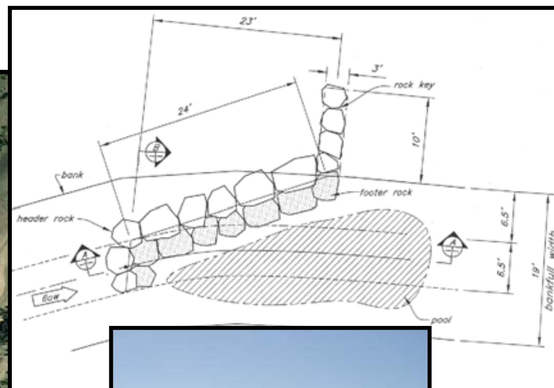
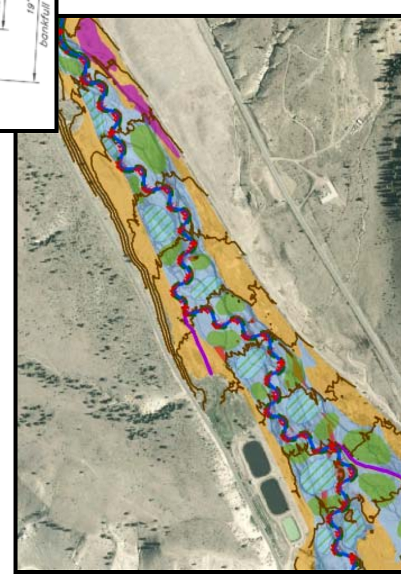
Willow Creek Stream Restoration: Planning Study

Mineral County, Colorado
April 2007





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ALAMOSA FIELD OFFICE
COLORADO STATE OFFICE
NATIONAL DESIGN, CONSTRUCTION AND SOIL MECHANICS CENTER

April 13, 2007

Willow Creek Stream Restoration: Planning Report

Job Number: CO-0405
Short Job Description: Willow Creek Stream Restoration
Location: City of Creede; Mineral County, Colorado
Summary: A plan detailing current conditions and proposed restoration options of the Willow Creek stream and floodplain downstream of Creede has been developed and is presented in this report.

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NRCS ***Helping People Help the Land***

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INTRODUCTION

Willow Creek downstream of Creede, Colorado is currently in an unstable, braided condition due to disturbance from historic mining activities. The 1.5 mile section of stream and floodplain from the mouth of Creede's flood-control flume to the confluence with the Rio Grande requires a restoration plan to provide alternatives on approaches to restore stream function and provide a more visually-pleasing entrance to the historic tourist-town of Creede.

Historic mining activities have negatively impacted the natural resources of the watershed surrounding the community of Creede, most visibly within the Willow Creek floodplain. Formed by the confluence of East and West Willow Creeks upstream of Creede, Willow Creek is a tributary of the Rio Grande. The ecosystem within Willow Creek's floodplain has had significant impairments due to historic mining activities and the resulting physical and chemical legacy (metals; especially cadmium, lead and zinc) from the mining and processing activities. Willow Creek is currently in a braided form (Figure 1), an unsightly and locally atypical geomorphic condition that, in combination with the water and soil contamination, has led to poor ecosystem function. The substantial water-quality impairments and poor morphologic conditions are preventing significant invertebrate and fish populations. Additional problems in this floodplain stem for poor grass and willow populations due to physical disturbance from the braiding, mechanized manipulation, lack of soil, and contaminated soils and groundwater. Additional photos illustrating the floodplain condition are provided in Figure 2.

The residents of the town of Creede and the surrounding community have developed a community-based effort to identify and address the most pressing environmental concerns with the Willow Creek watershed. The Willow Creek Reclamation Committee (WCRC) is directing efforts aimed at improving water quality and physical habitat in the watershed as part of a long-term watershed management program which focuses on restoring the stream and reducing impacts to the Rio Grande.

Figure 1: Current condition of Willow Creek floodplain.

The purpose of this planning report is to collect and present available data and publications on the floodplain into one package, to provide informed alternatives and recommendations for a restoration. Cost estimates are needed to seek out funding opportunities for the restoration and have been provided. Once funding is secured, a full design will then be needed for construction. Due to the high degree of destruction and neglect of the floodplain by the mining activities, the challenges of this project are substantial – the costs of a reconstruction will also be substantial.

Figure 2: Current condition of Willow Creek floodplain and watershed.

WATERSHED AND FLOODPLAIN OVERVIEW

Willow Creek is a 39.8 square mile watershed (Figure 3) located in the Upper Rio Grande basin in the San Juan Mountains. The watershed is located in the northern San Juan Mountains, between the elevations of 8584 and 13,896 feet in Mineral County. Average annual precipitation ranges from 11 to 33 inches, according to 1961 to 1990 PRISM estimates. The mainstem Willow Creek is formed by the confluence of East and West Willow Creeks 3.1 miles upstream of the Rio Grande. Tributaries to West Willow Creek include Nelson (Deerhorn) Creek. Tributaries to East Willow Creek include Whited Creek. Windy Gulch enters the mainstem Willow Creek just upstream of Creede.

The Rio Grande National Forest makes up the bulk of the land in the watershed. Private land ownership exists in Creede, in the floodplain downstream of Creede and within a number of private inholdings within the Rio Grande National Forest. Many of these inholdings are associated with the historic mining activities.

Willow Creek has had a substantial history of mining activities performed within its watershed. The principal metals that were produced in the Creede mining district were silver, lead, zinc, copper, gold. Substantial degradation of the environment has occurred from the mining and processing activities. The mines have been largely abandoned, with little post-mining rehabilitation planned or budgeted for by the mining companies.

The town of Creede, population 412 (in 2005), is located near the lower level of the watershed, approximately 2 miles upstream of the Rio Grande. Creede is the county seat of Mineral County. The average annual precipitation of Creede is 14.25 inches, for the years 1978 to 1983 and 1994 to 2006. On average, the wettest month in Creede is August (2.46 inches), while the driest month is December (0.55 inches). Average (1994 to 2006) monthly mean high temperatures range from 42.1 degrees F in December to 83.6 degrees F in July. Average monthly mean low temperatures range from 9.9 degrees F in December to 47.8 degrees F in July.

Willow Creek in Creede is conveyed by a masonry floodwater conveyance flume (Figure 77) that was designed and constructed by the U.S. Army Corps of Engineers. It was installed in the early 1950s. This flume has an approximate capacity of 1550 cfs through town, but the bridge at the downstream end of the flume will convey only 970 cfs before it would be overtopped (Yochum 2002).

The Willow Creek floodplain is illustrated in Figure 4. The floodplain is currently in a braided form from extensive mining-related disturbances. No vegetation has existed on a substantial portion of the floodplain since at least 1939. Pre-settlement, the floodplain consisted of a stable stream with an extensive willow population (Figure 66). The approximate area within the floodplain where restoration is needed (the proposed project area) is 208 acres. This area is primarily owned by three entities: Creede Resources (a subsidiary of the Hecla Mining Company); the Mineral County Fairgrounds Association; and Wason Ranch. Zimmerman owns a small portion of the floodplain at the Rio Grande confluence. Creede Mineral Resources in considering donating their portion of the floodplain to the City of Creede but the details of this transfer have yet to be finalized.

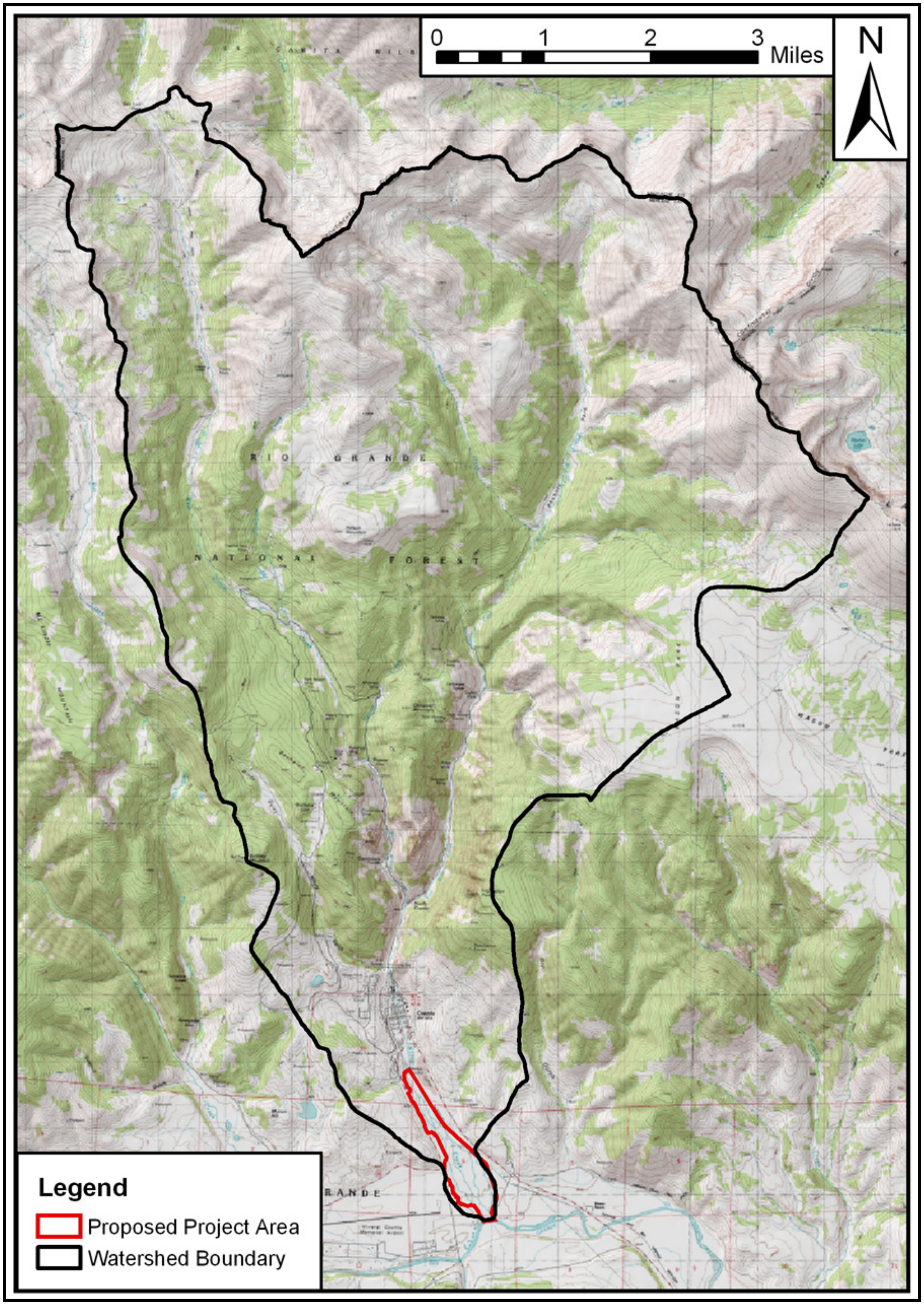


Figure 3: Willow Creek watershed.

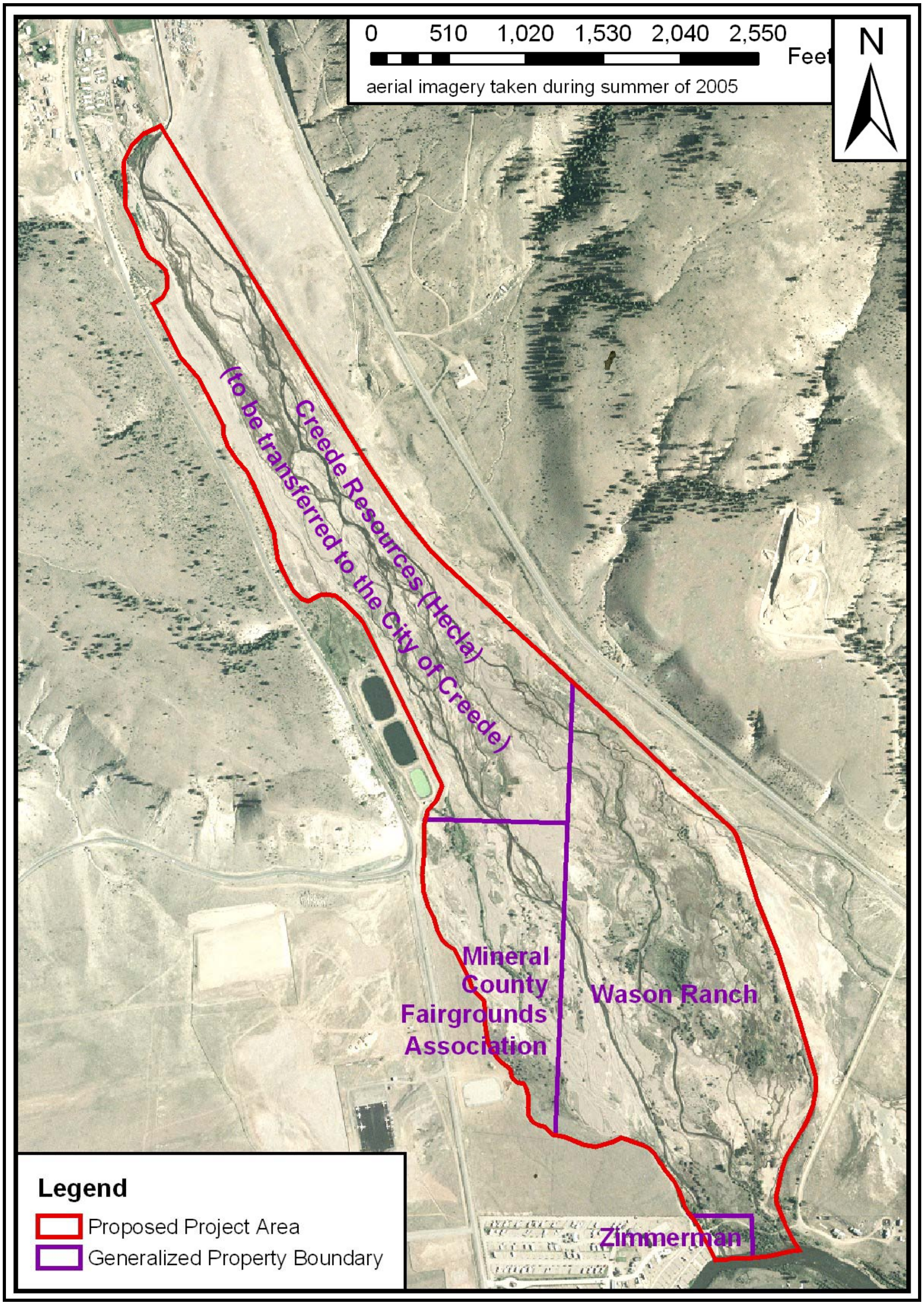


Figure 4: Floodplain overview.

RESTORATION OBJECTIVES

The Willow Creek Restoration Committee was formed to develop and implement a plan for rehabilitation of the Willow Creek watershed. A number of major and minor projects are needed to meet this rehabilitation goal, with the restoration of the floodplain being one of the major project needs. The WCRC's objectives for the stream restoration project are to:

A. Construct a geomorphically stable, meandering stream channel from the end of the existing flume to the Rio Grande.
B. Vegetate the riparian corridor with regionally appropriate herbaceous and woody vegetation.
C. Provide physical conditions so that, when water-quality improvements have been made within the watershed, proper biologic function of riparian corridor can be attained.
D. Monitor the channel morphology, vegetation success, and biologic re-colonization following construction.
E. Produce data, maps, and reports for dissemination of information regarding the approach to stream restoration and success.

To meet these objectives, the Willow Creek stream restoration will require the following tasks and results:

a) Evaluate floodplain conditions and restore natural stream processes to improve sediment transport, reduce erosion, and create better-functioning in-stream and riparian corridor habitat.
b) Identify the magnitude and extent of the floodplain sediment contamination and work with the Willow Creek Reclamation Committee, CDPHE and EPA to plan mitigation strategies, as they relate to the stream restoration.
c) Restore native and appropriate vegetation species to the floodplain, improving riparian habitat and providing essential long-term stream stability.
d) Improve long-term natural management of stream energy and sediment transport, through the reestablishment of a meandering stream with proper dimension, pattern and profile.
e) Control velocity and energy distribution, especially during the critical revegetation phase, through use of in-stream features, such as rock structures.
f) Provide stream diversions for existing water-rights obligations.
g) Establish wetlands for habitat and water quality improvements, where feasible and permitted.
h) Develop physical conditions that will allow proper biologic function (including a healthy fishery) of the riparian corridor once watershed-based water-quality improvements have been made.
i) Involve the community and respond to their needs.
j) Ensure that project proposals accommodate the needs of the fairgrounds project and Wason Ranch.

GEOLOGY

Al Albin, *Geologist*

The Creede Mining district is in the central part of the San Juan Volcanic Field. Between 27.8 and 26.4 Ma (million years ago), a sequence of large calderas formed in the central part of the San Juan Volcanic Field (Steven and Eaton, 1975). This is illustrated in Figure 5. Large-volume eruptions of ash and lava from these calderas produced nearly all of the rock units in the Creede area and for many miles around. The inception of high-silica, alkali rhyolite volcanism in this area coincides with the inception of basin and range faulting in the San Luis Valley segment of the Rio Grande trough (Lipman and Mehnert 1969, 1975).

La Garita caldera, 25 to 30 mi across, collapsed after the eruption of a huge volume of ash (480 to 960 mi^3) or more 27.8 Ma. Caldera collapse occurs when the surficial deposits overlying the magma chamber fall or subside into the evacuated magma chamber following a large eruption. After the collapse of the La Garita caldera which lies north and east of Creed, four or five other calderas formed along the western margin of the La Garita caldera. Only three are exposed sufficiently to be studied in detail (Steven and Eaton 1975). The earlier calderas are often obliterated by subsequent caldera formation or covered by subsequent ash or lava flows.

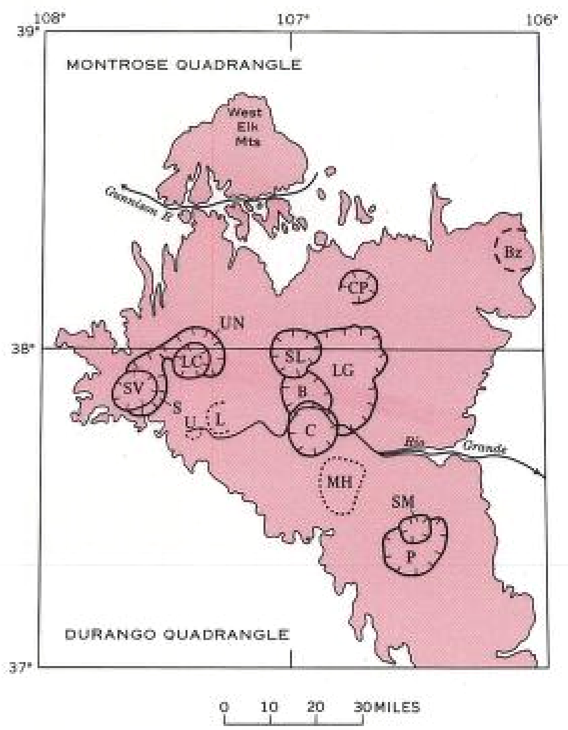


Figure 5: The San Juan volcanic field. The calderas in the central part of the volcanic field (oldest to youngest); LG, La Garita; B, Bachelor; SL, San Luis; and C, Creede. The town of Creede is on the northern edge of the Creede caldera. (Steven et. al. 1974).

The Bachelor caldera formed along the western edge of the La Garita caldera. The Bachelor Mountain tuff, between 27.8 and 26.7 Ma, accumulated to a depth of 1.5 km (1 mi) within the Bachelor caldera and forms the walls of most of the productive veins in the Creede district. The San Luis caldera formed to the north of the Bachelor caldera consuming the northern part of the older Bachelor caldera. The last of the calderas to form in this area was the Creede caldera, 20 km (12.5 mi.) in diameter. The caldera consumed the southern part of the Bachelor caldera. The town of Creede is located on the northern edge of the Creede caldera. The San Luis and the Creede calderas formed between 26.7 and 26.4 Ma.

The Creede Formation consists of streambed and lakebed deposits with volcanic ash, talus from the rim of the caldera and locally derived lava accumulated in shallow lakes that formed in a moat, a low-lying area around the periphery of the collapsed caldera. The Creede Formation also contains travertine deposited from hydrothermal springs.

Figure 6 illustrates the Geology of the Creede area. In this figure, the northern half of the Creede caldera is shown at the bottom of the map, with the resurgent dome shown as a semi circular feature south of the Rio Grande River. Outcrops of the Creede Formation are labeled Tc. Their semi circular form define the shape and extent of the caldera. The Rio Grande Valley follows the moat between the rim of the caldera and the resurgent dome in the center Creede area geology

After the Creede Formation filled the Creede caldera to overflowing, these deposits, along with older deposits within the Bachelor caldera, were faulted and mineralized. Mineralization occurred along a series of generally north to northwest striking, steeply dipping, normal faults that formed along the northeast margin of the Creede caldera. Offset on these faults formed a well defined graben about 6 km (3.7 mi) across. The faulting is thought to result from distension associated with the emplacement of intrusive magma beneath the Creede district. Deep circulation in a convecting hydrothermal system above the magma produced the mineralization in the open spaces between fault and fracture surfaces and within fault breccia. Sediments of the Creede Formation adjacent to the fault zones were also mineralized. This same process also produced the travertine deposits in the Creede Formation. The mineralization has been dated by the K-Ar method at 24.6 ± 0.6 Ma, approximately 2 million years after the youngest volcanism in the area. That faulting continued during and/or after mineralization is demonstrated by slickensides that are commonly found within the mineralized zones.

Minerals, Mineralization and Alteration

The principal metals produced in the Creede district are silver (Ag), lead (Pb), zinc (Zn), copper (Cu), gold (Au) found in veins in a system of open faults and fractures that strike generally north to northwest. Typically, the near-surface deposits are relatively low grade and unworkable. At greater depths richer ore is found and at still greater depths the ore gives way to lower-grade sulfide ores. The openness of the mineralized fault system allows easy access to meteoric water (water derived from rain and snow). Meteoric water percolating downward through the system oxidized and leached the upper part of the deposit. Oxide and sulfate ores were then precipitated at lower depths in the mineralized system enriching the existing sulfide ores. Below the zone where the precipitation

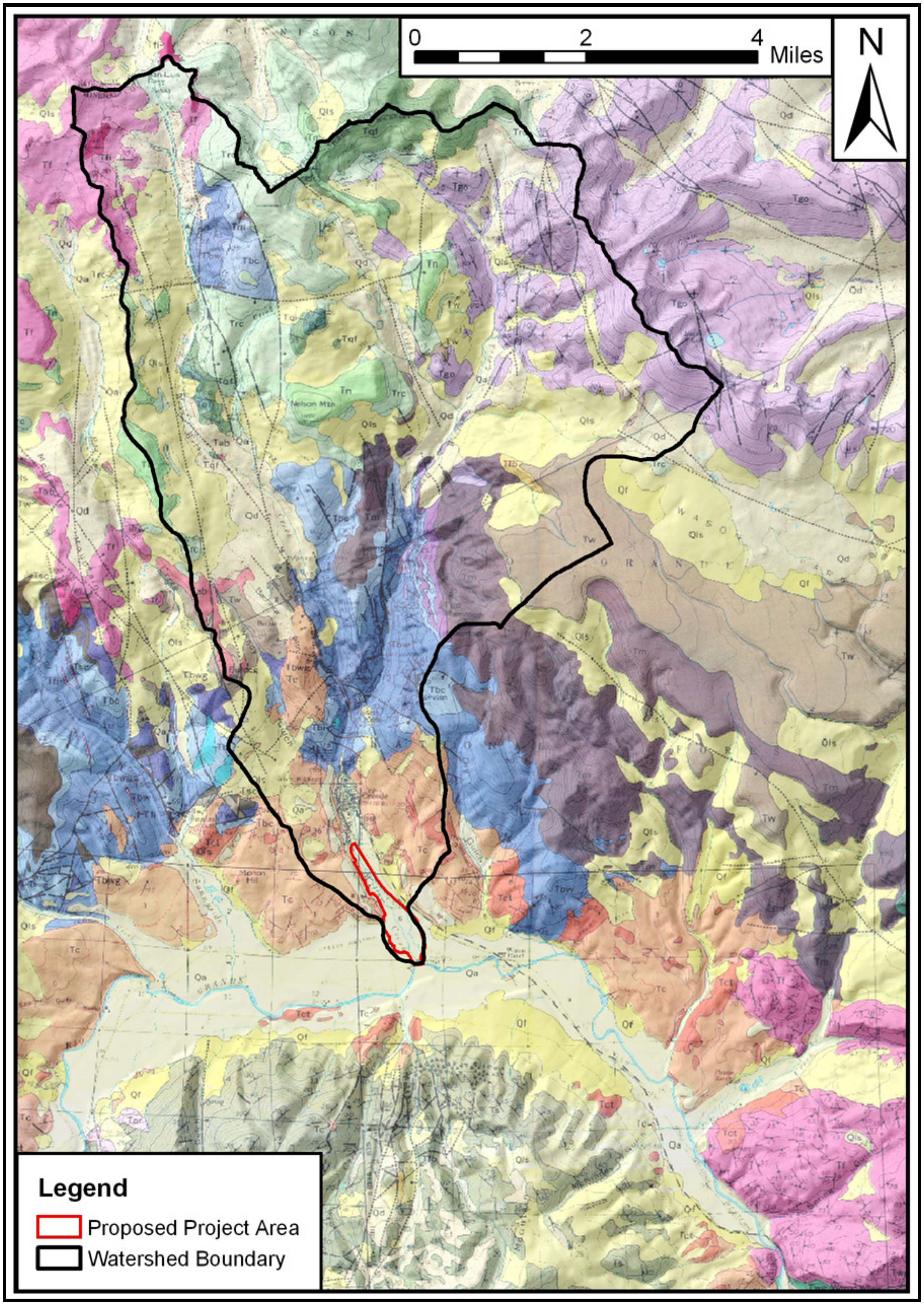


Figure 6: Geology of the Creede area (Steven and Ratte 1973).

occurred are lesser amounts of sulfate ores. This zone of mineralization has remained largely unchanged from its original composition (Emmons and Larsen 1923).

The primary, unaltered, ores are predominantly Ag-Pb-Zn-Fe sulfides and minor Cu sulfides with native Au. In the oxidized zone, silver occurs mainly as silver chloride and as native silver. Sphalerite (Zn-FeS) is also found. In the lower levels, silver is present in galena (PbS), sphalerite, pyrite (FeS), and thinly disseminated sulfides in quartz. Antimony and arsenic are not found in the district with the exception of a trace of antimony in some of the complex sulfide ores. All the Au in the district is associated with manganese dioxide, which has been reconcentrated by downward-moving water from material in which gold occurs sparingly (Emmons and Larsen 1923).

Ore Processing

Most of the ore processing that occurred in the Creede area was ore concentration. Ore was crushed and processed by various mechanical means that concentrated the ore minerals for shipment to smelters for further processing. These processes do not involve the addition of chemicals thus the waste products of these concentration processes have the same composition as the mineralized zones in the native rock itself.

HISTORIC AERIAL PHOTOGRAPHY

Steven Yochum, PE, *Hydrologist*
Al Albin, *Geologist*

Aerial photography of the Willow Creek floodplain was obtained from the U.S. Forest Service for the years 1939, 1958, 1964, 1973, and 1985.

Figure 8 provides 2005 photography, with outlines of mining structures and waste deposits indicated on at least one of the five historical aerial photography images. The cobble-sized deposits of waste rock prevalent throughout the floodplain have been ignored in the construction of this waste polygon. Additionally, a detail of some of these areas of concern superimposed upon 2002 aerial photography is shown in Figure 7, to illustrate how some of these historic feature locations relate to current indicators.

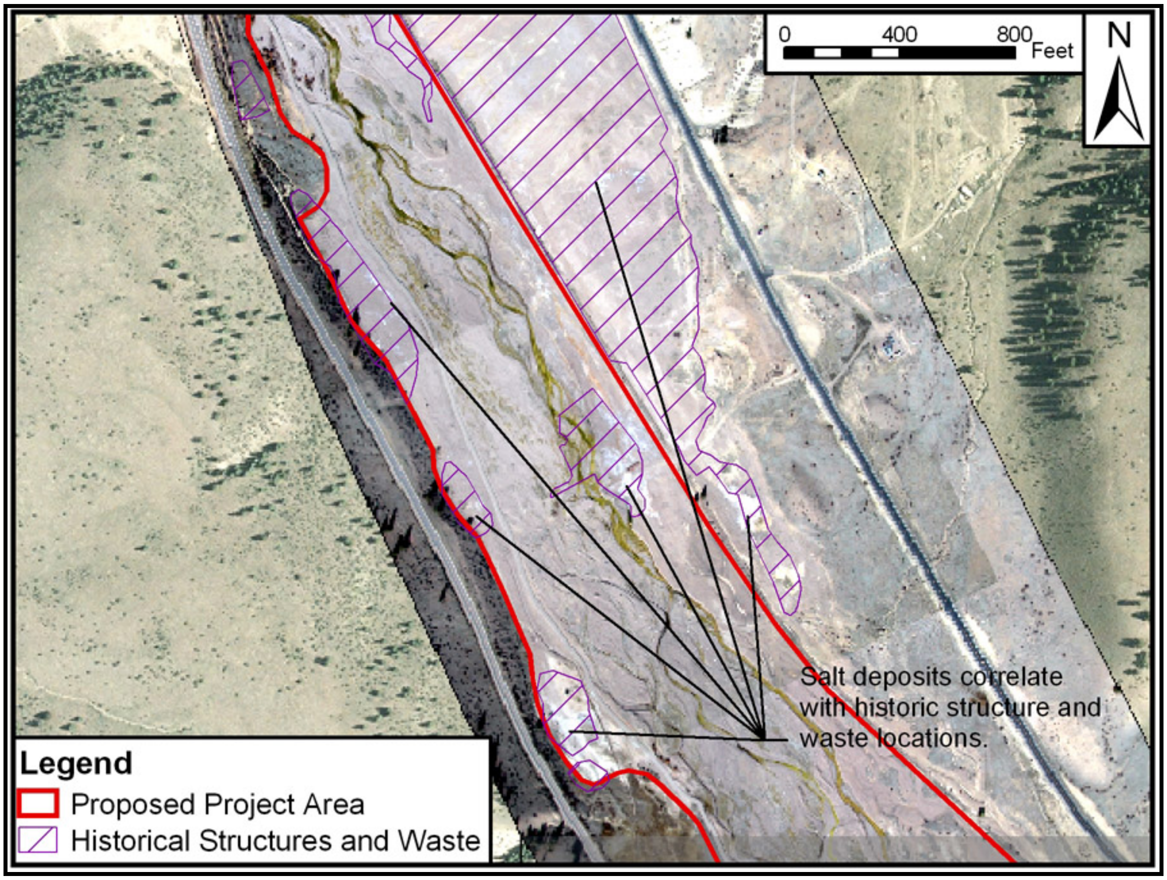


Figure 7: Historic mining structure and waste locations superimposed on 2002 aerial imagery.

Figures 9 through 13 provide aerial photography for 1939, 1958, 1964, 1973, and 1985. Large format versions of these images are provided as Figures A-1 through A-5.

A number of observations can be drawn from these aerial photography images:

- The stream has been in a braided form since at least 1939. (A historic photo, illustrated in Figure 66, indicates that the floodplain was vegetated and the stream was stable circa 1888-90.)

- Multiple-generations of mine waste structures and deposits have been located in and adjacent to the floodplain.
    - Signs of these structures and deposits are currently indicated by the obvious tailings impoundment to the less obvious salt deposits.
- The aerial photos from 1939 (Figure 9) shows a debris fan that begins near 6th street in Creede. From that point, the channel of Willow Creek broadens to fill the majority of the flood plain. The fan is constricted between the railroad embankment and the Emperious tailings pile and then broadens out again after the stream crosses under the railroad tracks. The fan is marked by a number of abandoned channels. This fan most likely is made up of waste rock from the mine working upstream of Creede that were transported during high flow events and deposited on the broader, gentle slopes of the valley below Creede.
- Aerial imagery taken in August of 2002, during the record drought indicated a number of salt deposits of unknown chemical content. These compounds may have migrated to the surface from lower contamination zones and not washed away due to the dry conditions. As illustrated in Figure 7, these deposits strongly correlate with the locations of historic waste structures and deposits.
    - Removal of this material may be deemed necessary.
    - These mitigation areas should be avoided with the stream restoration alignment.
- The extensive floodplain vegetation that used to envelope the floodplain, as illustrated in Figure 66, was covered by mine waste or removed before 1939.
    - Cobble-size mine waste was not included in the structure and waste deposit polygons provided in Figure 8.
- Most of the tailings currently located on Wason property were deposited before 1939. This is also supported by historic documentation, in the CULTURAL RESOURCES section.
    - However, additional dumping or shifting of this material may have occurred, as indicated by some areas previously vegetated (in 1973, for example) that were shown to be devegetated in 2002 with salt deposits.
    - There are some smaller areas indicated as having mine tailing deposits in 1939 that currently have vegetation.
- The Wason diversion has not substantially changed its location and form since 1939, continuously providing surface flow to the lower-east portion of the floodplain through irrigation waste flow (discussed in Hydrology section).
- Between 1939 to present, little change in floodplain vegetation has occurred, indicating that the floodplain and stream will take a great deal of time to naturally transform itself into a properly functioning stream.
    - This provides a strong argument for taking an active approach towards addressing the stream instability.

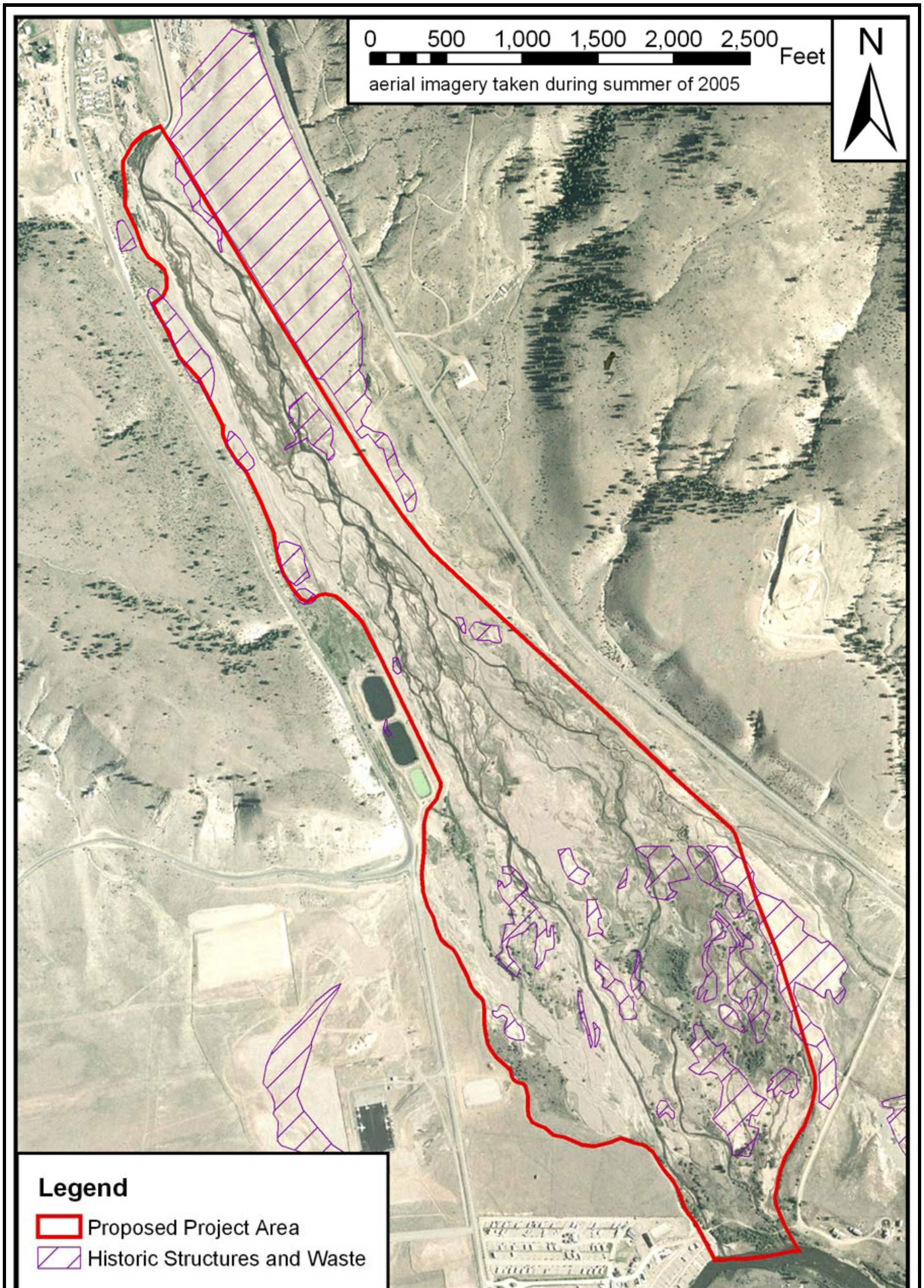


Figure 8: Likely historic mining-related structures and tailing locations. Waste rock locations have been ignored.

Figure 9: Historic aerial photography of floodplain, 10/5/1939.

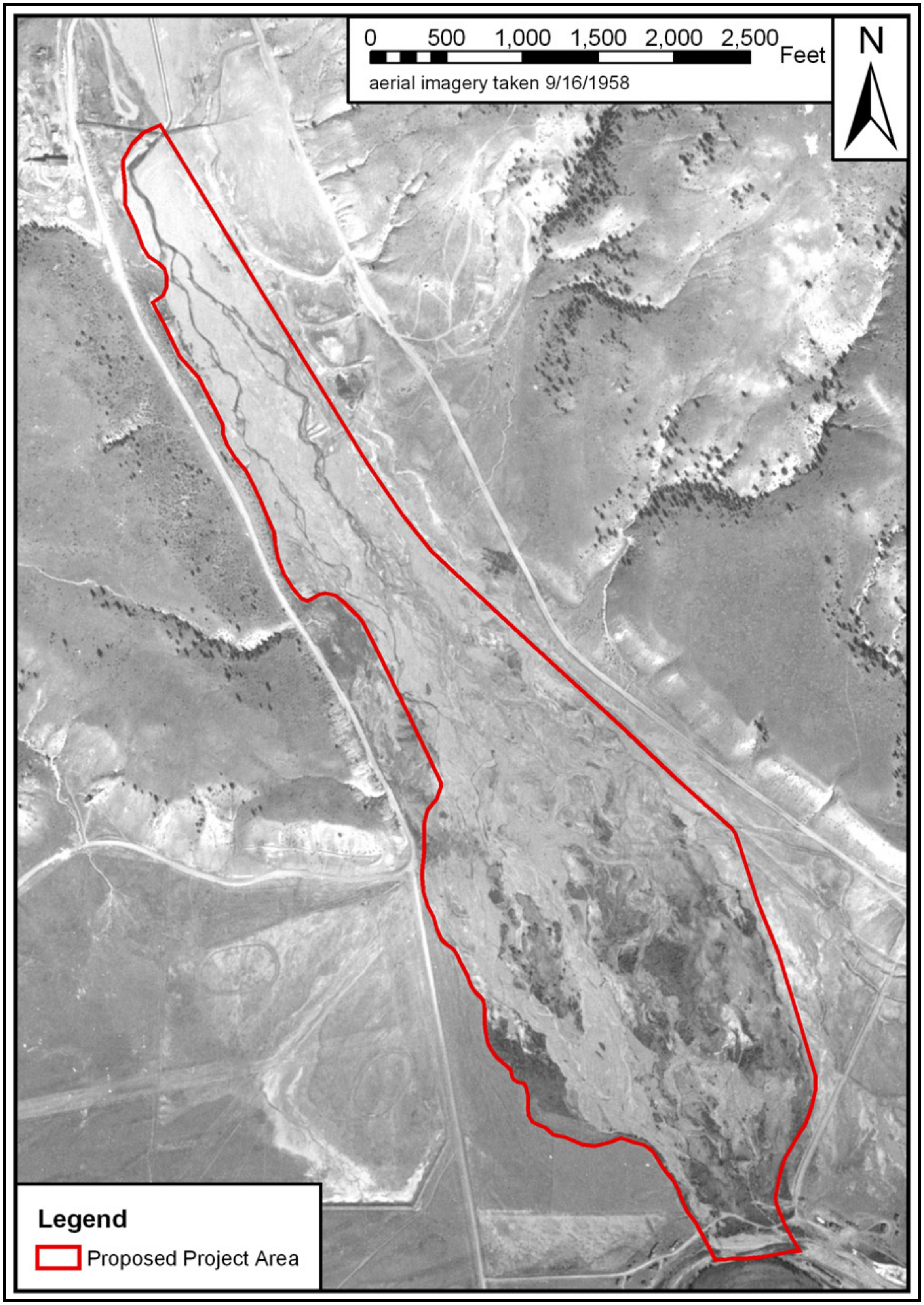


Figure 10: Historic aerial photography of floodplain, 9/16/1958.

