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

November 14, 2011

# *Muddy Creek Monitoring Report - 2011*

CDM

# Executive Summary

This monitoring report presents data collected on upper Muddy Creek in the Atlantic Rim area in 2011. 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, 2007). 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, 2007) 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 has been 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.

Field work in August 2011 included geomorphic and habitat monitoring. Water quality sampling is no longer conducted because the US Geological Survey (USGS) is collecting water quality on a monthly basis at a gage station (USGS 09258050 Muddy Creek above Olson Draw) located within the study site. Based on feedback provided by the agencies, two monitoring methods were modified this year. First, the Wolman pebble counts performed in previous years were replaced with the channel material characterization method of Rosgen (1996). Secondly, residual pool depth were no longer tied to stable riffles as had been the case in previous years; instead, the entire reach was measured to find residual pools regardless of the nature of the control sections, and these pool depths were averaged.

Channel material measurements were taken using the methods of Rosgen (1996). This method for stream characterization had not been used in the previous years of sampling, but was implemented this year as approved by the agencies. This method is not directly comparable to pebble count methods previously employed, and the data are presented as baseline data should the agencies continue monitoring of upper Muddy Creek. It was found that the three upstream sites had median particle sizes in the gravel range whereas the three downstream sites had median particle sizes in the sand or silt/clay ranges.

Residual pool depths were measured at all sites using the modified method agreed upon by the agencies. Because a different method was used to identify pools in previous years, no comparison of individual residual pool depths could be made. However, the average residual depths for the six sites, which ranged from 1.8 to 2.5 ft., were similar to the range of residual pool depths observed in previous years. The greater residual pool depths were generally found at the upstream sites.

In 2011 the six reference cross-sections (one at each site) were remeasured using a total station. Comparing the cross sections to those obtained in previous years, two cross-sections had minor changes, two experienced erosion on the right bank, and two experienced channel scour and erosion on the right bank. The amount of scour observed at two sites was greater than any previously observed and is a probable consequence of the very high runoff this year.

Embeddedness measurements were made according to the methods of Sennatt *et al.*, (2006), which are the methods used in past years. Almost all of the pools throughout the study had no particles to measure, and almost all of the riffles little visible silt. To attain measurable particles, areas just upstream or downstream of riffles were sampled, but the selection of these areas was targeted to obtain reasonable. Three of the six monitored sites had embeddeness measurement within ten percentage of points of those measured last year, one site had increased embeddedness, and two sites had silted in completely. Throughout this study, embeddedness measurements have provided data of questionable value on this largely silt bed stream, and other methods of substrate characterization may be more appropriate for monitoring the substrate changes in upper Muddy Creek.

Erosion pins were remeasured this year. Of the six erosion pins monitored, two showed no change from 2010, three showed bank erosion ranging from 0.13 to 0.45 ft., and one was buried by a slumping bank. For the pins that showed bank erosion, the erosion rate increased compared to 2010 when very little change was measured.

Based on comments received from the agencies on previous monitoring reports, bank stability was no longer evaluated using the Bank Erosion Hazard Index (BEHI) and Near Bank Stress metrics developed by Rosgen (1996). The agencies believed that sufficient baseline information had been collected on these bank stability indicators in previous years.

In summary, the changes in erosion rates and stream morphology between 2010 and 2011 were generally greater than those observed previously. This change correlates well with the high annual precipitation (highest in a 30-year period of record at an upstream station) and high peak flow observed in 2011 on Muddy Creek.

The four years of stream morphology and aquatic habitat data collected on Upper Muddy Creek represent a largely pre-development condition because very little oil and gas development has taken place in this segment of the Atlantic Rim Coal Bed Methane and Natural Gas development area. At this time no additional monitoring by Anadarko is planned because further development in Upper Muddy Creek is not planned. However, these four years of data can serve as a baseline for monitoring should future development occur in this area.

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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 2011. Camp, Dresser, and McKee, Inc., (CDM) is under contract with Anadarko Petroleum Corporation (Anadarko) to provide annual monitoring for geomorphology and aquatic habitat 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 up to 2,000 wells, and production of water (BLM, 2007). In 2011, there was no new road building or new drilling in the project area in the upper Muddy Creek drainage.

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 affect 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. The Muddy Creek Monitoring Plan (CDM, 2008) describes the monitoring objectives developed by CDM for the Muddy Creek Working Group in 2008 to guide annual monitoring activities on the Upper Muddy Creek. In 2011, the monitoring program was modified based on the agencies' recommendations and a field visit conducted before starting of the 2011 monitoring activities.

Initial monitoring activities for geomorphology, aquatic habitat and water quality were conducted by CDM between August 18 and 23, 2008. The results are summarized in the 2008 Muddy Creek Monitoring Report (CDM, 2009). The second monitoring event occurred between August 4 and 6, 2009, and results of this monitoring

event are summarized in the 2009 Muddy Creek Monitoring Report (CDM, 2010a). The third monitoring event was conducted between August 17 through 20, 2010 and results are summarized in the 2010 Muddy Creek Monitoring Report (CDM, 2010b). The last monitoring event occurred between August 24 and August 26, 2011 and is the subject of this monitoring report. Because Anadarko has decided not to expand the production operation in this area, the 2011 monitoring event is scheduled to be the last year of monitoring of the Upper Muddy Creek as part of the Atlantic Rim Coal Bed Methane and Natural Gas Project. Additional monitoring in the Upper of Muddy Creek may be conducted by the agencies.

Before commencement of the 2011 field activities, Anadarko and CDM met with the Agencies (Wyoming DEQ, BLM, Wyoming Game and Fish) in the field to discuss data collection procedures. Based on these conversations, and consequent recommendations, the Wolman pebble count procedure was replaced with a channel material characterization procedure that uses a stratified, systematic sampling method based on the frequency of riffles and pools occurring within a site (Rosgen, 1996). The method of obtaining residual pool depths was modified with input from the agencies to make the measurements independent of the stability of the downstream control that creates the pool. Although only one year of data has been collected using these modified methods, the 2011 monitoring event provides baseline information for comparison should the agencies decide to continue monitoring in the future. In accordance with previous agency comments (BLM, 2010), the 2011 monitoring program did not include Bank Erosion Hazard Index (BEHI) and Near-Bank Stress (NBS) methods or water quality data collection.

Water year 2011 had higher precipitation than average at the Divide Peak SNOTEL site, which is a nearby precipitation gage with 30 years of record (http://www.wcc.nrcs.usda.gov/snotel/Wyoming/wyoming.html). The 2011 precipitation at this site was 46.1 inches and the mean for the period of record is 34.2 inches. This is the highest precipitation amount in the 30-year period of record and is greater than the 2010 precipitation (39.9 in., the 2009 precipitation (42.4 in.), and the 2008 precipitation (36.9 in.). Although all monitoring took place during above-average precipitation years, the highest precipitation in the period of record that occurred in 2011 probably resulted in greatly increased runoff that caused correspondingly greater channel changes compared with previous years.

In July 2010, the US Geological survey (USGS) installed a new stream gage in the project area at the bridge located between Stations UMC2 and UMC3. This gage is designated USGS 09258050 Muddy Creek above Olson Draw, near Dad, Wyoming. This gage recorded a peak flow in 2011 of 486 cfs (provisional data) on April 19, 2011. This may be a higher peak flow than experienced during the previous three years based on the very wet conditions in spring 2011 although there are no previous peak flow data to compare with. The high flow may also have endured longer than normal. Gage records show that flows were above 50 cfs for about 86 consecutive days from April 1st to June 25th. During the monitoring event, flow at the gage was about 6.5 cfs, about 2 cfs higher than measured by CDM in 2010.

## 1.2 Project Organization

Monitoring of Upper Muddy Creek is the responsibility of Anadarko and its consultant. 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.

## 1.3 Report Organization

This is the fourth annual report of monitoring activities conducted by Anadarko on the Atlantic Rim Coal Bed Methane and Natural Gas Project. Section 2 of this report presents the results of the geomorphic and aquatic habitat monitoring. Appendices A through C present the data developed or collected in 2011 as part of this assessment and monitoring effort.

Comments were received from the agencies on the 2010 Monitoring Report on April 8, 2011 (BLM, 2011). Modifications to field procedures were implemented during the sampling event based on these comments, previous discussions with the agencies, and a field visit on August 24, 2011. BEHI and NBS methods as well as water quality measurements were not conducted during the 2011 monitoring activities based on 2010 agency recommendations. Therefore descriptions of these methods and results do not appear in this report.

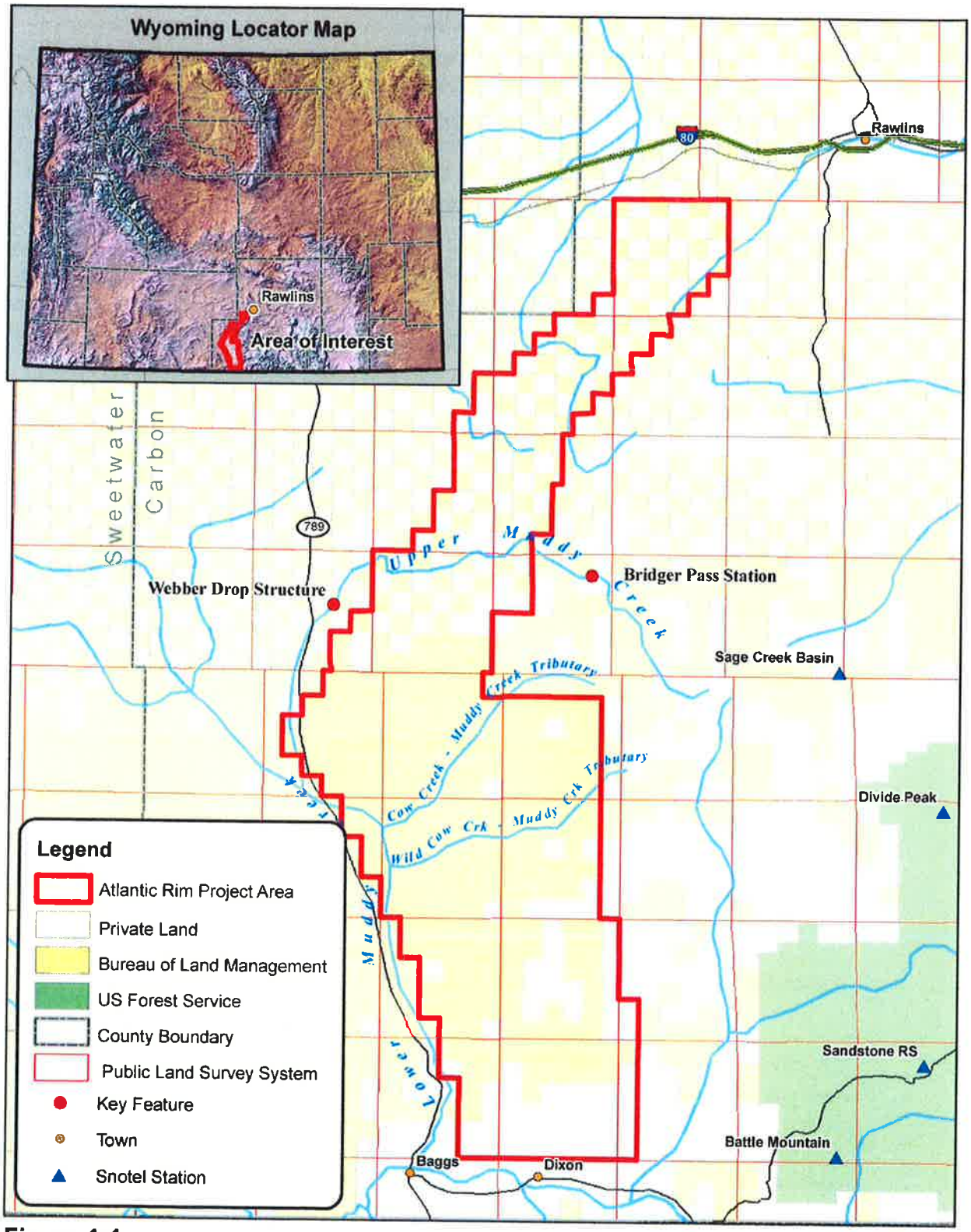


**Figure 1-1.**
**Atlantic Rim Project Area**
**Carbon County, Wyoming**

# Section 2 Geomorphic and Aquatic Habitat Monitoring

## 2.1 2011 Monitoring Event

Monitoring activities were conducted in Upper Muddy Creek during the period of August 24 through 26, 2011. The same six sites monitored during the previous monitoring activities were monitored during the 2011 event, and the work included geomorphic and aquatic habitat monitoring. The locations of the monitored sites are shown on Figure 2-1. Maps of each individual site are found in Appendix A.

