Atlantic Rim Coal Bed Methane and Natural Gas Project
Carbon County, Wyoming

February 5, 2009

Muddy Creek Monitoring Report - 2008

Muddy Creek Monitoring Report 2008

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Carbon County, Wyoming

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Executive Summary

This monitoring report presents data developed or collected on upper Muddy Creek in the Atlantic Rim area in 2008. Camp, Dresser, and McKee, Inc., (CDM) is under contract with Anadarko to provide annual monitoring for geomorphology, aquatic habitat, and water quality on this project. The Atlantic Rim Coal Bed Methane and Natural Gas Project in Carbon County, Wyoming is a coal bed methane and natural gas project being developed on public and private land by Anadarko and other operators. A particular concern on upper Muddy Creek is the maintenance of populations of non-game, native fish species, particularly the roundtail chub, bluehead sucker, and flannelmouth sucker (BLM, 2006). The general goal of monitoring on upper Muddy Creek is to determine if activities associated with the Atlantic Rim Project have an impact on upper Muddy Creek that adversely affects the non-game, native fish population.

Monitoring objectives for upper Muddy Creek have been developed based on the performance goals in the Record of Decision (BLM, 2006) for the Atlantic Rim Coal Bed Methane and Natural Gas Project. The performance goal for sensitive fish species is to "maintain adequate water quality, water quantity, species distribution, and aquatic habitat components." To determine if the Atlantic Rim Project has adverse impacts on the sensitive fish populations in the stream, a multi-parameter approach that encompasses geomorphology, hydrology, habitat features and water quality is recommended. All of these disciplines relate to sediment transport in the system, which is key to the health of the benthic macroinvertebrate populations and fish that feed on them. The objectives of this monitoring effort include:

- Measurement of sediment delivery from eroding streambanks.
- Measurement of habitat features and stream morphology.
- Measurement of in-stream sediment concentrations and other water quality parameters.

The monitoring effort in 2008 for upper Muddy Creek included an initial watershed assessment based on existing information, which summarized geology and soils, vegetation, climate, hydrology, expected runoff, geomorphology, and water quality.

The hydrology and expected runoff analysis for the upper Muddy Creek drainage investigated two natural gas development scenarios as well as the undeveloped condition. Among other findings, the runoff from a 2-year, 1-hour rain event in the basis is expected to produce a flow of about five cfs in upper Muddy Creek under either the developed or undeveloped scenarios. The difference between the two scenarios is only about 0.2 cfs. This follows from the relatively small expected difference in site averaged curve numbers (a measure of the ability of a soil to produce runoff), which vary from 82.33 in the undeveloped scenario to 82.47 in the most intense development scenario. This small difference in expected runoff flows within upper Muddy Creek under the developed and undeveloped scenarios suggests that development related sediment from runoff processes is manageable. If stormwater control Best Management Practices are used to capture sediment from development disturbed areas within the upper Muddy Creek drainage, there should not be a significant increase in sediment load from runoff processes.

It is apparent from visual inspection of the site that the Muddy Creek has incised its channel in the project area up to 15 feet within silt loam sediments, which are very erosive materials. The stream is prone to incision and channel degradation as demonstrated by the need for the Webber drop structure located about two-miles downstream of the project boundary. This structure prevents upstream migration of a headcut with a height of about 20 feet. The apparent lateral stability of the stream is related to its incised condition and steep banks, which although easily eroded are high enough that lateral erosion progresses relatively slowly.

Field work in August 2008 included a geomorphic stream survey and water quality sampling. The geomorphic stream survey followed Rosgen Level II survey procedures (Rosgen, 1994), which indicated the stream was generally a B6c type stream in an unstable and transitory state. The apparent difficulty in classifying this stream unambiguously probably stems from its evolutionary state. This channel is probably continuing to evolve and has not reached a stable configuration. In the past, downcutting has led to incised channels with many near-vertical banks. The future evolutionary path of the stream is not known at this time, but it might reasonably be expected to progess in one of two directions. The stream could continue to downcut resulting in an even more incised channel and higher banks. Alternatively, the stream may have achieved a more stable vertical profile with less downcutting expected in the future. If this is the case, it is expected that the meander bends will erode the banks further, leading to gradual widening of the channel and overbank areas and establishment of a new floodplain. Eventually, these changes should lead to a more stable geomorphic state, but the expected time frame is long because of the height of the banks and the quantity of sediment that must be moved is large.

Bed measurements were taken using Wolman pebble count methods (Wolman, 1954) and embeddedness measurements (Sennatt et al, 2006). The embeddedness measurements did not appear to have much utility as they were either zero in the riffles or 100% in the pools. **We recommend that embeddedness measurements be discontinued in future monitoring**. Bank stability was evaluated using the Bank Erosion Hazard Index and Near Bank Stress metrics developed by Rosgen (1994). Erosion pins were placed in banks at reference sections to aid future measurements of bank erosion rates.

There are a number of high (greater than 10 feet), vertical banks on the outside of bends in the study sites that show signs of recent collapse. However, the lateral rate of stream movement is not great, and the meander bends are remaining in the same approximate locations and not being cut off. This appears to be due to the large amount of sediment that is contained in the high banks and the inability of the stream to transport this sediment. Often water depths on bends, where one would expect to find a deeper pool, are rather shallow as the stream transport capacity is insufficient to transport the collapsed bank sediments downstream. The frequently observed silt deposits both in channel and on the overbanks are also indicators that the stream transport capacity is generally insufficient to deliver sediment downstream. This imbalance between sediment yield and sediment transport capacity serves to slow the rate of evolution of this stream towards a more stable configuration. This excess of sediment has probably caused the benthic macroinvertebrate populations in Muddy Creek to shift to a few species tolerant of degraded conditions, and the long-term health of benthic macroinvertebrate populations may be at risk from the predevelopment imbalance between sediment yield and transport.

Water quality of upper Muddy Creek at the low flow range (1.5 to 2.3 cfs) observed in August 2008 is unremarkable for this physiographic setting. Common ions of this mixed-ion water were within expected ranges, and total suspended sediment concentrations were reasonably low (about 10 mg/L). Total selenium was 0.002 mg/L or less, well below the chronic aquatic life standard. This water quality is similar to water quality observed by others at the upstream Bridger Pass Station in previous years.

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Section 1 Introduction

This monitoring report presents data developed or collected on upper Muddy Creek in the Atlantic Rim area in 2008. Camp, Dresser, and McKee, Inc., (CDM) is under contract with Anadarko to provide annual monitoring for geomorphology, aquatic habitat, and water quality on this project. The Atlantic Rim Coal Bed Methane and Natural Gas Project in Carbon County, Wyoming is a coal bed methane and natural gas project being developed on public and private land by Anadarko and other operators (Figure 1-1). Development is occurring in a 270,080 acre area and requires construction of roads, pipelines, well pads, compressor stations and gas processing facilities, drilling 2,000 wells, and production of water (BLM, 2006). The portion of the upper Muddy Creek drainage where development will take place is shown in Figure 2-1. A particular concern on upper Muddy Creek is the maintenance of populations of non-game, native fish species, particularly the roundtail chub, bluehead sucker, and flannelmouth sucker (BLM, 2006). The general goal of monitoring on upper Muddy Creek is to determine if activities associated with the Atlantic Rim Project have an impact on upper Muddy Creek that adversely affects the non-game, native fish population. The potential adverse effects caused by development will need to be compared to potential impacts due to other factors such as recreation and livestock grazing.

1.1 Background

The Atlantic Rim Coal Bed Methane and Natural Gas Project was proposed by Anadarko and other operators in 2001. The responsible agency for permitting the development is the Bureau of Land Management (BLM), which initiated scoping for an Environmental Impact Statement (EIS) in 2001. The Record of Decision (BLM, 2006) for the project was signed in 2007 and includes specific performance goals for the project. The performance goal for Muddy Creek sensitive fish is to "maintain adequate water quality, water quantity, species distribution, and aquatic habitat components." This is to be accomplished through use of Best Management Practices (BMPs), performance-based monitoring, and adaptive management. The monitoring program currently in place addresses activities that will take place on upper Muddy Creek.

1.2 Project Organization

Monitoring of upper Muddy Creek described in this plan is the responsibility of Anadarko and its consultant. Additional monitoring tasks are being conducted on upper Muddy Creek as well as on lower Muddy Creek and Muddy Creek tributaries by various agencies. Water quality data is collected throughout the Muddy Creek drainage by the Little Snake River Conservation District (LSRCD) as it has been in the past. The LSRCD also measures flows at these stations. The Wyoming Game and Fish Department (WGFD) is continuing fish distribution and population studies in the drainage as well. The BLM as the lead agency for the Atlantic Rim Coal Bed Methane and Natural Gas Development Project coordinates the various monitoring efforts through the Muddy Creek Working Group.

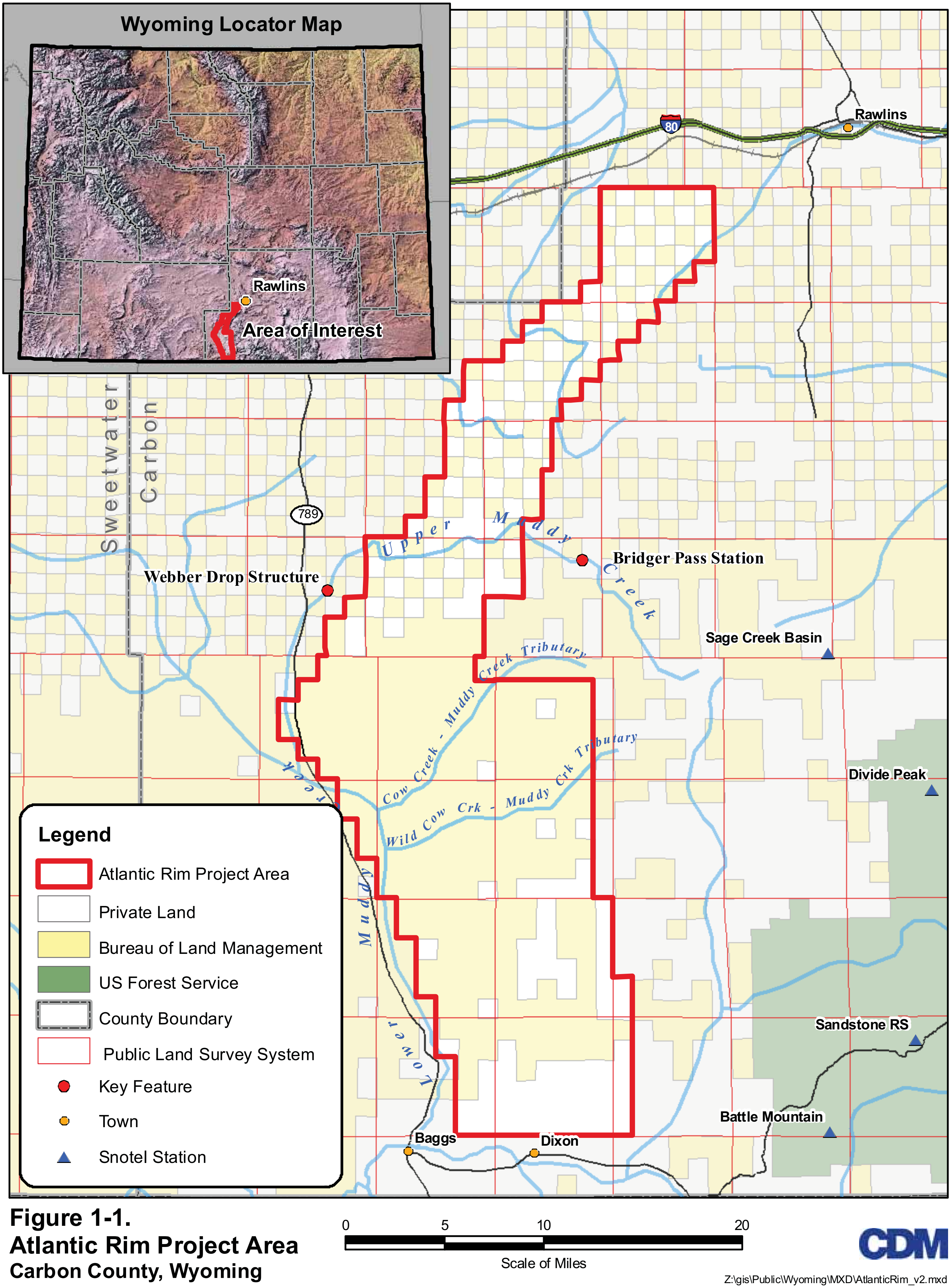

Figure 1-1.
Atlantic Rim Project Area
Carbon County, Wyoming

1.3 Monitoring Objectives

A monitoring plan for Muddy Creek was developed by CDM for the Muddy Creek Working Group in 2008 to guide annual monitoring activities on upper Muddy Creek. The Record of Decision (BLM, 2006) for the Atlantic Rim Coal Bed Methane and Natural Gas Project has specific performance goals including one for Muddy Creek sensitive fish species. The requirement is to "maintain adequate water quality, water quantity, species distribution, and aquatic habitat components." The primary concerns with development activities within upper Muddy Creek are the modification of flow regimes, potential increase in sediment delivery and transport, and potential impacts on channel stability and water quality. Increases in stream sediment load could adversely affect sensitive fish populations and distribution. Aquatic habitat and riparian habitat could also be degraded or lost.

To determine if the Atlantic Rim Project has adverse impacts on the sensitive fish populations in the stream, a multi-parameter approach that encompasses geomorphology, hydrology, habitat features and water quality is recommended. All of these disciplines relate to sediment transport in the system, which is key to the health of the benthic macroinvertebrate populations and fish that feed on them. The objectives of this monitoring effort include:

- Measurement of sediment delivery from eroding streambanks.
- Measurement of habitat features and stream morphology.
- Measurement of in-stream sediment concentrations and other water quality parameters.

This monitoring plan focuses on upper Muddy Creek within or near the project boundaries because this segment of Muddy Creek could potentially be directly affected by coal bed methane and natural gas development. This segment of Muddy Creek is also the best documented location of the sensitive fish species.

1.4 Report Organization

This is the first annual report of monitoring activities conducted by Anadarko on the Atlantic Rim Coal Bed Methane and Natural Gas Project. In addition to presenting the results of the monitoring event for 2008, this report includes a general watershed assessment, which is found in Section 2. Section 3 presents the results of the geomorphic and aquatic habitat monitoring, and Section 4 presents the water quality monitoring results. Appendices A through G present the data developed or collected in 2008 as part of this assessment and monitoring effort.

The watershed assessment in Section 2 sets the scene against which the monitoring data can be evaluated. Interpretations of the watershed assessment data, which is based on existing references, are developed in this report as appropriate. In addition, geomorphic assessment data collected in 2008 are interpreted to provide a characterization of upper Muddy Creek. However, this year's monitoring data are generally not interpreted unless there are existing data from previous years that have been developed with similar methods against which 2008 data can be compared. Evaluation of most monitoring data will be conducted in future years after sufficient data have been collected to provide meaningful comparison.

Section 2 Watershed Assessment

This watershed assessment briefly describes the geologic, vegetative, climatic, hydrologic, and geomorphic conditions in the upper Muddy Creek watershed based on existing information sources. A primary source is the *Final Environmental Impact Statement for the Atlantic Rim Natural Gas Field Development Project* developed for this project by BLM (2006). Water quality data previously collected by BLM and the LSRCD is also summarized and reviewed. Figure 1-1 shows the general project area and Figure 2-1 shows the upper Muddy Creek subbasin where it intersects the project development area.

2.1 Geology and Soils

According to the EIS for the Atlantic Rim Project, parent material for soils within the project area includes:

- "The marine sandstones and shales of the Lewis formation (Upper Cretaceous);
- The largely fluvial conglomerates, sandstones, mudstones, shales, and coals of the Lance Formation (Upper Cretaceous) and Fort Union formation (Paleocene);
- The fluvial sandstones and varigated mudstones of the Wasatch Formation (Eocene); and
- The conglomerates sandstones, and volcaniclastic mudstones of the Browns Park Formation (Miocene).

Slopewash debris and alluvium derived from those units also constitute parent materials for colluvial and alluvial soils." (BLM, 2006).

Soils in the project area were surveyed and described by Texas Resource Consultants (1981) and Wells (1981). These soil surveys were conducted for the BLM in cooperation with the National Resource Conservation Service, then called the Soil Conservation Service.

In the EIS, soil factors of concern for development were identified, and soils posing these concerns were identified by hydrologic unit code boundaries. For the Muddy-Creek Alamosa Gulch drainage, water erosion and runoff potential were identified as concerns in about 90% of the subwatersheds within the project area. The potential for these two factors to increase sediment delivery to streams under development and to impact water quality, aquatic life, and riparian vegetation is a primary reason for requiring monitoring of Muddy Creek.

Observation by CDM in the field indicates that the sediments forming the banks of upper Muddy Creek are typically silt loams. These are very erosive materials as

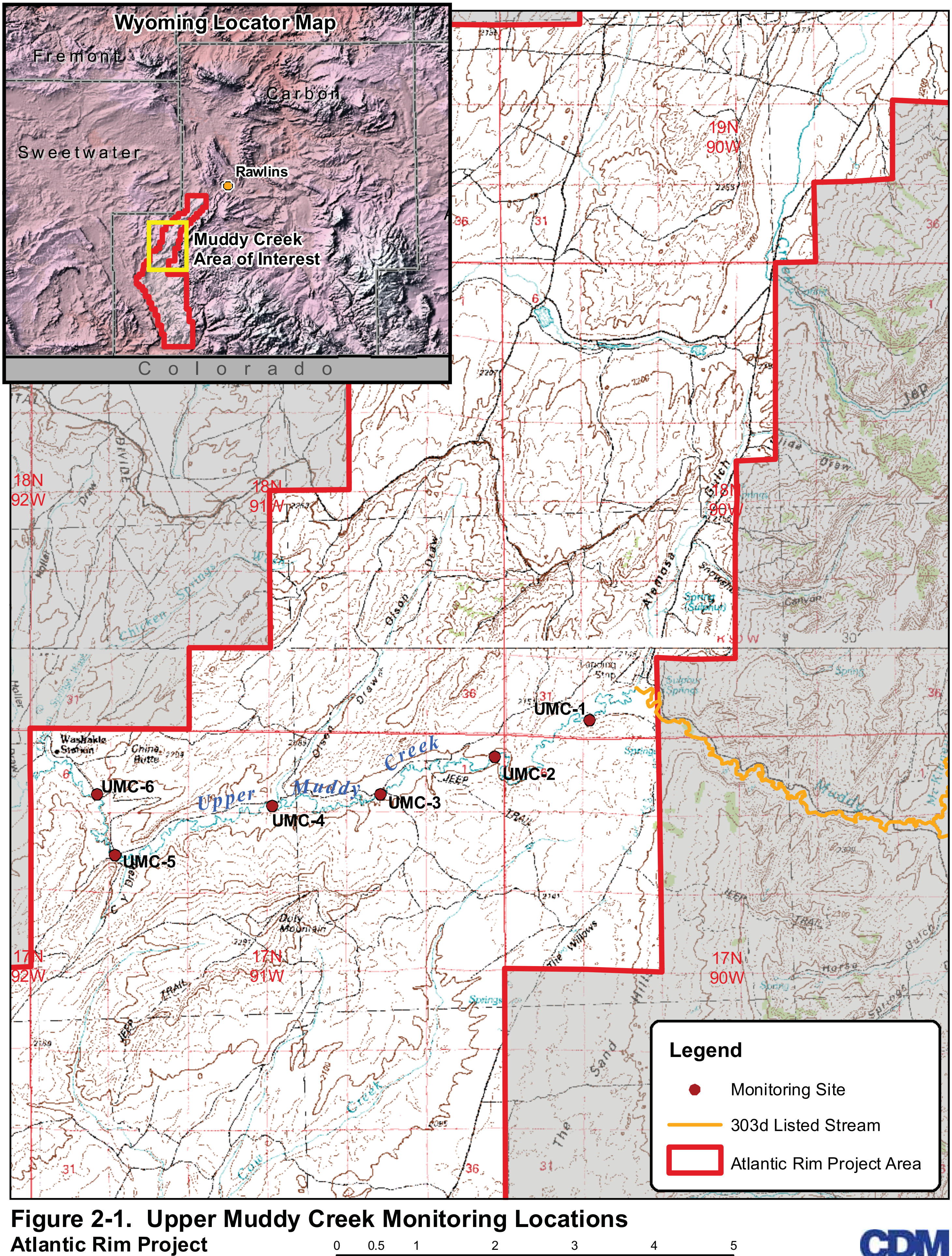

Figure 2-1. Upper Muddy Creek Monitoring Locations

Atlantic Rim Project

Carbon County, Wyoming

CDM

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documented in the soil texture values for silt loams used in the Revised Universal Soil Loss Equation (RUSLE), which indicate the highest sediment yields from silt soils (Hartman *et al*, 1992).

As an example of the erosiveness of soils consisting largely of silt, we have calculated expected sediment yields for silt slopes on a 500 foot long slope with a gradient of 5% for a vegetated as well as an unvegetated condition using the RUSLE. In a vegetative condition that may be representative of general range conditions in upper Muddy Creek (rangeland with 50% tall weed or shrub canopy and 40% ground cover), sediment yield for a 2 year, 24 hour storm would be expected to be about 0.27 tons per acre. However, if this slope is denuded, the sediment yield would be expected to be about 2.96 tons per acre, about ten times higher.

2.2 Vegetation

The project area lies within the Wyoming Basin (Level III) ecoregion and within the Rolling Sagebrush Steppe (Level IV) ecoregion (BLM, 2006). Two principle cover types dominate the vegetation in the project area, including the upper Muddy Creek watershed. These cover types are mountain big sagebrush and Wyoming big sagebrush. Tree species are rare in the project area with widely scattered juniper in the uplands and willow species along stream banks.

2.3 Climate

The project area is located in a semiarid (dry and cold), mid-continental climate regime with typically dry windy conditions, limited rainfall and long, cold winters (BLM, 2006). Meteorological measurements collected from 1979 to 2000 at Baggs, approximately 30 miles south of the project area at an elevation of 6,240 feet, are typical of lower elevations in the project region. Here the average precipitation is 10.7 inches per year with winter months being typically drier. Average daily temperatures range from 3 degrees Fahrenheit (°F) to 33°F in mid-winter and between 56°F and 75°F in mid-summer (BLM, 2006).

In the upper Muddy Creek drainage a BLM rain gage at Sulfur Springs, about three miles east of the eastern boundary of the project area, recorded a mean annual precipitation of 10.97 inches (BLM, 2006).

Data from four local National Resource Conservation Service SNOTEL sites (www.wcc.nrcs.usda.gov/snotel/Wyoming/wyoming.html) was also analyzed to provide current, detailed information on local precipitation. These stations are located in the Sierra Madre east and south of upper Muddy Creek and none is in the upper Muddy Creek drainage. Location, elevation, period of record, and precipitation information for the four sites are presented in Table 2-1.

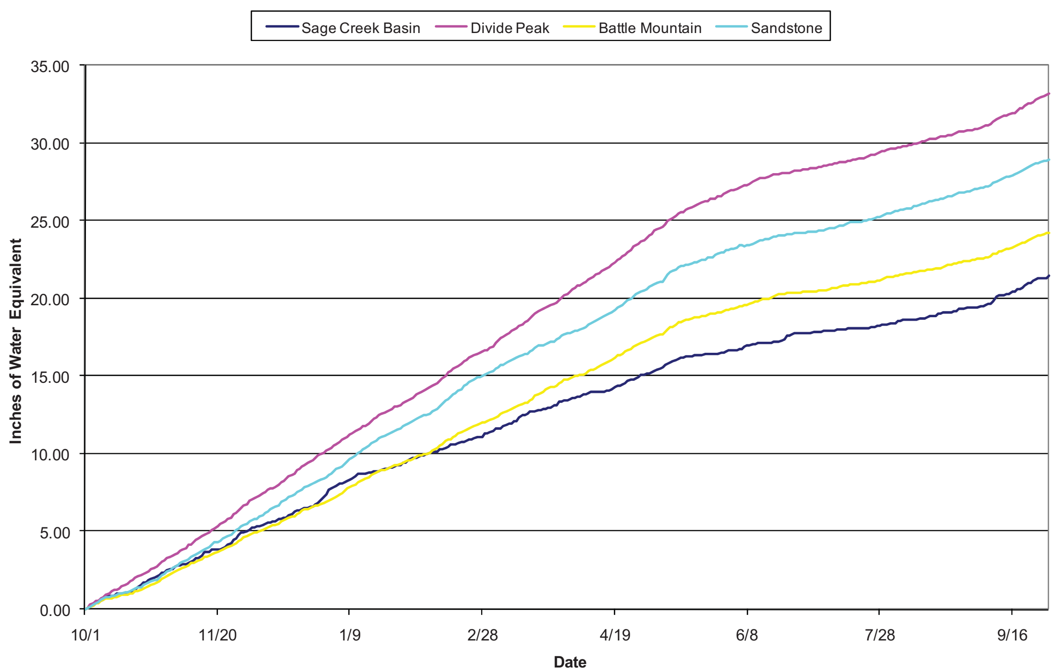
Table 2-1. SNOTEL stations selected for precipitation analysis

Station	Latitude	Longitude	Elevation (ft)	Period of Record	Mean Annual Precipitation (in.)
Battle Mountain	41°3' N	107°15' W	7,440	1986-2008	24.23
Sandstone RS	41°7' N	107°10' W	8,150	1986-2008	28.91
Divide Peak	41°18' N	107°9' W	8,880	1997-2008	33.18
Sage Creek Basin	41°24' N	107°15' W	7,850	2002-1997	21.47

Source: www.wcc.nrcs.usda.gov/snotel/Wyoming/wyoming.html

These stations have significantly higher precipitation amounts than the BLM Sulfur Springs station because they are nearer the Sierra Madre crest and at higher elevations. Although not representative of precipitation amounts likely to occur within the project area, they are probably representative of the precipitation that occurs in upper Muddy Creek above the project area. Figure 2-2 plots the mean cumulative precipitation amounts for these stations based on a water year (October through September). All stations show a somewhat decreased precipitation in the summer months and higher precipitation in other seasons.

Figure 2-2. Mean cumulative annual precipitation for selected SNOTEL sites



2.4 Hydrology

Muddy Creek is a 1,150 square mile watershed in the Colorado Basin (BLM, 2006). The stream originates on the continental divide in the Sierra Madre range and flows 106 miles to its confluence with the Little Snake River, a tributary to the Yampa River, near Baggs, Wyoming (Ellison et al, 2008). Although the U.S. Geological Survey maintains a stream gage (No. 09258980) near the confluence with Little Snake River, the lower portion of Muddy Creek is hydrologically different from the upper section, and gage information poorly represents flows on upper Muddy Creek. Upper Muddy Creek for purposes of this report is the portion above the Weber drop, a man-made drop structure located about a mile east (upstream) of the Highway 789 crossing. This stabilization structure prevents headcutting at this point and isolates the fish population of upper Muddy Creek.

Observers report that upper Muddy Creek flows intermittently through the project area in the summer months in many years. The LSRCD and BLM conducted flow measurements in conjunction with water quality monitoring in 1995, 1996 and 1997 (Hicks *et al*, 1999) and 2001, 2003 and 2004 (LSRCD, 2005). Although no continuous measurements were made within the Atlantic Rim Natural Gas Project Area, a station called "Bridger Pass" was established one-quarter of a mile below McKinney Creek, about three-miles upstream of the project area. Continuous flow data were collected at this station during the summer period in 1995, 1996, 1997, 2001, 2003 and 2004. Review of these data gives an approximate idea of the summer period hydrology of upper Muddy Creek in the project area. The hydrographs for the 2001, 2003 and 2004 summer-fall periods are presented in Appendix B.

Inspection of the hydrographs from the Bridger Pass Station flow recorder indicates two flow regimes of interest during most summers. The early season (May and June) shows flows initially as high as 68 cfs gradually decreasing to less than three cfs by late summer. The shape of this portion of the hydrograph appears to be dependent on the nature of the snow melt and spring to early summer precipitation pattern. In the late summer (mid-August through September), the base flow is generally less than three cfs with spikes up to 30 cfs that generally last less than a day or two. These spikes are presumably due to intense precipitation events such as thunderstorms that have often have relatively short durations. Table 2-2 summarizes the peak flow data for 2001, 2003, and 2004 at the Bridger Pass station for the summer to early fall period.

Table 2-2. Peak summer to early fall flows at Bridger Pass Station

Year	Date	Flow (cfs)
2001	October 10	4.2
2003	October 3	12.5
2004	September 20	29.8

Source: Little Snake River Conservation District electronic data files.

In some years late summer flows are less than one cfs, but flow has not ceased during any of the monitoring periods at this station.

2.5 Expected Runoff

In an effort to understand the potential effects of development in upper Muddy Creek on runoff, an analysis of estimated runoff under undisturbed and developed conditions was undertaken at the request of Anadarko. A memorandum providing details on the methods and analysis is attached in Appendix B. Using the Soil Conservation Service (now Natural Resource Conservation Service) curve number method, soil infiltration properties were estimated and expected runoff from relatively frequent (two year recurrence interval) storms were calculated. A GIS analysis of Natural Resource Conservation Service soil data for the area determined the hydrologic group of each soil type. Using standard NRCS guidance for range conditions (Chow, 1964, Table 21-12), curve numbers were assigned to each soil group and an average curve number (weighted by area) was developed for the upper Muddy Creek Basin. Two year recurrence storms for 1-hour, 6-hour and 24-hour durations were developed from the *Frequency Precipitation Atlas for the Western United States, Volume 2 – Wyoming* (Miller *et al*, 1973).

Table 2-3 presents results for a well density of eight per square mile with an average disturbance of 6.5 acres including rods and other non-well pad disturbance. The disturbed areas were assigned a higher curve number based on Chow (1964, Table 21-12), and the weighted average curve number recalculated.

Table 2-3. Predicted runoff amounts for undeveloped and developed project area.

		Undeveloped Scenario		Developed Scenario		
		CN =	82.33	CN =	82.47	
Event	**Precipitation**	**Runoff**	**Runoff**	**Runoff**	**Runoff**	**Percent**
2-yr. 1 hr.	0.52	0.0037	6.58	0.0041	7.24	10%
2-yr. 6 hr.	0.85	0.0690	123.21	0.0708	126.45	3%
2-yr. 24 hr.	1.2	0.2037	363.85	0.2070	369.84	2%

Note: Developed scenario assumes 8% disturbance area (6.5 acres per well)

The runoff may increase by as much as 10% after full development during short duration events because the undisturbed soils would infiltrate most of the precipitation; that is, less than 1% of the water would runoff. Thus, the small amount of disturbed area would produce a relatively large percentage increase in runoff. However, during longer duration storms, development would result in only a 2 to 3% increase in runoff because these events will create significant runoff even with undisturbed soils.

The disturbance analysis was also calculated with a lesser degree of disturbance, 4.8 acres per well pad, which reflect newer construction practices developed by Anadarko where utilities are buried in the roads resulting narrower road widths. Table 2-4 presents the results of this analysis.

Table 2-4. Predicted runoff amounts for undeveloped and developed project area – 6% disturbance.

		Undeveloped Scenario CN = 82.33		Developed Scenario CN = 82.44		
Event	**Precipitation**	**Runoff**	**Runoff**	**Runoff**	**Runoff**	**Percent**
2-yr. 1 hr.	0.52	0.0037	6.58	0.0040	7.10	8%
2-yr. 6 hr.	0.85	0.0690	123.21	0.0704	125.75	2%
2 yr. 24 hr.	1.2	0.2037	363.85	0.2063	368.55	1%

Note: Developed scenario assumes 6% disturbance area (4.8 acres per well).

This assumption on disturbance area leads to reduced runoff in the developed scenario with only 8% increase in runoff for the 1 hr. event and even smaller increases for the 6 hr. and 24 hr. events. Although this is a significant reduction in disturbance area (25%) from the previous scenario, it only results in a 2% difference in runoff volumes.

Using assumptions about the probable spatial and temporal extent of a 2-year, 1-hour event, is estimated that typical summer/early fall stream flows could in upper Muddy Creek to about five cfs under either the developed or undeveloped scenario. The difference between the two scenarios is only about 0.2 cfs.

A logical extension of this analysis would be to calibrate the runoff curve numbers for upper Muddy Creek using contemporaneous records of precipitation and stream gages. However, these types of data do not appear to be available in the project area. The three summer to early fall hydrographs at Bridger Pass Station reflect flows in the portion of Muddy Creek above the project area, and the nearest SNOTEL sites with continuous precipitation records are outside the upper Muddy Creek Basin. However, an analysis of the July through October period of the hydrographs suggests that the peak flows from these three periods (4.2 cfs, 12.5 cfs, and 29.8 cfs) may correspond approximately to the 1-year, 2-year, and 3-year recurrence interval events. If this is the case, and if the Bridger Pass Station is similar in hydrologic characteristics to the project area, a two-year local storm event could be more in the range of 12.5 cfs rather than the five cfs amount predicted by the runoff model. However, we do not know the duration of the event that caused the 12.5 cfs peak. If it had a longer duration than one hour, it could easily produce this amount of runoff with a more frequent event than 2-year event. Therefore, 12.5 cfs is probably an over estimate of the runoff produced by a 2-year, 1-hour storm.

Further information on the potential runoff model calibration can be obtained by looking at the precipitation frequency records for the two nearest SNOTEL sites. The maximum flow observed in summer/early fall at the Bridger Pass Station in 2004 was about 30 cfs on September 20th. The return periods for the corresponding precipitation event were about four-years at the Sage Creek Basin site and about 42 years at the Divide Peak site. If similar precipitation fell in the upper Muddy Creek Basin, the 30cfs peak corresponds to a storm event with a recurrence interval of at least four years, a relatively infrequent event. This suggests that 30 cfs events are relatively infrequent in the summer/early fall and a model that considers relatively frequent (2-year recurrence interval) storms should not generate this much runoff or flow, which it does not.

2.6 Geomorphology

Upper Muddy Creek within the project area is a low-gradient, meandering stream set within a wide valley flanked by hills and mountains. Upstream of the project area, upper Muddy Creek is more tightly constrained in a canyon that it has cut through the mountains that form a southern extension to the Atlantic Rim. Downstream of the project area, the Muddy Creek valley continues to broaden and flatten, eventually entering a man-made wetlands area west of Highway 789.

The elevation of Upper Muddy Creek at the downstream end of the project area is about 6,800 ft. and the elevation at the upstream end is about 6,940 ft. The stream is generally incised in deep beds of silt with relatively little sand, gravel or cobble available to form stable beds. It is apparent from visual inspection of the site that the Muddy Creek has incised its channel in the project area up to 15 feet within these sediments. The stream is prone to incision and channel degradation as demonstrated by the need for the Weber drop structure located about two-miles downstream of the project boundary. This structure prevents upstream migration of a headcut with a height of about 20 feet.

Color infrared orthophotos of the site are available for 1994 and black and white orthophotos are available for 2002 from the U.S. Geological Survey (USGS, 2002). These two photo sets were compared for the entire project area in GIS by overlaying them. Figure 2-3 is an example of the comparison in which the 2002 channel alignment has been traced and transferred to the 1994 photo. There is almost no discernable alignment change when the 2002 alignment (red line) is placed on top of the 1994 photo. Comparison of photos throughout the project area showed almost no discernable channel realignment in the eight year period. Cutoffs of meander bends would have been noted in this analysis but none were found within the project area. However, resolution of the photos is one meter and smaller realignments were not captured due to poor definition of streambanks and the water surface in some areas. The apparent lateral stability of the stream is related to its incised condition and steep banks, which although easily eroded are high enough that lateral erosion progresses relatively slowly.

2.7 Water Quality

Data collected at the LSRCD sampling station named "Bridger Pass", previously mentioned in Section 2.4, are the best representation of water quality upstream of the project area. Field parameters (temperature, pH, electrical conductivity, and dissolved oxygen) were collected hourly in the summer to fall period in 1995, 1996, and 1997 using Hydrolab instruments with data loggers (Hicks *et al*, 1999). The same field parameters were measured in 2001, 2003 and 2004 with the addition of

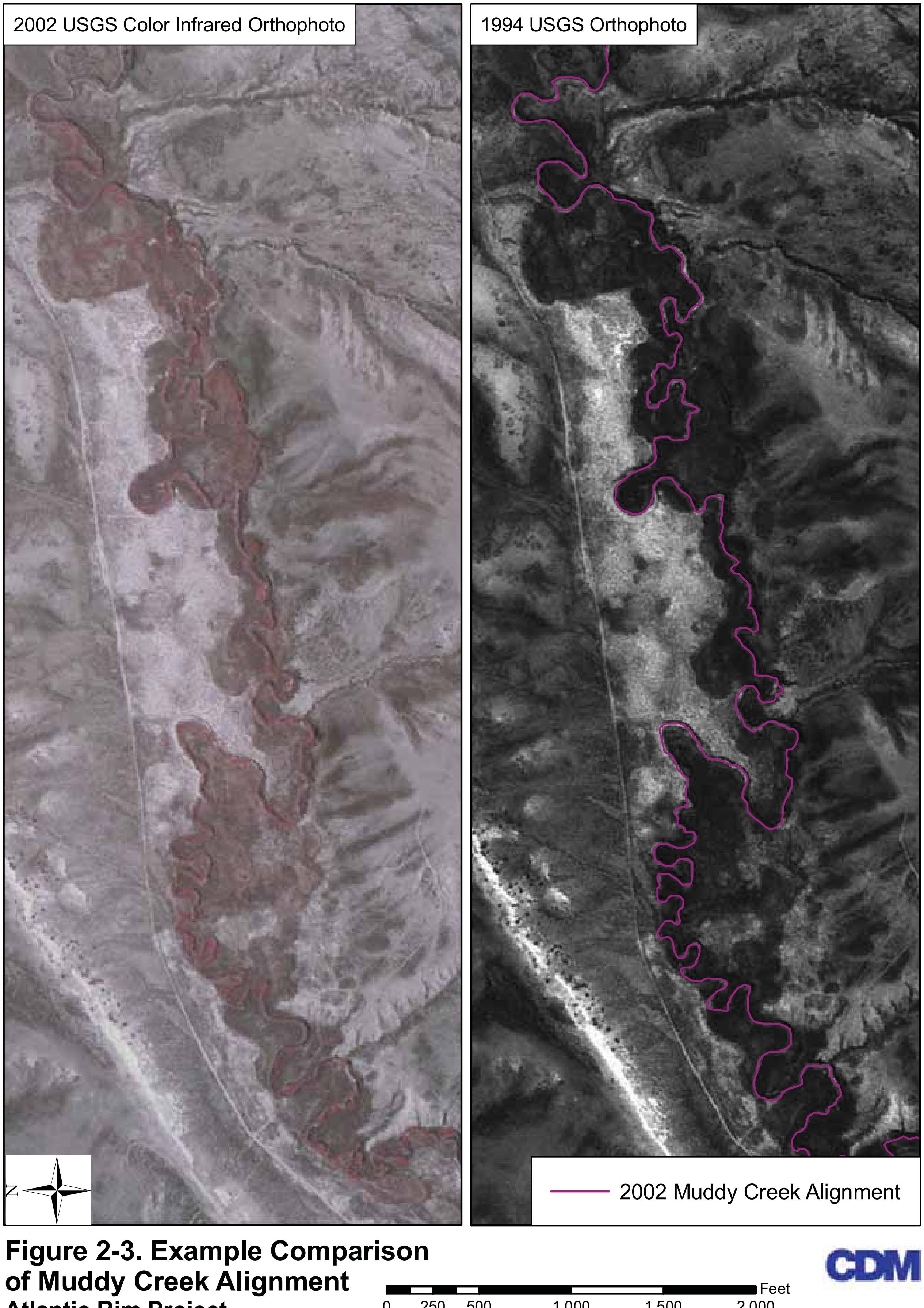


Figure 2-3. Example Comparison of Muddy Creek Alignment
Atlantic Rim Project
Carbon County, Wyoming

CDM

Z\:gis\private\Anadarko-Muddy\ortho-compare.mxd turbidity. Chemical data are available for 1999 through 2002 when one-time samples along with field parameters were collected at this station during low flow conditions (LSRCD, 2005). Table 2-3 summarizes the average values of continuously monitored field parameters for 1995 through 1997. Table 2-4 summarizes instantaneous data collected in 1999 through 2002. Table-2-5 summarizes common ion data from the grab samples collected in 1999 through 2002.

Table 2-5. Field Parameter Averages for Continuous Data – Upper Muddy Creek, Bridger Station

Year	Temp. (°C)	pH	EC (mS)	DO (mg/L)
1995	13.3	8.5	0.544	11.1
1996	13.9	8.5	0.635	9.6
1997(1)	17.3	8.4	5.18	N/A
Average	14.83	8.47	0.59(2)	10.35

Source: Hicks *et al*, 1999.

Notes: 1. Data for June and July only.
2. Excludes 1997 data because value for 1997 appears erroneous.

Table 2-6. Field Parameter Instantaneous Values – Upper Muddy Creek, Bridger Station

Date	Discharge (cfs)	Temp. (°C)	pH	EC (mS)	DO (mg/L)	Turbidity*
10/4/1999	5.56	4.51	8.43	0.67	11.66	28.3
9/20/2000	1.88	12.1	8.44	0.518	8.89	42.8
9/24/2001	2.45	8.16	8.3	0.45	8.98	25.7
9/23/2002	1.04	11	8.2	0.57	9.12	43.8
Average	2.73	8.94	8.34	0.55	9.66	35.15

*Nepholometric turbidity units (NTU)

Source: LSRCD, 2005.

Table 2-7. Common Ion Concentrations (mg/L) from Grab Samples – Upper Muddy Creek Bridger Station

Date	Ca	Mg	Na	K	CO_3	HCO_3	Cl	F	SO_4
10/4/1999	96	24	28	3.8	0	190	7.7	0.3	210
9/20/2000	60	18	20	2.5	5	130	5.2	0.2	150
9/24/2001	78	17	19	4.2	0	180	5.0	0.2	130
9/23/2002	72	17	18	4.3	0	180	5.2	0.2	150
Average	76.5	19	21.25	3.7	1.25	170	5.775	0.225	160

Source: LSRCD, 2005.

These data indicate that the water of Muddy Creek upstream of the project area has a relatively high pH (8+) typical of bicarbonate waters and a moderate concentration of dissolved constituents (EC = 0.5 to 0.6 mS corresponding to total dissolved solid approximately 300 to 400 mg/L). Oxygen levels are near or above saturation and turbidity levels are moderately high (35 NTU). Chemistry data indicate that hardness (magnesium and calcium) is relatively high (200 to 400 mg/l as $CaCO_3$) and that sulfate is an important anion.

Section 3 Geomorphic and Aquatic Habitat Assessment

3.1 2008 Monitoring Event

During the period August 18-23, Bill Bucher and Kim Chase of CDM traveled to the Rawlins, WY area to conduct monitoring and initial assessment field work in Upper Muddy Creek. Six sites in the project area were chosen previously by the Muddy Creek Working group, which includes BLM, Wyoming Game and Fish, Wyoming Department of Environmental Quality, CDM and Anadarko personnel as well as others. The locations of these sites are shown on Figure 3-1. Maps of each individual site are shown in Appendix C.

Monitoring activities performed at each site are described in the Muddy Creek Monitoring Plan (CDM, 2008). In summary, the following activities for geomorphic and aquatic habitat monitoring were performed:

- Upon arrival at a site, the area was assessed and six locations were chosen to survey cross-sections, including one section that was monumented to be re-surveyed annually. The monuments on both banks of the permanent cross section were located by a resource grade (meter accuracy) GPS receiver. Cross-section information is used to conduct a Rosgen Level II gemorphic classification and allow measurement of channel changes over time.

- Several banks representative of the site were selected for evaluation using the Bank Erosion Hazard Index (Rosgen, 1996). Each bank where BEHI was performed was photographed and located using GPS.

- Wolman pebble counts and embeddedness measurements were performed at riffles and other areas with appropriate bed material conditions.

- At each site, at least one bank erosion pin was installed and the protruding length noted.

- A survey was performed with a total station at each site establishing six cross-sections and sufficient thalweg points to define residual depth of pools. Pool areas were measured approximately using tape or rod.

At site UCM6, all field information was not collected because poor visibility in the tall grass at this site led to a close encounter with a rattlesnake. In the interest of safety, data collection was limited to information required for monitoring, and the survey data needed for geomorphic evaluation is incomplete.

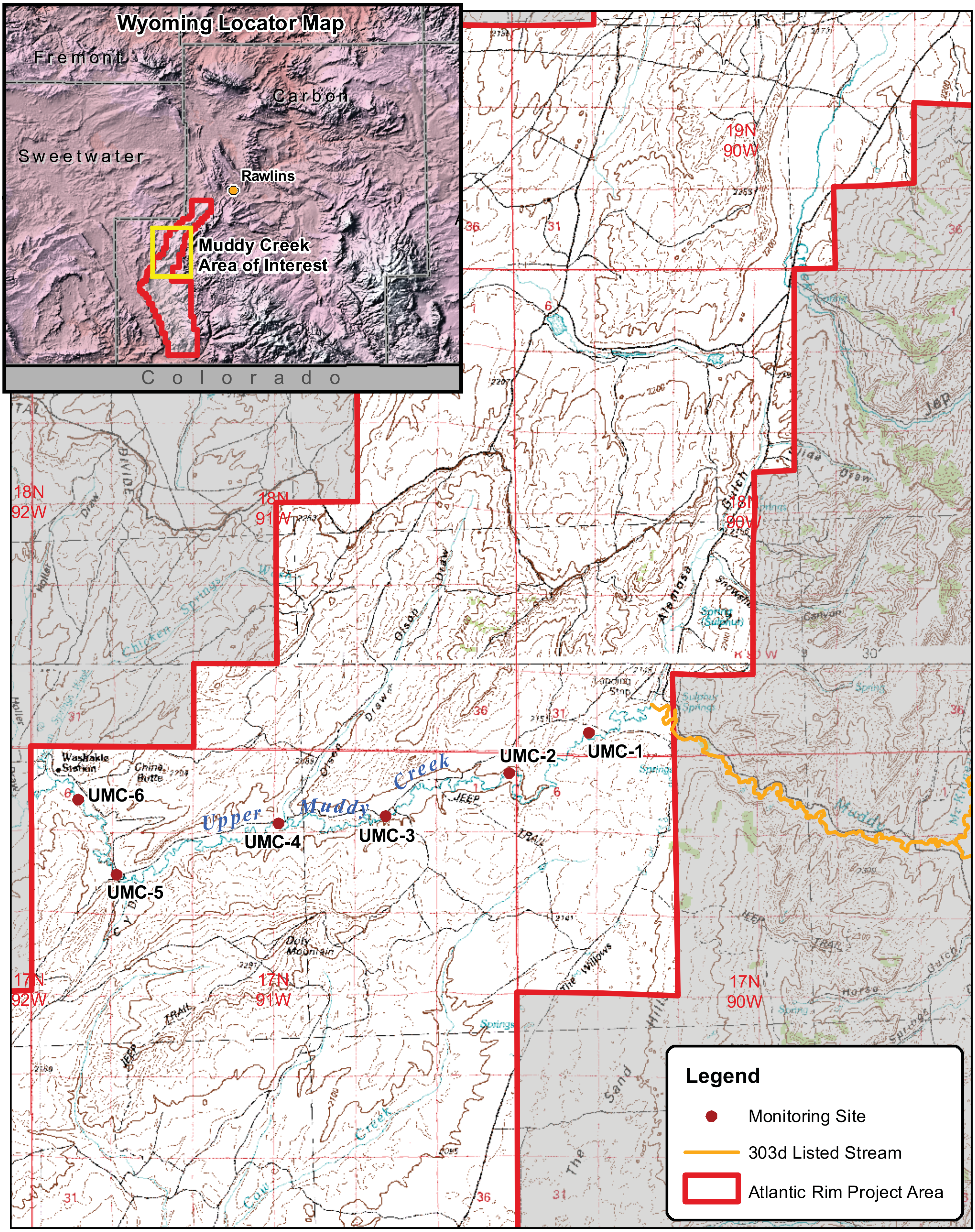


Figure 3-1. Upper Muddy Creek Monitoring Locations

Atlantic Rim Project

Carbon County, Wyoming

0 0.5 1 2 3 4 5

Scale of Miles

CDM

Z:\gis\Public\Wyoming\MXD\MuddyCreekMonitoringSites.mxd

3.2 Geomorphic Stream Survey

Channel form data was collected with both Global Positioning Systems and conventional surveys to provide information for the Rosgen Level II survey and a baseline for channel change measurements. The cross section survey was performed with a total station. Due to the lack of established control in the field, the surveys were carried out in an assumed coordinate system. In post-processing, the survey data were rotated and translated to fit the UTM coordinates measured using GPS. Appendix A presents locations of banks and reference pins in UTM coordinates obtained with resource grade GPS equipment. Appendix C shows plan views of the sites with the measured cross sections. Appendix D contains longitudinal profiles and photographs.