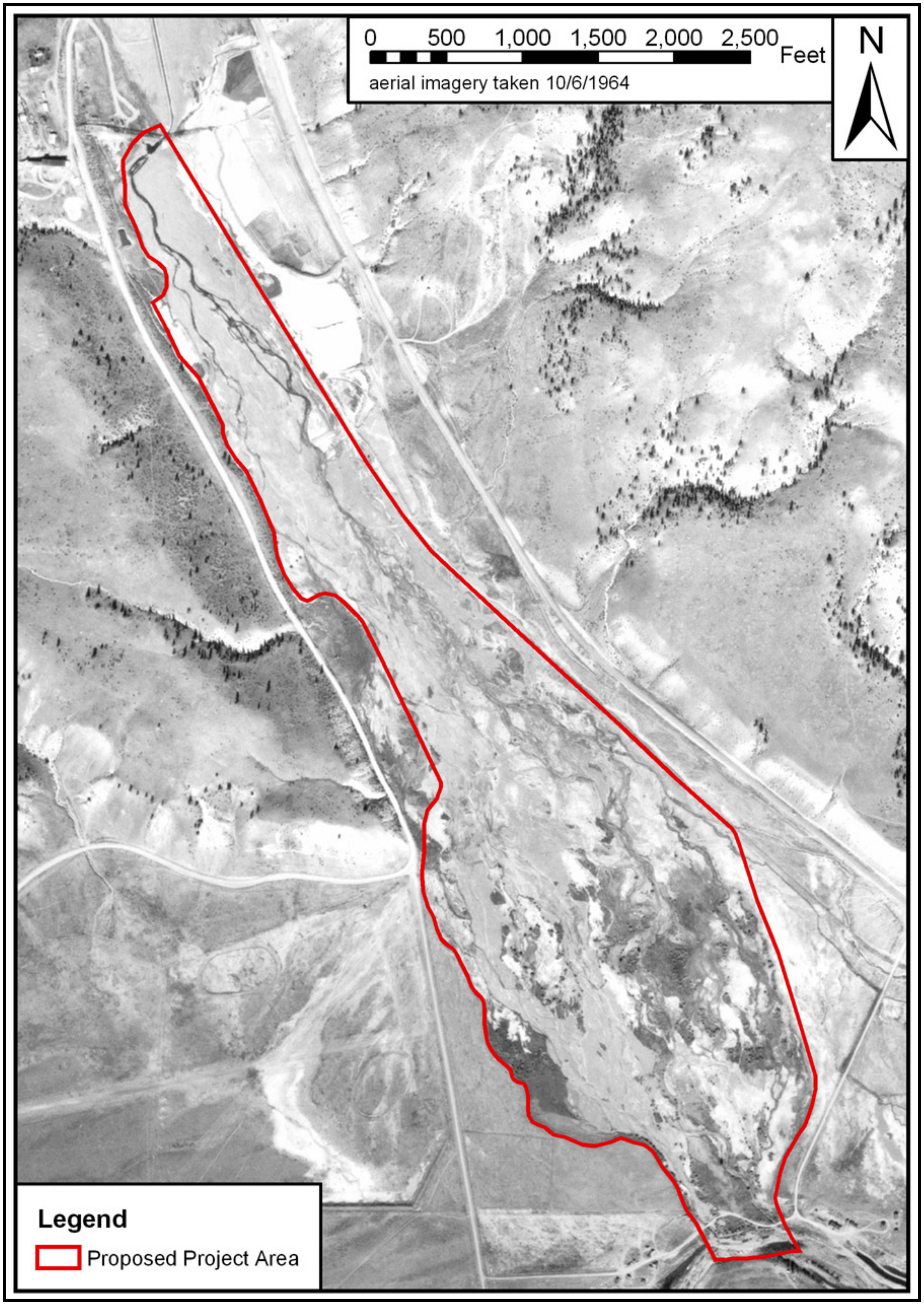


Figure 11: Historic aerial photography of floodplain, 10/6/1964.

Figure 12: Historic aerial photography of floodplain, 9/20/1973.

Figure 13: Historic aerial photography of floodplain, 9/12/1985.

MISCELLANEOUS HISTORIC INFORMATION

Terry McGowan, of Casey Resources, a consultant to Creede Resources
Steven Yochum, PE, *Hydrologist*

This section provides miscellaneous information regarding mining activities in and immediately adjacent to the Willow Creek floodplain, specifically in regard to the Emperious mill site and tailings impoundment. This information relates directly to the historic aerial imagery provided in the previous section, with larger formats of these images provided in Figures A-1 to A-5.

- The Humphreys mill was located north of Creede and used a flume to carry tailings to the south, discharging just north of the airport property.
- Humphrey mill tailings were also collected in an impoundment south of Creede in the area west of the Emperious Tailings Impoundment.
    - The tailings dam was apparently placed across the Willow Creek valley and eventually washed out.
    - A portion of this embankment is visible in the historical aerial image 10/5/1939, of Figure 9, with later successive photographs from 1958 to 1985 (Figures 10 through 13) showing steadily decreasing extent of this embankment, as the material was eroded away by Willow Creek.
- The first mill on the Creede Resources property was a 100-ton per day flotation mill built in 1937. This mill was located on the north side of the property and was destroyed by fire in August 1955.
    - This mill generated flotation tailings which were transported to the east of the Willow Creek valley via a flume, with these tailings deposited in the Emperious Tailings Impoundment.
    - This mill is visible in the northwest corner of historical aerial image 10/5/1939, of Figure 9.
- A 150-ton per day mill was constructed on the south side of the Property in June 1956 and operated until October 1976.
    - Deposition to the impoundment continued until October 1976.
    - This mill is visible in the northwest corner of historical aerial images from 1958 through 1985, of Figures 10 through 13.
- The process at the mill from 1937 to 1976 included flotation milling of rock ore into concentrates that were shipped to offsite smelters. The milled concentrates were stored in bermed concrete bins and 55-gallon drums, located near the east end of the mill.
- The mill at the Property was also used to crush bulk rock samples collected during investigations of the Creede Mining District in the early 1980s. The crushed rock was stored on the south side of the Property.
- Former employees at the facility indicated that extremely fine mill waste streams were directed to the Duck Pond building located on the southeast side of the property.
    - At this location, the waste stream was placed in a concrete lined “pond” where sediment was allowed to settle.
    - The waste stream from the concrete lined pond was then directed to four additional settling ponds, referred to as the Duck Ponds, located on the

    - east side of Highway 149, just south (hydraulically downgradient) of the Emperious Mill.
    - These settling ponds are most visible in historical aerial image 9/20/1973, of Figure 12.
    - In 1995, the Duck Pond areas and historic dikes (Humphreys) were remediated by removing sediments from these areas and placing this material in the southern end of the Emperious Tailings Impoundment. After placement, the material was then capped with gravels.
- The 150-ton per day Emperius Mill was demolished and the weigh scale building removed in October 1998. All materials were reportedly removed following local, state, and federal regulations for solid waste disposal.
- The impoundment consisted of three containment ponds (south, middle, and north ponds).
    - There were also three smaller "evaporation ponds" located immediately south (downstream) of the main tailings impoundment, situated on the valley floor.
    - These ponds are visible in the historical aerial images from 1958 through 1985, of Figure 10 through 13.
    - In 1989, the surface of the impoundment was graded and contoured, and six-inches of gravel were placed on the contoured surface.
- Martin Nelson conducted a thorough evaluation of tonnage and concentration grade of metals for the Emperius tailings impoundment in 1988.
    - Data used were from 22 new test holes, 21 survey points, and 63 old test holes.
    - Nelson calculated a tailings volume of 890,000 cubic yards (1.2 million tons at 20 cubic feet per ton).
    - Based on cross sectional drawings prepared by Nelson, the tailings impoundment was constructed on the surface of the valley floor and not an excavated pond impoundment. The ACOE report "Restoration of Abandoned Mines Program, Willow Creek Monitoring Well Installation Project, Creede, Colorado, April 2003" indicates that boring located on top of the tailings pile and drilled through the tailings pile encountered a clay layer approximately 4.2 feet thick beneath the tailings materials. This clay layer was assumed to be an engineered clay layer between the native soils and the tailings placed at the tailings facility.

FLOODPLAIN SURVEY

Larry Wilson, *Construction Engineer*
Frank Cure, *CAD Technician*
Steven Yochum, *Hydrologist*
Al Albin, *Geologist*

A survey of the floodplain downstream of Creede, within the proposed area of work, was conducted in the autumn of 2005. The survey was completed using a Trimble survey-grade GPS system. Over 30,000 survey data points were collected or imported from a previous survey of the fairgrounds site, from Davis Engineers. Figure 14 illustrates the points measured for the survey.

The survey contains a Trimble 5800 base station in conjunction with a Trimble 5800 rover and a Trimble ACU data collector. This equipment is capable of accuracies within .5 cm both horizontally and vertically. The data was collected over the course of several months by five operators. After all of the data was collected, it was compiled and put into a consistent projection (UTM 13 North, NAD 1983, Geoid 99) utilizing the Trimble Geomatics Office (TGO) software (Version 1.62, Build 17) where an output file was prepared. All of the data points were based off of an NFS OPUS Solution located at Latitude 37º49’48.92224” N and Longitude 106º54’42.12609” W and an ellipsoid height of 2620.828 meters.

Breaklines were also created for the project, to force feature linkage in the 2-foot contours deemed appropriate for this project. They were produced in AutoCAD Land Desktop(LDT), version 2005, though use of survey feature codes and 12-inch resolution aerial photography. The breaklines and survey points were used to develop a Triangular Irregular Network (TIN), from which the 2-foot contours were developed and additional analyses were performed. Due to the proprietary format issues, two TINs were developed: one in ESRI’s ArcGIS and another in AutoCAD LDT for earth movement quantities and eventual CAD design drawings.

Breaklines developed for the project are illustrated in Figure 15. The ArcGIS-created TIN is also illustrated in Figure 15 and 2-foot contours from the CAD TIN are provided in Figure 16. Higher resolution maps with 2-foot contours (from the CAD TIN) on 2005 aerial photography are provided as Figures A-6 and A-7.

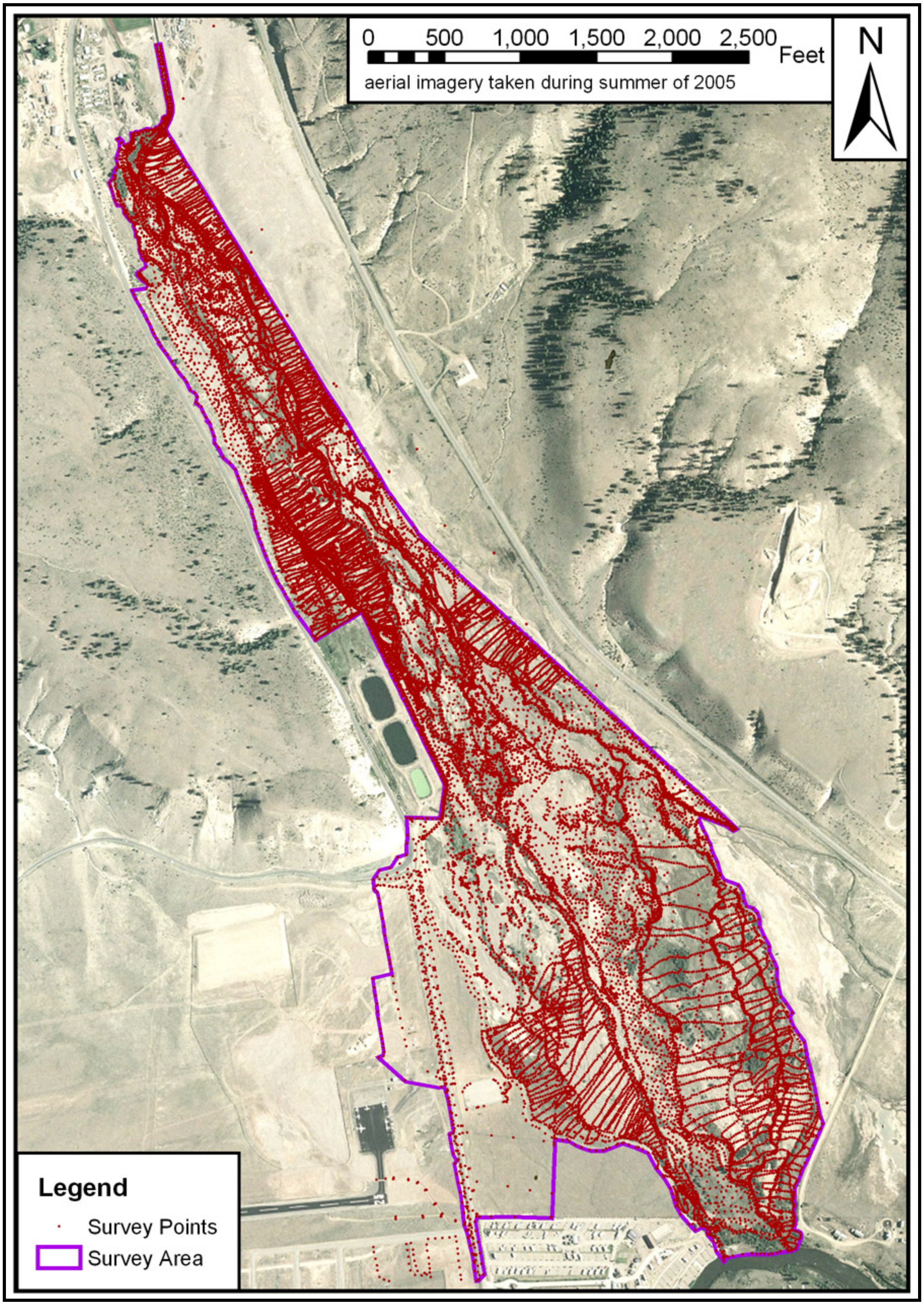


Figure 14: Survey points.

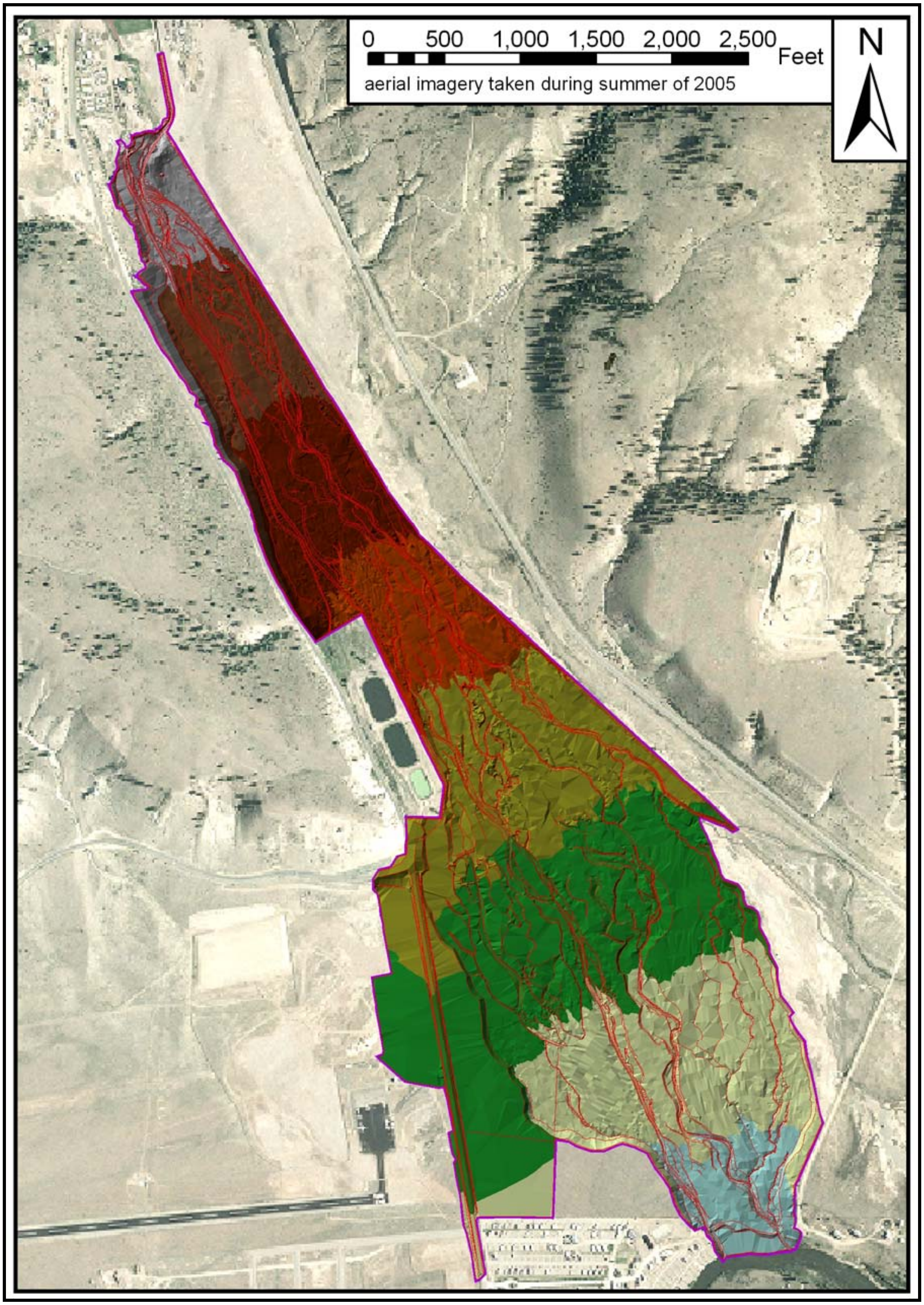


Figure 15: Floodplain survey, GIS TIN with breaklines.

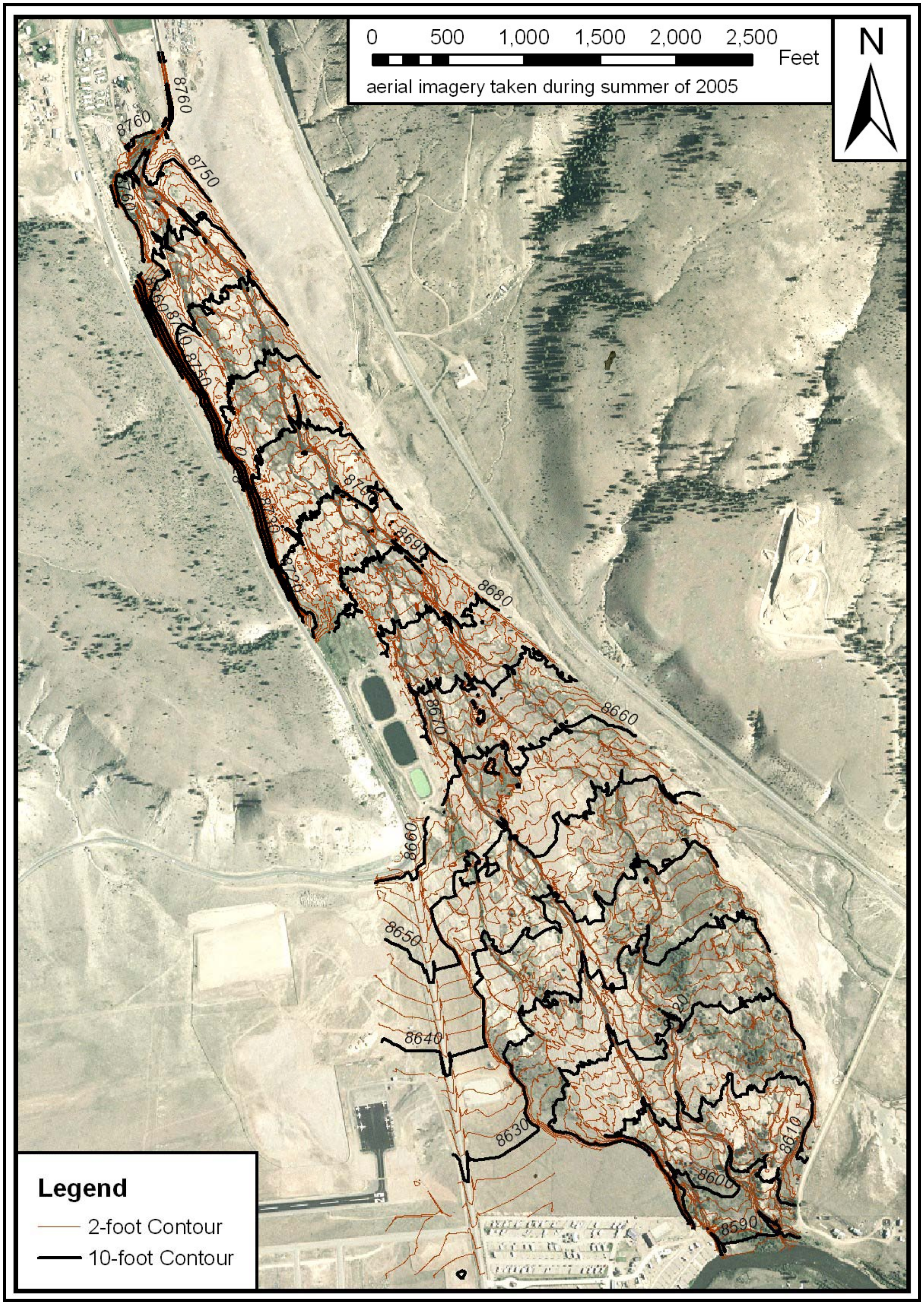


Figure 16: Floodplain survey, 2-foot contours (from CAD).

The existing water quality monitoring wells of the Willow Creek floodplain were included in the survey of the floodplain. These locations are provided in Table 1. Additionally, 17 monitoring pits were dug in August of 2005, with the results of this data collection provided in the groundwater quality section of this report. The locations of these pits are provided in Table 2.

Table 1: Well locations in floodplain, as measured by the NRCS.

ID	Northing (feet)	Easting (feet)	Casing Elevation (feet)	Ground Elevation (feet)
MW1	13740523.42	1089443.18	8619.12	8616.7
MW2	13742866.35	1088187.79	8659.32	8657.4
MW3	13742139.36	1086981.42	8654.56	----
MW5	13743801.45	1086997.58	8682.77	8681.5
MW7	13744397.95	1086487.62	8700.18	8698.1
MW8	13744673.49	1086562.07	8698.34	8696.7
MW9	13745235.87	1086214.73	8719.85	8718.1
MW10	13745202.33	1086047.88	8715.24	8713.8
MW11	13745700.23	1085892.04	8729.97	8728.2
MW13	13746695.20	1085078.82	8749.62	8748.2
MW14	13747125.43	1085207.59	8759.40	8758.2
MW15	13747601.16	1085407.87	8769.99	8768.6
MW16	13746116.16	1085654.48	8739.72	8738.0
MW17	13743671.69	1087463.35	8675.32	8673.4
MW18	13744139.03	1087251.49	8686.95	8684.9
MW19	13744505.65	1086444.94	8702.35	8700.1
MW20	13745252.38	1086198.48	8720.31	8718.6

Table 2: Monitoring pit locations in floodplain, as measured by the NRCS.

ID	Northing (feet)	Easting (feet)	Ground Elevation (feet)
MP1	13746463.84	1084859.71	8746.89
MP2	13746246.15	1085200.83	8739.01
MP3	13746034.35	1085465.32	8734.47
MP4	13745565.24	1085455.58	8725.55
MP5	13744905.08	1085781.41	8711.26
MP6	13744397.27	1085968.92	8700.68
MP7	13744006.34	1086100.96	8694.97
MP8	13744130.42	1086332.29	8691.74
MP9	13743640.85	1086567.28	8680.79
MP10	13742538.43	1086981.15	8657.16
MP11	13741865.91	1087207.69	8646.32
MP12	13741251.61	1087286.35	8635.43
MP13	13740724.18	1087963.73	8617.89
MP14	13742023.22	1088373.20	8639.04
MP15	13742993.20	1087544.01	8660.89
MP16	13745807.88	1085734.02	8727.45
MP17	13746257.52	1085428.14	8734.61

HYDROLOGY

Steven Yochum, *Hydrologist*

This extensive hydrology section records data collected and interpretations performed related to hydrology for the Willow Creek Stream Restoration.

Included in this section is an overview of available streamgage data, with analysis, and the presentation of discharge-frequency estimates for Willow Creek, which have been based upon a previous report by the NRCS and the Colorado Water Conservation Board merged with additional analyses. Primary watershed stream diversions are provided and water table mapping and results of monitoring well water level monitoring are provided, along with the approximate locations where the stream channels were giving and receiving with respect to groundwater. Depth to groundwater has been provided, for the autumn of 2005. Ground and surface water quality has been detailed. The extent of surface-saturated floodplain was provided. Pebble counts in the existing braided channel have also been provided. Finally, the results of a regional bankfull characteristics study have been provided.

Streamgage Data and Analysis

A streamgage was operated by the U.S. Geological Survey on Willow Creek at Creede from May 27, 1951 to September 30, 1982 (USGS 2006). The streamgage was located at the upstream end of the masonry flume that conveys flow through Creede. Both annual peak flow and average daily flow readings were gathered during the 32 years of peak flow record. Annual peak flow values are provided in Table 3. A log-Pearson analysis of these data are provided in Figure 18 and 19. A plot of average daily flow is provided in Figure 17.

Table 3: Annual peak flow record for the Willow Creek at Creede streamgage (ID 08216500).

Date	Peak Flow (cfs)	Peak Stage (ft)	Date	Peak Flow (cfs)	Peak Stage (ft)	Date	Peak Flow (cfs)	Peak Stage (ft)
5/27/1951	240	3.95	5/12/1962	394	4.10	6/10/1973	318	3.66
6/6/1952	305	4.32	5/5/1963	115	2.64	5/10/1974	111	2.64
5/26/1953	180	3.52	5/23/1964	198	3.16	6/5/1975	324	3.99
5/9/1954	72	2.44	5/21/1965	315	3.93	6/4/1976	165	3.05
6/6/1955	199	3.27	5/7/1966	250	3.33	5/9/1977	66	2.26
5/12/1956	114	2.76	5/9/1967	66	2.11	6/10/1978	164	3.12
6/5/1957	430	4.14	5/29/1968	280	3.62	6/6/1979	330	4.06
5/23/1958	410	4.16	5/20/1969	184	2.94	6/9/1980	261	3.60
6/5/1959	97	2.52	5/18/1970	345	3.72	6/7/1981	67	2.22
6/3/1960	260	3.59	5/27/1971	140	2.75	5/28/1982	196	3.20
5/22/1961	134	2.87	5/20/1972	116	2.58	----	----	----

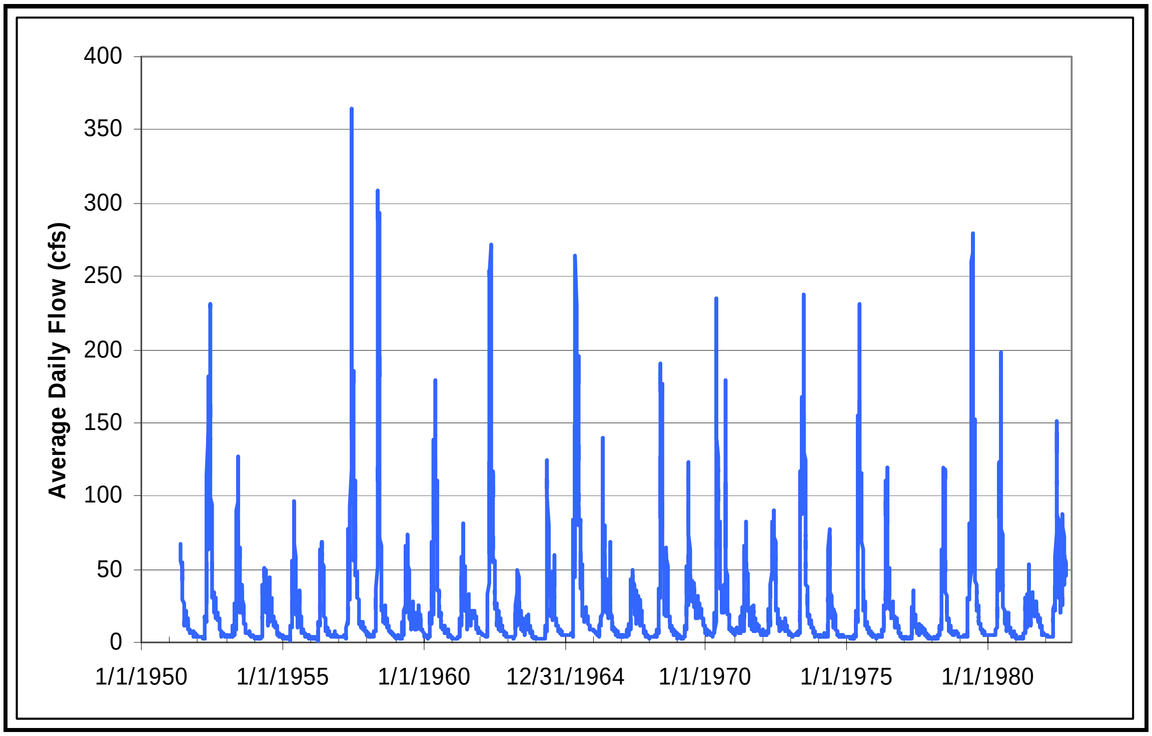


Figure 17: Average daily flow record the Willow Creek at Creede streamgage.

During the period of record, peak flow ranged from 66 cfs in 1977 to 430 cfs in 1957. All peaks occurred during May or June, indicating snowmelt as the principal influence to peak flow in this watershed. There is a record of a number of larger events having occurred in the watershed prior to the installation of the gage. Most of those were also snowmelt events (Mullen 1986), though the largest flood occurred in the Autumn of 1911 as a rain event.

As indicated in Table 4, average daily flow measurements throughout the period of record show minimum flows in Willow Creek during the months of November through March, with the least flow (4.1 cfs) in February, on average. The highest streamflow is typically in June (76.6 cfs), with May indicating the second highest flows, on average. The greatest average daily flow recorded during the period of record was on 6/6/1957, with 365 cfs of flow. The minimum average daily flow was recorded on 4/12/1955, with 1.9 cfs of flow.

As shown in Table 5, during the 31 years of complete record, average annual flow volume measured at the streamgage ranged from 5582 acre-feet in 1977 to 28,743 acre-feet in 1979. There is substantial fluctuation in flow volume yielded from this watershed.

Table 4: Monthly average of average daily flow, at the Willow Creek at the Creede streamgage.

Month	Average Flow (cfs)	Month	Average Flow (cfs)
January	4.3	July	29.5
February	4.1	August	20.8
March	4.7	September	15.2
April	15.0	October	10.1
May	66.5	November	7.2
June	76.6	December	5.2

Table 5: Annual flow volume at the Willow Creek at Creede streamgage. Water year is the period from October 1 through September 30.

Water Year	Volume (acre-feet)	Water Year	Volume (acre-feet)	Water Year	Volume (acre-feet)
1952	22,845	1963	7,450	1974	8,357
1953	12,125	1964	11,430	1975	20,010
1954	9,814	1965	26,327	1976	14,165
1955	10,397	1966	15,239	1977	5,582
1956	8,788	1967	9,802	1978	11,744
1957	27,232	1968	17,825	1979	28,743
1958	23,437	1969	14,073	1980	17,385
1959	10,676	1970	24,742	1981	9,071
1960	19,493	1971	12,383	1982	19,758
1961	10,763	1972	15,494	----	----
1962	22,213	1973	22,938	----	----

Log-Pearson Frequency Analysis Spreadsheet, Version 2.3, 1/2005. *Page 1 of 3*

Project: *Willow Creek Stream Restoration*
Streamgage: *Willow Creek at Creede*
Date: *11/24/2006* Performed By: *SEY*

Without Generalized Skew

Average: 5.2240
Standard Deviation: 0.56712226
Skew Coefficient[1]: -0.4134971

Length of systematic record: 32
Number of historic peaks: 0
Length of Data Record: 32
Length of Historic Record:[5] ----

With Weighted Generalized Skew

Generalized Skew Coefficient[3]:
Variance of Generalized Skew[3]:
A: -0.296920
B: 0.832491

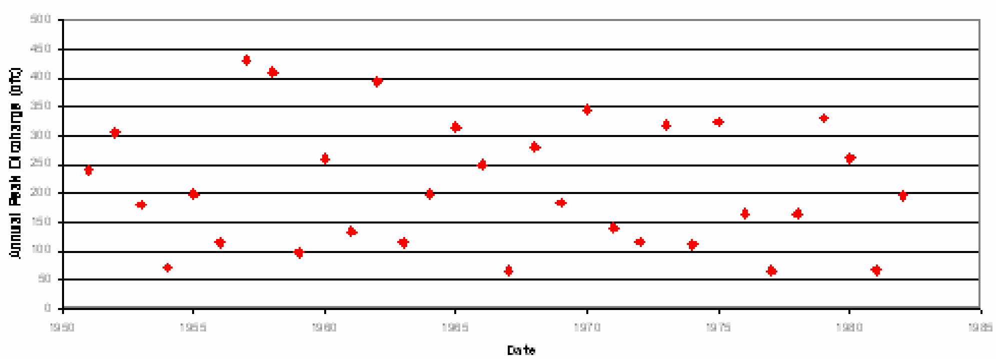
station skew: -0.413497
MSE Station Skew: 0.19166688
Weighted skew coefficient[1]: 0

Recurrence Interval[2] (years)	Percent Chance	K-Value	Ln(Q)	Peak[4] Discharge (cfs)	95% Confidence Limits Upper (cfs)	Lower (cfs)
200	0.5	2.188	6.4652	642	935	494
100	1	2.019	6.3691	584	831	455
50	2	1.826	6.2598	523	727	414
25	4	1.601	6.1319	460	622	370
10	10	1.229	5.9210	373	483	307
5	20	0.855	5.7090	302	376	253
2	50	0.068	5.2628	193	229	163
1.25	80	-0.815	4.7619	117	139	94
1.05	95	-1.753	4.2297	69	86	50
200	0.5	2.576	6.6849	----	----	----
100	1	2.326	6.5432	----	----	----
50	2	2.054	6.3889	----	----	----
25	4	1.751	6.2171	----	----	----
10	10	1.282	5.9511	----	----	----
5	20	0.842	5.7016	----	----	----
2	50	0.000	5.2240	----	----	----
1.25	80	-0.842	4.7465	----	----	----
1.05	95	-1.645	4.2911	----	----	----

(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation²) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with Variance of Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments:

Data Plot:



Peak Timing:

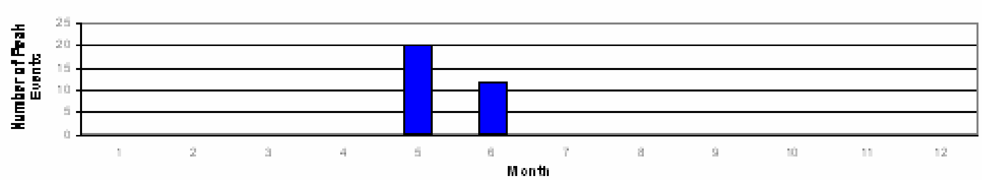


Figure 18: Frequency analysis (A) of streamgage 08216500.

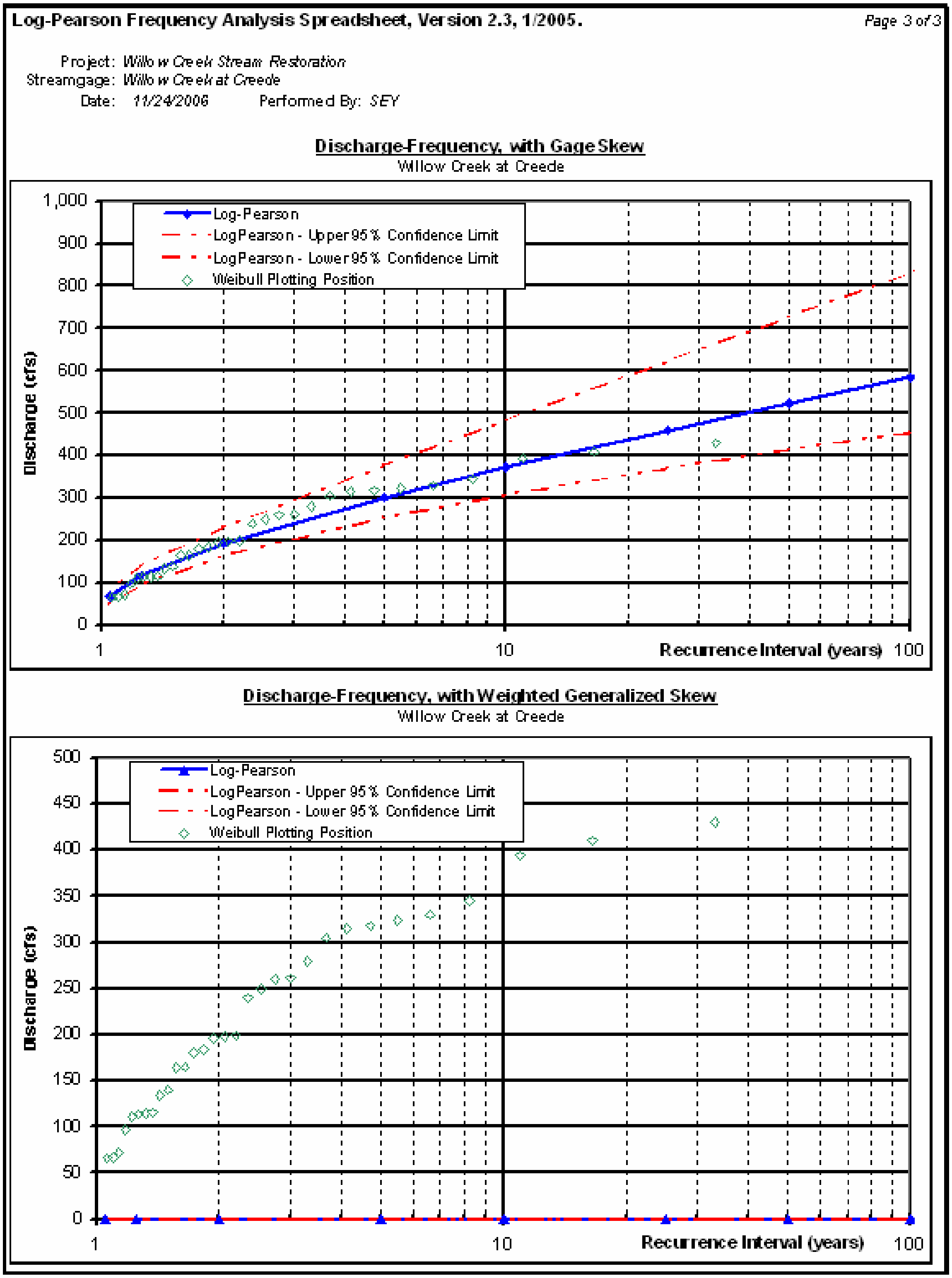


Figure 19: Frequency analysis (B) of streamgage 08216500.

Watershed Stream Diversions

Stream diversions were obtained through the Colorado Decision Support Systems (CDSS), which is a water management system developed by the Colorado Water Conservation Board and the Colorado Division of Water Resources. Table 6 lists the relevant diversions within the mainstem Willow Creek, along with support information.

The two most relevant diversions to the stream restoration are the Wason and Zimmerman ditches, which divert flow to the east and west of the Willow Creek floodplain, respectively. Structures for each of these diversions will need to be included in the stream restoration.

For the last 55 years, the Wason Ditch (ID 20-894), with a decreed capacity of 6.0 cfs, has diverted flow for all years except for 1971, when no water was available (CDSS 2006). When water was available, the volume diverted ranged from 396 acre-feet to 1808 acre-feet, with an average diversion of 1275 acre-feet.

For the last 46 years, the Zimmerman Ditch (ID 20-750), with a decreed capacity of 1.2 cfs, has diverted flow for only 15 years, even though water was available for an additional 10 years but was not diverted (CDSS 2006). Prior to 2005, the last year that flow was diverted was in 1995, even though water was available in 1997, 1999, 2000, 2001 and 2003. On average, water is available for diversion every 1.8 years. When water was available, the volume diverted ranged from 7.1 acre-feet to 121 acre-feet, with an average diversion of 52 acre-feet.

Table 6: Stream diversions of the Willow Creek watershed.

ID	Decreed Capacity (cfs)	Owner	Adj Date	Appro Date	Record Available	Volume Diverted		
						Max. (ac-ft)	Min. (ac-ft)	Ave. (ac-ft)
20-00894	6.0	Wason	5/1/1896	5/31/1879	1950-2004	1802	0	1275
20-00750	1.2	Zimmerman	4/9/1903	7/15/1895	1959-2004	121	0	52
20-01117	1.0	Creede	12/31/1975	12/28/1892	----	----	----	----

Discharge-Frequency Estimates

A number of discharge-frequency estimates have been computed at the Willow Creek at Creede, Colorado USGS gaging station. These estimates have a wide range, with 100-year discharges ranging from 1120 to 2300 cfs. The Natural Resources Conservation Service, in cooperation with the Colorado Water Conservation Board, performed an additional discharge-frequency analysis for the Willow Creek watershed to reduce the uncertainty of these estimates. Yochum and Hyde (2002) report the methodology and results of the analysis. This report is summarized below, with text and figures extracted from Yochum and Hyde (2002). Additionally, confidence limits have been added to the discharge-frequency computations. This previous work has also been modified for the more-frequent 1.25 and 2-year events, which are relevant for bankfull discharges in the stream restoration. **The recommended discharge-frequency estimates for the Willow Creek Stream restoration are provided in Table 7.**

Table 7: Discharge-frequency estimates for the mainstem Willow Creek.