Monitoring activities performed at each site are described in the Muddy Creek Monitoring Plan (CDM, 2008a). As previously mentioned, these activities were modified in 2011 based on agency comments and the field visit on August 24, 2011. In summary, the following activities for geomorphic and aquatic habitat monitoring were performed:

- The monumented, reference cross-sections located during the 2008 monitoring activities were re-surveyed. Cross-section information was collected to allow measurement of channel changes over time.
- Cross-sections were photographed as well as the stream upstream and downstream of the cross-sections. Cross-section photographic points were monumented with fence posts.
- Channel material was characterized (modification for 2011).
- Embeddedness measurements were performed.
- The bank erosion pins were measured and compared to the previous year and then pounded flush with the bank face.
- Residual depths of pools were measured (modified for 2011).

## 2.2 Geomorphic Monitoring

### 2.2.1 Cross-sections

The reference cross-section at each site was surveyed and compared to the previous years' surveys. The cross-sections surveyed during the previous field seasons are shown with the 2011 cross-sections in Appendix B, which also contains reference section photographs. The relevant changes in the sections are described here.

The reference sections at stations UMC3 and UMC6 have remained generally unchanged since 2009. At stations UMC1 XS-4 and UMC4 XS-3, large amounts of material were deposited on the right bank since 2010. Stations UMC2 XS-5 and UMC5 XS-3 show that large amounts of channel scour occurred since 2010 lowering

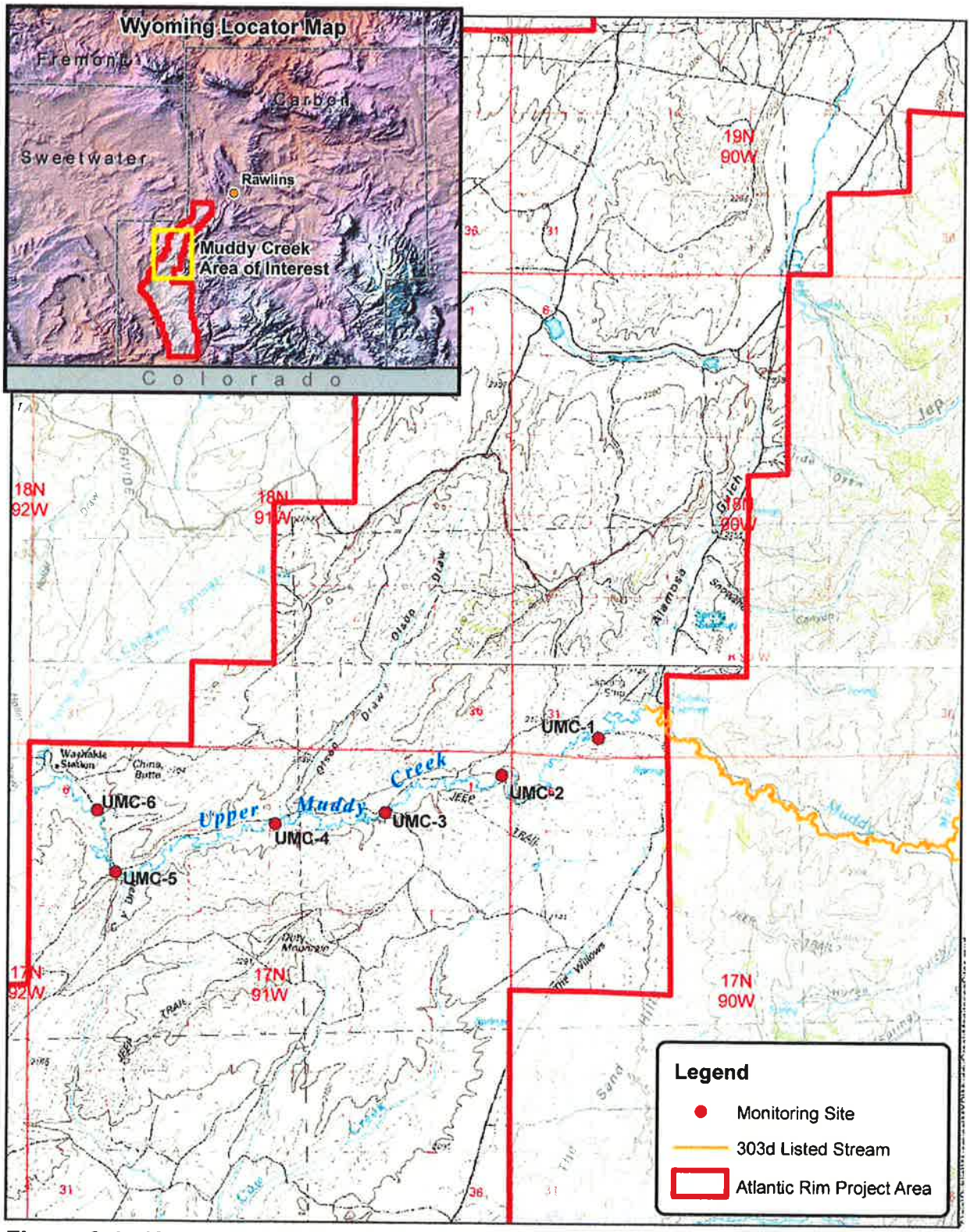


**Figure 2-1. Upper Muddy Creek Monitoring Locations**
**Atlantic Rim Project**
**Carbon County, Wyoming**

the thalweg by about three feet and eroding considerable material from the right bank. This amount of scour had not occurred in previous years and is undoubtedly due to the high runoff that resulted from the greatest precipitation amount in a 30-year period of record. This large variation in the amount of deposition and scour that occurs between consistently wetter than normal years demonstrates the highly dynamic response of this stream to variations in hydrology.

## 2.3 Bed Measurements

### 2.3.1 Channel Material Characterization

At the request of the agencies, the Wolman pebble count procedure was modified this year as described in *Applied River Morphology* (Rosgen, 1996) for characterization of channel materials. Rather than just characterizing gravel beds, which form a small portion of this silt-bed stream, this method provides a composite view of all the channel materials found in the stream. Instead of counting 100 individual pebbles at one distinct riffle, 10 particles were counted at 10 sections throughout the reach. The modified method divides the site into percentages of riffles and pools, and counts are performed throughout the site based on these percentages. For example, if the site length is composed of 30 percent riffles and 70 percent pools, ten individual particles were measured at 3 locations within riffles and 7 locations within pools with a total of approximately 100 individual counts. This method includes classification of fine particles (smaller than gravel) into sand fractions and silt/clay. The particles were sorted into standard size classes and a cumulative size distribution was plotted (Appendix C).

Table 2-1 summarizes the sampling scheme for each site and the median particle size ($d_{50}$).

**Table 2-1. Summary of Channel Material Characterization for 2011.**

| Site | Length of Pools (ft) | Length of Riffles (ft) | Total Length (ft) | Median Particle Size (mm) | Size Description |
|---|---|---|---|---|---|
| **UMC1** | 370 | 110 | 480 | 32-48 | Coarse gravel |
| **UMC2** | 555 | 145 | 700 | 8-12 | Medium gravel |
| **UMC3** | 600 | 170 | 770 | 16-24 | Coarse gravel |
| **UMC4** | 514 | 56 | 570 | 0.125-050 | Fine to medium sand |
| **UMC5** | 555 | 145 | 700 | 0.125-0.25 | Fine sand |
| **UMC6** | 445 | 25 | 470 | <0.062 | Silt and clay |

Most of Site UMC 6 is now composed of a pool formed behind a beaver dam that was first observed in 2010 (Figure 2-2). There is one riffle section (approximately 25 feet) below the beaver dam. The long pool formed by the beaver dam accounts for the channel material at Site 6 being composed largely of silt and clay.

Figure 2-3 shows all six channel material cumulative size distributions plotted on one logarithmic graph. The graph shows that the upper three sites (UMC1, UMC2, UMC3) have coarser gradations (median size is gravel) than the three lower sites

**Figure 2-2. Beaver Dam at Site UMC6, August 2011.**

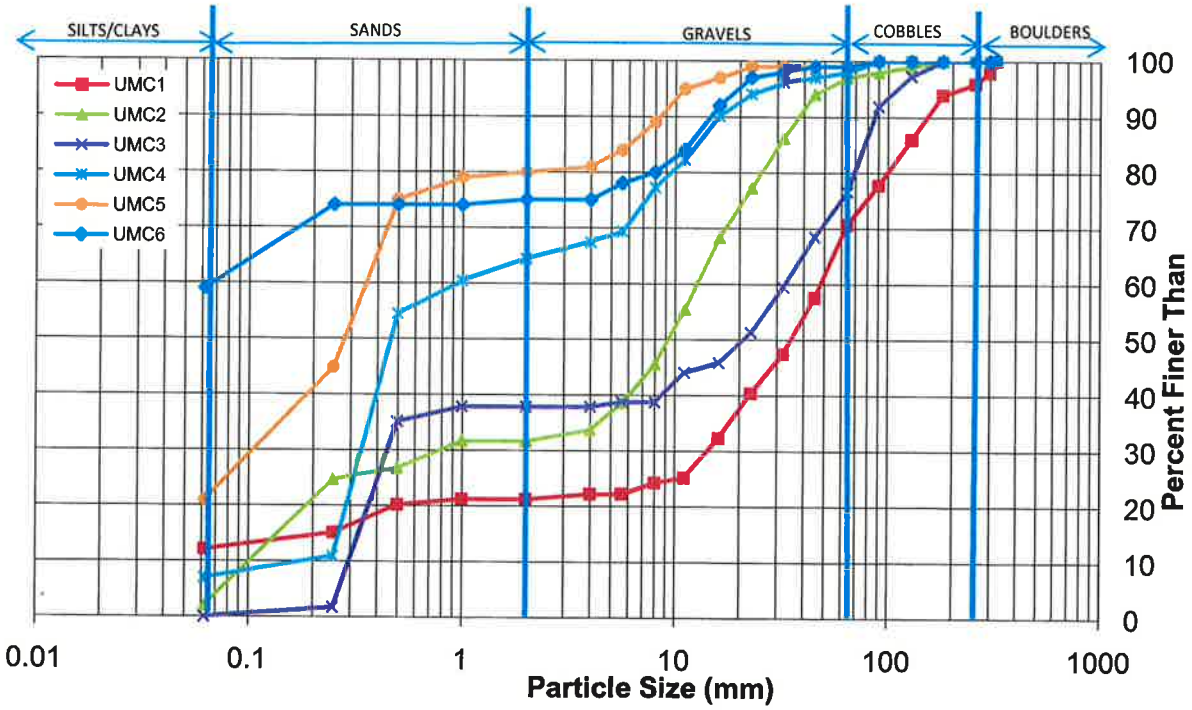


**Figure 2-3. Cumulative Particle Size Distributions for Muddy Creek Monitoring Sites.**



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(UMC, UMC5, UMC6), which have much finer gradations (median size is sand or silt). All sites display bimodal distributions with a peak in sand sizes and another peak in gravels. However, the ratio of particles in the two size distributions varies from the upper sites to the lower sites.

### 2.3.2 Embeddedness

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 30 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, UMC4, UMC5, and UMC6, all areas were either clean gravel or larger clasts with no siltation visible at the surface or the bed was entirely silt. Therefore, embeddedness measurements were not taken at these sites. The results of embeddedness measurements for the measured sites are shown in Table 2-2. 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 had no particles to measure, and almost all of the riffles little visible silt. Therefore, embeddedness has only been conducted on a limited portion of the bed, which does not account for the large portion of the bed that is almost entirely silt. It appears that embeddedness, a metric developed for gravel-bed streams, is not a particularly useful metric for a silt-bed stream like upper Muddy Creek. It is recommended that alternative metrics for siltation be investigated if monitoring is conducted in the future on this stream.

**Table 2-2: Average Embeddedness Values.**

| | | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|
| UMC1 | 30' below XS-1 Riffle | 32.0% | 58.0% | 63.7% | 50% |
| | 50' downstream of XS-2 | 52.7% | 61% | 66.7% | 67% |
| | Immediately below XS-5(1) | 52.7% | 40.7% | 45.3% | -- |
| UMC3 | Downstream of XS-1 Riffle | 38% | 51.3% | 52.7% | 68% |
| | Upstream of XS-6 | 31% | 42% | 46.8% | 54% |
| UMC4 | Upstream of XS-4 (1) | -- | 44% | -- | -- |

(1) In 2011 these locations were silted in and only unembedded fine gravel was observed.

## 2.4 Bank Stability

### 2.4.1 Erosion Pins

Erosion Pins were installed near the monumented cross-section at each site during the 2008 field investigation. An erosion pin is a four-foot steel bar driven horizontally into the bank. Pins were placed in vertical sections of bank that are likely to erode (for example, outside of bends) and that are difficult to monitor using surveyed cross-sections.