3.2.1 Planform

Throughout the project area, the stream is generally single-threaded and meandering. There is visual evidence of historic lateral migration; however, aerial photographs from 2002 and 1994 were compared and there is no evidence of discernable lateral movement in that time period.

Sinuosity at each site was measured in GIS using a 2002 color infrared aerial photograph (USGS, 2002). To obtain sinuosity, the length of the channel within each site was measured and divided by the measured valley length at the site. These results are presented in Section 3.3.

3.2.2 Longitudinal Profiles

During the course of the survey, thalweg points were taken at all cross-sections and at several intermediate points including riffle crests. Thalweg profiles for each site can be found in Appendix D.

3.2.3 Cross-sections

At each site, six cross-sections were surveyed, one of which was monumented for repeated surveys in the future. The exception is UMC6 where only the monumented cross-section was surveyed. The cross-sections are found in Appendix E.

3.3 Stream Classification and Evolution

For each site, parameters used for the Rosgen Level II classification were developed from survey data and other field measurements as well as planform information developed using GIS. Parameters such as entrenchment ratio and width to depth ratio were then averaged and used with other information to obtain a reach-averaged stream classification. The slope used in this evaluation was the bedslope across the entire site. At all sites, silt was the predominant bed material and was therefore used for classification. A summary of reach-averaged Rosgen parameters can be found in Table 3-1.

The comparison of the 1994 and 2002 channel locations presented in Section 2.5 indicates that major channel changes did not occur in the project area over this eight year period. The fact that no meander bend cutoffs occurred is evidence of a slow rate of lateral evolution. Although inspection of the stream indicates that significant sediment sources such as high banks are providing an overload of sediment to the stream, the very height of those banks and the amount of sediment generated that needs to be transported apparently slow the rate of lateral stream movement.

All sites appear to be in similar stages in their evolution. In the past, there has been significant downcutting on Muddy Creek, as indicated by the need to install the drop structure downstream of the site. Downcutting has led to incised channels with many near-vertical banks. The future evolutionary path of the stream is not known at this time, but it might reasonably be expected to progess in one of two directions. The stream could continue to downcut resulting in an even more incised channel and higher banks. Alternatively, the stream may have achieved a more stable vertical profile with less downcutting expected in the future. If this is the case, it is expected that the meander bends will erode the banks further, leading to gradual widening of the channel and overbank areas and establishment of a new floodplain. Eventually, these changes should lead to a more stable geomorphic state, but the expected time frame is long because of the height of the banks and the quantity of sediment that must be moved is large.

Discussion of the geomorphic classification of each site follows.

UMC1

At UMC1, the bedslope was .002 ft/ft and the channel sinuosity was 1.5. The width to depth ratio was 25 and the entrenchment ratio was 1.7. UMC1 is a Rosgen Type B6c, meaning that it has moderate entrenchment, width to depth ratio and sinuosity and a low slope. The numeral "6" indicates a silt bed material and the "c" indicates low slope.

UMC2

At UMC2, the bedslope was .0015 ft/ft and the channel sinuosity was 1.7. The width to depth ratio was 10.4 and the entrenchment ratio was 1.6. UMC2 was classified as a Rosgen Type B6c, despite the width to depth ratio being too low for this category (width to depth should be greater than 12). However, no other classification would match the parameters at this site and entrenchment ratio is considered to be a more important parameter in classification than width to depth ratio. UMC2 has moderate entrenchment and sinuosity and a low slope.

UMC3

At UMC3, the bedslope was .0015 ft/ft and the channel sinuosity was 1.3. The width to depth ratio was 20 and the entrenchment ratio was 1.8. UMC3 is a Rosgen Type B6c, meaning that it has moderate entrenchment, width to depth ratio and sinuosity and a low slope.

UMC4

At UMC4, the bedslope was .0008 ft/ft and the channel sinuosity was 1.3. The width to depth ratio was 12 and the entrenchment ratio was 3.3. UMC4 is a Rosgen Type C6c, meaning that it is slightly entrenched, has a moderate width to depth ratio and sinuosity and a low slope.

UMC5

At UMC5, the bedslope was .0006 ft/ft and the channel sinuosity was 1.6. The width to depth ratio was 10 and the entrenchment ratio was 2.1. UMC5 was classified as a Rosgen Type B6c, despite the width to depth ratio being too low for this category (width to depth should be greater than 12). However, no other classification would fit the parameters at this site and entrenchment ratio is considered to be a more important parameter in classification than width to depth ratio. UMC5 has moderate entrenchment and sinuosity and a low slope.

UMC6

Cross-section 3 was the only cross-section surveyed at UMC6. Bedslope is not available at this site due to the incomplete survey; therefore no slope qualifier is used in classification. The sinuousity at UMC6 was 3.5 due to the location of this reach on a tight horseshoe bend. The entrenchment ratio was 2.1 and the width to depth ratio was 7.9. This cross-section was classified as a B6, though the width to depth ratio is too low for this category. UMC6 has a moderate entrenchment and high sinuosity.

Table 3-1. Average geometric parameters for stream classification - Upper Muddy Creek Monitoring Sites.

Parameter	UMC1	UMC2	UMC3	UMC4	UMC5
Bankfull width (*ft*)	47.6	31.4	40.9	27.8	18.6
Mean depth (ft)	1.7	3.0	2.0	2.3	2.3
Maximum depth (ft)	3.6	4.9	4.3	5.1	4.3
Entrenchment width (ft)	69.2	48.7	106.8	91.0	38.6
Width/depth ratio	30.2	11.0	23.7	13.2	10.0
Entrenchment ratio	1.5	1.6	1.9	3.2	2.1
Classification (Rosgen)	B6c	B6c	B6c	C6c	B6c

The apparent difficulty in classifying this stream unambiguously probably stems from its evolutionary state. As previously discussed, this channel is probably continuing to evolve and has not reached a stable configuration. Originally this section of Muddy Creek was probably an E type stream that downcut over time. The downcutting resulted in a lower entrenchment ratio than an E type stream leading to the B classification. However, the stream still retains the low width to depth ratio (less than 12) of an E type stream in some areas. If the stream is no longer downcutting, it may eventually widen its channel and attain a more representative B classification type.

There are a number of high (greater than 10 feet), vertical banks on the outside of bends in the study sites that show signs of recent collapse. However, as indicated by the channel comparison presented in Section 2.5, the lateral rate of stream movement is not great, and the meander bends are remaining in the same approximate locations and not being cut off. This appears to be due to the large amount of sediment that is contained in the high banks and the inability of the stream to transport this sediment. Often water depths on bends, where one would expect to find a pool, are rather shallow as the stream transport capacity is insufficient to transport the collapsed bank sediments downstream. The frequently observed silt deposits both in channel and on the overbanks are also indicators that the stream transport capacity is generally insufficient to deliver sediment downstream. This imbalance between sediment yield and sediment transport capacity serves to slow the rate of evolution of this stream towards a more stable configuration.

3.4 Bed Measurements

Wolman pebble counts (Wolman, 1954) and embeddedness measurements were performed at three locations within each study reach if appropriate given the type of material found at a site. Pebble counts were performed by measuring 100 individual pebbles at each location with a gravelometer. The pebbles were sorted into standard size classes and then a cumulative size distribution was plotted. Pebble counts were only performed at riffles because pool materials were generally sand and silt and not amenable to this measurement. Only two pebble counts were performed at UMC4 because the reach only contained two riffles. UMC5 only had one riffle, so one pebble count was performed at this site. Similarly, UMC6 had two riffles and therefore, two pebble counts were performed. Plots of the cumulative size distributions can be found in Appendix E. In Table 3-2, D_{50} (median diameter) values for all measured cross-sections are displayed. A general trend can be seen of decreasing median size in the downstream direction. This result correlates both with the distance from the mountains east of the project area that are the presumed source of coarser material as well as the decreasing streambed slope, which restricts the downstream transport of coarser materials. Figure 3-2 contrasts a riffle at the upstream station (UMC1) where the substrate is gravel and cobble with the downstream station (UMC6), where the substrate is typically small gravel and sand.

The embeddedness measurement method followed the U.S. Geological Survey's National Water-Quality Assessment Program as described in Sennatt et al (2006). Embeddedness was measured by collecting 15 pebbles at each transect. The percent of the clast's height that was buried in silt was estimated. These percentages were then averaged to estimate embeddedness at that transect. At UMC2, 4, 5, and 6, all areas were either clean gravel or larger clasts with no siltation or the bed was entirely silt.

Table 3-2: D_{50} values at pebble count cross-sections.

Site	Cross-section and D_{50} range (mm)		
UMC1	**XS-1**	**XS-4**	**XS-6**
	22.6-32	90-128	64-90
UMC2	**XS-1**	**XS-3**	**XS-6**
	32-45	22.6-32	8-11
UMC3	**XS-1**	**XS-4**	**XS-6**
	45-64	45-64	45-64
UMC4	**XS-1**	**XS5**	
	22.6-32	11-16	
UMC5	**XS-1**		
	5.6-8		
UMC6	**XS-1**	**XS-4**	
	11-16	16-22.6	

Therefore, embeddedness measurements were not taken at these sites. Figure 3-3 shows the substrate at site at UMC1 just downstream of XS-1 and compares it with the totally embedded pool at site UMC5. The results of embeddedness measurements are shown in Table 3-3. It is important to note that these measurements were largely taken in transitional zones between riffles and pools. Almost all of the pools throughout the study reach were 100% embedded and, likewise, almost all of the riffles were 0% embedded.

Table 3-3: Average embeddedness values and locations.

UMC1	**Pool below XS-1**	**50' downstream of XS-2**	**Immediately below XS-5**
	32.0%	52.7%	52.7%
UMC3	**Top of pool below XS-1**	**Tail of pool above XS-4**	**Tail of pool upstream of XS-6**
	38%	48%	31%

Because a large percentage of upper Muddy Creek had either zero or complete embeddednesss of substrate, this measurement does not appear to have much utility for characterizing substrate in this stream. We recommend that embeddedness be discontinued in future monitoring.

3.5 Bank Stability

Several methods are being used to assess bank stability in Upper Muddy Creek. The monumented cross-sections will be re-surveyed annually to measure the extent of any erosion. Erosion pins were installed at each site to refine these measurements. In addition, the measurements for the Bank Erosion Hazard Index (BEHI) were taken and compiled along with Near Bank Stress (NBS) to provide a semi-quantitative measure of bank stability.

Figure 3-2: Typical riffle substrates – Upper Muddy Creek.

UMC1, XS-6

UMC 6, Riffle between XS-3 and XS-4

Figure 3-3: Typical pool substrates – Upper Muddy Creek.

UMC1, Downstream of XS-1 – 32% Embedded

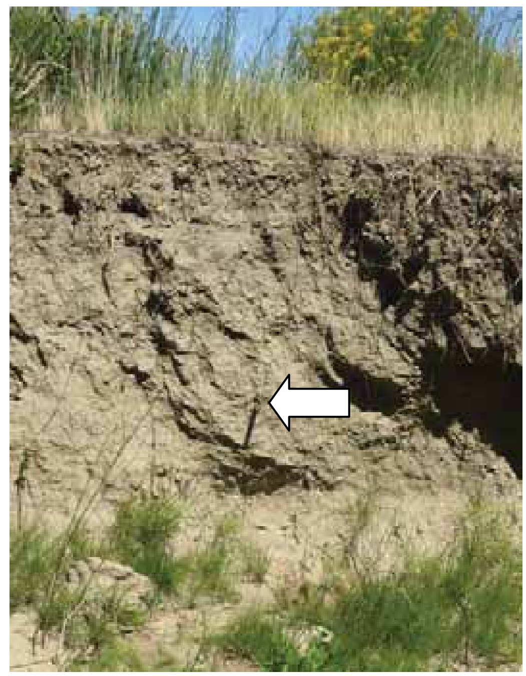
UMC5 Pool – 100% Embedded

3.5.1 Erosion Pins

Erosion Pins were installed near the monumented cross-section at each site. An erosion pin is a four-foot steel bar driven horizontally into the bank until a few inches protrude. Pins were placed in vertical sections of bank that are likely to erode (for example, outside of bends), and which are difficult to monitor using surveyed cross-sections. Typical erosion pin placements are shown in Figure 3-4. Generally an erosion pin was installed in at least one bank of the reference cross-section at each site to improve measurement of erosion at this section. The protruding length is measured initially and the measurement is repeated during future monitoring events. Locations and protruding lengths of erosion pins are shown in Table 3-4.

Figure 3-4. Typical erosion pin placements – Upper Muddy Creek.

Above Webber Drop, Left Bank Pin



UMC5, XS-5, Right Bank Pin

Table 3-4: Locations and protruding lengths of bank erosion pins

Site	Location	Length (ft)-Apr 2008	Length (ft)-Aug 2008
UMC1	XS-4, Right bank		0.33
UMC2	XS-5, Right bank		0.24
UMC3	XS-3, Right bank	0.22	0.27
UMC4	XS-3, Right bank		0.37
UMC5	XS-3, Right bank		0.38
Weber drop	Left bank	0.44	Not visible
Weber drop	Right bank	0.31	0.24
Rocky Crossing	Left bank	0.43	0.51

No interpretation of the pins installed in August will be possible until next year, but four pins were installed in April 2008 and were remeasured in August. The bank pin at UMC3 shows 0.05 ft. of erosion and the bank pin at Rocky Crossing (about 200 yards upstream of UMC3) shows 0.08 ft. of erosion in this period. The bank pins installed just upstream of the Webber drop structure are more difficult to interpret. The vertical portions of these banks were relatively low (1 to 2 feet), and the left bank pin was apparently buried by a slough of the bank. The right bank was affected by sloughing to a lesser degree since it was still exposed but had accreted 0.07 ft.

3.5.2 Bank Erosion Hazard Index

Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) methods are presented in *Applied River Morphology* (Rosgen, 1996). BEHI looks at five indices of bank stability and assigns numeric values to the observed conditions. The index values are summed and subjected to adjustment for bank material type and stratification to arrive at a qualitative descriptor of bank stability. At each site, BEHI was performed on the more susceptible bank at each cross-section unless neither bank was applicable.

Many of the evaluated banks displayed characteristics not accounted for in the BEHI method. For instance, many banks displayed two or more distinct bank angles. Often, the bank would have a low angle near the water and then have a slope near vertical at the top. In these cases, an average bank angle weighted by the height of each section was used.

Appendix E contains the evaluation for the BEHI at each evaluated bank, and Table 3-5 shows BEHI and Near Bank Stress ratings for all the evaluated banks. Photos of each bank are included in Appendix E as well. The BEHI ratings range from “moderate” to “extreme”, with most banks rating as “high” or “very high”. These ratings indicate that most of the measured banks had a high potential for erosion. UMC1 and UMC5 have the lowest ratings, whereas UMC6 has the highest ratings.

3.5.3 Near Bank Stress

NBS evaluates the rate at which a bank is expected to supply sediment to a stream based on the local hydraulic conditions. Several options are available for estimating the effects of bank stress in the *Watershed Assessment of River Stability and Sediment Supply* website of EPA (http://www.epa.gov/WARSSS/monitor/method.htm). Appropriate to the Level II investigation being conducted, the radius of curvature to width ratios were used in this investigation. The location of the bank on a straight reach or outside of bend was noted and NBS was not performed at such locations because the ratio would be infinite. Because a survey was not completed at UMC6, NBS was not evaluated at this site.

Values for NBS ranging from, “very low” to “extreme” are shown in Table 3-5. Sites UMC4 and UMC5 have the lowest NBS ratings because they have relatively straight channel alignments. Those banks with “high” or greater BEHI ratings and “high” or greater NBS ratings have the greatest potential for delivery of sediment to the stream.

Table 3-5: BEHI and NBS ratings

Site	Location	BEHI Rating	NBS Rating	Photo No.
UMC1	XS1, Left bank	High	Straight Reach	1
	XS1, Right bank	High	Straight Reach	2
	XS2, Right bank	High	Extreme	3
	XS4, Right bank	High	Straight Reach	4
	XS6, Left bank	Moderate	Extreme	5
	XS6, Right bank	Very High	Inside of bend	6
UMC2	XS1, Left bank	Very high	Extreme	7
	XS2, Right bank	High	Very high	8
	XS4, Left bank	High	Extreme	9
	XS5, Right bank	Very high	Moderate	10
	XS6, Right bank	Very high	Extreme	11
UMC3	XS1, Left bank	Very high	Moderate	NA
	XS2, Right bank	High	Extreme	12
	XS3, Right bank	Very high	Straight Reach	13
	XS5, Left bank	High	Extreme	14
	XS6, Right bank	High	Very high	15
UMC4	XS1, Left bank	High	Low	16
	XS3, Right bank	High	Very low	17
	XS6, Right bank	Very high	Moderate	18
UMC5	XS1, Right bank	High	Straight Reach	NA
	XS2, Right bank	High	Straight Reach	NA
	Below XS3, Right bank	Very high	Low	19
	XS4, Left bank	High	Straight Reach	20
	XS5, Right bank	High	Straight Reach	21
	XS6, Right bank	High	Very low	22
UMC6	XS1, Left bank	Extreme	N/A	NA
	XS3, Right bank	High	N/A	23
	XS4, Right bank	Extreme	Straight reach	24
	XS6, Left bank	Extreme	N/A	25

NA – Not available
Shading indicates reference section.

3.6 Residual Pool Depths and Areas

Residual pool depth refers to the depth of the pools remaining were the water to stop flowing, leaving water only in the pools. The depth was obtained by subtracting the elevation at the deepest point in a pool from the elevation of the riffle crest downstream of the pool. Pool area was obtained by multiplying the pool length by its average width. Depths may not be maximum pool depths because turbid water prevented visual identification of the deepest pool location. Residual pool depths, lengths, and areas are shown in Table 3-6.

Table 3-6. Summary of residual pool measurements.

Site	Downstream Riffle Section	Residual Pool Depth (ft)	Pool Length (ft)	Pool Area (ft^2)
UMC-1	XS-3	1.9	85	1530
UMC-1	XS-6	1.7	95	1330
UMC-2	XS-3	0.9	102	918
UMC-2	XS-5	2.0	151	1661
UMC-2	55' downstream of XS-6	1.4	134	1474
UMC-3	XS-3	1.3	235	2820
UMC-3	XS-6	2.4	185	2220
UMC-4	XS-3	0.5	108	864
UMC-4	XS-5	1.7	187	1496
UMC-5	XS-3	0.3	116	1044
UMC-5	XS-6	2.0	166	1328
Average		1.5	142	1517

Eleven pools were measured at the five monitoring sites with an average residual pool depth of 1.5 feet, an average length of 142 feet, and an average pool area a little greater than 1,500 square feet.

Section 4 Water Quality Sampling

4.1 Measurement Methods

During the 2008 site monitoring assessment, water quality samples were collected along with field measurements at three sites, UMC1, UMC3 and UMC6. These sites represent the upstream, middle and downstream portions of the project area on upper Muddy Creek. As described in the *Monitoring Plan* (CDM, 2008), measurements were taken for discharge, pH, electrical conductivity, temperature and turbidity. Discharge was measured with a Marsh-McBirney flow meter and field parameters, except for turbidity, were measured with a Datasonde Surveyor 4 system.

Water quality samples were collected for common ions, total suspended solid (TSS), and selenium. Common ions and the metals sample were grab samples. The *Monitoring Plan* called for depth integrated TSS sampling; however, the water depths were too shallow to permit sampling with the DH-48 sediment sampler. As an alternative, grab samples were collected at the center of the quartile flow sections and composited for the TSS sample. Our field filtering apparatus proved to be inadequate to filter the metals sample; therefore, the selenium analysis was a total metals measurement. There was some uncertainty in the calibration of the field electrical conductivity meter so samples were also collected for a laboratory measurement of electrical conductivity.

Samples were cooled with ice and delivered to Energy Laboratories in Helena, Montana on August 25th, 2008.

4.2 Water Quality Sampling Results

Field measurements measured during the August 2008 sampling event are summarized in Table 4-1.

Table 4-1. Field Parameters from August 2008 Water Quality Sampling – Upper Muddy Creek

Sample Site	Discharge (cfs)	pH	Temp. (°C)	EC (mS) - Field	EC (mS) - Lab	DO (mg/L)	Turbidity*
UMC1	2.29	7.77	14.4	0.548	0.556	7.32	14.9
UMC3	1.68	8.02	14.8	0.570	0.578	7.81	13.5
UMC6	1.46	8.02	22.6	0.607	0.616	7.5	14.8

* Nepholometric Turbidity Units (NTU)

Flow in upper Muddy Creek in the project area appeared to be continuous although the discharge decreased significantly through the project area. Field and laboratory electrical conductivities were similar at each site, and a gradual increase in electrical conductivity from upstream to downstream was noted. Dissolved oxygen values were similar between stations as were pH. The higher water temperature at UMC6 than upstream stations was in part due to the lower flow although time of day probably influenced it as well.

Table 4-2 presents the laboratory analytical data, and Appendix G contains the laboratory data sheets.

Table 4-2. Common Ions, Selenium and TSS from August 2008 Water Quality Sampling – Upper Muddy Creek. Concentrations are in mg/L.

Sample Site	Ca	Mg	K	Na	Alkalinity	Cl	SO_4	Total Se	TSS
UMC1	61	17	3	20	150	5	140	0.002	10
UMC3	06	19	3	25	150	6	150	0.002	11
UMC3-Dup	61	19	3	25	150	6	150	0.002	<10
UMC6	58	19	4	31	150	7	180	0.001	12
UMC-Blank	<1	<1	<1	<1	<4	<1	<1	<0.001	<10

Common ions were generally consistent between the three sampling sites with some increases in sodium and sulfate at UCM6, the downstream station. The total selenium concentration was 2 µg/L or less, below the chronic aquatic life standard of 5 µg/L . Total suspended solids (TSS) concentrations were in the range of 10 to 12 mg/L at the three sites.

The water quality measured in the project area during this sampling event was generally within the range of conditions observed from 2001 to 2004 at the Bridger Pass Station, about three miles upstream of the project area (see Section 2.6). Dissolved oxygen was higher at the Bridger Pass Station because water temperatures were generally lower during the sampling conducted there. However, turbidity appears to be lower within the project area than at Bridger Pass Station. This may be due to differences in cattle grazing patterns at the two sites at two different times. Common ions for the August 2008 sampling in the project area appear to be in similar or slightly lower ranges than those previously observed at Bridger Pass Station. The lower concentrations may be due to the dilution effect of higher flows measured in 2008.

4.3 Quality Assurance/Quality Control

Laboratory quality assurance/quality control (QA/QC) reports are included in Appendix G. All method blanks were below detection limits and all percent recoveries were within 20% of the control value except for one TSS laboratory control sample, which had a 79% recovery.

A field duplicate sample was collected at site UMC3 and analysis results for this sample are presented in Table 4-2. All parameters had zero relative percent difference between the duplicate and natural sample except for TSS. The natural TSS sample measured 11 mg/L and the duplicate was <10 mg/L. Because the measurements are near the detection limit, this relative percent difference is acceptable.

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Appendix A
Bank and Reference Section Locations

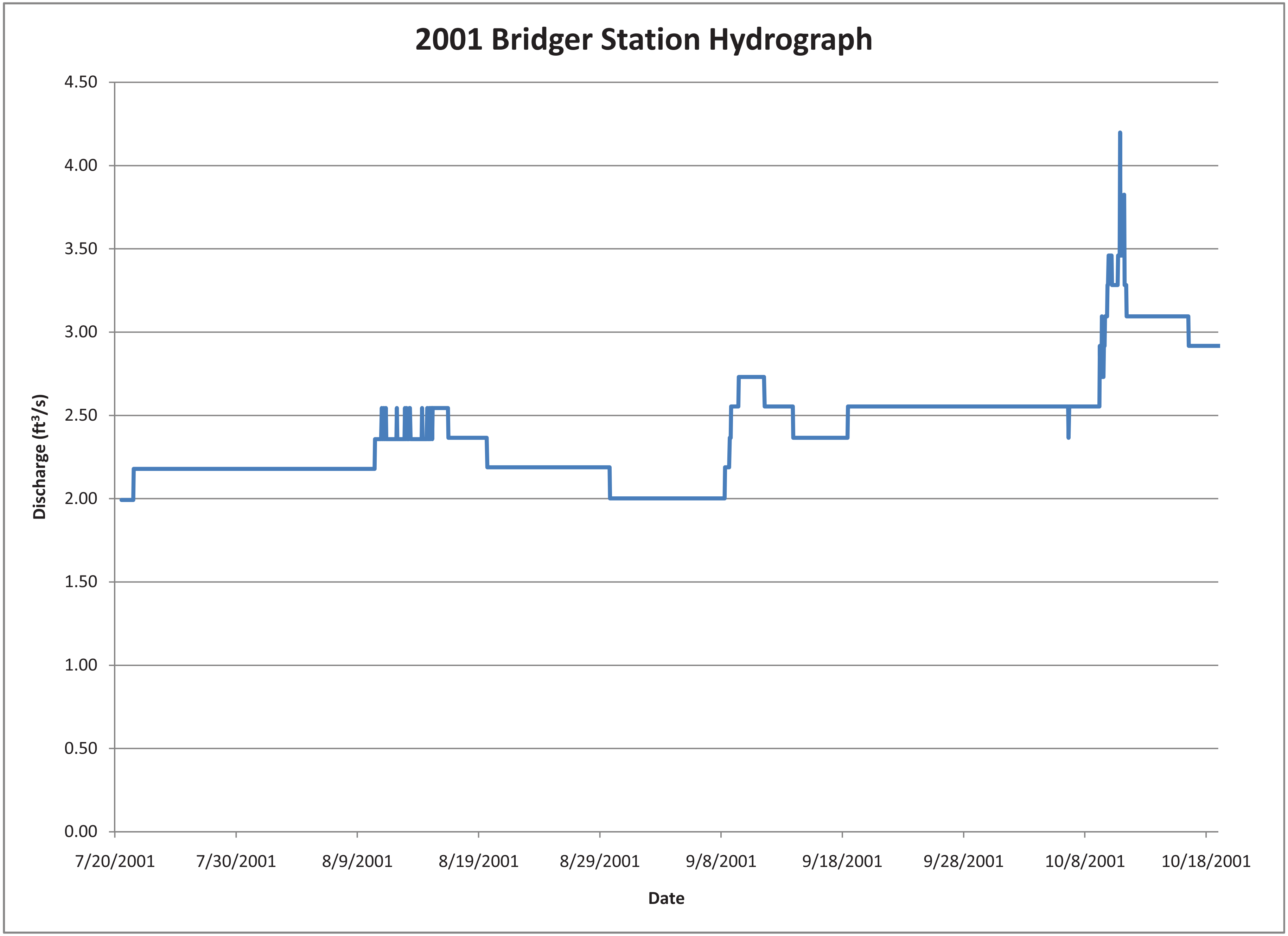
UPPER MUDDY CREEK MONITORING
BANK AND REFERENCE SECTION LOCATIONS
August 2008

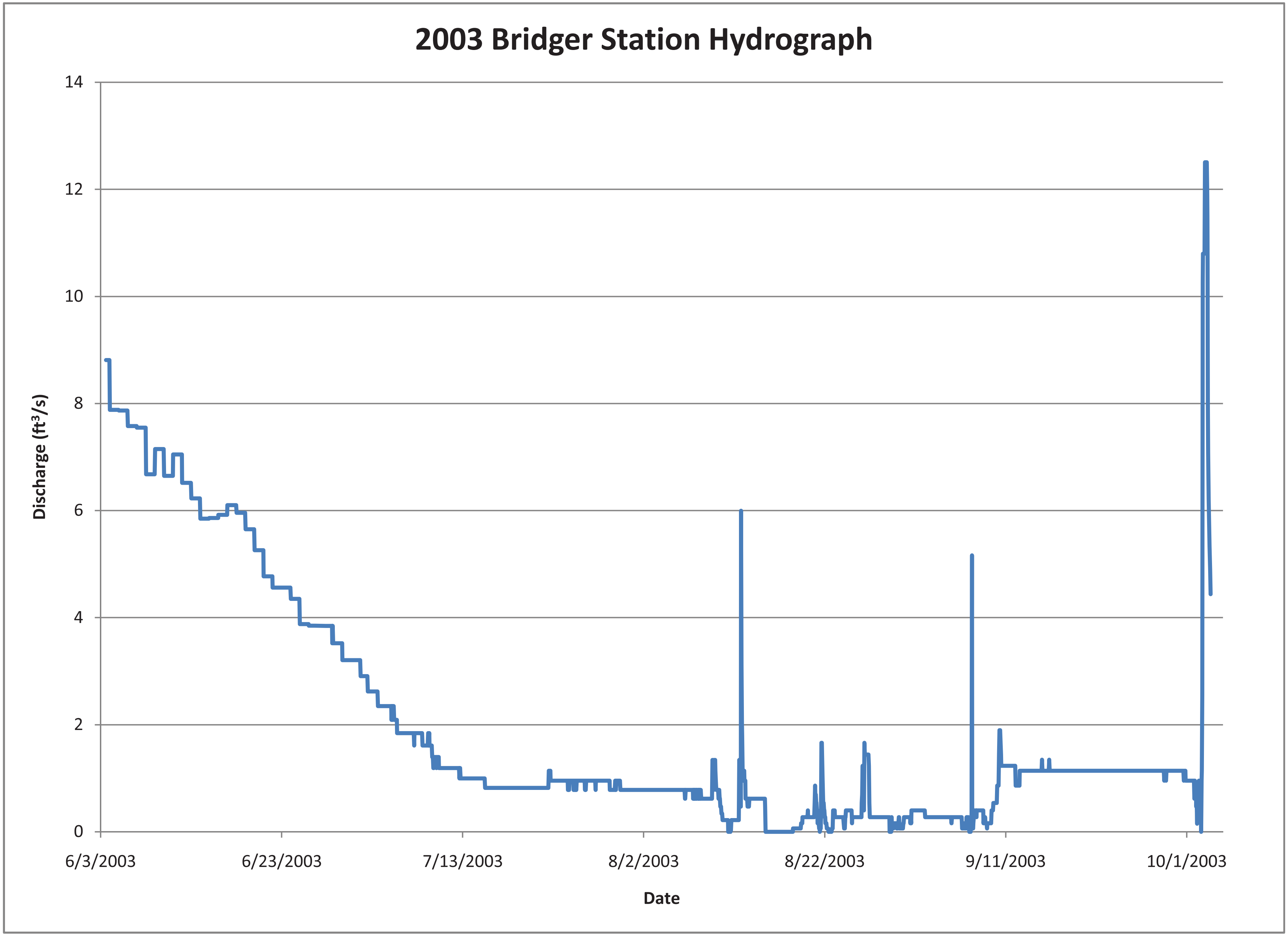
Location	Northing	Easting
umc1-xs4-rb	4595981.3	285983.2
umc1-xs6-brb	4595975.5	285967.1
umc1-xs6-blb	4595942.3	285971.6
umc1-xs4-brb	4595981.3	285984.3
umc1-xs4-twg	4595982.1	285987.1
umc1-xs1-blb	4596019.1	286012.2
umc1-xs1-brb	4596035.4	286020.0
umc1-xs2-trb	4596037.0	285986.7
umc2-xs1-blb	4595276.8	284029.7
umc2-xs2-brb	4595308.7	284023.8
umc2-xs4-blb	4595292.9	283985.0
umc2-xs5-trb	4595346.2	284014.7
umc2-xs5-rbpin	4595347.7	284017.5
umc2-xs5-lbpin	4595338.5	283998.2
umc2-xs6-brb	4595362.7	283990.8
umc3-xs3-rbpin	4594568.3	281609.2
umc3-xs6-brb	4594567.4	281558.1
umc3-xs5-blb	4594537.3	281577.8
umc3-xs3-trb	4594564.3	281616.4
umc3-xs3-lbpin	4594540.4	281618.6
umc3-xs1-blb	4594580.0	281677.3
umc3-xs2-trb	4594572.9	281631.5
umc4-xs1-blb	4594410.2	279480.5
umc4-xs3-rbpin	4594457.6	279495.7
umc4-xs3-trb	4594458.2	279494.5
umc4-xs6-brb	4594515.5	279405.8
umc4-xs3-lbpin	4594447.7	279477.7
umc5-xs1-brb	4593510.0	276262.4
umc5-xs2-brb	4593551.7	276252.5
umc5-xs3-brb	4593533.5	276226.8
umc5-xs4-blb	4593515.7	276215.1
umc5-xs6-brb	4593547.2	276176.4
umc5-xs3-lbpin	4593527.5	276239.7
umc6-xs3-brb	4594753.0	275927.3
umc6-xs4-brb	4594748.3	275893.3
umc6-xs6-blb	4594718.4	275857.8
umc6-xs3-lbpin	4594739.6	275916.9
umc6-xs3-rbpin	4594757.1	275931.4

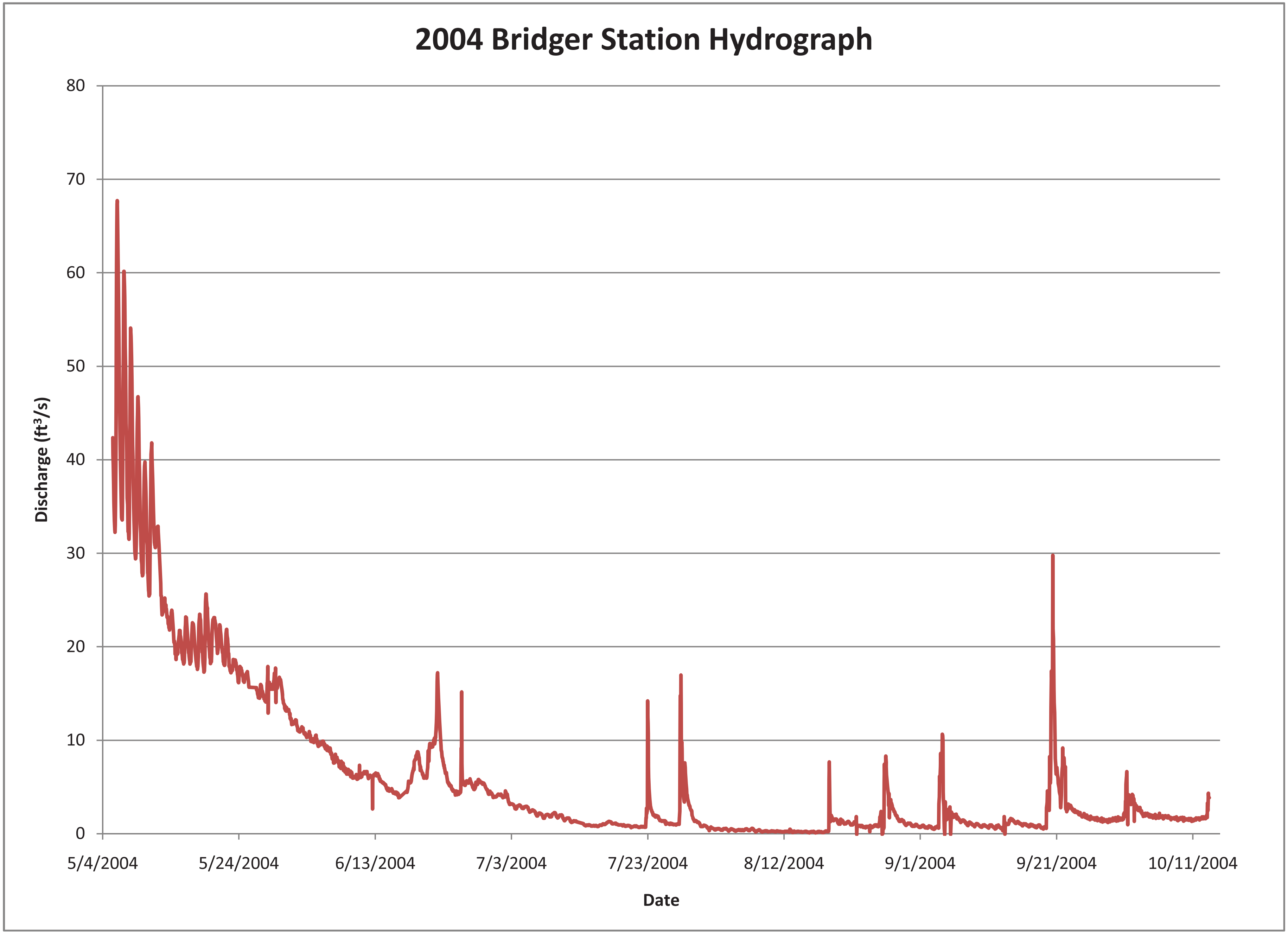
Coordinates are in UTM NAD83 Zone 13N
b=bottom, t=top, rb=right bank, lb=left bank,
pin refers to monuments for permanent cross-sections

Appendix B

Bridger Pass Station Hydrographs and Memorandum on Expected Runoff


2001 Bridger Station Hydrograph
Discharge (ft³/s)
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
7/20/2001
7/30/2001
8/9/2001
8/19/2001
8/29/2001
9/8/2001
9/18/2001
9/28/2001
10/8/2001
10/18/2001
Date


2003 Bridger Station Hydrograph
Discharge (ft³/s)
14
12
10
8
6
4
2
0
6/3/2003
6/23/2003
7/13/2003
8/2/2003
8/22/2003
9/11/2003
10/1/2003
Date


2004 Bridger Station Hydrograph
Discharge (ft³/s)
80
70
60
50
40
30
20
10
0
5/4/2004
5/24/2004
6/13/2004
7/3/2004
7/23/2004
8/12/2004
9/1/2004
9/21/2004
10/11/2004
Date

50 West 14th Street, Suite 200
Helena, Montana 59601
tel: 406 441-1400
fax: 406 449-7725

Memorandum

To: *Muddy Creek Working Group*

From: *Bill Bucher - CDM*

Date: *October 30, 2008, Revised December 29, 2008*

Subject: *Upper Muddy Creek – Expected Runoff Analysis*

In an effort to understand better potential effects of development in upper Muddy Creek on runoff, I performed calculations to estimate runoff from the undeveloped watershed and compare that with runoff expected under full development. The method used to estimate runoff was the Soil Conservation Service (SCS) curve number, which evaluates runoff amount from precipitation events based on soil infiltration properties. Using GIS analysis of Natural Resource Conservation Service soil survey information available at http://datagateway.nrcs.usda.gov/, hydrologic groups and their corresponding areas of occurrence were determined. The individual soil hydrologic groups (A, B, C or D) were assigned runoff curve numbers under the assumption that the hydrologic condition of the soils was rangeland in poor condition (Chow, 1964, Table 21-12). The curve numbers for each soil group were then weighted by the area of that group and the average curve number for the undeveloped condition calculated (see attached spreadsheet). The resulting curve number was 82.33, which lies between the B and C hydrologic soil groups.

To estimate the curve number under the developed condition, the following assumptions were made:

- Wells would be placed with an average density of eight wells per section (square mile).
- Each well would result in an average of 6.5 acres of disturbance including roads and other non-well pad disturbance.
- Development would not occur within a buffer extending one-quarter mile either side of Muddy Creek.
- The entire upper Muddy Creek watershed exclusive of the buffer zone within the project boundaries would be developed resulting in 234 wells.

- The disturbance will be distributed over the differing soil groups in proportion to their areas within the project area.

These assumptions result in 1,521 acres of disturbance out of a total of 21,439 acres in the project area. Using a runoff curve number of 84.38 for roads constructed in group B to C soils for the disturbed area (Chow, 1964, Table 21-12) and assuming the curve number on the undisturbed acreage remains 82.33, the average curve number for the project area becomes 82.47.

Runoff Predictions for 6.5 Acres Disturbance per Well Pad

To investigate how the higher average curve number increases runoff, three relatively frequent (2-year recurrence frequency) precipitation events were developed from the *Precipitation Frequency Atlas of the Western United States, Volume 2 - Wyoming* (Miller *et al*, 1973). Precipitation amounts for the 2-year recurrence frequency 1-hr, 6 hr., and 24 hr. duration events are shown in Table 1 along with runoff amounts calculated using the SCS method for both the undeveloped and fully developed conditions.

Table 1. Predicted runoff amounts for undeveloped and developed project area.

		Undeveloped Scenario CN = 82.33		Developed Scenario CN = 82.47		
Event	**Precipitation (in)**	**Runoff (in)**	**Runoff (ac-ft)**	**Runoff (in)**	**Runoff (ac-ft)**	**Percent Increase**
2-yr. 1 hr.	0.52	0.0037	6.58	0.0041	7.24	10%
2-yr. 6 hr.	0.85	0.0690	123.21	0.0708	126.45	3%
2-yr. 24 hr.	1.2	0.2037	363.85	0.2070	369.84	2%

Note: Developed scenario assumes 8% disturbance area (6.5 acres per well)

The runoff may increase by as much as 10% after full development during short duration events because the undisturbed soils would infiltrate most of the precipitation; that is, less than 1% of the water would runoff. Thus, the small amount of disturbed area would produce a relatively large percentage increase in runoff. However, during longer duration storms, development would result in only a 2 to 3% increase in runoff because these events will create significant runoff even with undisturbed soils.

Runoff Predictions for 4.8 Acres Disturbance per Well Pad

The preceding analysis was repeated using the assumption that only 6% of the development area was disturbed, which corresponds to about 4.8 acres per well site. This level of disturbance reflects new construction practice by Anadarko where utilities are buried under roads resulting in narrower road widths. Results of this analysis are in Table 2.

Table 2. Predicted runoff amounts for undeveloped and developed project area – 6% disturbance.

		Undeveloped Scenario CN = 82.33		Developed Scenario CN = 82.44		
Event	**Precipitation (in)**	**Runoff (in)**	**Runoff (ac-ft)**	**Runoff (in)**	**Runoff (ac-ft)**	**Percent Increase**
2-yr. 1 hr.	0.52	0.0037	6.58	0.0040	7.10	8%
2-yr. 6 hr.	0.85	0.0690	123.21	0.0704	125.75	2%
2 yr. 24 hr.	1.2	0.2037	363.85	0.2063	368.55	1%

Note: Developed scenario assumes 6% disturbance area (4.8 acres per well).

This assumption on disturbance area leads to reduced runoff in the developed scenario with only 8% increase in runoff for the 1 hr. event and even smaller increases for the 6 hr. and 24 hr. events. Although this is a significant reduction in disturbance area (25%) from the previous scenario, it only results in a 2% difference in runoff volumes.

Relationship of Storm Hydrology to Predicted and Observed Stream Hydrology

It is relevant to note that short duration events such as 1-hour storms are likely to be thunderstorm cells which will only affect a portion of the 33.5 square mile project area at any one time. Therefore, the runoff amounts for the 2-year, 1 hour events actually experienced during a single event will probably be much less than the amounts shown (6.58 and 7.24 acre feet for the 6.5 acre disturbance scenario). If a thunderstorm extends over a one-square mile area (typical of these storms) the contribution of runoff from that storm would only be about 0.20 acre-feet (undeveloped scenario) or 0.22 acre-feet (developed scenario). Looking at these numbers in terms of flow, this one-hour storm would increase average flow in a local stream by 2.4 cfs (undeveloped scenario) or 2.6 cfs (developed scenario). When compared to the typical late-season flows in upper Muddy Creek, which ranged from 1.5 cfs to 2.5 cfs this year (2008), the storm runoff would at least double stream flows to as much as five cfs. However, the difference between the developed and undeveloped scenarios is only 0.2 cfs which is a small increase compared to typical, late-season upper Muddy Creek flows.

A logical extension of this runoff analysis would be to calibrate the runoff curve numbers for upper Muddy Creek using contemporaneous records of precipitation and stream gages. However, these types of data do not appear to be available in the project area. The three summer to early fall hydrographs at Bridger Pass Station reflect flows in the portion of Muddy Creek above the project area, and the nearest SNOTEL sites with continuous precipitation records are outside the upper Muddy Creek Basin. However, some information can be extracted from the hydrographs and precipitation records that can offer perspective on the validity of this analysis.

As a first step towards calibrating the runoff analysis, I looked at the three hydrographs for the July through October periods in 2001, 2003 and 2004. The peak flows for this period for these three years are:

- 2001 4.2 cfs
- 2003 12.5 cfs
- 2004 29.8 cfs

Although higher flows typically occur prior to July, portions of the basin are either covered with snow and are still experiencing snow melt, which makes calibration of runoff much more difficult. Therefore, I chose the restricted record, which is also more completely represented in the hydrographs. Plotting the logarithms of these flows versus rank results in an almost straight line between the three points suggesting these points represent the frequent (one to three year) return frequency at this site. That is, 4.2 cfs is close to the one-year return flow, 12.5 cfs is close to the two-year return flow and 29.8 cfs is close to the three-year return flow. This tentative conclusion could easily be a chance occurrence and more data are needed to firm up this conclusion. However, if flows in the upper Muddy Creek project area are similar to those at Bridger Station, and a flow 4.2 cfs represents the minimum flow that is likely to occur in this period each year, the runoff event characterized as the 2-year, one hour flow is probably actually underestimated. The 2-year event should produce runoff closer to the 12.5 cfs flow observed in 2003. This suggests that runoff amounts may be underestimated by the current model. However, we do not know the duration of the event that caused the 12.5 cfs peak. If it had a longer duration than one hour, it could easily produce this amount of runoff with a more frequent event than 2-year event. Therefore, 12.5 cfs is probably an over estimate of the runoff produced by a 2-year, 1-hour storm.

The previous runoff analysis assumes a one-hour storm duration and a local storm scenario. Analysis of the 6 hr. and 24 hr. storms in terms of flow is more complicated because these are likely to be general storms that cover significant portions of the basin. Again, the runoff amounts listed in Table 1 are probably overestimates because the highest precipitation intensities will only occur over a portion of the basin. Methods for estimating areal reductions in precipitation amounts are available, but the computations become more complex and depend on expected storm paths and time of concentration calculations. These computations are beyond the scope of this exercise.

