PAP-761

Muddy Creek Demonstration Stream Restoration Research Project

Progress Report

Winter 1996-1997

by
Dr. Rodney J. Wittler

Progress Report

CRDA-96-1

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INTRODUCTION

This report summarizes progress on the part of the Reclamation Water Resources Research Laboratory (WRRL) during the period January 1, 1997 - March 31, 1997. The Principal Investigator is Dr. Rodney J. Wittler. This report includes details on the consolidation of all field data, progress on the three-dimensional CAD drawing/database for the project, and a list of publications or reports issued by Reclamation.

Background

This progress report concerns the efforts of a partnership of Federal and local government agencies and a local citizen task force to solve the water quality problems associated with the incision of Muddy Creek near Great Falls, Montana. The United States Bureau of Reclamation (Reclamation) and Greenfield Irrigation District (GID) are collaborating to reduce return flow to Muddy Creek. Reclamation, Cascade County Conservation District (CCCD), and the Muddy Creek Task Force (MCTF), are collaborating to stabilize the gradient and plan form of the stream. Funding for the original agreement came from a grant by the State of Montana to the Cascade County Conservation District. Mr. Alan Rollo is the Muddy Creek Task Force Coordinator. Funding for the amendment comes partially from a State of Montana grant ($10,000) and a grant by the National Fish and Wildlife Foundation ($41,000) to the Cascade County Conservation District. Funding is part of the Cooperative Research & Development Agreement (CRDA) 96-1 and its amendments between Reclamation and the CCCD.

There are eleven grade control structures named 1-A through 1-F, 2-A through 2-C, 2-E & 2-F. Figure 1 shows selected structure sites along Muddy Creek. The selection includes a sill constructed by the US Army Corps of Engineers. The sill, constructed in February, 1994, was designed for zero drop. Incision in Muddy Creek below the sill has led to a substantial drop across the sill at the present time. The total drop measured across the grade control structures, including the Corps sill, at a flow between 45 ft^3/s and 63 ft^3/s is 15.16 feet as of October, 1996. The total design drop for the 11 structures was 17 feet. Not including the Corps sill, the total drop is 15.16-1.19 or 13.97 feet. Therefore, we have achieved 13.97/17 or 82% of the design head, at the flow rate of roughly 45 ft^3/s. Including the Corps sill increases the measured drop to 87% of the design drop.

There are 160 barbs installed on Muddy Creek between Gordon and Vaughn, roughly 8 river miles. Figure 1 shows selected structure sites along Muddy Creek. Task force plans include installation of an equal number of barbs in this reach during the Fall of 1997. There are 33 barbs installed above Gordon, primarily in conjunction with the cutoff revetments in this reach. The Task Force plans include installation of 100-200 barbs in this reach. There are seven revetments and four cutoff revetments installed on Muddy Creek. Figure 1 shows these sites.

The Reclamation WRRL designed a low-cost culvert crossing for Muddy Creek in October 1996 and supervised construction in December 1996. The crossing design demonstrates dual functionality as a grade control structure and crossing. The crossing is in the vicinity of buildings owned by the Wohlgemuth family. Figure 1 shows the site.