The visible pins were measured during the 2009, 2010, and 2011 field activities and were compared to the measurements taken in previous years. The measurements and differences are shown in Table 2-3 below. After measurement in 2010, the bank pins were pounded flush so the length listed for 2011 corresponds to the amount of erosion observed between 2010 and 2011. The measurements indicate that erosion occurred at UMC1 XS-4, UMC4 XS-3, UMC5 XS-3, UMC XS-3 and Rocky Crossing with amounts of erosion ranging from 0.13 feet to 0.45 feet, generally higher erosion rates than experienced the previous years. Stations UMC2 XS-5 and UMC3 XS-3 did not indicate erosion. The pin at UMC3 XS-3 was buried by a slump and needed to be exposed by digging. The right bank at station UMC5 XS-2 experienced severe slumping and the pin could not be located. All erosion pins were pounded flush after measurement in 2011 except UMC4 XS-3, which was severely bent and could not be pounded flush. In general, the 2011 measurements indicate greater channel alterations than those observed in previous years.

**Table 2-3. Locations and lengths of Bank Erosion Pins.**

| Site | Location | Length (ft)-Aug 2008 | Length (ft)-Aug 2009 | Difference 2008-2009 | Length (ft)-Aug 2010 | Difference 2009-2010 | Length (ft)-Aug 2011 |
|---|---|---|---|---|---|---|---|
| UMC1 | XS-4, Right bank | 0.33 | 0.30 top<br>0.42 bottom | 0.09 | 0.52 | 0.10 | 0.60 |
| UMC2 | XS-5, Right bank | 0.24 | 0.30 top<br>0.25 bottom | 0.06 | 0.29 | -0.01 | No change |
| UMC3 | XS-3, Right bank | 0.27 | 0.35 | 0.13 | 0.39 | 0.04 | See note(1) |
| UMC3 | XS-5, Right bank | -- | -- | -- | -- | -- | No change |
| UMC4 | XS-3, Right bank | 0.37 | 0.42 | 0.05 | 0.41 | -0.01 | 0.45(2) |
| UMC5 | XS-3, Right bank | 0.38 | 0.35 | -0.03 | 0.35 | 0.00 | 0.40 |
| UMC5 | XS-2, Right bank | NM | 0.33 | -- | 0.33 | 0.00 | Not found |
| UMC6 | XS-3, Right bank | NM | 0.33 | -- | 0.32 | -0.01 | 0.13 |

NM – Not measured.
(1) Pin buried by collapsed bank.
(2) Pin severely bent; distance measured perpendicular distance from tip to face of bank.

## 2.5 Residual Pool Depths

Residual pool depth refers to the depth of the pools remaining when water stops flowing, leaving water only in the pools. The residual depth is obtained by subtracting the water depth at the downstream control that forms the pool from the water depth at the deepest portion of the pool. The method of measuring residual pool depth was modified this year at the recommendation of the agencies to allow collection of data regardless of the stability of the downstream control. During this monitoring event, the entire length of each site was walked from downstream to upstream and determinations were made where a controlling downstream section was identified. Then the deepest measurement upstream of this section was recorded and the next controlling section was found. This procedure resulted in residual pool depths being identified at more locations than previously. In previous years

measurements were tied to stable riffles, but with this method the residual depths are no longer necessarily tied to riffles.

Table 2-4 summarizes the measurement collected at each site in 2011. Average residual depths in 2011 ranged from 1.8 feet and 2.5 feet. Except for site UMC6, the downstream sites appeared to have smaller residual depths. At UMC6 XS-4 beavers have constructed a dam. The maximum pool depth behind the beaver dam at UMC6 was 4.2 feet but this was not included as a residual pool depth.

**Table 2-4. Summary of Average Residual Pool Depth Measurements in Upper Muddy Creek - 2011.**

| Site | Pool 1 (ft) | Pool 2 (ft) | Pool 3 (ft) | Pool 4 (ft) | Pool 5 (ft) | Pool 6 (ft) | Pool 7 (ft) | Average Residual Depth (ft) |
|---|---|---|---|---|---|---|---|---|
| UMC1 | 1.5 | 2.0 | 2.4 | 3.9 | 1.5 | | | 2.2 |
| UMC2 | 3.2 | 1.8 | 2.5 | 2.7 | 1.95 | 2.8 | | 2.5 |
| UMC3 | 3.4 | 0.7 | 3.1 | 1.0 | | | | 2.1 |
| UMC4 | 2.25 | 0.4 | 2.25 | 1.6 | 1.55 | 2.25 | 2.0 | 1.8 |
| UMC5 | 2.1 | 1.15 | 1.5 | 2.05 | 2.15 | | | 1.8 |
| UMC6 | 2.25 | 2.35 | | | | | | 2.3 |

Table 2-5 presents residual pool depth results from previous years using the stable riffle method for comparison with the modified method. Although there are undoubtedly differences caused by the change in methodology, the average residual depth appears to have increased at most reaches in 2011. This increase may be due to the greater scour that occurred in 2011, which may have deepened pools.

**Table 2-5. Previous Residual Pool Depths in Upper Muddy Creek Averaged by Reach.**

| | Average Residual Depth (ft) | | |
|---|---|---|---|
| Site | 2008 | 2009 | 2010 |
| UMC1 | 1.8 | 1.7 | 1.5 |
| UMC2 | 1.4 | 0.7 | 1.6 |
| UMC3 | 1.8 | 1.8 | 1.8 |
| UMC4 | 1.1 | 1.3 | Riffle shifted |
| UMC5 | 1.2 | 0.9 | Riffle shifted |
| UMC6 | NM | 2.3 | 2.0 |

NM – Not measured

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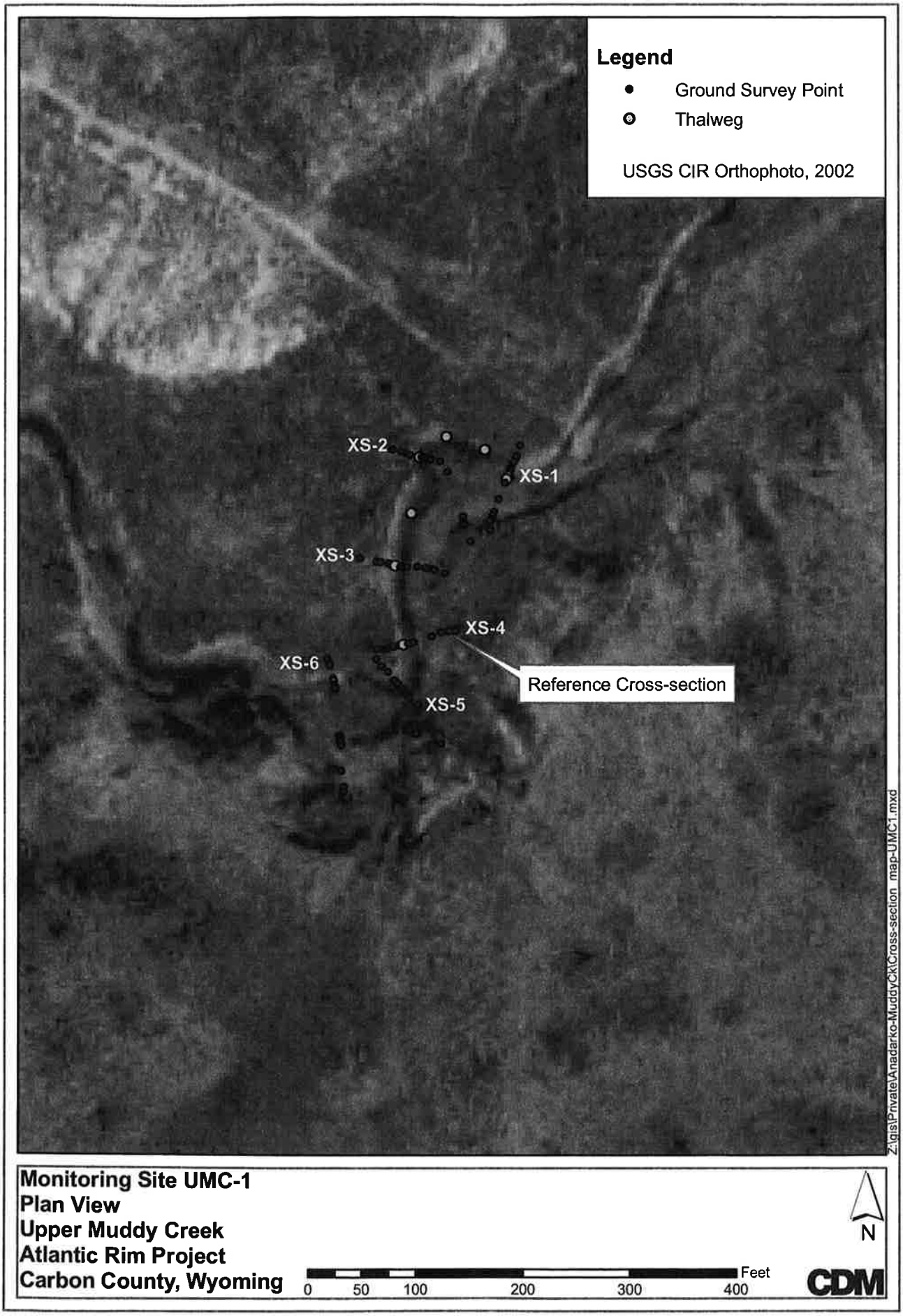
# Appendix A
## Monitoring Site Maps