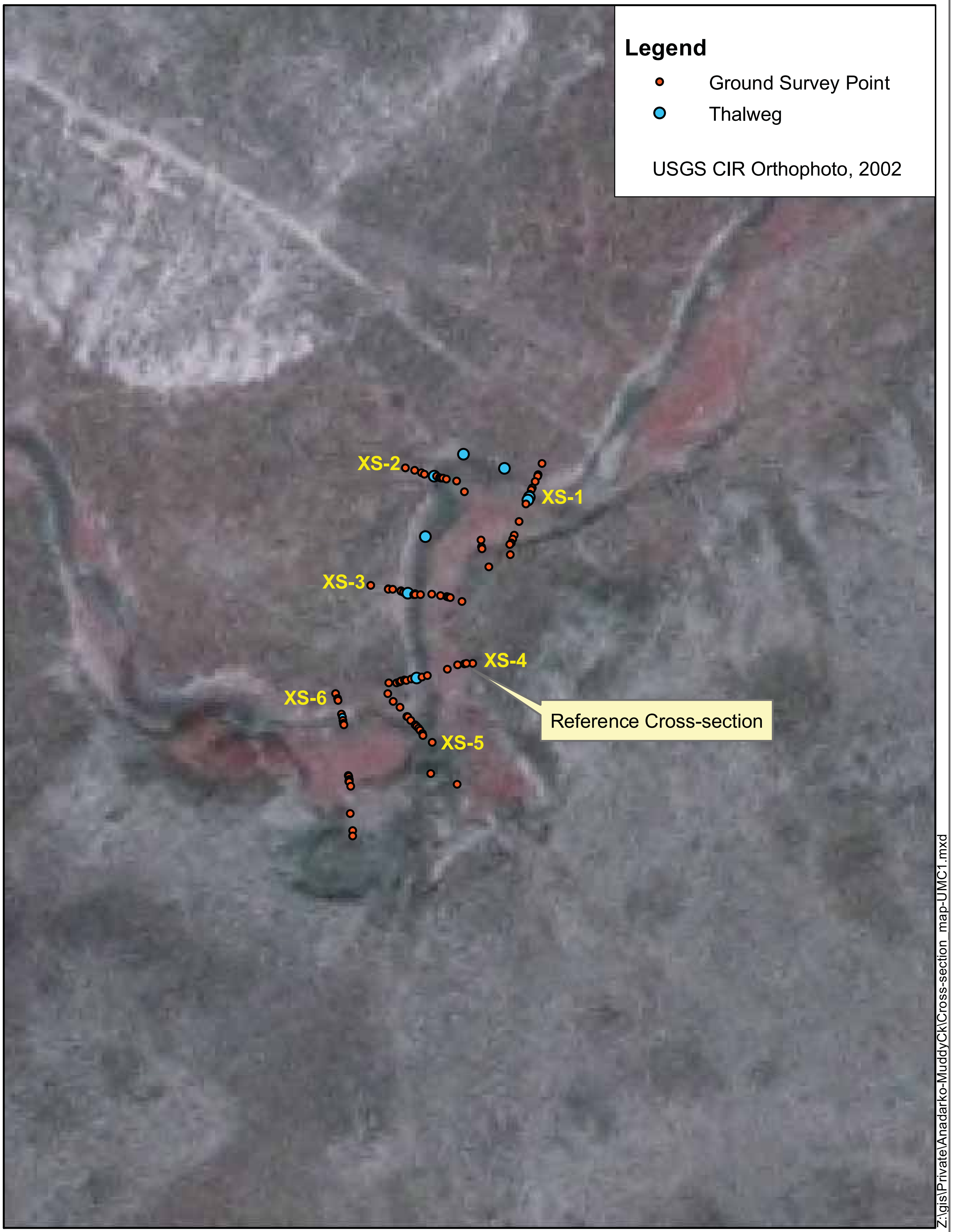
Revisiting the Bridger Pass Station flow records, and correlating them with precipitation records at SNOTEL stations suggests that the 2004 peak flow of 29.8 cfs in the July-October period has a recurrence interval at least as infrequent as four years rather than three years and possibly much less frequent. The storm that caused this peak runoff occurred from September 20^{th} to September 22nd, 2004, at the Bridger Pass Station. The Sage Creek Basin precipitation gage measured 1-inch of precipitation and the Divide Peak precipitation gage measured 2.2 inches of precipitation in a one day period during this three-day event. Analysis of the precipitation records at Sage Creek Basin suggests that a 1 inch event corresponds to a return frequency of at least four-years in the July through October time frame. Analysis of the longer period of record at Divide Peak suggests that 2.2 inches of precipitation corresponds to a return period of at least 42 years, longer than this station's 29 year period of record. Although it is not known how well these gages represented precipitation in upper Muddy Creek during this storm, it is likely that the 30 cfs peak observed at the Bridger Pass Station corresponds to an event that is no more frequent than a four year recurrence interval and possibly much less frequent. If this type of storm is truly an infrequent event in the summer/early fall period, this frequency analysis supports our hypothesis based on runoff calculations that relatively frequent (two year or less return interval) events on upper Muddy Creek are considerably less than 30 cfs.

References:

Chow, V. T., 1964. Applied Hydrology, Chapter 21. McGraw-Hill.

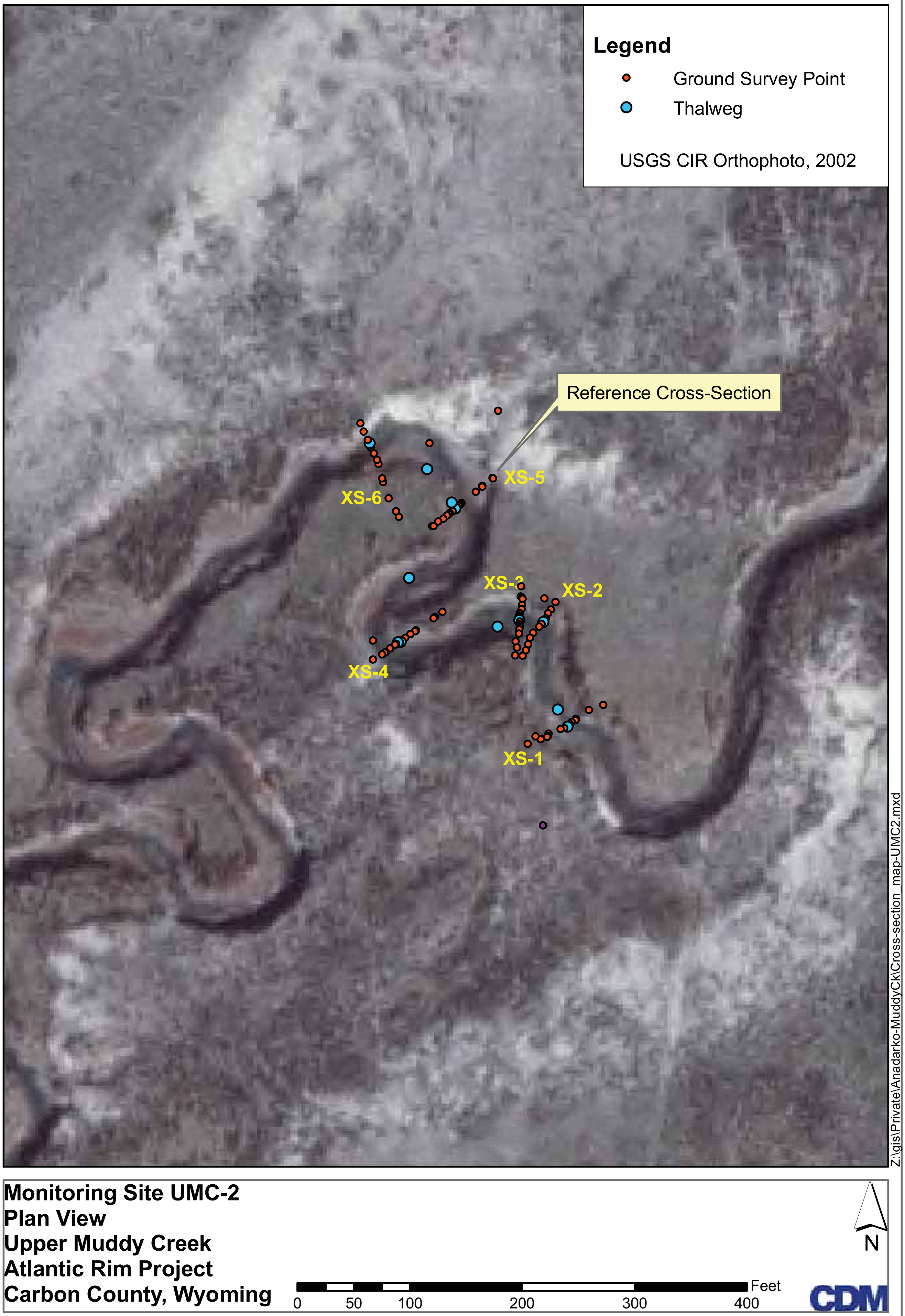
Miller, J.F., R.H. Frederick, R.J. Tracey, 1973. Precipitation Frequency Atlas of the Western United States, Volume 2 – Wyoming. National Oceanic and Atmospheric Administration.

Appendix C
Monitoring Site Maps and Photos

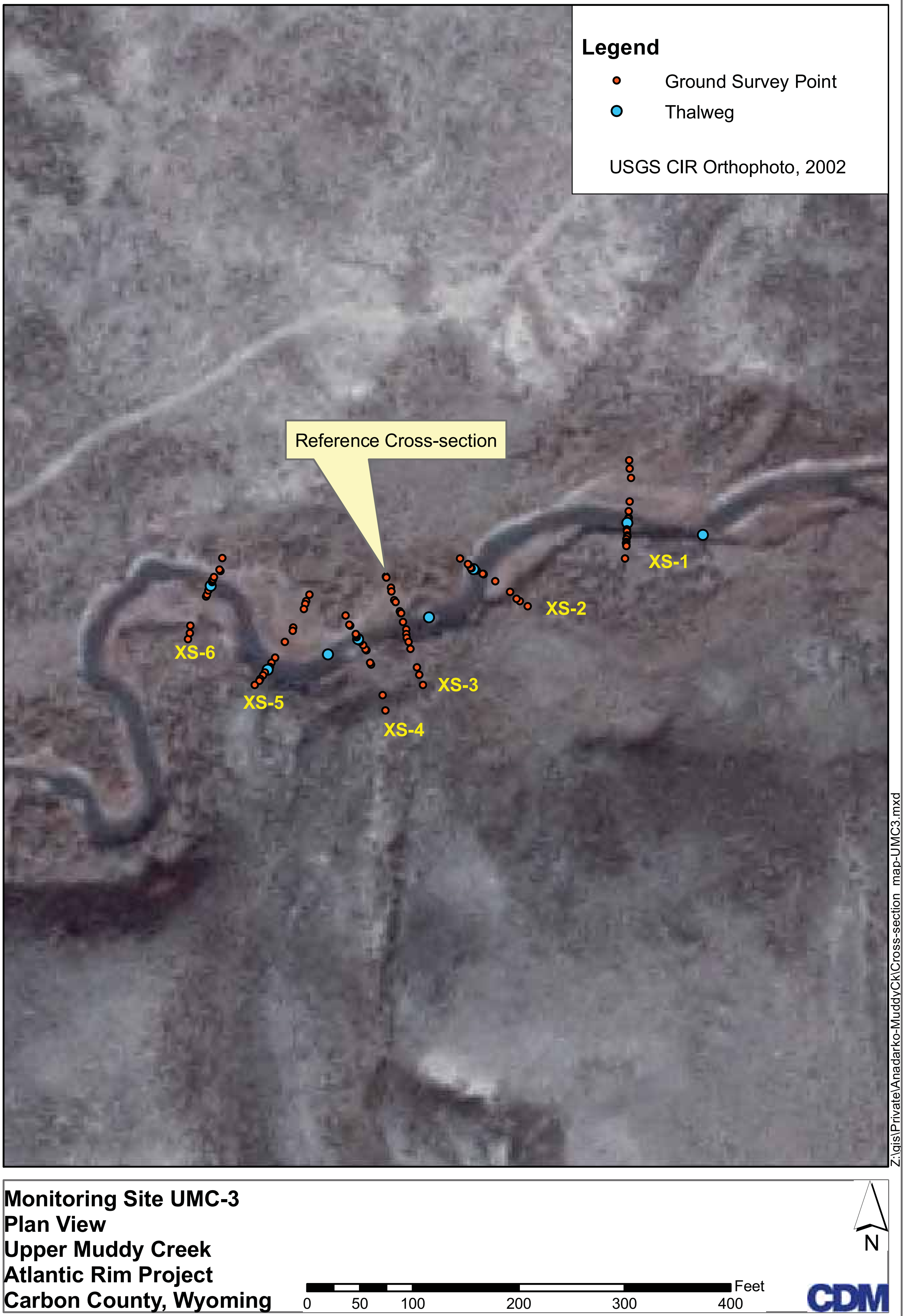


Monitoring Site UMC-1
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming

CDM

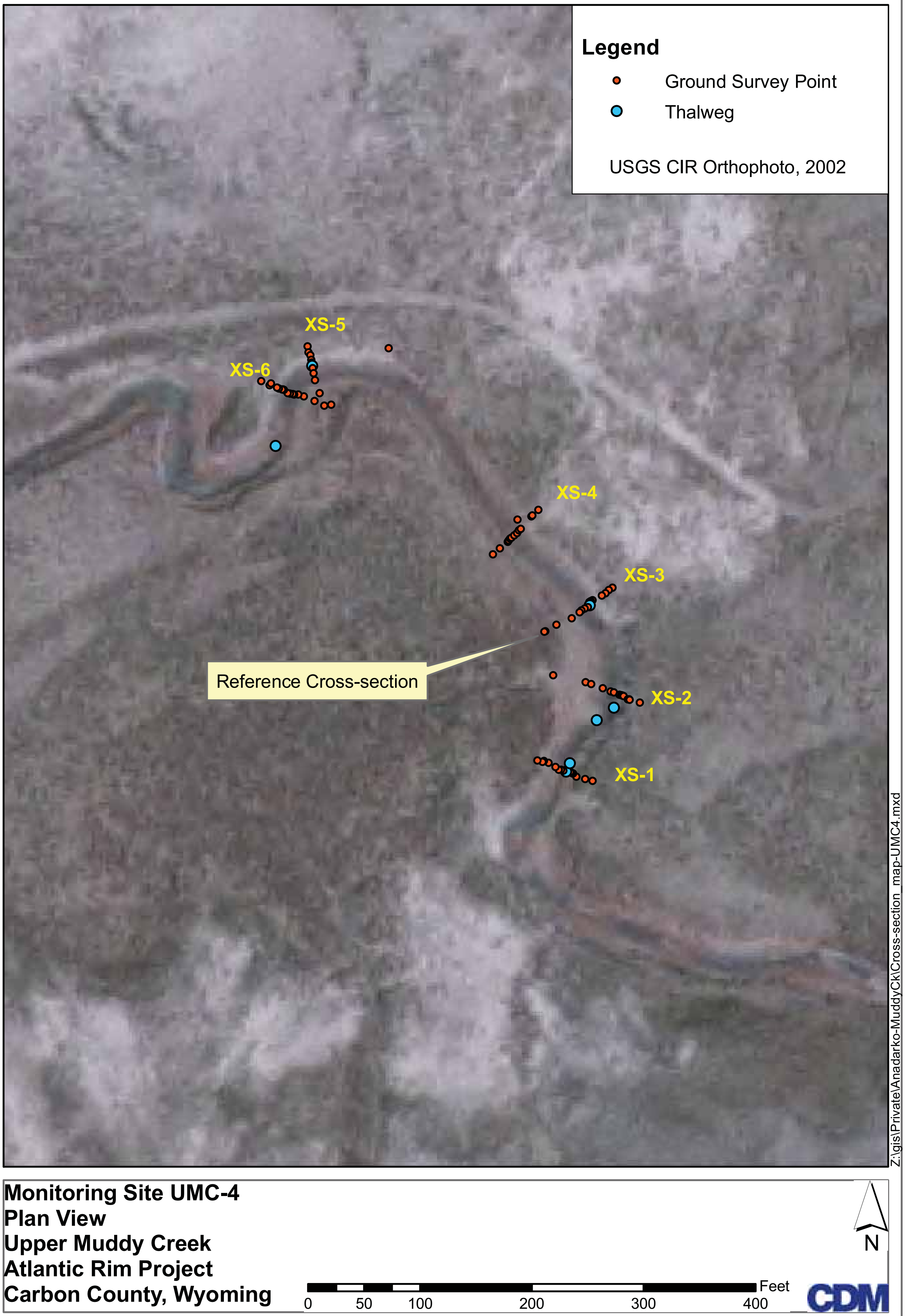


Monitoring Site UMC-2
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming

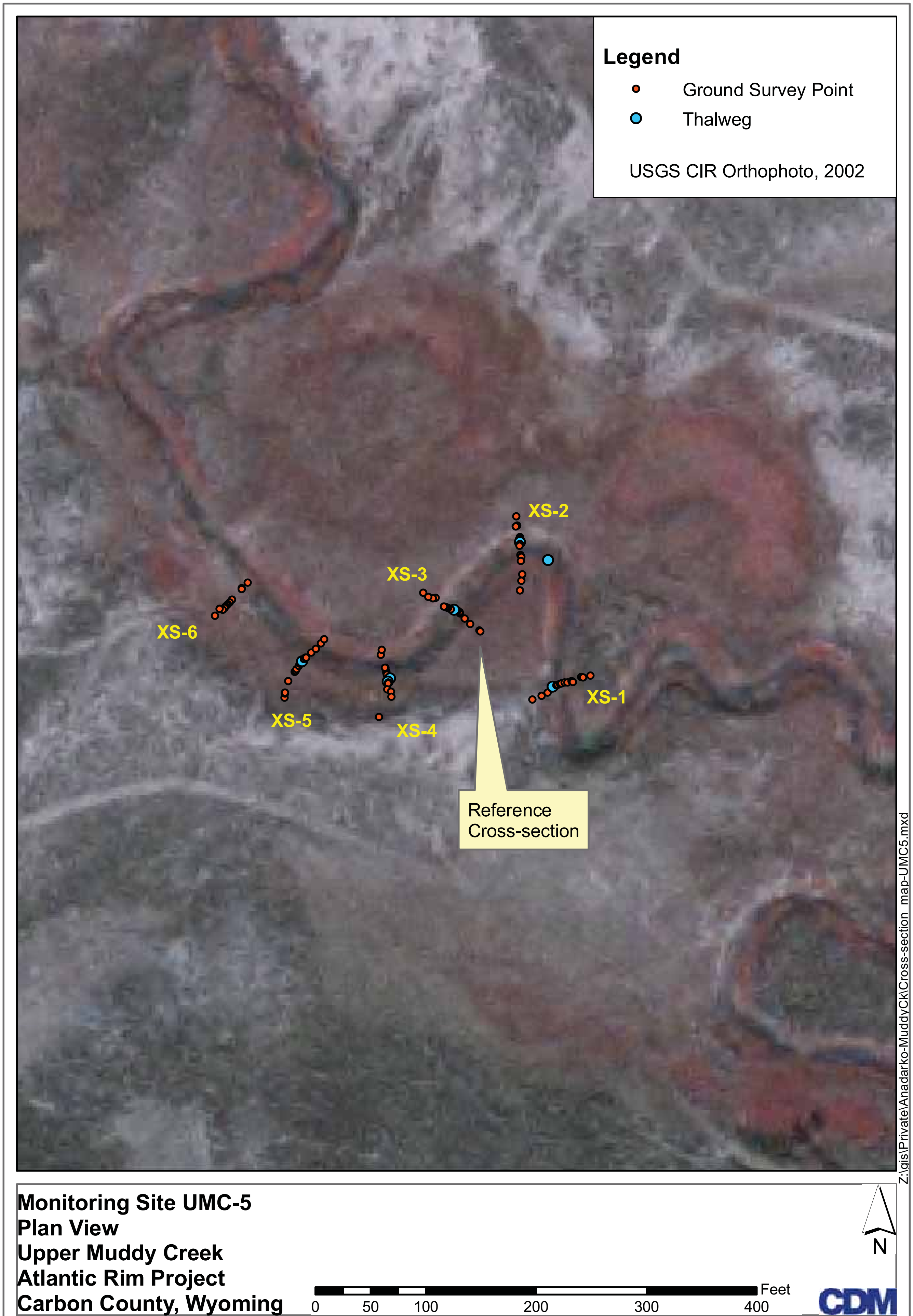


Monitoring Site UMC-3
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming

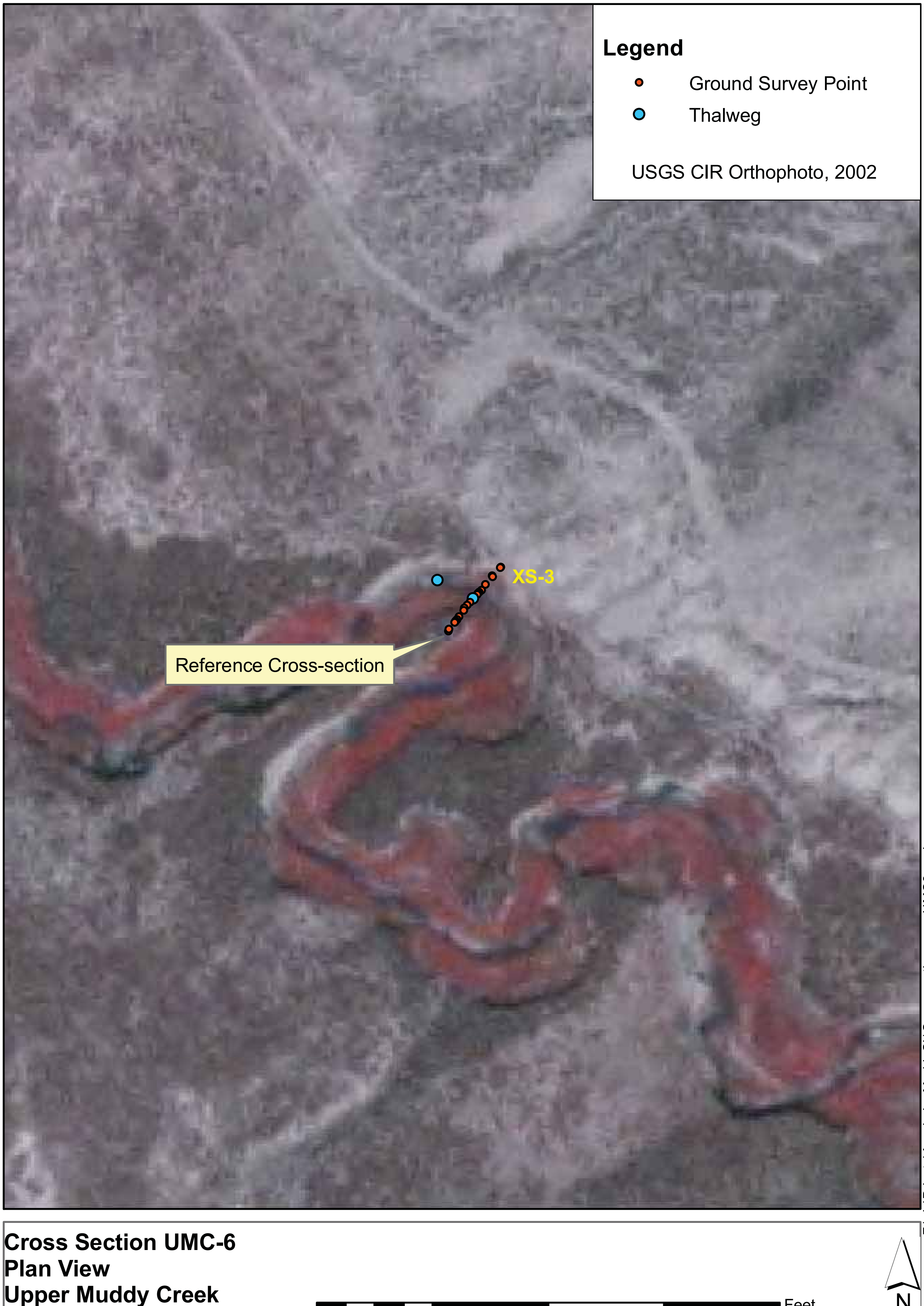
CDM



Monitoring Site UMC-4
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming



Monitoring Site UMC-5
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming



Z:\gis\Private\Anadarko-MuddyCk\Cross-section map-UMC6.mxd

Cross Section UMC-6
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming

CDM

REFERENCE SECTION PHOTOS


UMC-1, XS-4, View Upstream


UMC-1, XS-4, View Downstream


UMC-1 XS-4


UMC-2, XS-5, Right Bank


UMC2, XS-5, View Upstream


UMC2, XS-5, View Downstream

UMC 3, XS-3, View Upstream

UMC3, XS-3, View Downstream

UMC3, XS-3 Right Bank

UMC4, XS-3

UMC4, XS-3, View Upstream

UMC4, XS-3, View Downstream

UMC5, XS-3, View Upstream

UMC5, XS-3, View Downstream

UMC5, XS-3, Right Bank

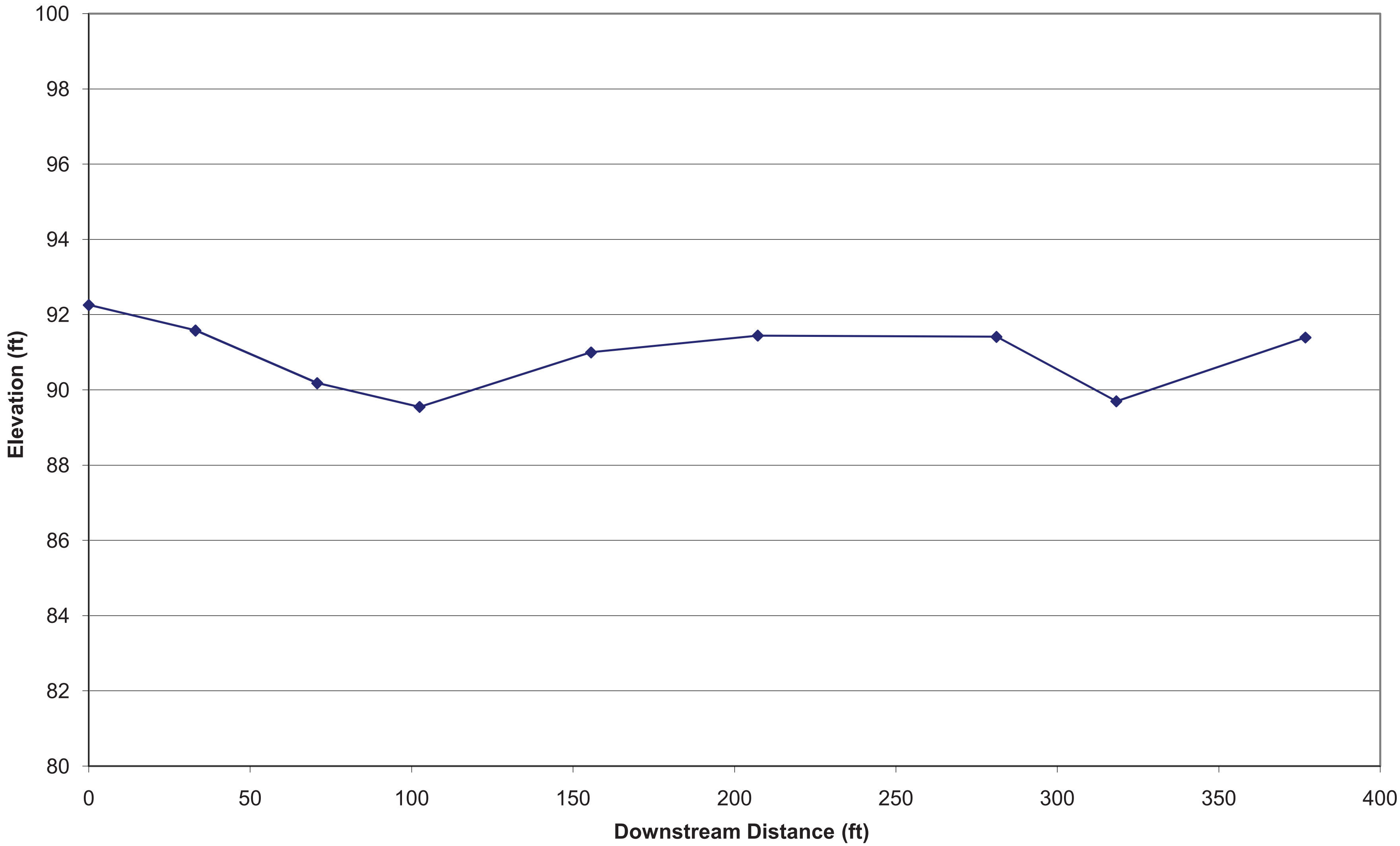
UMC6, XS-3, Right Bank

UMC6, XS-3, View Upstream

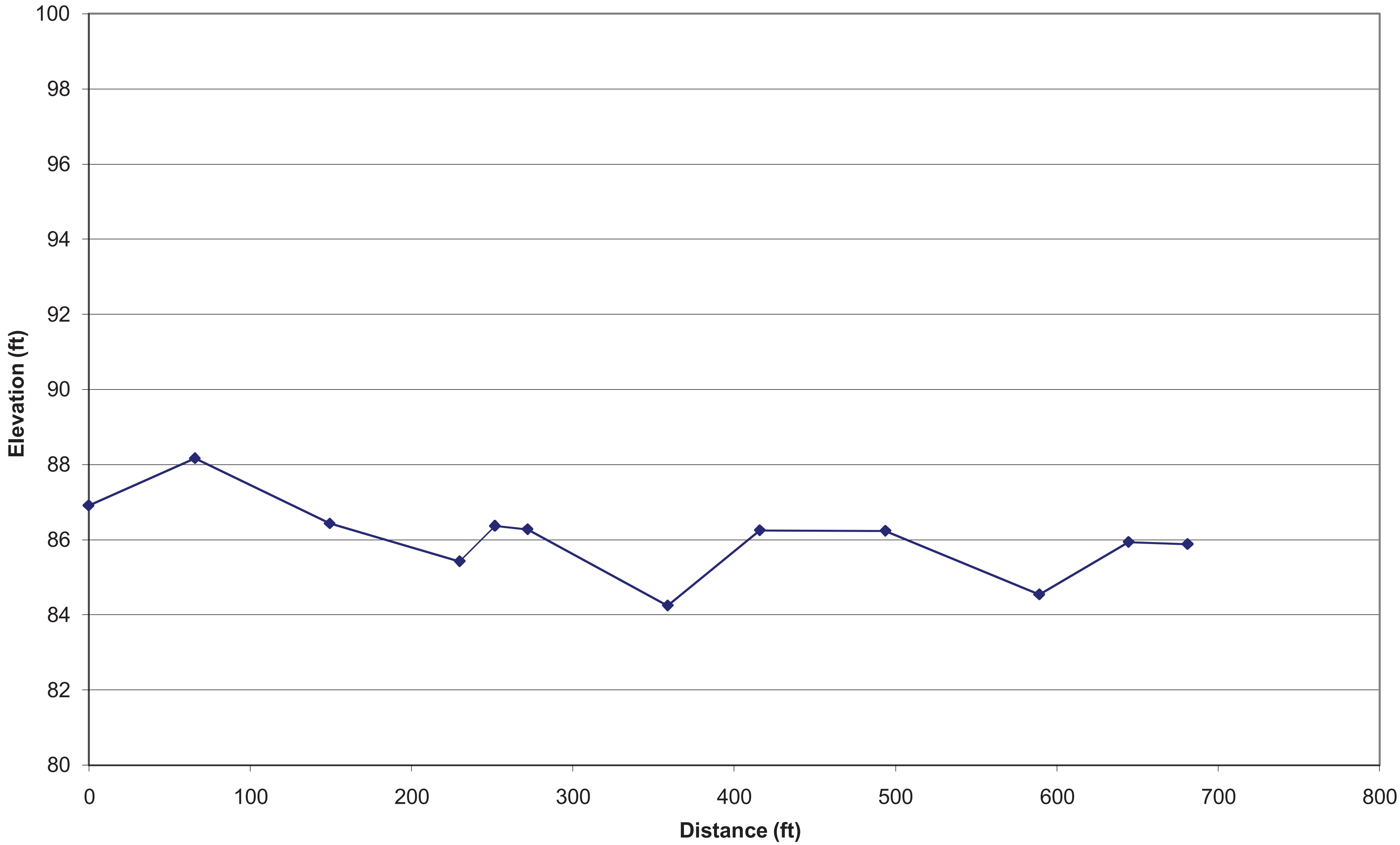
UMC6, XS-3, View Downstream

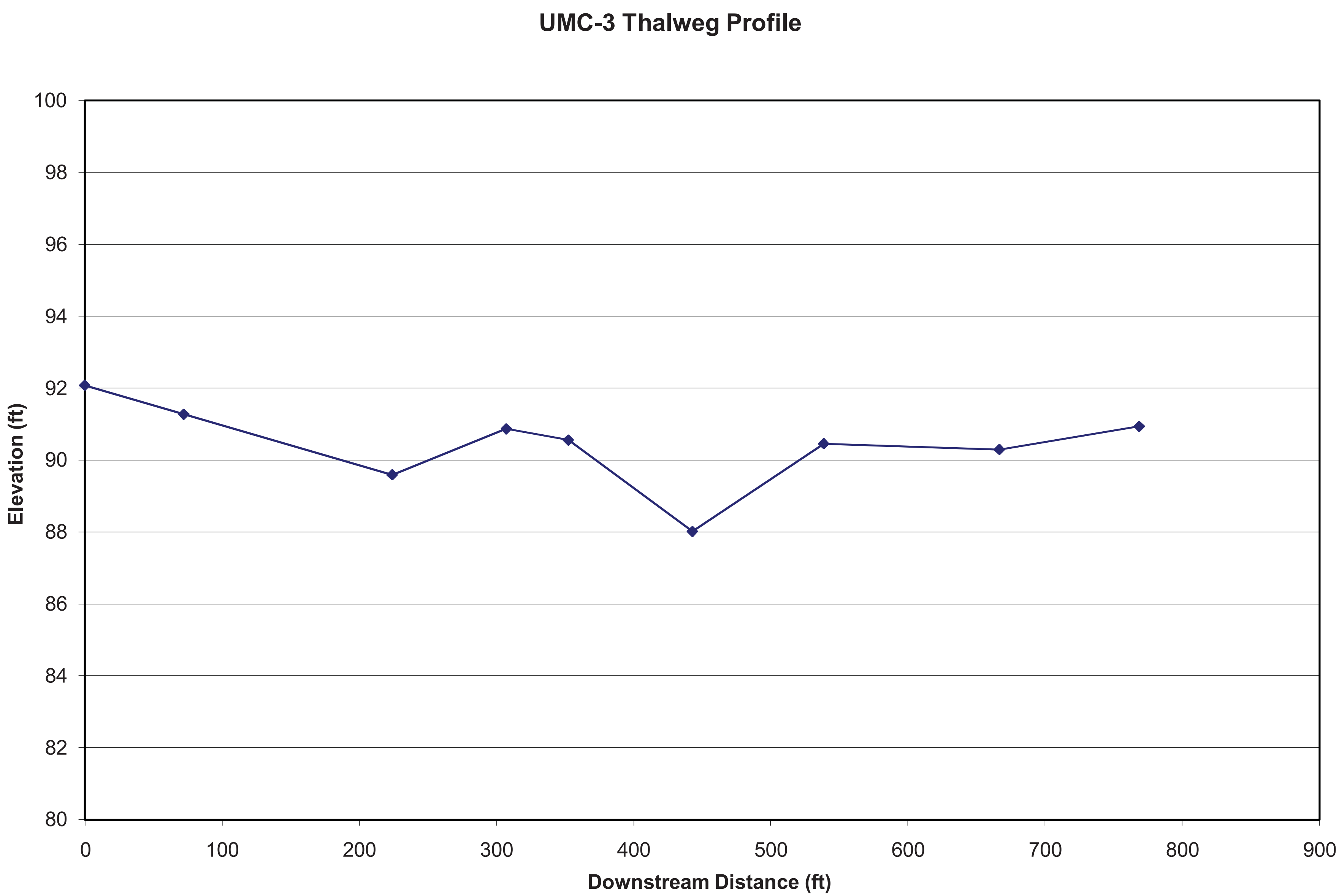
Appendix D
Thalweg Profiles

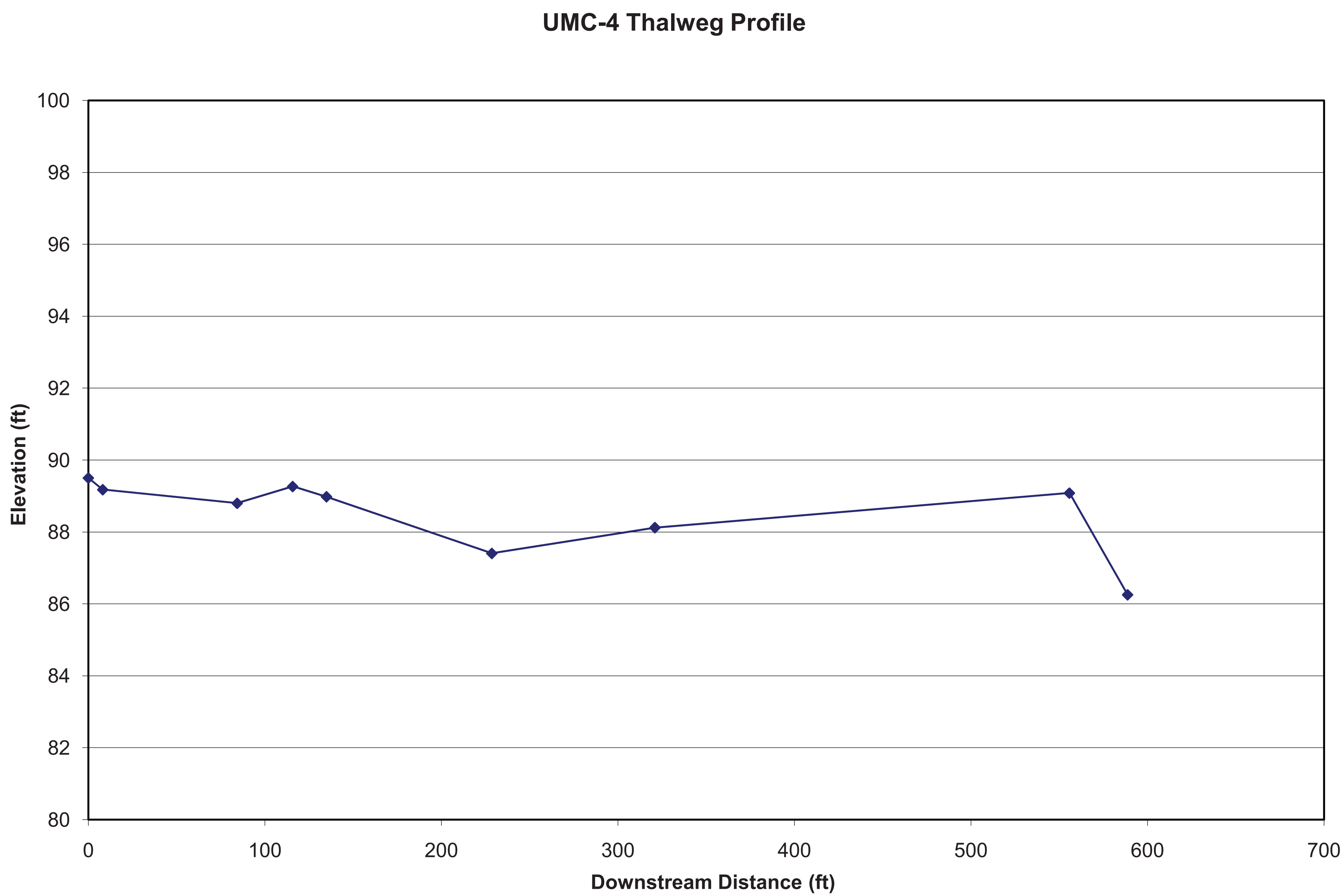
UMC-1
Thalweg Profile

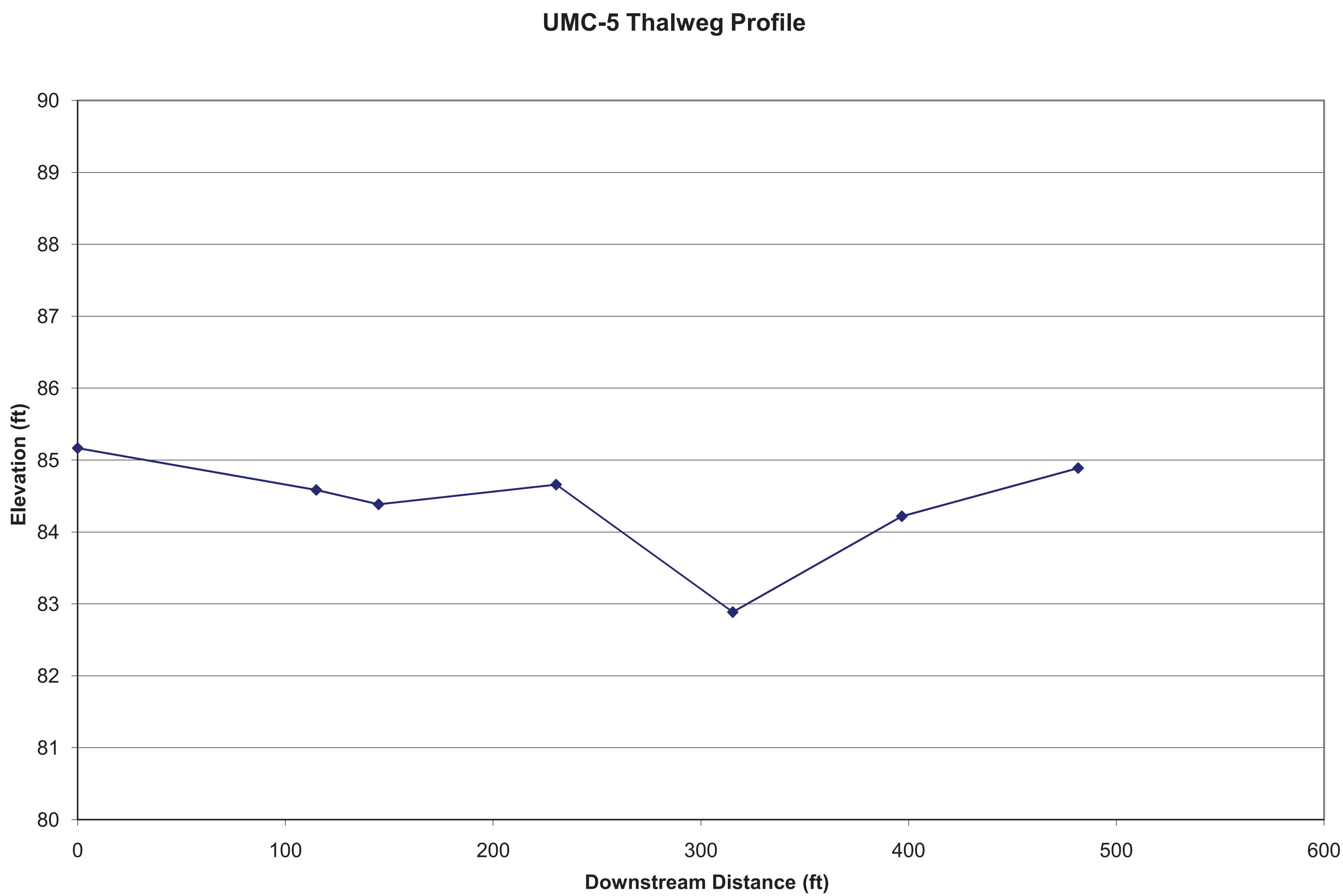


UMC-2 Thalweg Profile

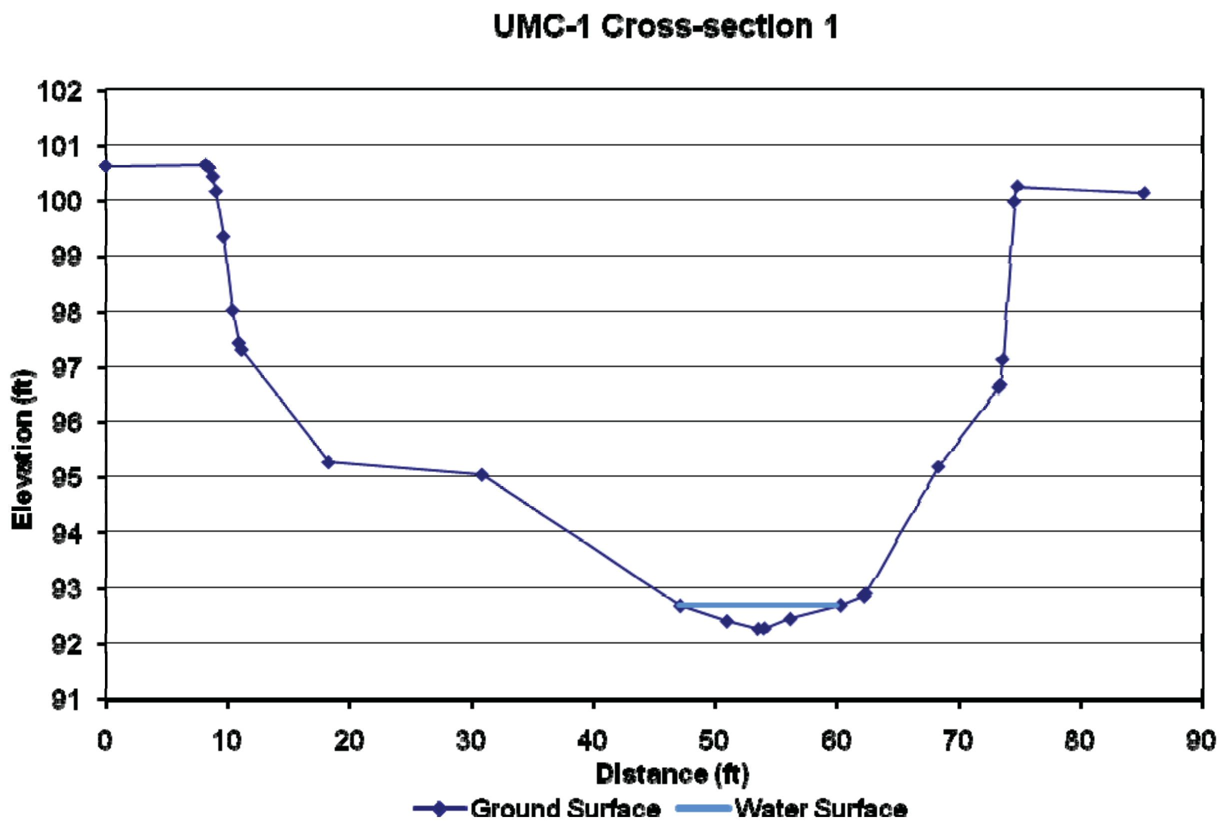



UMC-3 Thalweg Profile
Elevation (ft)
100
98
96
94
92
90
88
86
84
82
80
0
100
200
300
400
500
600
700
800
900
Downstream Distance (ft)


UMC-4 Thalweg Profile
Elevation (ft)
100
98
96
94
92
90
88
86
84
82
80
0
100
200
300
400
500
600
700
Downstream Distance (ft)


UMC-5 Thalweg Profile
Elevation (ft)
90
89
88
87
86
85
84
83
82
81
80
0
100
200
300
400
500
600
Downstream Distance (ft)

Appendix E
Cross-sections, BEHI Calculations and Bank Photos



UMC-1, Cross-section 1, Left bank

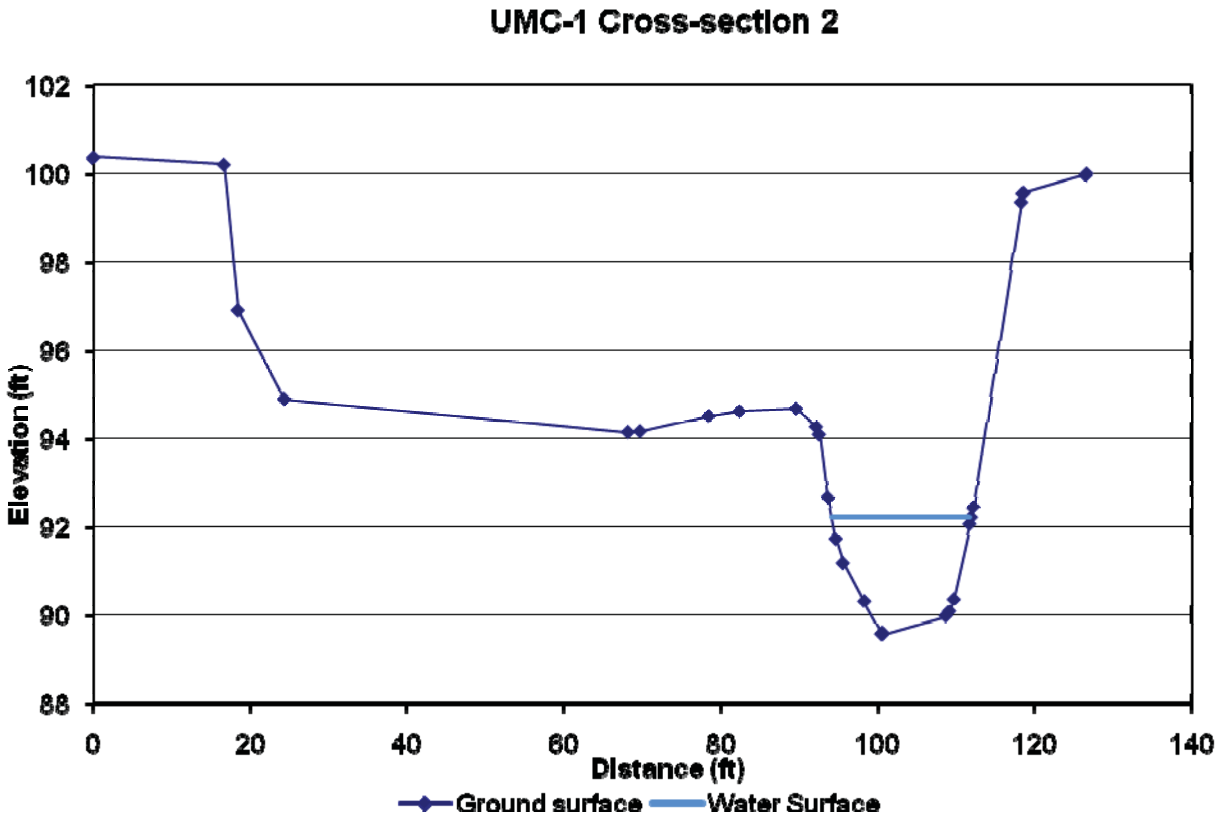
Category	**Value**	**Index**
Bank ht/Bankfull Depth	1.5	5.9
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	60	3.9
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	36.8
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 1: UMC1, XS-1, Left Bank