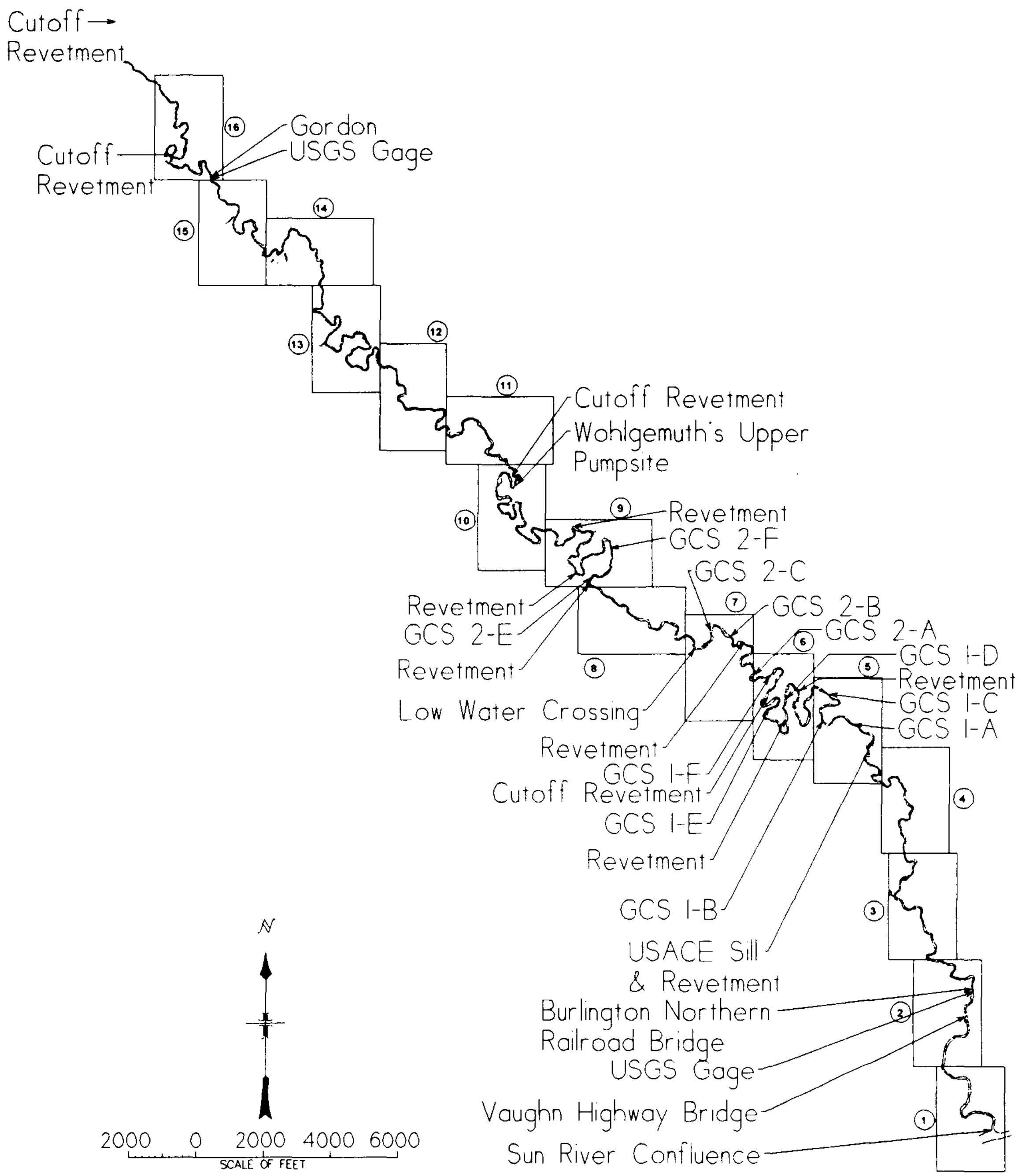

Figure 1. Selected sites along Muddy Creek.

WATER SURFACE PROFILE ANALYSIS

In October of 1993 and again in July of 1994 technicians of the Natural Resources Conservation Service (NRCS) surveyed the water surface of roughly a 4-mile reach of Muddy Creek. The Task Force informally designates this reach as the Phase I reach of the demonstration project. The Phase II reach is above the Phase I reach and extends roughly 4 stream miles upstream. As part of the CAD modeling of Muddy Creek the Task Force is assigning arbitrary reach names to reaches of the creek for identifying purposes. The water surface profiles in 1993 and 1994 show the pre-project stream gradient and the post-Phase I construction stream gradient. Figure 2 shows the two profiles.