ID	Description	Discharge Frequencies							
		100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.5-yr (cfs)	1.25-yr (cfs)
6480	Willow Crk at confluence with Rio Grande	1210	1050	890	690	550	230*	190*	140*
6490	Willow Crk at Railroad Crossing	1130	970	820	630	490	210*	170*	130*
6500	Willow Crk at Creede gaging station	1070	920	770	590	460	190*	160*	120*

* based on log-Pearson analysis of Willow Creek at Creede streamgage record

Summary of Previous Estimates

The U.S. Geological Survey (USGS) operated a streamgage on Willow Creek at Creede, Colorado from 1951 through 1982 (USGS 2006). This streamgage recorded annual flood peaks ranging from 66 cfs to 430 cfs. Due to the reported occurrence of a number of high flow events before the installation of this gage, it is generally believed that a frequency analysis based upon only these 32 years of record will lead to significantly underestimated discharge frequencies for higher, less-frequent flood events. However, these predictions do have application to more-frequent events.

Six large events reportedly occurred prior to the gage installation for the 1951 water year. Estimates of the peak discharge during each of these events, computed by the US Army Corps of Engineers (COE), ranged from 1200 to 1800 cfs. The reliability of these estimates can't be determined since the computations supporting these values have not been found.

Using the gage data as well as the additional historic data for flood events that occurred before the gage installation, a few sets of discharge-frequency estimates have been computed by the Colorado Water Conservation Board (CWCB) and the COE for the Willow Creek watershed at Creede. These estimates have a wide range, with 100-year discharges ranging from 1120 cfs to 2300 cfs. The uncertainty that is apparent from these diverse estimates encouraged the Natural Resources Conservation Service (NRCS), in cooperation of the CWCB, to perform an additional hydrologic analysis.

Regional Regression Analysis

A regional discharge-frequency analysis, using eighteen streamgages in and just downstream of the San Juan Mountains, was performed. This regional method provided results that were consistent within the watershed and agreed at the gaging station with the results from the CWCB's study, as well as an additional frequency analysis. Figure 20 provides a plot of the Willow Creek watershed, with the points of discharge-frequency computation.

Initially, a number of watershed characteristics were computed for each of the 18 regional watersheds. Multiple linear regression analyses, with numerous combinations of these explanatory variables and with discharge in both normal and natural logarithm space, were performed using the statistical software S-Plus. Five of the watershed characteristics, with discharge in logarithm space, were found to heavily influence the discharge prediction and result in significant t-values ($\geq |+/-2.0|$) for at least some of the return periods. To insure consistent results, the same variables were used for all return periods. The number of variables were minimized to maximize the degrees of freedom and the predictive power of the models. The five variables were drainage area, percent forest cover, minimum elevation of the watershed, a watershed length/width ratio and average annual precipitation.

Percent forest cover was defined from USGS 7.5 minute quadrangles. Minimum elevation was divided by 1000 in the regression, so that significant digits were preserved in the statistical output. Average annual precipitation was defined by the 1960-1990 PRISM value, at the watershed centroid. The watershed length/width (L/W) ratio was defined by a length measured by passing a line from or near the stream outlet through the centroid of the watershed and measuring the overall length. The width is measured by summing the maximum distances between the length axis and the sides of the watershed.

For additional definitions of these variables, see Yochum and Hyde (2002).

Statistical Diagnostics

A summary of several model diagnostics are provided in Table ?.

Table 8: Model diagnostics for model set 2, which includes Willow Creek at Creede. The range in t-values are absolute values and exclude the intercept term.

Diagnostic	100-yr	50-yr	25-yr	10-yr	5-yr	2-yr	1.25-yr
Range in t-values	2.9 to 8.9	2.8 to 10.0	2.5 to 10.3	1.9 to 9.6	1.4 to 8.6	0.9 to 7.1	0.7 to 6.2
Multiple R^2	0.95	0.95	0.95	0.94	0.93	0.89	0.86
F-statistic	42.2	49.7	49.9	40.1	30.4	19.6	14.4

The t-value statistic is useful in determining if an explanatory variable is significantly linearly related to a dependant variable. With an α of 0.05 (a 95% confidence interval), variables with t-values less than -2 or greater than +2 are considered statistically significant. The L/W ratio has the lowest (absolute) t-values in the models, ranging from 2.9 for the 100-year to 0.7 for the 1.25-year. These t-values indicate that the L/W ratio linearly explains the logarithm of discharge much better for less frequent events. This is not unexpected - the storage and attenuation that the L/W ratio is accounting for is less important for more frequent events.

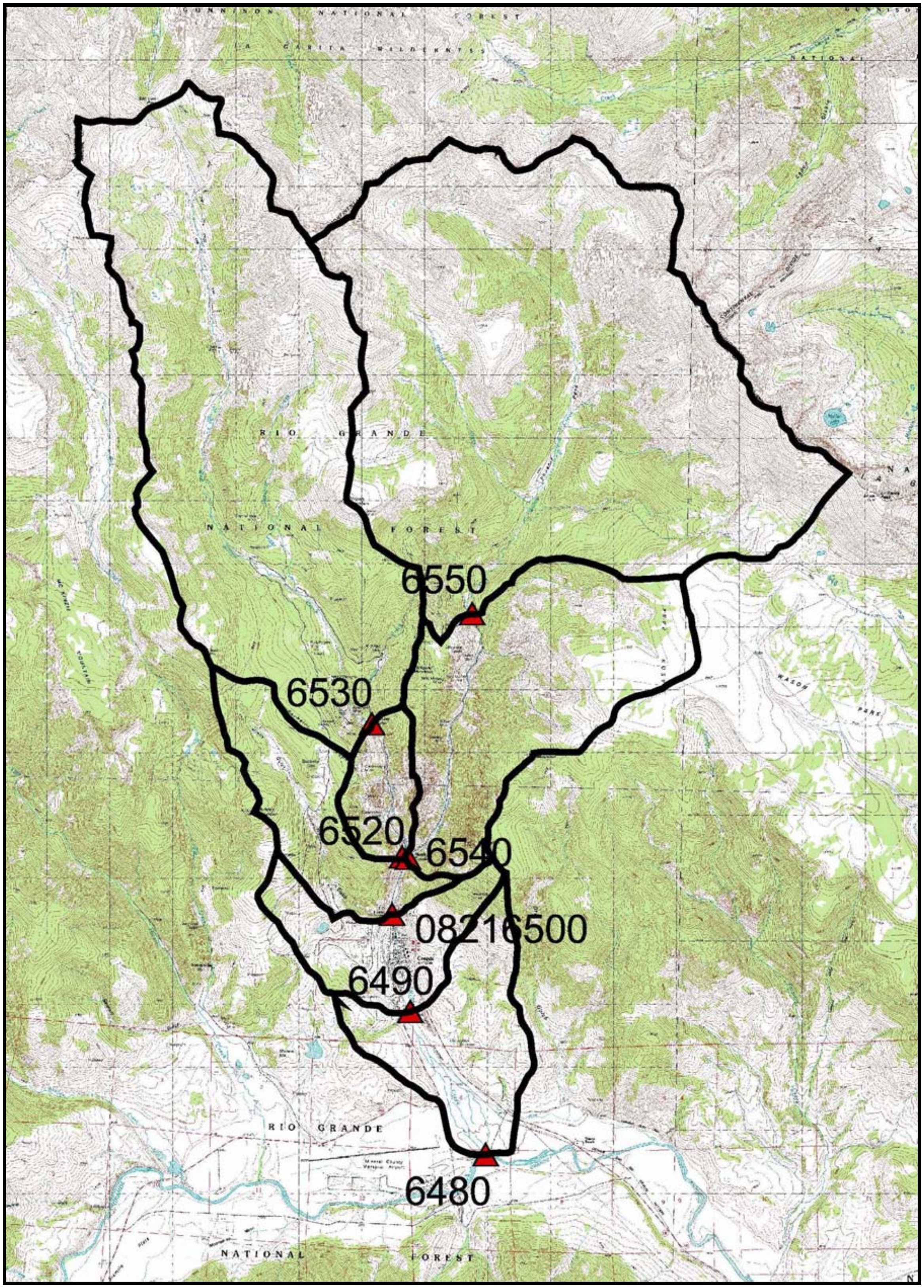


Figure 20: Willow Creek watershed, with catchments and points of discharge-frequency computation (which are indicated with triangles).

The R^2 statistic, or the fraction of the variance described by the explanatory variables, is useful in understanding the relative quality of the individual models. The higher the R^2, the greater the explanatory power of the model. However, R^2 is not a good tool for deciding to include additional variables since any explanatory variable (even random numbers) will increase R^2. The loss of a degree of freedom is not worth a small increase in R^2 (Helsel and Hirsch, 1992). The relative R^2s do indicate that the five selected variables better explain the variance for the 100-year through 5-year models than the 2-year and 1.25-year models. In general, the typically high R^2 indicate that these five explanatory variables explain most of the variance in the logarithm of the discharge for these 18 watersheds.

S-Plus provides an overall F-statistic. This test indicates how good a complex model is in comparison to no model at all. Like the R^2 parameter, this value is not very useful in determining the value in adding individual explanatory variables, but it is useful in judging how well a model is performing overall. This value indicates that the 50-year and 25-year events are best fitted, that the 100-year and 10-year are reasonably well fitted, and that the 2-year and 1.25-year are predicted the least well.

The five explanatory variables were not selected using a rigorous statistical method, such as a stepwise procedure, but were instead selected as follows. A watershed characteristic was considered a good explanatory variables if it, through hydrologic experience, had been found to be effective in regional analyses, if they had high t-ratios for at least some of the return periods, and if their inclusion provided a large increase in R^2 and provided a relatively large F-statistic. The number of variables were minimized to maximize the degrees of freedom of the models and increase the equations' predictive powers.

Regression Equations

Following are the regression equations, as developed using multiple linear regression, developed for the Willow Creek Stream Restoration:

$$\ln(100) = 9.9379 + 0.0087A - 0.0127F - 0.4523E - 0.2035LW + 0.0544P; \qquad (1)$$

$$\ln(50) = 9.6924 + 0.0090A - 0.0136F - 0.4574E - 0.1925LW + 0.0597P; \qquad (2)$$

$$\ln(25) = 9.4306 + 0.0093A - 0.0146F - 0.4634E - 0.1815LW + 0.0655P; \qquad (3)$$

$$\ln(10) = 9.0487 + 0.0097A - 0.0163F - 0.4741E - 0.1671LW + 0.0745P; \qquad (4)$$

$$\ln(5) = 8.7149 + 0.0100A - 0.0179F - 0.4852E - 0.1564LW + 0.0829P; \qquad (5)$$

$$\ln(2) = 8.1474 + 0.0105A - 0.0212F - 0.5100E - 0.1447LW + 0.0987P; \qquad (6)$$

$$\ln(1.25) = 7.6683 + 0.0108A - 0.0246F - 0.5391E - 0.1434LW + 0.1143P; \qquad (7)$$

where ln refers to the natural logarithm, 100, 50, 25, ect… is the return period of the prediction, A is the drainage area of the watershed in mi^2, F is percent forested, E is the minimum elevation of the watershed (feet)/1000, LW is the length-width ratio of the watershed and P is average annual precipitation (inches) at the watershed centroid, as defined by PRISM (1970-1990).

Confidence Limits

For the Willow Creek at the Rio Grande confluence site, the location used for the discharge-frequency values for the floodplain stream restoration, the following 95-percent confidence limit values were developed from S-Plus:

Table 9: Confidence limits of discharge-frequency predictions of Willow Creek at Rio Grande confluence (ID 6480), based upon regional regression equations.

Return-Period (years)	Peak Prediction (cfs)	Upper 95% Confidence Limit (cfs)	Lower 95% Confidence Limit (cfs)
100	1210	1740	850
50	1050	1530	710
25	890	1340	590
10	690	1160	420
5	550	970	300
2	350	800	150
1.25	230	690	75

Plots of the confidence limits on the predictions (in natural logarithm space), as developed in S-Plus, are provided in Figures 21 through 27. It is clear in these figures that the error bars become quite wide for more frequent events, indicating that these models predict less well.

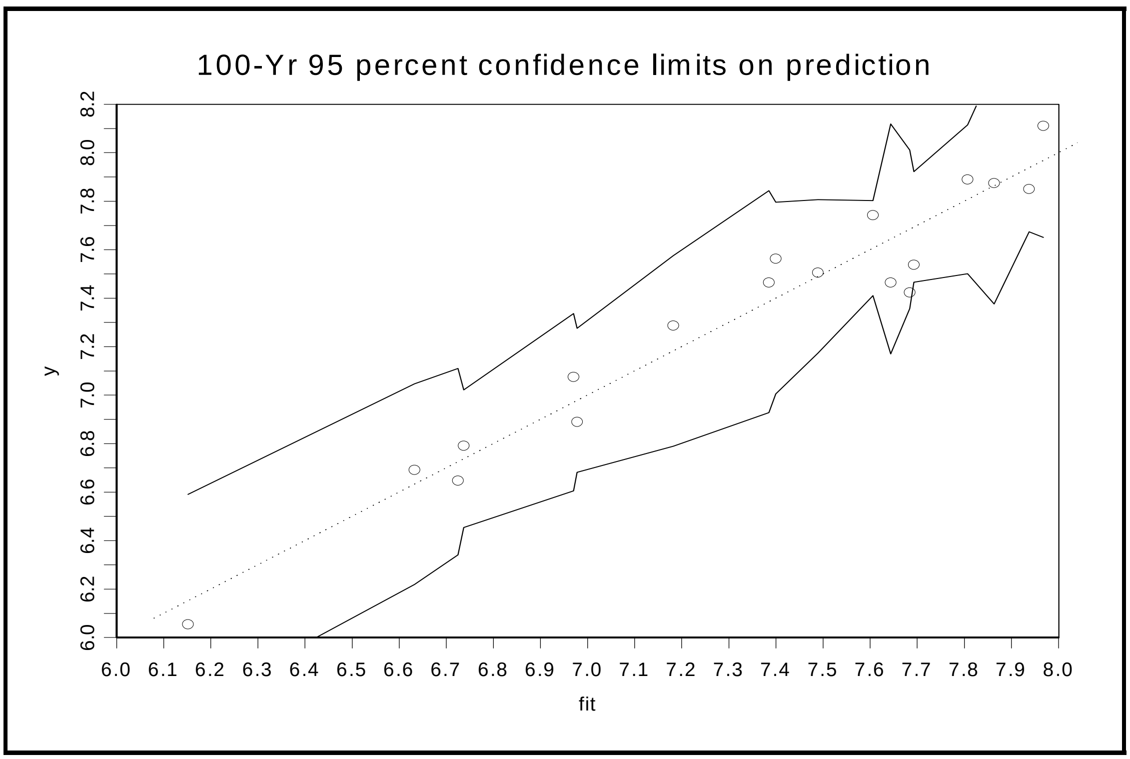


Figure 21: 100-year 95 percent confidence limits on prediction.

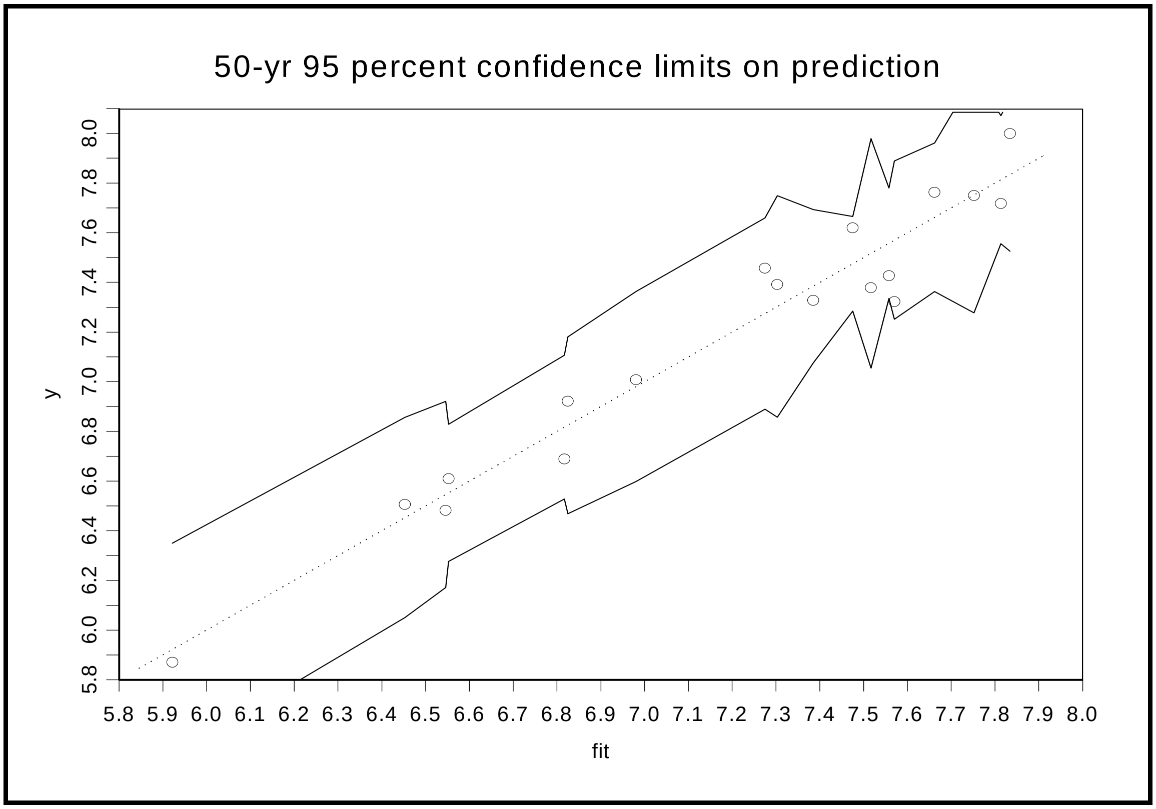


Figure 22: 50-year 95 percent confidence limits on prediction.

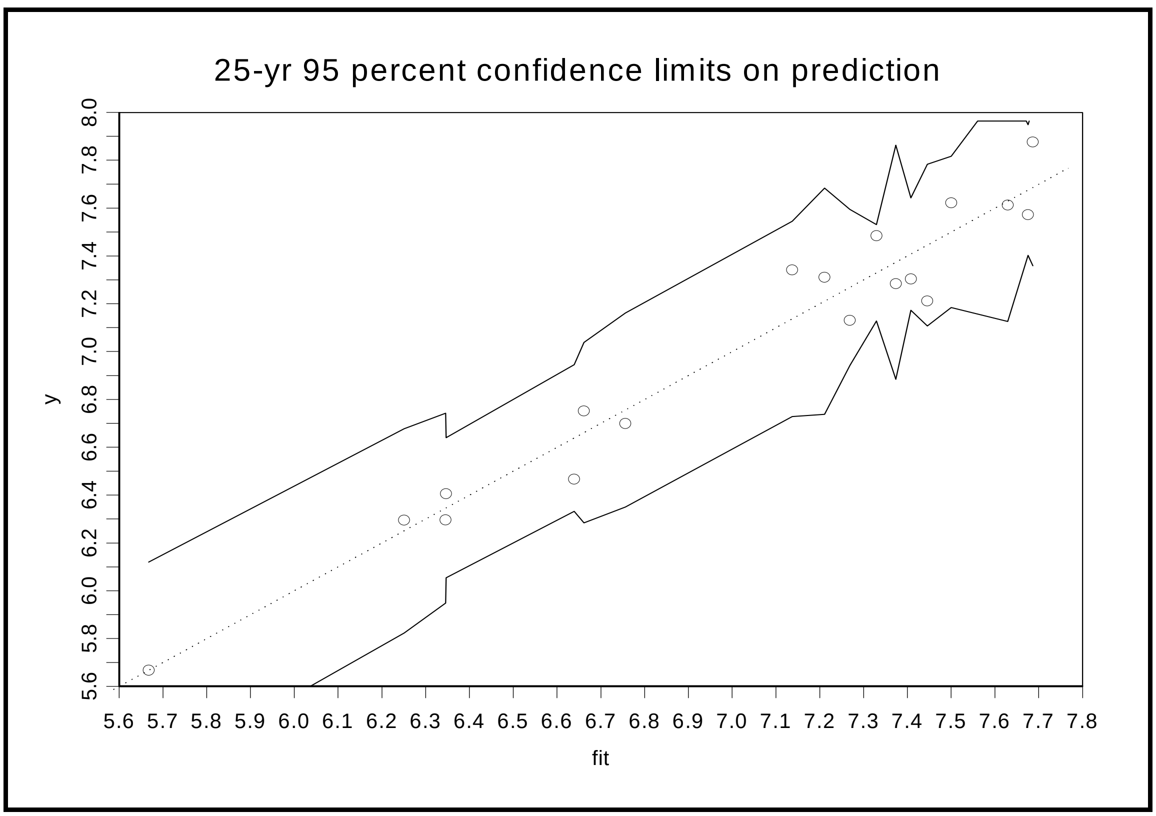


Figure 23: 25-year 95 percent confidence limits on prediction.

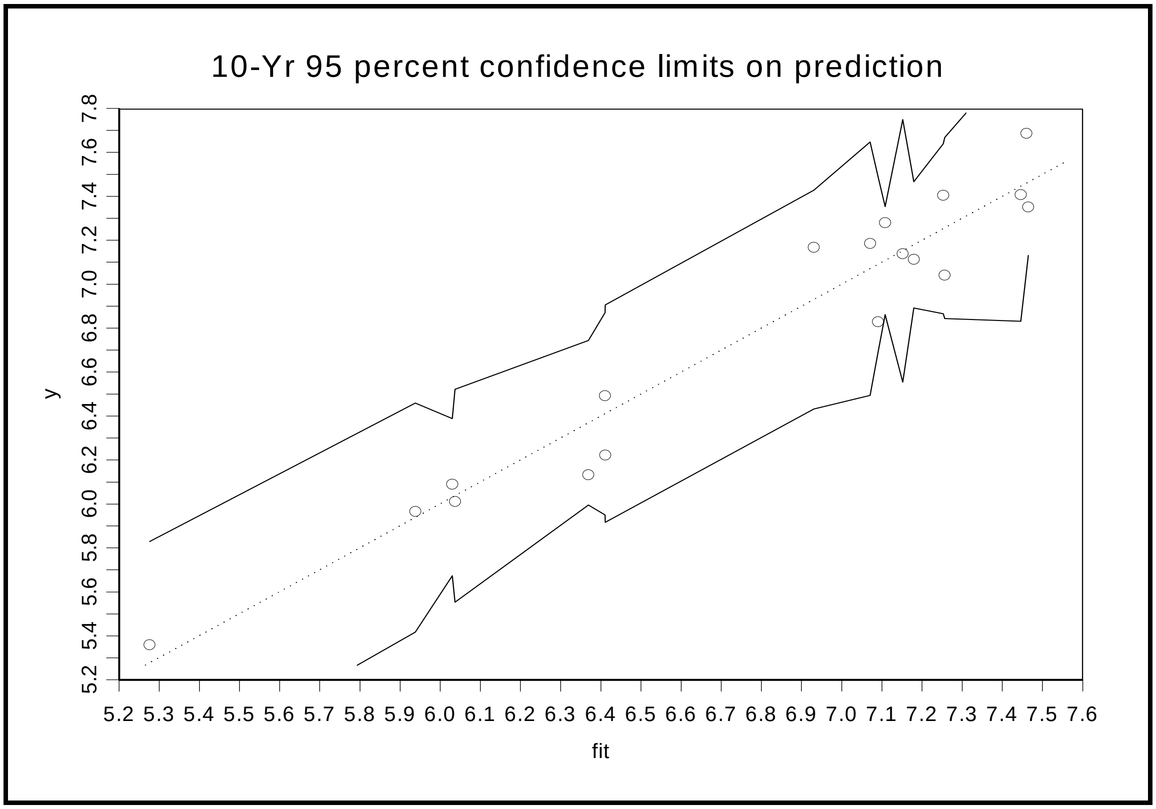


Figure 24: 10-year 95 percent confidence limits on prediction.

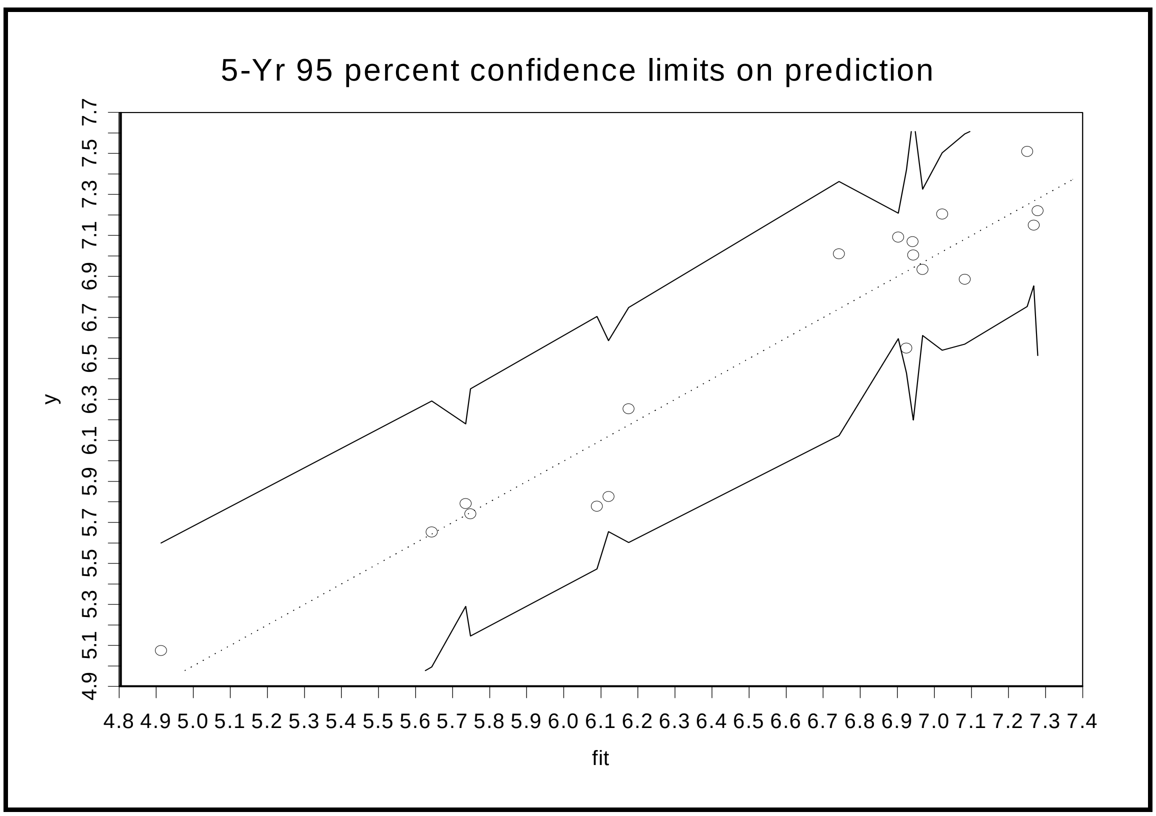


Figure 25: 5-year 95 percent confidence limits on prediction.

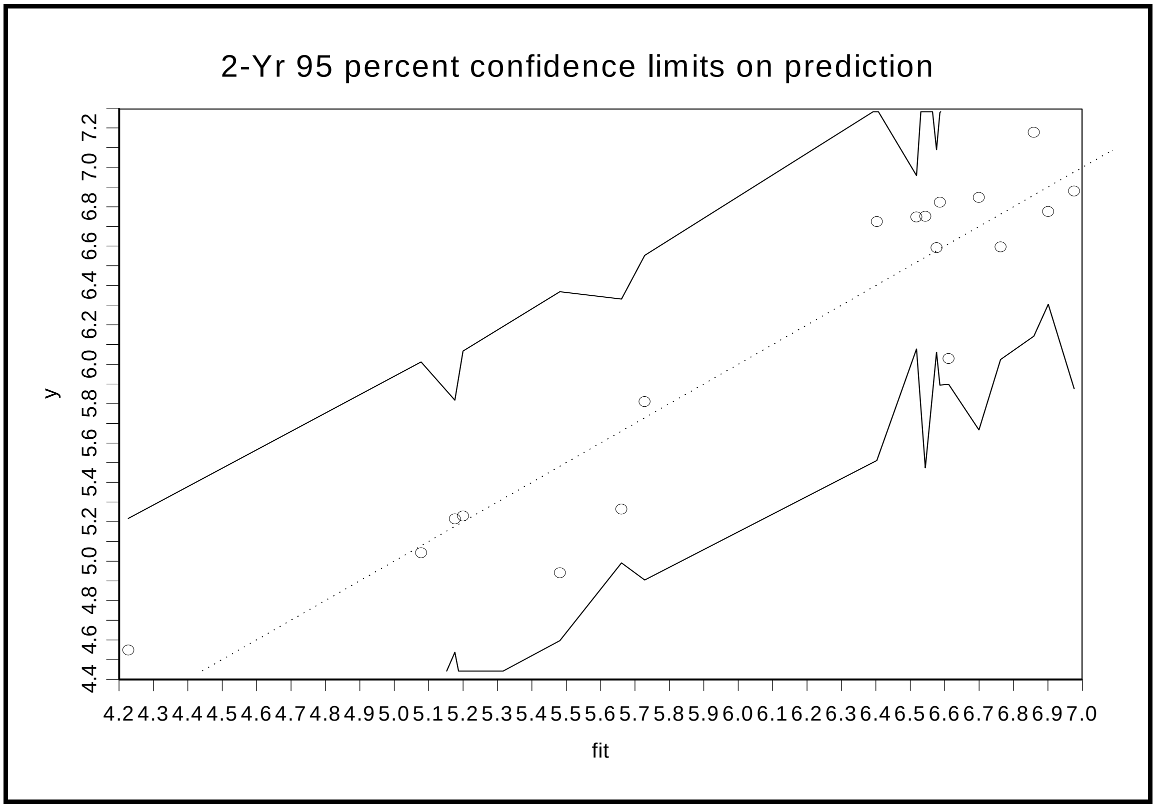


Figure 26: 2-year 95 percent confidence limits on prediction.

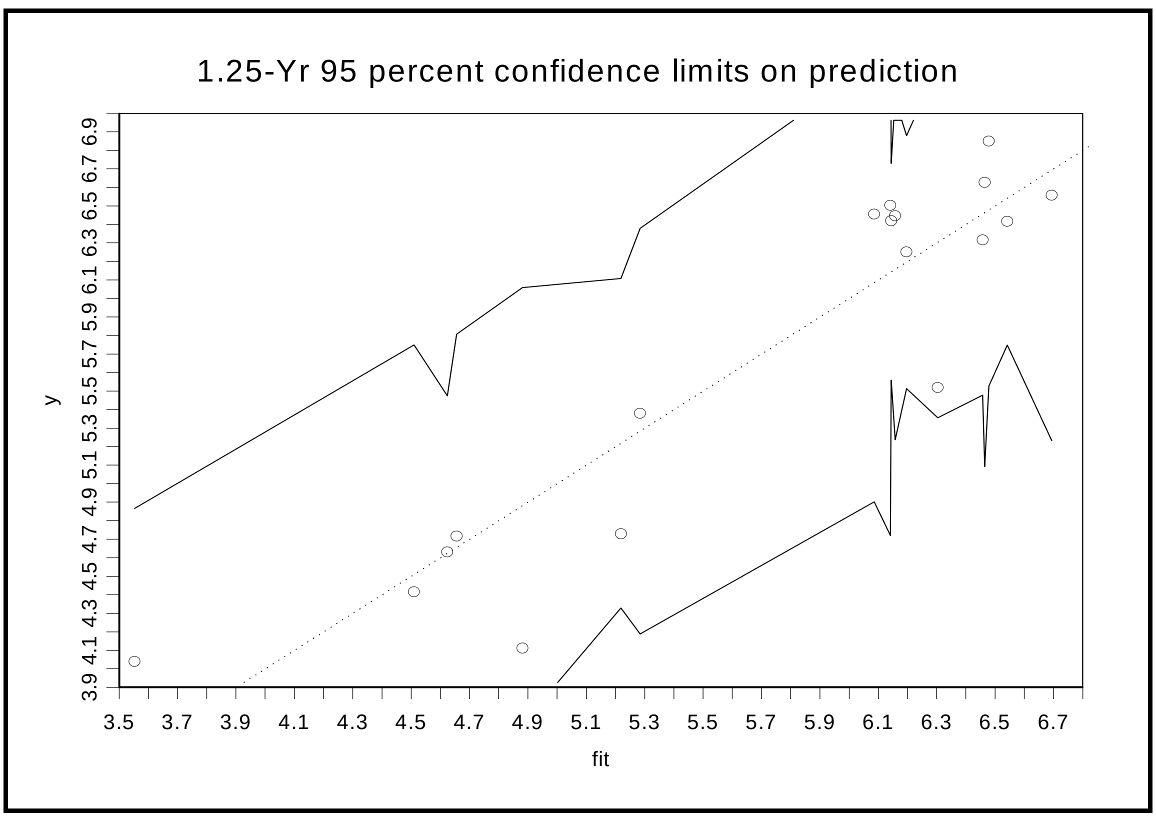


Figure 27: 1.25-year 95 percent confidence limits on prediction.

Bankfull Flow Prediction Modification

As shown in Figures 26 and 27 and tabulated in Table 9, the error bars for the 1.25-year and 2-year events are very wide. For the 1.25-year event, the regression equations predict a flow peak of 230 cfs, with 95% confidence limits of 75 and 690 cfs. Bankfull flows will have a return period between the 1.25 and 2 year event in this watershed. Hence, these wide error bars have immediate implications on the bankfull design.

The streamgage frequency analysis of the 32 years of record is deemed inappropriate for predicting low-frequency floods but is appropriate for predicting frequent events. The predictions made by the regional regression equations have been superseded by the log-Pearson frequency analysis results provided in Figure 18 for the 1.25 and 2-year events. This adjustment results in a substantial reduction in peak flow estimates for these frequent events. To adjust for increased drainage area for Willow Creek at the downstream limit of the flume and at the confluence with the Rio Grande, a simple linear correction factor was applied. The factors, developed from the regional regression equation results, are 1.09 for Willow Creek at the downstream limit of the flume and 1.2 for Willow Creek at the Rio Grande.

The results in Table 7 reflect these adjustments. The flood frequency estimates for Willow Creek at the Rio Grande confluence are graphically provided in Figure 28.

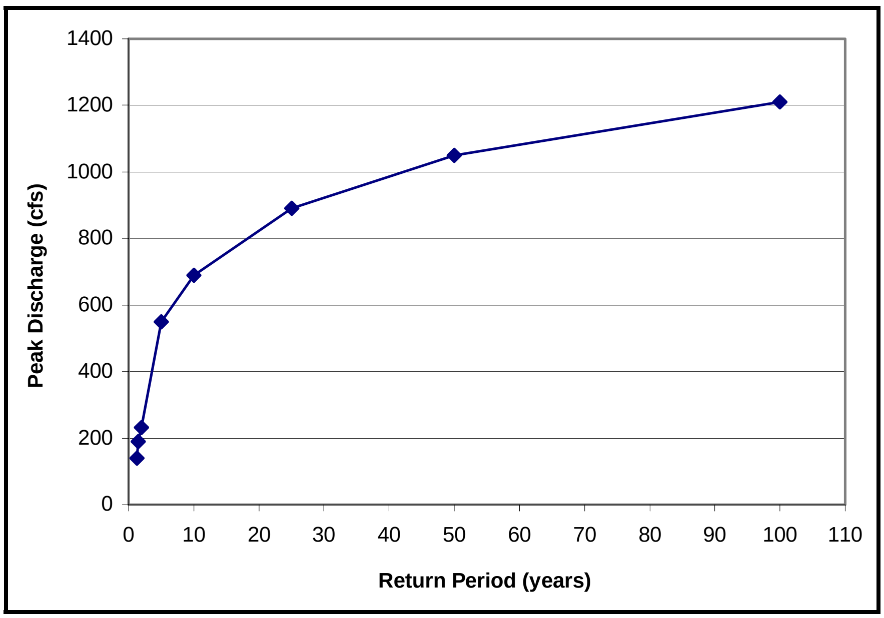


Figure 28: Frequency plot for Willow Creek at confluence with the Rio Grande.

Water-Table Mapping and Water Level Monitoring

Monitoring wells, monitoring pits and water surface elevations in the stream segments and wetlands were surveyed as a part of the floodplain survey during the autumn of 2005. Water surface levels in the wells and pits were measured from 8/9 to 8/11/2005. In all, these data provided 2536 points to construct a ground water table TIN and 2-foot contour map of the water table. Figure 30 provides these contours. Figure A-8 provides a more detailed map with plots of monthly water level measurements in the monitoring wells.

A number of inferences can be drawn from the "snap shot" of the water table that these contours provide. The spacing and orientation of the contours provides an estimate of gradient for groundwater flows passing through the alluvium. How the groundwater table contours interact with the surface water indicates where a surface stream is primarily giving or receiving groundwater. Figure 29 is provided, which shows a section of the valley in the middle of the floodplain where a branch of the stream has been diked to provide flow to the Wason diversion. Orange arrows indicate the direction of overall groundwater movement through the alluvium. This figure illustrates that, in general, groundwater movement is down valley, toward the Rio Grande. However, the stream segment that delivers water to Wason is artificially perched, with flow being lost to groundwater on both sides of the channel.

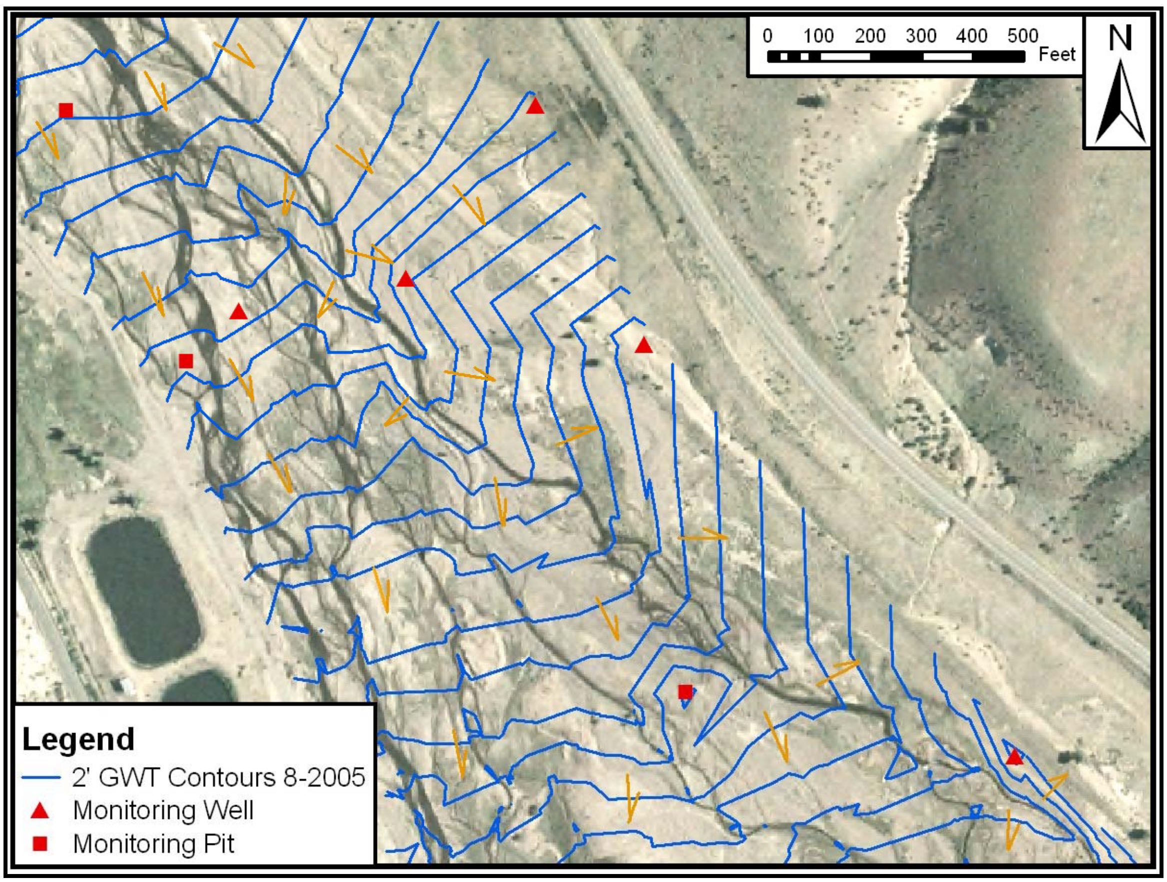


Figure 29: Groundwater table contour map detail, with orange flow gradient arrows.