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

N

0 50 100 200 300 400 Feet

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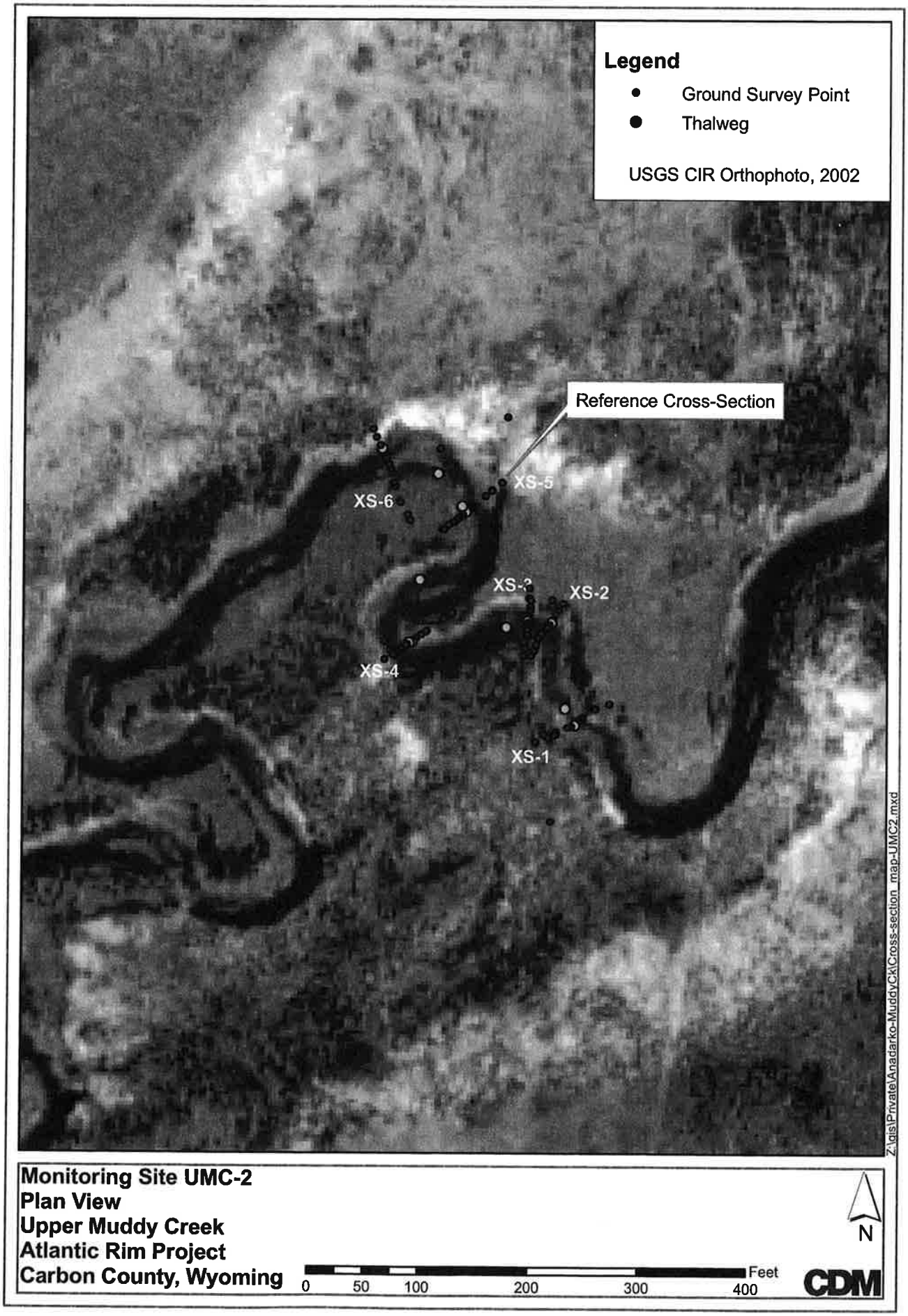
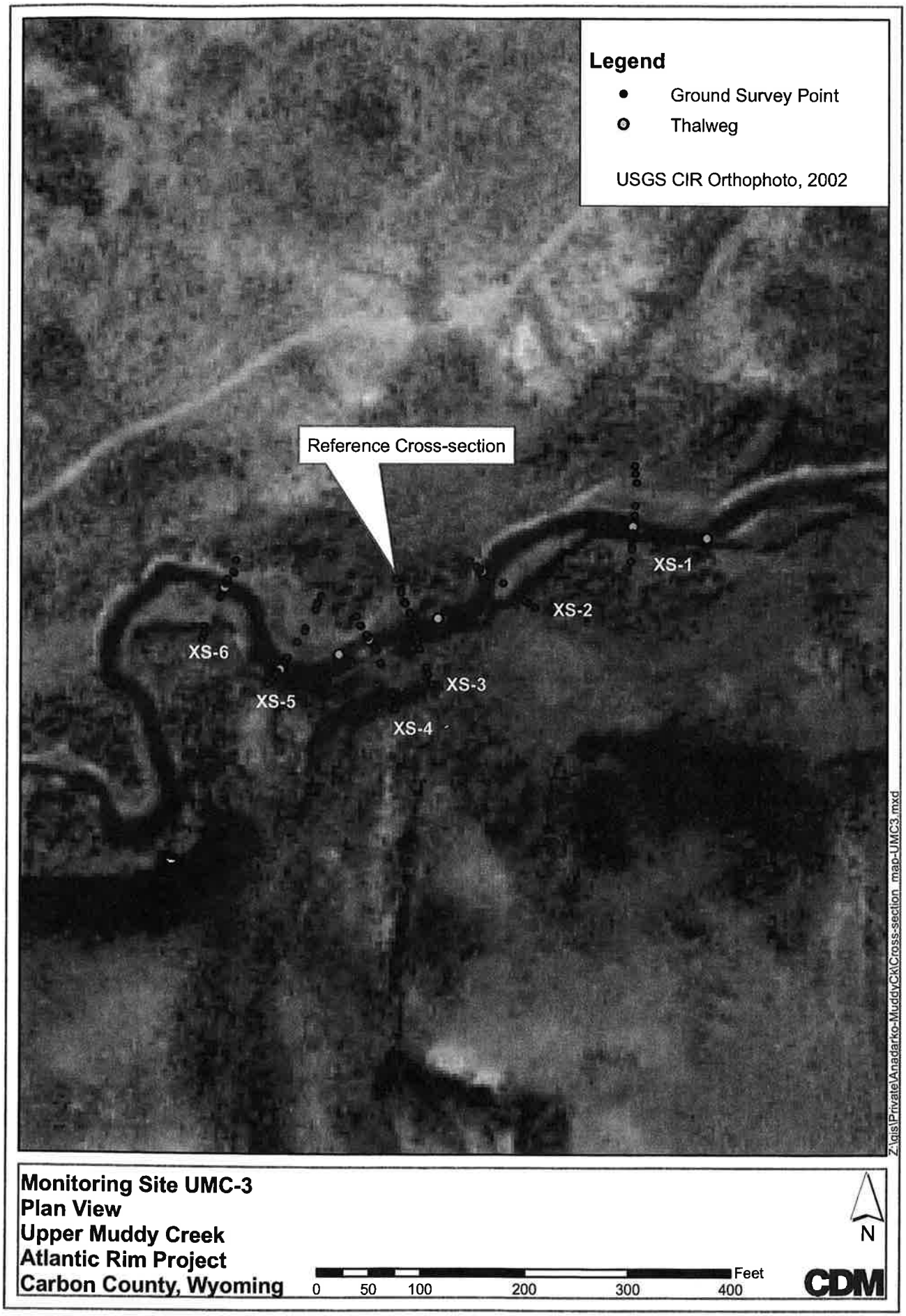
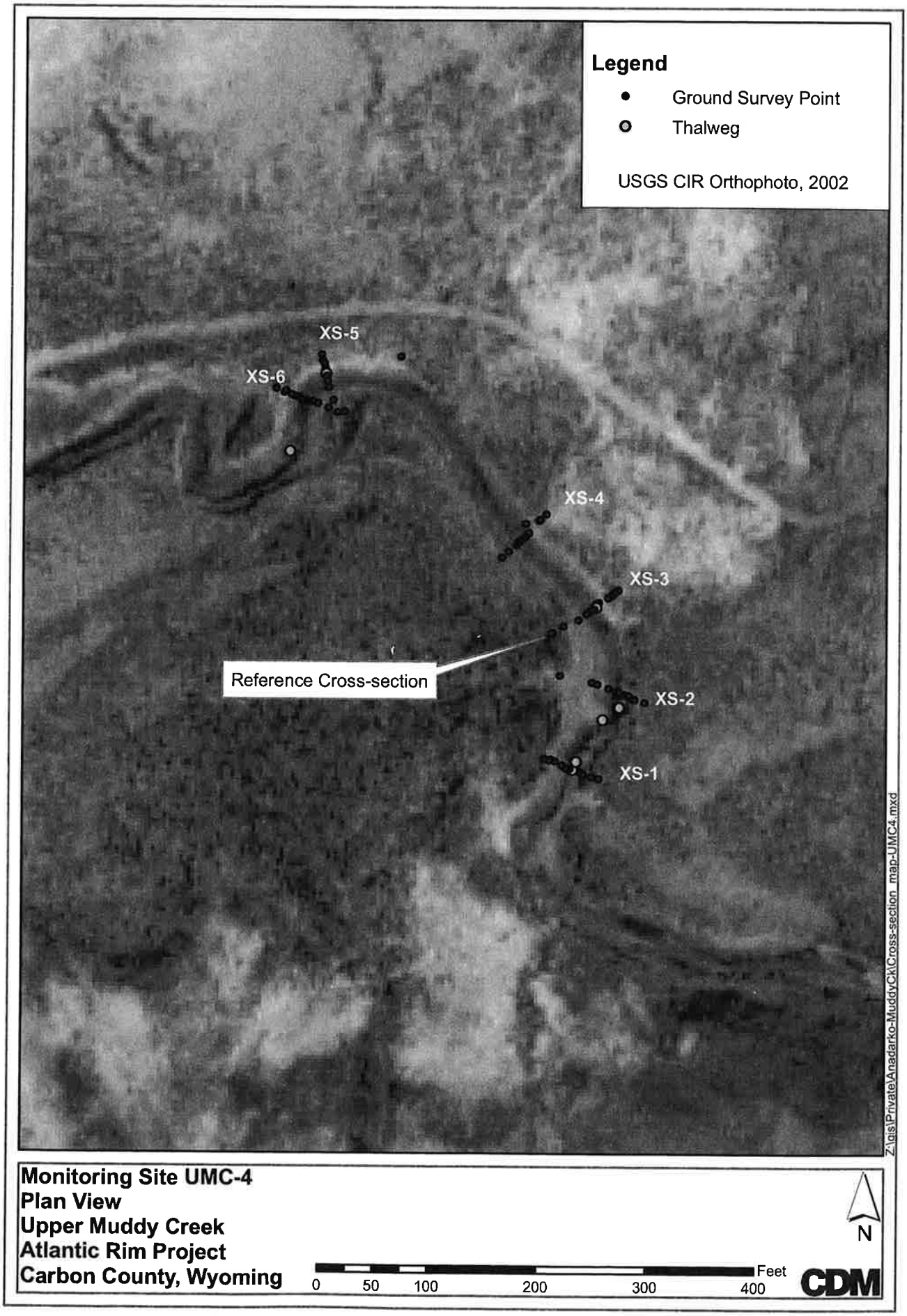
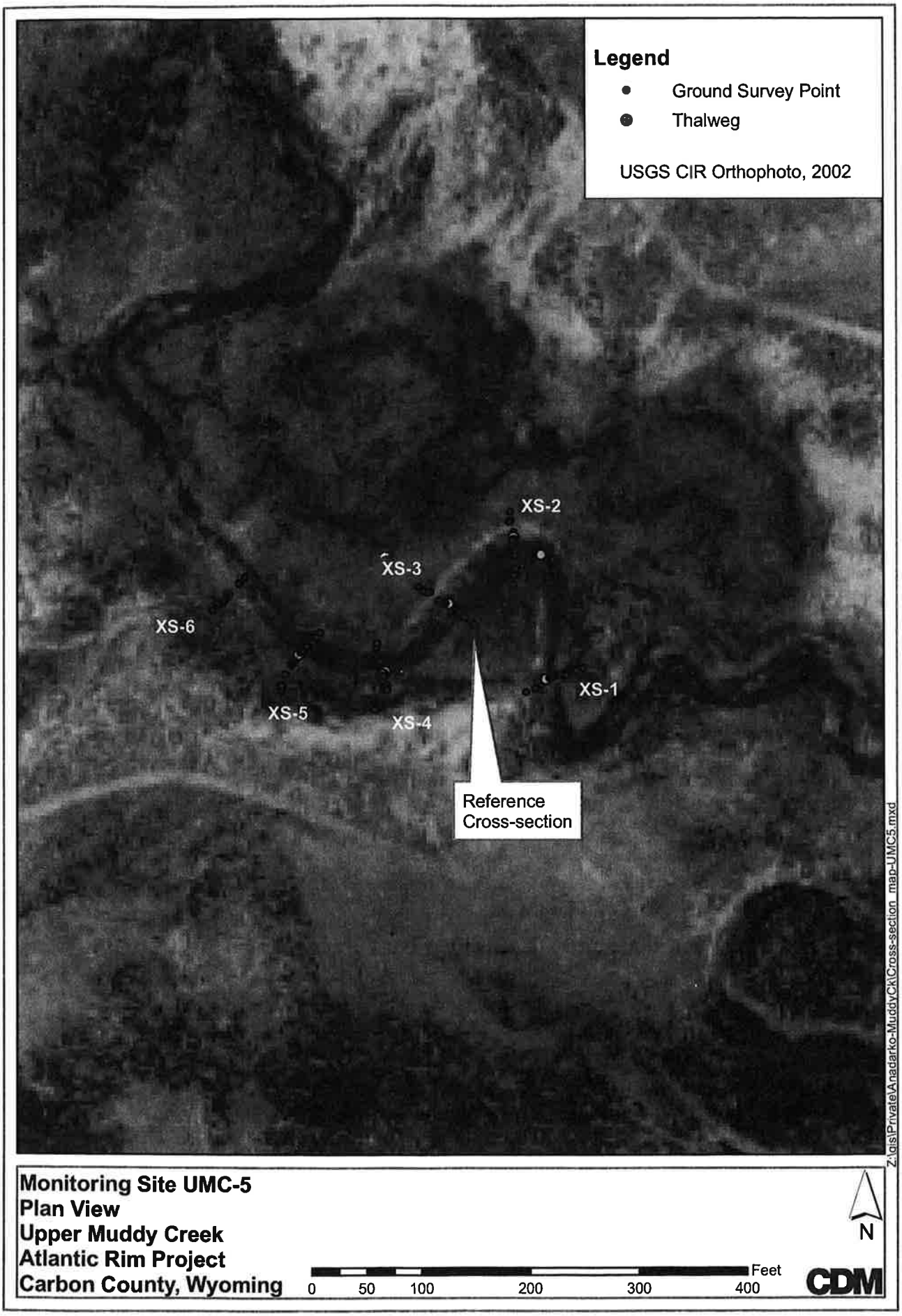
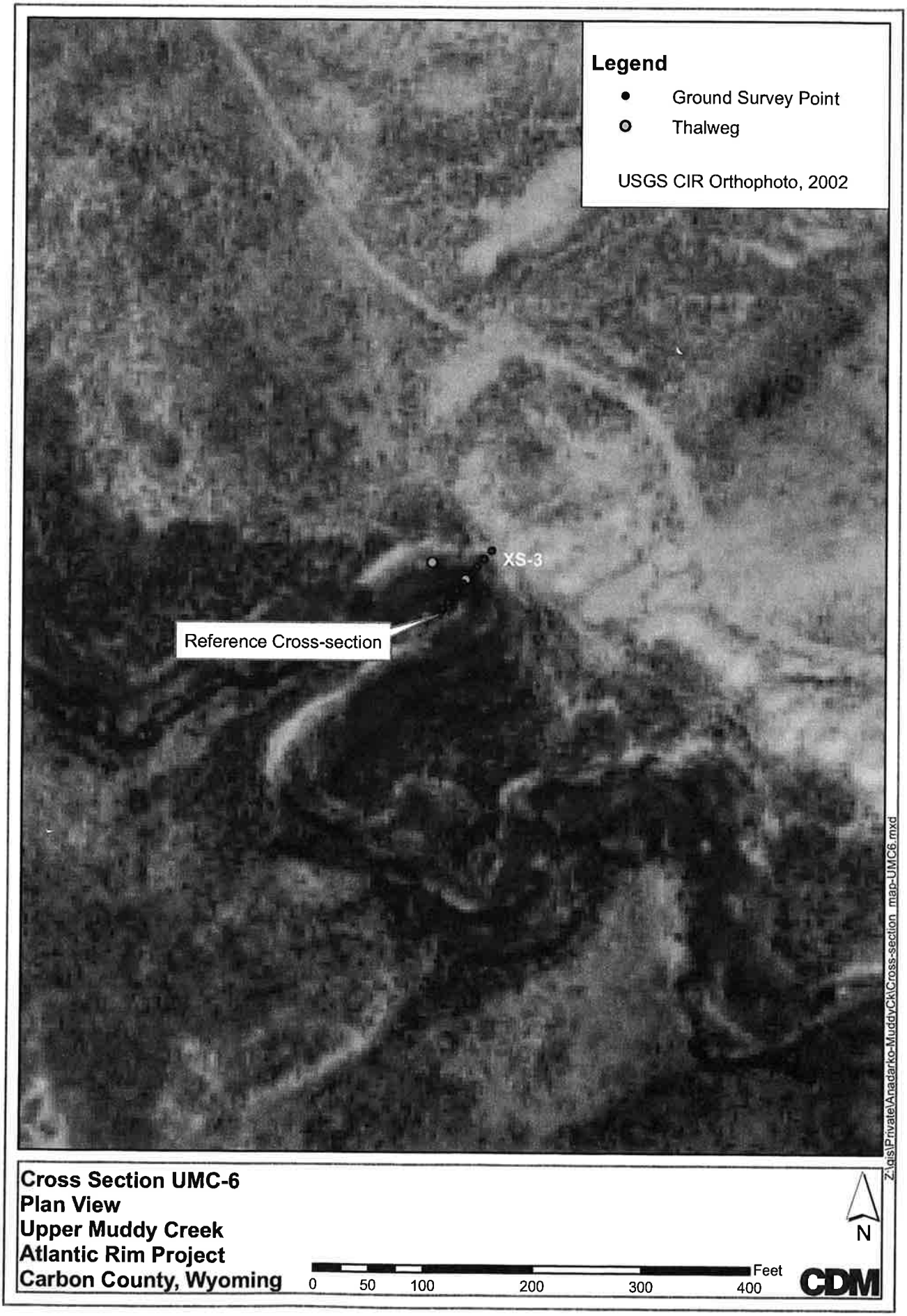