UMC-1, Cross-section 1, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.7	6.1
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	80-90	6.5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	39.6
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

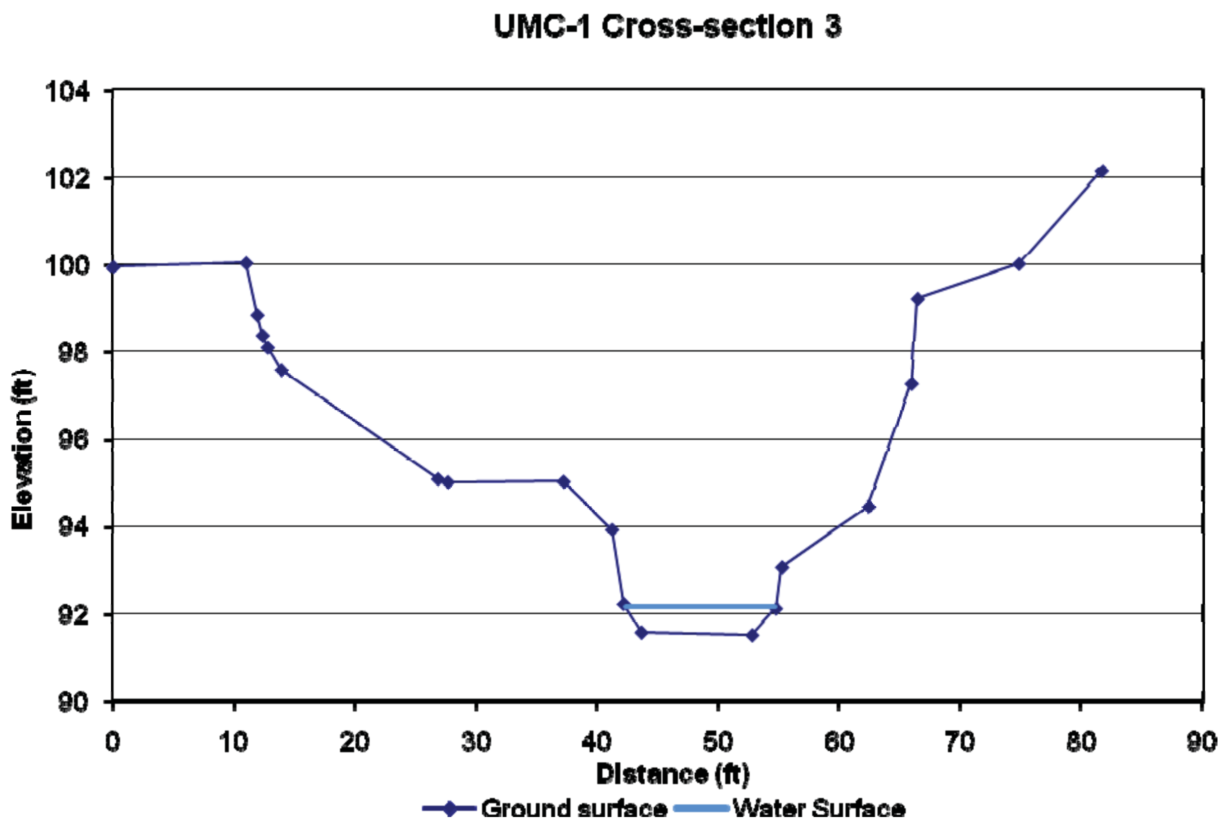
Photo2: UMC1, XS-1, Right Bank



UMC-1, Cross-section 2, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.7	6.2
Root Depth/Bank ht	0.2	6.5
Root Density	<5%	10
Bank Angle	60-70	5
Surface Protection	<5%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	37.7
BEHI Rating	--	**High**
Radius of Curvature	23	--
Bankfull Width	90.3	--
Rc/W	0.255	--
NBS Rating	--	**Extreme**

Photo 3: UMC1, XS-2, Right Bank


UMC-1 Cross-section 3
104
102
100
98
96
94
92
90
Elevation (ft)
0
10
20
30
40
50
60
70
80
90
Distance (ft)
Ground surface
Water Surface

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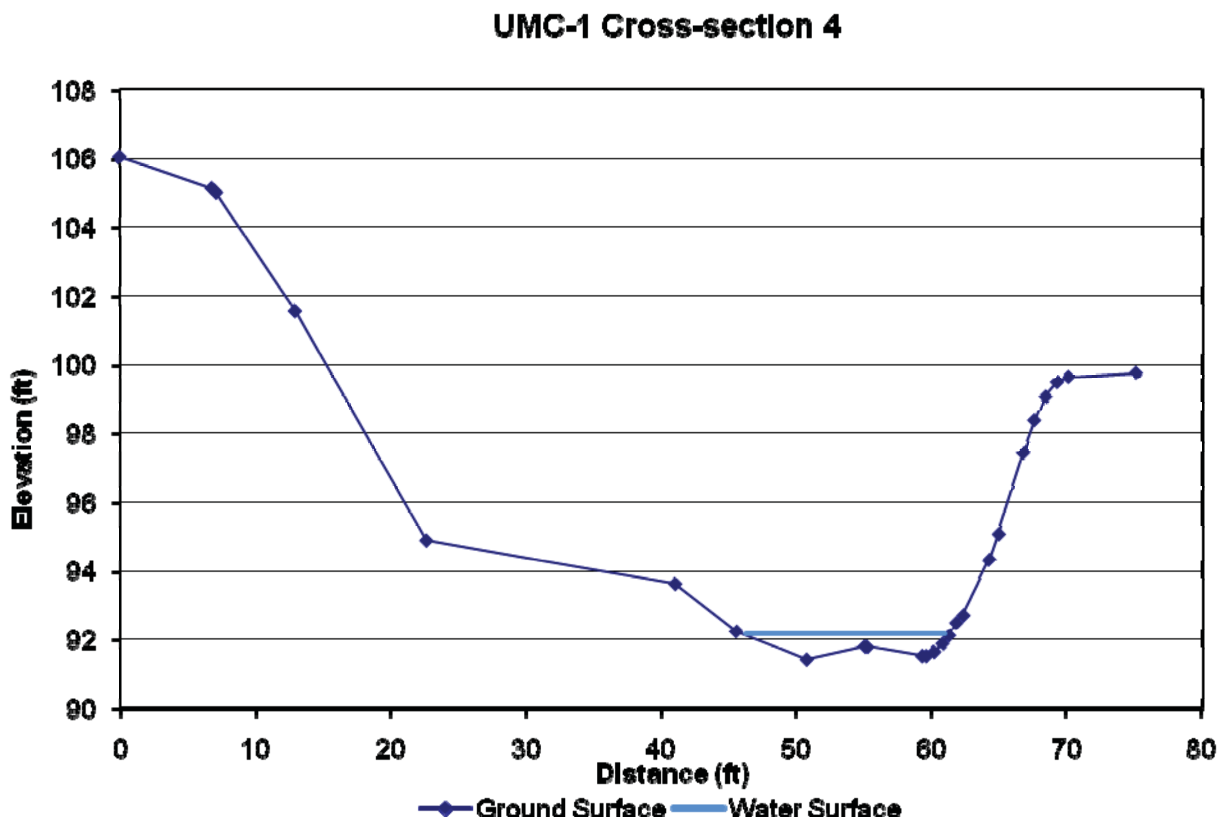

UMC-1, Cross-section 4, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.5	5.9
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	80-90	7
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	39.9
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 4: UMC1, XS-4, Right Bank

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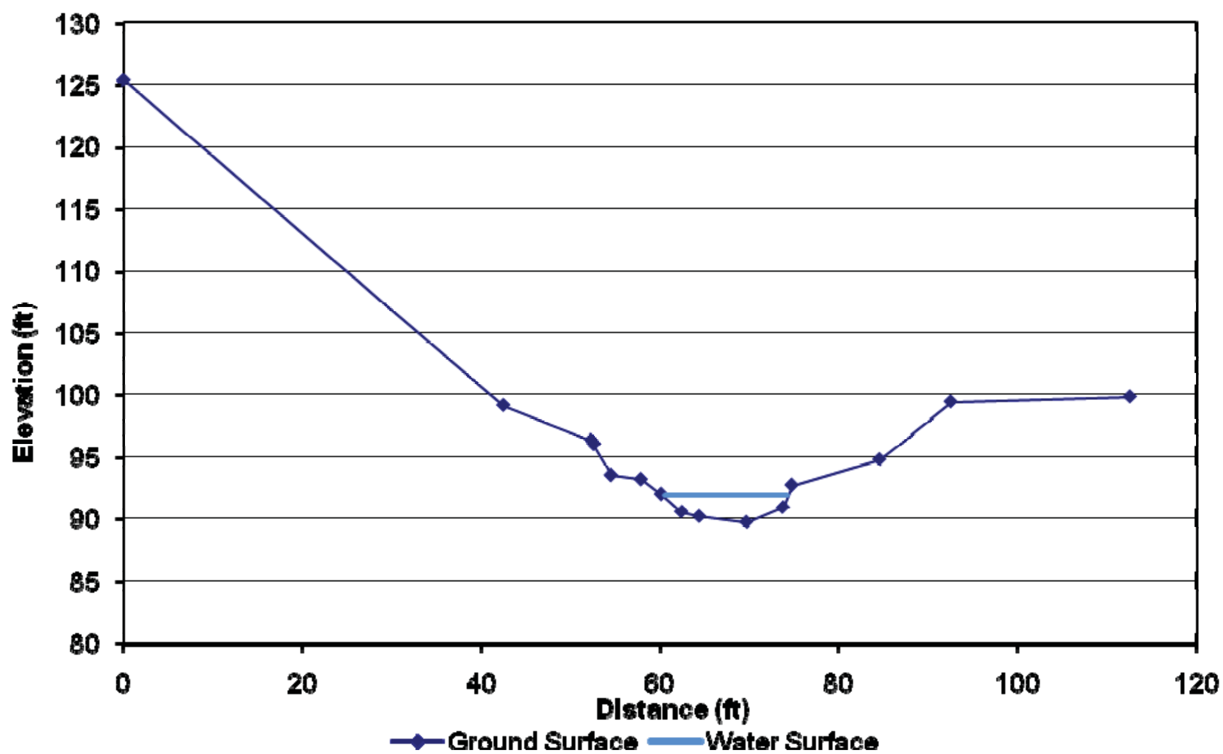
UMC-1 Cross-section 5



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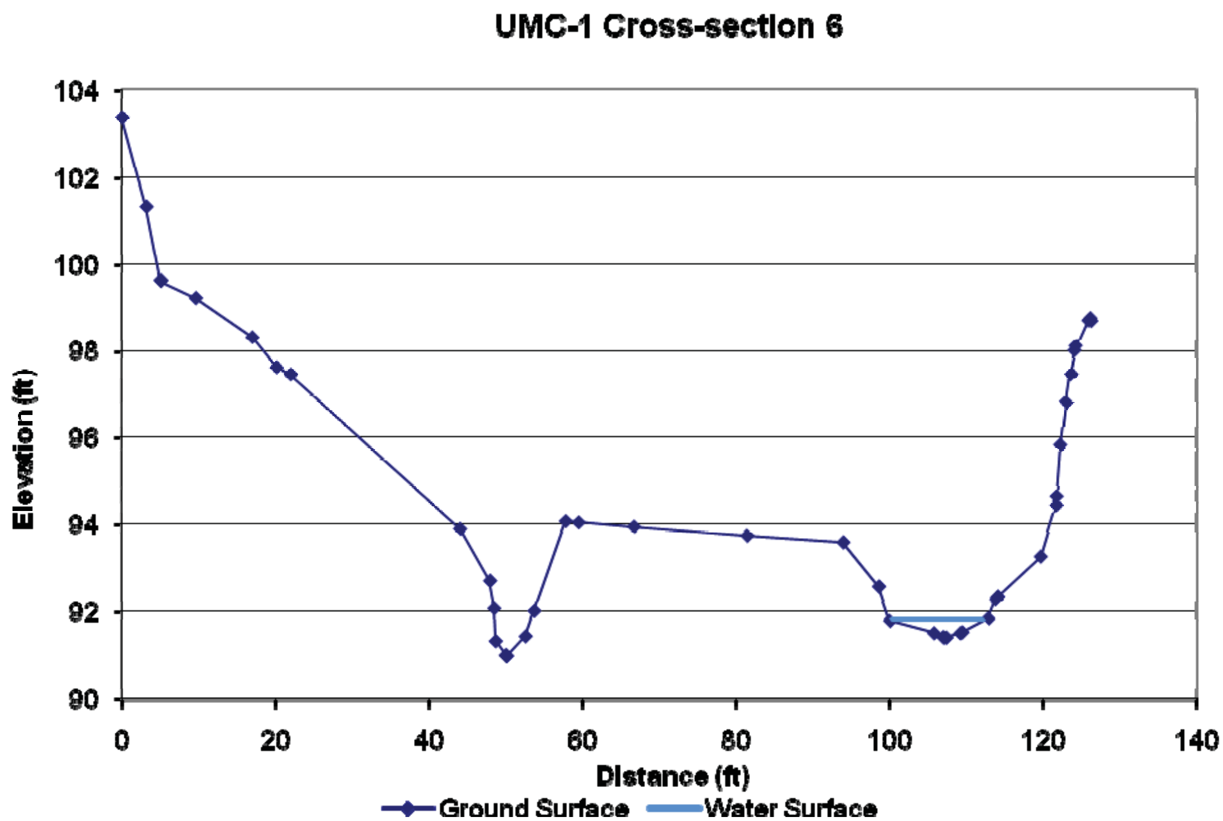


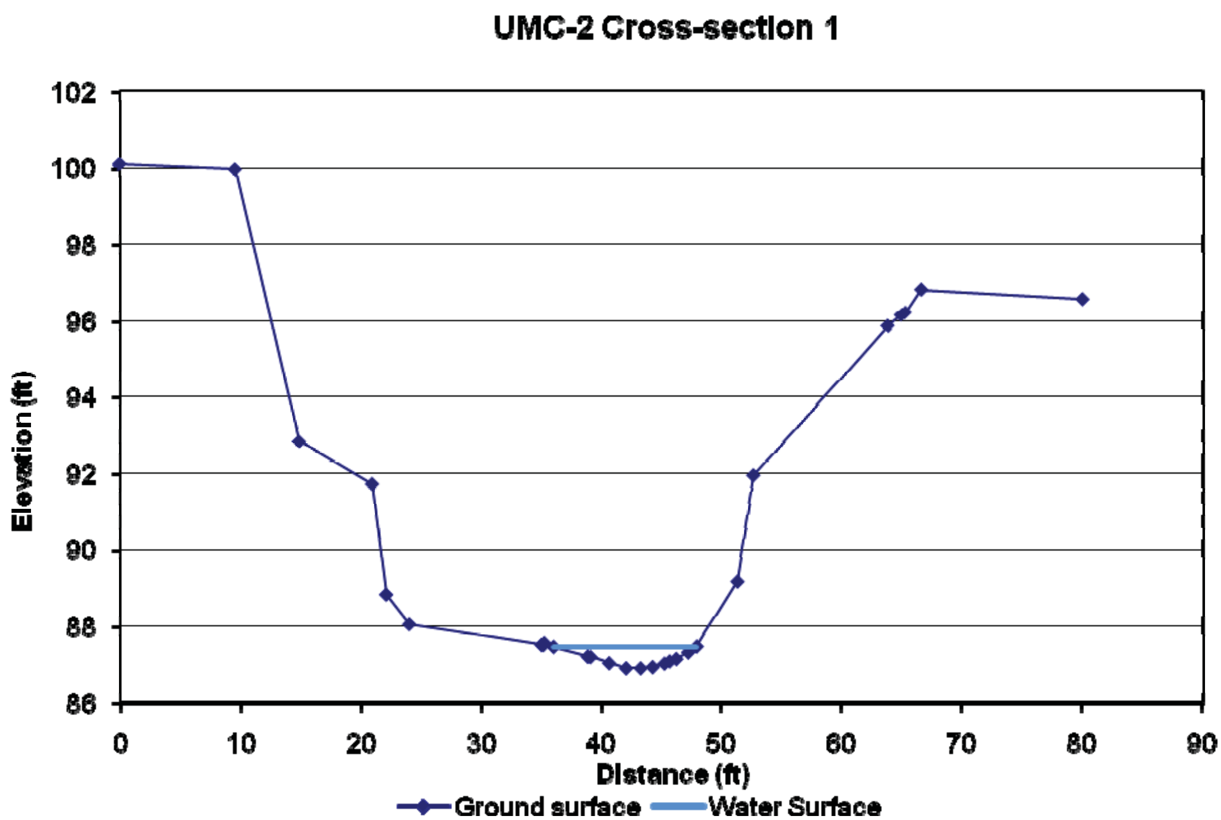
UMC-1, Cross-section 6, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	1	1
Root Depth/Bank ht	0.4	5
Root Density	<5%	10
Bank Angle	45-50	3
Surface Protection	10-20%	8
Bank Material	Silt	0
Stratification	None	0
Index sum	--	27
BEHI Rating	--	**Moderate**
Radius of Curvature	50	--
Bankfull Width	63	--
Rc/W	0.8	--
NBS Rating	--	**Extreme**

UMC-1, Cross-section 6, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	2.4	8.5
Root Depth/Bank ht	0.4	5
Root Density	<5%	10
Bank Angle	81-90	7
Surface Protection	<10%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	40.5
BEHI Rating	--	**Very High**
Radius of Curvature	Inside of bank	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 6: UMC1, XS-6, Right Bank



UMC-2, Cross-section 1, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	2.25	8.5
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	81-90	7
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	44
BEHI Rating	--	**Very High**
Radius of Curvature	47	--
Bankfull Width	32	--
Rc/W	1.5	--
NBS Rating	--	**Extreme**

Photo 7: UMC2, XS-1, Left Bank

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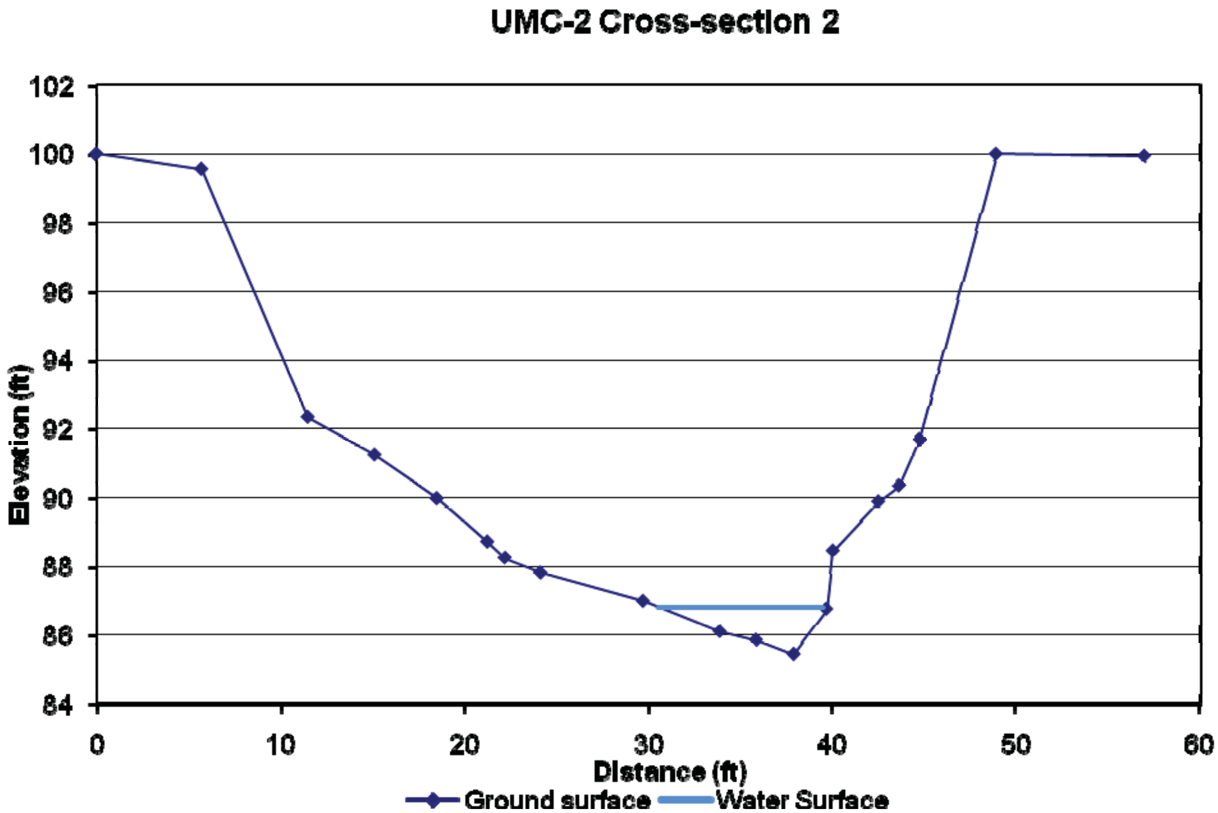

UMC-2, Cross-section 2, Right bank

Category	**Value**	**Index**
Bank ht/Bankfull Depth	2.25	8.5
Root Depth/Bank ht	0.3	5.9
Root Density	<5%	10
Bank Angle	72	5
Surface Protection	<5%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	39.4
BEHI Rating	--	**High**
Radius of Curvature	37	--
Bankfull Width	24	--
Rc/W	1.5	--
NBS Rating	--	**Very High**

Photo 8: UMC2, XS-2, Right Bank

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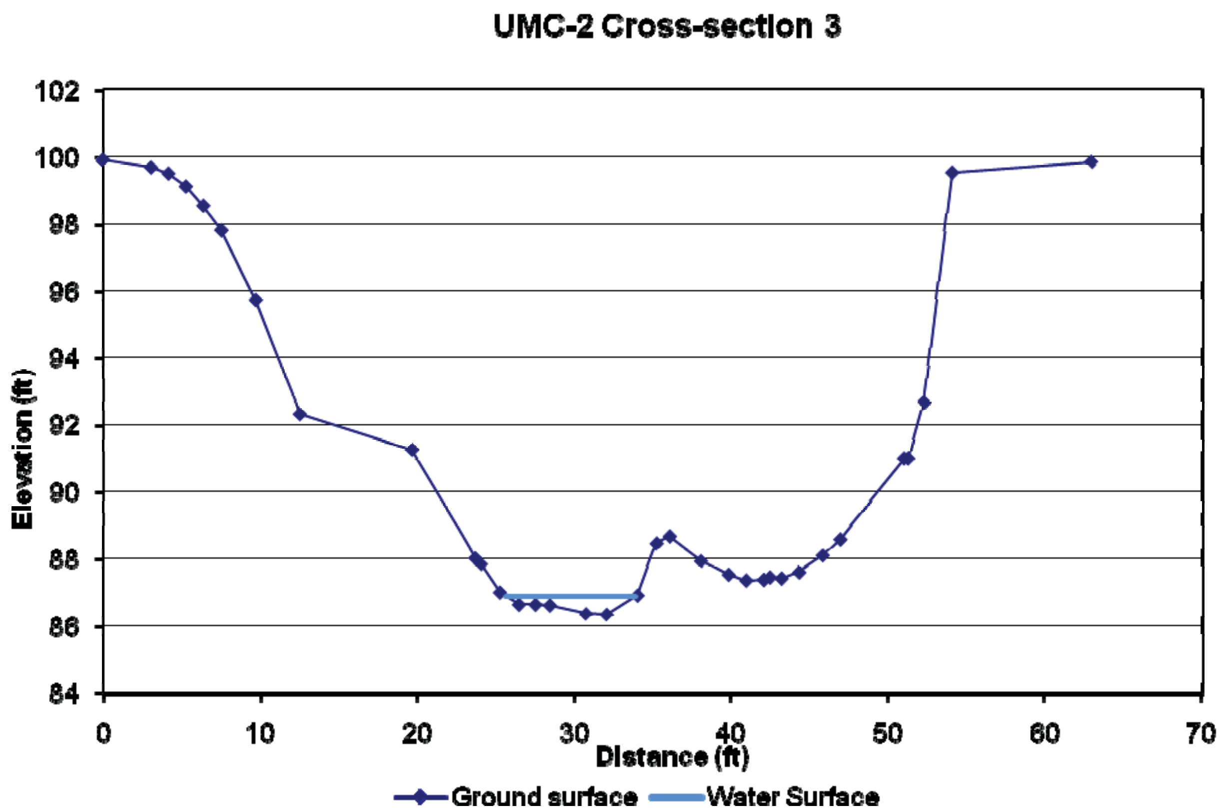
UMC-2 Cross-section 3
Elevation (ft)
102
100
98
96
94
92
90
88
86
84
0
10
20
30
40
50
60
70
Distance (ft)
Ground surface
Water Surface

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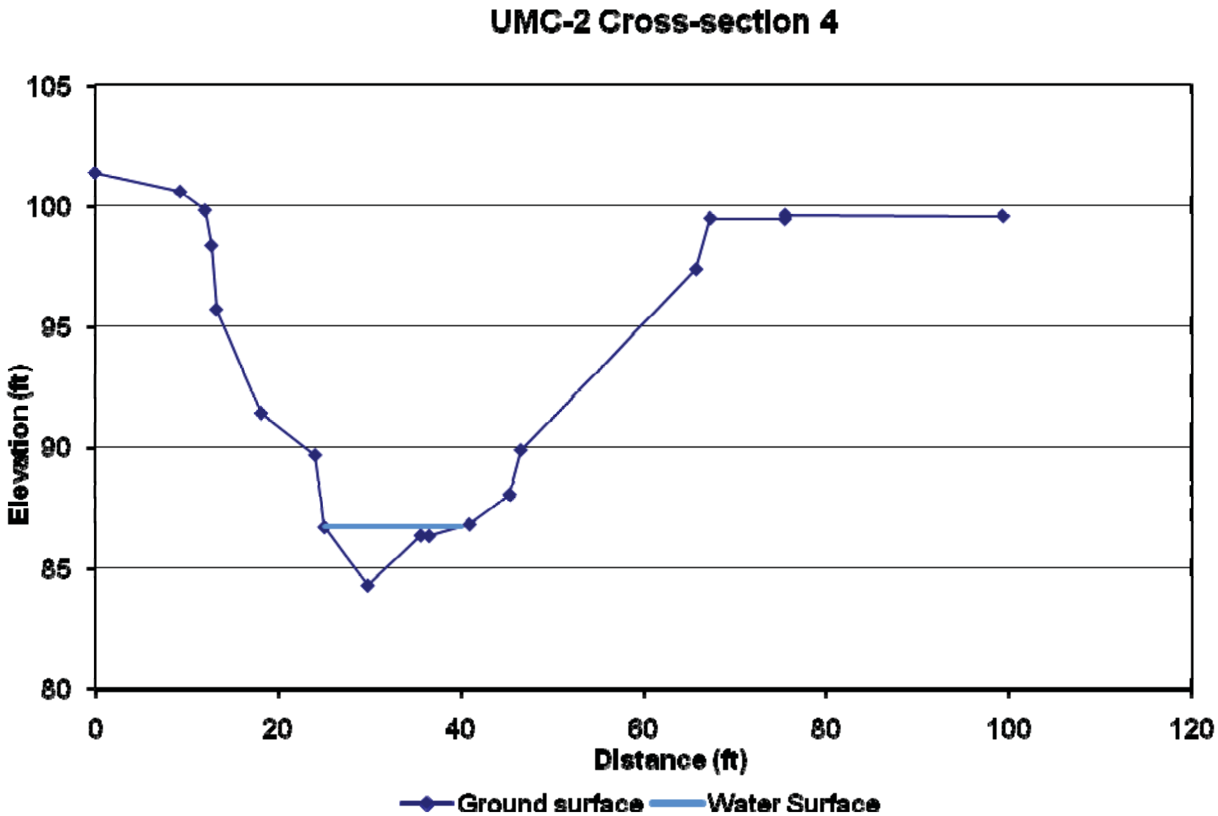

UMC-2, Cross-section 4, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	1.5	5.9
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	60-80	5
Surface Protection	<5%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	37.9
BEHI Rating	--	**High**
Radius of Curvature	32	--
Bankfull Width	23	--
Rc/W	1.4	--
NBS Rating	--	**Extreme**

Photo 9: UMC2, XS-4, Left Bank

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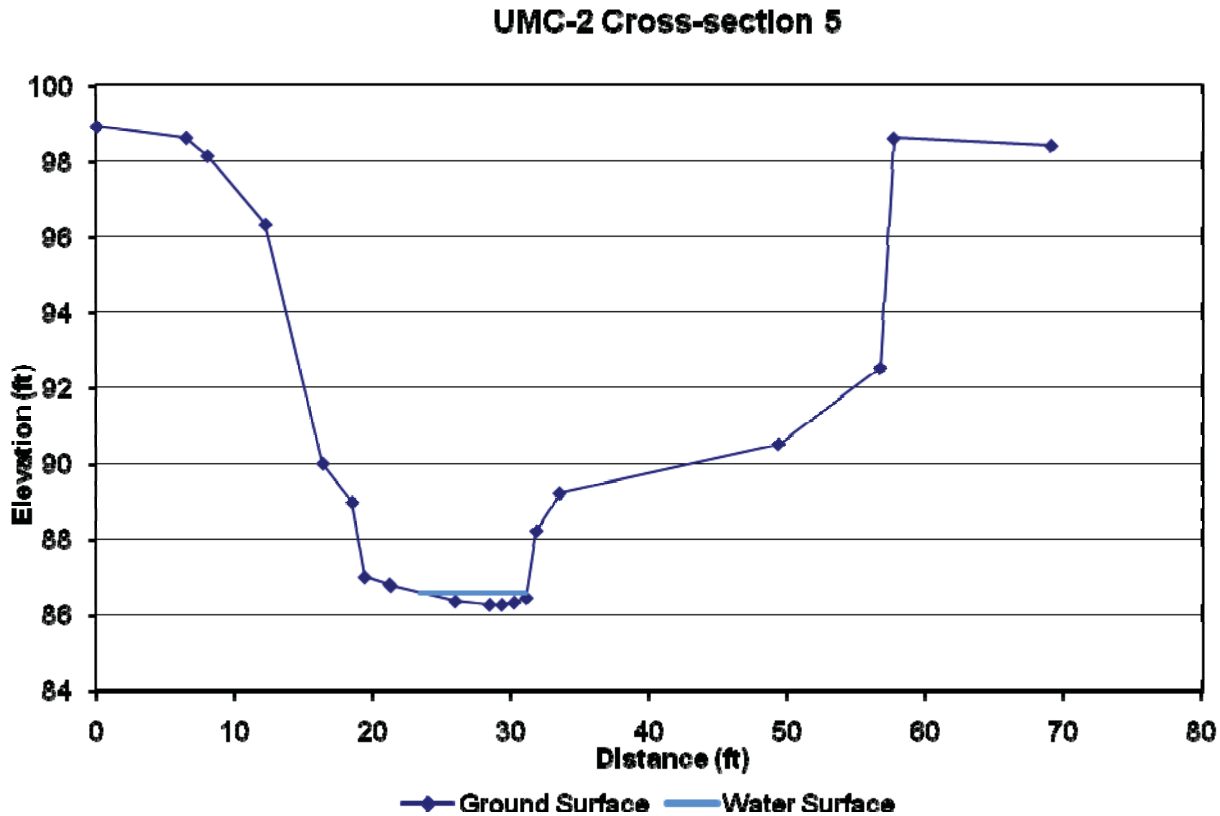

UMC-2, Cross-section 5, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	2.125	8.2
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	73	5.2
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	41.9
BEHI Rating	--	**Very High**
Radius of Curvature	73	--
Bankfull Width	33	--
Rc/W	2.2	--
NBS Rating	--	**Moderate**

Photo 10: UMC2, XS-5, Right Bank

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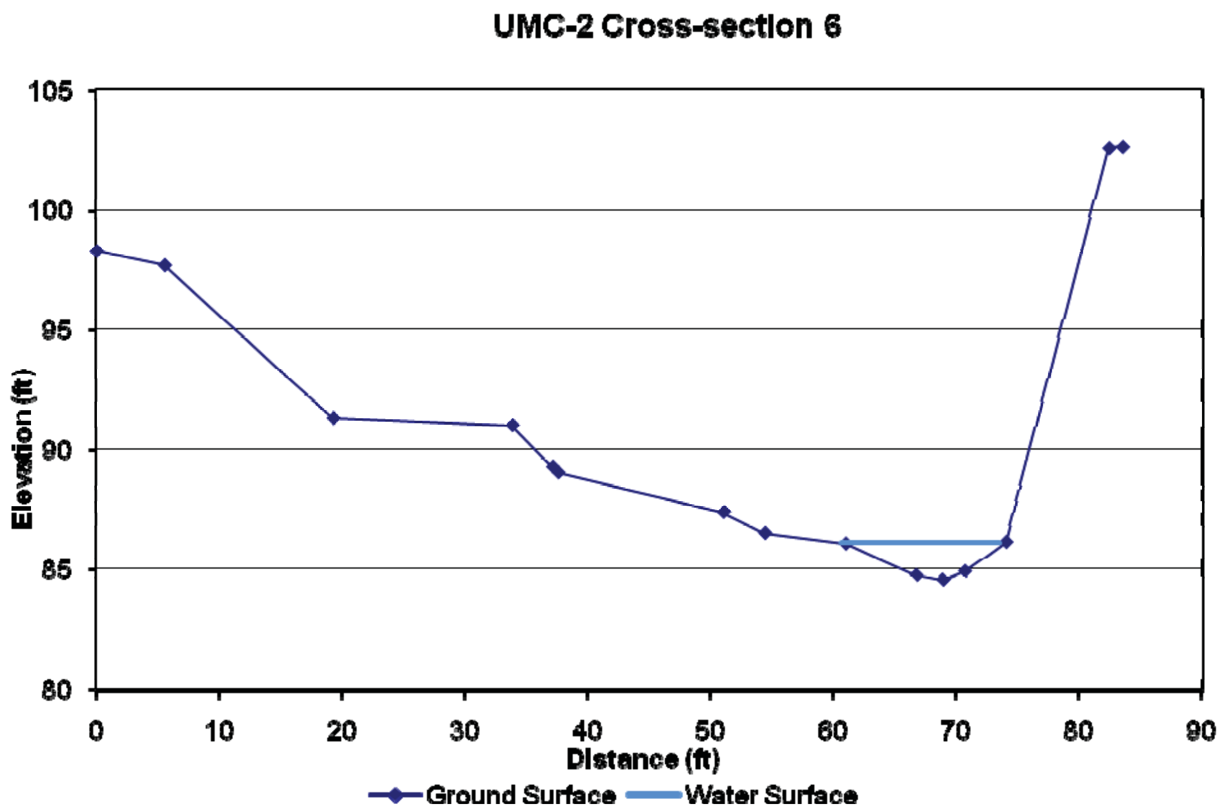

UMC-2, Cross-section 6, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	4.3	10
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	80-90	7
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	45.5
BEHI Rating	--	**Very High**
Radius of Curvature	45	--
Bankfull Width	37	--
Rc/W	1.2	--
NBS Rating	--	**Extreme**

Photo 11: UMC2, XS-6, Right Bank

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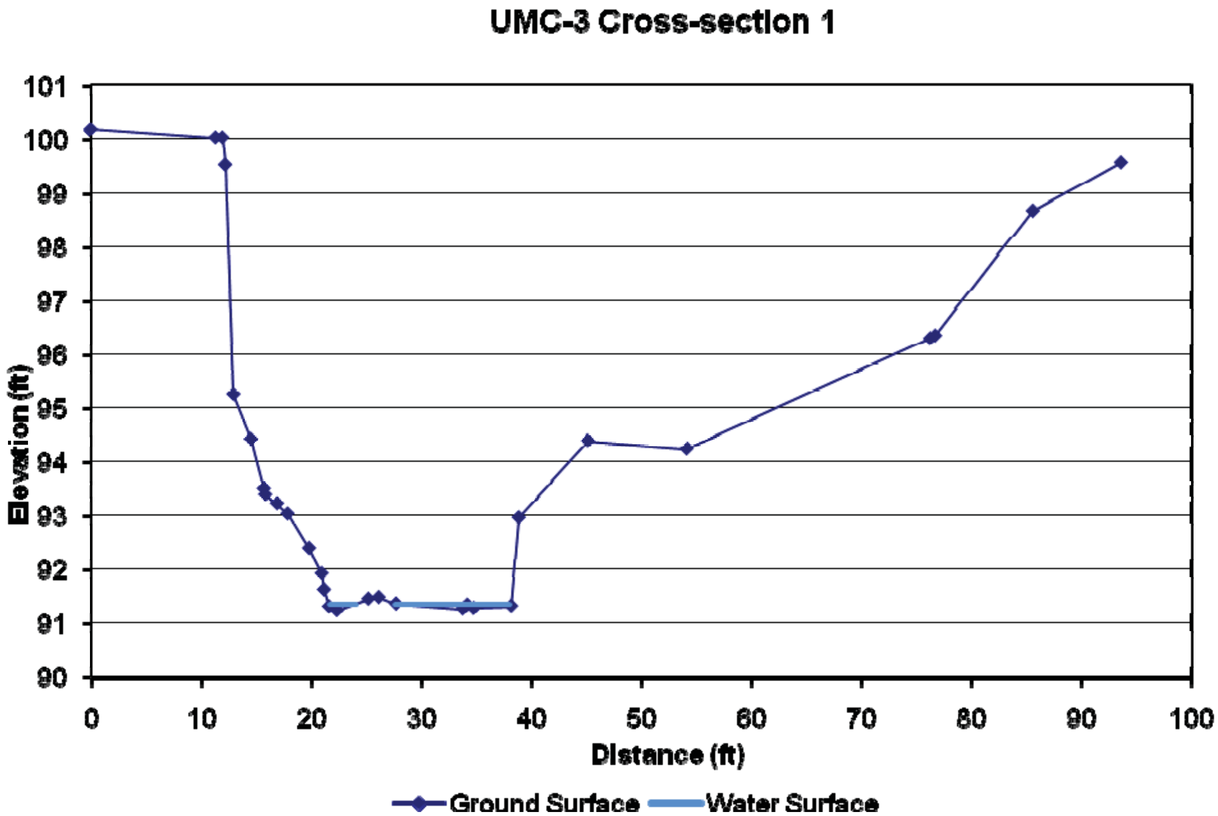

UMC-3, Cross-section 1, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	2.2	8.2
Root Depth/Bank ht	0.3	9.5
Root Density	<5%	10
Bank Angle	72	5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	42.7
BEHI Rating	--	**Very High**
Radius of Curvature	86	--
Bankfull Width	42	--
Rc/W	2.1	--
NBS Rating	--	**Moderate**

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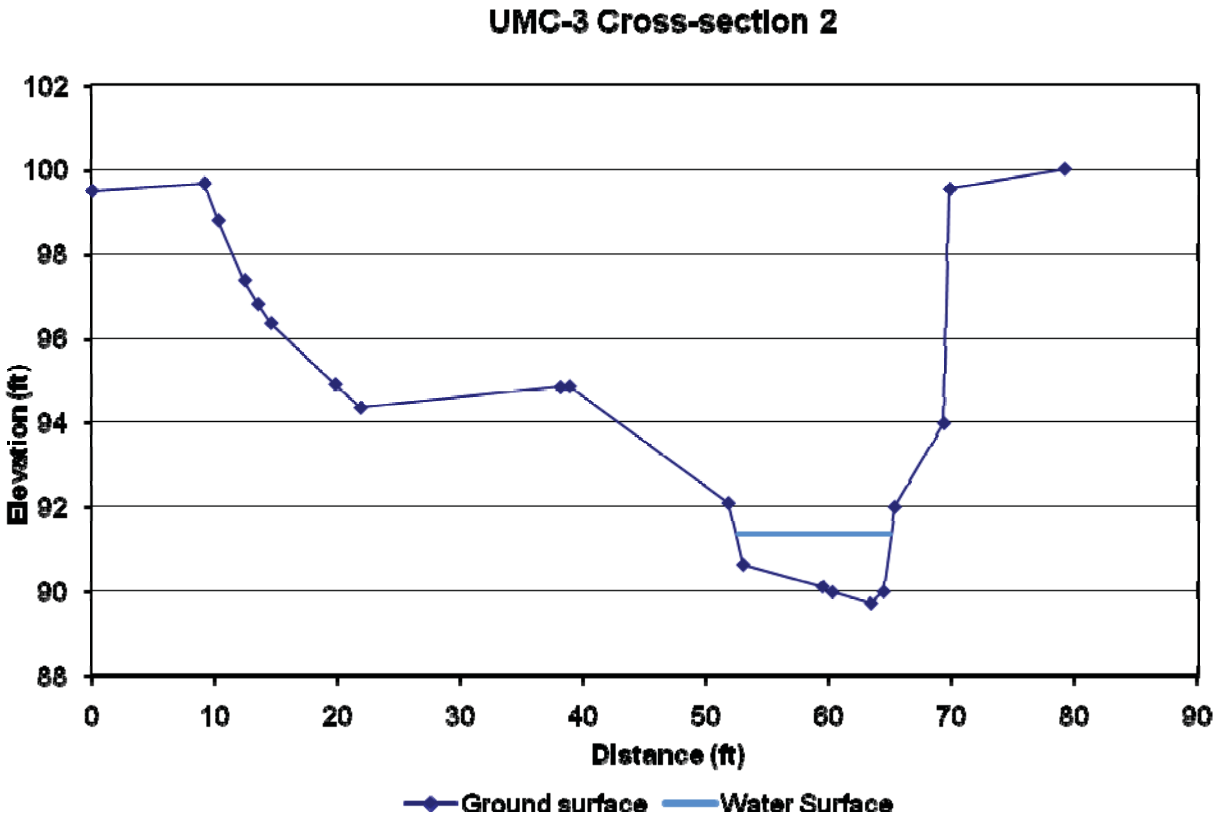

UMC-3, Cross-section 2, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.1	1.9
Root Depth/Bank ht	0.7	3
Root Density	<5%	10
Bank Angle	80-90	7
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	31.9
BEHI Rating	--	**High**
Radius of Curvature	53	--
Bankfull Width	50	--
Rc/W	1.1	--
NBS Rating	--	**Extreme**

Photo 12: UM3, XS-2, Right Bank

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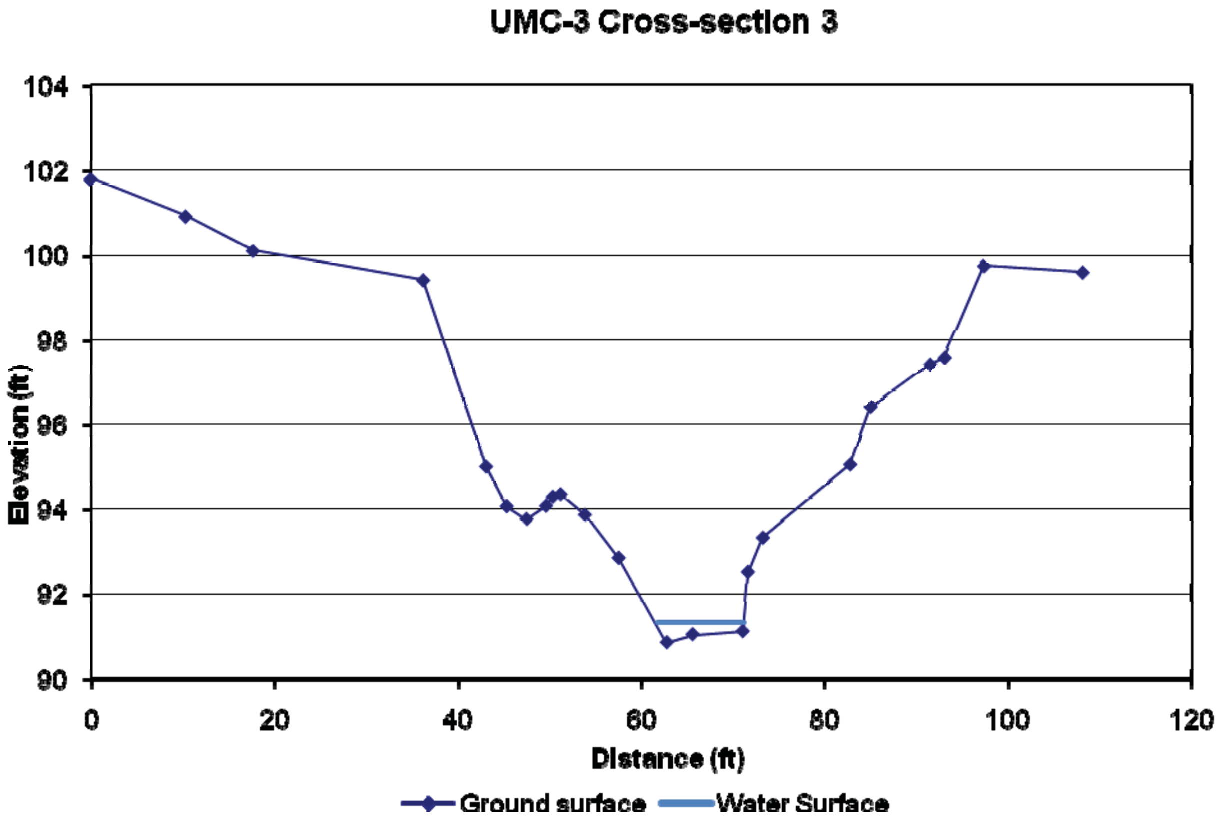

UMC-3, Cross-section 3, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.7	6.5
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	80-90	7
Surface Protection	5%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	40.5
BEHI Rating	--	**Very High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 13: UMC3, XS-3, Right Bank