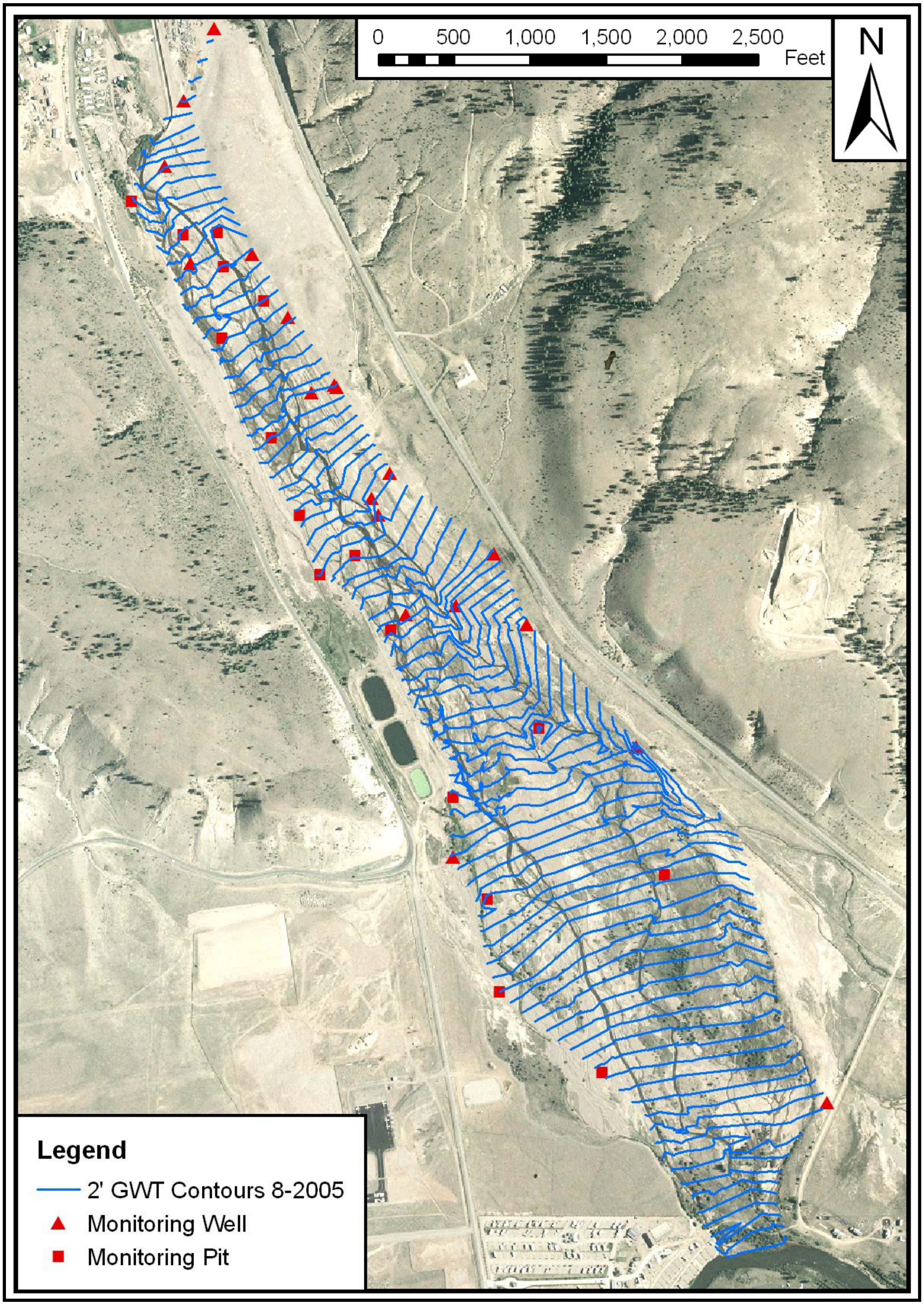


Figure 30: Water table contour map of the floodplain, with 2-foot contours.

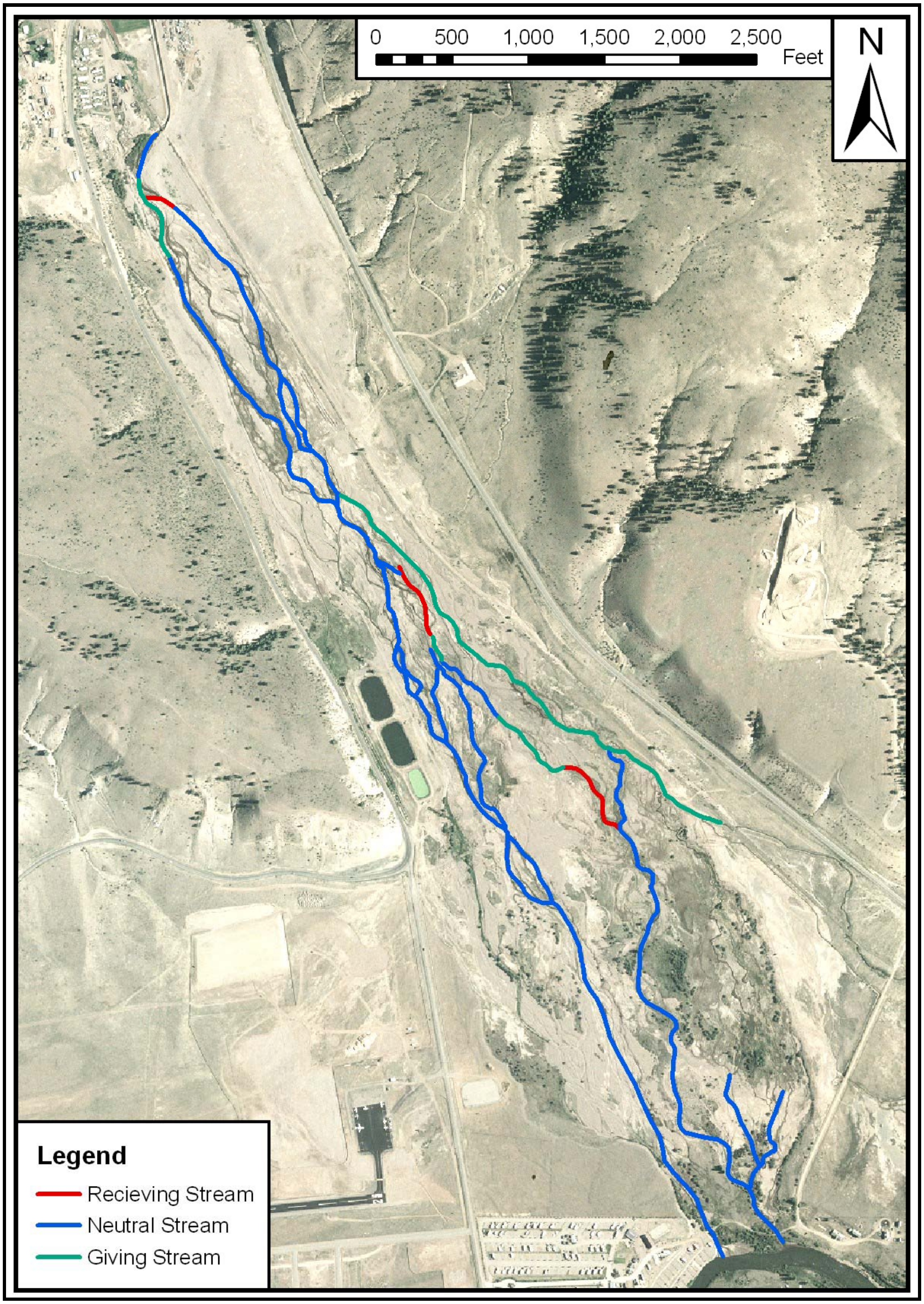


Figure 31: Approximate portions of the floodplain where streamflow is giving, receiving or neutral with respect to groundwater, in the Autumn of 2005.

This interpretation has been applied to the Willow Creek floodplain in its entirety to produce Figure 31, which indicates sections of stream that are giving, receiving or neutral, with respect to groundwater. This is an approximate method, with only blatant interpretations provided. It assumes uniform composition of the substrate, conditions for only the time of year that measurements were collected, and illustrates interactions for the current braided form. Despite these limitations, this method does indicate stream segments in the Willow Creek floodplain that contribute substantial flows to groundwater. It shows the important result that the stream segment on the eastern portion of the floodplain, which delivers water to the Wason Diversion, is perched, is providing flow to the groundwater, and acts as a groundwater divide.

The USGS report *Evaluation of Metal Loading to Streams near Creede, Colorado, August and September 2000* (Kimball et. al. 2006) documents a hydrologic study of the floodplain before the flood of May 2005 that shifted and increased the braiding of the Willow Creek floodplain. A sketch of the USGS sampling is provided in Figure 32. This figure indicates where small quantities of flow were documented to be flowing into the stream, with these locations marked by a red circle. The seeps had low pHs (3.42 and 2.95) and high specific conductivities (2050 and 2770 uS/cm). Sampling point 8220 on a braid of Willow Creek also indicated depressed pH (6.84) compared to typical streamflow pH (average of 7.32). The close proximity of these seeps with the groundwater contamination plume associated with the Imperious Tailings pile (Figure 46) leads to the conclusion that Willow Creek is receiving a small amount of the flow from the plume just upstream of where the perched stream to the Wason diversion is initiated.

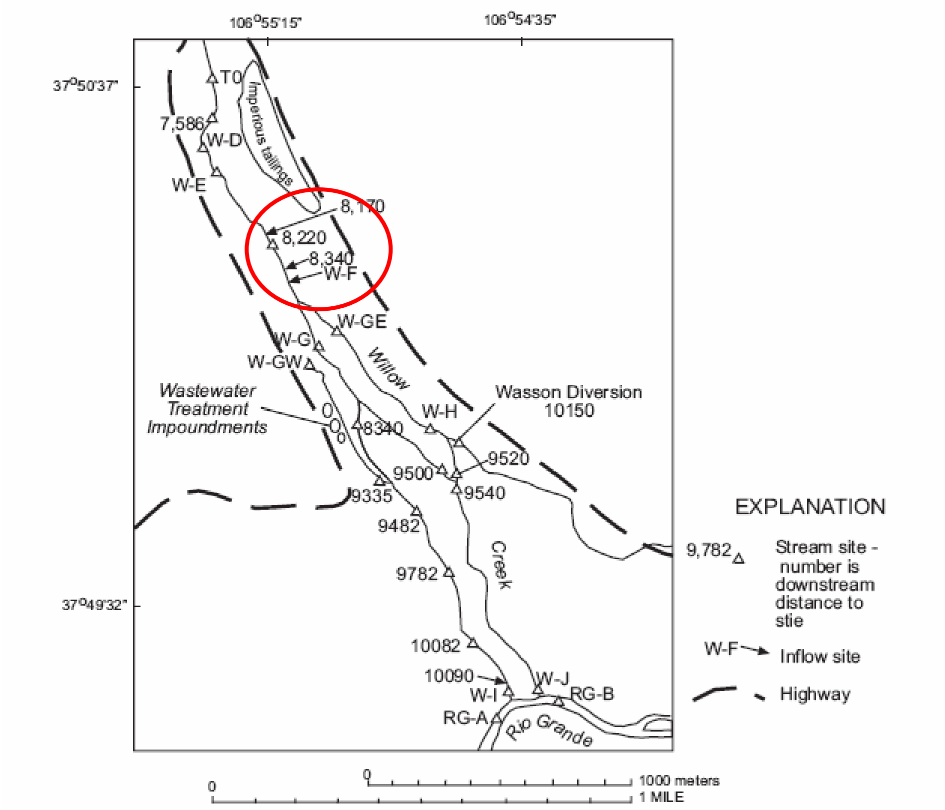


Figure 32: USGS water quality sampling points (Kimball et. al. 2006).

Seasonal Variability in Well Depths

From April 2005 through May 2006 fourteen floodplain observation wells were monitored for stage on a monthly basis. Seasonal variability in water table level measurements were observed in most wells. These well level measurements are shown in Figures 33 through 39. The measurements themselves are provided in Appendix C.

Illustrations showing level variability of wells 1 and 2 are provided in Figure 33. Monitoring well 1 had a substantial annual cycle in water levels, with 7.1 feet of fluctuation. The annual pattern is very distinct, with the highest levels in August and the lowest levels in March. Considering the location of this well, this fluctuation may likely be related to the Wason diversion. Monitoring well 2 had a substantial fluctuation in water levels, with 5.7 feet of variability. A seasonal pattern may be evident, but not as distinctly as well 1. This well is immediately adjacent to the Wason ditch, before the second flow control structure.

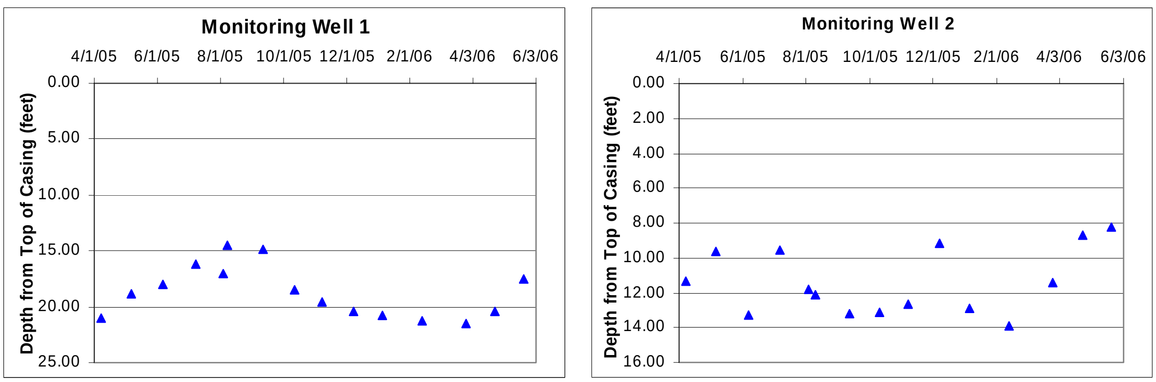


Figure 33: Water level variability of monitoring wells 1 and 2.

Illustrations showing level variability of wells 3 and 5 are provided in Figure 34. Monitoring well 3 had minor variability in measured water levels, with only 0.5 feet of fluctuation. This well is immediately adjacent to a planned constructed wetland, on the Mineral County fairgrounds property. The minor fluctuations indicate a stable ground water table for this wetland. Monitoring well 5, which is near the edge of the contamination plume, had a moderate amount of variability of water levels, with 1.8 feet of fluctuation.

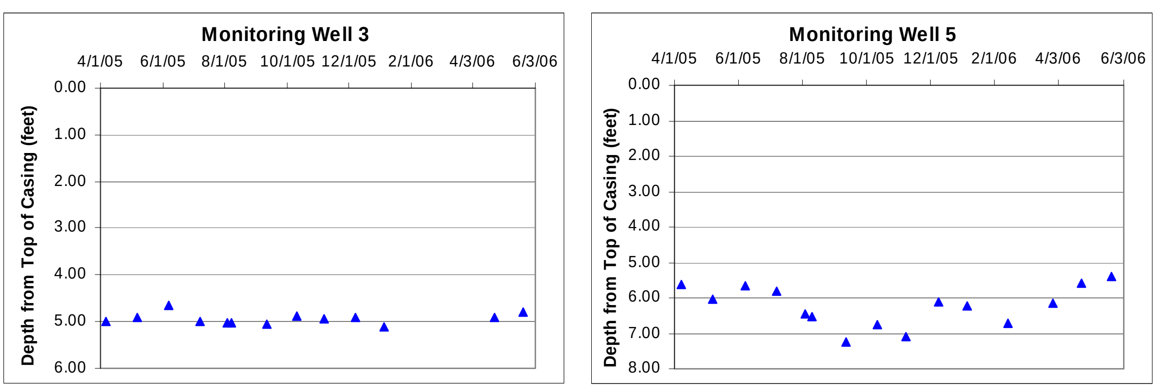
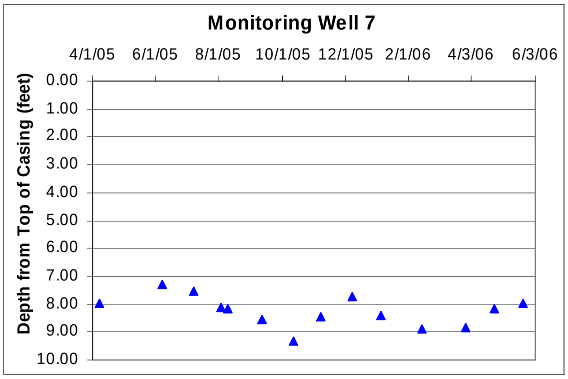


Figure 34: Water level variability of monitoring wells 3 and 4.

Illustrations showing level variability of wells 7 and 8 are provided in Figure 35. Monitoring well 7 had a moderate amount of variability in measured water levels, with 2.0 feet of fluctuation. The data indicate possible dual-peaked seasonal variability. This well is near the edge of the groundwater contamination plume. Monitoring well 8 also had a moderate amount of variability of water levels, with 1.6 feet of fluctuation. An increasing depth-to-groundwater trend may exist for this well in the groundwater contamination plume.



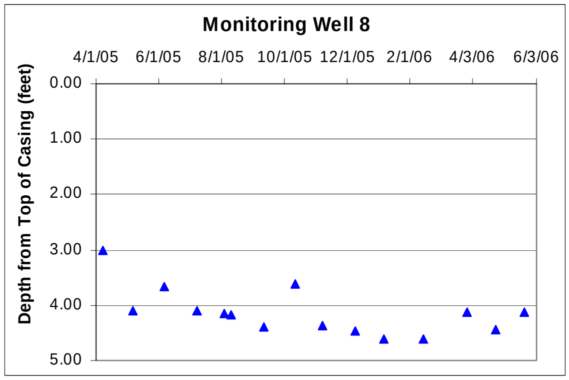
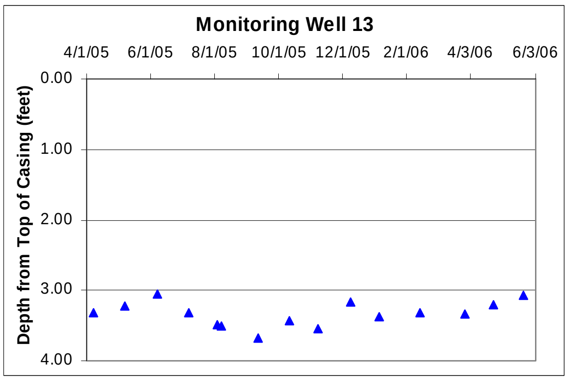


Figure 35: Water level variability of monitoring wells 7 and 8.

Illustrations showing level variability of wells 13 and 14 are provided in Figure 36. Monitoring well 13 had a low amount of variability in measured water levels, with 0.6 feet of fluctuation. The data indicate seasonal variability. Monitoring well 14 had a moderate amount of variability of water levels, with 1.7 feet of fluctuation. The data also indicate seasonal variability.



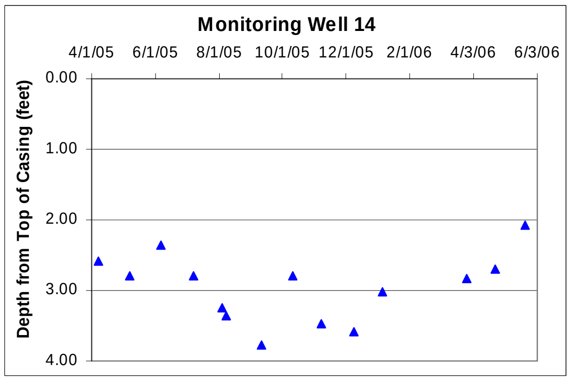


Figure 36: Water level variability of monitoring wells 13 and 14.

Illustrations showing level variability of wells 15 and 16 are provided in Figure 37. Monitoring well 15 had a moderate amount of variability in measured water levels, with 2.2 feet of fluctuation. The data indicate likely seasonal variability. This well is the northern-most monitoring, and is upstream of the contamination plume. Monitoring well 16 also had a moderate amount of variability of water levels, with 1.2 feet of fluctuation. Seasonal variability is not evident in this well.

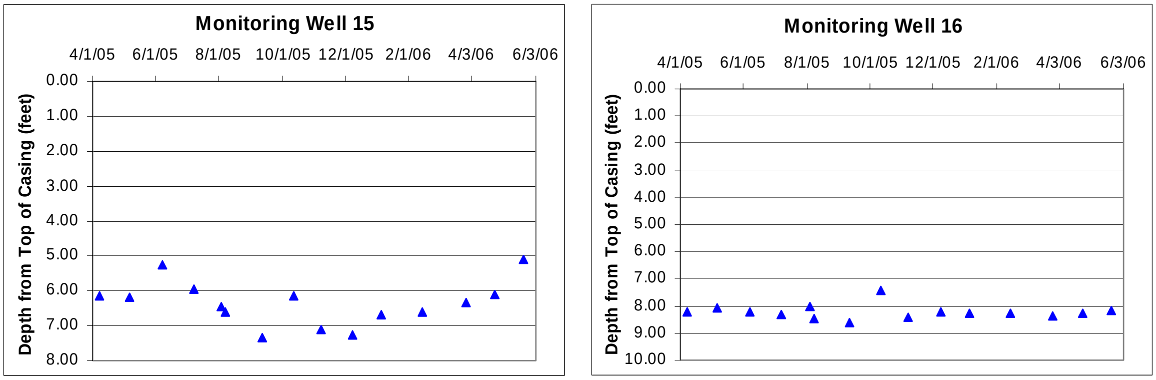


Figure 37: Water level variability of monitoring wells 15 and 16.

Illustrations showing level variability of wells 17 and 18 are provided in Figure 38. Monitoring well 17 had a moderate amount of variability in measured water levels, with 2.2 feet of fluctuation. The data indicate possible seasonal variability. Monitoring well 18 also had a moderate amount of variability of water levels, with 1.7 feet of fluctuation. Seasonal variability is not evident in this well.

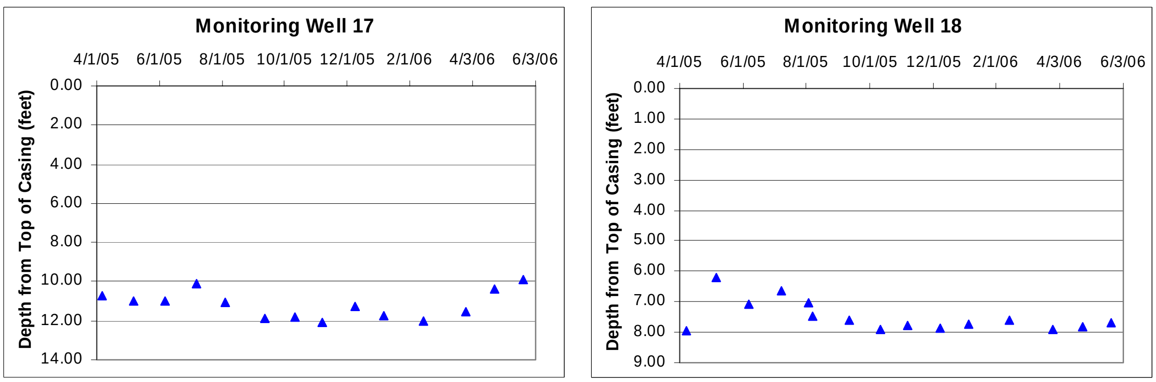


Figure 38: Water level variability of monitoring wells 17 and 18.

Illustrations showing level variability of wells 19 and 20 are provided in Figure 39. Monitoring well 19 had a low amount of variability in measured water levels, with 0.8 feet of fluctuation. Seasonal variability is not evident. Monitoring well 20 had a moderate amount of variability of water levels, with 1.1 feet of fluctuation. Seasonal variability is also not evident in this well.

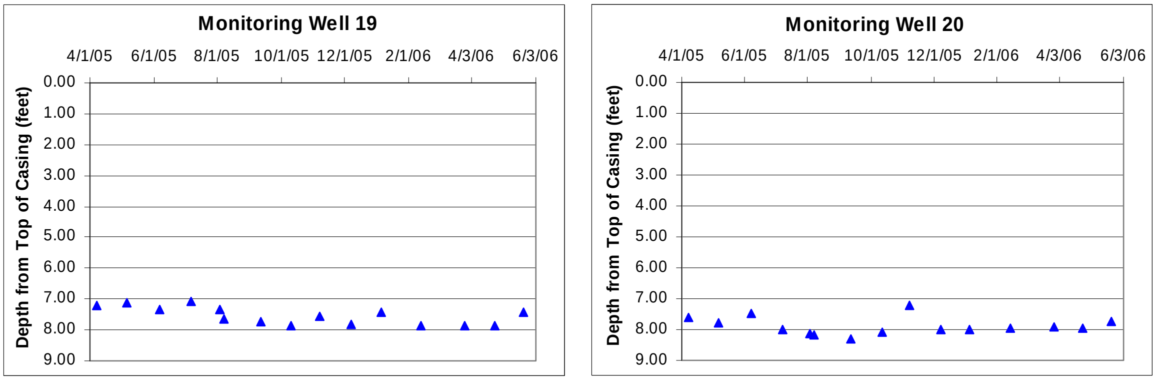


Figure 39: Water level variability of monitoring wells 19 and 20.

Depth to Groundwater

A depth to groundwater map was created by simply subtracting the water-table TIN from the ground surface TIN. This is a useful product, with application to revegetation efforts, wetland establishment, and building foundation design applications, among other things. Figure 40 provides a plot of the depth to groundwater. A higher-resolution plot can be found in Figure A-9.

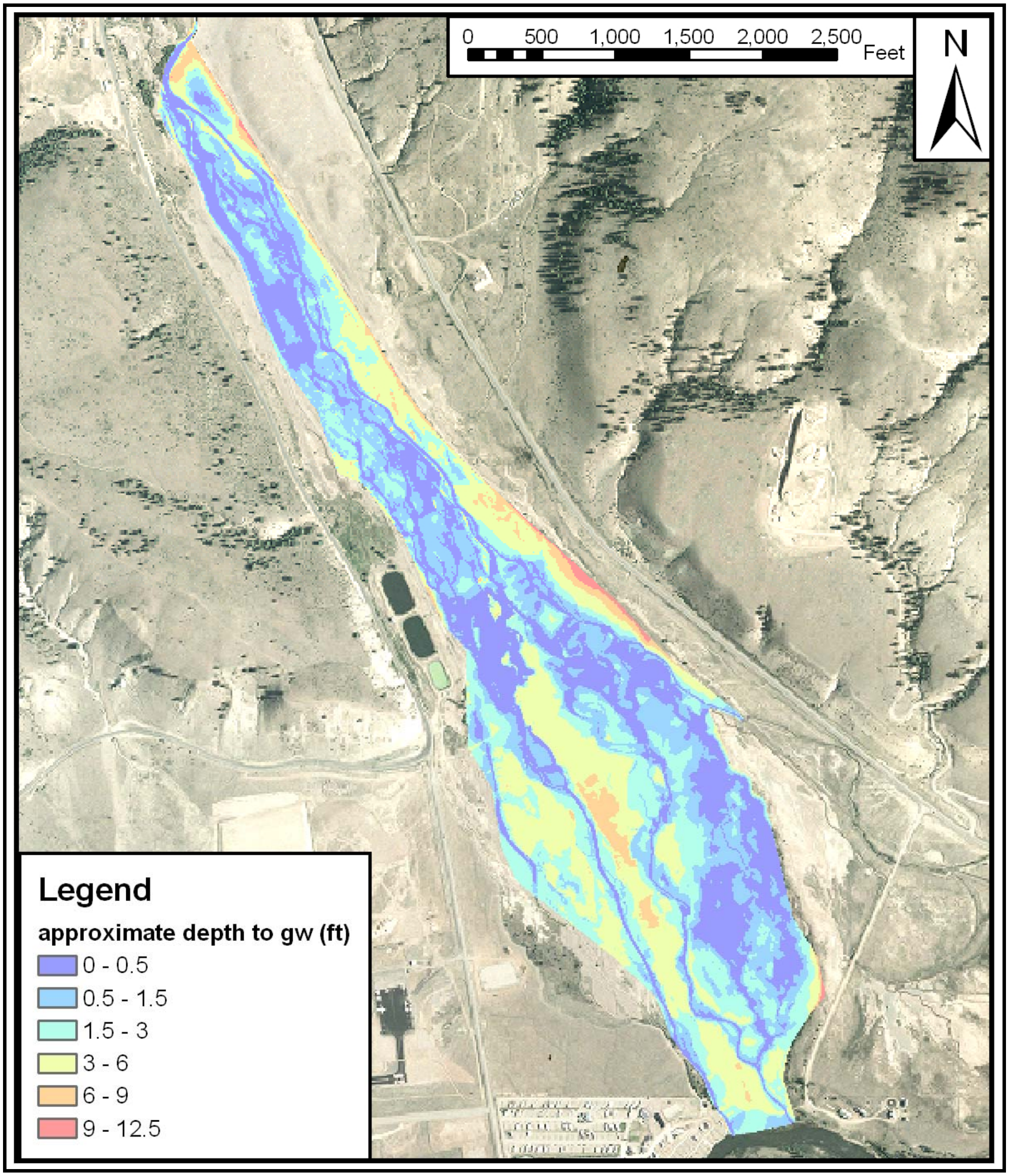


Figure 40: Approximate depth to groundwater, in feet.

Ground-Water Quality

Groundwater quality in the Willow Creek floodplain has been previously monitored and documented by the Willow Creek Reclamation Committee. Results from this monitoring are provided in WCRC (2004b) as well as in EPA (2005). A summary of the previous findings are summarized here. Additionally, the data used in the previous reports have been combined with the results of additional sampling and field parameter collection to provide this interpretation.

Twenty monitoring wells have been drilled into the alluvium of the floodplain. These wells are illustrated in Figure 41. The majority of these wells are located on the east side of the floodplain in the vicinity of the Emperious tailings pile. In addition, 17 monitoring pits were dug in the floodplain to supplement the monitoring well data (Figure 41). Water levels and field parameters were measured and some water samples were collected from these pits. Analysis results of the dissolved constituents (filtered in the lab) are provided in Table 10.

As documented in WCRC (2004b), the elevated constituents found in groundwater of the floodplain were zinc, manganese, magnesium, and cadmium. Dissolved lead was not typically found to be exceptionally elevated in the floodplain. The most contaminated wells are MW8, MW9, MW10, MW11, MW16, MW18, MW19 and MW20. Dissolved zinc levels in all the wells range from <5 to 679,250 ug/l. Dissolved cadmium levels in the wells range from <0.1 to 1539 ug/l. Dissolved lead levels in the wells range from <1 to 149 ug/l.

In regard to allowable concentrations, the Colorado Department of Public Health and Environment (CDPHE), in cooperation with the EPA, sets table value standards for contaminants for agricultural and human use. For zinc, a 2000 ug/l standard has been set for agricultural purposes while 5000 ug/l has been set for drinking water. For cadmium, a 10 ug/l standard has been set for agricultural purposes while 5.0 ug/l has been set for drinking water. For lead, a 100 ug/l standard has been set for agricultural purposes while 50 ug/l has been set for drinking water (EPA 2006).

As documented in EPA (2006), the health impacts of excess cadmium in drinking water can cause kidney damage.

Plots of dissolved zinc and cadmium in the upper half of the floodplain, extracted from WCRC (2002b), are provided in Figures 42 and 43. Please note that some well IDs in these plots are incorrect.

Figure 41: Groundwater monitoring wells and pits of the Willow Creek floodplain.

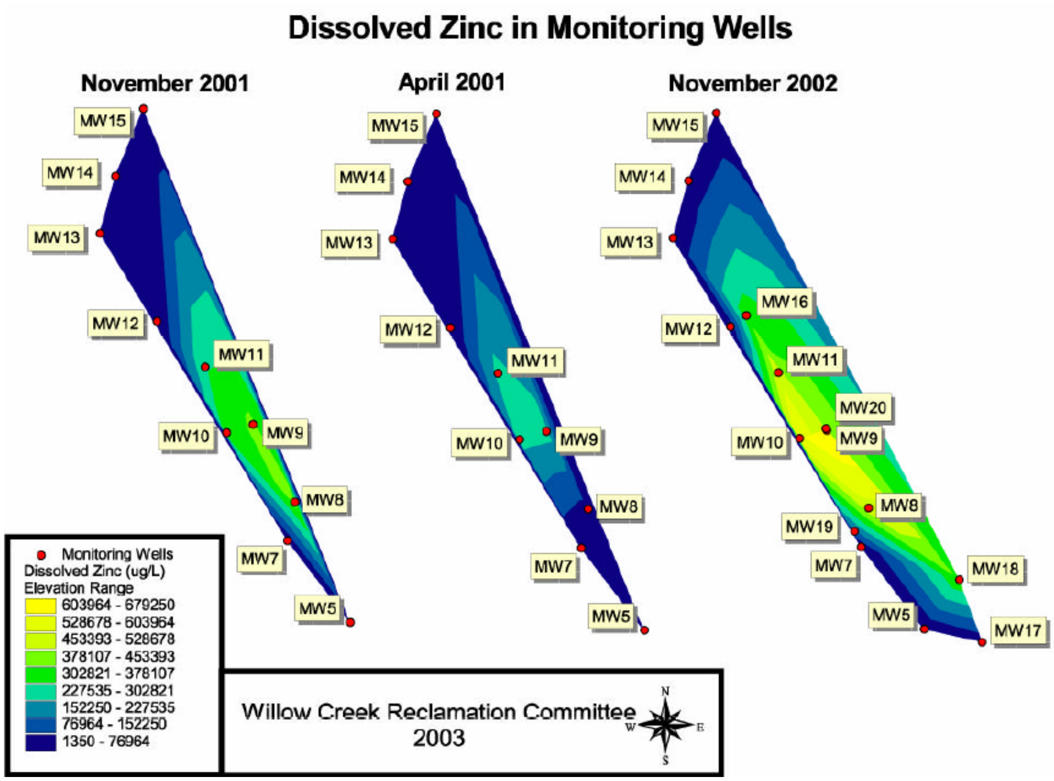


Figure 42: Dissolved zinc in monitoring wells (from WCRC 2004b).

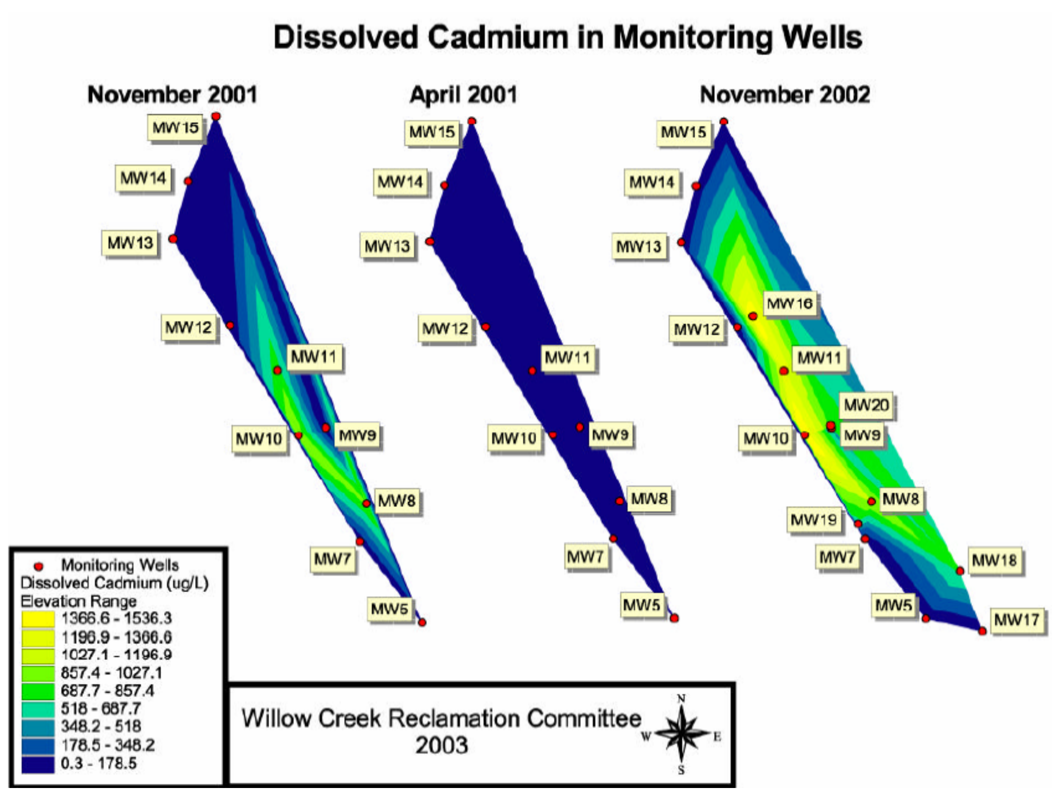


Figure 43: Dissolved cadmium in monitoring wells (from WCRC 2004b).

Table 10: Monitoring pit dissolved water-quality analysis results. Analyses performed at the NRCS National Soil Survey Center.

ID	PitID	Date	AL (mg/l)	Ca (mg/l)	Fe (mg/l)	K (mg/l)	Mg (mg/l)	Na (mg/l)	Sr (mg/l)	Ag (ug/l)
S05CO079-004A	MP4	38573.00	<0.012	22.89	<0.0066	1.26	1.92	6.06	0.19	0.40
S05CO079-004B	MP4	38574.00	<0.012	23.73	<0.0066	1.16	1.99	6.79	0.19	0.38
S05CO079-004C	MP4	38575.00	<0.012	24.63	<0.0066	1.26	2.08	6.67	0.20	0.45
S05CO079-001A	MP2	38573.00	<0.012	18.51	<0.0066	1.24	1.57	5.89	0.17	0.38
S05CO079-001B	MP2	38574.00	<0.012	19.23	<0.0066	1.12	1.63	6.38	0.17	0.40
S05CO079-001C	MP2	38575.00	<0.012	19.28	<0.0066	1.16	1.63	6.17	0.17	tr
S05CO079-002A	MP3	38573.00	<0.012	17.69	<0.0066	1.89	1.89	11.40	0.15	0.36
S05CO079-002B	MP3	38574.00	<0.012	18.14	<0.0066	2.08	1.96	10.89	0.15	0.41
S05CO079-002C	MP3	38575.00	<0.012	18.39	<0.0066	2.11	1.90	9.47	0.15	0.36
S05CO079-006	MP17	38573.00	1.05	30.35	<0.0066	3.80	3.99	13.77	0.23	0.72
S05CO079-007	MP16	38573.00	133.10	109.91	13.60	3.58	31.04	18.74	0.43	7.08
S05CO079-008	MP6	38573.00	<0.012	21.64	<0.0066	1.27	1.89	6.05	0.16	0.47
S05CO079-009	MP7	38573.00	<0.012	48.97	<0.0066	2.35	4.05	10.33	0.34	0.73
S05CO079-010	MP9	38573.00	<0.012	22.38	<0.0066	1.34	2.03	6.19	0.17	0.41
S05CO079-011	MP10	38573.00	<0.012	27.92	<0.0066	1.53	2.38	7.45	0.19	0.46
S05CO079-012	MP11	38573.00	<0.012	30.04	<0.0066	8.19	3.27	31.70	0.21	0.79

		As (ug/l)	Ba (ug/l)	Be (ug/l)	Cd (ug/l)	Co (ug/l)	Cr (ug/l)	Cu (ug/l)	Mn (ug/l)	Ni (ug/l)
S05CO079-004A	MP4	<3.8	150.24	<0.01	24.04	1.39	<0.18	5.94	<0.13	5.78
S05CO079-004B	MP4	<3.8	252.16	<0.01	23.39	1.40	<0.18	6.09	<0.13	5.83
S05CO079-004C	MP4	<3.8	193.02	<0.01	24.61	1.50	<0.18	4.57	<0.13	5.72
S05CO079-001A	MP2	<3.8	133.77	<0.01	18.73	1.54	<0.18	10.28	<0.13	6.02
S05CO079-001B	MP2	<3.8	207.52	<0.01	19.11	1.48	<0.18	8.71	<0.13	5.76
S05CO079-001C	MP2	<3.8	169.17	<0.01	18.14	1.42	<0.18	6.37	<0.13	5.78
S05CO079-002A	MP3	<3.8	413.98	0.01	70.30	2.15	<0.18	5.76	141.3	7.14
S05CO079-002B	MP3	<3.8	314.08	0.01	77.16	2.25	<0.18	5.51	173.2	6.66
S05CO079-002C	MP3	<3.8	202.55	0.01	62.09	1.91	<0.18	4.53	101.7	6.24
S05CO079-006	MP17	tr	191.31	0.99	118.03	3.90	<0.18	107.08	2185.3	8.45
S05CO079-007	MP16	32.2	5.18	27.20	1412.06	136.07	26.94	3281.57	12103.0	66.63
S05CO079-008	MP6	<3.8	162.31	<0.01	34.80	1.47	<0.18	7.08	13.5	4.42
S05CO079-009	MP7	30.7	89.65	0.02	22.93	2.43	<0.18	4.75	1552.3	4.55
S05CO079-010	MP9	<3.8	177.55	<0.01	31.26	1.36	<0.18	6.25	<0.13	5.50
S05CO079-011	MP10	<3.8	193.29	0.01	33.17	1.33	<0.18	5.78	<0.13	5.14
S05CO079-012	MP11	9.92	224.72	<0.01	29.05	1.67	<0.18	14.43	488.87	5.76

		P (ug/l)	Pb (ug/l)	Sb (ug/l)	Sn (ug/l)	Sr (ug/l)	V (ug/l)	W (ug/l)	Zn (ug/l)	
S05CO079-004A	MP4	<18.1	6.03	<1.7	9.68	280	5.89	49.0	4336	
S05CO079-004B	MP4	<18.1	3.48	<1.7	9.45	283	6.01	47.9	4257	
S05CO079-004C	MP4	<18.1	<1.1	<1.7	9.51	285	5.93	50.0	4359	
S05CO079-001A	MP2	<18.1	<1.1	<1.7	9.51	243	5.99	45.1	4021	
S05CO079-001B	MP2	<18.1	<1.1	<1.7	9.74	247	5.99	45.1	4028	
S05CO079-001C	MP2	<18.1	<1.1	<1.7	9.79	249	5.91	44.6	4018	
S05CO079-002A	MP3	<18.1	<1.1	tr	9.05	242	6.08	164.3	10406	
S05CO079-002B	MP3	<18.1	<1.1	tr	9.40	243	6.02	181.9	11088	
S05CO079-002C	MP3	<18.1	<1.1	tr	9.50	240	6.13	138.4	9521	
S05CO079-006	MP17	<18.1	280.87	<1.7	8.45	351	5.73	274.0	13855	
S05CO079-007	MP16	tr	1900.37	<1.7	11.56	633	6.14	4209.4	29661	
S05CO079-008	MP6	<18.1	5.32	tr	8.43	245	5.94	67.8	4827	
S05CO079-009	MP7	<18.1	1.84	3.57	7.97	457	5.90	90.4	6249	
S05CO079-010	MP9	<18.1	<1.1	<1.7	8.45	255	6.04	63.5	4700	
S05CO079-011	MP10	<18.1	<1.1	<1.7	8.10	282	6.28	69.6	5043	
S05CO079-012	MP11	1084.88	5.90	tr	10.76	359	7.75	54.5	4280	

As noted in WCRC (2004b), it was found that pH can be a good indicator for groundwater contamination in the floodplain. Plots of (field) pH versus dissolved cadmium and zinc concentrations in groundwater of the Willow Creek floodplain are provided in Figures 44 and 45. These plots indicate that the use of this field parameter can quickly help identify potentially greater or lesser levels of contamination. It can also help identify trends in a particular well.