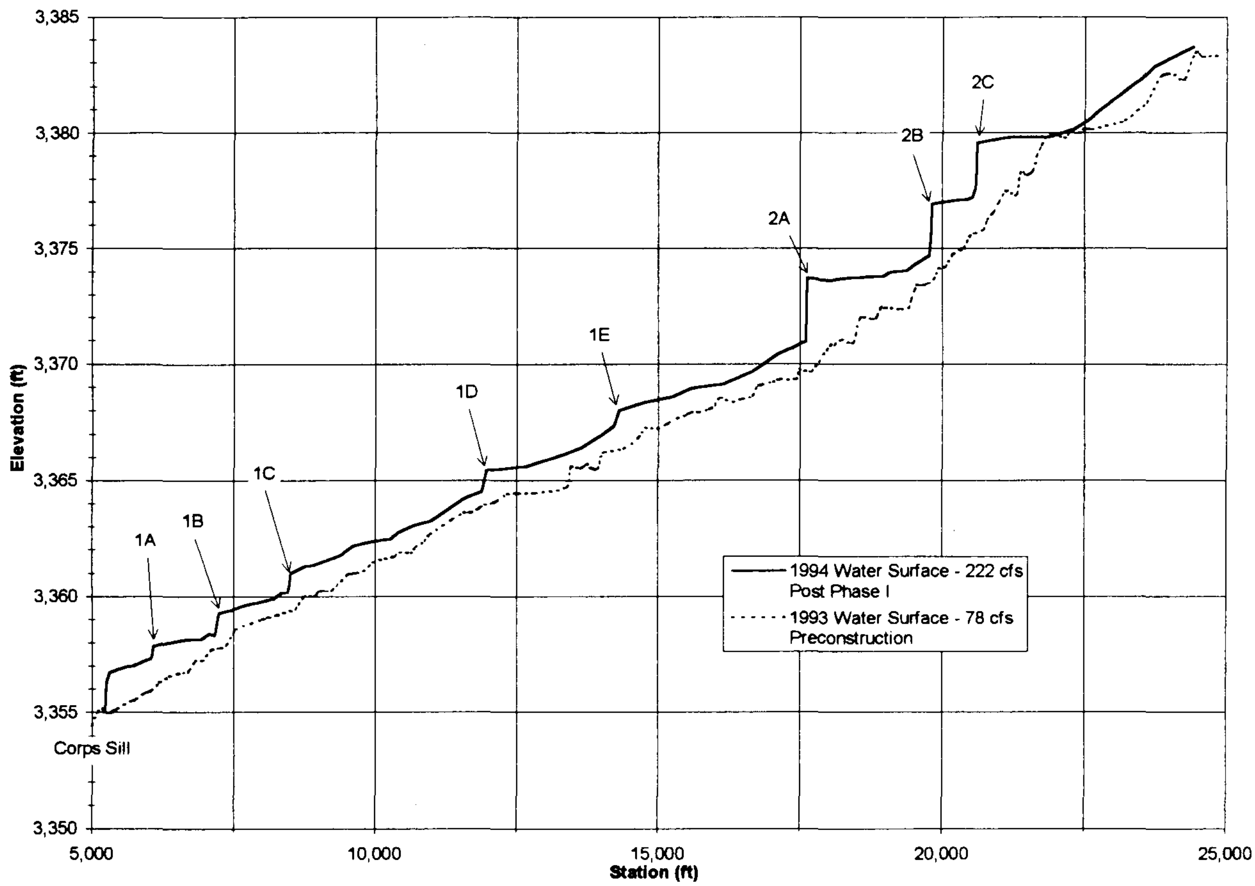

Figure 2. Water surface profiles from October 1993 (Pre-project) and July 1994 (Post-Phase I Construction).

Conclusions From 1993 Water Surface Survey - Structure Design and Location

The purpose of the 1993 water surface profile survey was to gather design information and to get the first real view of the hydraulic conditions of the creek. Two publications describe how the survey was utilized. The first, "Gradient and Plan Form Stabilization of an Incising Stream" [1] gives an overall view of the design process for the barbs, grade control structures, and the siting process of the structures based upon the water surface profile. The second "Siting Low Profile Grade Control Structures for the Muddy Creek Demonstration Stream Restoration Research Project" [2] details the specific procedure for taking water surface profile data and siting proposed grade control structures.

The 1993 water surface profile shows three distinct sub-reaches in the Phase I reach defined by the relative magnitude of the water surface gradient, or slope. In the lower sub-reach the gradient is relatively shallow. In the upper third of the Phase I reach the gradient is significantly steeper, indicating the presence of numerous head cuts and active incision. Just above this steepest sub-reach the stream returns to a relatively shallow gradient, along the Burlington Northern railroad opposite the Wohlgemuth buildings. The Task Force concluded that in Phase I grade control was warranted in these sub-reaches for the purpose of halting incision and stabilizing the bed of the creek. During Phase II the Task Force concentrated on plan-form stability using barbs and vegetation techniques, in the Phase I and Phase II reaches.

Structure Heights and Range of Influence

The Task Force installed grade control structures of two heights, one-foot, and two-foot, in the Phase I reach. The heights are design hydraulic head, that is the grade control structures were designed for either one or two feet of hydraulic head across the structure. The one-foot structures, 1-A through 1-E were constructed in the early spring of 1994. The two-foot structures, 2-A through 2-C were constructed in the late spring of 1994. An additional one-foot structure, 1-F, was constructed in December, 1994, following the first season of operation of the structures. Wittler described the structure designs in the paper "Features of a Chevron Weir Rock Ramp." [3]

The spacing between the structures was based upon an estimate of the stable channel slope. In a true "stair-step" system the tail water from a downstream structure would submerge the toe of an upstream structure. Figure 2 shows that the two-foot structures achieve this type of hydraulic behavior, while the one-foot structures do not. The range of hydraulic influence between the one-foot structures was over estimated during the design process. However, economically speaking, the one-foot structures are very successful. They stabilize the shallow gradient portions of the Phase I reach, and they cost less to construct than the two-foot structures. The two-foot structures are also very successful. In the steepest portion of the Phase I reach, the portion suffering the greatest incision and erosion, the two-foot structures have completely stabilized the gradient without perching the stream. The hydraulic influence of the two-foot structures was estimated correctly during the design process.