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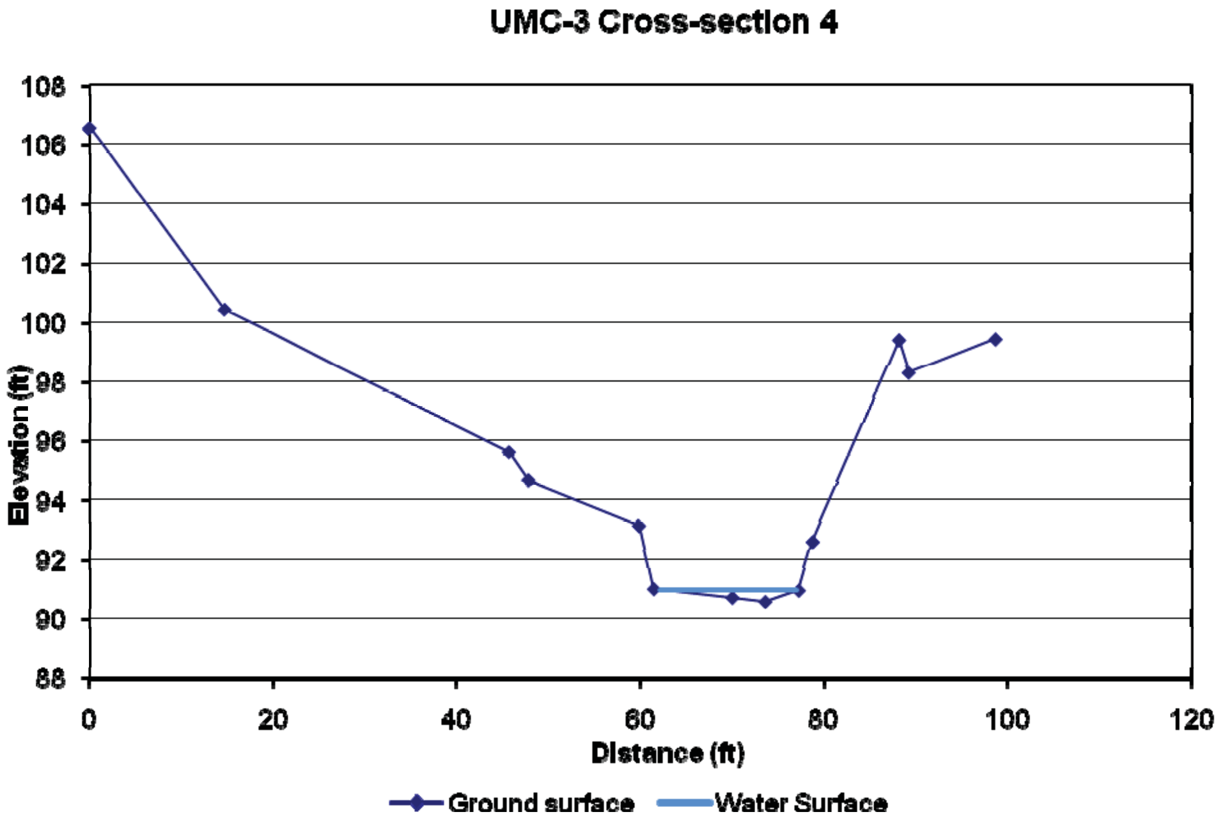
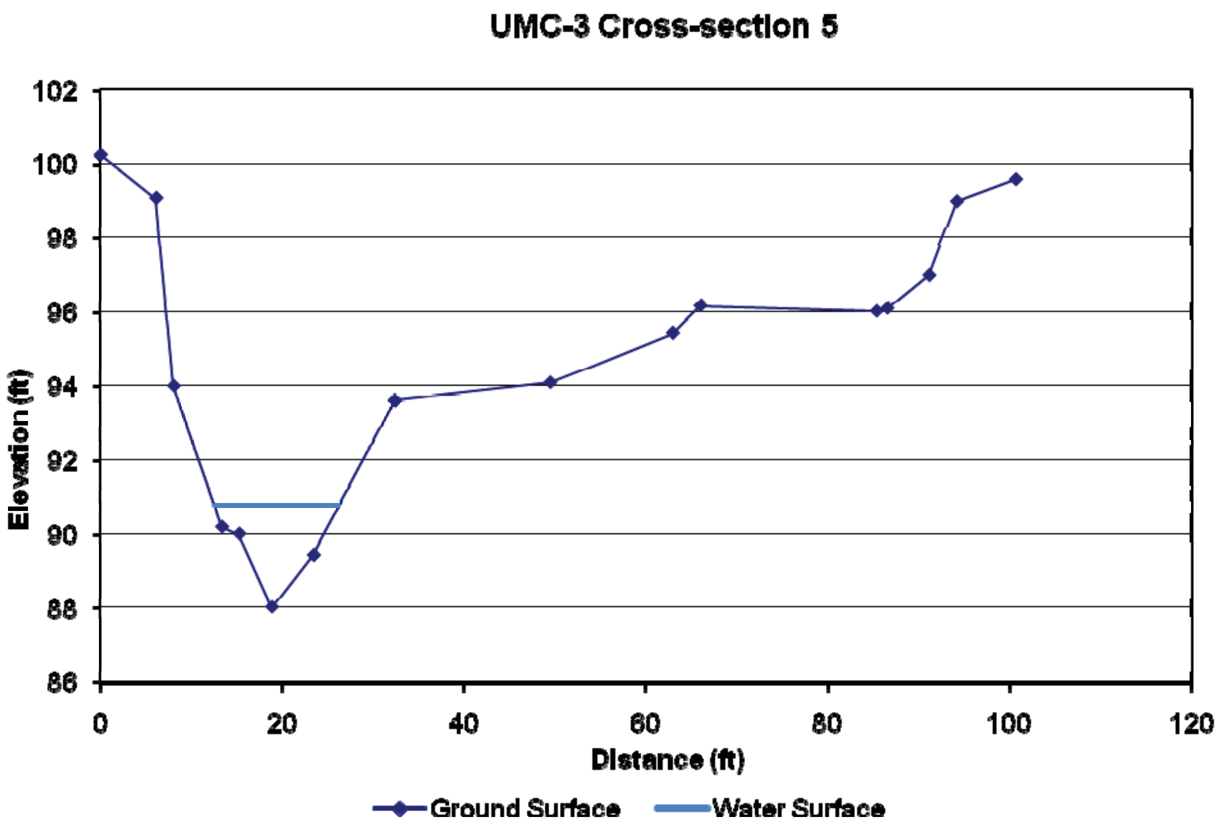

UMC-3 Cross-section 4
Elevation (ft)
108
106
104
102
100
98
96
94
92
90
88
0
20
40
60
80
100
120
Distance (ft)
Ground surface
Water Surface



UMC-3, Cross-section 5, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	1.1	1.9
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	60-80	5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	33.9
BEHI Rating	--	**High**
Radius of Curvature	48	--
Bankfull Width	41	--
Rc/W	1.2	--
NBS Rating	--	**Extreme**

Photo 14: UMC3, XS-5, Left Bank

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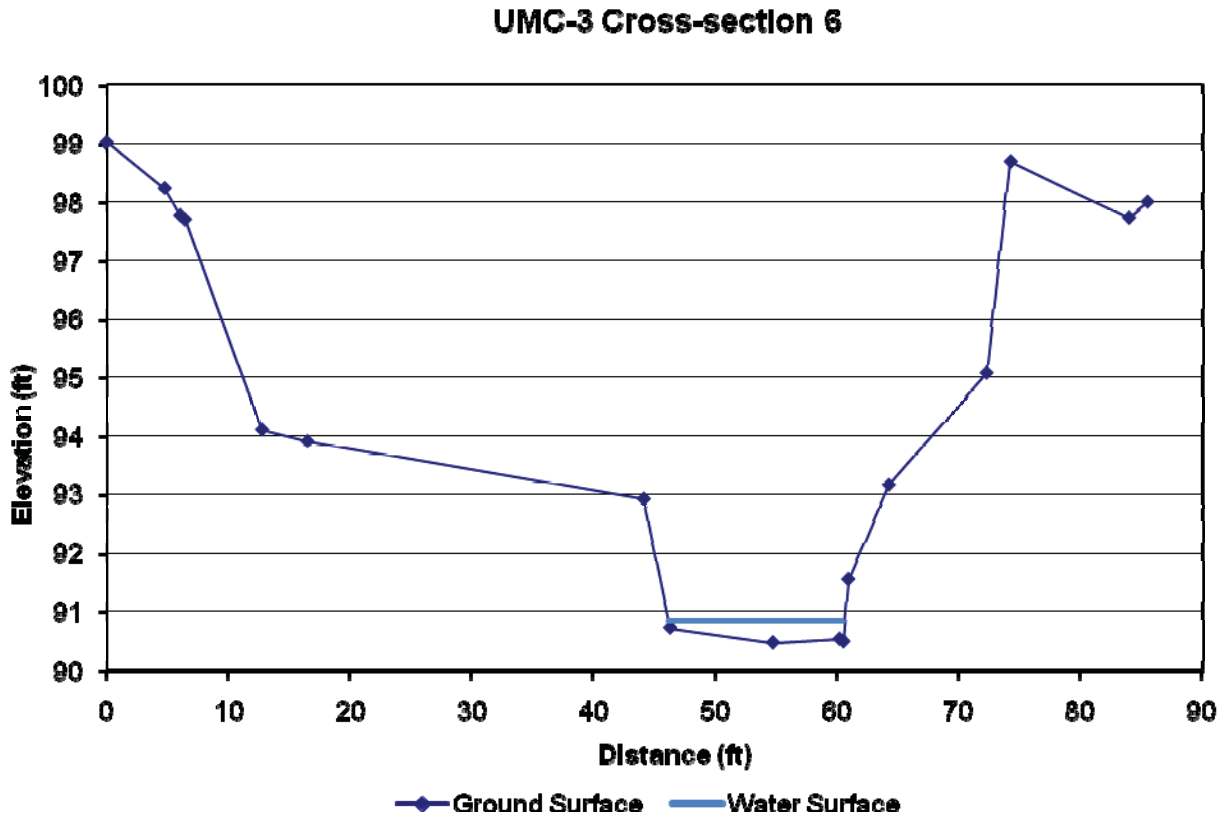

UMC-3, Cross-section 6, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.4	5.5
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	65	4.5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	37
BEHI Rating	--	**High**
Radius of Curvature	96	--
Bankfull Width	56	--
Rc/W	1.7	--
NBS Rating	--	**Very High**

Photo 15: UMC3, XS-6, Right Bank

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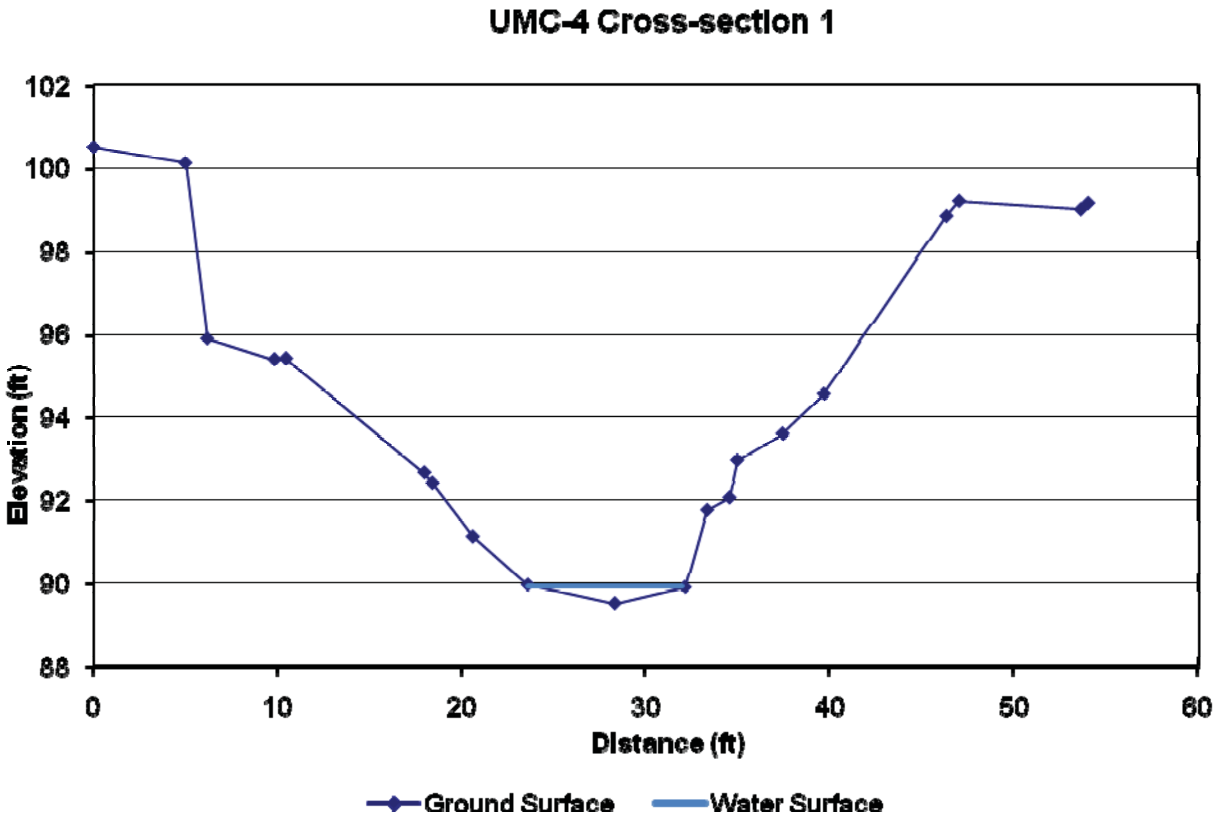

UMC-4, Cross-section 1, Left bank

Category	**Value**	**Index**
Bank ht/Bankfull Depth	2.0	7.9
Root Depth/Bank ht	0.3	5.9
Root Density	<5%	10
Bank Angle	69	5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	38.8
BEHI Rating	--	**High**
Radius of Curvature	57	--
Bankfull Width	22	--
Rc/W	2.6	--
NBS Rating	--	**Low**

Photo 16: UMC4, XS-1, Left Bank

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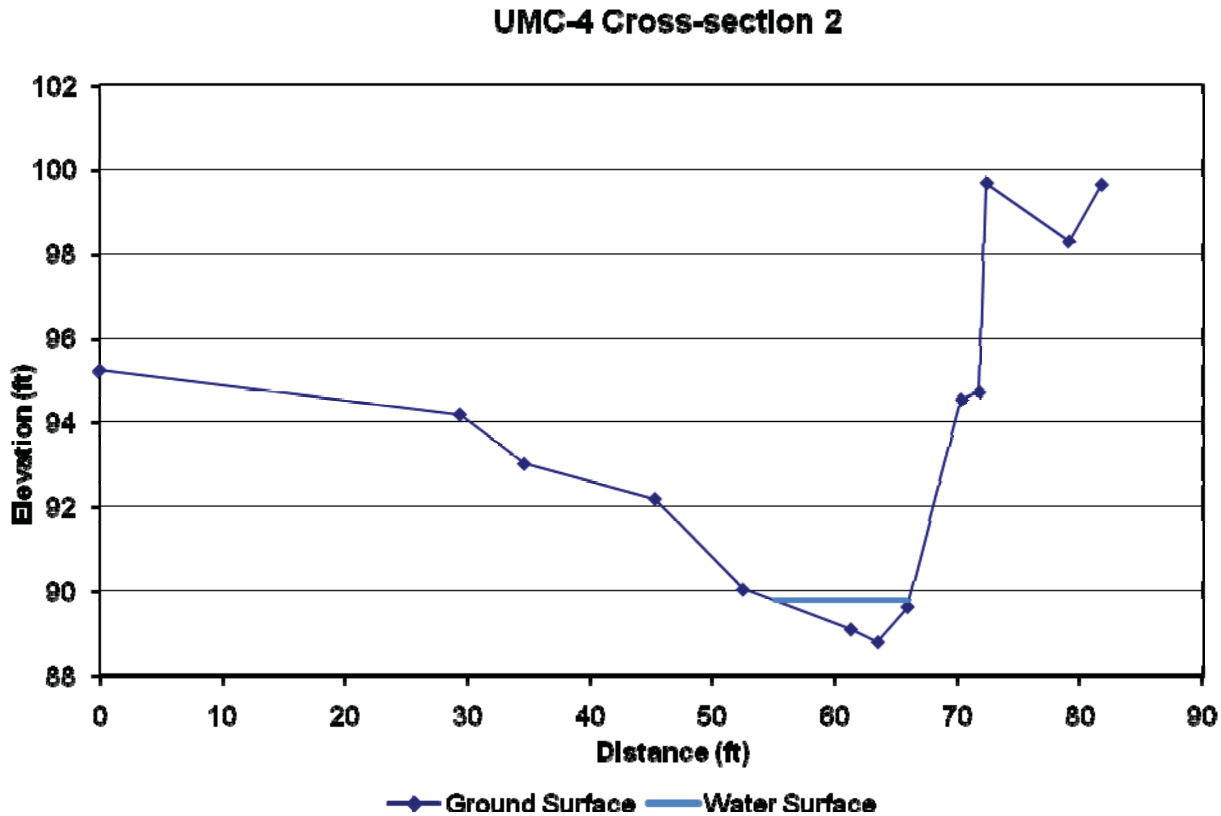

UMC-4 Cross-section 2
102
100
98
96
94
92
90
88
Elevation (ft)
0
10
20
30
40
50
60
70
80
90
Distance (ft)
Ground Surface
Water Surface

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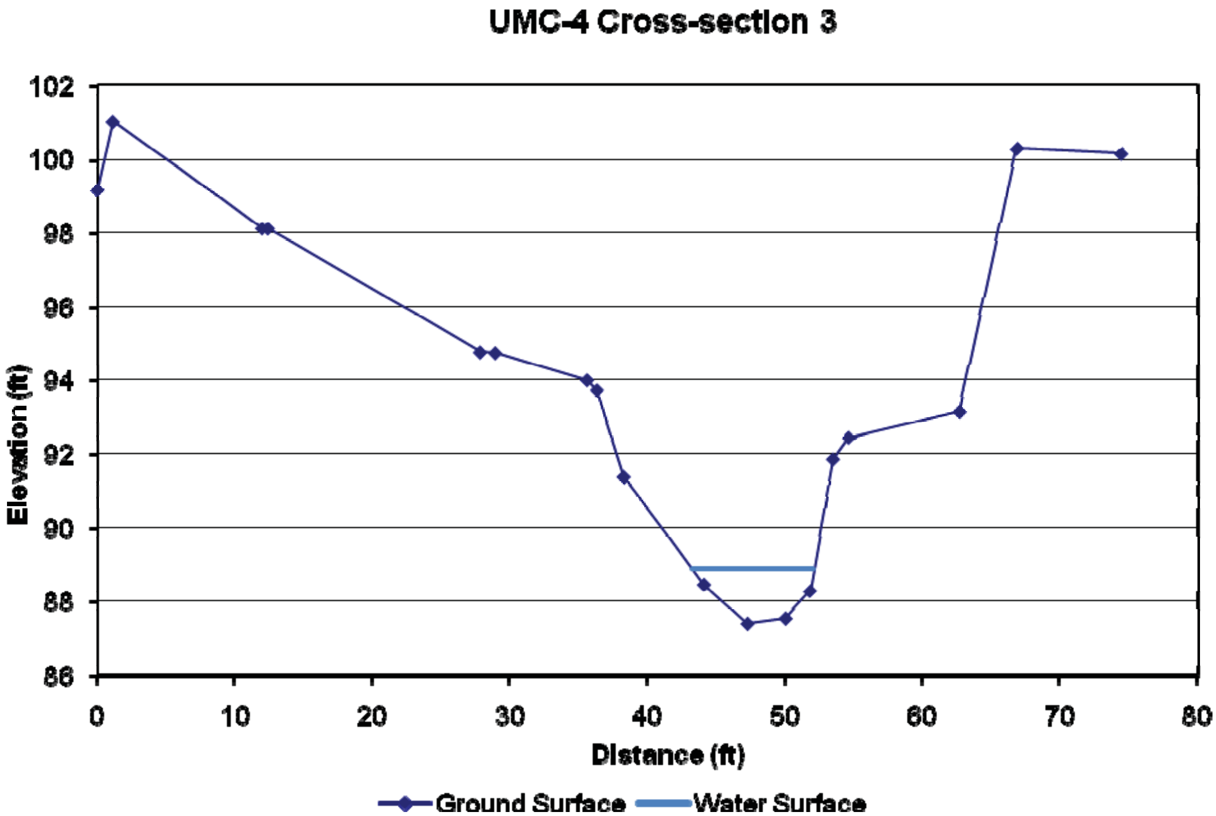

UMC-4, Cross-section 3, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.3	4.5
Root Depth/Bank ht	0.3	5.9
Root Density	<5%	10
Bank Angle	>90	8.5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	38.9
BEHI Rating	--	**High**
Radius of Curvature	121	--
Bankfull Width	26	--
Rc/W	4.7	--
NBS Rating	--	**Very Low**

Photo 17: UMC4, XS-3, Right bank

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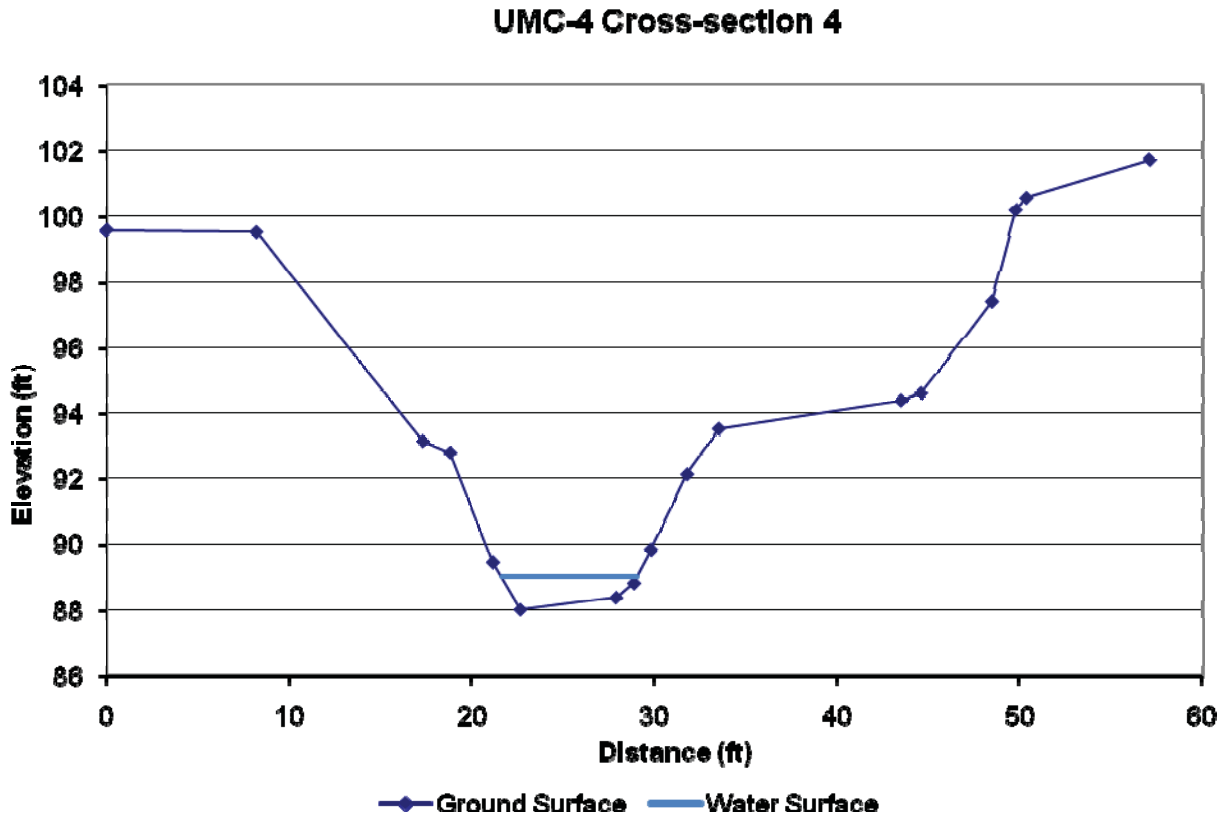
UMC-4 Cross-section 4
104
102
100
98
96
94
92
90
88
86
Elevation (ft)
0
10
20
30
40
50
60
Distance (ft)
Ground Surface
Water Surface

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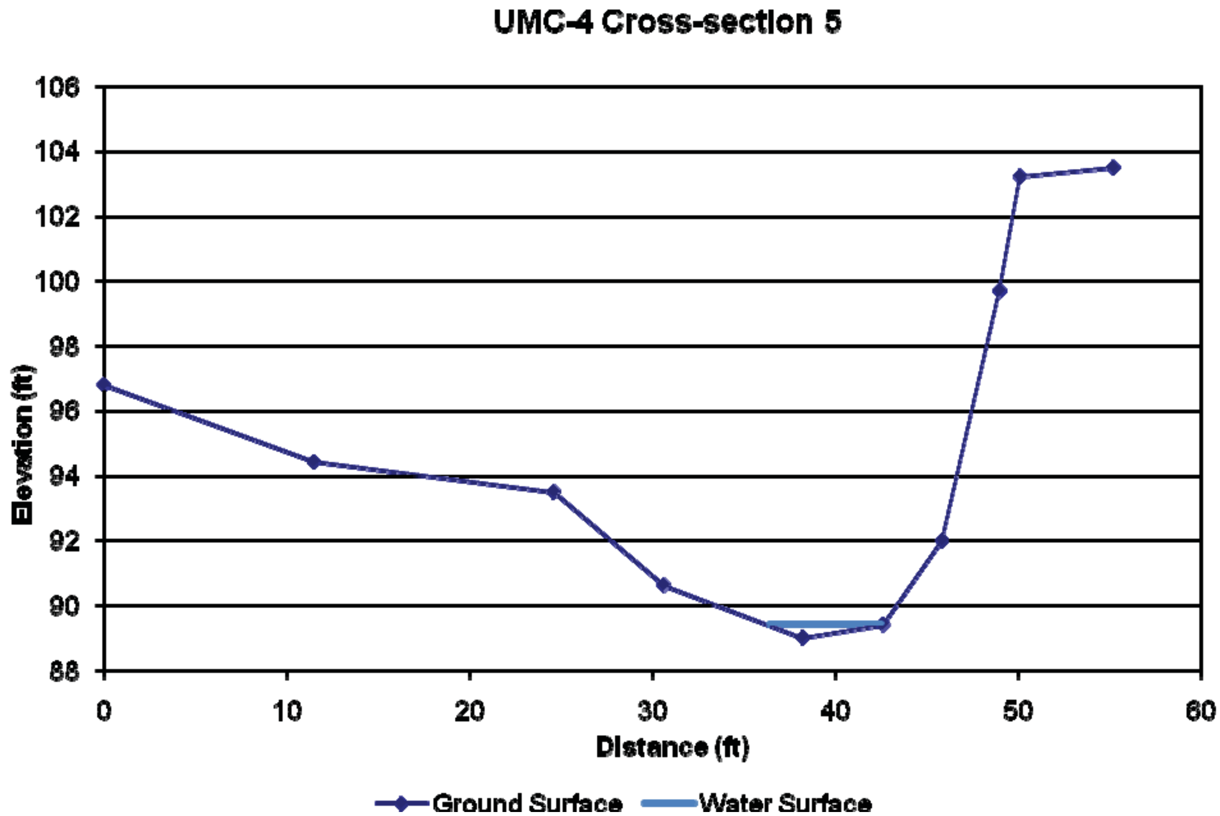
UMC-4 Cross-section 5
106
104
102
100
98
96
94
92
90
88
Elevation (ft)
0
10
20
30
40
50
60
Distance (ft)
Ground Surface
Water Surface

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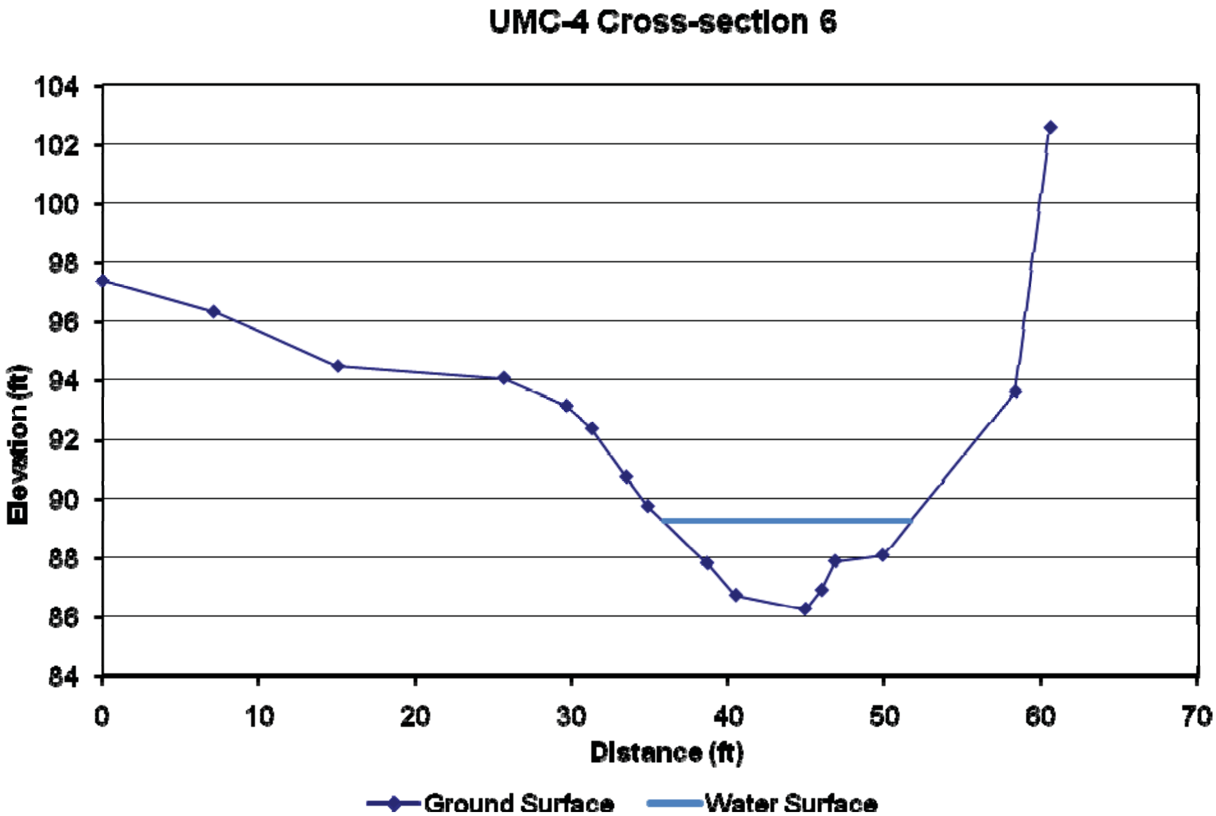

UMC-4, Cross-section 6, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	2.4	8.5
Root Depth/Bank ht	0.2	7
Root Density	<5%	10
Bank Angle	82	6
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	41.5
BEHI Rating	--	**Very High**
Radius of Curvature	43	--
Bankfull Width	21	--
Rc/W	2.1	--
NBS Rating	--	**Moderate**

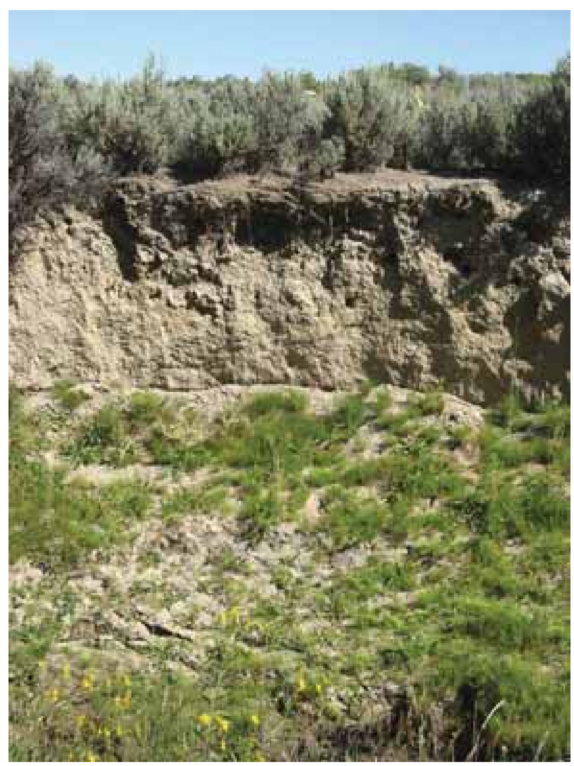

Photo 18: UMC4, XS-6, Right Bank

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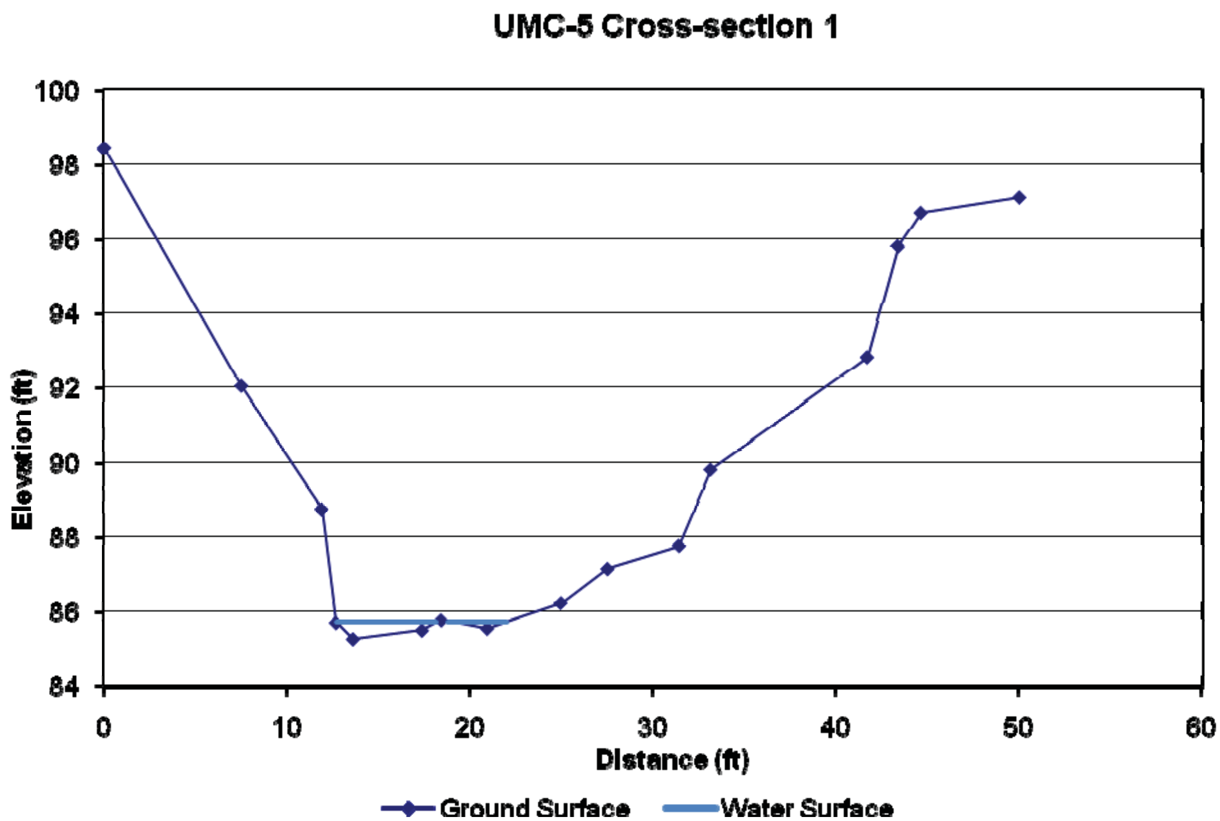
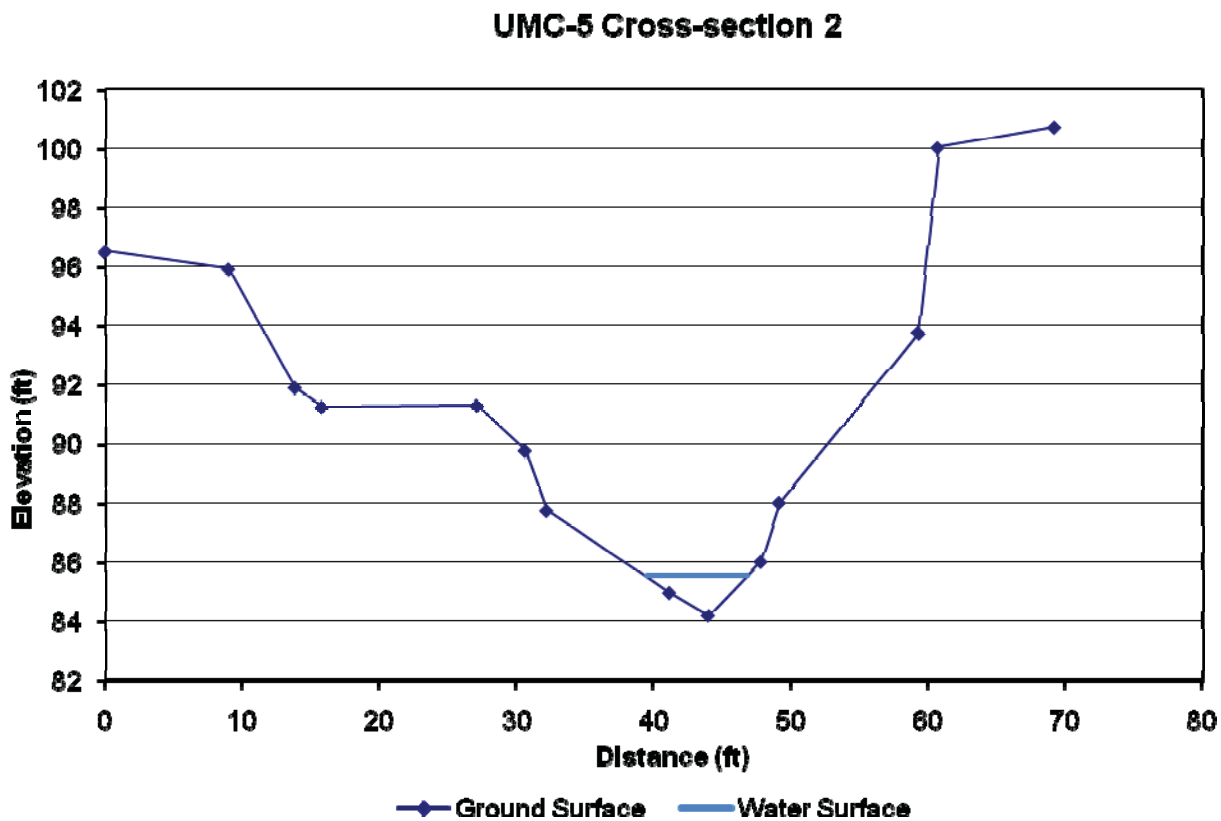


UMC-5, Cross-section 1, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	3.2	10
Root Depth/Bank ht	0.3	5.9
Root Density	<5%	10
Bank Angle	52	3.6
Surface Protection	25%	6.5
Bank Material	Silt	0
Stratification	None	0
Index sum	--	36
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**



UMC-5, Cross-section 2, Right bank

Category	**Value**	**Index**
Bank ht/Bankfull Depth	2.3	8.3
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	73	5.2
Surface Protection	24%	6.5
Bank Material	Silt	0
Stratification	None	0
Index sum	--	38.5
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

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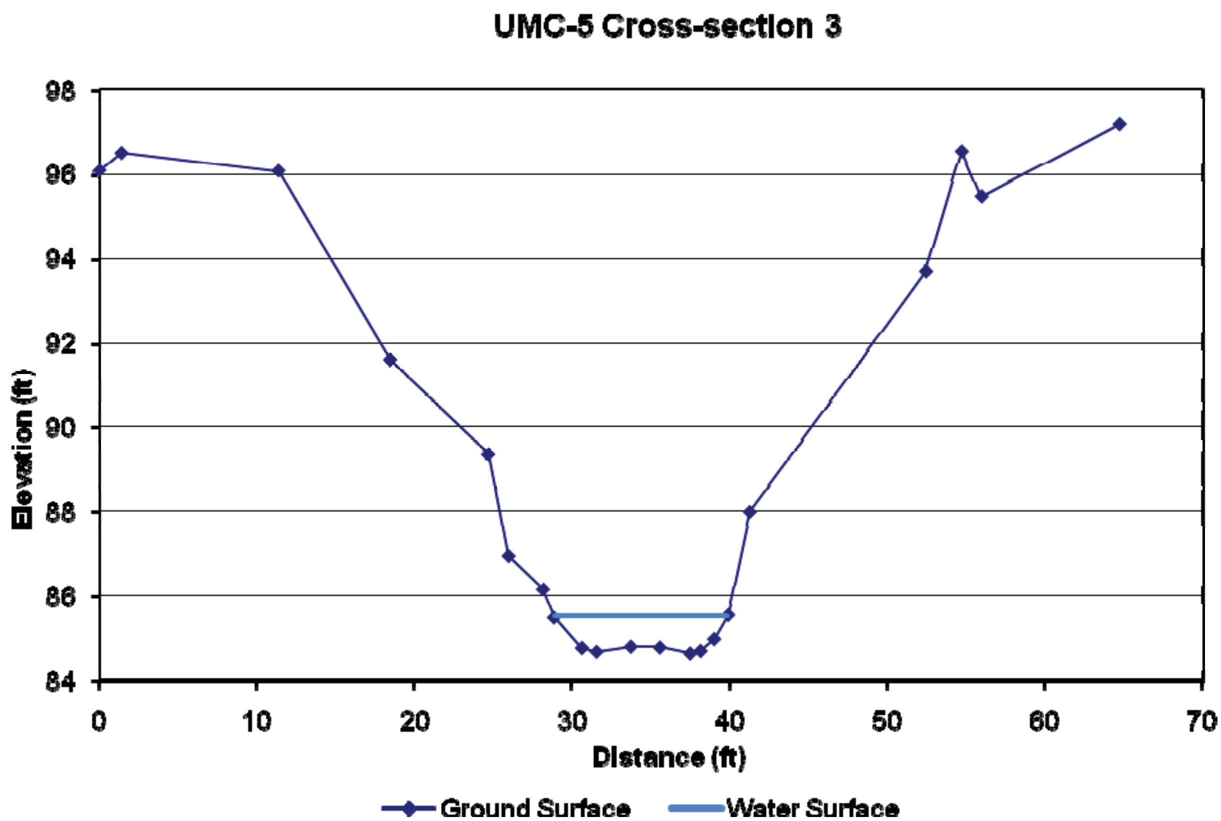
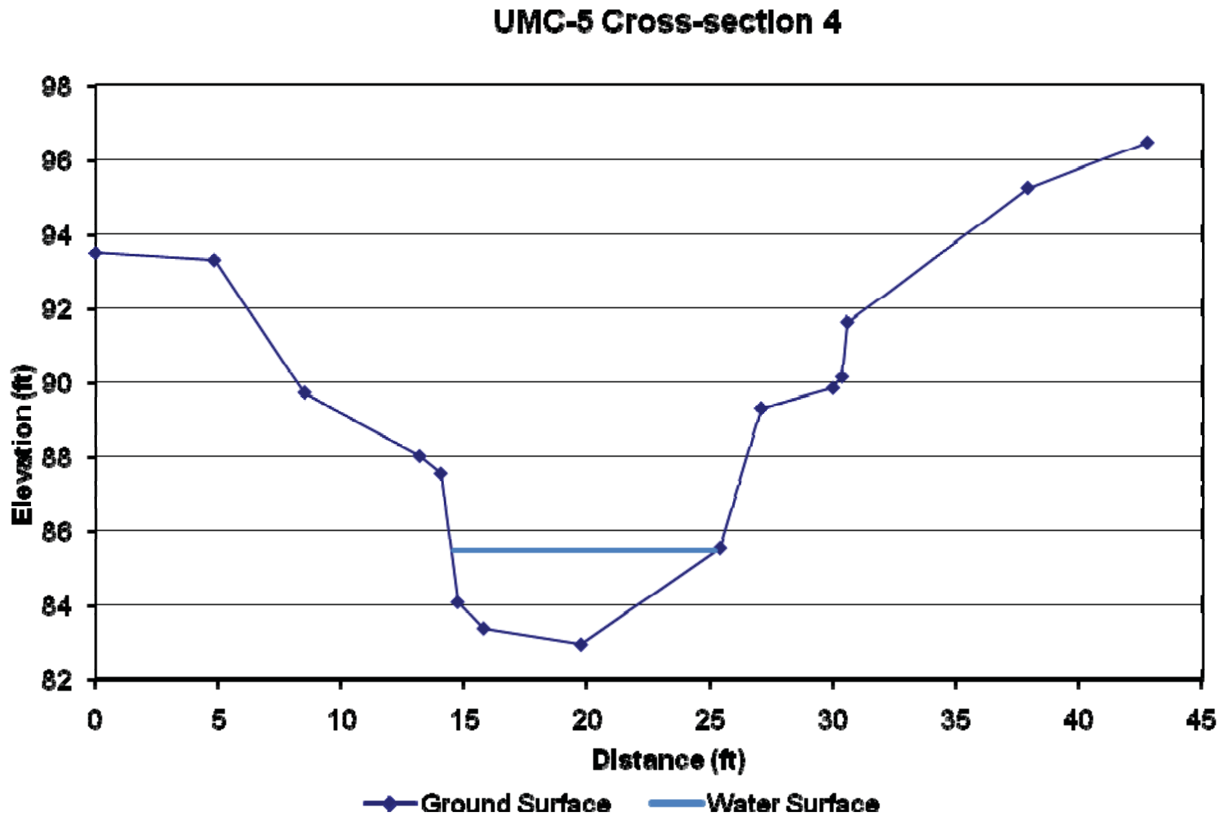


UMC-5, Cross-section 3, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	2.6	8.7
Root Depth/Bank ht	0.2	7.4
Root Density	<5%	10
Bank Angle	67.5	5
Surface Protection	10%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	41.1
BEHI Rating	--	**Very High**
Radius of Curvature	43	--
Bankfull Width	16	--
Rc/W	2.8	--
NBS Rating	--	**Low**

Photo 19: UMC5, XS-3, Right Bank



UMC-5, Cross-section 4, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	1.6	6
Root Depth/Bank ht	0.3	5.9
Root Density	<5%	10
Bank Angle	69	5
Surface Protection	30%	5.9
Bank Material	Silt	0
Stratification	None	0
Index sum	--	32.8
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 20: UMC5, XS-4, Left Bank

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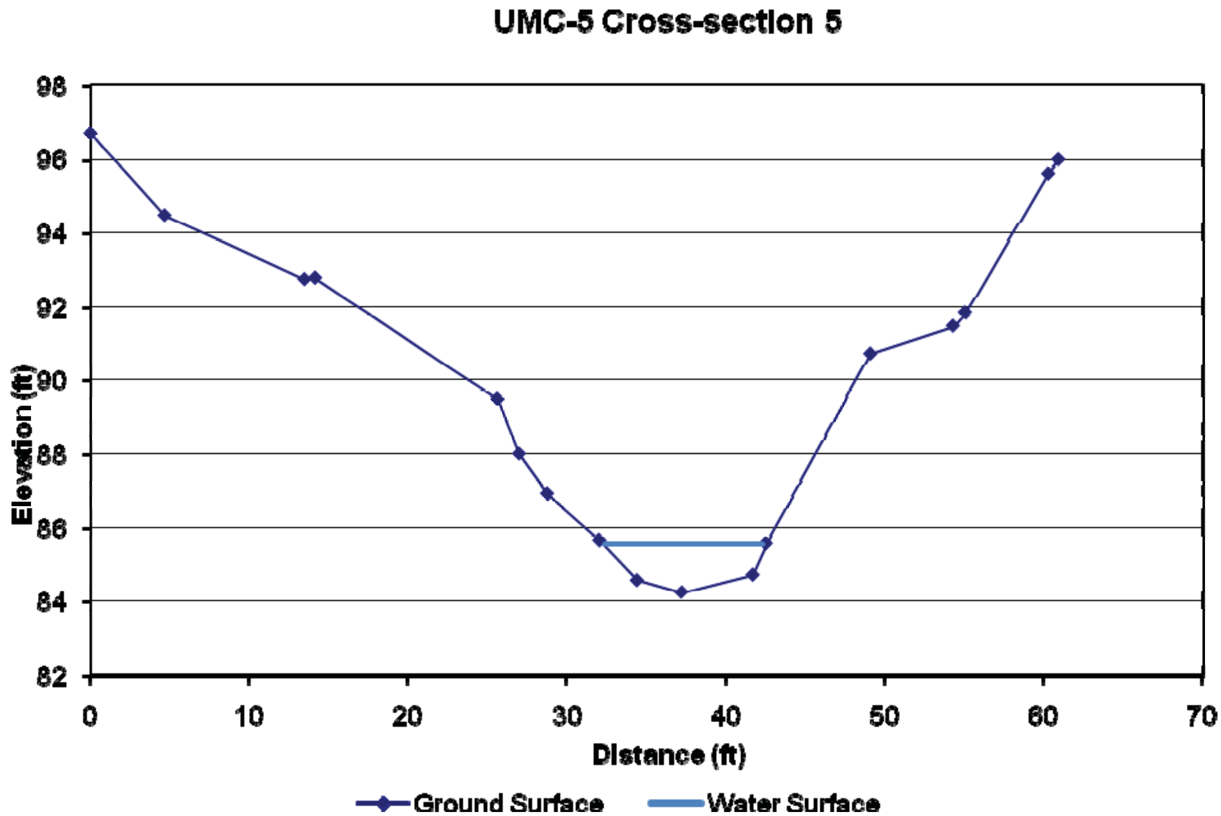