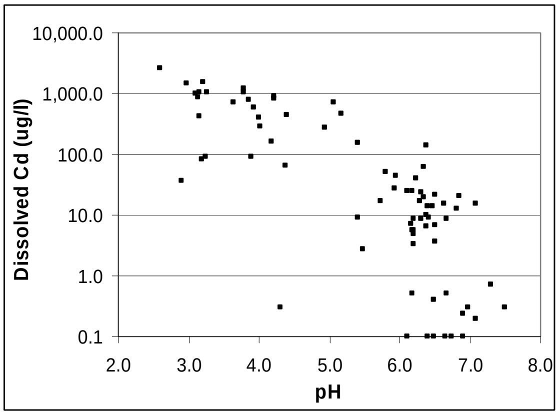


Figure 44: Dissolved Cd versus pH.

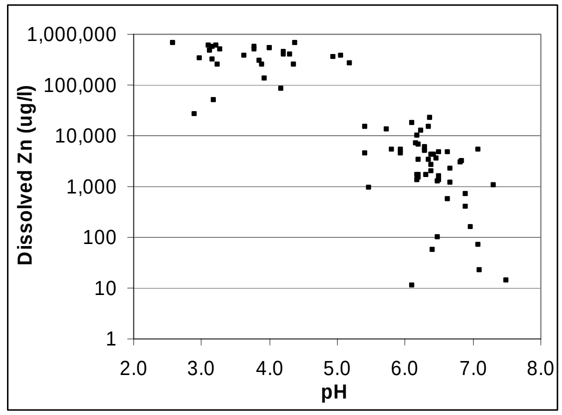


Figure 45: Dissolved Zn versus pH.

With the approach of using pH as an indicator of groundwater contamination, pH was measured in the majority of monitoring wells and all monitoring pits within the floodplain in August of 2005. Figure 46 illustrates the pH variability of the floodplain groundwater. Data for monitoring wells with insufficient diameter to allow use of the water-quality monitoring probe (wells with less than 2” diameter casings) were not collected. However, data for wells 8 and 14 were added from late June 2005 measurements made by the EPA.

This relationship can be powerful to the Willow Creek Reclamation Committee in that it can allow low cost but frequent monitoring of groundwater quality, for early detection of movement of the groundwater contamination plume. If downward trends in pH are found in a well, then the Committee can be warned of potential movement of the contamination plume. This warning can then be followed up by water quality sampling and analytical analysis.

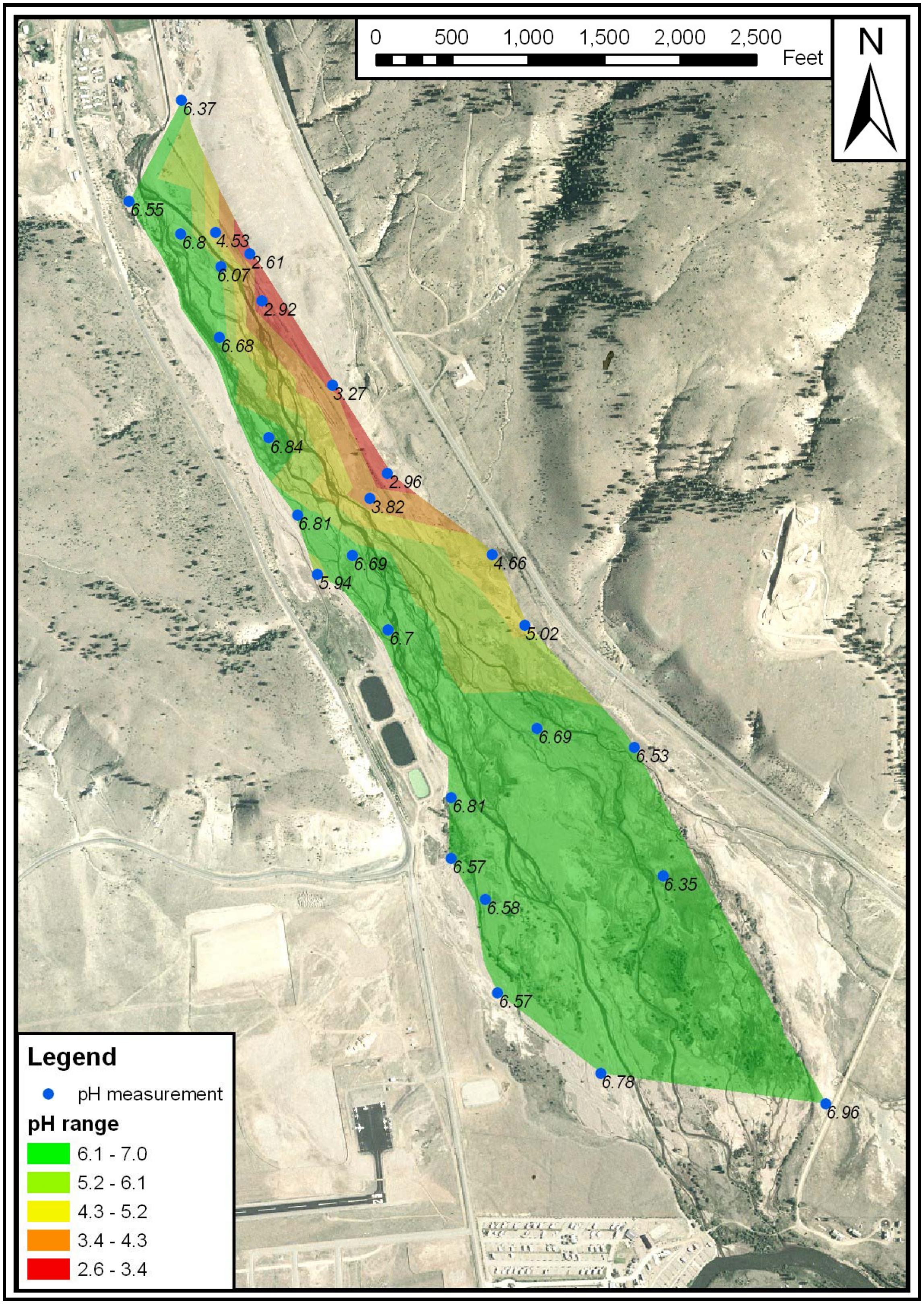


Figure 46: pH levels in the groundwater of the Willow Creek floodplain, summer of 2005. Low pH levels indicate groundwater contamination.

Surface Water Quality

Surface water quality in the Willow Creek floodplain has been previously monitored by and documented by the Willow Creek Reclamation Committee. Results from this monitoring are provided in WCRC (2004a) as well as in EPA (2005). A summary of the previous findings are summarized in this section. Additional data gathered for this planning effort, specifically from two deployments of a logging multi-parameter probe, are also provided.

Water quality in the two upper branches of Willow Creek, specifically West Willow and East Willow Creeks, as well as mainstem Willow Creek, have been documented in WCRC (2004a). It has been found that zinc, cadmium and lead exceed Colorado Table Value Standards (TVS). A summary of conditions, from WCRC (2004a), is provided below:

> *The Willow Creek Watershed contains Stream Segments 6 and 7 in the Rio Grande Basin, and Classifications include Recreation 1a, Aquatic Life Cold 1, and Agriculture. Surface water quality is affected for more than 7 miles of Willow Creek and its tributaries, with nearly 5 miles above state water quality standards for heavy metals and pH. For Segment 7, which constitutes the lower, heavily mined areas of the creek, there is a temporary modification (expires 2007) to recognize existing water quality instead of state standards for organic and inorganic parameters. Willow Creek from the confluence of East and West branches to the Rio Grande is recommended for the 2004 Colorado impaired waters list (303d) for pH. The Rio Grande River below the confluence with Willow Creek (Segment 4) has also been recommended for the 2004 303d list for high levels of zinc (38 mile reach) and cadmium (7 mile reach). Classifications for Segment 4 include Recreation 1a, Aquatic Life Cold 1, Water Supply, and Agriculture.*

Surface water sampling synoptics were conducted primarily in the spring, just before peak snowmelt runoff when access to the upper watershed is permitted by the snowpack. Additional sampling has been preformed in the autumn, during low flow. Sites were sampled upstream, within, and downstream of suspected stream metal loading. In-field data collection consisted of discharge, pH, temperature, conductivity and dissolved oxygen. Composite or grab samples were collected for analytical analysis. Synoptics were performed on 9/18-19/1999, 5/16-18/2000, 5/22-23/2001, 5/2/2002, 5/8/2003, 5/6/2004 and 5/3/2005. Additional, selective, sampling was performed by the Willow Creek Reclamation Committee.

Colorado Table Value Standards, for aquatic life, were computed for the synoptics from measured hardness values (WCRC 2004a).

Additional water quality sampling and analyses were performed by the USGS (Kimball et. al. 2006). The abstract of this report is provided below:

> *Decisions about remediation of mine drainage on the watershed scale require an understanding of metal contributions from all sources to be able to choose the best sites for remediation. A hydrologic framework to study metal loading in the Willow Creek watershed, a tributary to the Rio Grande River near Creede,*

Colorado, was established by conducting a series of tracer-injection studies. Each study used the tracerdilution method in conjunction with synoptic sampling to determine the spatial distribution of discharge and concentration. Discharge and concentration data were then used to develop mass-loading curves for the metals of interest. The discharge and load profiles (1) identify the principal sources of load to the streams; (2) demonstrate the scale of unsampled, dispersed subsurface inflows; and (3) estimate the amount of natural attenuation. The greatest source of metal loads was from the Nelson Tunnel on West Willow Creek, which contributed 158 kilograms per day of zinc to the stream. Additional loading from other dispersed, subsurface inflows along West Willow Creek added substantial loads, but these were small in comparison to the loads from the Nelson Tunnel. No significant contributions of metal load from potential sources occurred along East Willow Creek. The lack of measurable loading may be a result of previous remedial actions along that stream. The lower Willow Creek section had relatively small contributions of load compared to what had been contributed upstream. This watershed approach provides a detailed snapshot of metal load for the watershed to support remediation decisions and quantifies processes that affect metal transport.

The water quality of East, West and mainstem Willow Creeks are each summarized in the following sections.

East Willow Creek

An illustration indicating sampled locations in East Willow Creek is provided in Figure 49. Figures illustrating measured cadmium, lead and zinc concentrations and load for the 2000 and 2001 synoptics are provided in Figures 47 and 48.

A pH range of 5.9 to 8.0, with an average of 7.2, has been measured from 1999 to 2005, for the main stream sampling locations. Measured inflows have a pH range of 4.3 to 7.8, with an average of 6.5. It appears that East Willow Creek has good buffering capacity.

As documented in WCRC (2004a), concentrations of silver, arsenic, copper and selenium have been found to be near or below the detection limit for East Willow Creek. Concentrations of Cadmium, Lead and Zinc have been found to be above the chronic Table Value Standards in East Willow Creek at the confluence with West Willow Creek (Figure 47). Loads for these constituents are provided in Figure 48.

As is obvious in Figures 47 and 48, substantial inflows of contaminates are occurring in the vicinity of sampling sites EW-K and EW-H, as well as more gradual but consistent loading from EW-F to EW-A. Point sources of metal loading to the stream include Solomon Mine adit (EW-SMA) and Solomon Wetlands (EW-SMD). In September 1999, the Solomon wetlands accounted for 58% of the increase in Zinc between sites EW-H and EW-G (WCRC 2004a), indicating that this adit and associated wetlands are primary sources of metals in East Willow Creek.

East Willow Creek is a substantial source of metal contamination in the Willow Creek Watershed. Consistent and substantial exceedence of Colorado chronic Table Value Standards indicate that water quality is a substantial barrier to reestablishing a healthy aquatic ecosystem in the Willow Creek floodplain.

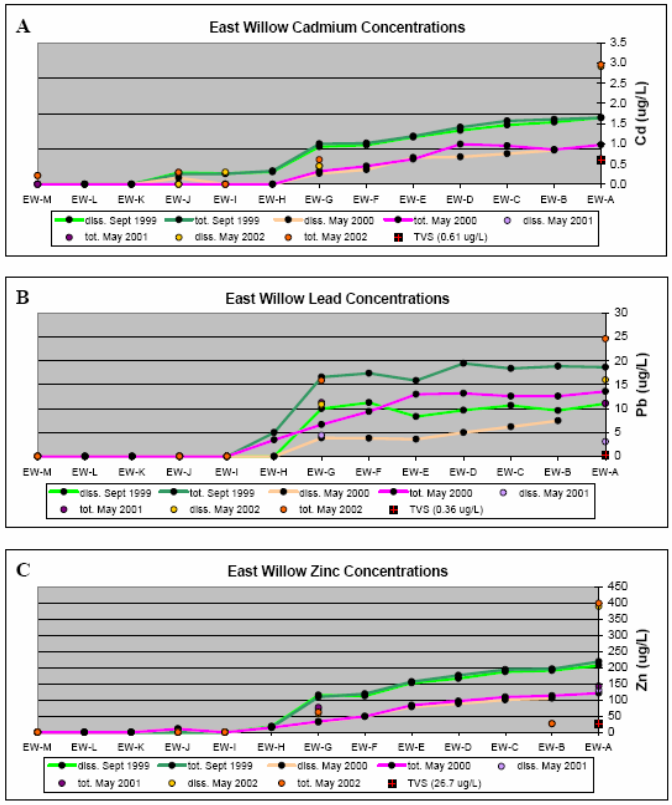


Figure 47: East Willow Creek cadmium (A), lead (B) and zinc (C) concentrations (WCRC 2004a). Table Value Standards (TVS) also shown.

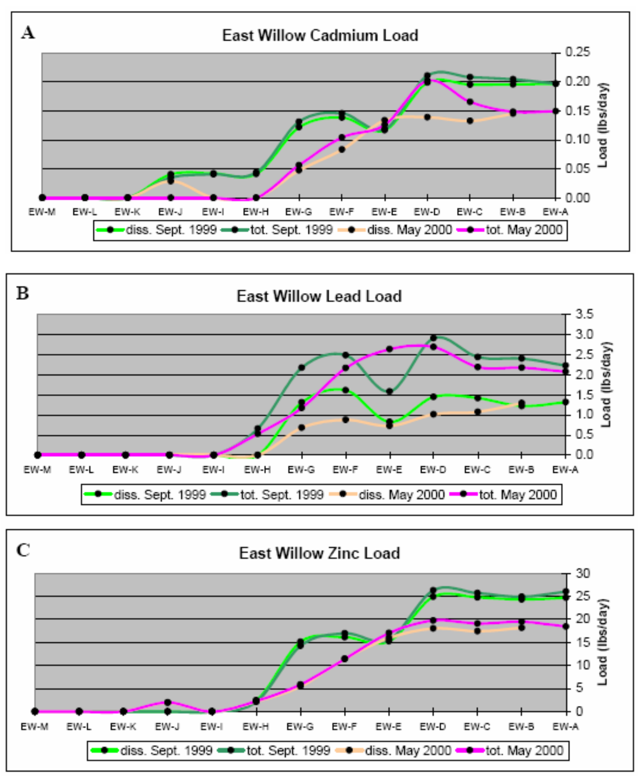


Figure 48: East Willow Creek cadmium (A), lead (B) and zinc (C) loads (WCRC 2004a).

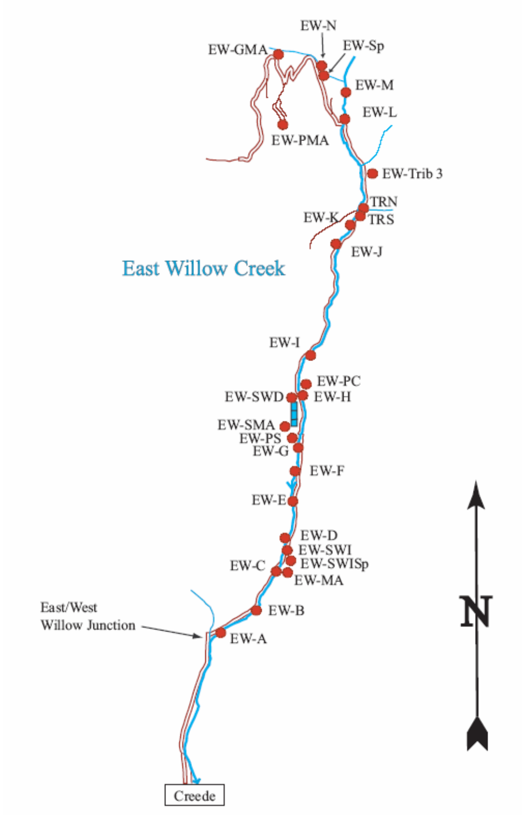


Figure 49: East Willow Creek sampling locations (from WCRC 2004a).

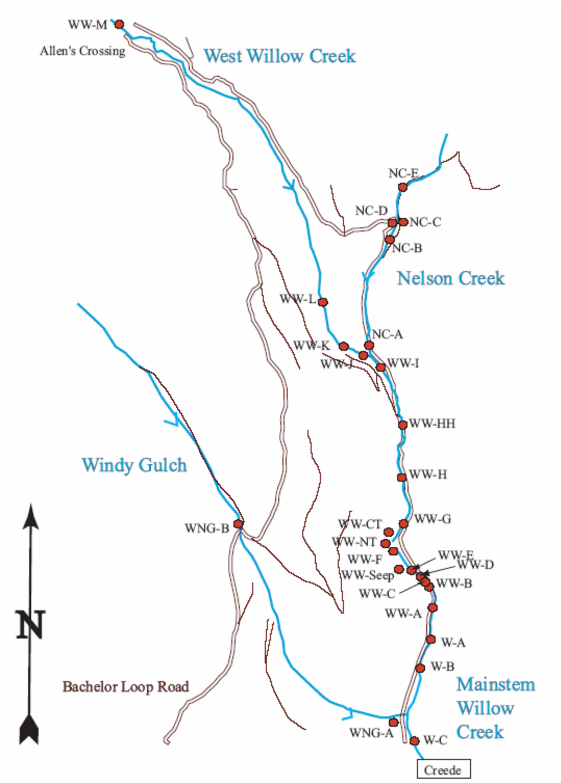


Figure 50: West Willow Creek sampling locations (from WCRC 2004a)

West Willow Creek

An illustration indicating sampled locations in West Willow Creek is provided in Figure 50. Figures illustrating concentrations and load for the 2000 and 2001 synoptics are provided in Figures 51 through 54.

A pH range of 6.3 to 8.0, with an average of 7.3, has been measured from 1999 to 2005, for the main stream sampling locations. Measured inflows, excluding Nelson Creek, have a pH range of 3.7 to 7.4, with an average of 5.3. Nelson Creek has a pH range of 3.2 to 7.5, with an average of 5.9. West Willow Creek also has good buffering capacity.

As documented in WCRC (2004a), concentrations of silver, arsenic, and selenium have been found to be below the detection limit for West Willow Creek. Concentrations of aluminum, cadmium, copper, lead and zinc have been found to be above the chronic Table Value Standards in lower West Willow Creek at the confluence with West Willow Creek (Figures 51 and 52). Loads for these constituents are provided in Figures 53 and 54.

As is obvious in Figures 51 through 54, substantial inflows of contaminates are occurring from WW-L to WW-I and WW-G to WW-D. Documented point sources of metal loading to West Willow Creek include Nelson Creek (downstream of WW-I), a seep at the Commodore (WW-CT, downstream of WW-G) and the Nelson Tunnel (WW-NT, upstream of WW-F). The Nelson tunnel is the largest contributor of metals in the Willow Creek watershed (Kimball et. al. 2006).

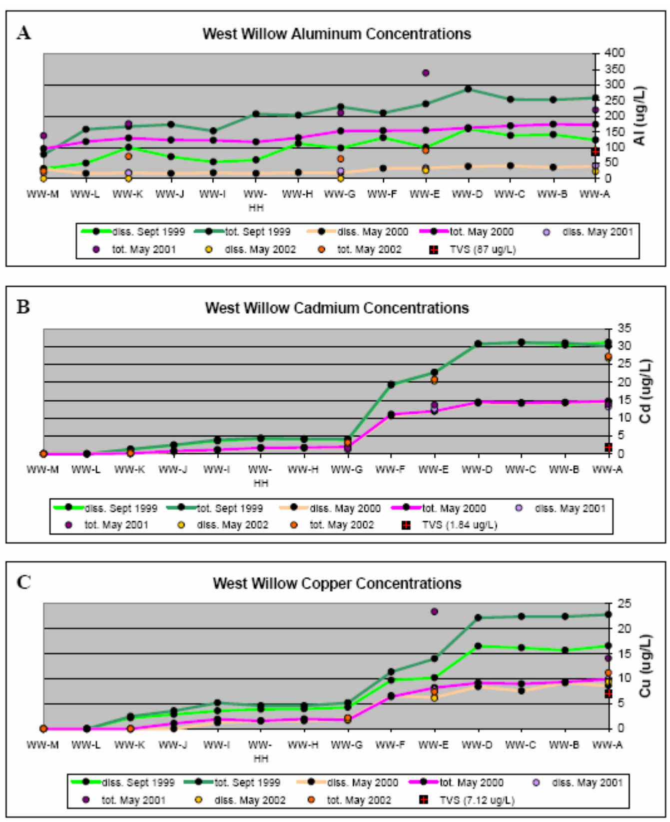


Figure 51: West Willow Creek aluminum (A), cadmium (B) and copper (C) concentrations (WCRC 2004a). Table Value Standards (TVS) also shown.

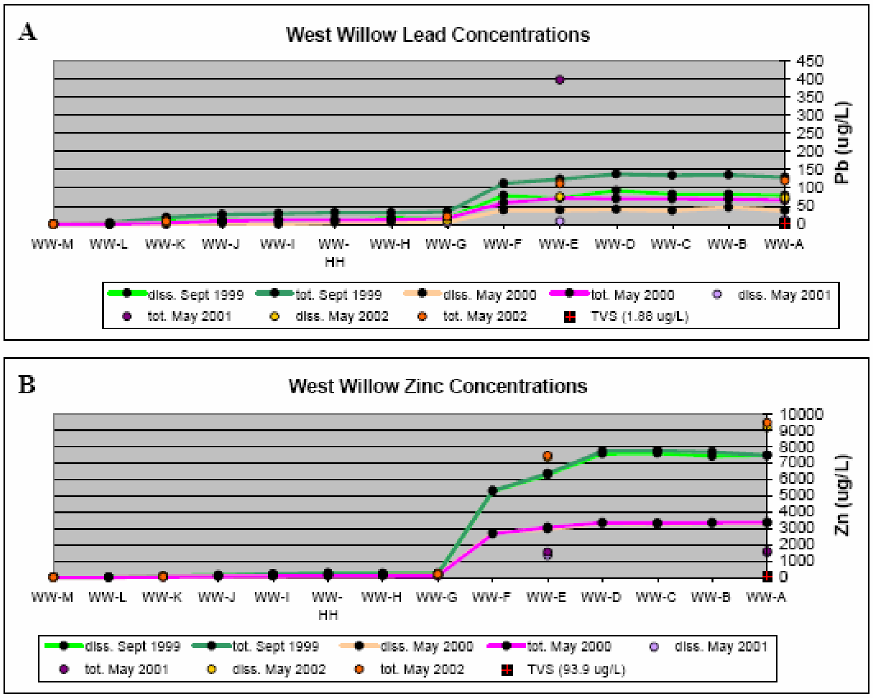


Figure 52: West Willow Creek lead (A) and zinc (B) concentrations (from WCRC 2004a). Table Value Standards (TVS) also shown.

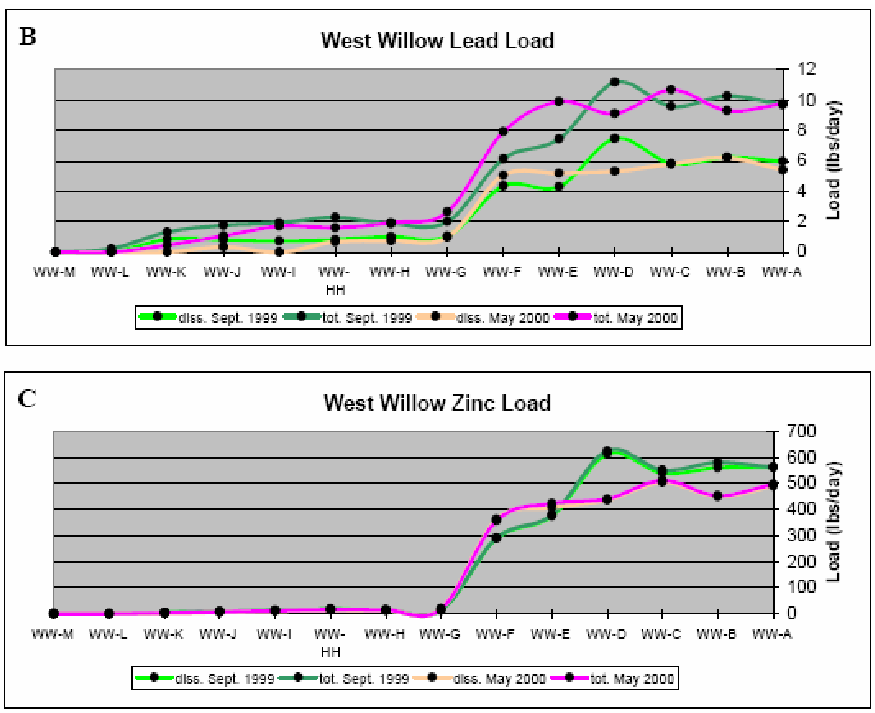


Figure 53: West Willow Creek lead (B) and zinc (C) loads (WCRC 2004a).

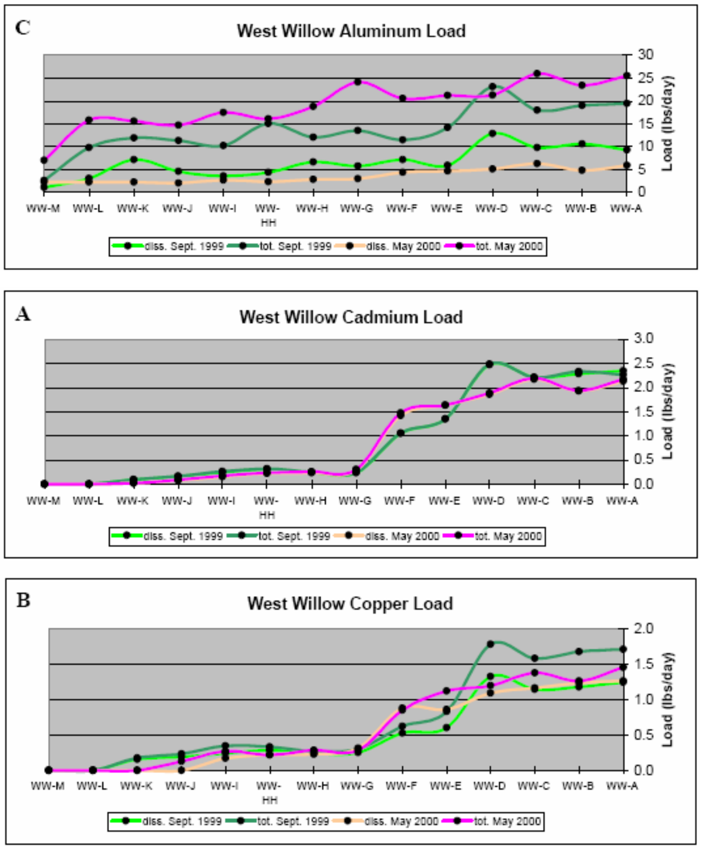


Figure 54: West Willow Creek aluminum (C), cadmium (A) and copper (B) loads (WCRC 2004a).

A snowmelt-related flood occurred in late May of 2005. This flood caused extensive damage on West Willow Creek, causing the failure of a large culvert and eroding mine waste and tailings and other mining-related material (Figure 55). Much of this debris was deposited in the Willow Creek floodplain, downstream of Creede within the proposed stream restoration area. As of late 2006, this reach on West Willow Creek has yet to be stabilized.

Figure 55: West Willow reach of instability, on 5/25/2005.

Substantial material was eroded during the May of 2005 flood event. A photograph of the confluence of West and East Willow Creeks, dated 5/25/2005, is provided in Figure 56.

Figure 56: Confluence of West (left) and East (right) Willow Creeks on 5/25/2005.

A logging multi-parameter probe was deployed from 4/7 to 5/23/2005 on West Willow Creek just upstream of the confluence with East Willow Creek (site WW-A). The probe was removed on 5/23 to save the probe from flood hazards. The flush of eroded material was initiated before the probe was removed, as is illustrated by the sudden drop in pH (4.8 minimum) and increase in conductivity (520 uS/cm maximum). Measurements from this deployment are shown in Figure 57.

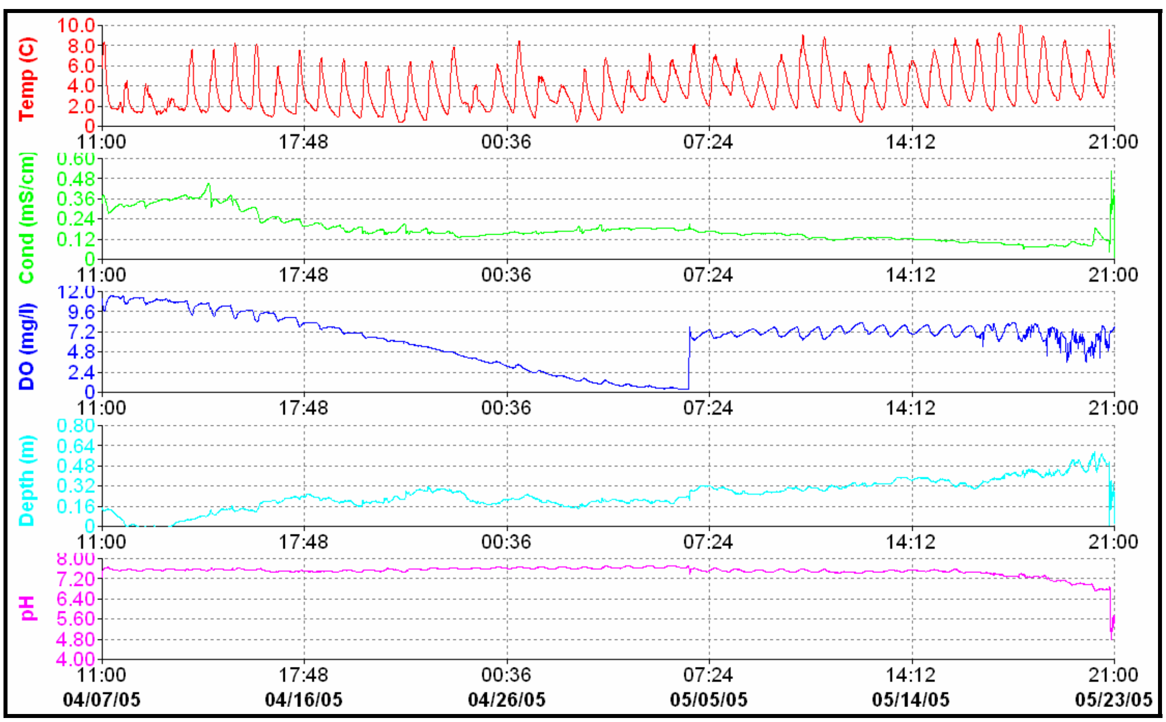


Figure 57: West Willow Creek probe deployment, Spring of 2005.

There is often an inverse relationship between pH and metal concentration – lower pH indicates higher metal concentrations. The multiparameter probe data indicate that a substantial quantity of metals were transported down West Willow Creek during this event.

Grab sampling of the flood waters at site WW-A on 5/23/2005 confirm the high metal concentrations. The concentrations measured of this flow were exceedingly high, with measurements more than an order of magnitude greater than average. The measured values for five key metals are provided in Table 11. Average concentrations at sampling site WW-A are also provided, for comparison purposes. Considering that these samples were collected during a flood event, it is clear that a large load of metals was transported down Willow Creek and into the Rio Grande during the flood of 2005.

Table 11: Grab sample concentrations from site WW-A, on 5/23/2006. Average concentrations for site WW-A are also provided.

Constituent	Concentration (ug/l)	
	Grab Measurement	Average at WW-A
Aluminum	946	50
Cadmium	384	18
Copper	492	10
Lead	2600	43
Zinc	53,200	4830

There is no documentation of a fish kill occurring in the Rio Grande during this flood. The Wagon Wheel Gap streamgage station is the closest gage to Willow Creek. The average daily flow on 5/23 was 3460 cfs. The annual peak flow for 2005 of this partially-regulated river was 4410 (on 5/22/2005), which, from a log-Pearson analysis of 50 years of record, corresponds to a 10-year event. The contaminates from Willow Creek were apparently sufficiently diluted to prevent a fish kill.

West Willow Creek is a substantial source of metal contamination in the Willow Creek Watershed, both during low flows and flood events. Consistent and substantial exceedence of Colorado chronic Table Value Standards indicate that water quality is a substantial barrier to reestablishing a healthy aquatic ecosystem in the Willow Creek floodplain. This is in addition to the potential erosion of mining debris on West Willow creek during future floods, which have the potential to cause failure of a stream restoration on lower Willow Creek.

A primary concern of the Willow Creek Reclamation Committee is the metal content of flow entering West Willow Creek from the Nelson tunnel. Sampling of this inflow and other Willow Creek waters indicate that the Nelson Tunnel contributes the majority of metal loading in the watershed. To assess the impact of potential Nelson Tunnel water treatment, an analysis was performed of the available data, to determine impacts of the proposed water treatment on dissolved water quality concentrations and loads on Willow Creek. Only samples taken with flow measurements and during synoptics were useable, which provided 6 data points. Discharge measurement quality for the Nelson Tunnel flow varies - this analysis is approximate. Also, all metal loads were assumed to have been removed from the flow, which is not realistic for an actual treatment method.

Results of this analysis are provided in Table 12. During the synoptics, Nelson tunnel total cadmium load was found to range from 23 to 63 percent of the total cadmium load in Willow Creek just upstream of the flume (site W-C), with an average of 42 percent. Nelson total lead load ranged from 15 to 68 percent of the total load in Willow Creek, with an average of 49 percent. Nelson total zinc load ranged from 35 to 69 percent of the total load in Willow Creek, with an average of 61 percent. Dissolved proportional values are similar in magnitude and range as total, with the exception of lead which has an unusually low dissolved component in Willow Creek at site W-C.

This analysis indicates that, if Nelson water is treated, a substantial portion of the metal loading will be eliminated. Lead concentrations would fall below acute Table Value Standards (TVS) at times. However, metal concentrations in Willow Creek would still be above chronic TVS unless other contaminant reduction projects are performed. It is possible that, due to geologic conditions, the natural levels of these metals are high in this drainage and that even pre-mining water quality would violate current chronic TVS.

Table 12: Cadmium concentration in Willow Creek at site W-C, with and without Nelson Tunnel contamination. TVS is computed using W-C hardness.

	Nelson Tunnel			Willow Creek as measured			Willow Creek computed (no Nelson)			Table Value Standard	
	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Acute (ug/l)	Chronic (ug/l)
5/3/2005	0.56	85	92	21.7	8.1	8.4	21.7	5.9	6.0	1.4	1.2
5/6/2004	0.65	176	174	67.1	7.1	7.2	67.1	5.4	5.5	0.9	0.8
5/8/2003	0.45	177	164	11.3	13.1	13.4	11.3	6.1	6.9	2.1	1.5
5/2/2002	0.47	214	213	14.1	14.8	15.1	14.1	7.7	8.0	2.4	1.7
5/16/2000	0.98	259	259	47.2	8.5	8.6	47.2	3.1	3.2	1.1	1.0
9/18/1999	0.77	242	243	37.7	12.6	12.5	37.7	7.6	7.6	0.7	0.7

Table 13: Lead concentration in Willow Creek at site W-C, with and without Nelson Tunnel contamination. TVS is computed using W-C hardness.

	Nelson Tunnel			Willow Creek as measured			Willow Creek computed (no Nelson)			Table Value Standard	
	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Acute (ug/l)	Chronic (ug/l)
5/3/2005	0.56	435	467	21.7	5.0	33.0	21.7	----	20.9	24.8	1.0
5/6/2004	0.65	888	932	67.1	6.0	60.0	67.1	----	51.0	14.5	0.6
5/8/2003	0.45	806	833	11.3	27.0	58.0	11.3	----	24.9	35.5	1.4
5/2/2002	0.47	1022	1057	14.1	32.0	58.0	14.1	----	22.7	42.3	1.6
5/16/2000	0.98	1184	1206	47.2	16.0	37.0	47.2	----	12.0	19.6	0.8
9/18/1999	0.77	1440	1491	37.7	33.0	56.0	37.7	----	25.5	12.0	0.5

Table 14: Zinc concentration in Willow Creek at site W-C, with and without Nelson Tunnel contamination. TVS is computed using W-C hardness.

	Nelson Tunnel			Willow Creek as measured			Willow Creek computed (no Nelson)			Table Value Standard	
	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Discharge (cfs)	Dissolved (ug/l)	Total (ug/l)	Acute (ug/l)	Chronic (ug/l)
5/3/2005	0.56	57,320	59,270	21.7	2171	2266	21.7	684	728	56	57
5/6/2004	0.65	72,870	73,790	67.1	1271	1252	67.1	570	542	37	38
5/8/2003	0.45	79,220	77,510	11.3	4009	4165	11.3	865	1089	74	74
5/2/2002	0.47	88,390	89,960	14.1	4296	4371	14.1	1348	1370	85	85
5/16/2000	0.98	32,362	31,890	47.2	1874	1912	47.2	1202	1250	47	47
9/18/1999	0.77	89,800	90,100	37.7	2831	2846	37.7	997	1006	32	33

Mainstem Willow Creek

An illustration indicating sampled locations on Willow Creek is provided in Figure 58. Figures illustrating concentrations for the 2000 and 2001 synoptics are provided in Figures 59 and 60.