Flow Rate Difference

The mean flow during the 1993 survey was 78 ft^3/s while during the 1994 survey the flow was 222 ft^3/s. This difference causes the general offset between the two surveyed profiles. No attempt to directly compare the two surveys is possible because of the highly non-linear hydraulic effects of increasing stage along with increasing discharge. However, the relative differences between the two water surfaces are visually apparent from the figure.

Conclusions From 1994 Water Surface Survey

The 1994 survey confirmed the visual observations of the Task Force. Ponding between the two-foot structures was evident. The backwater influence from 1-E was not reaching 2-A, necessitating the construction of 1-F downstream of 2-A. The Task Force has not reached any conclusions about the range of influence of the one-foot structures. Some feel that additional structures are necessary in the spaces between the one-foot structures, resulting in a true "stair step" hydraulic regime. The Task Force position at this time is to observe while continuing progress in other reaches of Muddy Creek.

CAD Database

Task A4 - CAD Based Three-dimensional Model of Project Area

Task A4 of the amended CRDA requires Reclamation to incorporate all surveying data provided by the NRCS into a three-dimensional CAD based model of the project area. The basis of the model is the 1995 topographic survey of the demonstration reach by the Muddy Creek Task Force. The model will include pre-construction cross-sectional surveys, water surface profiles, and the exhaustive cross-sectional survey completed by NRCS in the spring of 1995. The first step in the creation of this model is to transform all project survey data to the State Plane Coordinate System. Table 1 lists the types and years of project surveys.

Table 1. Types and years of surveys.

Year	Type of Survey	Incorporated into CAD?
1993	Water Surface Profile (Phase I Reach)	No
1993-94	Selected Cross Sections (Phase I Reach)	No
1994	Water Surface Profile (Phase I Reach)	No
1995	Aerial Topographic (Mouth to above Gordon)	Yes
1995	Cross Section (Phase I Reach)	Yes
1995	Water Surface Profile (Phase II Reach)	No

Translation to State Plane Coordinate System (SPCS)

At the beginning of the project in 1993 the Task Force began surveying portions of Muddy Creek. The first surveys assessed the creek and provided information for determining the course of the restoration project. The first data included the October 1993 water surface profile, followed by selected cross section surveys at potential grade control structure sites. The survey coordinate system was an arbitrary XYZ system established by the surveying technicians. The elevation of the coordinate system was obtained from a USGS quad map of the area.

In 1995 the Task Force contracted for a topographic photogrammetric survey of the stream corridor from the confluence with the sun to roughly 5 stream miles above Gordon. The topographic survey coordinate system is the State Plane Coordinate System (SPCS). Merging all project survey data required a translation, rotation, and scaling of the data in the arbitrary system to the SPCS. The merging process is a least squares adjustment in two dimensions, more commonly referred to as an Affine Coordinate Transformation. Additional surveying indicated that the vertical difference between the two coordinate systems was 0.94 feet, with the arbitrary system being the lower of the two. Table 2 shows the common points between the two systems as well as the observed and transformed coordinates. Equation 1 shows the equations and coefficients that transform the data from the arbitrary system to the SPCS. Equation 2 shows the bulk rotation angle, α, and scaling factor, λ, between the two systems.

Plane Similarity Coordinate Transformation

Dr. Albert Barnes, formerly of Colorado State University, Fort Collins, Colorado, produced the affine coordinate transformation. The expressions for the Easting (E) and Northing (N) are shown in equation 1 along with the expression coefficients. Equation 2 gives the angle, α, and scaling factor, λ, between the two systems, without the horizontal or vertical translation. The vertical translation, arbitrary to SPCS is +0.94 feet. The horizontal translation is given by the coefficients a_0 and b_0.

Table 2. Common points between MCTF arbitrary coordinate system and State Plane Coordinate System. (All units are feet)