UMC-5, Cross-section 5, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	1.9	7.5
Root Depth/Bank ht	0.2	7.5
Root Density	<5%	10
Bank Angle	61	4
Surface Protection	34%	5.5
Bank Material	Silt	0
Stratification	None	0
Index sum	--	34.5
BEHI Rating	--	**High**
Radius of Curvature	Straight	--
Bankfull Width	--	--
NBS Rating	--	**N/A**

Photo 21: UMC5, XS-5, Right Bank

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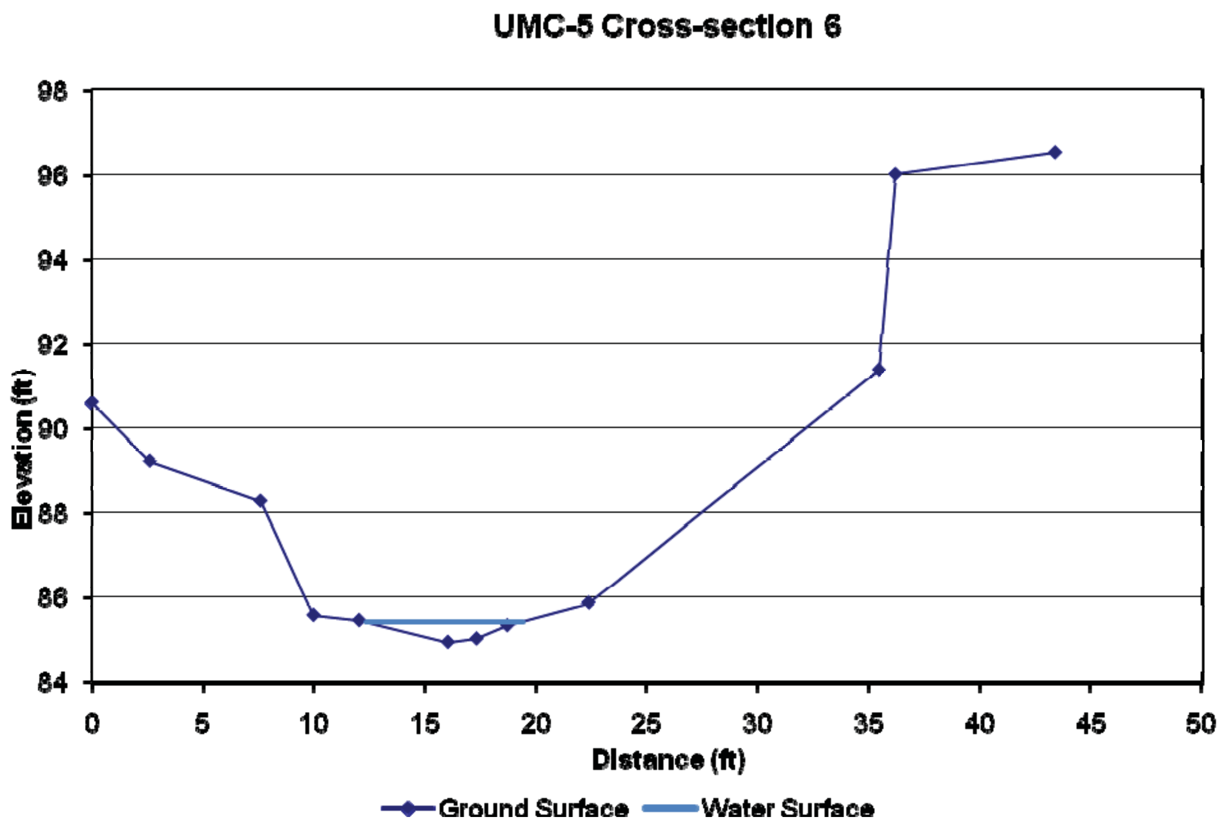

UMC-5, Cross-section 6, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	2.4	8.5
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	71	5
Surface Protection	28%	6.1
Bank Material	Silt	0
Stratification	None	0
Index sum	--	38.1
BEHI Rating	--	**High**
Radius of Curvature	91	--
Bankfull Width	21	--
Rc/W	4.4	--
NBS Rating	--	**Very Low**

Photo 22: UMC5, XS-6, Right Bank

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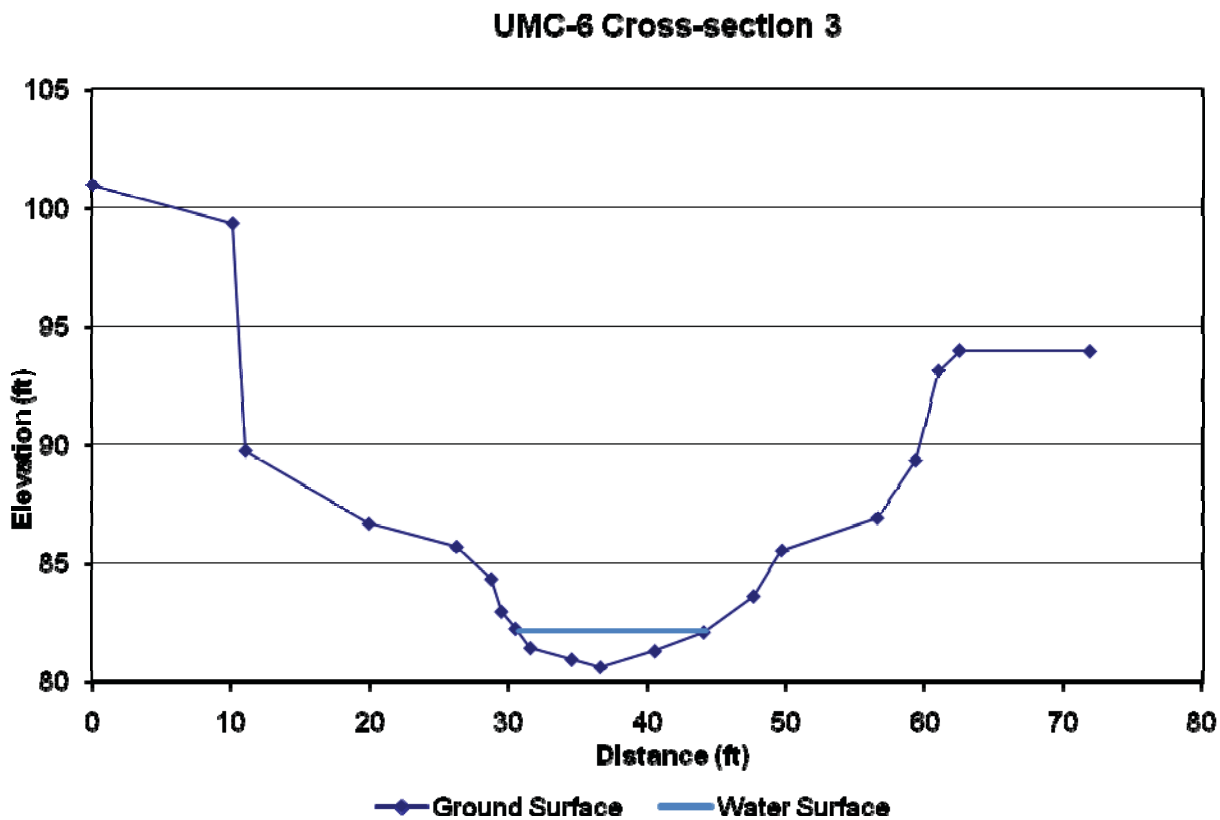


UMC-6, Cross-section 3, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	4.1	10
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	63	4.1
Surface Protection	27%	6.2
Bank Material	Silt	0
Stratification	None	0
Index sum	--	38.8
BEHI Rating	--	High

Photo 23: UMC6, XS-3, Right Bank

UMC-6, Cross-section 1, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	3.1	10
Root Depth/Bank ht	0.1	8.5
Root Density	<5%	10
Bank Angle	>90	8.5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	47
BEHI Rating	--	**Extreme**

UMC-6, Cross-section 4, Right bank

Category	Value	Index
Bank ht/Bankfull Depth	4.2	10
Root Depth/Bank ht	0.05	10
Root Density	<5%	10
Bank Angle	>90	8.5
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	48.5
BEHI Rating	--	Extreme

Photo 24: UMC6, XS-4, Right Bank

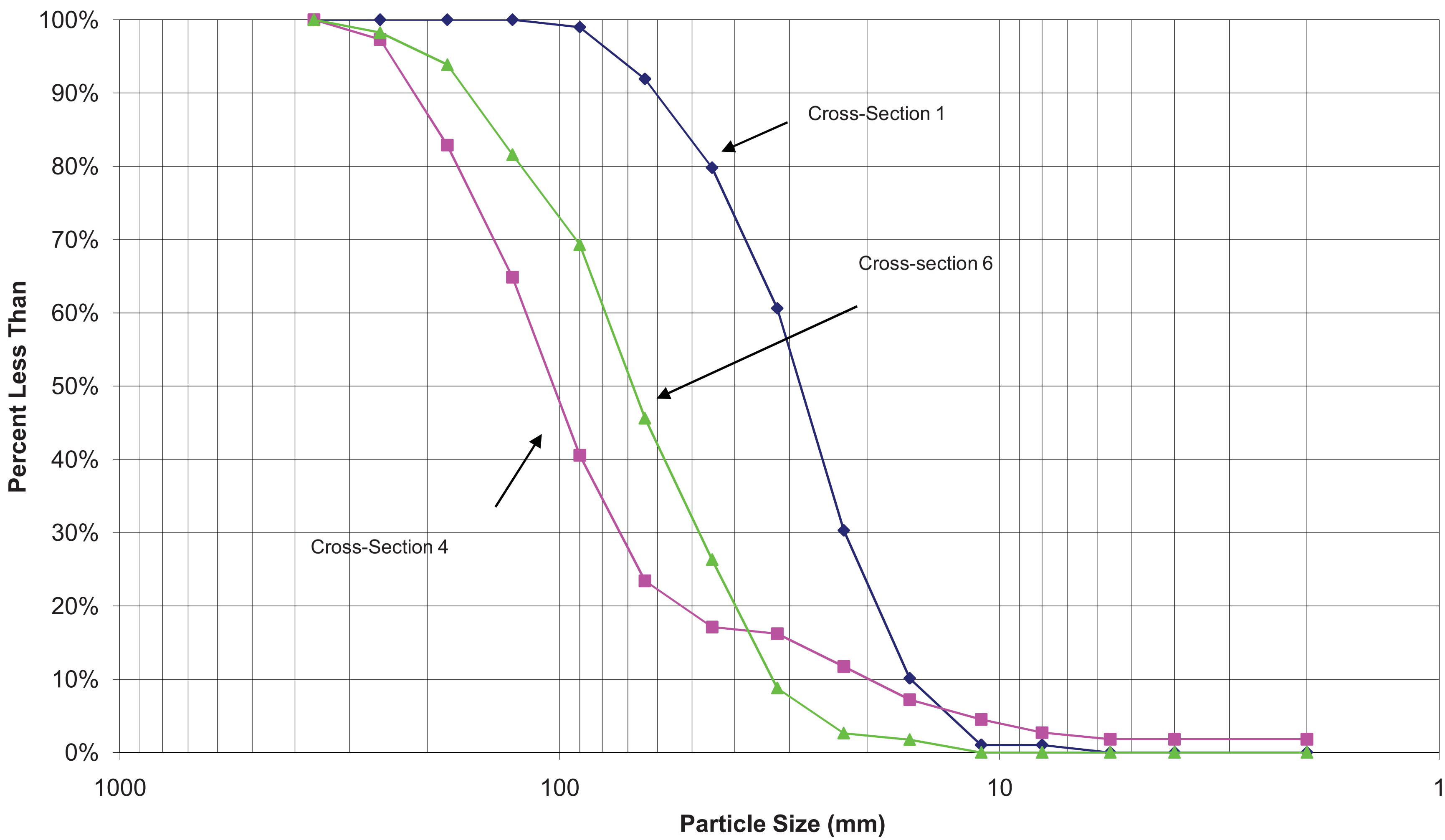
UMC-6, Cross-section 6, Left bank

Category	Value	Index
Bank ht/Bankfull Depth	3.0	10
Root Depth/Bank ht	0.17	7.7
Root Density	<5%	10
Bank Angle	90	7.9
Surface Protection	0%	10
Bank Material	Silt	0
Stratification	None	0
Index sum	--	45.6
BEHI Rating	--	**Extreme**

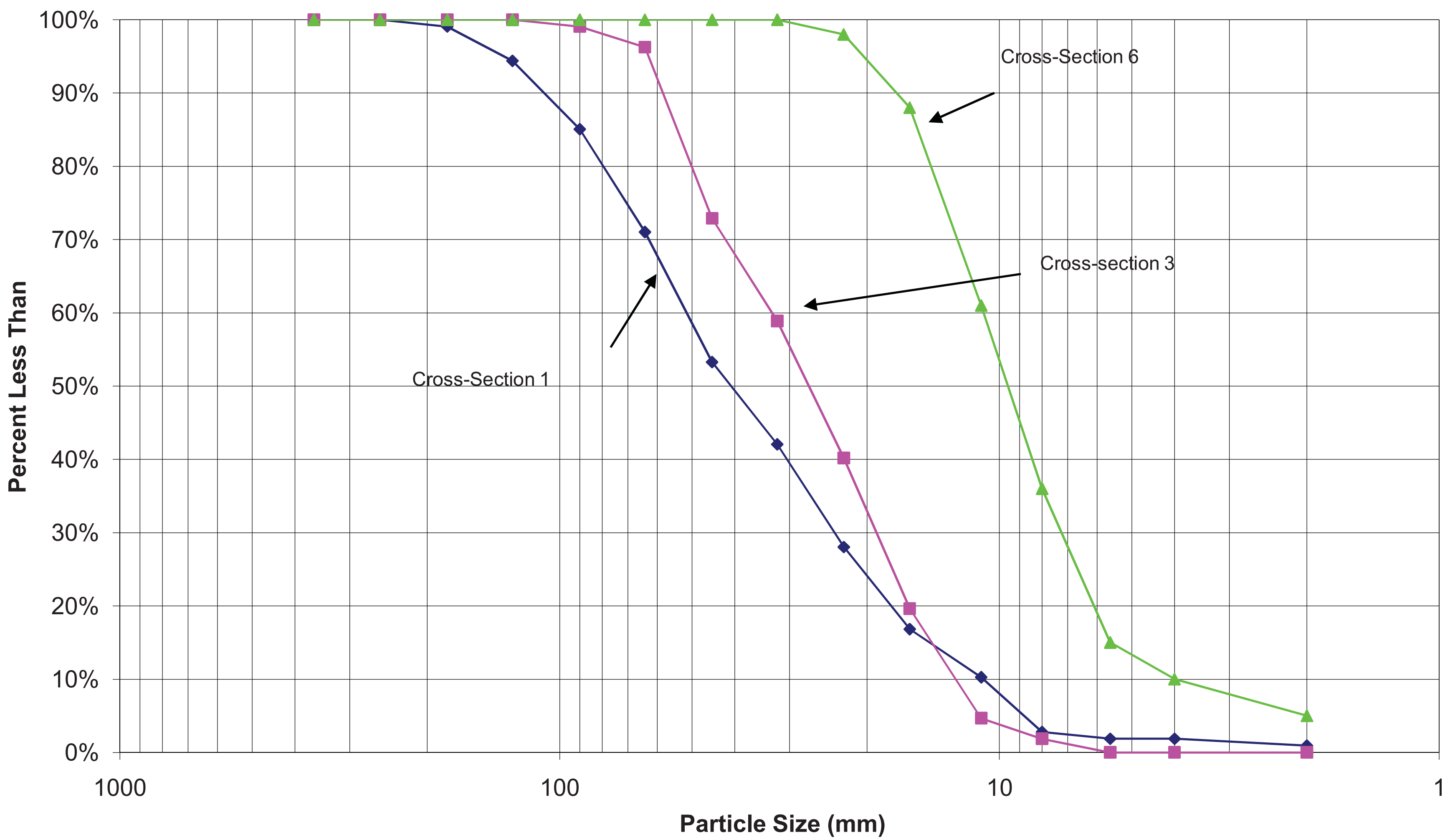
Photo 25: UMC6, XS-6, Left Bank

Appendix F
Cumulative Sediment Size Distribution Charts

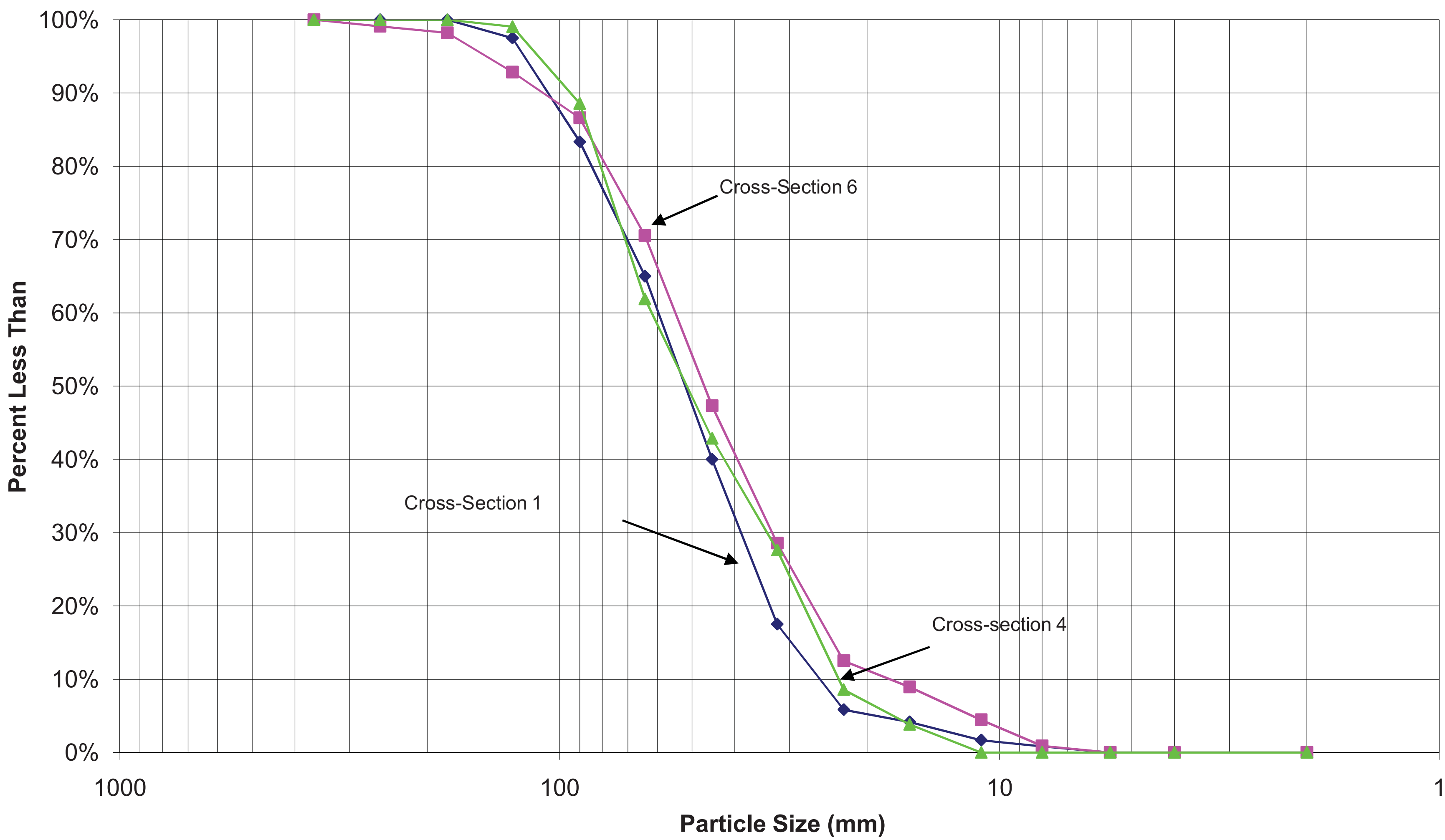
UMC-1
Pebble Count Cumulative Size Distributions
Upper Muddy Creek, Carbon County, Wyoming



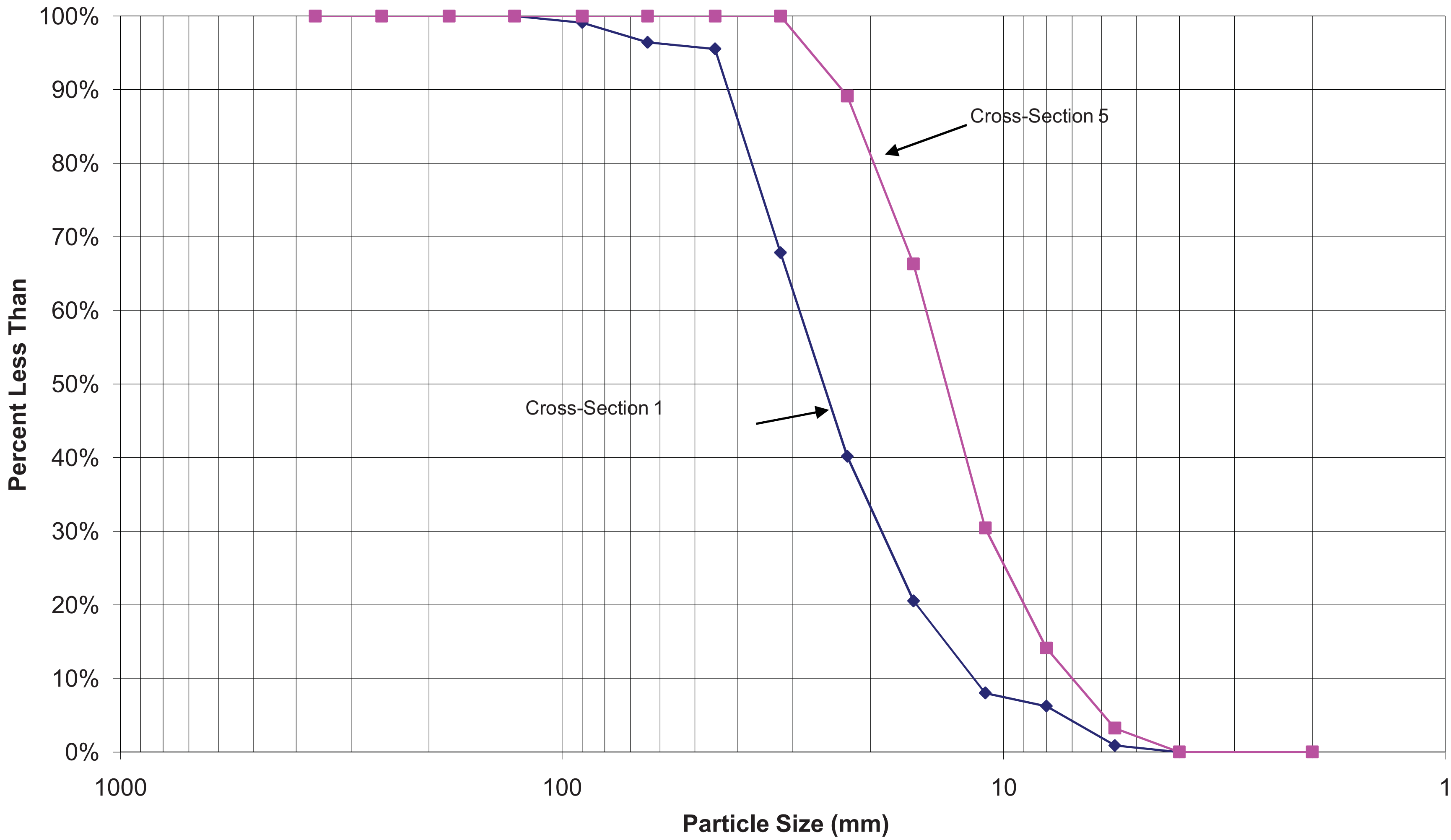
UMC-2
Pebble Count Cumulative Size Distributions
Upper Muddy Creek, Carbon County,Wyoming



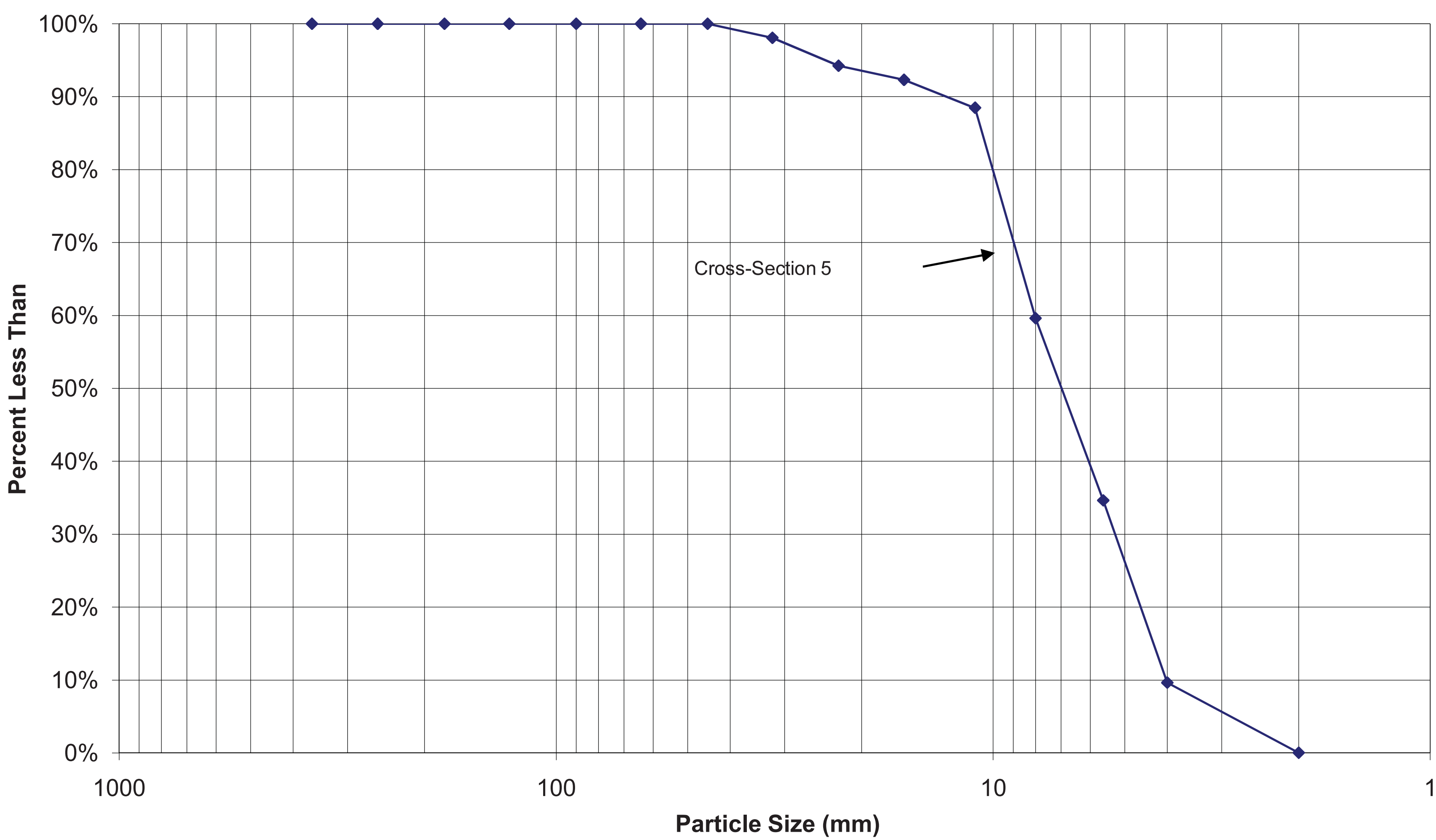
UMC-3
Pebble Count Cumulative Size Distributions
Upper Muddy Creek, Carbon County, Montana



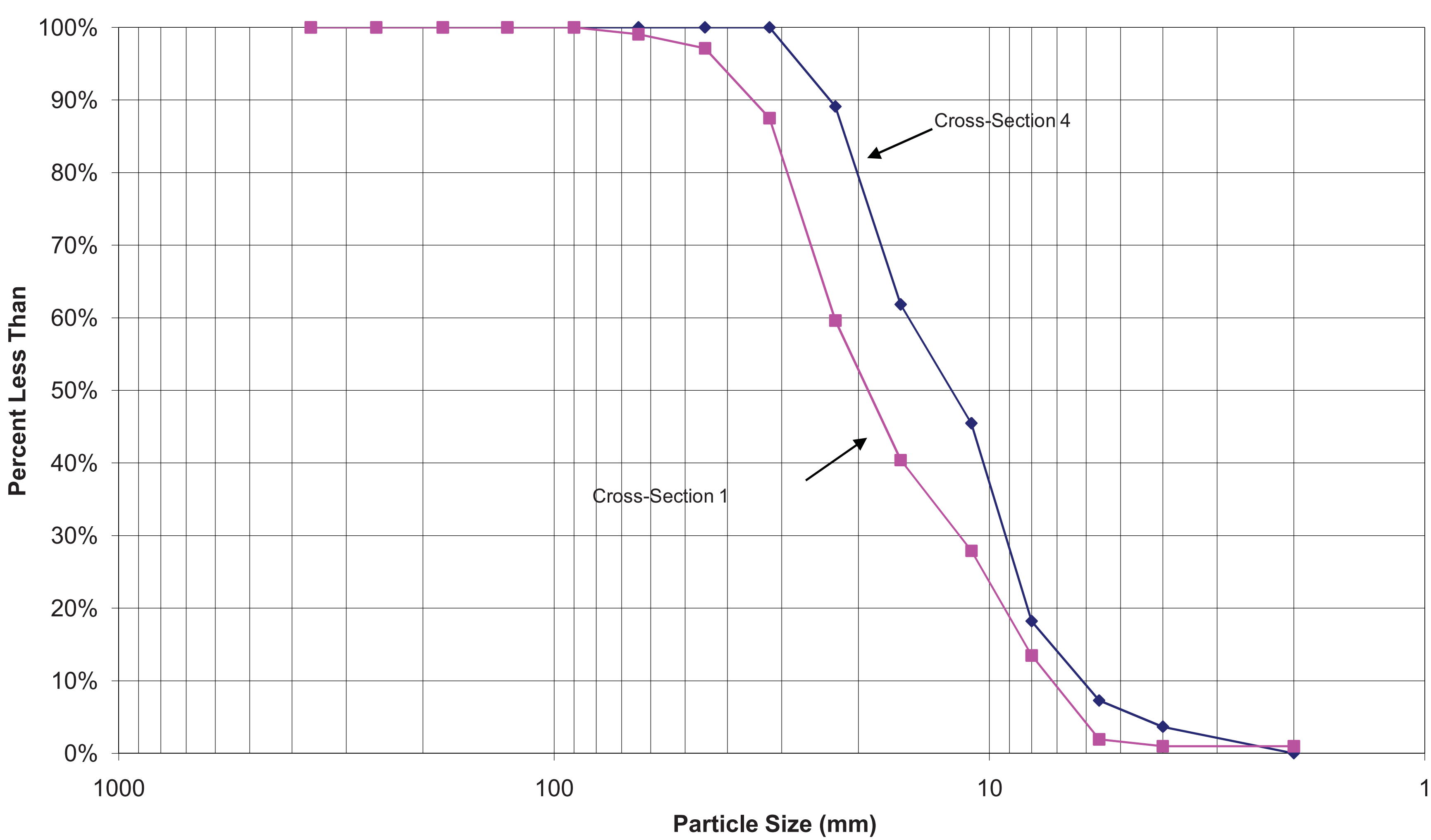
UMC-4
Pebble Count Cumulative Size Distributions
Upper Muddy Creek, Carbon County, Wyoming



UMC-5
Pebble Count Cumulative Size Distributions
Upper Muddy Creek, Carbon County, Wyoming



UMC-6
Pebble Count cumulative Size Distributions
Upper Muddy Creek, Carbon County, Montana



Appendix G
Laboratory Data Sheets

ENERGY LABORATORIES, INC. * 3161 E Lyndale (59604) * PO Box 5688 * Helena, MT 59601
Toll Free 877.472.0711 * 406.442.0711 * FAX 406.442.0712 * helena@energylab.com

ANALYTICAL SUMMARY REPORT

September 11, 2008

Camp Dresser and McKee Inc
50 W 14th St Ste 200
Helena, MT 59601

Workorder No.: H08080397 Quote ID: H310

Project Name: Anadarko Upper Muddy Creek Monitoring

Energy Laboratories Inc received the following 6 samples from Camp Dresser and McKee Inc on 8/25/2008 for analysis.

Sample ID	Client Sample ID	Collect Date	Receive Date	Matrix	Test
H08080397-001	UMC-1	08/19/08 17:50	08/25/08	Aqueous	Metals by ICP/ICPMS, Total Alkalinity Conductivity Anions by Ion Chromatography Metals Digestion by EPA 200.2 Solids, Total Suspended
H08080397-002	UMC-1	08/23/08 8:30	08/25/08	Aqueous	Conductivity
H08080397-003	UMC-3	08/21/08 9:50	08/25/08	Aqueous	Metals by ICP/ICPMS, Total Alkalinity Conductivity Anions by Ion Chromatography Metals Digestion by EPA 200.2 Solids, Total Suspended
H08080397-004	UMC-3 Duplicate	08/21/08 9:55	08/25/08	Aqueous	Same As Above
H08080397-005	UMC-6	08/22/08 16:00	08/25/08	Aqueous	Same As Above
H08080397-006	UMC-Blank	08/23/08 12:40	08/25/08	Aqueous	Same As Above

BRANCH LABORATORY LOCATIONS
eli-b - Energy Laboratories, Inc. - Billings, MT, EPA # MT00005
eli-c - Energy Laboratories, Inc. - Casper, WY, EPA# WY00002
eli-g - Energy Laboratories, Inc. - Gillette, WY, EPA# WY00006
eli-h - Energy Laboratories, Inc. - Helena, MT, EPA# MT00945
eli-r - Energy Laboratories, Inc. - Rapid City, SD, EPA# SD00012
eli-t - Energy Laboratories, Inc. - College Station, TX, EPA# TX01520

SUBCONTRACTING ANALYSIS
Subcontracting of sample analyses to an outside laboratory may be required. If so, ENERGY LABORATORIES, INC. will utilize its branch laboratories or qualified contract laboratories for this service. Any such laboratories are indicated within the Laboratory Analytical Report.

SAMPLE TEMPERATURE COMPLIANCE: 4°C (±2°C)
Temperature of samples received may not be considered properly preserved by accepted standards. Samples that are hand delivered immediately after collection shall be considered acceptable if there is evidence that the chilling process has begun.

ELI appreciates the opportunity to provide you with this analytical service. For additional information, including certifications, and analytical services visit our web page www.energylab.com.

Report Approved By: [signature]

CDM

Chain of Custody Record

Project Manager: Bill Bucher

Task Order: Anadarko - Upper Muddy Creek Monitoring

Chain of Custody No.: H08080397-001 thru 006

SAMPLE ID	DATE	TIME	SAMPLE MEDIA	TYPE OF SAMPLE COMP./GRAB		SAMPLER'S INITIALS	ANALYSES	NO. OF CON-TAINERS	REMARKS	PRES. USED
UMC-1	8/19/08	17:50	Water	~~C~~	(GRAB)	WHB	A	1	1 liter	1
UMC-1	8/19/08	16:40	"	G		WHB	Total Selenium	1	250 ml	1,3
UMC-1	8/23/08	0830	"	G		WHB	EC	1	250 ml.	1
UMC-3	8/21/08	0950	"	C		WHB	A	1	1 liter	1
UMC-3	8/21/08	0950	"	G		WHB	Total Selenium	1	250 ml	1,3
UMC-3	8/21/08	0950	"	G		WHB	EC	1	250 ml	1
UMC-3	8/21/08	0955	"	C		WHB	A	1	1 liter-duplicate	1
UMC-3	8/21/08	0955	"	G		WHB	Total Selenium	1	250 ml-duplicate	1,3
UMC-6	8/22/08	1600	"	C		WHB	A	1	1 liter	1
UMC-6	8/22/08	1600	"	G		WHB	Total Selenium	1	250 ml	1,3
UMC-6	8/22/08	1600	"	G		WHB	EC	1	250 ml	1
UMC-Blank	8/23/08	1240	"	G		WHB	A	1	1 liter	1
UMC-Blank	8/23/08	1240	"	G		WHB	Total Selenium	1	250 ml	1,3

Analyses:
A - sulfate, chloride, alkalinity, anions, TSS
- Total Selenium – originally dissolved but filtration apparatus was insufficient
- Electrical conductivity – added because of uncertainty in field meter.

Preservatives Used:
1 - Ice
2 - H_2SO_4
3 - HNO_3

Sampled By (sign) William W. Bucher / / /

Relinquished By (sign):	Relinquished By (sign):	Relinquished By (sign):	Relinquished By (sign):
(1) ____	(2) ____	(3) ____	(4) ____
Date/Time:	Date/Time:	Date/Time:	Date/Time:
Received By (sign):	Received By (sign):	Received By (sign):	Received By (sign):
(1) ____	(2) ____	(3) ____	(4) ____
Date/Time:	Date/Time:	Date/Time:	Date/Time:

Courier and Airbill No.:	Laboratory Name and Address:	Received for Laboratory By (sign):	Date/Time:
N/A	Energy Laboratories 3161 E. Lyndale Helena, MT. 59601	[signature]	8-25-08 11:00

temp 9.3

BLANK COC.xls

ENERGY LABORATORIES, INC. • P.O. Box 5688 • 3161 East Lyndale Ave. • Helena, MT 59604
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Energy Laboratories Inc
Workorder Receipt Checklist

Camp Dresser and McKee Inc

H08080397

Login completed by: Roxanne L. Tubbs

Date and Time Received: 8/25/2008 11:00 AM

Reviewed by: JBB

Received by: wjj

Reviewed Date: 8/29/08

Carrier name: Hand Del

Shipping container/cooler in good condition?	Yes ☑	No ☐	Not Present ☐
Custody seals intact on shipping container/cooler?	Yes ☐	No ☐	Not Present ☑
Custody seals intact on sample bottles?	Yes ☐	No ☐	Not Present ☑
Chain of custody present?	Yes ☑	No ☐	
Chain of custody signed when relinquished and received?	Yes ☑	No ☐	
Chain of custody agrees with sample labels?	Yes ☑	No ☐	
Samples in proper container/bottle?	Yes ☑	No ☐	
Sample containers intact?	Yes ☑	No ☐	
Sufficient sample volume for indicated test?	Yes ☑	No ☐	
All samples received within holding time?	Yes ☑	No ☐	
Container/Temp Blank temperature:	9.3°C On Ice		
Water - VOA vials have zero headspace?	Yes ☐	No ☐	No VOA vials submitted ☑
Water - pH acceptable upon receipt?	Yes ☑	No ☐	Not Applicable ☐

Contact and Corrective Action Comments:

Use Quote 310, except total selenium instead of dissolved selenium per COC and K. Mainzhausen. 8/25/08 rt

LABORATORY ANALYTICAL REPORT

		Revised Date:	10/27/08
Client:	Camp Dresser and McKee Inc	**Report Date:**	09/11/08
Project:	Anadarko Upper Muddy Creek Monitoring	**Collection Date:**	08/19/08 17:50
Lab ID:	H08080397-001	**DateReceived:**	08/25/08
Client Sample ID:	UMC-1	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Solids, Total Suspended TSS @ 105 C	ND	mg/L		10		A2540 D	08/26/08 15:12 / abb
INORGANICS							
Alkalinity, Total as CaCO3	150	mg/L		4		A2320 B	08/28/08 13:27 / abb
Chloride	5	mg/L		1		E300.0	08/28/08 17:28 / skd
Sulfate	140	mg/L		1		E300.0	08/28/08 17:28 / skd
METALS, DISSOLVED							
Calcium	61	mg/L		1		E200.7	10/07/08 09:40 / sld
Magnesium	17	mg/L		1		E200.7	10/07/08 09:40 / sld
Potassium	3	mg/L		1		E200.7	10/07/08 09:40 / sld
Sodium	20	mg/L		1		E200.7	10/07/08 09:40 / sld
METALS, TOTAL							
Selenium	0.002	mg/L		0.001		E200.8	08/29/08 19:38 / eli-b

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

		Revised Date:	10/27/08
Client:	Camp Dresser and McKee Inc	**Report Date:**	09/11/08
Project:	Anadarko Upper Muddy Creek Monitoring	**Collection Date:**	08/23/08 08:30
Lab ID:	H08080397-002	**DateReceived:**	08/25/08
Client Sample ID:	UMC-1	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Conductivity	556	umhos/cm		1		A2510 B	08/27/08 10:53 / abb

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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LABORATORY ANALYTICAL REPORT

		Revised Date:	10/27/08
Client:	Camp Dresser and McKee Inc	**Report Date:**	09/11/08
Project:	Anadarko Upper Muddy Creek Monitoring	**Collection Date:**	08/21/08 09:50
Lab ID:	H08080397-003	**DateReceived:**	08/25/08
Client Sample ID:	UMC-3	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Conductivity	578	umhos/cm		1		A2510 B	08/27/08 10:54 / abb
Solids, Total Suspended TSS @ 105 C	11	mg/L		10		A2540 D	08/27/08 15:23 / abb
INORGANICS							
Alkalinity, Total as CaCO3	150	mg/L		4		A2320 B	08/28/08 13:32 / abb
Chloride	6	mg/L		1		E300.0	08/28/08 17:47 / skd
Sulfate	150	mg/L		1		E300.0	08/28/08 17:47 / skd
METALS, DISSOLVED							
Calcium	60	mg/L		1		E200.7	10/07/08 09:42 / sld
Magnesium	19	mg/L		1		E200.7	10/07/08 09:42 / sld
Potassium	3	mg/L		1		E200.7	10/07/08 09:42 / sld
Sodium	25	mg/L		1		E200.7	10/07/08 09:42 / sld
METALS, TOTAL							
Selenium	0.002	mg/L		0.001		E200.8	08/29/08 19:44 / eli-b

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

LABORATORY ANALYTICAL REPORT

		Revised Date:	10/27/08
Client:	Camp Dresser and McKee Inc	**Report Date:**	09/11/08
Project:	Anadarko Upper Muddy Creek Monitoring	**Collection Date:**	08/21/08 09:55
Lab ID:	H08080397-004	**DateReceived:**	08/25/08
Client Sample ID:	UMC-3 Duplicate	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Solids, Total Suspended TSS @ 105 C	ND	mg/L		10		A2540 D	08/26/08 15:13 / abb
INORGANICS							
Alkalinity, Total as CaCO3	150	mg/L		4		A2320 B	08/28/08 13:37 / abb
Chloride	6	mg/L		1		E300.0	08/28/08 18:07 / skd
Sulfate	150	mg/L		1		E300.0	08/28/08 18:07 / skd
METALS, DISSOLVED							
Calcium	61	mg/L		1		E200.7	10/07/08 09:45 / sld
Magnesium	19	mg/L		1		E200.7	10/07/08 09:45 / sld
Potassium	3	mg/L		1		E200.7	10/07/08 09:45 / sld
Sodium	25	mg/L		1		E200.7	10/07/08 09:45 / sld
METALS, TOTAL							
Selenium	0.002	mg/L		0.001		E200.8	08/29/08 19:51 / eli-b

Report Definitions:
RL - Analyte reporting limit.
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MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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LABORATORY ANALYTICAL REPORT

Revised Date: 10/27/08
Report Date: 09/11/08
Collection Date: 08/22/08 16:00
DateReceived: 08/25/08
Matrix: Aqueous

Client: Camp Dresser and McKee Inc
Project: Anadarko Upper Muddy Creek Monitoring
Lab ID: H08080397-005
Client Sample ID: UMC-6

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Conductivity	616	umhos/cm		1		A2510 B	08/27/08 10:59 / abb
Solids, Total Suspended TSS @ 105 C	12	mg/L		10		A2540 D	08/27/08 15:23 / abb
INORGANICS							
Alkalinity, Total as CaCO3	150	mg/L		4		A2320 B	09/03/08 09:25 / kjw
Chloride	7	mg/L		1		E300.0	08/28/08 18:26 / skd
Sulfate	180	mg/L		1		E300.0	08/28/08 18:26 / skd
METALS, DISSOLVED							
Calcium	58	mg/L		1		E200.7	10/07/08 09:47 / sld
Magnesium	19	mg/L		1		E200.7	10/07/08 09:47 / sld
Potassium	4	mg/L		1		E200.7	10/07/08 09:47 / sld
Sodium	31	mg/L		1		E200.7	10/07/08 09:47 / sld
METALS, TOTAL							
Selenium	0.001	mg/L		0.001		E200.8	08/29/08 20:43 / eli-b

Report Definitions:
RL - Analyte reporting limit.
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MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

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LABORATORY ANALYTICAL REPORT

		Revised Date:	10/27/08
Client:	Camp Dresser and McKee Inc	**Report Date:**	09/11/08
Project:	Anadarko Upper Muddy Creek Monitoring	**Collection Date:**	08/23/08 12:40
Lab ID:	H08080397-006	**DateReceived:**	08/25/08
Client Sample ID:	UMC-Blank	**Matrix:**	Aqueous

Analyses	Result	Units	Qualifiers	RL	MCL/ QCL	Method	Analysis Date / By
PHYSICAL PROPERTIES							
Solids, Total Suspended TSS @ 105 C	ND	mg/L		10		A2540 D	08/26/08 15:13 / abb
INORGANICS							
Alkalinity, Total as CaCO3	ND	mg/L		4		A2320 B	09/03/08 09:25 / kjw
Chloride	ND	mg/L		1		E300.0	08/28/08 18:46 / skd
Sulfate	ND	mg/L		1		E300.0	08/28/08 18:46 / skd
METALS, DISSOLVED							
Calcium	ND	mg/L		1		E200.7	10/07/08 09:50 / sld
Magnesium	ND	mg/L		1		E200.7	10/07/08 09:50 / sld
Potassium	ND	mg/L		1		E200.7	10/07/08 09:50 / sld
Sodium	ND	mg/L		1		E200.7	10/07/08 09:50 / sld
METALS, TOTAL							
Selenium	ND	mg/L		0.001		E200.8	08/29/08 20:50 / eli-b

Report Definitions:
RL - Analyte reporting limit.
QCL - Quality control limit.
MCL - Maximum contaminant level.
ND - Not detected at the reporting limit.