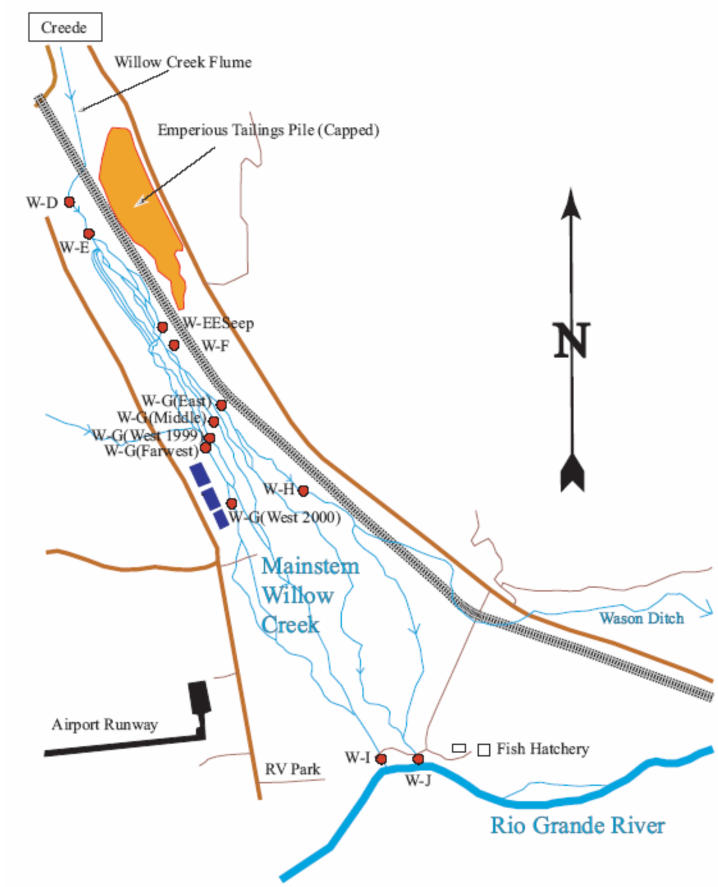


Figure 58: Mainstem Willow Creek sampling locations (from WCRC 2004a).

A pH range of 4.9 to 9.0, with an average of 7.4, has been measured from 1999 to 2005, for the main stream sampling locations. As documented in WCRC (2004a), concentrations of silver, arsenic, and selenium have been found to be at or below the detection limit for the mainstem Willow Creek. Concentrations of aluminum, cadmium, copper, lead and zinc have been found to be above the chronic Table Value Standards in Willow Creek.

Two floodplain seeps have been documented by both the Willow Creek Reclamation Committee and the USGS in the vicinity of the Emperious tailings pile (Figure 32). USGS sampling measured a pH of 3.42 for seep LW-8340, with aluminum, cadmium, copper, lead and zinc concentrations of 120,000 ug/l, 1300 ug/l, 2400 ug/l, 3000 ug/l and 320,000 ug/l, respectively. The sampling measured a pH of 2.95 for seep W-F, with aluminum, cadmium, copper, lead and zinc concentrations of 130,000 ug/l, 2100 ug/l, 2400 ug/l, 550 ug/l and 420,000 ug/l, respectively. With such concentrations, these seeps indicate a likely direct hydrologic connection between the groundwater plume (Figure 46) with Willow Creek. Discharge is quite small though, so metal loading to Willow Creek will also be small given normal circumstances. There are no other documented inflows to Willow Creek.

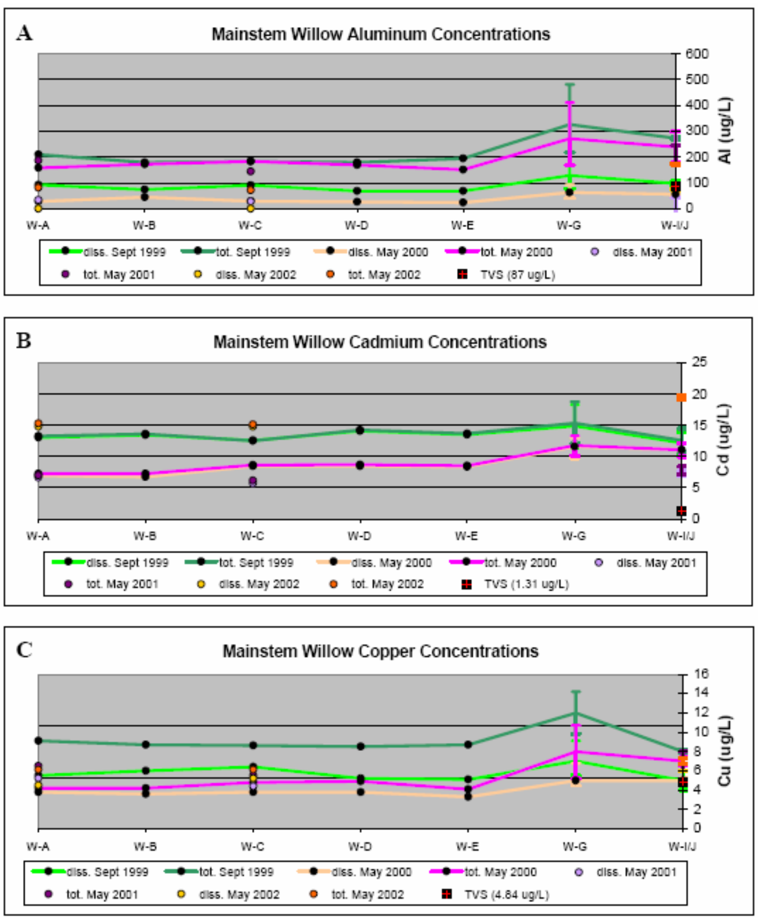


Figure 59: Willow Creek aluminum (A), cadmium (B) and copper (C) concentrations (WCRC 2004a). Table Value Standards (TVS) also shown.

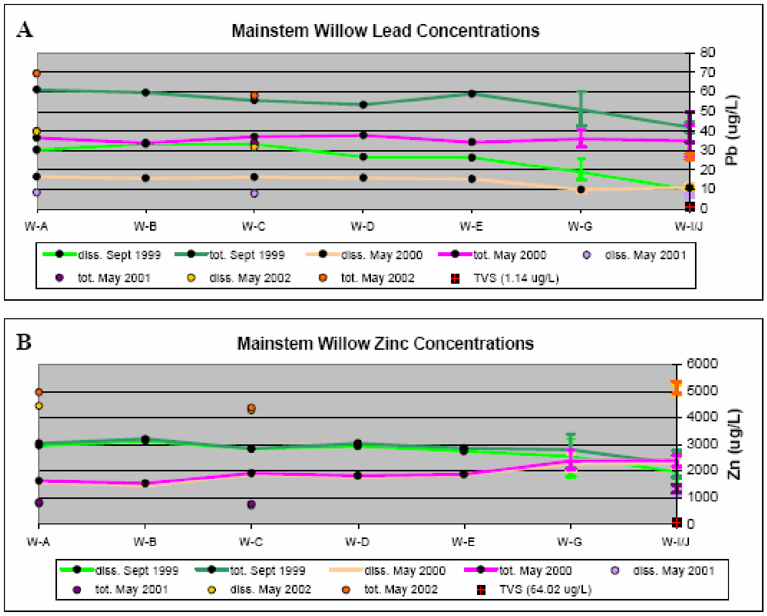


Figure 60: Willow Creek lead (A) and zinc (B) concentrations (WCRC 2004a). Table Value Standards (TVS) also shown.

A logging multi-parameter probe was deployed from 8/12 to 9/15/2005 on Willow Creek at the downstream end of the flume. Measurements from this deployment are shown in Figure 61. Diurnal fluctuations of all constituents were measured. No spikes in pH were recorded, indicating that any summer (monsoon) rains that occurred likely did not flush a significant quantity of metals down Willow Creek.

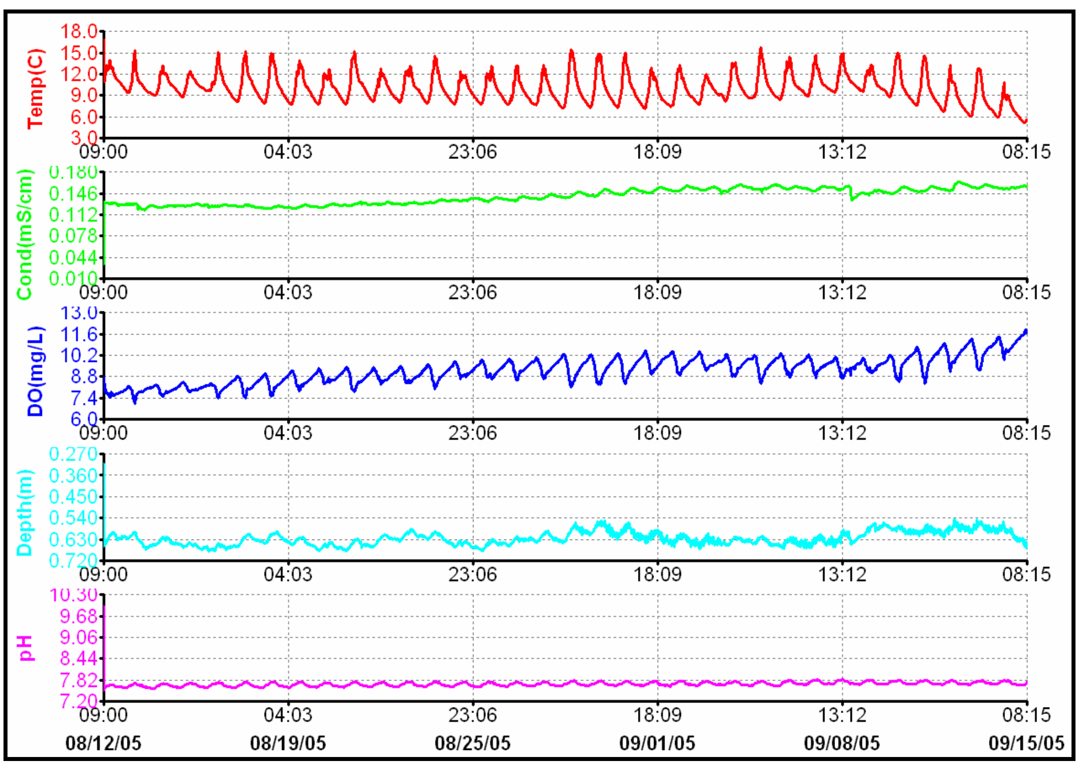


Figure 61: Willow Creek probe deployment, late summer of 2005.

Historic Water-Quality Data

Historic water-quality data was collected during previous planning studies performed by the Natural Resources Conservation Service (then known as the Soil Conservation Service). Sampling locations included East and West Willow Creek, Willow Creek, tailing ponds outlets, and the Rio Grande. The quality of this data is not known. Data from these analyses, with a sketch of the sampling locations, are provided in Appendix B.

The historic water quality data indicate that high contamination levels were released out of at least three ponds via surface flow during the period sampled. Analyses of samples collected in 1965 and 1966 from the surface effluent out from the main tailings pond indicates pH ranging from 4.0 to 5.7, lead concentration from *not detected* to 7200 ug/l, zinc concentrations from 10,500 to 1,200,000 ug/l and cyanide concentrations from 550 to 1000 ug/l. Analyses of samples collected in 1965 and 1966 from the surface effluent out from a smaller pond located between the stream and the railroad tracks, at the location of the old Humphrey's tailings pond, indicates pH ranging from 3.2 to 4.2, lead concentration from *not detected* to 2600 ug/l, zinc concentrations from 800 to 540,000 ug/l and cyanide concentrations from 40 to 100 ug/l. Analyses of samples collected from the effluent out from the mill to the "duck pond", on the west side of the floodplain, indicates pH ranging from 3.6 to 10.2, lead concentration from *not detected* to 7200 ug/l, zinc concentrations from *not detected* to 67,000 ug/l and cyanide concentrations from 550 to 600 ug/l.

Extent of Surface-Saturated Floodplain

It has been suggested that extensive wetlands be added to the floodplain, to add habitat and ecological diversity to the floodplain. If water quality improvement can be made to the floodplain, then this will be an excellent addition to the project. Several options within this planning document include this as an aspect of the proposal.

A potential issue that may limit or prevent the addition of wetlands to the floodplain is water rights. The addition of wetlands within the floodplain of a sinuous channel may increase evapo-transpiration and water use within the floodplain. However, the current braided form already has an extensive evapo-transpiration component since the greatly over-widened channel provides a great deal of surface area exposure.

To assess the current land area that is surface saturated, aerial photography in the near-infrared was flown during August of 2005, during the monsoon season. The aerial extent of the floodplain's surface-saturated land is illustrated in Figure 62. Table 15 lists the surface area of the floodplain that is estimated to be saturated, divided among the three primary properties.

Table 15: Estimated surface-saturated floodplain in Willow Creek Floodplain, August 19, 2005.

	Total Floodplain Area (acres)	Surface-Saturated Area (acres)
Creede Resources (Hecla)	85.7	23.1
Mineral County Fairgrounds	28.9	3.6
Wason Ranch	91.1	35.1

Using the proposed preliminary stream geometry of 20 feet width and 11,600 feet meander length, as detailed in the PRELIMINARY MORPHOLOGICAL DESIGN section, the stream will require approximately 5.3 acres of wetted aerial extent within the Creede Resources and Fairgrounds properties. Assuming that no net gain will be allowed in saturated land, this leaves a potential 21.4 acres of wetland enhancement for development in the Creede Resources and Fairground portion of the floodplain.

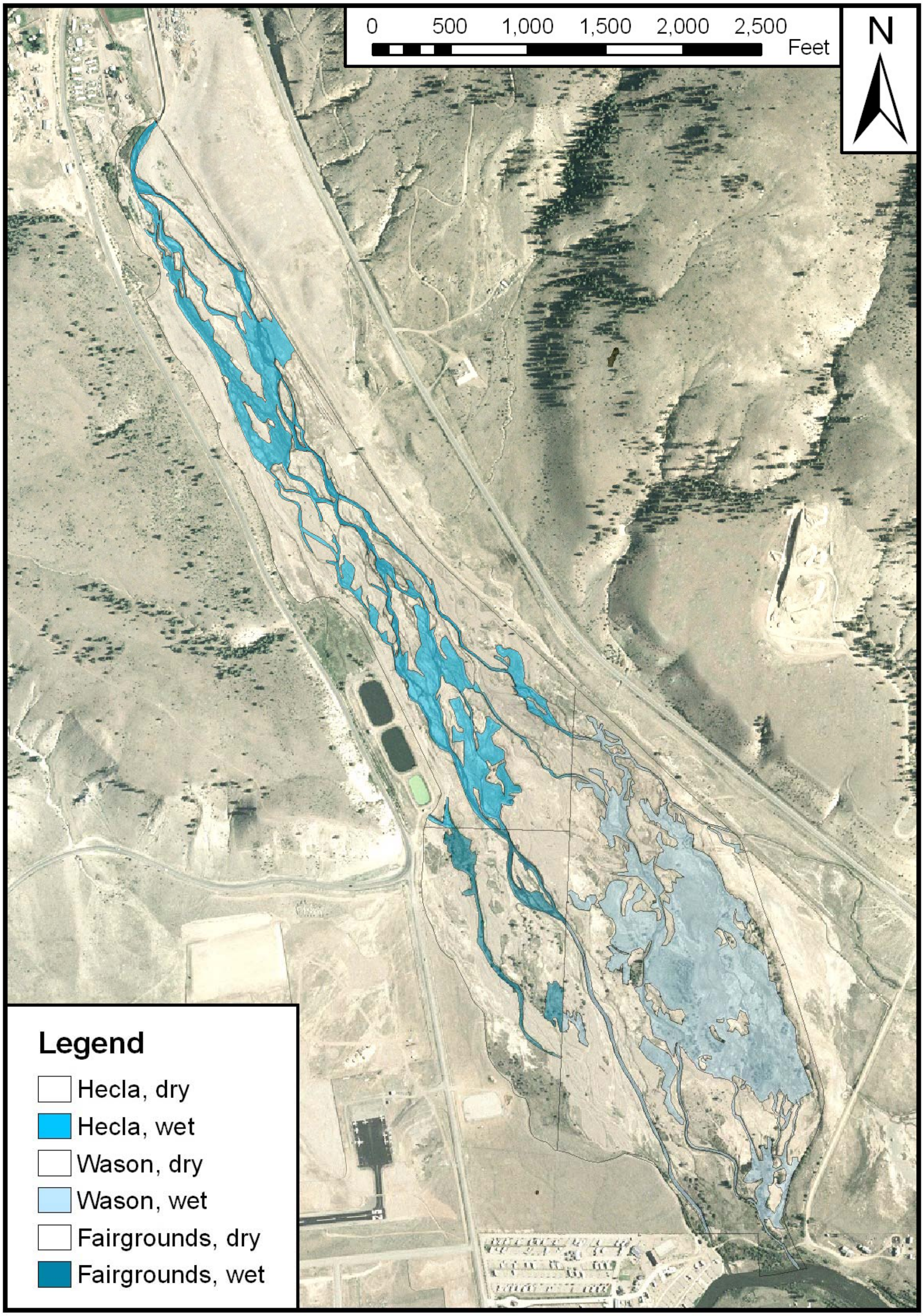


Figure 62: Approximate surface-saturated floodplain, August 19, 2005.

Bed Material

The pebble-count method was used to characterize the bed material size of the existing braided channel. The modified Wolman method, as presented in Rosgen (1996), was used in this study. This method samples within the bankfull channel for 20 to 30 bankfull widths on a proportional basis to the bed features of the stream reach.

As illustrated in Figure 63, two pebble-counts were employed to determine the stream bed material size of the floodplain: an upper reach that was 250 feet in length; and a middle reach that was 280 feet in length. The reaches were sampled approximately evenly throughout the entire length (since little to no bed form exists in the braided channel) for the entire bankfull channel width on 8/11/2005.

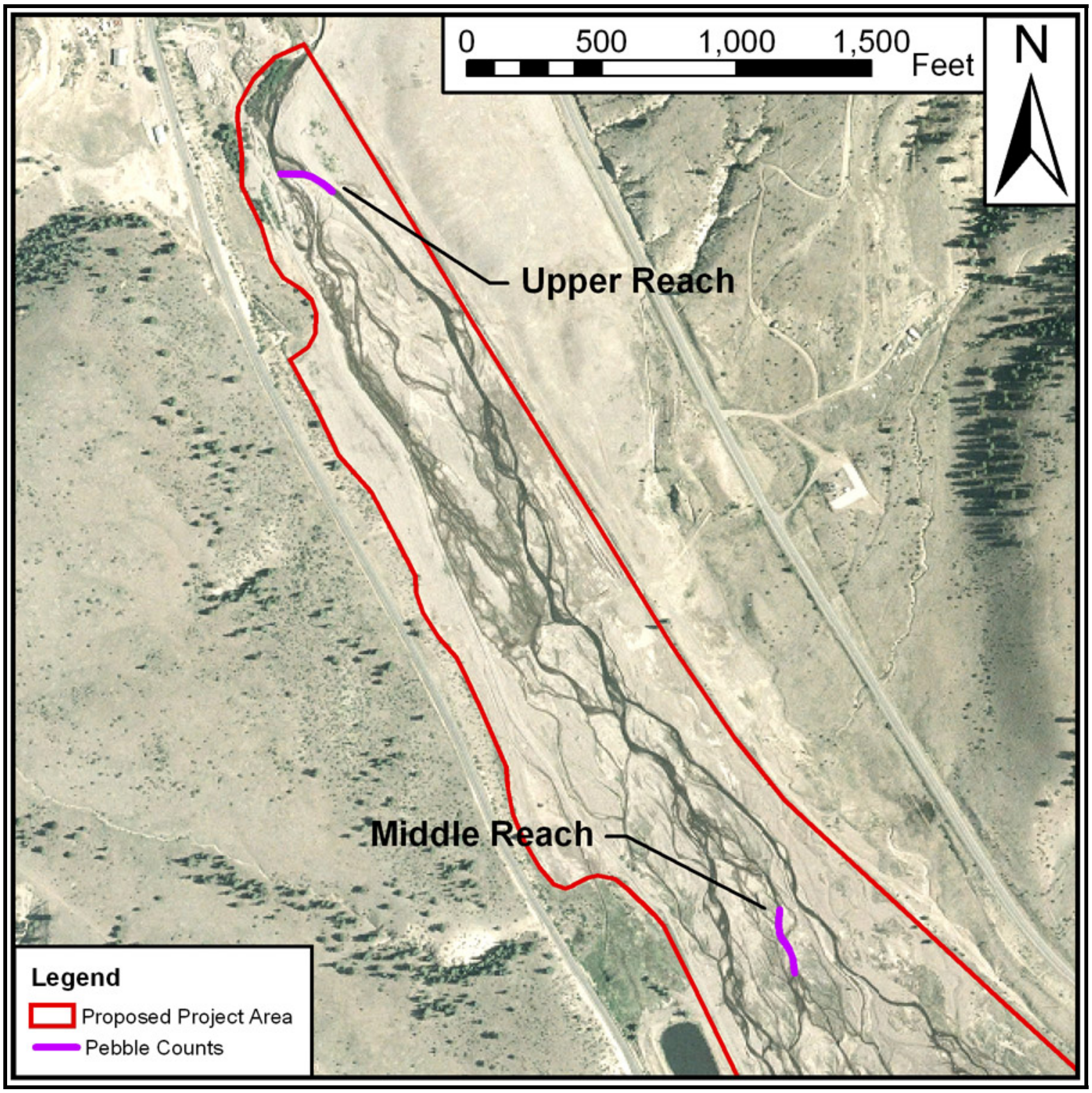


Figure 63: Upper and middle pebble count reaches.

The pebble-count distributions are provided in Figures 64 and 65. For the upper reach the D_{50} and D_{84} were 47 mm (very coarse gravel) and 103 mm, respectively. For the middle reach the D_{50} and D_{84} were 15 mm (medium gravel) and 62 mm, respectively. The D_{100} of both reaches was 180 mm. Both reaches indicate a bimodal distribution, with the middle reach indicating a stronger bimodal pattern. The second class of commonly-moved material is a fine to coarse sand. The presence of this material indicates a substantial source of sediment, which is expected considering the numerous instabilities and source material available in the watershed.

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	1	1.00	1.00
0.062 - 0.125	0	0.00	1.00
0.125 - 0.25	6	6.00	7.00
0.25 - 0.50	4	4.00	11.00
0.50 - 1.0	1	1.00	12.00
1.0 - 2.0	0	0.00	12.00
2.0 - 4.0	0	0.00	12.00
4.0 - 5.7	0	0.00	12.00
5.7 - 8.0	4	4.00	16.00
8.0 - 11.3	5	5.00	21.00
11.3 - 16.0	4	4.00	25.00
16.0 - 22.6	2	2.00	27.00
22.6 - 32.0	7	7.00	34.00
32 - 45	15	15.00	49.00
45 - 64	8	8.00	57.00
64 - 90	22	22.00	79.00
90 - 128	15	15.00	94.00
128 - 180	6	6.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

Particle Size Analysis

D16 (mm)	8
D35 (mm)	32.87
D50 (mm)	47.38
D84 (mm)	102.67
D95 (mm)	136.67
D100 (mm)	180
Silt/Clay (%)	1
Sand (%)	11
Gravel (%)	45
Cobble (%)	43
Boulder (%)	0
Bedrock (%)	0

Total Particles = 100

D 50 47.38 mm

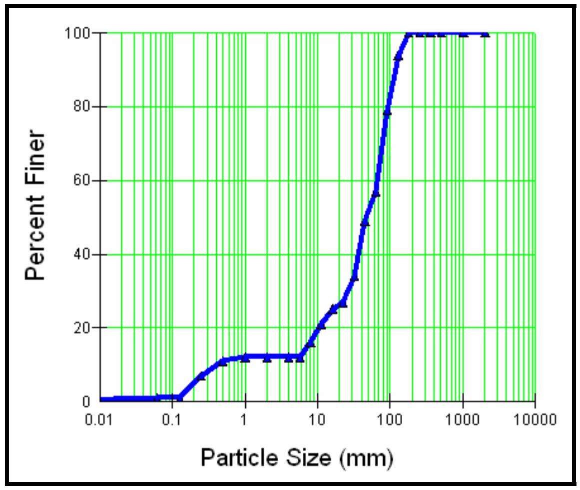


Figure 64: Upper reach pebble count data and plot.

Size (mm)	TOT #	ITEM %	CUM %
0 - 0.062	7	7.00	7.00
0.062 - 0.125	6	6.00	13.00
0.125 - 0.25	2	2.00	15.00
0.25 - 0.50	12	12.00	27.00
0.50 - 1.0	1	1.00	28.00
1.0 - 2.0	0	0.00	28.00
2.0 - 4.0	0	0.00	28.00
4.0 - 5.7	3	3.00	31.00
5.7 - 8.0	2	2.00	33.00
8.0 - 11.3	9	9.00	42.00
11.3 - 16.0	11	11.00	53.00
16.0 - 22.6	9	9.00	62.00
22.6 - 32.0	6	6.00	68.00
32 - 45	5	5.00	73.00
45 - 64	12	12.00	85.00
64 - 90	11	11.00	96.00
90 - 128	2	2.00	98.00
128 - 180	2	2.00	100.00
180 - 256	0	0.00	100.00
256 - 362	0	0.00	100.00
362 - 512	0	0.00	100.00
512 - 1024	0	0.00	100.00
1024 - 2048	0	0.00	100.00
2048 -	0	0.00	100.00

Particle Size Analysis

D16 (mm)	0.27
D35 (mm)	8.73
D50 (mm)	14.72
D84 (mm)	62.42
D95 (mm)	87.64
D100 (mm)	180
Silt/Clay (%)	7
Sand (%)	21
Gravel (%)	57
Cobble (%)	15
Boulder (%)	0
Bedrock (%)	0

Total Particles = 100

D 50 14.72 mm

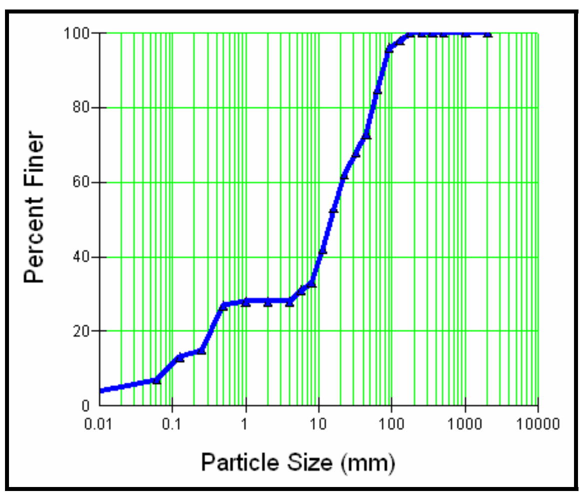


Figure 65: Middle reach pebble count data and plot.

Pre-Mining Willow Creek Morphological Condition

As shown in Figure 66, the Willow Creek floodplain was stable at the time of settlement, with dense willow vegetation and no stream braiding. The stream was very likely a stable, meandering stream of either a single-thread of multi-thread form, as is currently seen in less-disturbed streams of the area. Recreating such a stable stream form is the preference of the Willow Creek Stream Restoration and the community of Creede. Methodology for developing proper geometry for a multi-thread stream does not yet exist - a single thread approach will be used in this plan.

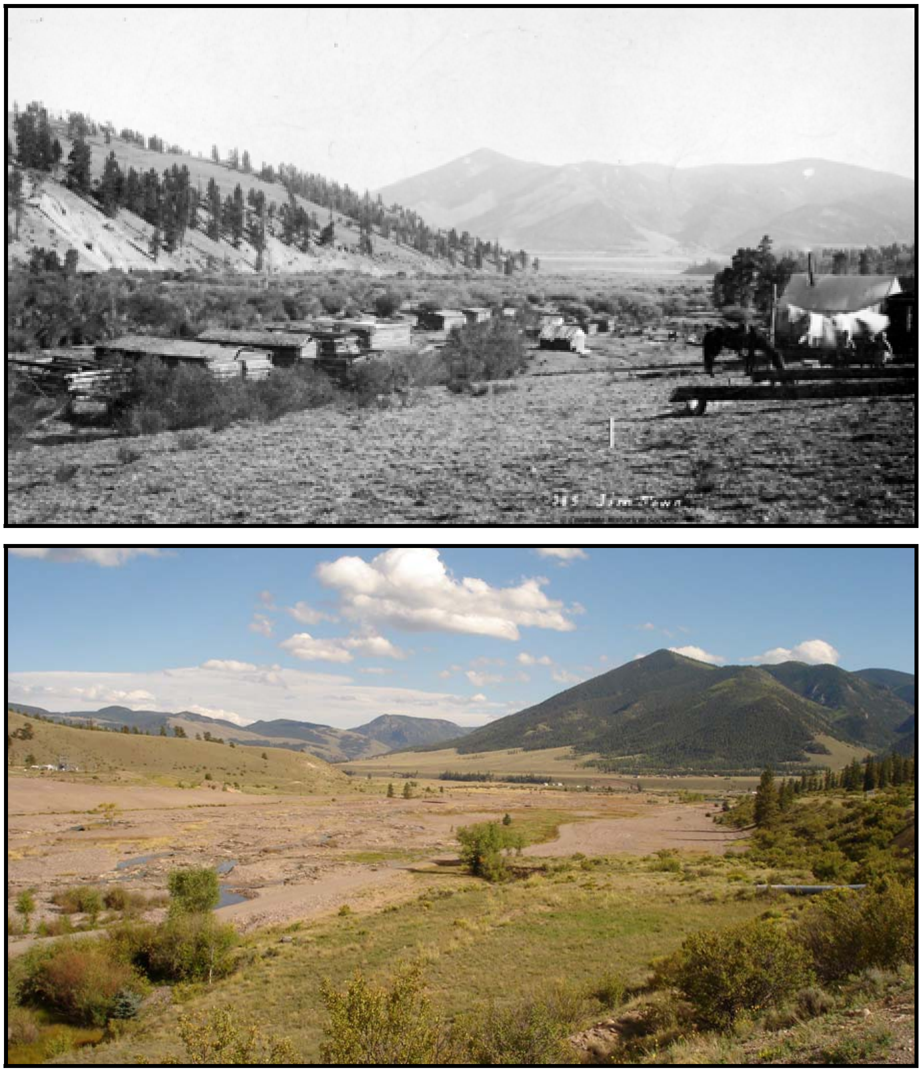


Figure 66: Willow Creek floodplain (upper), circa 1888-90 (EPA 2006), with comparison photo (lower) taken in 2005.

Regional Bankfull Characteristics

The report *Regional Bankfull Characteristics for the Lower Willow Creek Stream Restoration* (Yochum 2003) was produced to document bankfull stream data collected and statistical analysis performed on those data to extrapolate predictions to the Willow Creek floodplain. Following is a summary of the data, analysis and results of the study, for application to the Willow Creek stream restoration. This text has been extracted from Yochum (2003).

From the confluence of East and West Willow Creeks to the Rio Grande River, there are no stable natural reaches to act as a reference reach for the design of the stream restoration. Streams in adjacent watersheds are likely to offer reference reach opportunities for predicting stream characteristics through the use of dimensionless ratios, as discussed in Rosgen 2003, but this approach has limited use in the determination of bankfull area. Bankfull area is, arguably, the most important parameter in a restoration due to bankfull flow's significance in sediment transport and stream stability (Wolman and Miller 1960; Leopold et al 1964; Leopold 1994; Rosgen 1996). To attain more confidence in a restoration design, regional curves for predicting bankfull area, as well as bankfull width and sinuosity, have been developed and applied specifically to Willow Creek.

Stable reaches throughout the upper Rio Grande watershed have been surveyed to measure their bankfull characteristics. Reaches were separated by climatic zone and relevant bankfull characteristics were regressed to develop prediction equations that were then applied to Willow Creek.

Regional regression relationships for both bankfull area and width were developed to apply to the Lower Willow Creek stream restoration design. Sinuosity was also analyzed on a regional basis for application to the project design. Watersheds and reaches analyzed in the regional analysis are indicated in Figure 67. Thirty-year average precipitation estimates, from PRISM, have been provided to illustrate the precipitation variability.

Bankfull Area and Width

As discussed in Leopold (1994), streams, from a physical standpoint, are conveyance systems that transport both water and sediment. Local erosion and deposition are natural processes that allow the creation of the bankfull channel. This bankfull channel marks a balance between very frequent low-magnitude events and less frequent high-magnitude events. Very small events are not very effective at transporting sediment, since they perform little work though they do occur often. High discharge events can cause a great deal of erosion and deposition - they can perform a great deal of work and are very effective. But such events occur infrequently. Hence, it is logical that there is some intermediate discharge, neither high nor low, that is both sufficiently frequent and sufficiently effective to be most important in maintaining a channel. This point has been determined to be the channel-forming discharge, which is near coincidence with bankfull discharge. Bankfull area is the cross-sectional area of a stream where flow is at bankfull channel capacity.

While local erosion and deposition is a natural process for all streams, the rates of erosion and deposition can vary widely, with high rates often associated with sparsely vegetated streams, such as the braided stream of Lower Willow Creek, or during significant periods of climatic adjustment (Leopold 1994). On the opposite side of the spectrum, channels bound by well-vegetated streambanks can be very stable. For example, the relatively pristine Thurra River in southeastern Australia has documented lateral average migration

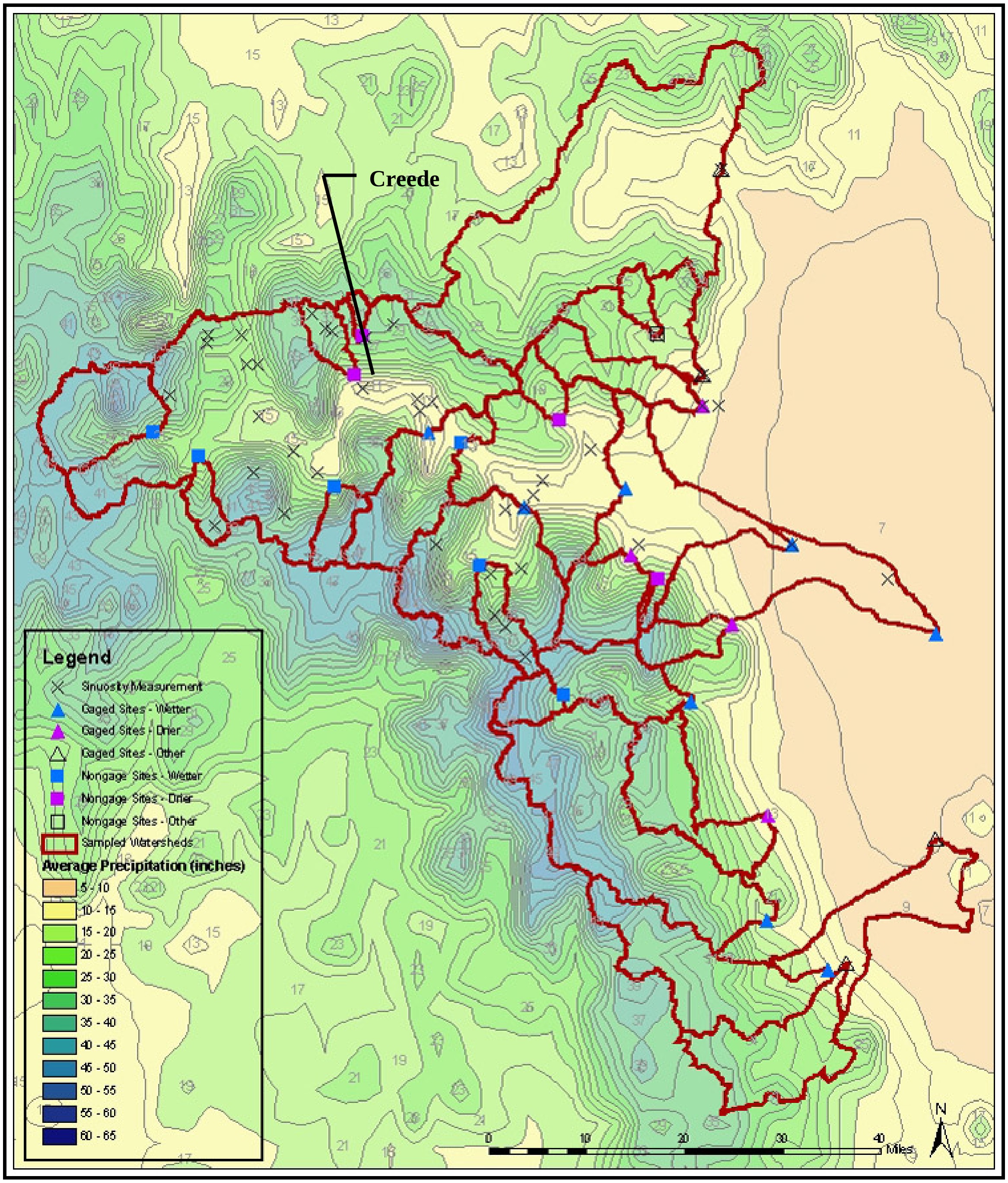


Figure 67: Watersheds and stream reaches used in analysis. Thirty-year average precipitation estimates (from PRISM) are also provided.

rates of 3.6 to 7.8 ft per 100 years and average floodplain deposition rates of 0.1 ft per 100 years. Cutoffs and major channel avulsions have been documented as occurring, on average, once in 1000 and 5000 years, respectively, for this well-vegetated sand-bed stream (Brooks and Brierley 2002).

Both reference reaches and regional bankfull characteristic analyses rely upon stable stream channels to gather information. The reaches in this regional analysis used only sites that were single thread (no islands or braiding) with well-established vegetation. Beyond the typical three terraces expected in the dominant valley type, some sites did express low terraces, which may indicate relatively recent bank stability problems, but existing conditions of reaches used in the analysis were good.

The field determination of bankfull stage is the important parameter to identify in this type of study. The procedure used to identify bankfull has been presented in Leopold 1994 and Rosgen 1996. Specifically, within a stream length of 10 to 20 bankfull widths, indicators were noted and flagged, assuring consistency within the reach. Low terraces were noted to prevent the misidentification of them as bankfull indicators. The bankfull indicators themselves included the presence of a floodplain at the elevation of incipient flooding; breaks in slopes of banks; change in particle size distribution; staining of rocks; exposed root hairs below an intact soil layer; and the location of lichens, alders, and willows (used with caution, especially considering the number of recent dry years). The flat depositional tops of floodplains and breaks in slopes were given precedence as indicators.

In regional analyses of this type it is traditional to only use reaches at or near streamgages. Such a practice is important for QA/QC reasons. Bankfull stage can be converted to bankfull discharge and a return period at the gage. Bankfull flow has been shown to occur at a frequency from 1 to 2 years (Rosgen 1996) and 1 to 2.5 years (Leopold 1994). Knowing this, it is then possible to compare the return period of the bankfull indicator with the expected range to judge if the indicator is appropriate.

The standard procedure is to run a longitudinal profile to the gage, specifically to the staff plate, and then use the gage's rating table to convert this stage to a discharge. A frequency analysis is performed on the gage's data to convert the discharge to a return period. However, this standard procedure was complicated in this regional analysis due to the lack of staff plates at all gages operated by the Colorado Division of Water Resources, as well as oftentimes mediocre to poor quality stream reaches at the gage. These poorer stream reaches were due to bridge constrictions, grazing practices, or Parshall flumes being used for gaging. In such situations, reaches a distance upstream or downstream of the gage were used. These reaches were not of sufficient distance to significantly alter discharge frequencies but were oftentimes distant enough to require extensive longitudinal profiles across multiple property boundaries, an undesirable situation.

To simplify this situation, bankfull areas were applied to the Manning's equation to attain a discharge that was then compared to the gage's discharge-frequency relationship to attain a return period of bankfull flow. Manning *n* values, which along with the normal depth assumption are the weak link in this approach, were chosen using the guides and procedures set forth in Chow (1959), Arcement and Schneider (1989), and Brunner

(2002). Return periods ranged from 1.3 to 1.8 for the seventeen streamgaged reaches sampled. These values fall within the expected range, indicating reasonably accurate selection of bankfull indicators.

Through the use of average precipitation (PRISM), gage discharge-frequency relationships, and bankfull characteristics, reaches were separated into two climatic zones. Relationships were developed to predict bankfull area and width within these zones. Several reaches were identified that did not appear to fall into either of the quantified climatic zones. These sites likely represent additional climate zones, with insufficient data to fully characterize. Mainstem streams are included in the high precipitation zone, with percent irrigated area being an important explanatory variable. Lower precipitation reaches were identified as tributary streams on leeward, rain-shadowed watersheds.

A reasonable number of data points are necessary to characterize the spatial variability of bankfull area and width in high relief areas. Using only the gaged sites (indicated in Figure 67) will lead to a similar problem occurring within the upper Rio Grande basin. The lack of gages of similar size and in vicinity to Willow Creek also causes prediction problems. Thus, it was necessary to characterize the climatic zones within this highly variable region by using eleven additional ungaged reaches. Potential quality assurance problems resulting from the lack of discharge-frequency relationships at these ungaged sites was compensated for by choosing reaches that had excellent bankfull indicators.

Results of this analysis are shown graphically in bankfull area versus drainage area (and percent irrigated) and bankfull width versus drainage area (and percent irrigated) of Figure 68.

For the lower precipitation regime (which includes Willow Creek at Creede), bankfull area was found to be approximated by

$$A_B = 11.39(1.622)^{\log(A_D)} \tag{8}$$

where A_B is bankfull area in square feet and A_D is drainage area in square miles. This simple linear regression model has an associated R^2 of 0.84 and an F-statistic of 32.2. Eight sites were used to generate the prediction. Drainage areas ranged from 2.7 to 103.5 square miles.