Field ID	*Observed Y-Coordinate*	*Observed X-Coordinate*	*Transformed Northing*	*Transformed Easting*
STA A	9752.10	9237.80	1220966.62	1461864.46
MM4	7965.54	8797.22	1221300.22	1463672.72
STA B	10000.07	10000.10	1221558.86	1461325.08
MM9	14907.00	6398.20	1216260.27	1458337.80
TBM 1	9634.40	3396.92	1215695.67	1464374.09
STA D	11239.63	11251.33	1222188.52	1459681.55
H4	14571.50	18151.60	1227102.23	1453808.99
TBM 10	3422.27	17614.30	1231198.76	1464183.73
TOP BOLT	14321.10	17614.00	1226715.62	1454258.15
STA H3	14691.90	17258.85	1226239.67	1454066.54
STA H2	15275.95	16688.45	1225479.97	1453769.25
MM3	13174.73	18619.97	1228103.29	1454888.39
STA I	14786.60	18919.50	1227713.09	1453297.24

$$\begin{aligned} E &= a_0 + a_1 X - b_1 Y \\ N &= b_0 + b_1 X + a_1 Y \end{aligned} \tag{1}$$

$$\begin{aligned} a_0 &= 1474545.46 \quad a_1 = -0.41131558 \\ b_0 &= 1216564.83 \quad b_1 = 0.91071221 \end{aligned}$$

$$\begin{aligned} \alpha &= 114°23'27'' \\ \lambda &= 0.99928884 \end{aligned} \tag{2}$$

Hydraulic Modeling

The cross-section data from 1995 and the water surface profile data from 1994 were analyzed by the Center for River and Stream Studies (CRSS) at Colorado State University using computer programs developed by the U.S. Army, Corps of Engineers (USACE). Two computer programs, HEC-2 and SAM, have primarily been used for hydraulic and sediment transport analyses. HEC-2 [6] has been used in the analysis and in design of measures for stabilization of streams, and has served as a basis for sediment transport analysis. Hydraulic analyses were conducted using the U.S. Army Corps of Engineers HEC-2 water surface profile model. The HEC-2 output is used to: 1) define the hydraulic conditions and bank full discharge; 2) define hydraulic parameters for sediment transport and related analyses; and 3) define water surface elevations for flows of given recurrence intervals. The channel cross-sections used in the hydraulic investigation are those from the field survey. Proper use and calibration of the HEC-2 model is enhanced by the field observations. Figure 3 shows the HEC-2 cross sections generated from data of the 1995 cross section survey.

SAM is a series of computer programs that allow a flexible approach for the computation of sediment transport at a section, sediment yield, channel roughness, and related computations. Copeland [4] explained the analytical approach for using the SAM program, which couples resistance and sediment transport equations to solve for the channel dimensions of width, depth, and slope. A family of solutions for width and slope is computed that provides for water and sediment continuity for a cross-section. SAM also provides for compositing several cross-sections within a reach to provide a reach-average condition.

Sediment transport modeling has three primary functions. First, the model is used to predict the locations of aggradation and degradation along the channel. Second, the model is used to determine the effective discharge, or range of effective discharges for the channel. The effective discharge or range of discharges are those that transport the majority of sediment and, therefore, do most of the geomorphic work in the channel (Andrews[5]). Third, the model is used to determine the sediment yield from the watershed. Ideally, the sediment yield should be divided into channel and non-channel sources. The model also can be used to determine the reduction in sediment yield or the aggradation or degradation effects of any remedial measures.

The SAM program was utilized to develop estimates of sediment yield from Muddy Creek based on the annual discharge depicted in the two flow-duration curves, using the stream survey conduct by NRCS, and based on computations of the total sediment load using Brownlie's equation for transport. The total annual yield comparison was made by computing the sediment discharge for each of ten discharges along the flow duration curves, and the sediment discharge was multiplied by the average number of days per year the flow is expected. For example, 1574 ft^3/s flow transports much more sediment than 318 ft^3/s flow, but fortunately 1574 ft^3/s occurs infrequently. Therefore, each of the annual sediment yield amounts predicted is a duration weighted sum.

No detailed survey of Muddy Creek prior to the 1994 construction season was available; however, an HEC-2 and SAM computation of sediment yield was estimated for the condition immediately before grade control structure construction by deleting the cross-sections describing the structures. This was compared to the surveyed condition immediately following construction. As expected, the structures initially resulted in little difference in sediment yield. The purpose of the grade control structures is to halt channel incision, i.e., the incision of the stream bed.

Halting channel incision and construction of the barbs along the bank stabilize the materials along the channel and allow vegetation to initiate. Therefore, the significant improvement in reduction of sediment to the Sun River downstream will come from two aspects of the construction: 1.) Grade control structures stop channel incision and barbs reduce bank erosion, both are eliminating sediment sources; 2.) The barbs, and vegetation that will develop as the degradation is halted and bank erosion is reduced, produce channel roughness that decreases the efficiency of the flow to transport sediment. Vegetation functions as roughness to reduce transport efficiency and to make the banks more resistant to erosion. Without vegetation, the stabilization of Muddy Creek would depend more heavily on riprap placement, and would be more expensive to construct and less aesthetically pleasing.