Legend
Ground Survey Point
Thalweg
USGS CIR Orthophoto, 2002
Reference Cross-Section
XS-5
XS-6
XS-3
XS-2
XS-4
XS-1
Z:\gis\Private\Anadarko-MuddyCk\Cross-section_map-UMC2.mxd
Monitoring Site UMC-2
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming
N
0
50
100
200
300
400
Feet
CDM


Legend
Ground Survey Point
Thalweg
USGS CIR Orthophoto, 2002
Reference Cross-section
XS-1
XS-2
XS-3
XS-4
XS-5
XS-6
Z:\gis\Private\Anadarko-MuddyCk\Cross-section_map-UMC3.mxd
Monitoring Site UMC-3
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming
N
0 50 100 200 300 400
Feet
CDM


Legend
Ground Survey Point
Thalweg
USGS CIR Orthophoto, 2002
XS-5
XS-6
XS-4
XS-3
Reference Cross-section
XS-2
XS-1
Z:\gis\Private\Anadarko-MuddyCk\Cross-section_map-UMC4.mxd
Monitoring Site UMC-4
Plan View
Upper Muddy Creek
Atlantic Rim Project
Carbon County, Wyoming
N
0
50
100
200
300
400
Feet
CDM




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


Legend
Ground Survey Point
Thalweg
USGS CIR Orthophoto, 2002
XS-3
Reference Cross-section
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
N
0
50
100
200
300
400
Feet
CDM

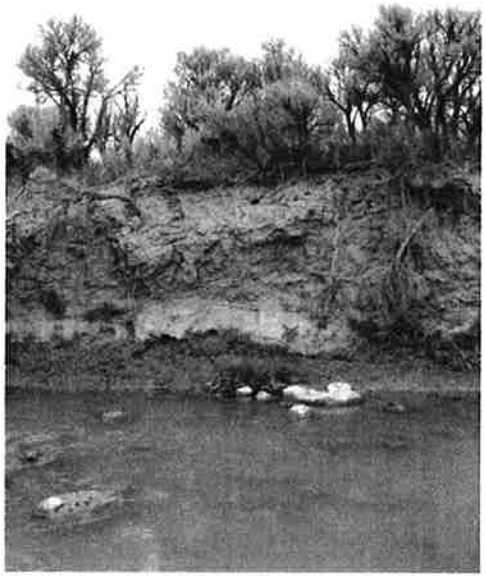
**UPPER MUDDY CREEK MONITORING**
**BANK AND REFERENCE SECTION LOCATIONS**
**August 2008**

| 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

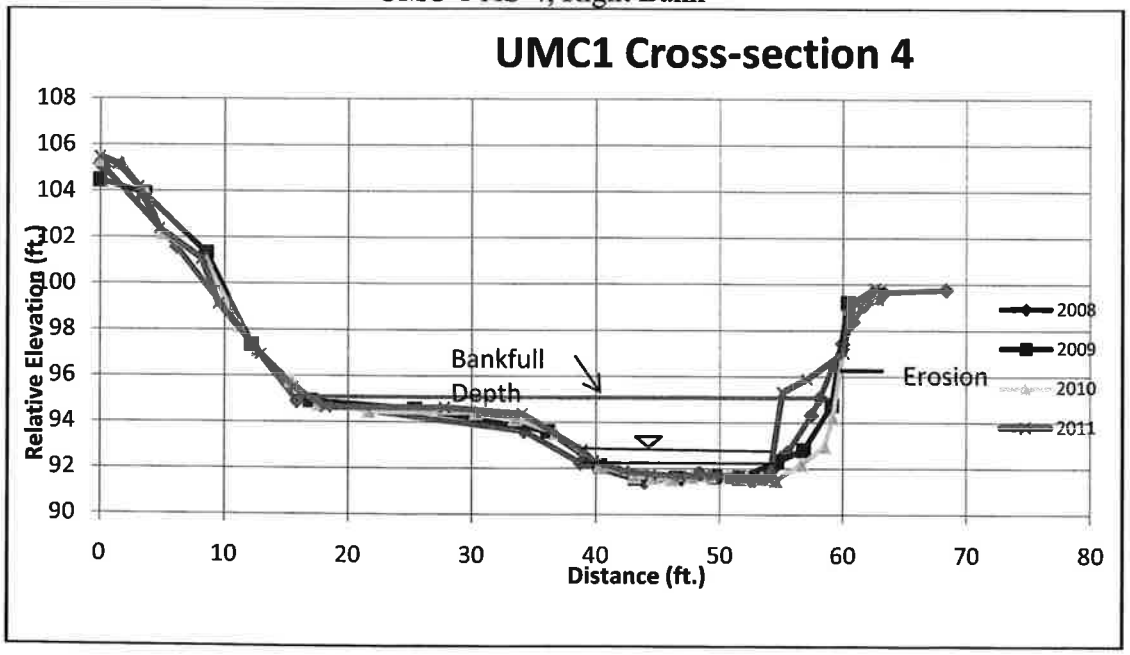
# Appendix B
## Reference Section Photos and Cross-Sections