QA/QC Summary Report

Client: Camp Dresser and McKee Inc | **Report Date:** 09/11/08
Project: Anadarko Upper Muddy Creek Monitoring | **Work Order:** H08080397

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
Method: A2320 B						Analytical Run: TITTR_080828A			
Sample ID: CCV1_080828A	Continuing Calibration Verification Standard							08/28/08 12:03	
Alkalinity, Total as CaCO3	1000	mg/L	4.0	101	90	110			
Method: A2320 B						Batch: 080828A-ALK-W			
Sample ID: MBLK1_080828A	Method Blank				Run: TITTR_080828A			08/28/08 09:38	
Alkalinity, Total as CaCO3	ND	mg/L	1						
Sample ID: LCS1_080828A	Laboratory Control Sample				Run: TITTR_080828A			08/28/08 09:43	
Alkalinity, Total as CaCO3	590	mg/L	4.0	98	90	110			
Sample ID: H08080360-001AMS	Sample Matrix Spike				Run: TITTR_080828A			08/28/08 10:28	
Alkalinity, Total as CaCO3	690	mg/L	4.0	96	90	110			
Sample ID: H08080360-001AMSD	Sample Matrix Spike Duplicate				Run: TITTR_080828A			08/28/08 10:33	
Alkalinity, Total as CaCO3	670	mg/L	4.0	92	90	110	2.8	20	
Sample ID: H08080395-001ADUP	Sample Duplicate				Run: TITTR_080828A			08/28/08 13:06	
Alkalinity, Total as CaCO3	43	mg/L	4.0				2.4	20	
Method: A2320 B						Batch: 080903A-ALK-W			
Sample ID: MBLK1_080903A	Method Blank				Run: TITTR_080903A			09/03/08 09:07	
Alkalinity, Total as CaCO3	ND	mg/L	1						
Sample ID: LCS1_080903A	Laboratory Control Sample				Run: TITTR_080903A			09/03/08 09:15	
Alkalinity, Total as CaCO3	600	mg/L	4.0	99	90	110			
Sample ID: H08080440-001AMS	Sample Matrix Spike				Run: TITTR_080903A			09/03/08 10:13	
Alkalinity, Total as CaCO3	590	mg/L	4.0	96	90	110			
Sample ID: H08080440-001AMSD	Sample Matrix Spike Duplicate				Run: TITTR_080903A			09/03/08 10:24	
Alkalinity, Total as CaCO3	600	mg/L	4.0	96	90	110	0.5	20	
Method: A2510 B						Analytical Run: COND_080827A			
Sample ID: CCV3_080827A	Continuing Calibration Verification Standard							08/27/08 10:49	
Conductivity	148	umhos/cm	1.0	100	90	110			
Method: A2510 B						Batch: 080827A-COND-PROBE-W			
Sample ID: LCS1_080827A	Laboratory Control Sample				Run: COND_080827A			08/27/08 10:38	
Conductivity	712	umhos/cm	1.0	99	90	110			
Sample ID: H08080397-004ADUP	Sample Duplicate				Run: COND_080827A			08/27/08 11:28	
Conductivity	577	umhos/cm	1.0				0.0	10	

Qualifiers:

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

QA/QC Summary Report

Client: Camp Dresser and McKee Inc **Report Date:** 09/11/08
Project: Anadarko Upper Muddy Creek Monitoring **Work Order:** H08080397

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
Method: A2540 D							Batch: 080826A-SLDS-TSS-W		
Sample ID: MBLK1_080826A	Method Blank				Run: SOLIDS_080826A			08/26/08 15:11	
Solids, Total Suspended TSS @ 105 C	ND	mg/L	1						
Sample ID: LCS1_080826A	Laboratory Control Sample				Run: SOLIDS_080826A			08/26/08 15:11	
Solids, Total Suspended TSS @ 105 C	1590	mg/L	10	79	70	130			
Method: A2540 D							Batch: 080827A-SLDS-TSS-W		
Sample ID: LCS1_080827A	Laboratory Control Sample				Run: SOLIDS_080827B			08/27/08 15:22	
Solids, Total Suspended TSS @ 105 C	1710	mg/L	10	86	70	130			
Sample ID: MBLK1_080827A	Method Blank				Run: SOLIDS_080827B			08/27/08 15:22	
Solids, Total Suspended TSS @ 105 C	ND	mg/L	1						
Method: E200.8							Batch: B_34393		
Sample ID: MB-34393	Method Blank				Run: SUB-B116741			08/29/08 17:58	
Selenium	6E-05	mg/L	2E-05						
Sample ID: LCS5-34393	Laboratory Control Sample				Run: SUB-B116741			08/29/08 18:05	
Selenium	0.4846	mg/L	0.0050	97	85	115			
Sample ID: B08082666-004BMS5	Sample Matrix Spike				Run: SUB-B116741			08/29/08 19:57	
Selenium	0.4897	mg/L	0.0050	98	70	130			
Sample ID: B08082666-004BMSD5	Sample Matrix Spike Duplicate				Run: SUB-B116741			08/29/08 20:31	
Selenium	0.4975	mg/L	0.0050	99	70	130	1.6	20	

Qualifiers:

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

QA/QC Summary Report

Client: Camp Dresser and McKee Inc **Report Date:** 09/11/08
Project: Anadarko Upper Muddy Creek Monitoring **Work Order:** H08080397

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
Method: E200.8									Analytical Run: SUB-B116741
Sample ID: QCS-080514A, 080514B, Initial Calibration Verification Standard									08/29/08 10:44
Selenium	0.050	mg/L	0.0050	100	90	110			
Sample ID: QCS-080514A, 080514B, Initial Calibration Verification Standard									08/29/08 14:17
Selenium	0.051	mg/L	0.0050	102	90	110			
Method: E200.8									Batch: B_R116741
Sample ID: LRB Method Blank					Run: SUB-B116741				08/29/08 11:11
Selenium	ND	mg/L	0.0001						
Sample ID: LFB Laboratory Fortified Blank					Run: SUB-B116741				08/29/08 11:17
Selenium	0.046	mg/L	0.0050	91	85	115			
Sample ID: B08082666-006BMS Sample Matrix Spike					Run: SUB-B116741				08/29/08 20:57
Selenium	0.0514	mg/L	0.0050	103	70	130			
Sample ID: B08082666-006BMSD Sample Matrix Spike Duplicate					Run: SUB-B116741				08/29/08 21:03
Selenium	0.0505	mg/L	0.0050	101	70	130	1.9	20	
Sample ID: B08082640-001BMS Sample Matrix Spike					Run: SUB-B116741				08/29/08 19:11
Selenium	0.1189	mg/L	0.0050	119	70	130			
Sample ID: B08082640-001BMSD Sample Matrix Spike Duplicate					Run: SUB-B116741				08/29/08 19:18
Selenium	0.1174	mg/L	0.0050	117	70	130	1.2	20	

Qualifiers:

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

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QA/QC Summary Report

Client: Camp Dresser and McKee Inc **Report Date:** 09/11/08
Project: Anadarko Upper Muddy Creek Monitoring **Work Order:** H08080397

Analyte	Result	Units	RL	%REC	Low Limit	High Limit	RPD	RPDLimit	Qual
Method: E300.0								Analytical Run: IC101-H_080828A	
Sample ID: CCV	Continuing Calibration Verification Standard							08/28/08 13:35	
Chloride	25	mg/L	1.0	101	90	110			
Sulfate	100	mg/L	1.0	101	90	110			
Sample ID: ICV	Initial Calibration Verification Standard							08/28/08 13:54	
Chloride	25	mg/L	1.0	99	90	110			
Sulfate	100	mg/L	1.0	101	90	110			
Method: E300.0								Batch: R48000	
Sample ID: LFB	Laboratory Fortified Blank				Run: IC101-H_080828A			08/28/08 14:14	
Chloride	9.2	mg/L	1.0	92	90	110			
Sulfate	37	mg/L	1.0	92	90	110			
Sample ID: MBLK	Method Blank				Run: IC101-H_080828A			08/28/08 14:33	
Chloride	ND	mg/L							
Sulfate	ND	mg/L							
Sample ID: LCS	Laboratory Control Sample				Run: IC101-H_080828A			08/28/08 15:12	
Chloride	88	mg/L	1.0	100	90	110			
Sulfate	28	mg/L	1.0	98	90	110			
Sample ID: H08080395-002A MS	Sample Matrix Spike				Run: IC101-H_080828A			08/28/08 16:10	
Chloride	26	mg/L	1.0	104	90	110			
Sulfate	110	mg/L	1.0	104	90	110			
Sample ID: H08080395-002A MSD	Sample Matrix Spike Duplicate				Run: IC101-H_080828A			08/28/08 16:30	
Chloride	25	mg/L	1.0	100	90	110	3.6	20	
Sulfate	100	mg/L	1.0	100	90	110	3.4	20	
Sample ID: H08080402-003A MS	Sample Matrix Spike				Run: IC101-H_080828A			08/28/08 21:02	
Chloride	32	mg/L	1.0	101	90	110			
Sulfate	120	mg/L	1.0	100	90	110			
Sample ID: H08080402-003A MSD	Sample Matrix Spike Duplicate				Run: IC101-H_080828A			08/28/08 21:21	
Chloride	31	mg/L	1.0	97	90	110	2.6	20	
Sulfate	120	mg/L	1.0	100	90	110	0.0	20	

Qualifiers:

RL - Analyte reporting limit.

ND - Not detected at the reporting limit.

Appendix H

Monitoring Plan

Atlantic Rim Coal Bed Methane and Natural Gas Project
Carbon County, Wyoming

August 2008

Muddy Creek Monitoring Plan

CDM

Contents

Section 1 Introduction

This monitoring plan has been prepared to guide geomorphic, aquatic habitat, and water quality monitoring on upper Muddy Creek in the Atlantic Rim Project area. The Atlantic Rim Coal Bed Methane and Natural Gas Project in Carbon County, Wyoming is a coal bed methane and natural gas project to be developed on public and private land by Anadarko and other operators (Figure 1-1). Development will occur in a 270,080 acre area and requires construction of roads, pipelines, well pads, compressor stations and gas processing facilities, drilling 2,000 wells, and production of water (BLM, 2006). The portion of the upper Muddy Creek drainage where development will take place is shown in Figure 1-2. A particular concern on upper Muddy Creek is the maintenance of populations of non-game, native fish species, particularly the roundtail chub, bluehead sucker, and flannelmouth sucker (BLM, 2006). The general goal of monitoring on upper Muddy Creek is to determine if activities associated with the Atlantic Rim Project have an impact on upper Muddy Creek that adversely affects the non-game, native fish population. The potential adverse effects caused by c development will need to be compared to potential impacts due to other factors such as recreation and livestock grazing.

1.1 Background

The Atlantic Rim Coal Bed Methane and Natural Gas Project was proposed by Anadarko and other operators in 2001. The responsible agency for permitting the development is the Bureau of Land Management (BLM), which initiated scoping for an Environmental Impact Statement (EIS) in 2001. The Record of Decision (BLM, 2007) for the project was signed in 2007 and includes specific performance goals for the project. The performance goal for Muddy Creek sensitive fish is to "maintain adequate water quality, water quantity, species distribution, and aquatic habitat components." This is to be accomplished through use of Best Management Practices (BMPs), performance-based monitoring, and adaptive management. This monitoring plan addresses monitoring activities that will take place on upper Muddy Creek.

1.2 Project Organization

Monitoring of upper Muddy Creek described in this plan is the responsibility of Anadarko and its consultant. Additional monitoring tasks will be conducted on upper Muddy Creek as well as on lower Muddy Creek and Muddy Creek tributaries by various agencies. Water quality data will be collected throughout the Muddy Creek drainage by the Little Snake River Conservation District (LSRCD) as it has been in the past. The LSRCD will also measure flows at these stations. The Wyoming Game and Fish Department (WGFD) will continue fish distribution and population studies in the drainage as well. The BLM as the lead agency for the Atlantic Rim Development Project will coordinate the various monitoring efforts through the Muddy Creek Working Group.

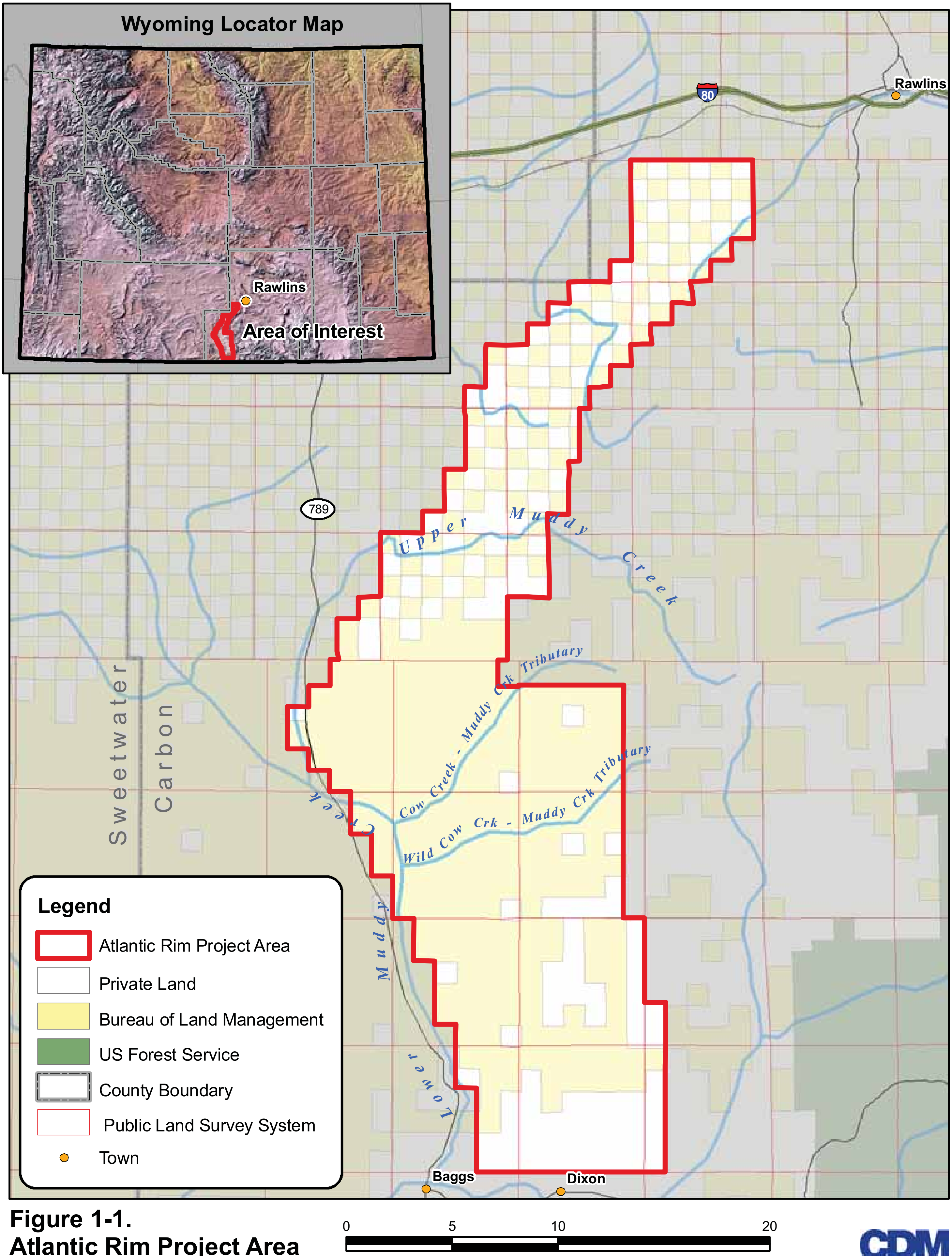

Figure 1-1.
Atlantic Rim Project Area
Carbon County, Wyoming

CDM

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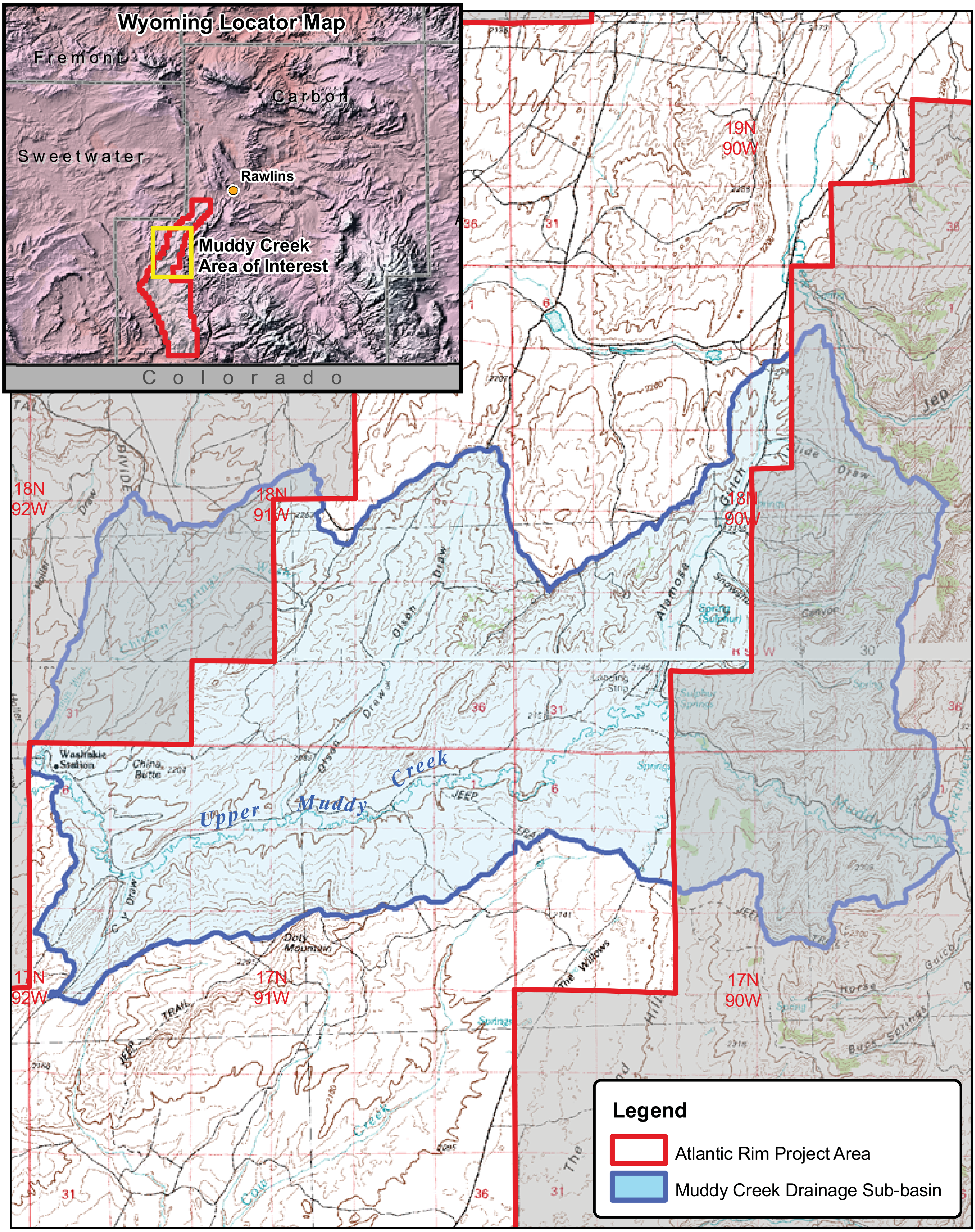

Figure 1-2. Muddy Creek Area
Atlantic Rim Project
Carbon County, Wyoming

CDM

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1.3 Monitoring Objectives

The Record of Decision (BLM, 2007) for the Atlantic Rim Project has specific performance goals including one for Muddy Creek sensitive fish species. The requirement is to "maintain adequate water quality, water quantity, species distribution, and aquatic habitat components." The primary concerns with development activities within upper Muddy Creek are the modification of flow regimes, potential increase in sediment delivery and transport, and potential impacts on channel stability and water quality. Increases in stream sediment load could adversely affect sensitive fish populations and distribution. Aquatic habitat and riparian habitat could also be degraded or lost.

To determine if the Atlantic Rim Project has adverse impacts on the sensitive fish populations in the stream, a multi-parameter approach that encompasses geomorphology, hydrology, habitat features and water quality is recommended. All of these disciplines relate to sediment transport in the system, which is key to the health of the benthic macroinvertebrate populations and fish that feed on them. The objectives of this monitoring effort include:

- Measurement of sediment delivery from eroding streambanks.
- Measurement of habitat features and stream morphology.
- Measurement of in-stream sediment concentrations and other water quality parameters.

This monitoring plan focuses on upper Muddy Creek within or near the project boundaries because this segment of Muddy Creek could potentially be directly affected by coal bed methane and natural gas development. This segment of Muddy creek is also the best documented location of sensitive fish species.

Specific tasks that will be performed to accomplish the above objectives are listed below and developed in detail in Sections 2 and 3 of this plan.

For Streambank Erosion:

- Survey and monument cross-sections for repeated surveys in reaches of interest.
- Place bank pins at or near sections for verification of section data.

For Geomorphology and Habitat Features:

- Perform Rosgen Level II stream survey including bankfull determination, cross-section measurement, longitudinal profiles, pool/riffle length, spacing, and ratios.
- Measure residual pool depth and area.
- Evaluate bed material using Wolman pebble count, inventory of bedrock and other hard surfaces.

- Measure embeddedness.
- Evaluate bank stability using the Bank Erosion Hazard Index method and Near Bank Stress (NBS) methods.
- Survey vegetative stream cover.

For Sediment and Water Quality:

- Sample for total suspended solids, field parameters, dissolved selenium, and common ions using standard field sampling methods and laboratory analysis.
- Measure instantaneous discharge during sample collection.

Section 2 Geomorphic and Aquatic Habitat Monitoring

This section describes the timing, location, and methods planned for monitoring of geomorphic and aquatic habitat features in upper Muddy Creek. The timing of water quality monitoring, which is described in the next section, will coincide with monitoring the geomorphic components and aquatic habitat features, but locations may differ because of differing objectives.

2.1 Monitoring Period and Frequency

Monitoring is initially planned to occur annually. It is likely that the monitoring protocols will be revised over time based on the results of data collected. Monitoring will take place in late summer during a period of low flow. Although low flow periods often exhibit the highest concentrations of dissolved constituents in water, higher sediment concentrations would be expected during spring high flows. However, the watershed is largely inaccessible during the high flow period because of snow and wet conditions. Other reasons for monitoring during the low flow period are that the geomorphic and aquatic habitat monitoring protocols are more easily and more accurately performed when flows are low.

Prior to the first monitoring event, currently planned for August 2008, a reconnaissance level assessment of the watershed will be undertaken by agency personnel and CDM to document the present watershed condition and identify reaches where monitoring is most needed. The initial assessment work will continue during the monitoring event in August, which will combine assessment work with monitoring. In following years, only monitoring tasks will be conducted. Section 2.3 clarifies which tasks are specific to 2008 and which are planned for annual monitoring.

2.2 Study Reach Locations

The objective of geomorphic and aquatic habitat monitoring is to monitor potential impacts of development on the stream geomorphology and habitat features of upper Muddy Creek. The initial site visit conducted on July 17 and 18, 2008 found a highly sinuous and deeply entrenched stream throughout the project area. The degree of bank instability appeared to be related largely to the bank heights, which varied from site to site. Based on this assessment, monitoring sites were selected to cover the observed range of bank heights as well as provide good spatial coverage of the drainage. Two of the monitoring sites also correspond to sites that have established cross-sections which were presumably monitored in the past. Figure 2-1 shows the selected monitoring locations. The study reaches will be of sufficient length to capture the range of physical and habitat parameters typical of that stream type and may be up to 600 feet in length.

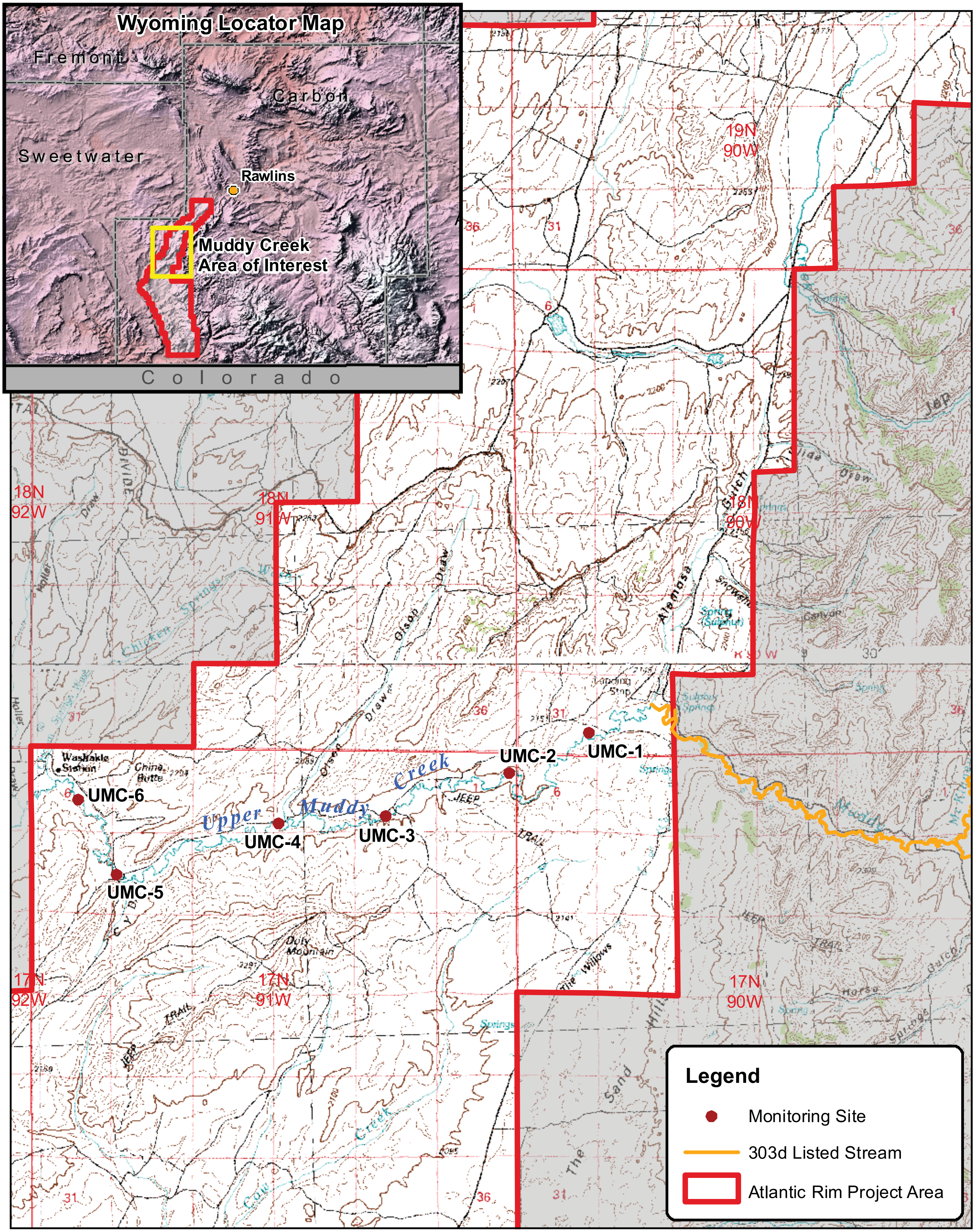

Figure 2-1. Upper Muddy Creek Monitoring Locations

Atlantic Rim Project

Carbon County, Wyoming

CDM

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2.3 Monitoring Methods

Monitoring methods for geomorphic and aquatic habitat have been selected based on the goals for the study, input from the agencies, and CDM's experience with watershed assessments in other areas. These methods include a Rosgen Level 2 survey, bed measurements, bank stability evaluation, and aquatic habitat feature measurements.

2.3.1 Initial Geomorphic Stream Survey

In 2008, the initial assessment of upper Muddy Creek will generally follow the methods of David Rosgen outlined in his book *Applied River Morphology* (Rosgen, 1996); specifically, the Level II method described in Chapter 5 will be followed. This method results in a stream classification according to the author's system but also develops many important stream parameters in the process. It requires surveys of longitudinal profile as well as surveys of cross-sections at riffle and pools. The purpose of this initial assessment is to determine the general geomorphic condition of the stream. In particular, the assessment will indicate the relative stability of the channel and what the probable evolution of the stream would be under natural conditions. Measurements to be taken at each study reach include:

- Longitudinal profile of thalweg, water elevation, bankfull indicators, terraces, bars.
- Cross-sections across the floodplain at riffle and pool locations within the reach (about six per study reach).
- Riffle–pool spacing and pool lengths.
- Bed material size using the Wolman (1954) pebble count method.

These measurements are supplemented by measurement of stream sinuosity, which will be measured from high resolution mapping rather than in the field.

Field measurements will be supplemented by photographs and a plan-view sketch of the features of each reach. Important geomorphic features such as bed rock outcrops will be noted on the field sketches.

The Level II analysis uses the aforementioned field measurements to calculate of a number of parameters:

- Channel (riffle to riffle) slope,
- Bankfull maximum depth,
- Floodprone area width,

- Bankfull surface width,
- Bankfull mean depth,
- Entrenchment ratio,
- Width/depth ratio, and
- Dominant bed material (D_{50} size).

In addition, for each pool, the residual depth and area will be determined, parameters not specifically included in the Level II method. Pool/riffle ratios will also be calculated based on the riffle spacing and pool length measurements.

Stream geomorphology measurements will generally follow those of Harrelson et al. (1994) although measurements will be taken with a total station to permit efficient data collection with a two-person team. Benchmarks will be set locally on a local datum and will be located horizontally with a resource grade Global Positioning (GPS) receiver. Bench marks will consist of iron rebar driven in the ground and guarded by a steel fence post.

2.3.2 Annual Geomorphic Stream Monitoring

The initial geomorphic assessment of upper Muddy creek is intended to determine the general geomorphic character of the stream and will not be repeated in its entirety every year because stream types change slowly over time, if at all. However, certain measurements will be repeated every year such as channel cross-section and residual pool depth and area because these characteristics are sensitive to short term change that could be induced by development. Bed particle sizes, embeddedness, and bank stability will also be monitored on an annual basis. Table 2-1 summarizes the differences between initial monitoring and annual monitoring.

At each of the study reaches, an average of one cross-section will be monumented with rebar and fence posts at each end of the section. This section will be surveyed in order to allow repetition of the survey in the future. This section will generally be selected at a location that has the potential to indicate erosion and section change. However, the monumented sections at reference reaches, which represent the desired condition on the stream, would represent a more stable condition for comparison purposes. Note that generally only one section will be monumented and remeasured in each study reach. The other initial survey sections, which are selected to represent the riffle and pool sections of the stream, are not necessarily representative of conditions that indicate the stability of the channel and will be located with wooden stakes.

Table 2-1. Monitoring Elements, Muddy Creek, Atlantic Rim Coal Bed Methane and Natural Gas Project

Task	2008Assessment Monitoring	Annual Monitoring
Level II Geomorphic Survey		
Longitudinal profile	yes	no
Cross sections	yes	no
Permanent cross sections	yes	yes
Riffle – pool spacing	yes	no
Residual pool depth	yes	yes
Bed Measurements		
Bed material size	yes	yes
Embeddedness	yes	yes
Bank Stability		
Erosion Pin Measurement	yes	yes
Bank Hazard Erosion Index	yes	yes
Aquatic Habitat Features		
Overhanging Vegetation Cover	yes	yes

Monuments will consist of steel fence posts and rebar at each end of the cross section. The purpose of the repeated measurements will be to allow estimation of the rate of streambank and bed erosion (or aggradation). If a permanent section established by the LSRCD is encompassed by a study reach and that section serves the goals of this study, that section will be used as the permanent section for this study reach. Photos of the monumented section as well as other noteworthy features of the study reach will be taken.

Residual pool depths and areas throughout the study reaches will also be measured on an annual basis to monitor potential sedimentation or scour effects.

2.3.3 Bed Measurements

Bed measurements are important for evaluating geomorphic stability as well as habitat. Variations in bed particle size over time may indicate aggradation or erosion of the bed material. The standard method for evaluating materials with coarse grained beds is the Wolman pebble count mentioned above (Wolman, 1954) and is described in detail in Harrelson et al. (1994). Wolman pebble counts will be performed at three cross-sections within each study reach. One hundred sample pebbles will be taken from the stream bed using a standard method such as gathering the pebble at the toe of your boot at each step. The length of the intermediate axis of each pebble will be measured using a gravelometer, and the number of particles falling in standard size categories recorded on a field data sheet. The locations of the riffle reaches measured will be recorded with a GPS receiver. A typical field form for recording a pebble count is found in Appendix A.

During data analysis, the cumulative size distribution for each pebble count will be plotted and the D_{50} size (median size) calculated.

Embeddedness is an important aquatic habitat measurement because it measures the amount of siltation in a streambed. Normally siltation is undesirable because it reduces habitat for benthic macroinvertebrates and spawning areas for fish. Embeddedness measures the amount of silt in a coarse grained (gravel, cobble, boulder) bed. The embeddedness measurement method will follow the U.S. Geological Survey's National Water-Quality Assessment Program as described in Sennatt et al (2006). This method measures or estimates the percentage of a particle's total height that is buried by fine sediment (less than 2 mm). Fifteen particles are selected at random at three transects. Locations of these sections will be documented with a GPS receiver.

2.3.4 Bank Stability

Several measures of bank stability will be employed. First, the annual remeasurement of the monumented cross-section for each study reach will indicate if banks are eroding. These monumented cross-sections will be selected at points where bank erosion is most likely to occur in the reach. To provide a more precise measurement of bank movement, erosion pins will be driven near the monumented cross sections at points most susceptible to bank erosion or collapse. Generally two bank pins will be placed near each permanent cross-section. Erosion pins are four foot steel bars driven horizontally in a bank until only several inches are protruding. The protrusion is measured and then remeasured in future monitoring events to determine if bank erosion or collapse has occurred. This method of measurement is described in Field Methods and Procedures part of the *Watershed Assessment of River Stability and Sediment Supply* website of EPA (http://www.epa.gov/WARSSS/monitor/method.htm).

Finally, bank stability will be rated semi-quantitatively at each cross-section according to the Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) methods, which are presented in *Applied River Morphology* (Rosgen, 1996). BEHI looks at five indices of bank stability and assigns numeric values to the observed conditions. The index values are summed and subjected to adjustment for bank material type and stratification to arrive at a qualitative descriptor of bank stability. NBS evaluates the rate at which a bank is expected to supply sediment to a stream based on the local hydraulic conditions. Several options are available for estimating the effects of bank stress in the WARSSS manual. Appropriate to the Level II investigation being conducted, the radius of curvature to width ratio will be used in this investigation. The location of the bank on a straight reach or outside of bend is noted. Information on the BEHI and NBS methods and a field rating sheet are included in Appendix A.

BEHI and NBS will be measured at the two banks with erosion pins within each study reach and up to eight additional banks that are susceptible to erosion within each study reach. These locations will not necessarily correspond to cross-section locations measured during the initial geomorphic stream assessment. However, the same bank locations will be evaluated using BEHI and NBS in each annual monitoring event. Bank locations will be recorded with a GPS receiver, and photos of the banks will be taken.

2.3.5 Aquatic Habitat Features

Aquatic habitat features add complexity and heterogeneity to a stream, which are generally important to the health of aquatic life. These habitat features are varied and can include large rocks in the channel, drops, large woody debris, overhanging banks, vegetation cover that extends over the channel and any other feature that provides cover or other needed habitat for aquatic animal life. Also included as habitat features are drops and pools with adequate residual depths, which will be identified through the stream survey. It is not expected that the stream will contain significant amounts of large rock or large woody debris although, if found, these features will be noted on the field sketches.

Section 3
Water Quality Monitoring

3.1 Water Quality Monitoring Objectives

The objective of this surface monitoring program is to assess the water quality of upper Muddy Creek within or near the Atlantic Rim Project Area and compile a data set starting with a baseline. The data set will be used to identify trends in water quality within the stream potentially caused by coal methane development and to determine the effectiveness of BMPs and reclamation efforts. If the data shows undesired effects on the water quality that could impact sensitive fish species or aquatic habitat, Best Management Practices (BMPs) can modified to achieve the desired effects.

3.2 Sampling Locations and Frequency

As mentioned in the ROD, monitoring must occur for several years before any trends can be identified. Therefore, it is assumed that this sampling program will initially be performed annually.

Sampling will be conducted annually during low-flow conditions at three locations within the upper Muddy Creek project site; one upstream, one downstream and one approximately half way between the other two locations. Figure 3-1 shows the sampling locations. Station locations have been recorded with a GPS receiver. The first surface water quality sampling activities are scheduled for August 2008 and will be conducted in conjunction with the geomorphic and aquatic habitat monitoring activities.

3.3 Sampling Parameters and Analytical Methods

Field parameters will be measured by using a Datasonde/Surveyor 4 System with integrated parameters measurement equipment or approved equal. The following parameters will be measures at each sampling location approximately in the middle of the stream and recorded in the project field logbook: pH, temperature, dissolved oxygen (DO), turbidity, and specific conductance. All parameter measurement sensors will be calibrated at the factory before bringing the instrument to the field for use. The pH and DO sensors will be calibrated in the field prior to use on a daily basis and the calibration noted.

Surface water samples will be collected in laboratory supplied containers containing preservatives as appropriate for calcium, magnesium, sodium, potassium, chloride, , sulfate and total alkalinity. These samples will be collected at each location by submerging the bottle by hand (dip) approximately in the middle of the stream and allowing the container to fill as the container is brought up to the surface.

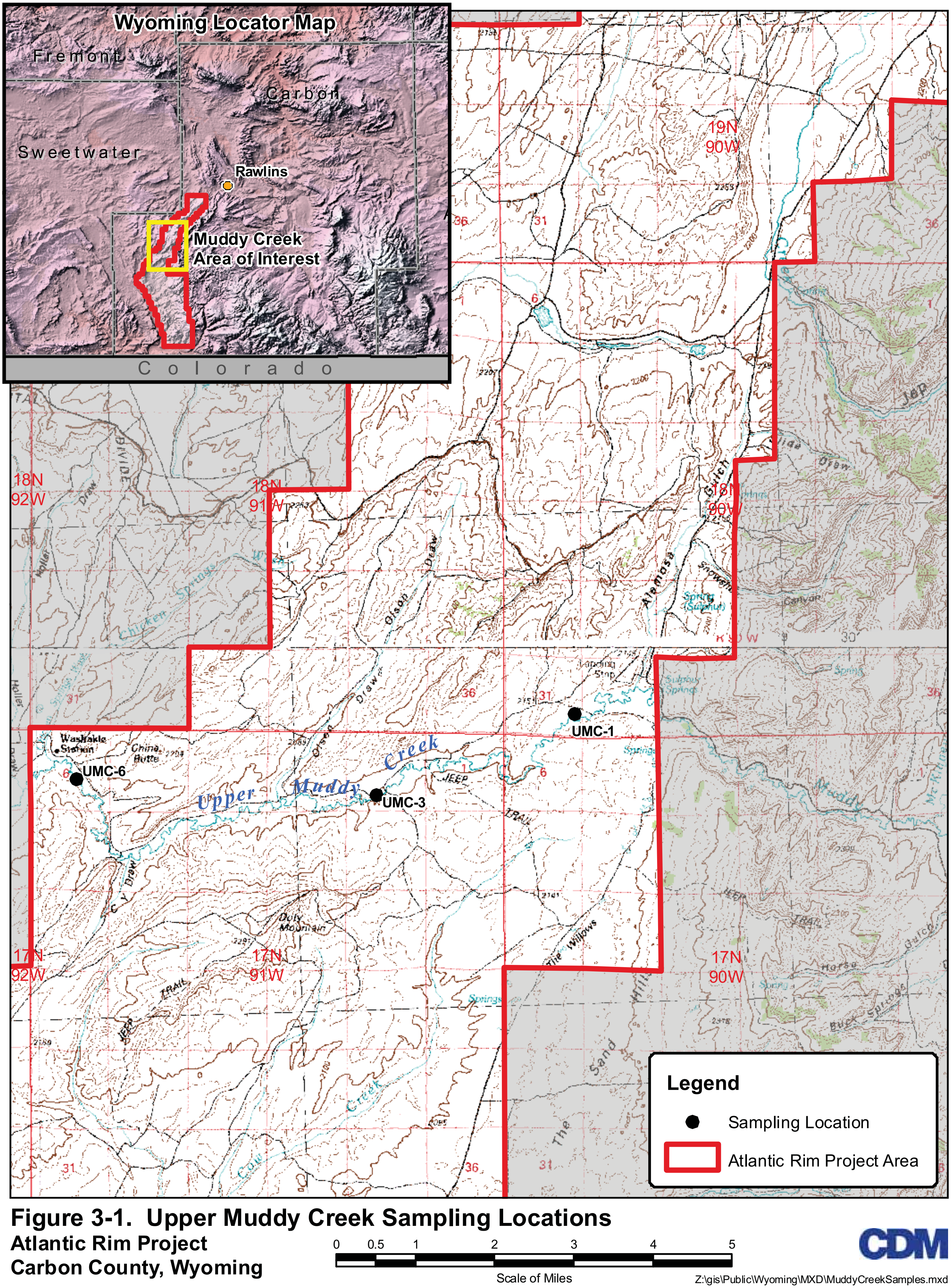

Figure 3-1. Upper Muddy Creek Sampling Locations
Atlantic Rim Project
Carbon County, Wyoming

CDM

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In addition, Total Suspended Solids (TSS) samples will be collected in laboratory supplied containers according to the Sample Collection and Treatment Section of *Field Guidelines for Collection, Treatment, and Analysis of Water Samples, Montana District*. Appropriate pages of this method are included in Appendix B. To ensure representative TSS samples, integrated samples will be collected using the equal-discharge-increment (EDI) method along each channel cross section. This method requires that the field team determine at least five equal-discharge increments for each cross-section prior to commencing the sampling activities. The total flow in the creek will first be determined using the equal-width-increment (EWI) method which will be used to determine the location of each flow increment. All measurement will be recorded in the field logbook.

Each sampling container will be labeled with the following information:

- Project identification,
- Date,
- Time,
- Sampler's initials, and
- Sample identification number or location.

The samples will be placed in a container chilled with ice immediately after collection and submitted to Energy Laboratories for analysis. Chain-of-custody forms will be completed and accompany the samples to the laboratory.

Samples will be analyzed in accordance with the EPA analytical methods listed in Table 3-1. The selected methods should be appropriate for this study because the reporting limits are lower than the previously collected sample results reported by BLM and LSRCD. If, in the future, the reporting limits appear not to provide the necessary resolution, alternative methods will be used.

Table 3-1 summarizes the samples parameters, analytical methods, reporting limits, sample containers, preservatives, and holding times for each parameter.

3.4 Quality Control/Quality Assurance

One surface water field duplicate and one field blank will be collected during the surface water sampling activities and analyzed for the same parameters listed in Table 3-1.

The field duplicate precision criterion for water samples is 20 percent relative percent difference (RPD) for concentrations greater than five times the reporting limit. If a result of the duplicate sample exceeds the 20 percent RPD criterion for that parameter, the associated field sample will be qualified as estimated and flagged with a J or UJ, respectively.

Table 3-1. Analytical Methods and Reporting Limits

Parameter	Analytical Method (1)	Reporting Limit	Container Requirement	Preservative	Holding Times
Common Ions: Sulfate Chloride	 EPA 300.0 EPA 300.0	 1 mg/L 1 mg/L	 250 ml (P)	 Cool, 4°C Not Required	 28-days
Cations (Ca, Mg, Na, K)	ICP-MS (EPA 200.7-8)	1 mg/L	125 ml (P)	HNO_3 to pH < 2	6 months
Total Alkalinity	EPA 310.1/A2320B	1 mg/L	100 ml (P)	Cool, 4°C Not Required	14 days
Dissolved Selenium	EPA 200.7-8	0.001 mg/L	100 ml (P)	Cool, 4°C H_2SO_4 to pH<2	28 days
Total Suspended Solids (TSS)	A 2540-D	10 mg/L	250 ml	Cool, 4°C Not Required	7 days

Notes:
ICP-MS – Inductively Coupled Plasma – Mass Spectrometry.
(P) – Plastic bottle
(1) – As described in USEPA (1993) and APHA (1992).

Section 4 Reporting

After completion of field activities and receipt and quality control of laboratory data, an annual data report will be prepared. The report for the initial monitoring year will also include information on the watershed and initial stream assessment information that will not be collected in future years. This information includes a description of the watershed, its existing sediment sources, and geomorphic stream classifications. The initial report will include interpretation of the assessment data such as determining Rosgen stream types, pool/riffle ratios, and bankfull flows. Monitoring data will be summarized in tabular form and a description of the existing condition provided. Based on monitoring results, recommendations for modifications to the monitoring program will be presented.

In following years, the annual report will summarize data collected in that year, compare it to the previous year's data, and note any significant changes in conditions. Recommendations for possible modification of BMPs and operations in the watershed will be presented as well as recommendations for modifications to the monitoring program. The reports will contain appendices presenting field data sheets, sketches, site photos, and laboratory data sheets.

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APPENDIX A
Geomorphic and Aquatic Habitat Methods and Forms

PEBBLE COUNT FORM

Site: ______________________ Date: ______________________

Section: ______________________ Party: ______________________

Size (mm)	Particle Count (less than size)	Count	Cum. Count	Cum. Percent
2				
4				
5.6				
8				
11				
16				
22.6				
32				
45				
64				
90				
128				
180				
Total:				

PEBBLE COUNT FORM

Site: ______________________ Date: ______________________

Section: ______________________ Party: ______________________

Size (mm)	Particle Count (less than size)	Count	Cum. Count	Cum. Percent
2				
4				
5.6				
8				
11				
16				
22.6				
32				
45				
64				
90				
128				
180				
Total:				

Bank Erosion Prediction (BEHI, NBS)

The prediction of stream bank erosion rates uses the **"Bank Assessment for Non-point source Consequences of Sediment" (BANCS)** method. This method as published by Rosgen (2001a) utilizes two bank erodibility estimation tools: the **Bank Erosion Hazard Index (BEHI)**, and **Near Bank Stress (NBS)**. The application involves evaluating the bank characteristics and flow distribution along river reaches and mapping various risk ratings commensurate with bank and channel changes. An estimate of erosion rate is made, and then multiplied times the bank height times the length of bank of a similar condition, providing an estimate of cubic yards and/or tons of sediment/year. This information can be compared to the sediment yield data to apportion the amount of sediment potentially contributed by streambanks.

The relationships developed to convert measurements of streambank variables into risk categories are shown along with bank erosion and bank angle illustrations in **Figures 112 to 114** (Rosgen, 2001a). A sketch of a streambank and some of the variables surveyed and calculated is shown in **Worksheet 20** (PDF, 38 kb, 1 p.). The use of channel materials, bank stratification and all of the variable ratios and ranges are summarized in the Bank Erosion Hazard Index (BEHI) form (**Worksheet 21**, PDF, 40 kb, 1 p.).