Without more data than is presently available, computation of channel roughness is not possible and estimates of these values must be made based on experience. Assuming a Manning roughness coefficient (n) of 0.035 as applicable to the 1994 condition, a value of 0.05 is used as the roughened condition, which represents a 30% increase in channel roughness. Computation of the annual sediment yield using the average duration curve developed from 1935 to 1993 data, assuming a 30% increase in channel roughness to n=0.05 results in a 42% decrease in sediment yield.

Another factor that can be identified to reduce sediment yield is reduction in annual discharge by controlling irrigation return flow. In the sediment yield computations for a reduced discharge, the flow duration curve based on 1935 to 1943 data was used. Using the HEC-2 and SAM computations with the lower roughness (n=0.035), reducing the annual flow to match the 1935-43 duration curve would result in a 38% reduction in annual sediment yield.

The peak sediment discharge occurs at a stream discharge of roughly 320 ft^3/s. For the discharges analyzed along each line of four sediment yield scenarios, the duration of a particular water discharge and the capacity of that discharge to transport sediment can be combined to compute the total amount of sediment that will be transported in an average year. For the Muddy Creek data analyzed, 320 ft^3/s is that discharge that transports the most sediment. This flow is significant for rehabilitation planning: 1.) Reducing the duration of 320 ft^3/s and greater flows will significantly reduce sediment yield; 2.) Increasing the roughness for the 320 ft^3/s flow will decrease sediment transport capacity.

Sub-Tasks to Complete CAD Model

As of the second quarter of FY 1997 the following steps are complete towards accomplishing Task A4.

1. Transformation of all survey data to the SPCS.
2. Receipt of the 1995 aerial topography from the contractor in three-dimensional, AutoCAD R13 format.
3. Combining Hydraulic modeling data, HEC-2 or HEC-RAS, with aerial topography.
4. Locations of grade control structures
5. Comparison of water surface profiles from 1993 and 1994.
6. Preliminary delineation of MCTF named sub-reaches in Muddy Creek corridor.

The following sub-tasks remain, and also point towards additional field based tasks for supporting construction and restoration activities.

1. Location of cultural resources (CAD)
2. As-builts for GCS
3. All structures added to CAD
4. RAS model for Phase I reach (95 X-section extents) This River Analysis System (RAS) model will supersede the HEC-2 model currently in use by the Task Force.
5. Comparison of 77 or earlier, 90, & 95 topography
6. Updated field data plan including:
   a. Water surface profile (Corps sill to above Gordon?)
   b. X-section survey (repeat)
   c. Close the traverse
   d. Selected x-sections above and below Phase I reach

Additional field and analysis activities include:

1. Resurvey, photograph, and assess the performance of each structure including all barbs and revetments.

2. Bank stability modeling

3. Compilation & expansion of conference papers

4. Barb design guidance

5. Construction planning

6. Construction activities

7. Report on water quality based upon USGS data analysis

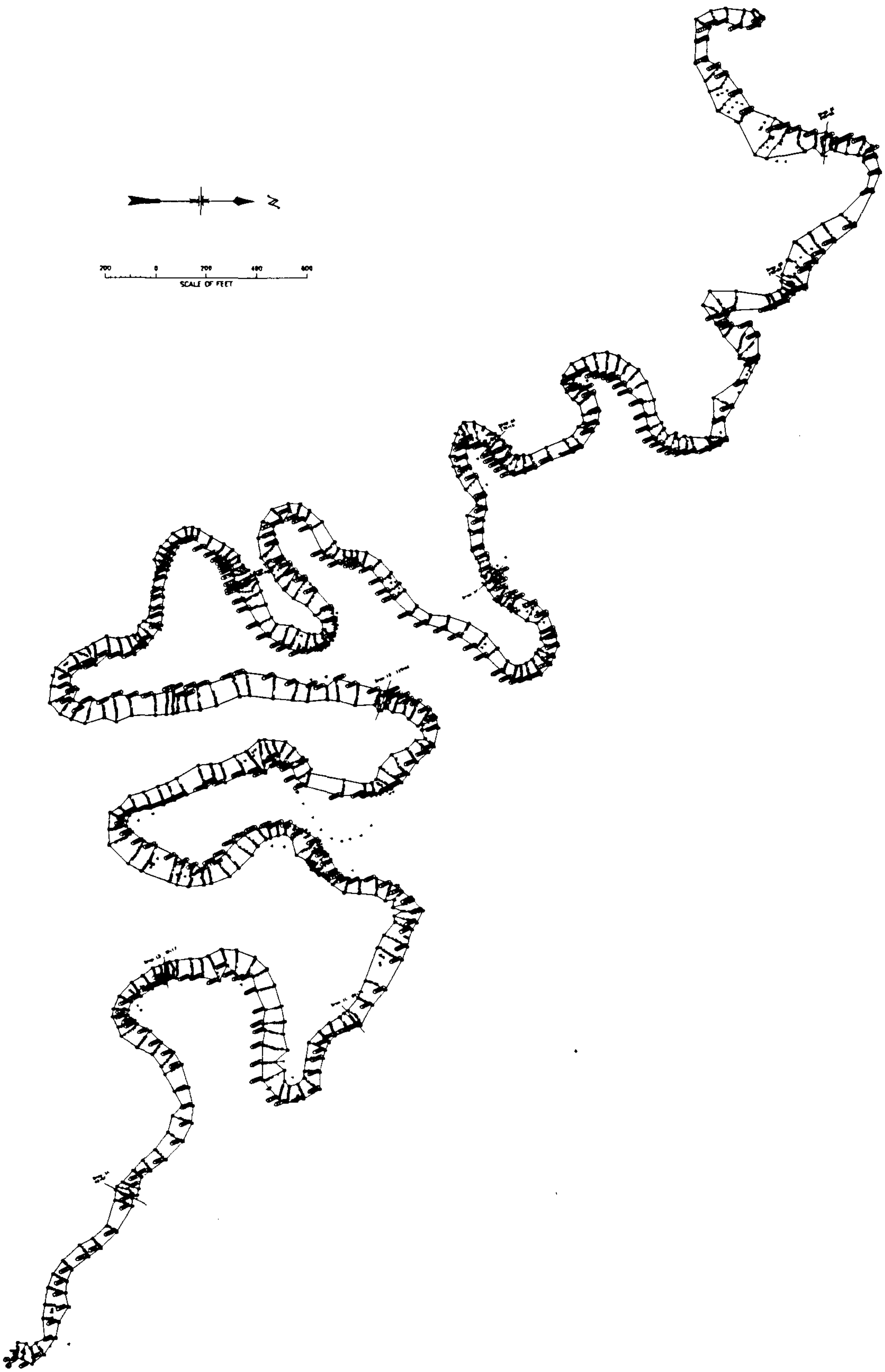

Figure 3. Combination of 1995 cross-section survey (Phase I) and HEC-RAS sections.

PUBLICATIONS & REPORTS

In May the Task Force and Reclamation will present five papers at the conference "Management of Landscapes Disturbed by Channel Incision, *Stabilization, Rehabilitation, Restoration,* May 20-22, 1997, Oxford, Mississippi. Reclamation and the Muddy Creek Task Force are hosting a session at the conference titled "Western Incised Channel Restoration: Engineering, Biology, and Cultural Resources." The titles, authors, and abstracts from the papers are listed below.

The conference provides a forum for technology transfer among researchers, scholars, potential users, state engineers, environmental engineers, fisheries and wildlife personnel, general contractors, etc. in the field of upland soil erosion/control, sediment yield, channel stabilization, bank erosion, stream ecology, restoration, and environmental impact. The Demonstration Erosion Control (DEC) Project seeks to develop and demonstrate a watershed or systems approach to address problems associated with watershed instability: erosion, sedimentation, flooding, and environmental degradation. Initiated by the federal government in 1984, DEC demonstration activities are targeted at 15 watersheds comprising 6,000 square km within the Yazoo River Basin in the Lower Mississippi Valley with measured suspended sediment yields averaging about twice the national average. The DEC Project is conducted through cooperative efforts of several agencies and institutions. The U.S. Army Corps of Engineers (Corps), Vicksburg District; and U.S. Department of Agriculture (USDA) Natural Resources Conservation Service are responsible for planning, design and construction; while the USDA Agricultural Research Service National Sedimentation Laboratory, the Corps Waterways Experiment Station, the University of Mississippi, and the U.S. Geological Survey are responsible for research and monitoring.

At the completion of the DEC project over 2,300 grade control structures (drop structures and drop pipes), about 72 flood water retarding structures, over 200 debris basins, and about 500 km of bank stabilization will have been built. Notable advances in land treatment, stable channel assessment, stream bank erosion, stream habitat restoration, computational and physical modeling of rivers, sediment transport fundamentals, and grade control structure design have been recorded in literature published by DEC-affiliated engineers and scientists. DEC-developed technology is available and intended to be transferred to other agencies and institutions to address watershed and channel erosion problems nationwide and worldwide to enhance the conservation of natural resources.

Our participation in this conference shows that significant projects are on-going west of the Mississippi, leading the way towards advanced stream restoration techniques and projects in this region.