2008



2010

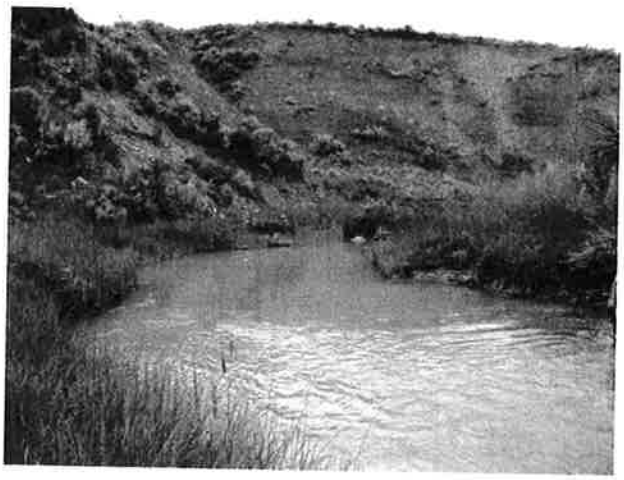
UMC-1 XS-4, Right Bank



2008

2010

UMC-1, XS-4, View Upstream

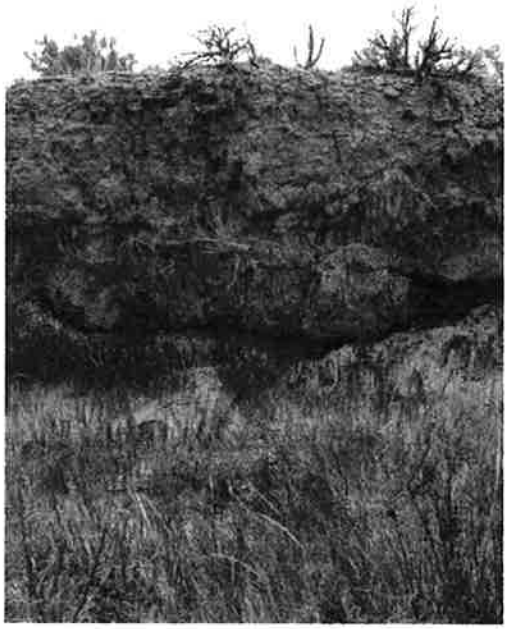


2008

2010

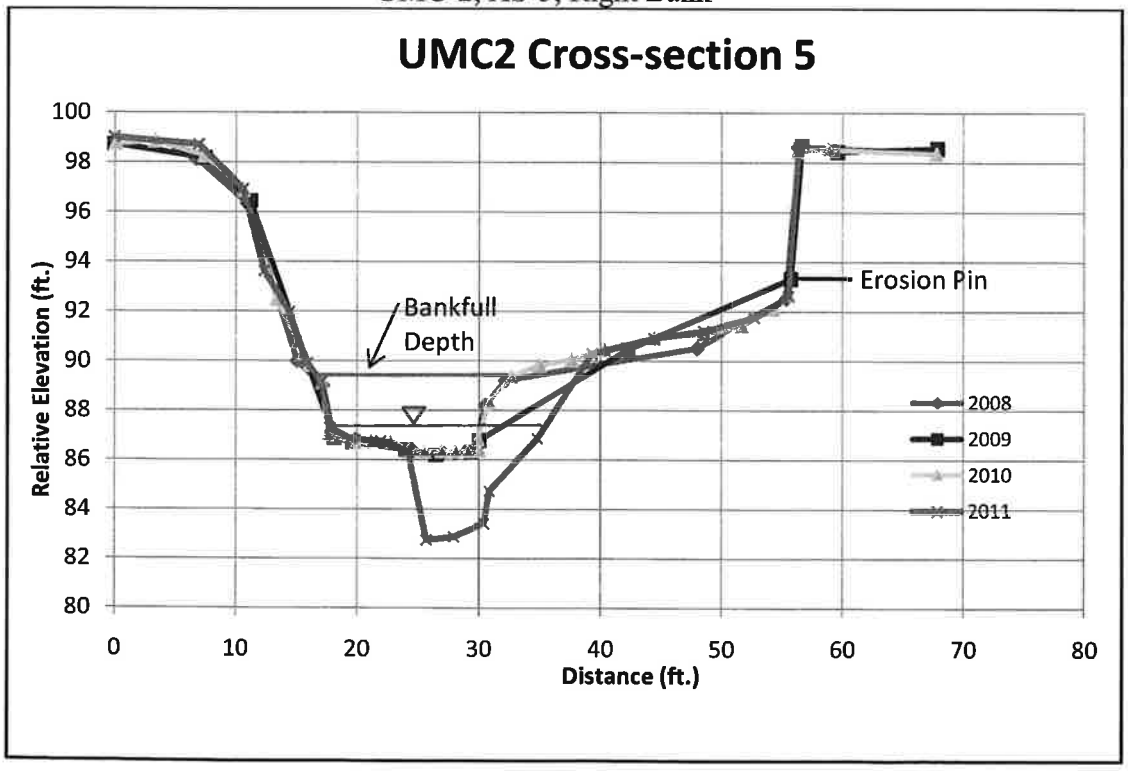
UMC1, XS-4, View Downstream

2008



2011

UMC-2, XS-5, Right Bank



2008

2011

UMC2, XS-5, View Upstream

2008

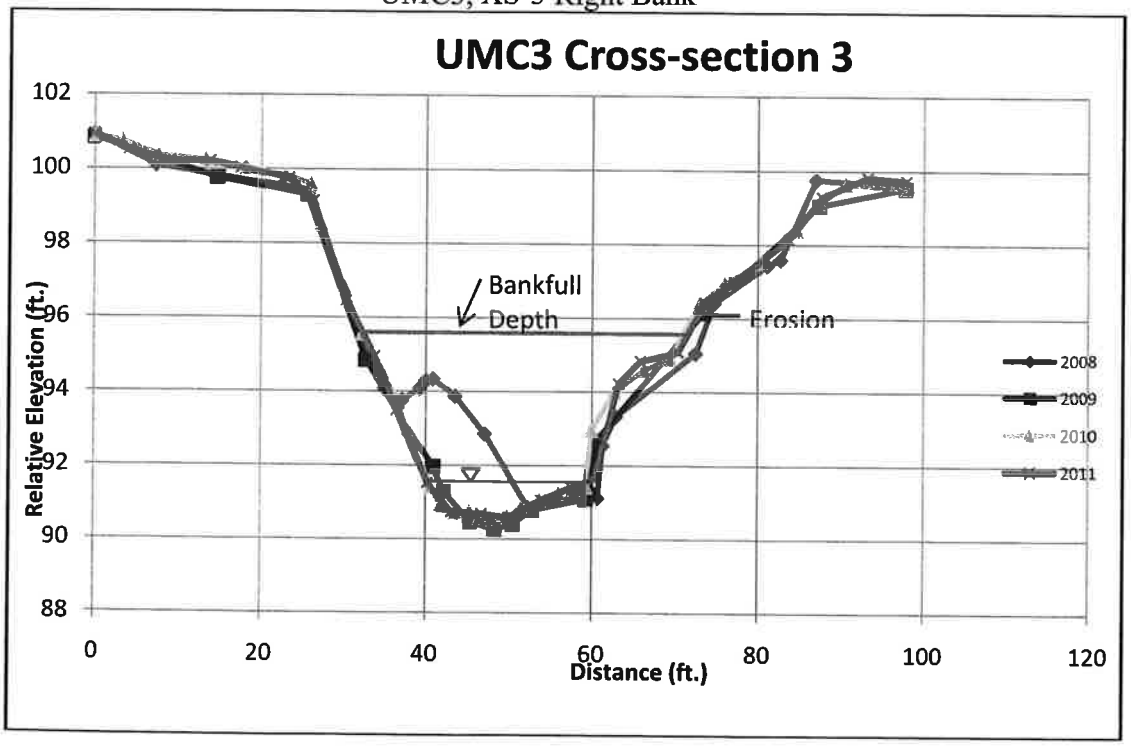
2011

UMC2, XS-5, View Downstream

2008

2011

UMC3, XS-3 Right Bank



2008

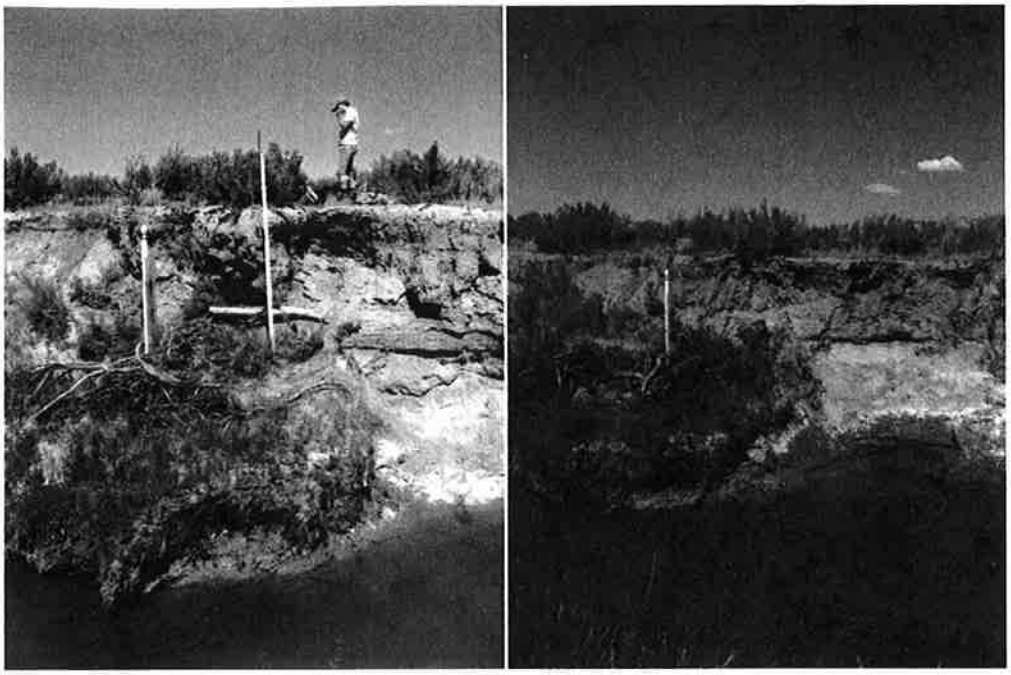
2011

UMC 3, XS-3, View Upstream

2008

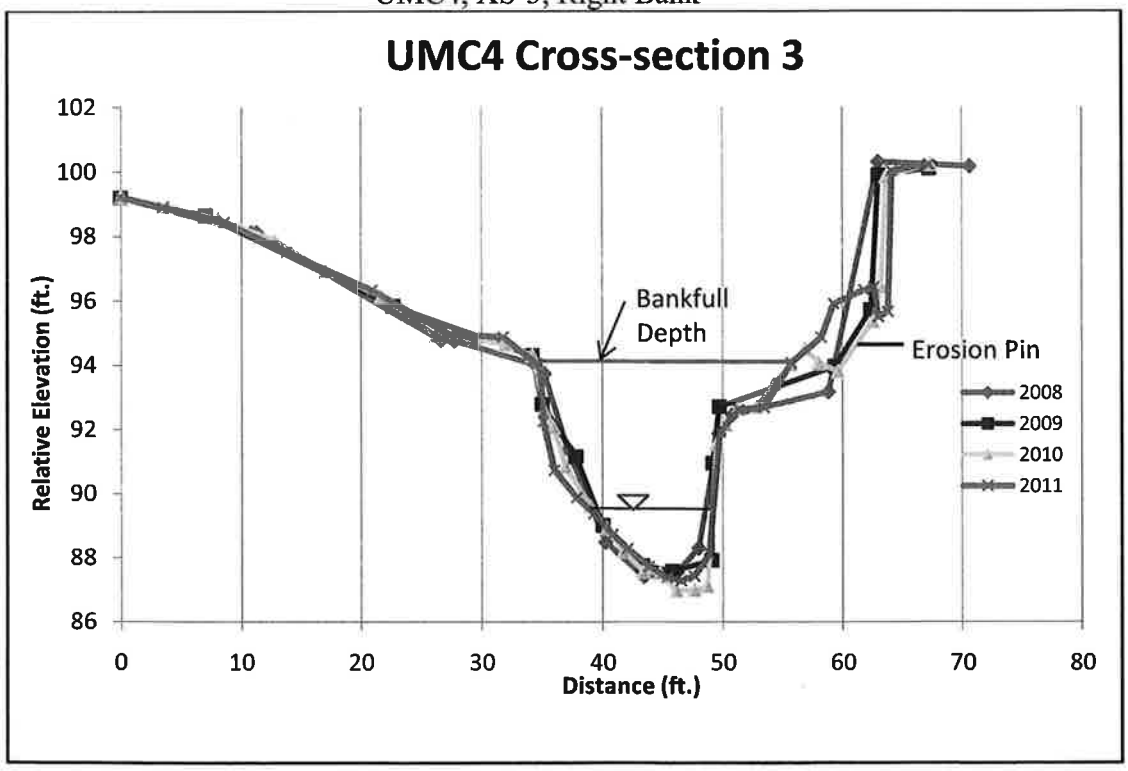
2011

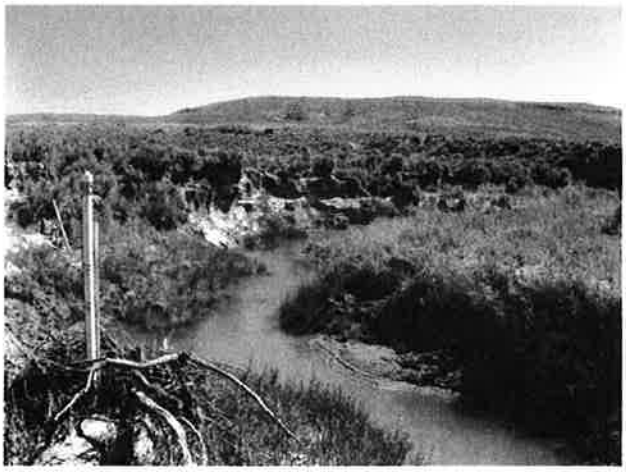
UMC3, XS-3, View Downstream