Figure 112. Streambank erodibility criteria used for the BEHI rating (Rosgen 1996, 2001a)

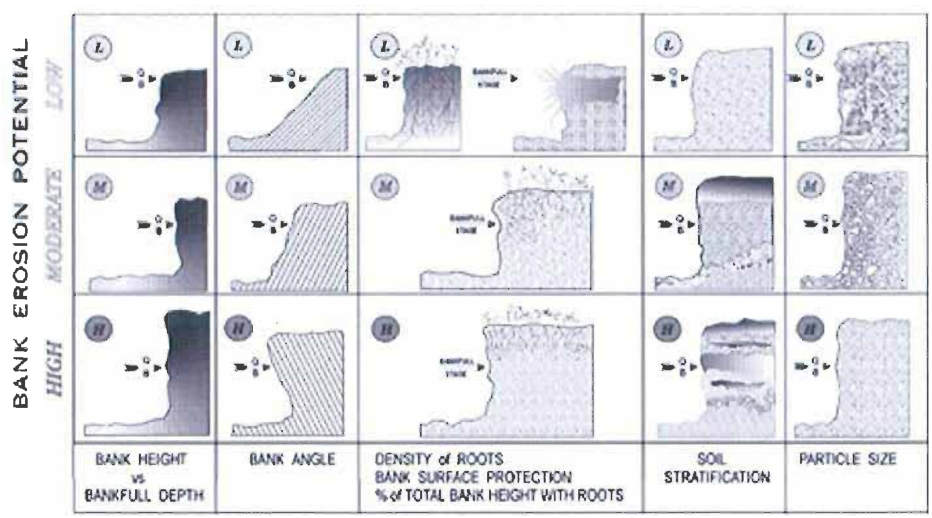


Figure 113. Illustrated examples of the five BEHI criteria

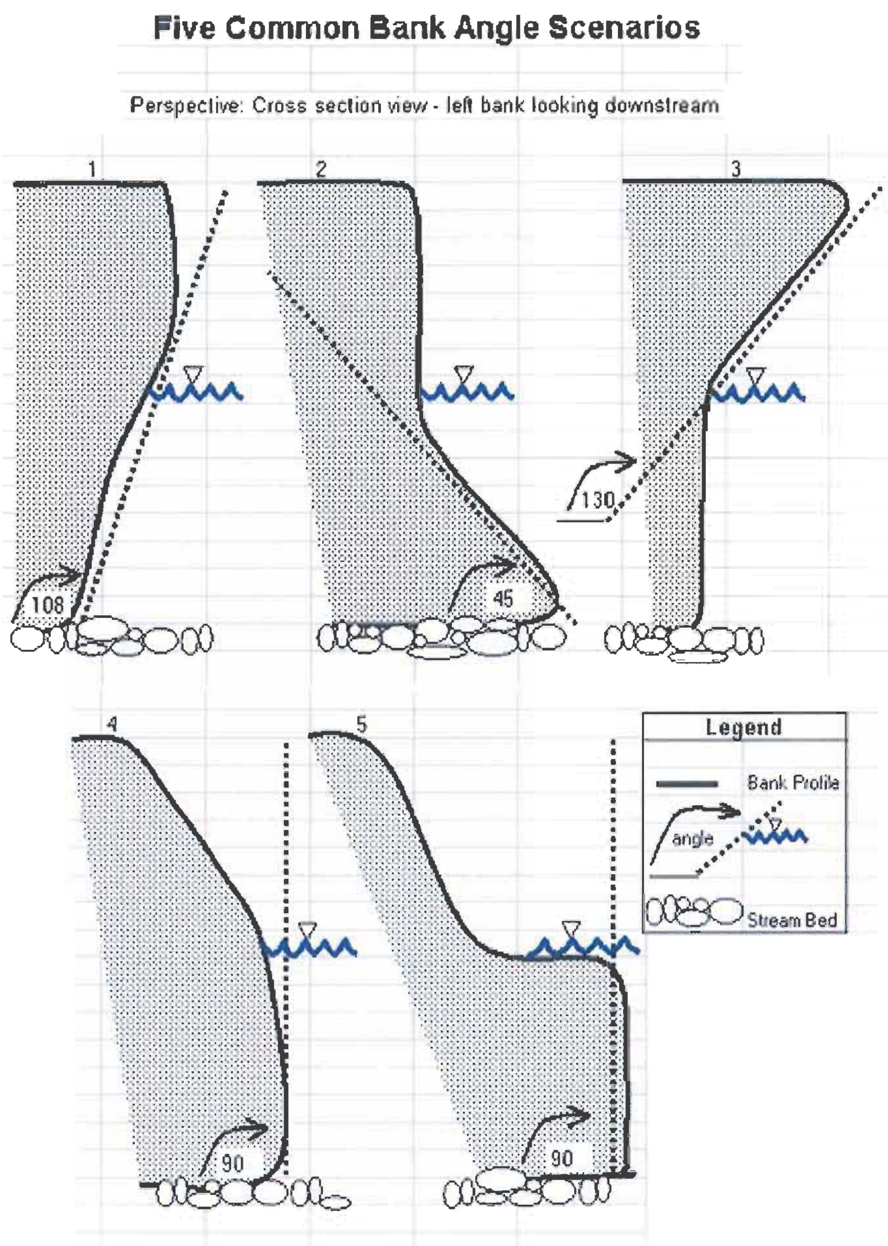


Figure 114. Common bank angle scenarios

Table 18. Velocity gradient and near-bank stress indices		
Bank Erosion Risk Rating	Velocity Gradient	Near-bank stress/shear stress
Very Low	Less than 0.5	Less than 0.8
Low	0.5 - 1.0	0.8 - 1.05
Moderate	1.1 - 1.6	1.06 - 1.14
High	1.61 - 2.0	1.15 - 1.19
Very High	2.1 - 2.4	1.2 - 1.6
Extreme	Greater than 2.4	Greater than 1.60

Worksheet 21. Summary of bank erosion hazard index (BEHI)

Bank Erosion Hazard Rating Guide

Stream Reach Date Crew

Bank Erosion Potential			Bank Height/ Bankfull Ht	Root Depth/ Bank Height	Root Density %	Bank Angle (Degrees)	Surface Protection%
	Bank Height (ft): Bankfull Height (ft):						
VERY LOW		Value	1.0-1.1	1.0-0.9	100-80	0-20	100-80
		Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
LOW		Value	1.11-1.19	0.89-0.5	79-55	21-60	79-55
		Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
MODERATE		Value	1.2-1.5	0.49-0.3	54-30	61-80	54-30
		Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
HIGH		Value	1.6-2.0	0.29-0.15	29-15	81-90	29-15
		Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
VERY HIGH		Value	2.1-2.8	0.14-0.05	14-5.0	91-119	14-10
		Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
EXTREME		Value	>2.8	<0.05	<5	>119	<10
		Index	10	10	10	10	10
		Choice	V: I:	V: I:	V: I:	V: I:	V: I:
	V = value, I = index				**SUB-TOTAL** (Sum one index from each column)		

Bank Material Description:

Bank Materials

- **Bedrock** (Bedrock banks have very low bank erosion potential)
- **Boulders** (Banks composed of boulders have low bank erosion potential)
- **Cobble** (Subtract 10 points. If sand/gravel matrix greater than 50% of bank material, then do not adjust)
- **Gravel** (Add 5-10 points depending percentage of bank material that is composed of sand)
- **Sand** (Add 10 points)
- **Silt Clay** (+ 0: no adjustment)

BANK MATERIAL ADJUSTMENT

Stratification Comments:

Stratification

Add 5-10 points depending on position of unstable layers in relation to bankfull stage

STRATIFICATION ADJUSTMENT

VERY LOW	LOW	MODERATE	HIGH	VERY HIGH	EXTREME
5-9.5	10-19.5	20-29.5	30-39.5	40-45	46-50

Bank location description (circle one)

Straight Reach Outside of Bend

GRAND TOTAL

BEHI RATING

Worksheet 22A. Various field methods of estimating Near-Bank Stress risk ratings for the calculation of erosion rate.

Estimating Near-Bank Stress (NBS)

Stream: Location: Date: Crew:

Methods for Estimating Near-Bank Stress

(1) Transverse bar or split channel/central bar creating NBS/high velocity gradient: **Level I - Reconnaissance.**

(2) Channel pattern (Rc/W): **Level II - General Prediction.**

(3) Ratio of pool slope to average water surface slope (S_p/S): **Level II - General Prediction.**

(4) Ratio of pool slope to riffle slope (S_p/S_{rif}): **Level II - General Prediction.**

(5) Ratio of near-bank maximum depth to bankfull mean depth (d_{nb}/d_{bkf}): **Level III - Detailed Prediction.**

(6) Ratio of near-bank shear stress to bankfull shear stress (τ_{nb}/τ_{bkf}): **Level III - Detailed Prediction.**

(7) Velocity profiles/Isovels/Velocity gradient: **Level IV - Validation.**

Level I

(1) Transverse and/or central bars - short and/or discontinuous. NBS = High/Very High

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

Chute cutoffs, down-valley meander migration, converging flow (Figure X). NBS = Extreme

Level II

(2)	Radius of Curvature Rc (feet)	Bankfull Width W_{bkf} (feet)	Ratio Rc/W	Near-Bank Stress

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

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

Dominant Near-Bank Stress

Level III

(5)	Near-Bank Max Depth d_{nb} (feet)	Mean Depth d (feet)	Ratio d_{nb}/d	Near-Bank Stress

(6)	Near-Bank Max Depth d_{nb} (feet)	Near-Bank Slope S_{nb}	Near-Bank Shear Stress τ_{nb} (lb/ft^2)	Mean Depth d (feet)	Average Slope S	Shear Stress τ (lb/ft^2)	Ratio τ_{nb}/τ	Near-Bank Stress

Level IV

(7)	Velocity Gradient (ft/s/ft)	Near-Bank Stress

Converting Values to a Near-Bank Stress Rating

Near-Bank Stress Rating	Method Number (1)	(2)	(3)	(4)	(5)	(6)	(7)
Very Low	N/A	>3.0	< 0.20	< 0.4	<1.0	<0.8	<1.0
Low		2.21 - 3.0	0.20 - 0.40	0.41 - 0.60	1.0 - 1.5	0.8 - 1.05	1.0 - 1.2
Moderate		2.01 - 2.2	0.41 - 0.60	0.61 - 0.80	1.51 - 1.8	1.06 - 1.14	1.21 - 1.6
High	See (1) Above	1.81 - 2.0	0.61 - 0.80	0.81 - 1.0	1.81 - 2.5	1.15 - 1.19	1.61 - 2.0
Very High		1.5 - 1.8	0.81 - 1.0	1.01 - 1.2	2.51 - 3.0	1.20 - 1.60	2.01 - 2.3
Extreme		< 1.5	> 1.0	> 1.2	> 3.0	> 1.6	> 2.3

Overall Near-Bank Stress Rating

APPENDIX B
Depth-Integrated Sampling Methods From USGS Open File report 85-409

SAMPLE COLLECTION AND TREATMENT

General considerations

Many of the dissolved ions normally present in natural waters may be lost from the water sample before it is analyzed in the laboratory because of such chemical and physical reactions as oxidation, reduction, precipitation, adsorption, and ion exchange. Therefore, some properties or constituents such as specific conductance, temperature, dissolved oxygen, alkalinity, and bacteria may change dramatically within a few minutes or hours after sample collection. Immediate analysis in the field is required if accurate results for these parameters are to be obtained. Samples for other constituents may be stabilized by preservative treatment. Some examples of preservative treatment are refrigeration to minimize chemical and biological change due to biologic activity and the addition of acid to prevent the precipitation of cations.

Analysis for "total recoverable" and "total" constituents requires a raw (unfiltered) sample of the water sediment mixture; analysis for "dissolved" constituents requires a filtered sample (generally, through a 0.45 micrometer membrane filter). Other analyses may require bottom material, residue of a filtered sample, or biological material obtained on an artificial substrate. The type of sample treatment required is designated by the U.S. Geological Survey Central Laboratory and defined in their "Service Catalog." Specified sample containers also are listed. Preservatives and bottles are available upon request from the Central Laboratory. Policies of contract laboratories may differ somewhat regarding preservatives and sample containers.

Samples are to be shipped from the field to the laboratory with no delay--preferably the day they were collected. An exception might be when samples are collected near the end of the week and there is reason to believe the shipment will arrive and be held in the Post Office over the weekend. In such instances the nutrients, and other samples requiring cooling, must be held in a dark, refrigerated condition. Another exception to the immediate shipment of samples involves daily samples collected by field observers for the analysis of specific conductance. For practicality, these samples are shipped to the District Laboratory on a monthly basis.

Methods of ground-water sampling

The unstable nature of many chemical and physical properties in ground water requires special collection procedures for samples. In addition, the geochemical controls and nature of the aquifer system may further complicate the method by which samples are collected. The following are general guidelines to use in collection of samples from springs and wells. More detailed information can be found in Wood (1976).

Sampling from springs

For sampling springs in unconsolidated deposits, a well point or slotted pipe can be driven into the ground to a depth of 1 meter or less adjacent to the spring. If the flow is not artesian, the sample can be collected using a small pitcher pump. Plastic pipe and plastic well screen are used for trace metal samples. To sample large upwelling springs, submersible electric pumps placed at the mouth of the spring by hand or attached to a pole generally work well. When sampling for trace metals, plastic is used for the pump housing, pump impellers, and tubing.

Sampling from wells

Wells are pumped prior to sampling to ensure that stagnant water is flushed from the system and the sample is representative of water in the aquifer. Samples are not collected until temperature, specific conductance, and pH remain at constant values. The sample is collected near the wellhead before the water has gone through pressure tanks, water softeners, or other treatment. When wells are not equipped with pumps, a submersible pump with an outside power source is preferred. A pitcher pump may be used if the water level is within about 7 meters of the surface. If pumping cannot be done, a small-diameter point sampler can be used, but only after the well has been bailed until temperature, specific conductance, and pH are constant. Bailers and point samplers usually contaminate the sample with oxygen.

Well packers can be used to sample from individual aquifers tapped by multiscreen or open-hole wells receiving water from several aquifers. Such wells often are avoided in sampling for geochemical studies because of greater costs involved in the use of packers.

Methods of surface-water depth-integrating sample collection

Proper sampling techniques are important to ensure that a sample is representative of the flow in the cross section. The most complete discussion of sampling techniques is found in the report "Field Methods for Measurement of Fluvial Sediment," (Guy and Norman, 1970). Some aspects of sampling are included also in other Geological Survey Techniques of Water-Resources Investigations manuals (see list of references) and quality of water technical memorandums (unpublished).

The number of verticals to be sampled at a site relates primarily to the collection of a representative sample in the cross section and secondarily to the volume of the sample required. With few exceptions, samples that are to be analyzed for suspended sediment or total recoverable constituents need to be collected by using water-sediment, depth-integrating samplers. Instances where use of these samplers are not required are as follows:

1. Extreme low flow where the use of the sampler is impractical. Samples may be collected by immersing the bottle by hand (dip).

2. Under extreme cold temperatures when freezing conditions preclude the use of the normal sampler. In such instances the tubular insert sampler is used. To the degree that is possible, sampling methodology is to be compatible with that used with other type samplers; that is, depth integration and multiple verticals.

3. Samples collected for dissolved chemical constituents that are well mixed within the section. If field measurements of specific conductance show the water to be well mixed, a sample obtained at a single vertical near the centroid of flow may be assumed to be representative of the total flow.

4. Collection of sterile aseptic samples for bacteria work. These samples may be collected at midstream by hand dipping if the stream is wadeable, or otherwise by using the tubular insert sampler with a sterile sample container inserted.

Samples collected at remote sites by automatic samplers need to be retrieved at the earliest possible time. Samples collected in this manner will be analyzed only for constituents that do not require onsite preparation and will be assumed to be representative of that particular flow event. Except for suspended sediment, an aliquot from each bottle collected will be composited to form one sample per event; the appropriate begin and end dates and times for the flow event will be entered into storage, thus indicating a composite sample of the event. When possible, adequate cross-section samples are to be obtained and analyzed for nutrients, bacteria and other scheduled constituents such as suspended organic carbon (SOC), total organic carbon (TOC), and dissolved organic carbon (DOC).

Samples collected by automatic samplers for suspended-sediment concentrations will be analyzed individually and the specific conductance will be measured for each sample. Cross-section samples are to be collected at appropriate intervals, using either the equal-discharge-increment (EDI) method or the equal-width-increment (EWI) method to obtain cross-section coefficients. The coefficients are then applied to the concentration determined at a single vertical to obtain a value that is representative of the average concentration in the cross section.

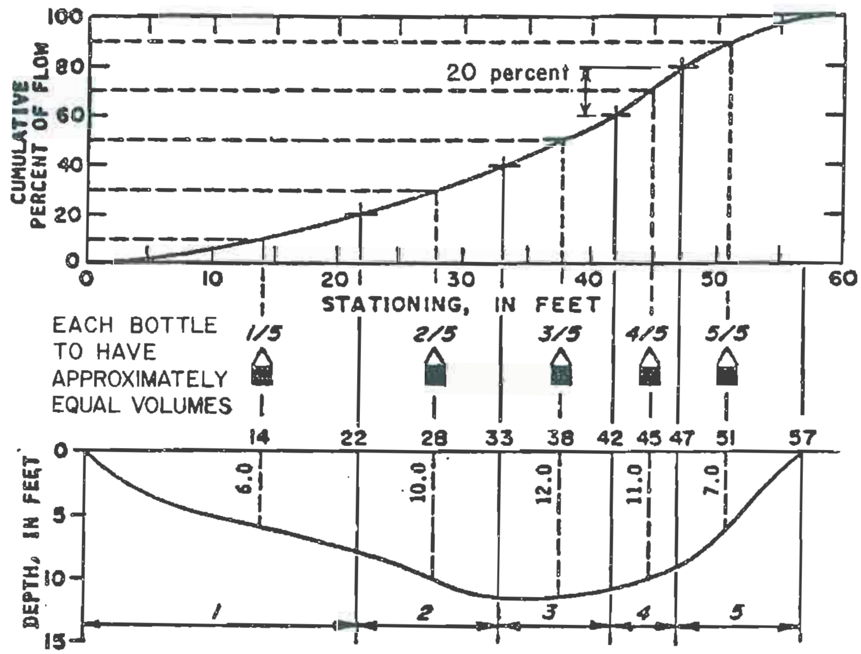
If a representative sample can be obtained by sampling at one vertical, then obtain the volume of sample required at one vertical near the centroid of flow. However, if samples are to be collected at a single vertical for suspended sediment or any of the total or total recoverable chemical constituents, sufficient data must be available to document that materials suspended in the flow are uniformly distributed throughout the cross section. If such data are not available or if flow conditions dictate that suspended materials are not uniformly distributed throughout the cross section, multiple verticals need to be sampled using either the EDI method or the EWI method.

EDI method of sampling for suspended sediment, total recoverable and dissolved chemical constituents, and phytoplankton

The EDI method, in which samples are obtained at the centroids of equal discharge increments, is usually limited to streams having stable channels where discharge rating curves vary little during a year. This method requires that field personnel have knowledge of the streamflow distribution in the cross section before sampling verticals can be selected. If such information can be obtained, the EDI method can save time and labor over the EWI method, especially on larger streams, because fewer verticals are required. To select sampling verticals for the EDI method when prior knowledge of the flow is available, graphs of cumulative discharge in percent of total discharge versus distance from the left or right bank are prepared for low-, medium-, and high-flow conditions for the site. For streams where the EDI method is applicable, these graphs are used as sampling instructions that can be kept in the shelter at the site and in the field vehicle.

The number of equal-discharge increments required to divide the cross section will depend on the size of the river and will generally range from 4 to 10 (fig. 1).

Sampler D-49: nozzle size 3/16-inch ID. Stream width 57 feet; maximum stream depth 12 feet; maximum velocity, 5.0 feet per second; width of section containing 20 percent of flow; variable, 5 to 22 feet; 20 percent of flow per section will give five sampling verticals; transit rate (from nomograph) variable, 0.3-2.0 feet per second.



[ft, feet; ft/s, feet per second; s, seconds]

Increment No.	Percent discharge	Increment width (ft)	Increment depth (width)	Velocity (ft/s)	Maximum transit rate (ft/s)	Transit rate[1] (ft/s)	Total transit time[1] (s)
1	20	22	6	2.0	1.2	0.3	42
2	20	11	10	4.0	1.6	1.1	14
3	20	9	12	5.0	2.0	1.6	9
4	20	5	11	4.0	1.6	1.2	13
5	20	10	7	3.0	1.2	.6	25

[1]Using pint sample container and filling to about 85 percent of capacity

Figure 1.--The equal-discharge-increment (EDI) sampling method.

The initial selection of parts into which the cross section is to be divided for the EDI method is not governed by any predetermined number of sampling points, but rather is chosen on the basis of the following:

1. A discharge measurement is made at the cross section where sampling is to be done. From this measurement, a graph can be constructed using cumulative percent discharge plotted against cross-section stationing. If the cross section is stable, the graph may be used to determine sampling points without having to make a discharge measurement. However, this graph needs to be verified occasionally with computations from recent discharge measurements. Commonly a series of discharge measurements representing low, medium, and high flows is plotted on a single graph and used throughout the range. An example of this type of graph is shown as figure 2.

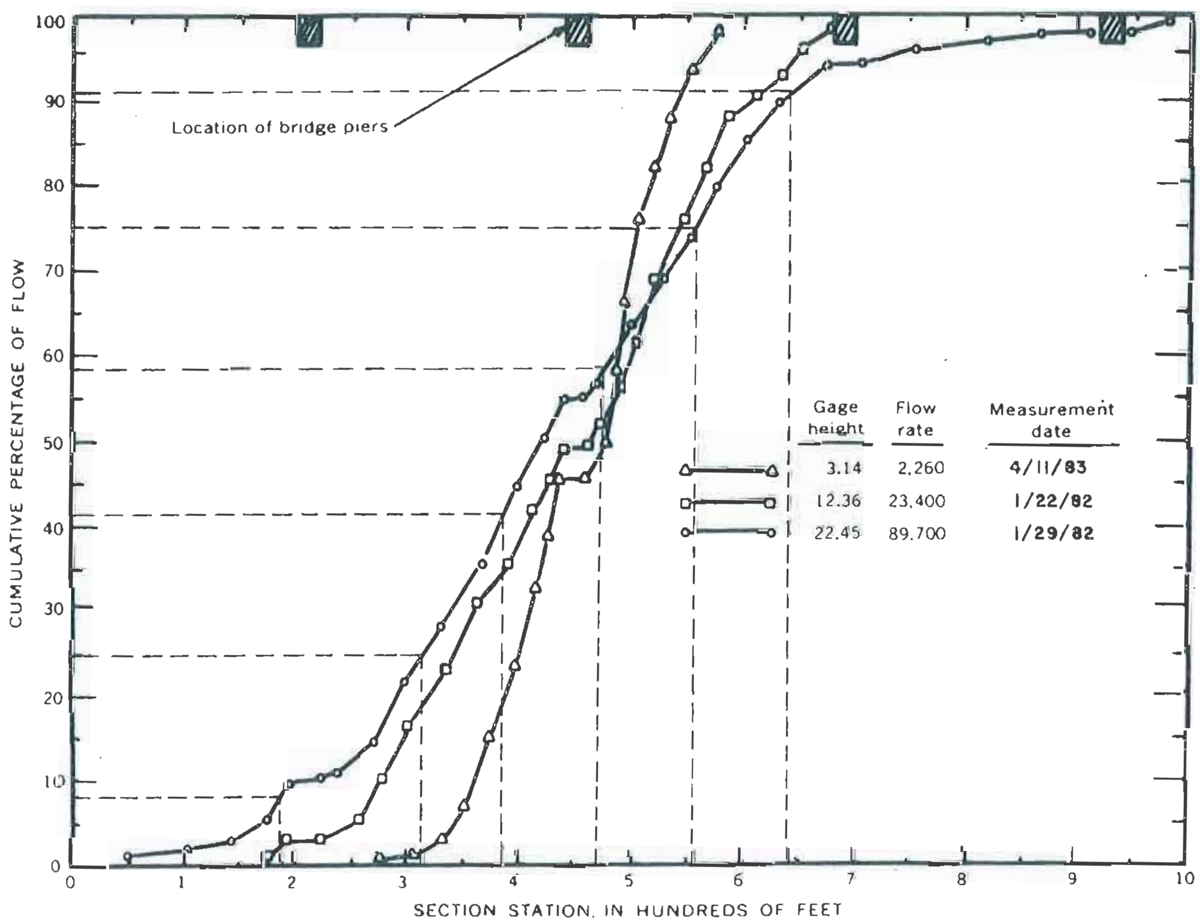


Figure 2.--Cumulative percentage of the total water discharge for three rates of flow with distance across the stream section. Broken lines indicate the stationing of centroids for six eqaul-discharge increments during high flow. Gage height in feet; flow rate in cubic feet per second.

2. A visual inspection of the cross section is made noting the location, if any, of still-water areas or filaments of faster than normal flow, and piers or other obstructions. Cross-sectional surveys of specific conductance, temperature, pH, and dissolved oxygen are made on a seasonal basis to determine if mixing is a problem.

3. Based on the information from the discharge measurement, the visual inspection of the cross section, previous cross sectional surveys, and other information such as laboratory considerations, the decision is made, usually in the relatively calm atmosphere of the office, as to the number of parts needed to adequately define the concentration of suspended sediment in transport through the cross section. The larger the variability in the section and the larger the stream, the more increments will be selected. The final decision as to the number of increments will rest with the District Water Quality Specialist.

Using the EDI method, samples are then collected at the center of each increment of flow as determined from a streamflow measurement or from a cumulative discharge graph. Each bottle is filled to no more than 3 inches from the top. Overfilling can cause secondary circulation, resulting in enrichment of heavy particles in the sample that is not representative of the water-sediment mixture flowing down the stream. Care is needed not to bump the sampler against the streambed causing bed material to rise and enter the bottle. Each bottle is visually inspected; if found to contain excess amounts of large particles, it is emptied, rinsed, and refilled.

[BECAUSE BOTTLES REPRESENT EQUAL PORTIONS OF FLOW, EACH BOTTLE MUST CONTAIN APPROXIMATELY EQUAL VOLUMES OF WATER-SEDIMENT MIXTURE]

The length of immersion time of the sampler can be determined from figure 3. General guidelines for the EDI method of sampling are as follows:

1. Determine the number and locations of verticals to be sampled on the basis of flow conditions and the volume of water needed for analysis. For many streams about four to eight verticals will be sufficient. For example, if six verticals are selected, each of the verticals (stations) needs to be at the centroid of 16.7 percent increments of the discharge--that is, at stations of cumulative discharges of 8.3, 25, 41.7, 58.3, 75 and 91.7 percent. If any of the stations selected are at or near bridge piers or other obstructions where turbulence interferes with the streamflow lines, the sampling station is to be moved a sufficient distance from the obstruction to minimize the effects of the turbulence.

2. After the locations of the sampling stations have been determined, select and assemble the proper sampling and support equipment and safety equipment, such as cones and signs.

3. Read and record the gage height and time at which sampling is begun.

4. Move sampling and support equipment to first station to be sampled.

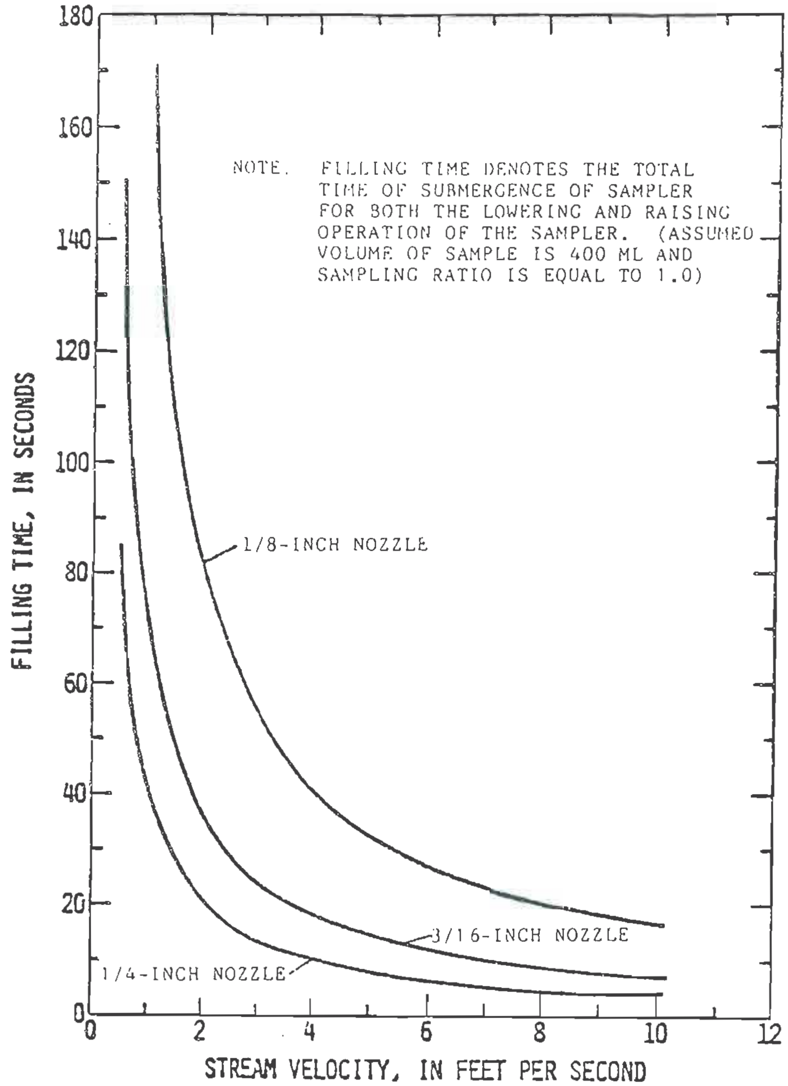


Figure 3.--Time for a suspended-sediment sample bottle of 1-pint capacity to be filled to about 85 percent of capacity.

5. Estimate the sampler transit rates and times from the depths and velocities of flow in each vertical. The transit rate in a vertical needs to be kept constant throughout at least a single direction of travel in that vertical when using the EDI method. The relationship between stream velocity and corresponding filling time (time of submergence of the sampler) for both the pint and quart bottles is shown in figures 3 and 4. A nomograph is given in figure 5 for which the average sampler transit rate and filling time can be determined, given the depth of the vertical and the mean velocity of flow in the vertical.

6. If concentrations of suspended sediment and chemical constituents are to be determined for the stream, collect from each vertical a separate 1-pint

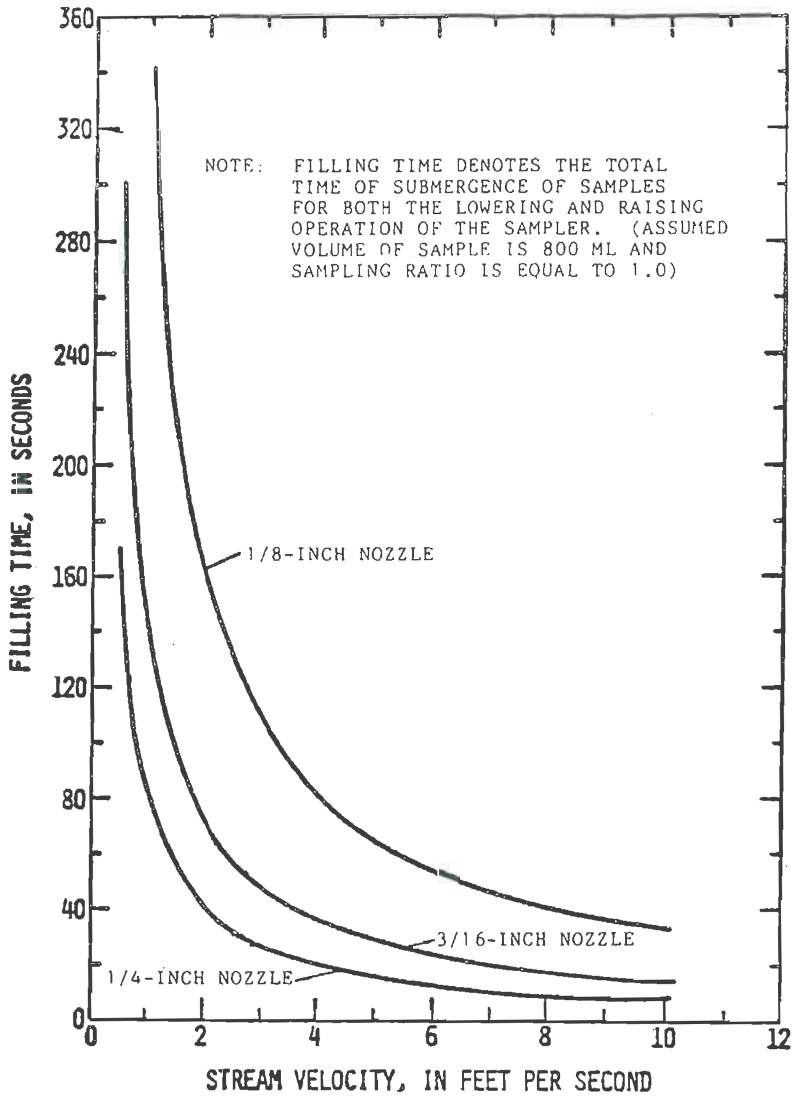
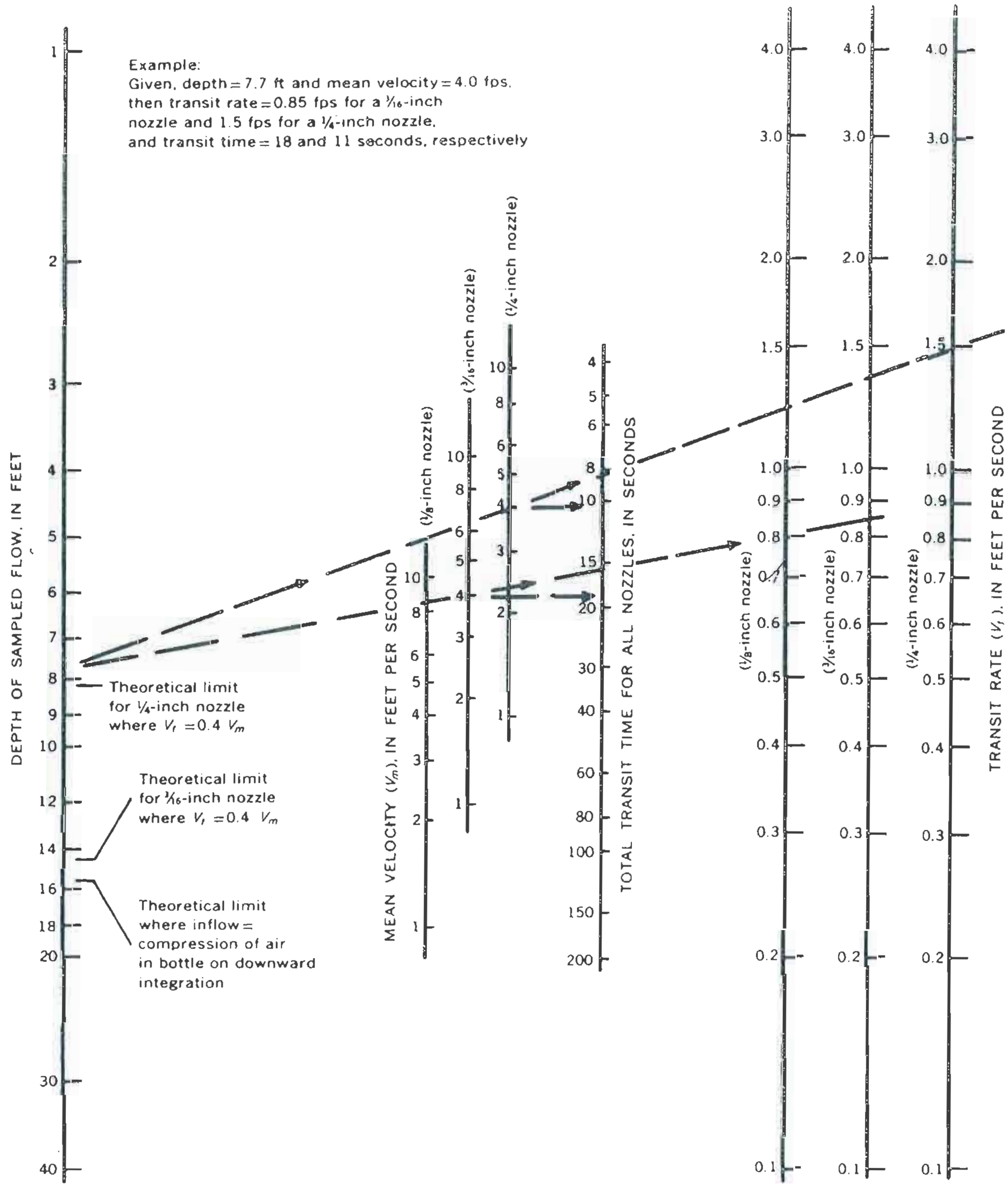


Figure 4.--Time for a suspended-sediment sample bottle of 1-quart capacity to be filled to about 85 percent of capacity.

sample for suspended sediment and 1-pint or 1-quart samples for chemical constituents. The same pint or quart glass bottle is used for each vertical in the cross section for chemical constituents. (Swirl the pint or quart sample gently to keep sediment suspended and pour into churn after sampling each vertical).

[THE INDIVIDUAL DEPTH-INTEGRATED SAMPLES FOR THE DETERMINATION OF DISSOLVED OR TOTAL CHEMICAL CONSTITUENTS (EXCEPT THOSE FOR TOC, DOC, SOC, O&G, BACTERIA, AND PESTICIDES) ARE TO BE COMPOSITED IN THE CHURN SPLITTER]



ROUND TRIP (STREAM SURFACE TO BED AND RETURN) SUSPENDED-SEDIMENT SAMPLER TRANSIT RATE AND TRANSIT TIME FOR 1/8-, 3/16-, AND 1/4-INCH INTAKE NOZZLES, GIVEN THE SAMPLING DEPTH AND MEAN VELOCITY OF FLOW.

Figure 5.--Sampler transit rate and transit time for a 1-pint sample container to be filled to about 85 percent of capacity.

The volume of the sample collected at a vertical is dependent primarily upon the stream velocity and the depth. Because the operator has no control over these factors, the volume of the sample is regulated by selecting a nozzle of appropriate size or by varying the total time of submergence of the sampler. However, the operator has the option of making any number of up and down trips in each vertical.

7. If either the pint or quart container becomes completely filled during a sampling operation, discard the sample, as it will not be representative, and collect another sample.

8. Label each of the pint samples for suspended sediment analysis with the following information:

   a. Station number, name, and location of the stream.
   b. Date.
   c. Mean time and gage height (or discharge) for the period of sample collection (after step 10).
   d. Sampling location (location in the vertical section).
   e. Water temperature.
   f. Initials of sample collector.

9. Read and record the gage height and time at which sample collection was completed.

10. Calculate and record on the field notes the mean time and gage height for the period of sample collection.

11. Complete field measurements, filtration, and preservation of samples as applicable.

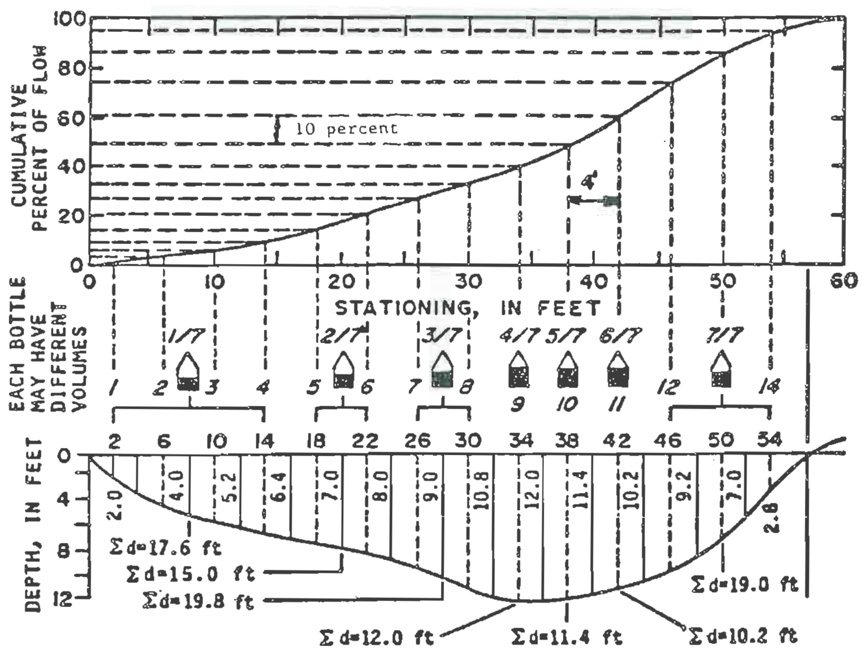
12. Disassemble and clean samplers as described in the section "Methods of Cleaning Samplers and Support Equipment."

EWI method of sampling for suspended sediment, total recoverable and dissolved chemical constituents, and phytoplankton

On wadeable streams and any stream that is subject to a shifting channel, sampling is generally easiest using the EWI method, formerly called ETR or equal-transit-rate method. A shifting channel makes it impossible to establish a set of percentage-discharge curves applicable from one visit to the next. Thus, if a water-discharge measurement is not made immediately before collection of water-sediment samples at these sites, the EWI method is to be used.

The EWI method requires equal spacing of several verticals across the cross section (fig. 6) and an equal transit rate, both up and down, in all verticals. In the EWI method, the width of the stream is determined by reference to a tagline across the stream or to the markings on a bridge rail or a cableway. The stream width is then divided into a number of intervals of equal width, the number of intervals being dependent on channel width, apparent uniformity of lateral sediment distribution, and depth and velocity distribution across the stream.

Sampler D-49; nozzle size 1/4-inch ID; width 57 feet; maximum depth 12 feet; average velocity, 3.5 feet per second; width of section containing 10 percent of flow at deep fast section 4.0 feet; 4 feet wide sections will give 14 sampling verticals; transit rate (3.5 ft/s x 0.4) 1.4 feet per second.



Sampling vertical No.	Percent of flow	Station No.	Width of increment (ft)	Transit rate (ft/s)	Percent of sample
1	2	2	4	1.4	--
2	4	6	4	1.4	--
3	6	10	4	1.4	--
4	10	14	4	1.4	16.6
5	16	18	4	1.4	--
6	22	22	4	1.4	14.2
7	28	26	4	1.4	--
8	34	30	4	1.4	18.7
9	42	34	4	1.4	11.3
10	50	38	4	1.4	10.8
11	62	42	4	1.4	10.2
12	76	46	4	1.4	--
13	88	50	4	1.4	--
14	96	54	4	1.4	18.2

Figure 6.--The equal-width-increment (EWI) sampling method.

The intervals used in EWI sampling are not selected on any predetermined number of sampling points, but rather on the basis of the following: 1) Visually inspect the stream from bank to bank, observing the velocity and depth distribution as well as apparent distribution of sediment in the cross section, 2) determine the size of interval that represents approximately 10 percent of the flow at that part of the cross section where the "unit width discharge" is largest or the greatest concentration of sediment is moving. This interval size must then be used for the ENTIRE EWI cross section and will govern the number of intervals used. The number of sections is generally not less than 10 nor more than 20.

Sampling verticals are at the center of the selected intervals unless obstructions such as piers are present. For example, in a stream 57 feet wide that has been divided into 14 intervals of 4 feet each, the first sampling vertical would be 2 feet from the water's edge and subsequent verticals would be at 6 feet, 10 feet, 14 feet, and so forth, from the starting point water edge. Even if the flow is divided, as in a braided channel, the sampling intervals must be identical from channel to channel and an identical transit rate must be used at each sampling vertical.

Figure 2 may be used as a guideline in selecting transit rates. The proper transit rate is one that gives a full bottle at the vertical having the greatest "unit width discharge." The maximum transit rate must not exceed 0.4 times the mean velocity, and the minimum rate must be sufficiently fast to keep from overfilling any of the sample bottles. Consequently, the transit rate to be used is limited by conditions (depth and velocity) at the sampling vertical containing the largest discharge per foot of width (largest product of depth times velocity).

A vertical transit rate not exceeding 40 percent of the stream velocity will satisfy all the limitations expressed for vertical transit rate (Guy and Norman, 1970). At this transit rate and with the axis of the sampler parallel to the flow, the resultant angle of approach of flow to the nozzle is about 20 degrees. According to the report (p. 32), the sampling error of concentration will be about 1 percent for 0.45-mm particles when the angle of approach is 20 degrees.

After selection of the sampling intervals, the vertical transit rate, the proper sampler, and proper nozzle size, sampling may be started from either bank. The sampler containing the sample bottle is lowered from the surface of the water to the streambed and immediately raised back to the surface, all at a constant rate and with the nozzle pointed directly into the flow. Care is needed not to disturb the streambed by bumping the sampler onto it or material dislodged from the bed may enter the nozzle, giving erroneous results. Each bottle is to be inspected and if coarse bed material is present, the bottle is emptied, rinsed, and resampled using the same sampling intervals or stations.

Several verticals may be sampled using the same bottle until the bottle is filled to within about 3 inches from the top. Do not fill the bottle more than this, as secondary circulation and enrichment of heavy particles may occur and the sediment concentration in the bottle will not be the same as the water-sediment mixture flowing in the stream. If overfilling does occur, the bottle is emptied, rinsed, and resampled using the same sampling intervals or stations.

When no more verticals can be safely sampled without overfilling the bottle, replace the full bottle with an empty one and continue sampling in the same manner until all verticals have been sampled. This procedure is the same whether sampling by wading methods or by reel and cable suspensions.

General guidelines for the EWI method of sampling are as follows:

1. Set out safety equipment where applicable (such as cones and signs) and assemble sampling equipment.

2. Locate the vertical containing the largest discharge per foot of width (largest product of the depth times velocity) by sounding for depth and estimating the velocity at several verticals near the center of flow.

3. If pint samples for suspended sediment and quart samples for chemical constituents are to be collected, determine the transit rates at the maximum discharge vertical for both the pint and quart containers.

   [ONCE DETERMINED, THIS TRANSIT RATE MUST BE USED FOR ALL OTHER VERTICALS]

4. From observations of depth, width, velocity, and sediment characteristics of the streamflow and a knowledge of the volume of sample required for analysis, determine the number of verticals to be sampled.

5. Determine the width of the segment to be sampled or the distance between verticals by dividing the stream width by the number of verticals decided upon. The stream width is determined from a tagline or from station markings on cableways and bridge railings. For example, if the stream width is 164 feet and the number of verticals is 10, the width of each segment to be sampled is 16.4 feet. For practical purposes, a vertical spacing of 16 feet is used. Thus, the location of the first vertical to be sampled would be at 8 feet. The second vertical would be located at 8 + 16 = 24 feet and so on (8, 24, 40, 56, 72, 88, 104, 120, 136, and 152 feet).

6. After determining the sampler transit rate and the number and locations of the verticals to be sampled, read and record the gage height and the time at which sampling is begun.

7. Move sampling and support equipment to first station to be sampled.

8. If concentrations of suspended sediment and chemical constituents are to be determined for the stream, collect separate samples for suspended sediment (in pint milk bottles) and chemical constituents (in quart bottles). A pint or quart bottle may be used to obtain samples from several verticals, provided the containers do not become completely filled. The individual suspended-sediment samples are not composited in the churn splitter by field personnel. The same quart glass bottle for chemical constituents is used for each vertical in the cross section. (Swirl the quart sample gently to keep sediment suspended and pour into churn after sampling each or several verticals.)

9. If either the pint or the quart container becomes completely filled during a sampling operation, discard the sample, as it will not be representative, and collect another sample.

[THE VOLUME OF THE SAMPLE WILL VARY CONSIDERABLY FROM VERTICAL TO VERTICAL WHEN USING THE EWI METHOD]

If the depth and velocity vary greatly within the cross section, the volume of sample from some of the verticals will be very small. Thus, the total volume in the churn spitter, after all verticals have been sampled, may be insufficient for analytical requirements. If so, a second set of samples all at the same transit rate will be needed for all verticals. It must be remembered that complete sets of samples are to be collected--that is, sampling cannot be terminated until the far side of the stream is reached.

10. After sampling has been completed, label each of the pint sediment samples with the following information:

    a. Station number, name, and location of the stream.
    b. Date.
    c. Mean time and gage height (or discharge) for the period of sample collection (after step 12).
    d. Sampling location (location in vertical section).
    e. Water temperature.
    f. Initials of sample collector.

11. Read and record the gage height and time at which sample collection was completed.

12. Calculate and record on the field notes the mean time and gage height for the period of sample collection.

13. Complete field measurements, filtration, and preservation of samples as applicable.

14. Disassemble and clean samplers as described in the section "Methods of cleaning samplers and support equipment."

Other methods of surface-water sample collection

Because of Central Laboratory requirements for samples, and the possibility of contamination from the churn splitter and other circumstances, samples for some analyses may be collected by depth-integration samplers at a reduced number of verticals.

Organic constituents (to be analyzed by the Central Laboratory).--The possibility of contamination from the churn splitter precludes its use for compositing and splitting of samples for the analysis of organic constituents. All samples for analysis of organic constituents are to be collected in glass sample bottles. The Central Laboratory requires a 1-liter sample each for herbicides and insecticides. Both samples may be collected with a depth-integrating sampler with a nylon nozzle and silicone rubber gasket from a single vertical near the centroid of flow. If the depth and velocity permit the collection of a multivertical sample