Case Study: Muddy Creek, Montana

R.J. Wittler, S.D. Keeney, A.W. Rollo, C.C. Watson

ABSTRACT

The Muddy Creek Task Force under the auspices of the Cascade County Conservation District began a Stream Restoration Project on Muddy Creek in 1993. The Task Force is using the latest stream restoration and watershed planning technology to enhance water quality, fisheries, and wildlife habitat in the Muddy Creek watershed. Reclamation, the Natural Resources Conservation Service, Greenfield Irrigation District, and the Muddy Creek Task Force, are collaborating on the project. This report summarizes progress to date while illustrating the successful implementation of some advanced restoration technology.

Cultural Resources Considerations for Stream Restoration Projects

R.J. Wittler, M. Andrews, E.I. Friedman

ABSTRACT

Cultural resources are remnants of previous cultures. Traditional methods of archaeology are useful for discovering and investigating cultural resources. Stream restoration projects on public lands or by state or federal officials must by law consider the consequences of disturbing cultural resources during restoration activities. This paper discusses the management of cultural resources applied to stream restoration projects. Two case studies illustrate cultural resources considerations for stream restoration projects.

Field Data Plan for Muddy Creek

R.J. Wittler, D.R. Eby, D.L. Burgett, A.W. Rollo

ABSTRACT

This paper describes the evolution of the field data plan for the Muddy Creek Stream Restoration project. The paper includes descriptions of the various types of data collected over the course of the three year project. An overall view of the project at the beginning is the characteristic of a good field data plan. The overall view should include a thorough search for all previous aerial photography and topography. A search for photographs by local citizens, newspapers, and agencies is very valuable for establishing the condition of the stream and watershed before, during, and after disturbance. Of great use is a high-resolution aerial survey of the project reach at the smallest affordable contour interval. Cross-sectional data, both current and historical, is very valuable from an analysis standpoint. Hydraulic analysis requires cross-sectional data along the reach.

Building Banks on Muddy Creek With Barbs

R.J. Wittler, S.D. Keeney, D.R. Eby, D.L. LaGrone

ABSTRACT

Barbs are jetties that extend from the bank and angle down into the channel, and upstream into the thalweg. Barbs vary in size depending upon channel size, shape and flow levels. Typical barb construction uses rock whose size primarily depends on stream velocity. Barbs are an effective alternative for bank stabilization problems. Barbs build stream banks and create riparian areas by trapping bedload and suspended sediments. Other names of barbs include jetties, toe dikes, groins, habitat sills, and bendway weirs.

Barbs displace high-velocity flow in the outside of bends away from the bank and create back flow cells at the base of the stream bank. At low flow, eddying between barbs causes sediment deposition. During higher flows, turbulence against vertical or overhanging banks causes bank collapse into areas between barbs. Bank collapse stops once the banks have reached a threshold slope. Low flow eddying maintains sediment between barbs. Sediment accumulation between barbs eventually results in riparian development. Over time the barbs become less visible as sediment accumulates and riparian vegetation develops.

The Muddy Creek Partnership: How to Restore a Stream

A.W. Rollo, D.L. Burgett, R.J. Wittler, S.D. Keeney

ABSTRACT

The Muddy Creek Demonstration Stream Restoration Research Project near Great Falls, Montana began in 1993. The Project is the result of a cooperative effort and partnership between Federal, State, and County agencies, and a local citizen task force. Together this interagency, interdisciplinary group is working to find solutions to the water quality problems originating in Muddy Creek. Muddy Creek is a tributary of the Sun River in the Upper Missouri River Basin. The Creek drains approximately 314 square miles of agricultural land. Muddy Creek borders the downstream edge of the Greenfield Irrigation District. The creek intercepts return and waste flow increasing base flow, causing extensive erosion of the fine grained alluvial soils. The primary erosion mechanism is incision followed by large scale bank slumping in the creeks lower reaches. The sediment transported by Muddy Creek decreases water quality in the Sun and Missouri Rivers.

In 1993, the state of Montana stepped in at the request of concerned citizens to look at ways to resolve the massive erosion problem of Muddy Creek. They were able to bring together a significant number of interested parties that were willing to work together to resolve the water quality problem. At the outset, the partners knew that they could not restore Muddy Creek overnight. They also knew that large amounts of federal dollars would not be available. Thus they would need new innovative ideas and cost-effective approaches. The partners established a task force as part of a consensus building process. The process allowed for open discussion, and contributes to a feeling of ownership for the outcome of the project. The Muddy Creek Task Force now gives progress reports to a larger group of interested individuals, communities and agencies, concerned with the Muddy Creek sediment issue.

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