2008 2011

UMC4, XS-3, Right Bank

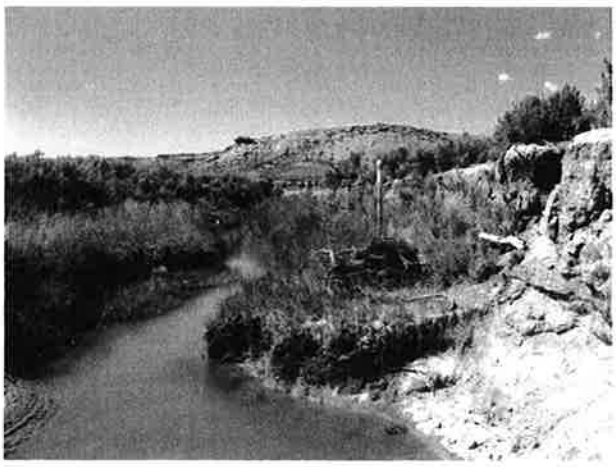




2008

2011

UMC4, XS-3, View Upstream



2008

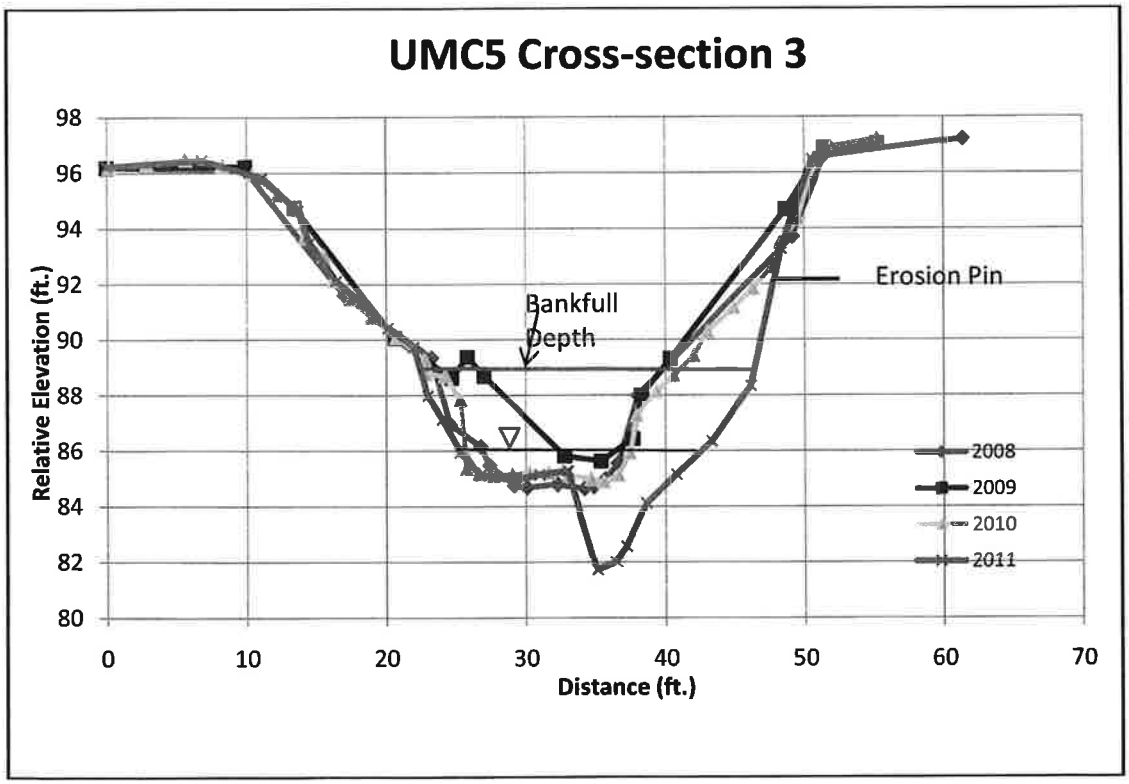
2011

UMC4, XS-3, View Downstream

2008

2011

UMC5, XS-3, Right Bank



2008

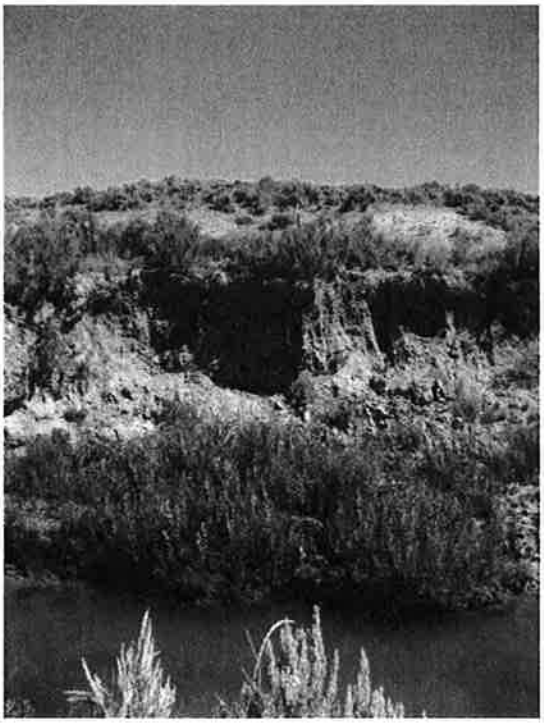
2011

UMC5, XS-3, View Upstream

2008

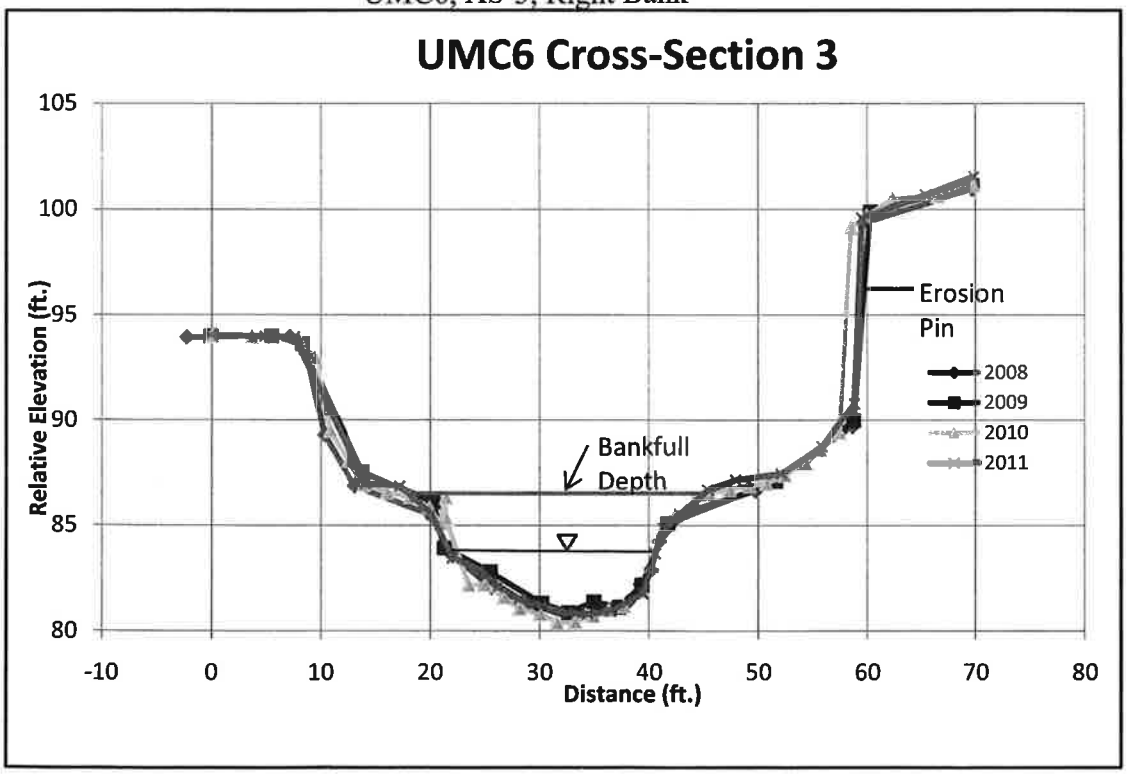
2011

UMC5, XS-3, View Downstream



2008 2011

UMC6, XS-3, Right Bank

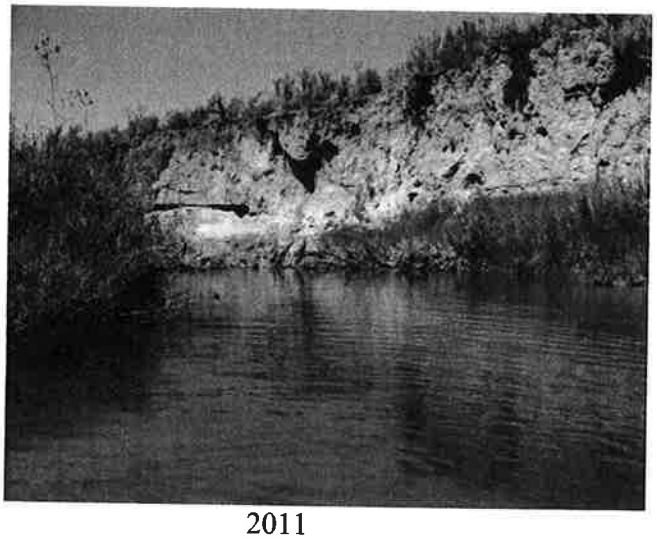


2008

2011

UMC6, XS-3, View Upstream

2008

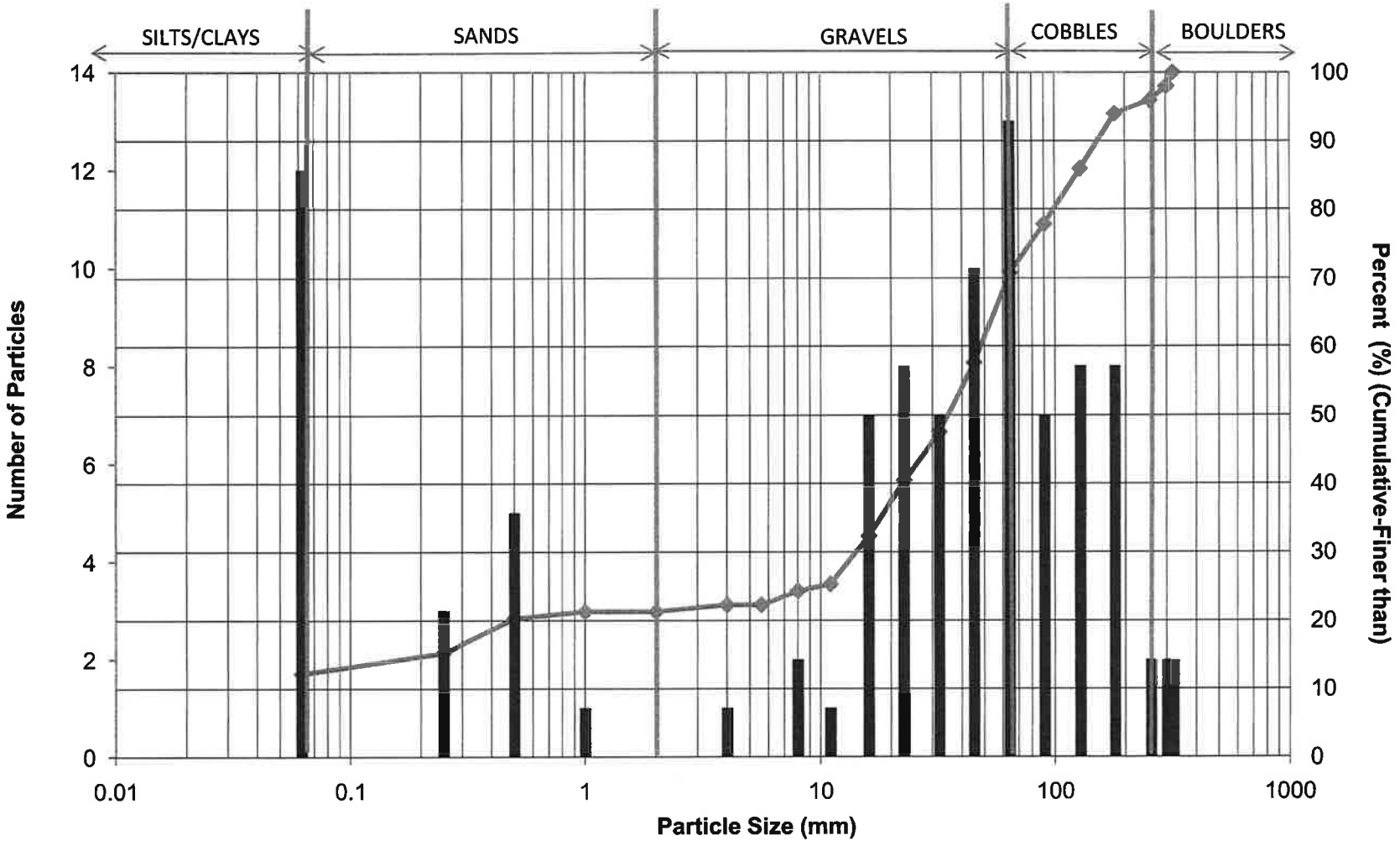


2011

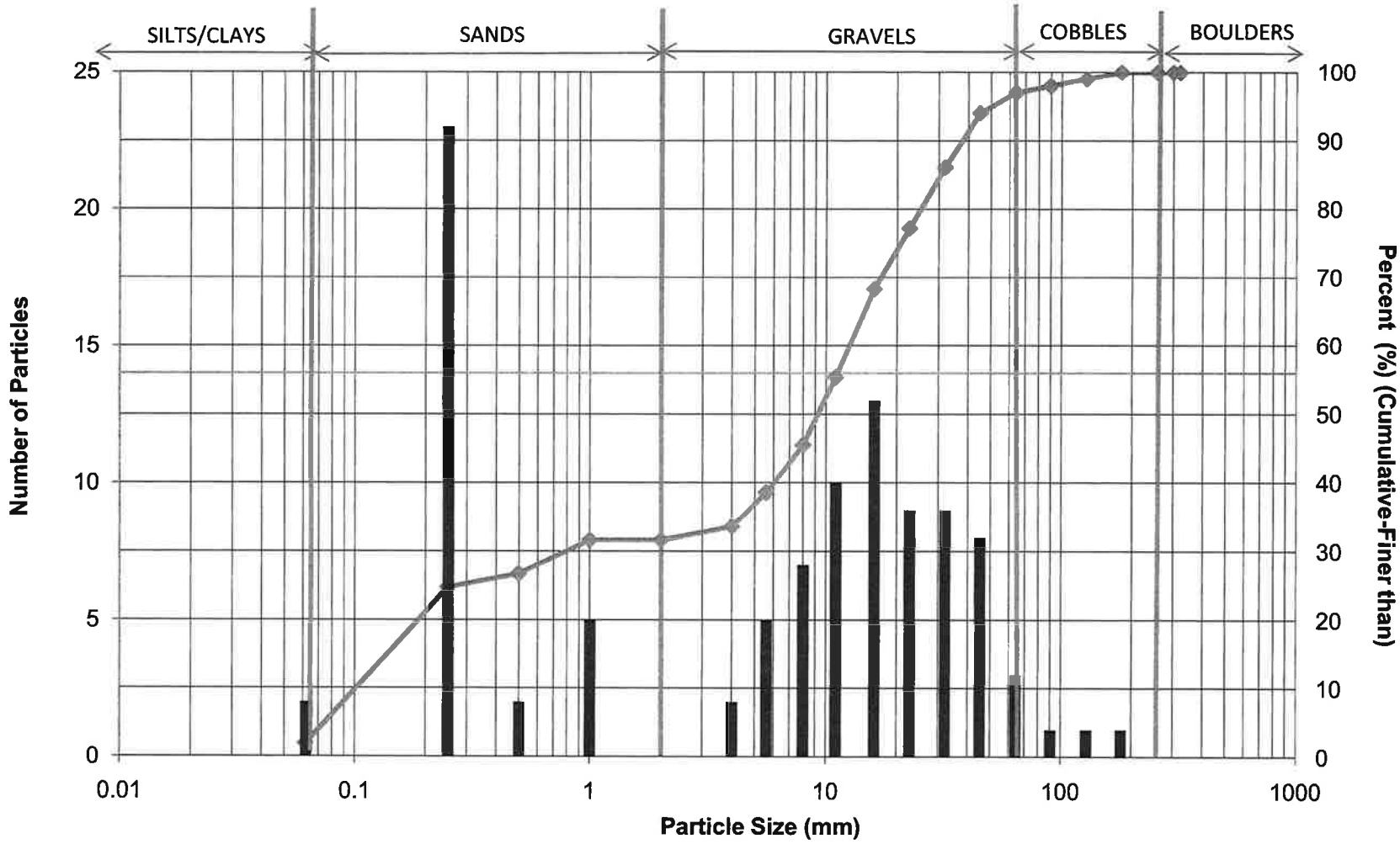