For the lower precipitation regime, bankfull width was found to be approximated by:

$$W_B = 8.706(1.591)^{\log(A_D)} \tag{9}$$

where W_B is bankfull width in feet an A_D is drainage area in square miles. This simple linear regression has an associated R^2 of 0.84 and an F-statistic of 31.8.

For the higher precipitation regime, bankfull area was found to be approximated by

$$A_B = 5.174(4.969)^{\log(A_D)}(0.9634)^{I_P} \tag{10}$$

where A_B is bankful area in square feet, A_D is drainage area in square miles, and I_P is percent irrigated area. Importantly, percent irrigated represents the total irrigated area diverted from the stream above the point of interest (not just the irrigated area within the watershed) as a ratio to total contributing drainage area. This multiple linear regression

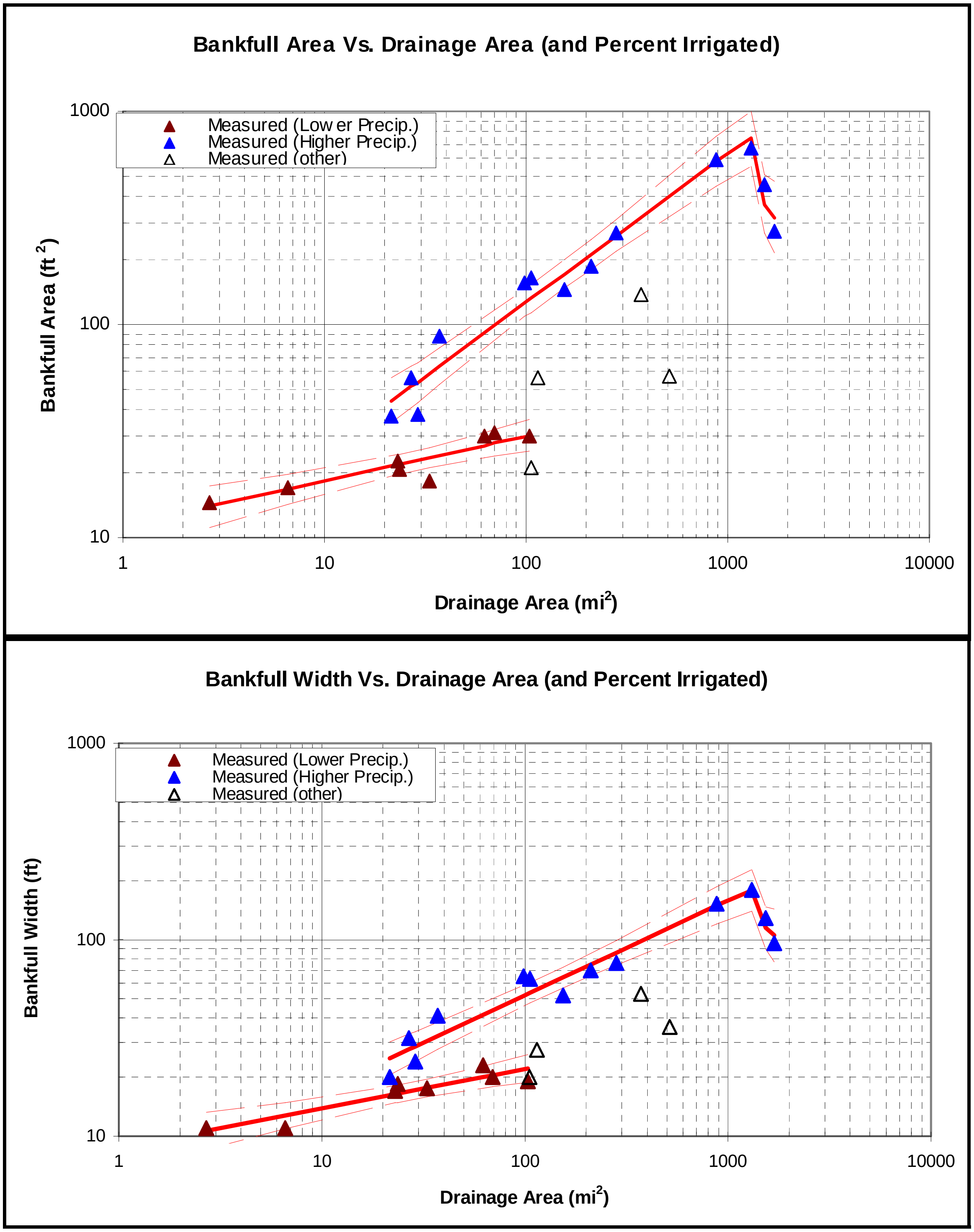


Figure 68: Bankfull area and width vs. drainage area and percent irrigated, with 95% confidence limits of the fitted values.

model has an associated R^2 of 0.96 and an F-statistic of 109.6. Thirteen sites were used to generate the regression. Drainage areas ranged from 21.6 to 1681 square miles, with percent irrigated area ranging from 0 to 28.2.

For the lower precipitation regime, bankfull width was found to be approximated by:

$$W_B = 5.653(3.040)^{\log(A_D)}(0.9768)^{I_P} \quad (11)$$

where W_B is bankfull width in feet an A_D is drainage area in square miles, and I_P is percent irrigated area. This multiple linear regression has an associated R^2 of 0.94 and an F-statistic of 83.1.

A limited number of data points were used to generate these bankfull area and width relationships. Thirteen data points were used in the higher precipitation regime and eight data points were used in the lower regime. Five data points were also found to not fit either of the curves – they appear to fall into different and undefined climate zones. More data could better define these relationships or illuminate other relationships. Due to the possible specification of unknown climate zones within this region, application of these equations must be done with care. With respect to Lower Willow Creek, the lower curve is considered applicable since several of the sites are immediately adjacent to or within the Willow Creek watershed and the Willow Creek watershed falls within a relatively lower precipitation regime.

Tables of watershed characteristics, reach characteristics and predictions are provided in Appendix A of Yochum (2003).

Sinuosity

Stream channels are very rarely straight – there is almost always a degree of sinuosity in all streams, at least in the thalweg (deepest portion of the channel). A great deal of frictional loss occurs due to sinuosity, with the curves representing a large proportion of the resistance and energy losses for a number of stream types (Leopold 1994). Sinuosity is defined as

$$K = \frac{VS}{CS} = \frac{VL}{CL} \quad (??)$$

where K is sinuosity, VS is valley slope, CS is channel slope, VL is valley length and CL is channel length.

To allow prediction of an average sinuosity for Lower Willow Creek, sinuosity and valley slope was measured for 40 sites within the upper Rio Grande watershed and plotted. Stream types for these measurements are not precisely known since this work was performed remotely using topography maps and aerial imagery. Sinuosity ranged from 1.13 to 2.79 while valley slope ranged from 0.060 to 0.00065 ft/ft. The sinuosity and valley slope data are provided in Figure 69 and Appendix B of Yochum (2003). Locations of sinuosity measurements have been provided in Figure 67.

Sinuosity measurements were made from aerial photography while valley slopes were measured from stream contour crossings on USGS quadrangles. Since specific sites were not visited to measure valley slope, these data should be considered approximate.

Measurements were limited to locations where the streams are not obscured by vegetation in aerial photography. Locations that are constrained by valleys were not used. Effort was made to identify constraint from high terraces. Effort was also made to identify straightening though the presence of oxbow lakes and old channels appearing on aerial photographs, indicating a greater natural sinuosity than currently exists. These reaches were removed from the analysis.

For the mainstem Rio Grande, archived aerial photographs were used by Agro Engineers to identify past channel locations for the Rio Grande Headwaters Restoration Project (2001). The GIS layers created through this interpretation were used to assess the level of straightening during the past 60 years and estimate sinuosity for the Monte Vista measurement site.

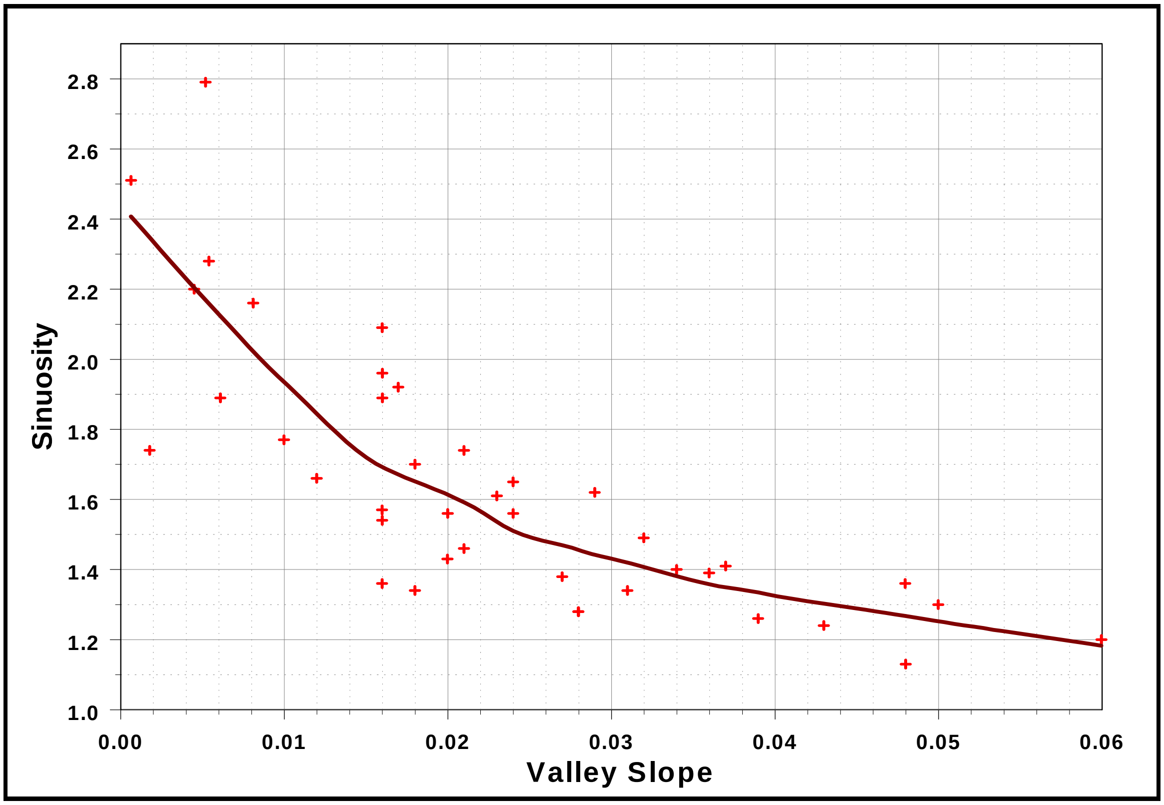


Figure 69: Sinuosity versus valley slope (in feet/feet) in the Upper Rio Grande watershed, with a Loess Curve (locally-weighted linear regression).

Though a trend is evident, scatter in these data are also evident – in addition to measurement error, other variables beyond valley slope influence sinuosity. Such variables may include bed material size, climate, and vegetation type and prevalence.

A local regression (loess) curve has been provided in the sinuosity versus valley slope plot. Loess is a generalization of running means, with individual curve points being weighted in a linear regression by its distance from the point of interest. Connecting the points creates the smooth curve. Use of the curve enables the prediction of an average sinuosity for specific valley slopes in the Upper Rio Grande watershed.

Application to Willow Creek

Equations 1 and 2 were implemented to predicted bankfull area and width for the Lower Willow Creek. A drainage area of 40.3 square miles was used for these computations. Results are provided in Table 16.

An average sinuosity for the Lower Willow Creek was predicted through the use of Figure 6, through the use of a 0.022 ft/ft valley slope. For consistency with how the figure was created, valley slope was computed from USGS topography. Results are provided in Table 16.

Table 16: Predicted bankfull characteristics for Lower Willow Creek.

Bankfull Area (ft^2)	24.8
Bankfull Width (ft)	18.3
Sinuosity	1.57

Use of these values would create a stream with an average depth of 1.35 ft, a width/depth ratio of 13.4, and an average channel slope of 0.014 ft/ft. With the dominant gravel bed material, these parameters would create a Rosgen type C4 stream.

Reference Reach

Stream dimension, pattern and profile need to be properly defined in a stream reconstruction. With the current lack of full understanding of the complex physical processes at work within stream systems and the subsequent lack of computer models capable of predicting all of the required stream characteristics for a fully functioning stream, stream restorations like Willow Creek benefit from use of a reference reach. A reference reach is a fully functioning stream reach that is used to extrapolate information from for the restoration design. This reference reach is used in a quantitative manner as a template to predict the proper dimension, pattern and profile of the restored stream (Rosgen 1996) and must be of the same valley type and of similar hydrologic, hydraulic, bed material, and sediment flow characteristics (Rosgen 1996, Shields et al 2003). A reference reach is valuable in the design a stream that can transport its sediment load, maintain stable banks and bed, and provide suitable habitat for aquatic and riparian life. However, a reference reach should not be solely relied upon – sediment transport computations and other advanced morphological techniques should also be applied in a restoration design.

A number of streams were assessed to determine their appropriateness as a reference reach for the Willow Creek restoration. After performing a survey of the area, Lower Miners Creek and Lime Creek (just above FR 526) were found to have the best potential. With additional fieldwork, however, Lower Miners Creek was found to be either suffering negative impacts from grazing practices, causing bank instabilities and poor section geometry in one reach or was heavily influenced by the action of beaver, causing inappropriate geometric form for use as a reference reach in another reach. Lime Creek was found to have greater potential for use as a reference reach. It has excellent bed form, as shown in Figure 70. Due to time constraints for performing field work during the 2006 season, sufficiently-detailed reference reach data were not collected for this study. The stream restoration design will need to collect additional data to fully define the restored stream characteristics.

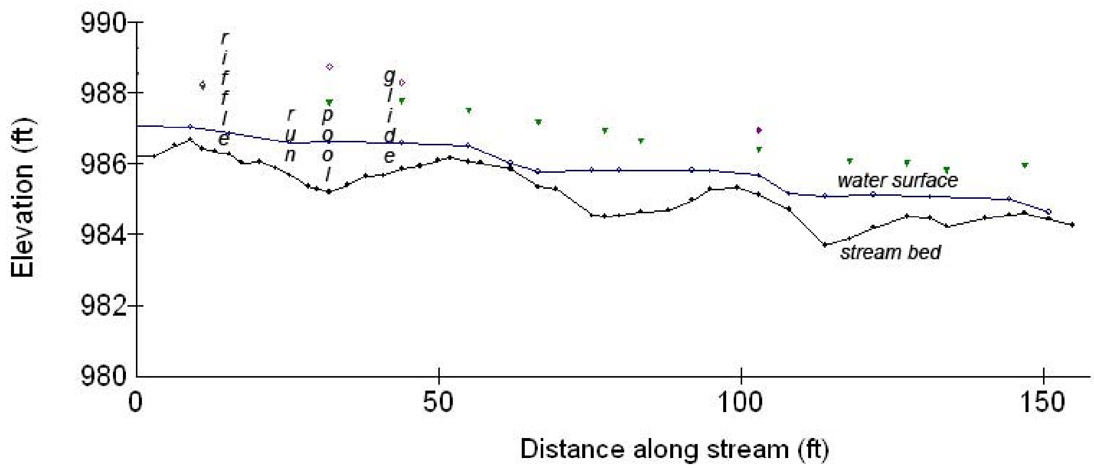


Figure 70: Bed profile of Lime Creek just above FR 526.

BIOLOGY

Steven Yochum, *Hydrologist*

A biological assessment of the Willow Creek watershed was performed using data collected from 1999 to 2001, with sampling performed by U.S. Fish and Wildlife Service's Environmental Contaminates Program and volunteers. This assessment was not a complete inventory of aquatic resources in the watershed, but was instead intended to evaluate aquatic communities upstream and downstream of the mining-impacted areas. The assessment results have been documented in WCRC (2004c). The following is a summary of the methodology, results and discussion.

Methodology

As documented in WCRC (2004c), the sampling was performed at water-quality sampling sites, as shown in Figure 71. Fish were sampled using back-pack electrofishing equipment over four days, on Sept 21-24, 1999. A Seber-LeCren Estimator was used to calculate density and biomass using one pass. Estimates using this method and one pass are rough and no confidence intervals were calculated. Macroinvertebrates were sampled on Sept 22, 1999 and May 16-18, 2000. One third of each sample was sent to University of Wyoming for identification. The benthic macroinvertebrate communities were evaluated to determine distribution of metal-intolerant and metal-tolerant species. Invertebrates were collected from eight sites on May 22, 2001 for metals analysis. Samples were analyzed for aluminum, arsenic, cadmium, calcium, copper, iron, lead, magnesium, manganese, and zinc. The metals data was analyzed to assess dietary intake estimates, to determine potential harm to wildlife. Additionally, an aquatic habitat assessment was performed in the Autumn of 1999 following Rapid Bioassessment Protocal (RBP) and Stream Reach Inventory/Channel Stability Index (SRI/CSI) methodology. The method compares reaches of interest to reference site, to provide ratings of channel conditions.

Results

As documented in WCRC (2004c), in East Willow Creek, fish were captured at each sampling site with a slight decrease in abundance from upstream to downstream (Figure 72). All of the fish captured, with one exception, were brook trout (*Salvilinus fontinalis*). One brown trout (*Salmo trutta*) was captured, at site EW-I. In West Willow Creek, fish were captured at four of five sampled sites, with abundance decreasing from upstream to downstream (Figure 72). No fish were found at site WW-A, which is downstream of the Nelson Tunnel and just upstream of the East Willow Creek confluence. Brook trout were the dominant species but brown trout were also found at WW-K and WW-I. In mainstem Willow Creek, only two brown trout were captured, one each at site W-I and W-J just above the confluence with the Rio Grande. Results for fish abundance and biomass are provided in Figures 72 and 73.

As documented in WCRC (2004c), macroinvertebrate representative taxa included mayflies (Order Ephemeroptera), stoneflies (Order Plecoptera), caddisflies (Order Trichoptera), beetles (Order Coleoptera), true flies (Order Diptera), water mites (Class Arachnida), bivalve molluscs (Class Bivalva), snails (Class Gastropoda) and flatworms (Class Turbellaria). The total abundance of invertebrates belonging to the orders

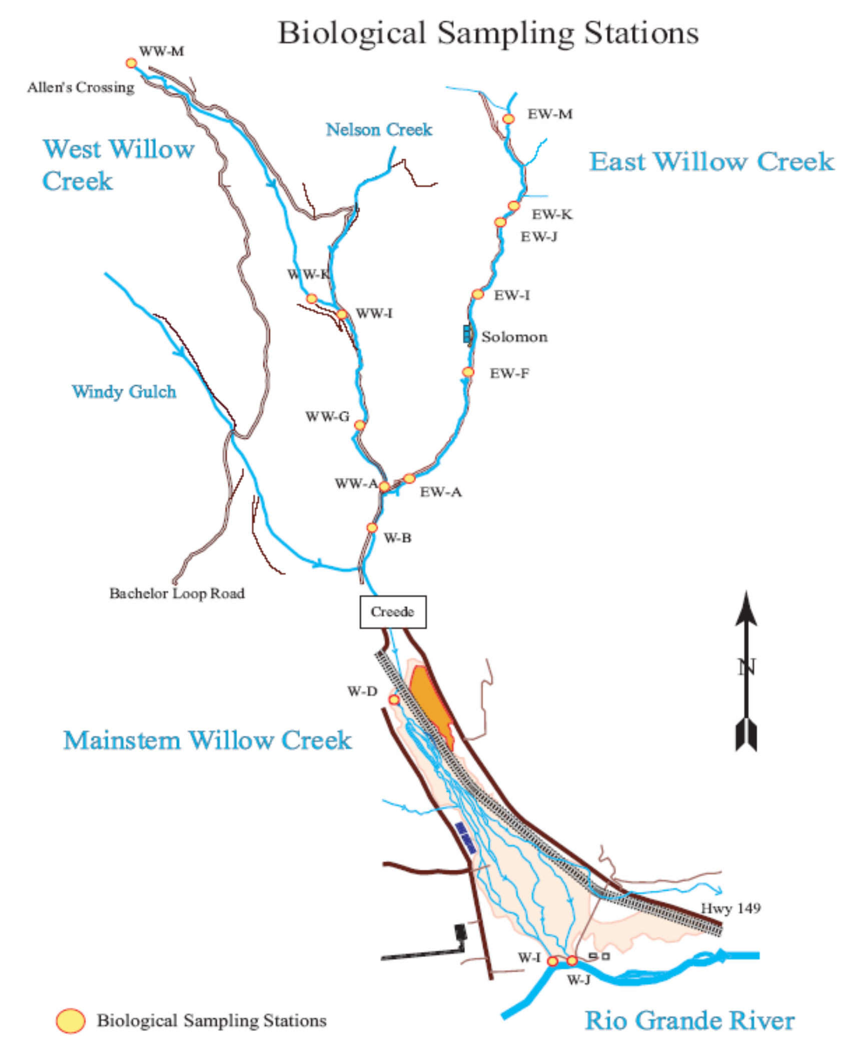


Figure 71: Willow Creek watershed biological sampling stations (WCRC 2004c).

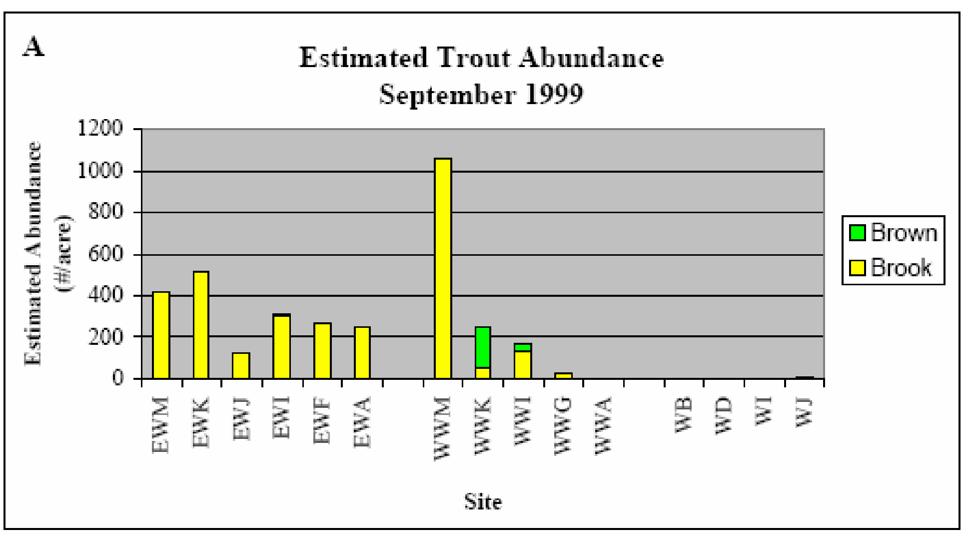


Figure 72: Trout abundance in East, West and Mainstem Willow Creeks (WCRC 2004c).

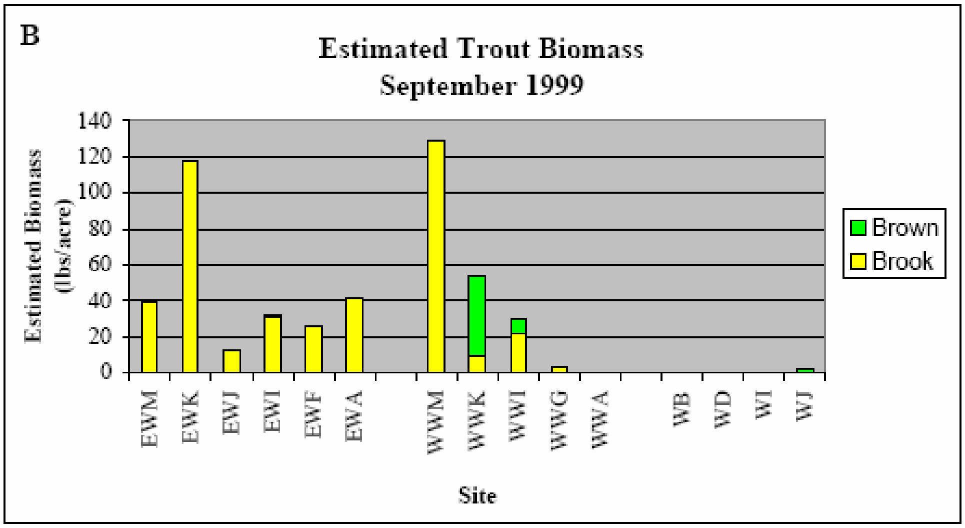


Figure 73: Trout biomass in East, West and Mainstem Willow Creeks (WCRC 2004c).

Ephemeroptera, Plecoptera and Trichoptera (EPT) were also determined. Results for both the total abundance and species abundance are provided in Figures 74 and 75.

The results of the aquatic habitat assessment, performed in September of 1999 on East, West and mainstem Willow Creeks, are provided in Table 17.

Table 17: Aquatic habitat scores, September 1999 (WCRC 2004c).

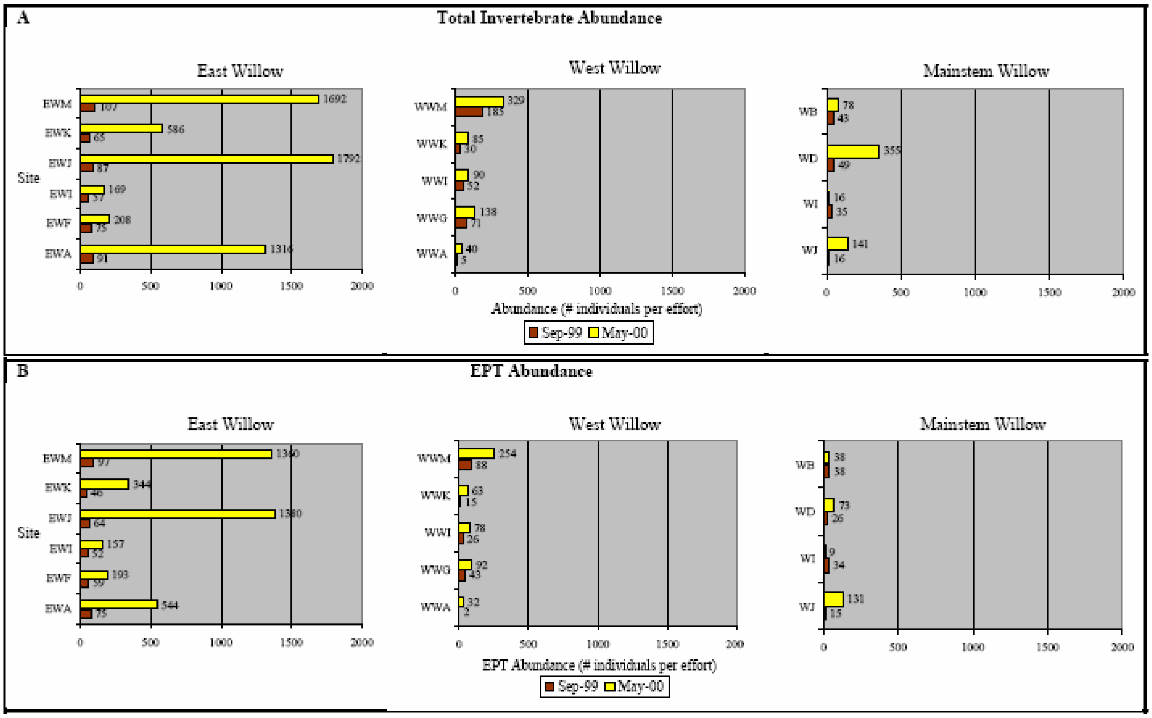


Figure 74: Total and EPT abundance of sampled macroinvertebrates (WCRC 2004c).

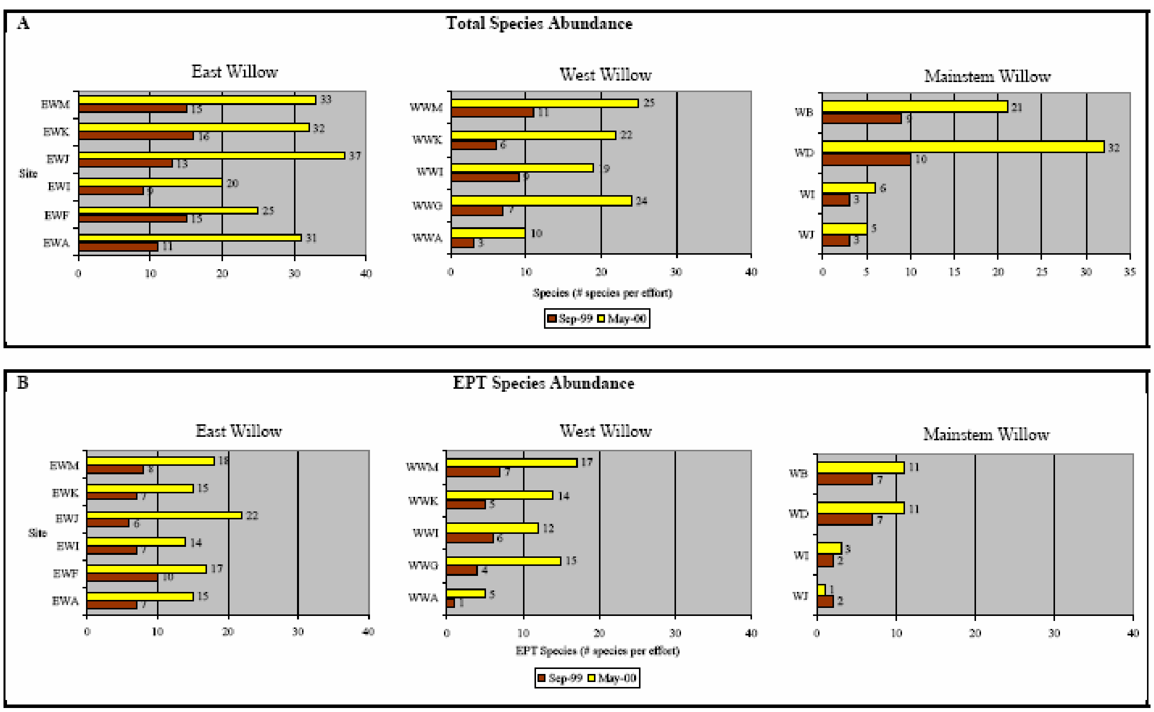


Figure 75: Total species and EPT species abundance of sampled macroinvertebrates (WCRC 2004c).

Discussion

The following is a summary of discussion points primarily provided in WCRC (2004c).

East Willow Creek

As documented in WCRC (2004c), the biological assessment of East Willow Creek indicates a self-sustaining population of brook trout. Most size classes were found at every sample site on the creek, despite chronic Table Value Standards being often exceeded on East Willow Creek (WCRC 2004a). Thirty to 60 day exposure studies have shown that cadmium concentrations between 1 and 3 ug/l in low alkalinity water can cause reduced growth, survival and fecundity in Brook Trout (Eisler 2000).

Sites EW-F and EW-I are located in a steam reach that has had a stream enhancements project constructed in 1991 (WCRC 2004c). A biologic assessment performed by the Colorado Division of Wildlife in 1987 found only three fish at their sampling site upstream of North Creede. The WCRC assessment captured 34 fish at a similar sampling location – the stream enhancement appears to have been effective at increasing fish populations.

Invertebrate tissue analyzed from East Willow Creek are below concentrations that should effect fish. Arsenic is an exception – this concentration fell above the no effect benchmark. However, it is still below concentrations expected to impact growth (WCRC 2004c).

Most stream segments analyzed on East Willow Creek were found to have a “good” SRI/CSI habitat rating, indicating that the stream segments were “partially supporting” to “supporting” an acceptable level of biologic health (WCRC 2004c). One exception, which was rated “poor”, was site EW-F, located just below the Solomon Adit.

Macroinvertebrates in East Willow Creek consisted of metals-tolerant taxa, such as caddisflies (Hydropsychidae), mayflies (Baetidae) and true flies (Orthoclasiimae). Taxa that tend to be intolerant of metals, such as Heptageniid mayflies and Rhyacophilid caddisflies, generally decrease from upstream to downstream (WCRC 2004c).

West Willow Creek

As documented in WCRC (2004c), brook trout were captured at most sites on West Willow Creek. Some brown trout were also captured, at sites WW-K and WW-I. The upper most site, WW-M, contains a self-sustaining brook trout population. Downstream of the mining-impacted areas, the sampled sites provided fewer captured fish with the populations not likely being self sustaining (WCRC 2004c). Substantial physical barriers exist, which will prevent upstream movement of fish.

Invertebrate tissue analyzed from West Willow Creek indicate concentrations less than benchmark values for sites WW-M and WW-I (WCRC 2004c). Invertebrates were not found at site WW-A, likely due to elevated metal concentrations in the water at this site.

West Willow Creek habitat quality received “poor” to “good” SRI/CSI ratings, with RBP scores ranging from “non-supporting” to “supporting” (WCRC 2004c).

Macroinvertebrates in West Willow Creek consisted of metals-tolerant taxa, such as mayflies (Baetidae) and true flies (Orthoclasiimae chironomids). Taxa that tend to be intolerant of metals, such as Heptageniid mayflies, Chloroperlid stoneflies, and Rhyacophilid caddisflies, generally decreased from upstream to downstream (WCRC 2004c).

Mainstem Willow Creek

Only two fish were collected in the mainstem Willow Creek, just above the confluence with the Rio Grande. Considering their proximity to the Rio Grande and the water-quality of Willow Creek, these fish were likely from the Rio Grande (WCRC 2004c).

According to WCRC (2004c), invertebrate tissue samples generally indicate metal concentrations for arsenic, copper and zinc that exceed dietary exposure concentrations for fish. Sites W-I and W-J have substantially higher concentrations of arsenic, cadmium, copper, lead and zinc in macroinvertebrate tissues. Metals in the Willow Creek floodplain are biologically available and being accumulated by invertebrates (WCRC 2004c).

Mainstem Willow Creek sampling sites received a “fair” to “fair-poor” SRI/CSI habitat rating, which reflect that virtually no fish were found (WCRC 2004c). The physical form of a braided channel, without pools and cover, is poor habitat for fish.

According to WCRC (2004c), macroinvertebrate communities in the mainstem Willow Creek consisted of metals-tolerant taxa such as mayflies (Baetidae), and true flies (Orthocladiinae chironomids). Taxa that are less tolerant of metals were at low abundance.

The results of the East Willow Creek assessment are a bit encouraging. Despite exceedence of chronic aquatic life water quality criteria (WCRC 2004a), East Willow Creek has a self-sustaining population of brook trout. This indicates that if the substantial mine effluents on West Willow Creek are eliminated so that the water quality of West Willow is improved to a level similar to East Willow Creek, Willow Creek downstream of Creede has the potential for sustaining a population of brook trout once physical improvements (i.e. the stream restoration) are made. However, the legacy of mine waste processing and storage in the Willow Creek floodplain may provide biologically available metals from within this stream segment itself, possibly reducing the effects of water-quality improvements in the watershed and reducing the potential for creating a self-sustaining fish population within the restored stream. Stream channelization from the current braided form will decrease the surface area of interaction with the floodplain material, potentially decreasing the collection of any biologically-available metals.

SOILS

Rebecca Burt, *Soil Scientist*
Tom Weber, *Soil Scientist*

The purpose of this soils work was to collect soil and associated water samples for the NRCS Soil Survey Laboratory characterization of the Willow Creek floodplain. Sampling was performed based on judgment of visible differences in soil characteristics. The sampled sites are indicated in Figure 76.

The soil and water sampling assessed contamination from non-point sources of metals from historical mining activities as follows: (1) suite of metals present in water and soils; (2) extent and variability of dispersal in soils along the creek; (3) general levels dispersed; and (4) possible correlation of metal levels in soils and/or associated water with vegetation or lack thereof along the stream.

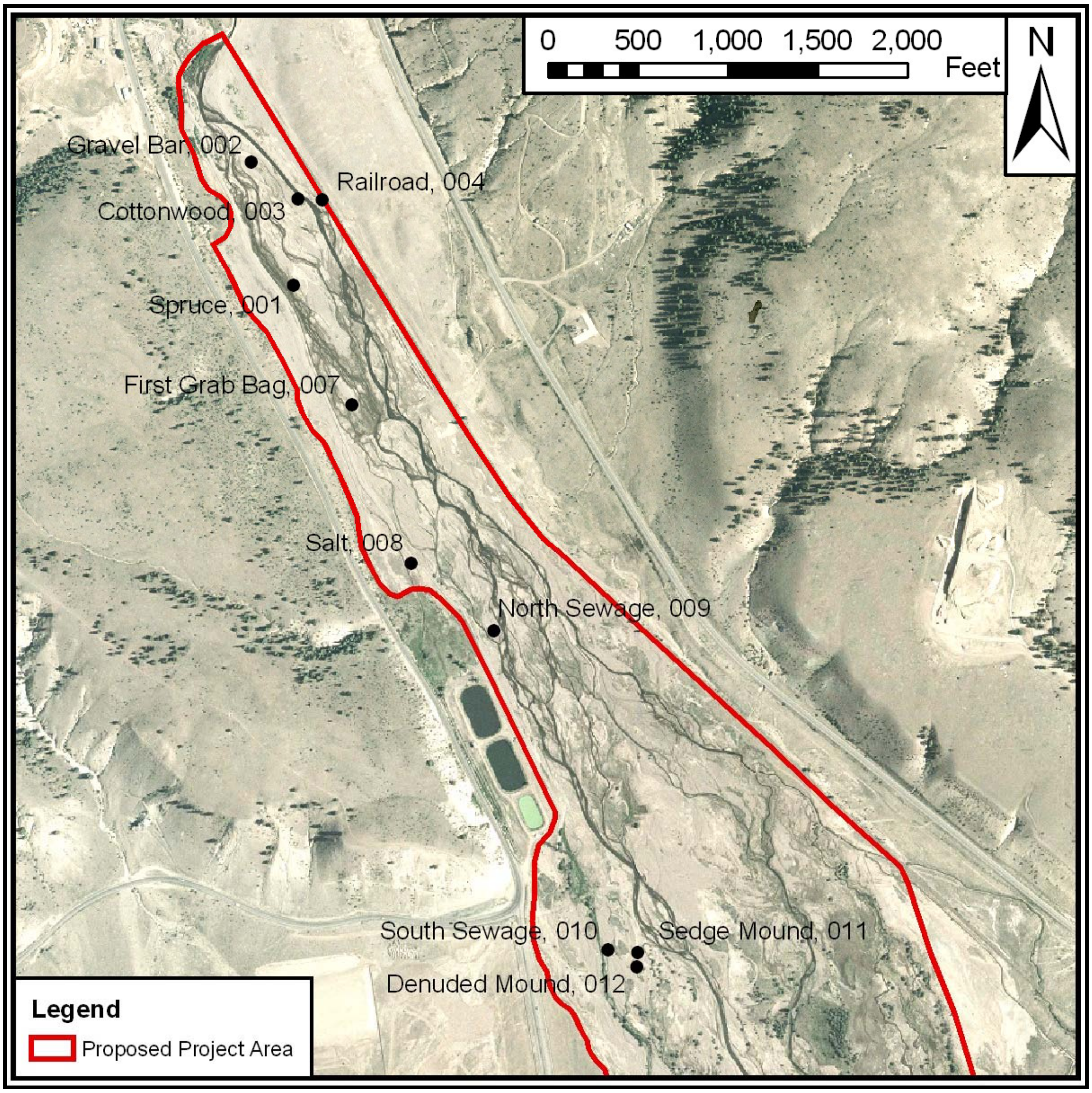


Figure 76: Soil sampling locations.

Table 18: General soil description, from USFS 1996.

LANDTYPE SYMBOL. 105
LANDTYPE UNIT. Tufted Hairgrass/Sedge on Floodplains, Aquic Cryofluvents Soils
NCSS MAP UNIT NAME. Aquic Cryofluvents, 0 to 5 percent slopes

This unit occurs on floodplains. The main plant association is tufted hairgrass/sedge. Elevations range from 8,600 to 9,400 feet. This map unit comprises approximately 1,320 acres, or 0.1 percent of the west part of the Rio Grande National Forest.

CLIMATE

Mean Annual Precipitation. 17 to 20 inches
Average Air Temperature. 38 degrees F
Frost Free Growing Season. 45 to 80 days
Runoff Season. March-May; in some years, snowpack may be absent due to exposure and snowmelt

Snowpack Information

	February	March	April	May
Snowpack Depth (in)	7-18	12-23	13-29	0-14
Water Content (in)	2.5-6.3	3.5-8.1	4.0-10.2	0-5.0

Source: NRCS Snow Survey, 1994. Ranges are estimates based on graph extrapolations.

(For more Climate data see Tables 1,2, and 3)

SOILS

Classification. Aquic Cryofluvents
Composition of Soils In This Map Unit. Aquic Cryofluvents located on gently sloping floodplains and low terraces account for about 85 percent of this unit.
Inclusions. Included are small areas of Cryaquolls and Cryohemists soils on more poorly drained sites. Some units south of Creede have inclusions of soil with a 2 to 24 inch thick layer of acid overwash material from acid mine tailings. Included areas total about 15 percent of this map unit.
Surface Stones. This landtype typically does not have stones or boulders on the surface over most of the area.

