	49
#4, 4.75mm	40
#8, 2.36mm	36
#10, 2.00mm	35
#16, 1.18mm	31
#30, 0.60mm	29
#40, .425mm	27
#50, .300mm	25
#100, .150mm	19
#200, .075mm	15

NOTES:

Reviewed by: _____

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	2
SAMPLE SOURCE:	TEST PIT 015137296	**DATE SAMPLED:**	8/31/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	100
2 in / 50mm	94
1 1/2 in / 37.5mm	91
1 in / 25 mm	83
3/4 in / 19 mm	79
1/2 in / 12.5 mm	73
3/8 in / 9.5 mm	69
#4, 4.75mm	61
#8, 2.36mm	55
#10, 2.00mm	54
#16, 1.18mm	41
#30, 0.60mm	35
#40, .425mm	29
#50, .300mm	25
#100, .150mm	18
#200, .075mm	12

NOTES:

Reviewed by: _____

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE 1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	3
SAMPLE SOURCE:	TEST PIT 015317296	**DATE SAMPLED:**	9/1/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	82
2 in / 50mm	61
1 1/2 in / 37.5mm	53
1 in / 25 mm	46
3/4 in / 19 mm	41
1/2 in / 12.5 mm	39
3/8 in / 9.5 mm	37
#4, 4.75mm	33
#8, 2.36mm	26
#10, 2.00mm	24
#16, 1.18mm	14
#30, 0.60mm	9.2
#40, .425mm	5.9
#50, .300mm	3.3
#100, .150mm	1.2
#200, .075mm	0.8

NOTES:

Reviewed by: _____

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE 1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	4
SAMPLE SOURCE:	TEST PIT 015494872	**DATE SAMPLED:**	9/10/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	90
2 in / 50mm	84
1 1/2 in / 37.5mm	76
1 in / 25 mm	70
3/4 in / 19 mm	69
1/2 in / 12.5 mm	66
3/8 in / 9.5 mm	64
#4, 4.75mm	54
#8, 2.36mm	41
#10, 2.00mm	37
#16, 1.18mm	21
#30, 0.60mm	19
#40, .425mm	17
#50, .300mm	15
#100, .150mm	12
#200, .075mm	8.5

NOTES:

Reviewed by: _____

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE 1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	5
SAMPLE SOURCE:	TEST PIT 015336069	**DATE SAMPLED:**	9/21/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	97
2 in / 50mm	85
1 1/2 in / 37.5mm	71
1 in / 25 mm	57
3/4 in / 19 mm	49
1/2 in / 12.5 mm	40
3/8 in / 9.5 mm	36
#4, 4.75mm	29
#8, 2.36mm	23
#10, 2.00mm	21
#16, 1.18mm	14
#30, 0.60mm	11
#40, .425mm	9.5
#50, .300mm	7.3
#100, .150mm	3.8
#200, .075mm	2.1

NOTES:

Reviewed by: _____

TETRA TECH

PROJECT:	CLARK FORK RIVER, REACH A, PHASE 1	**PROJECT NO:**	114-560156-200
LOCATION:	WARM SPRINGS, MONTANA	**WORK ORDER NO:**	1
MATERIAL:	BULK SAMPLE	**LAB NO:**	6
SAMPLE SOURCE:	TEST PIT 015266690	**DATE SAMPLED:**	9/24/2009

SIEVE ANALYSIS OF FINE AND COARSE AGGREGATES (ASTM C136/C117)

SIEVE SIZE	% PASSING
6 in / 152mm	100
4 in / 100mm	100
3 in / 75mm	94
2 in / 50mm	84
1 1/2 in / 37.5mm	80
1 in / 25 mm	69
3/4 in / 19 mm	59
1/2 in / 12.5 mm	48
3/8 in / 9.5 mm	44
#4, 4.75mm	35
#8, 2.36mm	25
#10, 2.00mm	23
#16, 1.18mm	15
#30, 0.60mm	12
#40, .425mm	9.3
#50, .300mm	6.3
#100, .150mm	2.6
#200, .075mm	1.5

NOTES:

Reviewed by: _____