UMC6, XS-3, View Downstream

# Appendix C
## Channel Material Size Distributions

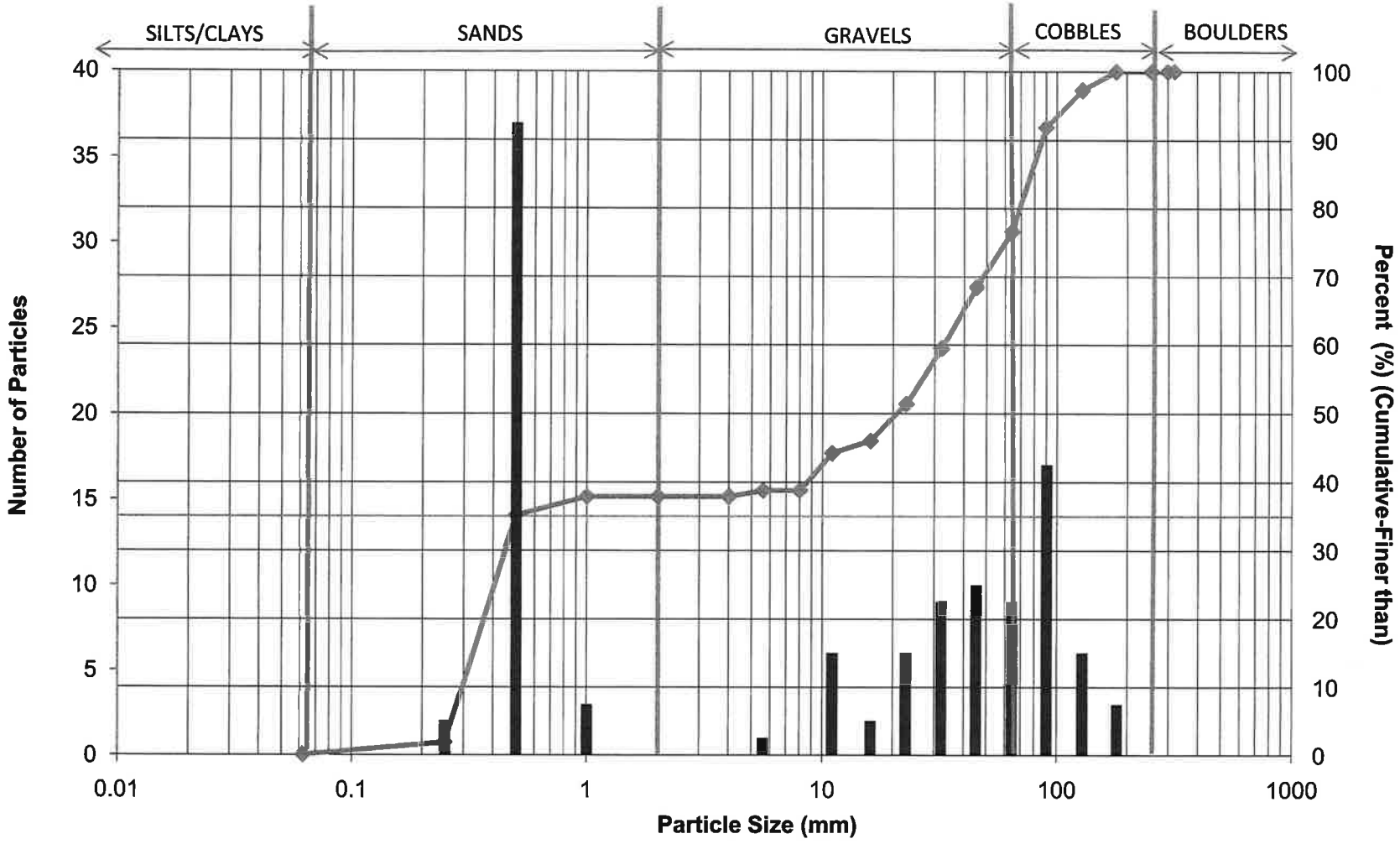
**UMC1 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**



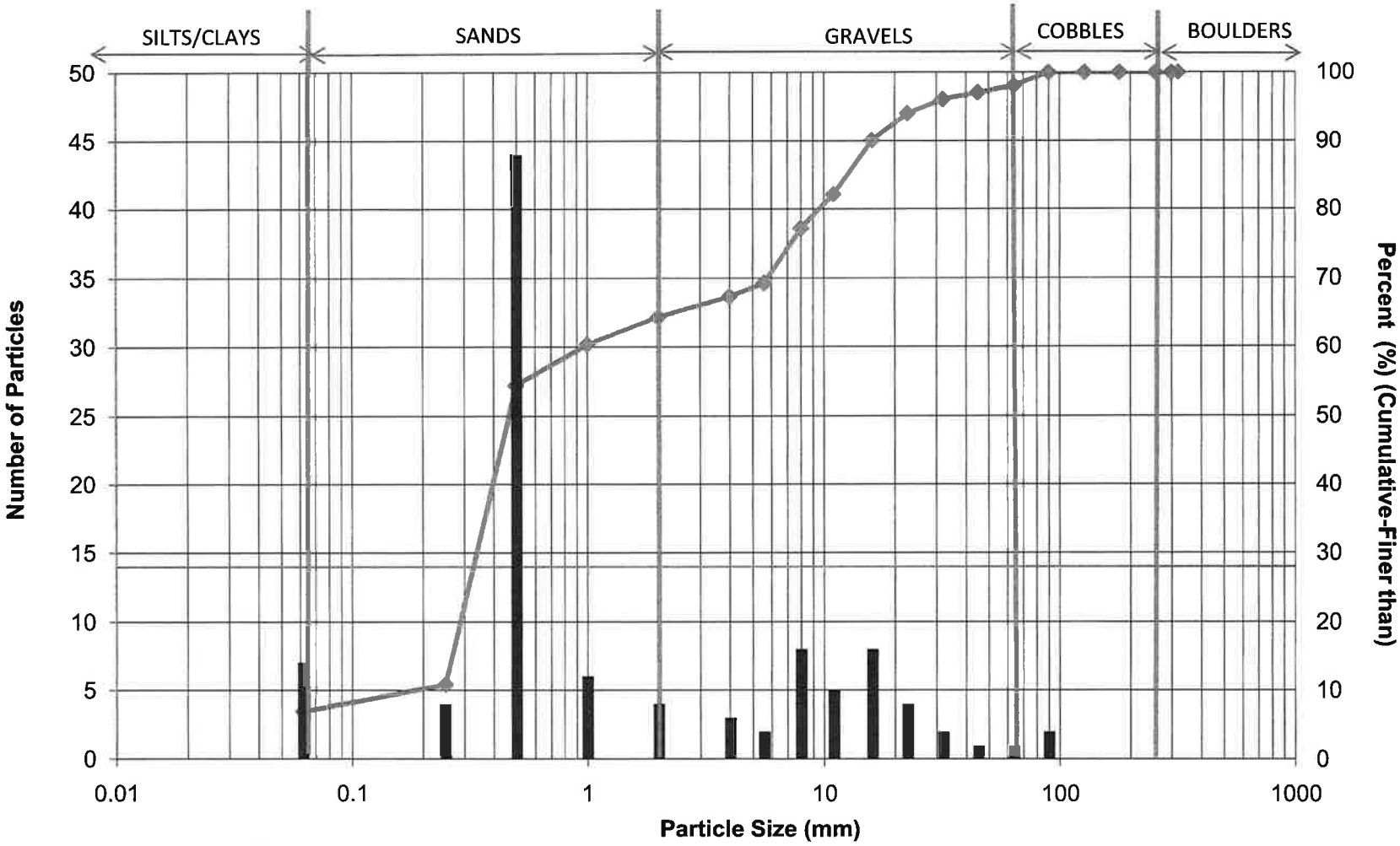
**UMC2 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**



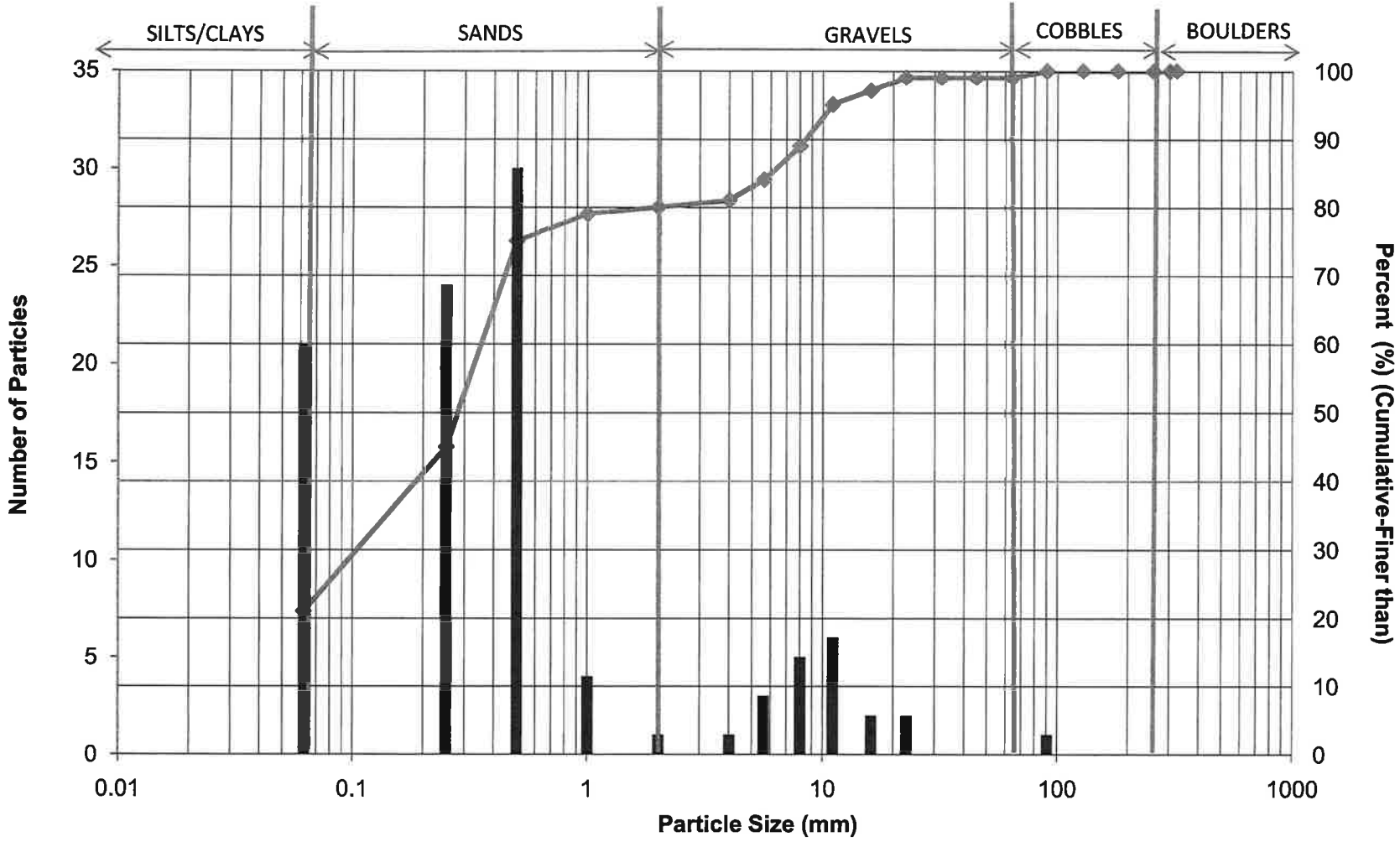
**UMC3 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**



**UMC4 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**



**UMC5 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**



**UMC6 - Channel Material Characterization**
**Size Distributions**
**Upper Muddy Creek, Carbon County, Wyoming**