Soil Types and Brief Descriptions

Soil Type	Soil Horizon Thickness, Color and Texture
Aquic Cryofluvents	**0 to 3 in.** very dark grayish brown very gravelly sandy loam **3 to 12 in.** dark yellowish brown very gravelly loamy sand; few fine faint very dark brown mottles **12 to 18 in.** brown very gravelly fine sandy loam; few fine faint very dark brown mottles **18 to 60 in.** dark brown extremely gravelly sand; common fine faint yellowish brown mottles

(For more detailed Soils data see Tables 12 and 13)

LANDFORMS

Landform. Floodplains
Landform Components. valley floors, valley bottoms, valley trains, floodplains, first terraces, wetlands, bogs, riparian, alluvium, beaver ponds, flashflooding
Mass Movement Potential. very low

POTENTIAL NATURAL VEGETATION

Potential Natural Vegetation. tufted hairgrass/sedge
Plant Associations Component Plants. bluegrass, Arizona fescue, Rocky Mountain iris, willow, baltic rush, shrubby cinquefoil, milkvetch
NRCS Range Site. Mountain Meadow #241
Effective Rooting Depth. 0.5 to 3 feet depending on depth and duration of water table
pH Range. 6.6 to 7.8

EXISTING VEGETATION

RIS Cover Type, Acres and Percent of Map Unit

rush species, wet sedge species	2	100

The acres were determined by comparing RIS database information with soil maps. The acreage figure here may not match that in the map unit heading.

SOIL AND WATER FEATURES

Soil Type. Aquic Cryofluvents
Permeability. rapid
Drainage Class. poorly drained
Available Water Capacity. very low
Runoff. slow
Water Table Depth. 0.5 to 3.0 feet from Apr through Nov
Flooding. occasional

(For more Soil and Water data see Table 13)

MANAGEMENT INTERPRETATIONS

Soil Features that Are Unique or that Limit Potentials. Flooding and high water table limit most uses.

Past History of Use. Much of this unit occurs near Creede, and has been affected by past mining and outwash deposits from that mining.
Landscape Level Natural Disturbance Processes. Occasional floods occur on this unit. The soil itself is layered which means it was depositied by various flood events over the years.
Erosion Hazard. low due to gentle slopes.

Timber Management (See Table 5)
Soil Potential for Unsurfaced Roads. poor due to wetness
Suitable Timber Lands Rating. unsuitable, non-forested
Site Index. n/a
Reforestation Potential. n/a
Soil Limitations for Haul Roads and Skid Trails. severe due to wetness
Soil Limitations for Log Landings. severe due to wetness
Soil Limitations for Equipment Operability for Logging Areas. severe due to wetness
Soil Limitations for Total Tree Harvest. n/a
Soil Limitations for Seedling Mortality. n/a
Soil Limitations for Plant Competition. n/a

Range Management. Expect 600 lb/ac/yr in unfavorable years, 900 lb/ac/yr in median years, and 1,200 lb/ac/yr air dry production in favorable years.

Fire Management
Soil limitations for prescribed burning. slight
Engineering Interpretations. see Table 11
Revegetation Potential. fair
Recommended Seed Mixes. foothills mix

Soil Characteristics

The soils in the affected area below the town of Creede have been surveyed as part of the Rio Grande National Forest, West Part, portion of the San Juan and Rio Grande National Forests, and published in USFS (1996). The Landtype Unit is characterized as Tufted Hairgrass/Sedge on Floodplains, Aquic Cryofluvents Soils. Of particular note are the plant associations and composition, and the physical and chemical properties of the soils for this broadly defined unit. This information is provided in Table 18. This data may help to serve as reference site material when considering pre-mining conditions on the floodplain.

Soils are primarily coarse-textured with clay mineralogy. For sampled soils, the pH (1:1 water) for surface materials ranges from 5.4 to 6.8 (strongly acid to neutral), with the exception of the Denuded Mound soil with an extremely acidic pH of 4.6. Soil pH is defined as the negative logarithm of the hydrogen ion concentration. Hydrogen ion concentration increases 10x fold for every unit drop in pH. Soil pH is one of the most indicative of soil properties and a good indicator of the relative availability of plant nutrients. The primary effect of soil pH on plant growth is not so much the (H+) or (OH-) but the associated chemical environments, i.e., effect on ion activities that affect the toxicity of elements like Al and Mn or on the relative availability of plant nutrients (e.g., magnesium, calcium, phosphate, sulfur, nitrate, etc.). For example, nitrogen availability is at a maximum between pH 6 and 8 because the mineralization of N from organic matter is at a maximum in this range. The availability of P in an acid soil is reduced by the precipitation and adsorption of P by Fe and Al components (Foth and Ellis, 1988). The maximum level of P in solution (if present) will be in soils with a pH between 6.5 and 8.0, the range in which some of the study soils fall. Dissolution of Mn at low pH may cause Mn toxicity, especially in soils with a high percentage of Mn minerals.

Highest and lowest amounts of soil Pb are found in the adjacent Denuded Mound and Sedge Mound sites, respectively. Additionally, lead availability in soil is influenced by pH, increasing with decreasing pH. Soil pH of the Denuded Mound and Sedge Mound sites is 4.6 (very strongly acid) versus 5.6 (moderately acid) respectively. The lowest and greatest amounts of trace elements in the soils are found in the Sedge Mound and Denuded Mound sites, respectively, with most of the disparity explained by the greater amount of Pb in the Denuded Mound site, exceeding all other sites by several fold. This would help to explain the stark difference in appearance from vegetated versus barren sites exemplified by the Denuded Mound and Sedge Mound soils. These data suggest that a correlation may exist between metal levels in soils and/or associated water with vegetation or lack thereof along the stream. In circumstances along Willow Creek, soil pH can be used as a useful indicator of potential availability of these metals.

Major and trace element data provide some insights into potential toxicities and/or deficiencies. While these total elemental data are not a measure of the bioavailable fraction, the quantification of the total or total extractable pool of trace elements has been a common procedure for studies assessing environmental levels or background levels in soils (Shacklette and Boerngen, 1984; Shuman, 1985; Holmgren et al., 1993; Mermut et al., 1996; Chen et al., 1999; Wilson et al., 2001; Burt et al., 2003). This pool is routinely determined not only because these data are important to any overall assessment of the fate, bioavailability, and transport of trace elements (e.g., surface or groundwater waters) but also due to the lack of a widely applicable method to assess the bioavailable fraction.

While the total trace element data do not comment on the bioavailability of these elements, they do provide good information on the total pool that could become available under certain environmental conditions. Additionally, other soil/water properties such as pH can be as used as reasonably good indicators of potential availability.

Soil-Associated Water Chemistry

The water samples are less acidic than most of the sampled soils, with pH ranging from 6.5 to 7.5 (slightly acid to slightly alkaline). In general, the water samples associated with the more acidic pH's were those associated with the soil pits (e.g., Cottonwood S05CO-079-002B, pH 6.5) rather than the creek or channels, with the exception of the one replicate on the second-day sampling of the Creek Water (S05CO-079-003B-2, pH 6.6). The relatively lower pH for the water from the soil pits and for the water from the second day sampling of the Creek Water may be due in part to the capturing of more sediment in the sample compared to the other samplings.

As water moves through soils and rocks, its pH may increase or decrease as additional chemical reactions occur. The pH within streams can impact toxic materials, with high acidity or alkalinity tending to convert insoluble metal sulfides to soluble forms thereby increasing the concentrations of toxic metals.

Water Cations and Anions: Cations (Ca, Mg, Na, K) and anions (CO_3, HCO_3, F, Cl, PO_4, Br, OAc, SO_4, NO_2, and NO_3) in the water samples were determined by ion chromatography. In all water samples, the predominant and often only species of cations are Ca and Mg, and the anions are HCO_3 and SO_4, the exception being the third-day sampling of the channel (S05CO-079-004F-1) showing OAc (acetate). Carbonate buffering results from chemical equilibrium between calcium, carbonate, bicarbonate (HCO_3), carbon dioxide, and hydrogen ions in the water and carbon dioxide in the atmosphere. Buffering causes waters to resist changes in pH (Wetzel, 1975). The amount of buffering is primarily determined by carbonate and bicarbonate concentration which are introduced into the water from dissolved calcium carbonate (i.e., limestone) and similar minerals in the watershed. Glucose is the primary product of photosynthesis, with acetate (OAc) forming from the glucose as plants decompose. In most water samples, the cations and anions do not balance or equate, with the anions greater than the cations. This indicates the presence of other cations in the water samples that are unaccounted for by this method.

Water Geochemistry: Major elements (Ca, Mg, Al, Fe, K, Mg) are reported for water samples as mg/L (ppm) in solution. In general, data show Ca > Na > Mg > K, with no detectable amounts of Fe and Al. These trends are in good agreement among sampled water sites. The Al and Fe would not be expected to be detected, as the pH of many of these water samples are at or near neutral.

The geochemistry of water samples associated with the soil pits appear to show higher levels of trace elements compared to stream samplings. The tentative conclusion was that the geochemistry data for water samples appear to indicate that under some circumstances (e.g., decrease in pH and change in redox concentrations), metals may be desorbing from the sediments and solubilizing in the water. These circumstances may include when the water flow is physically obstructed causing the water to pool and stagnate. Additionally, the water data appears to indicate that the stream system may have a reasonably good buffering system, with low daily variability in pH and EC. Water data also appear to show the concentration of species of ions is consistent on a daily basis in the time frame of the sampling.

Relatively high amounts of Pb in the soils compared to water samples may be reflective of its relative low mobility in soils, accumulating primarily on the surface where it increasing presence can begin to affect soil microflora, and by Pb not being readily soluble in water, typically found in low concentrations.

Trace elements (Ag, As, Ba, Be, Cd, Co, Cr, Cu, Mn, Ni, P, Pb, Sb, Sn, Sr, V, W, Zn) are reported as µg/L (ppb) in solution. In general, data show Zn > Ba > Mn > W > Cd > Sn > Cu ~ Ni ~ V > Ag. These trends are in good agreement among sampled water sites. These trends, in terms of elements of potential concern, are also in agreement with reports by the Willow Creek Reclamation Committee (1999-2002). Arsenic, P, and Sb are not detected in water samples. Lead is only reported in the creek water samples, with the greatest amount (149.58 µg/L) in one replicate of the second-day sampling (S05CO-079-003B-2). As I mentioned earlier in regards to the lower pH for S05CO-079-003B-2 (pH 6.6) compared to other water samples, the Pb value may be due in part to the capturing of more sediment in the sample compared to the other samplings. In general, metals may be desorbed from the sediment if the water has increases in salinity, decreases in redox potential (oxygen deficient), or decreases in pH.

The amounts of Zn in the water samples (ranging from 11088.27 to 98.12 µg/L) far exceed all other trace elements. Cadmium (ranging from 1.0 to 77.16 µg/L) most often exists in small quantities in Zn ores. Cadmium loading rates have been established by the EPA, related to the cation exchange capacity and pH of the soil. Zinc is easily adsorbed by mineral and organic substances, and its chemistry is complex in terms of its various combined ionic forms. Zn is one of the most readily soluble of all the heavy metals in soils.

The water samples associated with soil pits appear to show the highest levels of trace elements. For example, the Cottonwood Water (S05CO-079-002B) show Zn, Cd, Ba, and Mn levels of 11088.27, 77.16, 314.08, and 173.17 µg/L, respectively.

VISUAL ASSESSMENT

Rosanna Brown, *Landscape Architect*

Creede, Colorado is a popular tourist destination. Many visitors and locals enjoy participating in outdoor activities, such as hiking, horseback riding, fishing and bike riding. Aesthetics and the preservation of natural resources are paramount to the success of the Lower Willow Creek Restoration Project. By evaluating the project's resources using *Procedure to Establish Priorities in Landscape Architecture* (SCS 1978), it was determined that this project is a High Priority Area. Involving a landscape architect in the early phases of reconnaissance and design will help to ensure the identification and preservation of the natural landscape components deemed valuable by the USDA-Natural Resources Conservation Service.

The town of Creede is nestled in a valley shaped by Willow Creek and the mountains nearby. The center of town straddles the creek which is contained in a rock-lined, concrete flume (Figure 77). Houses sit eerily perched at the rushing water's edge. The picturesque setting and the vernacular architecture tell a tale of days gone by- a story many tourists come to hear and one the locals hold dear. Historic buildings are preserved, and structures used for housing, shops, and restaurants are nicely appointed and neatly painted in bright, clear colors.

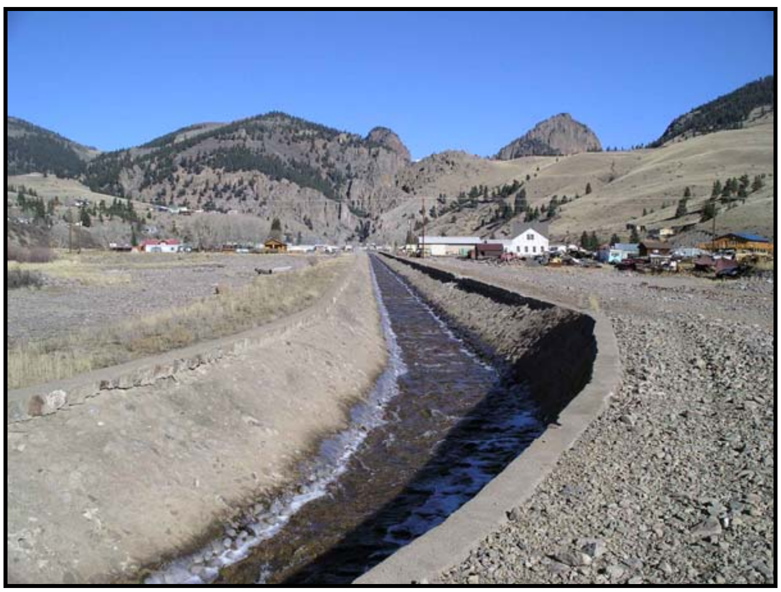


Figure 77: Rock-lined concrete flume as it passes through Creede.

The project site is within the floodplain area located downstream of town. Lower Willow Creek is highly visible to a large number of viewers, regardless of whether they are looking at the valley from Creede, or approaching town from Colorado State Road 149. Years ago, when the silver mines upstream of town were active, the mine tailings were transported to this site, via railroad, and stockpiled. No mine reclamation activities have been implemented and, as a result, the valley remains a highly unstable, and unsightly, floodplain that has been neglected over the past several decades, and the abandoned rail line remains in place (Figure 78).

Figure 78: View of the floodplain looking east showing mine tailings (barren material), and the abandoned rail line (visible line in the center of photo).

The scenery adjacent to the project area helps enhance the overall impression of the project's setting. The landforms are distinctive, with massive mountain tops that serve as a backdrop for Creede. The visual diversity of this setting is striking and is dominated by very prominent geomorphology

Vegetation is scarce in the highly disturbed portions of the floodplain. Just beyond the margins of the most traumatized areas, there is evidence of fertile soils which sustain a variety of species of flora. Native grasses and forbs cover the rocky soils (Figure 79). Upon closer inspection, blankets of grayish-greens and browns of the sages, mosses, and lichens reveal that the soils can serve as very hospitable growing environments (Figure 80).

Figure 79: Native grasses and forbs.

Figure 80: Smaller- scale vegetation.

Looking towards the horizon in any direction, the vegetation displays of the surrounding viewshed appear as random, cascading patches of lush evergreens and deciduous trees, primarily aspen. Autumn provides dramatic displays of sparkling yellow aspens sharply contrasted with dark green conifers.

Snow melt from the Rio Grande National Forest winds its way down the slopes and forms rushing streams known as East Willow Creek and West Willow Creek. These two watercourses merge into Willow Creek and are carried through Creede in a rock-lined, concrete flume. Willow Creek is then deposited downstream of town where it encounters depositional materials and quickly becomes braided and ill-defined. On the project site, the stream has very limited visual value and ceases to be the dominant feature it was upstream of Creede. Approximately three-quarters of a mile downstream of the flume, the stream becomes better defined as a series of sinuous strands weave their way through Wason Ranch (Figure 81). Eventually, the creek spills into the Rio Grande, where many people enjoy fishing and rafting.

Figure 81: Willow Creek, Wason Ranch (Creede, CO)

Given the many natural features present on this project's site, and the amazing natural features surrounding it, consideration of the landscape architectural components should begin at the earliest possible time in the planning process. This requires that a professional landscape architect be involved throughout the project's development, especially during both the planning and design phases. This visual assessment of Lower Willow Creek has illustrated the importance of identifying the general landscape quality and the landscape priorities which will help guide the planning objectives in the early portions of the project's development.

VEGETATION

Cynthia Villa, *Range Management Specialist*

The Natural Resources Conservation Service (NRCS) defines riparian zones as natural ecosystems occurring along watercourses or water bodies, occupying the transitional area between terrestrial and aquatic ecosystems (Carlson, Conaway, Gibbs, and Hoag, 1995). Riparian ecosystems of the semiarid West are extremely rich in flora and fauna due to the abundant resources it offers: cover, abundant food, travel corridors, and water. Riparian systems support the highest species richness of all major ecosystem types in Colorado, but have the smallest extent, covering only 1-2 percent of the land area (Fitzgerald, Meaney, and Armstrong, 1994).

Many plant species found in riparian areas have adapted and are limited to riparian habitats; these species are referred to as obligate riparian species. Some plant species found in riparian habitats may also occupy the surrounding uplands; these species are referred to as facultative riparian species. A local example of a facultative species is tufted hairgrass. Some riparian areas may include plant species restricted to the local riparian habitat, but can be found in non-riparian habitats at higher, cooler locations; these species are referred to as restricted riparian species (Dick-Peddie 1993). A local example of a restricted riparian species would be aspen, which may be common along streams, but also form large stands on mountain slopes.

Although plant communities and composition are highly variable elements in riparian corridors, vegetation plays an important role in determining stream corridor condition and vulnerability. The vegetation of an area usually forms layers, commonly discussed as vertical and horizontal structure. The complexity of vegetation layers provides an important role in proper community function. A varied complexity of trees, shrubs, forbs, and grasses will hold the streambank soil in place, especially during high water flow periods. Vegetation traps sediments and nutrients from surface runoff and prevents them from entering the aquatic system. The dense matrix of roots in the riparian zone serves as an effective filter of shallow groundwater. Water quality is improved through filtration and the trapping of sediment, nutrients (particularly nitrogen dissolved in groundwater), and pollutants. Riparian areas also act as a sponge by absorbing floodwaters; the water is then slowly released over a period of time, which minimizes flood damage and sustains higher base flows during late summer.

Riparian vegetation communities are typically structurally complex and provide many different habitats and support a diverse array of animal species. The multiple layers of vegetation provide multiple niches for many species of insects and wildlife. Canopies of plants growing on streambanks provide shade, cooling stream water, while root systems stabilize and moderate erosion processes and create overhanging banks, providing habitat for fish and other aquatic organisms.

The project area and the adjacient stream corridor were assessed for current vegetation type and condition. From this assessment, recommendations have been made on the type and methods of revegetation. A search of wetland and riparian literature was reviewed for this revegetation report. This was not an exhaustive search, although the pool of literature is extensive.

The project site was separated into three areas: wetland, floodplain, and upland. The majority of this report is targeting the floodplain and wetland areas, although species recommendations are provided for the upland areas. The proposed extent of floodplain an upland areas of the restoration are shown in Figure 82. Potential wetland areas are illustrated with alternatives 3 and 5, in the RESTORATION ALTERNATIVES section.

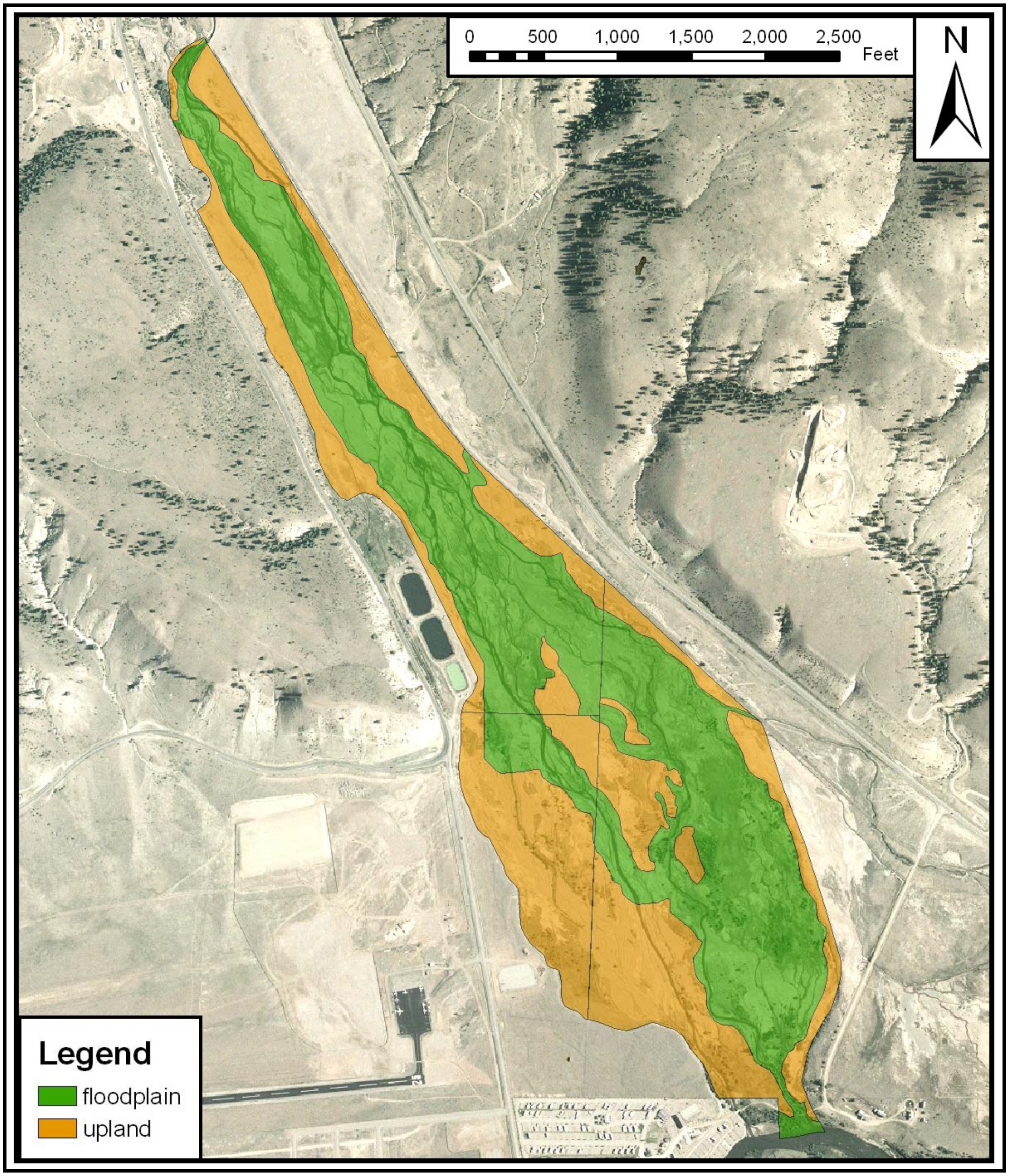


Figure 82: Restored extent of floodplain and upland areas.

Purpose

- Streambank stabilization will be required following construction to provide long-term stream stability.
- Improve water quality in the Rio Grande by trapping sediments and retaining heavy metals and other pollutants in the Willow Creek floodplain.
- Provide habitat for plants and animals.
- Increase opportunity for recreation and education.
- Improve the aesthetics of the corridor for the community and visitors.

Objectives

- Restore the vegetation on the project site which cannot be stabilized through normal succession.
- Revegetate riparian corridor with regionally appropriate grasses, shrubs, and trees.
- Stabilize areas with expected soil erosion by wind and/or water.

Current Condition

Distribution and characteristics of vegetation communities are determined by climate, water availability, topography, as well as the chemical and physical properties of the soil. Soil chemical and physical properties are major drivers on this site. Results from soil sampling conducted in 1999 by US Forest Service Soil Scientist John Rawinski, illustrate that soils of the site do not support much surface organic matter, while nutrient analyses demonstrate low natural levels of nitrogen, phosphorus, and potassium.

Due to the poor soil conditions combined with poor water quality, plant diversity throughout the site is extremely low for a riparian area. Floristic inventories were conducted in June 1999 by Dean Erhard, ecologist with US Forest Service and June 2005 by the Natural Resources Conservation Service. The species found in the surveys are provided in Tables 19 and 20. The vegetation along this corridor is primarily found along the water courses and areas that are sub-irrigated. The vegetation of these areas is dominated by graminoids with some wetlands and bands of willows found on the Wason Property and a band of willows found on Mineral County Fairground property to the south of the property, as well as scattered willows towards the northern boundary.

The dominant graminoids found along the channels of the floodplain were tufted hairgrass (*Deschampsia caespitosa*), redtop bent (*Agrostis stolonifera*), bluejoint reedgrass (*Calamagrostis canadensis*), water sedge (*Carex aquatilis*), and obtuse sedge (*Carex obtusata*). Other graminoids observed in sub-irrigated areas of the floodplain were slender wheatgrass (*Elymus trachycaulus*) and Baltic rush (*Juncus balticus*). Water sedge dominated the wetlands.

Grasses of the drier, gravelly areas of the floodplain and the upland areas consisted of western wheatgrass (*Pascopyrum smithii*), Arizona fescue (*Festuca arizonica*), sheep fescue (*Festuca ovina*), mat muhly (*Muhlenbergia richardsonis*), Kentucky bluegrass (*Poa pratensis*), nodding brome (*Bromus anomalus*), smooth brome (*Bromus inermis*), and bottlebrush squirreltail (*Sitanion hystrix*).

Large mats of cushion buckwheat (*Eriogonum ovalifolium*) were observed towards the south eastern portion of the property. Soil samples were taken throughout the floodplain, and the soils which support these mounds had the lowest pH value (4.6) found on site.

Many species of willows were observed and identified throughout the floodplain: Bebb willow (*Salix bebbiana*), Drummond's willow (*Salix drummondiana*), narrowleaf willow (*Salix exigua*), Geyer's willow (*Salix geyeriana*), sandbar willow (*Salix interior*), strapleaf willow (*Salix ligulifolia*), and mountain willow (*Salix monticola*) were the most common. Peachleaf willow (*Salix amygdaloides*) and diamondleaf willow (*Salix planifolia*) were also identified, although isolated in very small numbers.

Table 19: Floristic inventory species list, 1999.

Scientific Name	Common Name	F/G/S/T
Adenolinum lewsii	blue flax	F
Cerastium strictum	mouse-ear chickweed	F
Erigeron vetensis	fleabane	F
Eriogonum flavum	buckwheat	F
Ipomopsis aggregata	scarlet gilia	F
Mertensia lanceolatum	bluebells	F
Packera dimorphophylla	groundsel	F
Penstemon strictus	beardtongue	F
Potentilla ambigens	cinquefoil	F
Potentilla hippiana	cinquefoil	F
Ranunculus sp.	buttercup	F
Taraxacum offinale	dandelion	F
Agrostis gigantea	redtop	G
Calamagrostis canadensis	blue-joint reedgrass	G
Carex aquatilis	water sedge	G
Carex obtusata	obtuse sedge	G
Chondrosum gracile	blue grama	G
Deschampsia caespitosa	tufted hairgrass	G
Elymus longifolius	squirreltail	G
Elymus trachycaulus	slender wheatgrass	G
Festuca arizonica	Arizona fescue	G
Juncus balticus	Baltic rush	G
Koeleria macrantha	junegrass	G
Muhlenbergia filiculmis	slimstem muhly	G
Muhlenbergia sp. possible	mat muhly	G
Pascopyrum smithii	western wheatgrass	G
Poa pratensis	Kentucky bluegrass	G
Pediocactus simpsonii	ball cactus	S
Pentaphylloides floribunda	shrubby cinquefoil	S
Ribes cereum	squaw current	S
Rosa woodsi	wild rose	S
Salix geyeriana	Geyer willow	S
Salix monticola	mountain willow	S
Picea pungens	Blue spruce	T

F- forb, G- graminoid, S- shrub, T- tree
Floristic inventory conducted by USFS Ecologist Dean Erhard

Table 20: Floristic inventory species list, 2005. Red font indicates a noxious weed.

Scientific Name	Common Name	Family/Tribe	A/P	N/I	pH Range
Achillea lanulosa	western yarrow	Asteraceae	P	N	6.0 - 8.0
Allium geyeri var. *tenerum*	wild onion	Liliaceae	P	N	NA
Artemisia frigida	fringed sage	Asteraceae	P	N	7.0 - 9.0
Cicuta douglasii	western water hemlock	Apiaceae	P	N	4.8- 7.0
Cirsium arvense	Canada thistle	Asteraceae	P	I	NA
Cirsium undulatum	wavyleaf thistle	Asteraceae	P	N	NA
Eriogonum flavum	alpine golden buckwheat	Polygonaceae	P	N	NA
Linaria vulgaris	yellow toadflax	Scrophulariaceae	P	I	NA
Medicago sativa	alfalfa	Fabaceae	P	I	6.2 - 7.2
Potentilla gracilis var. *elmeri*	combleaf cinquefoil	Rosaceae	P	N	NA
Potentilla hippiana	woolly cinquefoil	Rosaceae	P	N	NA
Salsola iberica	Russian thistle	Chenopodiaceae	A	I	NA
Agropyron smithii	western wheatgrass	Triticeae	P	N	4.5 - 9.0
Agropyron trachycaulum	slender wheatgrass	Triticeae	P	N	6.0 - 7.2
Agrostis stolonifera	redtop bent	Aveneae	P	I	5.0 - 7.5
Bromus anomalus	nodding brome	Poeae	P	N	5.4 - 7.9
Bromus inermis	smooth brome	Poeae	P	I	5.5 - 8.0
Carex aquatilis	water sedge	Cyperaceae	P	N	4.0 - 7.5
Deschampsia caespitosa	tufted hairgrass	Aveneae	P	N	4.8 - 7.2
Festuca arizonica	Arizona fescue	Poeae	P	N	6.3 / 7.7
Festuca ovina	sheep fescue	Poeae	P	N	5.5 - 7.5
Juncus balticus	Baltic rush	Juncaceae	P	N	6.0 - 9.0
Muhlenbergia richardsonis	mat muhly	Eragrosteae	P	N	7.5 - 9.5
Poa pratensis	Kentucky bluegrass	Poeae	P	I	5.0 - 8.4
Sitanion hystrix	bottlebrush squirreltail	Triticeae	P	N	NA
Cercocarpus montanus	mountain-mahogany	Rosaceae	P	N	6.0 - 8.0
Chrysothamnus nauseosus	rubber rabbitbrush	Asteraceae	P	N	7.5 - 8.7
Chrysothamnus viscidiflorus va	lanceleaf rabbitbrush	Asteraceae	P	N	6.0 - 8.4
Potentilla fruticosa	shrubby cinquefoil	Rosaceae	P	N	5.0 - 8.0
Prunus virginiana	chokecherry	Rosaceae	P	N	5.2 - 8.4
Rhus aromatica	skunkbrush	Anacardiaceae	P	N	NA
Ribes cereum	wax currant	Grossulariaceae	P	N	6.5 - 7.5
Ribes inerme	white-stemmed gooseberry	Grossulariaceae	P	N	6.0 - 7.5
Ribes wolfii	Wolf's currant	Grossulariaceae	P	N	NA
Rosa woodsii	Woods' rose	Rosaceae	P	N	5.0 - 8.0
Salix bebbiana	Bebb willow	Salicaceae	P	N	5.5 - 7.5
Salix drummondiana	Drummond's willow	Salicaceae	P	N	5.2 - 7.4
Salix exigua	narrowleaf willow	Salicaceae	P	N	6.0 - 8.5
Salix geyeriana	Geyer's willow	Salicaceae	P	N	6.5 - 7.5
Salix interior	sandbar willow	Salicaceae	P	N	NA
Salix ligulifolia	strapleaf willow	Salicaceae	P	N	5.5 - 7.5
Salix monticola	park willow	Salicaceae	P	N	5.0 - 7.0
Salix planifolia	diamondleaf willow	Salicaceae	P	N	4.5 - 6.0
Picea engelmannii	Engelmann spruce	Pinaceae	P	N	6.0 - 8.0
Picea pungens	Colorado blue spruce	Pinaceae	P	N	5.5 - 7.8
Pinus contorta	lodgepole pine	Pinaceae	P	N	6.2 - 7.5
Pinus ponderosa	ponderosa pine	Pinaceae	P	N	5.0 - 9.0
Populus angustifolia	narrowleaf cottonwood	Salicaceae	P	N	6.0 - 7.5
Pseudotsuga menziesii	Douglas-fir	Pinaceae	P	N	5.0 - 7.5
Salix amygdaloides	peachleaf willow	Salicaceae	P	N	6.0 - 8.0

N- Native, I- Introduced; A- Annual, P- Perennial; ph range correlates to the range of species' growth tolerance
*Floristic inventory conducted by NRCS-Range Specialist Cindy Villa & Plant Material Specialist Pat Davey

Numerous other shrubs were identified throughout the floodplain. Rubber rabbitbrush (*Chrysothamnus nauseosus*), shrubby cinquefoil (*Potentilla fruticosa*), Wolf's currant (*Ribes wolfii*), and white-stemmed gooseberry (*Ribes inerme*) were commonly observed along mesic areas on the western side. Wood's rose (*Rosa woodsii*), lanceleaf rabbitbrush (*Chrysothamnus viscidiflorus* var. *lanceolatus*), chokecherry (*Prunus virginiana*), wax currant (*Ribes cereum*), and skunkbrush (*Rhus aromatica*) were identified further upland.

Revegetation Trials

Grass revegetation trials in an upland area of high disturbance (on the site of a former tailings evaporation pond) were conducted through the growing season from 1999 to 2003. The treatments on grass seeding plots included lime, fertilizer, compost, and topsoil applications. The results varied and were highly dependant on water availability. Plots with lime, fertilizer, compost, and topsoil applications all responded well during favorable moisture years.

Tree planting trials began in 2000. Trials included fascines, cottonwood poles, and potted trees. The willow poles and fascines were taken from an on-site location; cottonwood poles were imported from Conejos County; potted trees were provided by Colorado State University seedling program. Potted trees had the highest survival rate. Pole plantings that were midway up the bank performed the best. Poles above this location suffered from lack of water, whereas poles at streambed elevation were saturated far too long and rotted. Upland trees that were irrigated by volunteers and protected with sunscreens on south and west sides from sun and wind also did well.

Revegetation

The ability of soil to store and cycle nutrients and other elements depends on the properties and microclimate of the soil and the soil's community of organisms. These factors also determine the soil's effectiveness at filtering, buffering, degrading, immobilizing, and detoxifying other organic and inorganic materials (Federal Interagency Stream Restoration Working Group, 1998) therefore; **reincorporating topsoils into the local substrate is crucial and necessary**.

Mycorrhizal fungi are necessary components of a natural functioning ecosystem. They attach themselves to plant roots and provide a significant benefit to the plant's overall establishment, vigor, nutrient uptake, and performance. Mycorrhizal fungi may be depleted or eliminated in disturbed landscapes. Mycorrhizal inoculum provides a bridge for the return of native mycorrhizal fungi to the soil profile. It is particularly effective on shallow or nutrient poor soils. Soil microfauna are an essential element in the revegetation of this site. Using rooted plant materials that are inoculated or naturally infected with mycorrhizal fungi are very effective (Federal Interagency Stream Restoration Working Group, 1998). Soil that has been inoculated with beneficial bacteria can be purchased or inoculum can be applied prior to or in the same application as seeding.

Recommendations

High density mass planting using hardwood cuttings, willow clumps, bareroot plants, rooted cuttings and container transplants on streambanks is necessary to provide adequate bank stabilization after stream reconstruction. Riparian plantings using on-site willow clumps is preferred, if available, for quick establishment and adequate protection of stream banks. If onsite willows are not available, container transplants may be best. For willows planted along the waterline, use of a single species for the full length of the reach is preferred, so that varying plant sizes and shapes do not push flow behind the planted line (Hoag 1993b). Establishment of high density vegetation on the outside of the meander bends is a high priority to establish root density and cohesion within to the alluvial material in this high stress zone. If substantial vegetation density is not established along the outside bends within a relatively short period of time, project failure may result.

The list of cultivars and species recommended is based on the results of floristic inventories conducted in during the 1999 and 2005 growing season, as well as research conducted on species that were observed on reference reaches and through mine reclamation and revegetation literature searches. An abbreviated list (all species, but not all descriptors) of recommended species is provided in Table 21. A complete list is provided in Appendix D, as Table D-1.

The recommended species list is categorized and sorted first by life form; then by habitat [upland, floodplain, wetland]; then alphabetically by scientific name. Included in the list is common name, family or tribe for grass species, life cycle (annual, biennial, perennial [A/B/P]), whether the species is native or introduced [N/I], seasonal growth [cool or warm season], species pH tolerance [pH min-max], and saline tolerance.

Extensive descriptions of existing and proposed floodplain vegetation, including typical growth conditions and its utilization by wildlife, are provided in Appendix E. Vegetation tolerance of low pH, and relevance to areas with site disturbance and mining impacts are discussed.

Any plants that are on the plant species list that are not listed in the narrative portion of this report (Appendix E), will work as replacement or alternative species. Plants should be native to Colorado, acclimated to Mineral County's elevation and short growing season, and provide the same function as the plant substituted.

Use any of the willows listed within this report to plant as willow clumps, live poles, or fascines (bundles) along streambanks that will experience higher velocities. Use tree type willows, such as peachleaf willow, narrowleaf cottonwood, black cottonwood, and alder for the upper banks and floodplain areas. Use any of the willows listed within this report to plant along the inner elbow of bends. When fish habitat is a consideration, plant taller canopied willows and cottonwoods on the south side of the stream to provide shade. Plant any of the shrubs listed for the floodplain on the mid and upper banks and the floodplain for added structural support and diversity. Bare-root, potted, and container plant materials are best used on mid to upper banks and floodplain where water inundation and erosion is minimal (Hoag 1993b).

There are several sources available for obtaining the vegetation required for this project. Cuttings and clump plantings may be collected from local lands provided the land owners have given their permission. Cuttings and seeds could be harvested and planted on site to create a temporary nursery. This would ensure that an ample supply of locally grown and acclimated materials would be available when planting operations begin. Additionally, cuttings and rooted materials could be purchased from nurseries specializing in plants to be used for soil bioengineering purposes.

When collecting from local sources, time the harvesting so cuttings are taken from live, dormant willows and cottonwoods in the late fall, winter, or very early spring before the buds begin to break.

Table 21: Recommended plant species list, by habitat (floodplain, wetland or upland).

Scientific Name	Common Name	Family/Tribe	A/P	N/I	pH range	Habitat
Graminoids						
Agropyron trachycaulum	slender wheatgrass	*Triticeae*	P	N	6.0 - 7.2	floodplain
Deschampsia caespitosa	tufted hairgrass	*Aveneae*	P	N	3.3 - 7.2	floodplain
Elymus canadensis	Canada wildrye	*Triticeae*	P	N		floodplain
Leymus cinereus	Basin wildrye	*Triticeae*	P	N		floodplain
Phleum alpinum	alpine timothy	*Meliceae*	P	N		floodplain
Agrostis scabra	ticklegrass	*Aveneae*	P	N		wetland
Calamagrostis canadensis	bluejoint reedgrass	*Aveneae*	P	N	4.5 - 8.0	wetland
Calamagrostis inexpansa	northern reedgrass	*Aveneae*	P	N	5.5 - 8.0	wetland
Calamagrostis neglecta	slimstem reedgrass	*Aveneae*	P	N		wetland
Carex aquatilis	water sedge	*Cyperaceae*	P	N	4.0 - 7.5	wetland
Carex nebrascensis	Nebraska sedge	*Cyperaceae*	P	N	5.7 - 7.4	wetland
Glyceria striata	fowl mannagrass	*Meliceae*	P	N	4.0 - 8.0	wetland
Agropyron smithii	western wheatgrass	*Triticeae*	P	N	4.5 - 9.0	upland
Bouteloua gracilis	blue grama	*Chlorideae*	P	N	6.6 - 8.4	upland
Festuca arizonica	Arizona fescue	*Poeae*	P	N	6.3 - 7.7	upland
Oryzopsis hymenoides	Indian ricegrass	*Stipeae*	P	N	6.6 - 8.6	upland
Poa secunda	Sandberg's bluegrass	*Poeae*	P	N	6.5 - 8.2	upland
Shrubs						
Chrysothamnus viscidiflorus v	lanceleaf rabbitbrush	*Asteraceae*	P	N	6.0 - 8.4	floodplain
Cornus sericea	red-osier dogwood	*Cornaceae*	P	N	5.5 - 7.5	floodplain
Potentilla fruticosa	shrubby cinquefoil	*Rosaceae*	P	N	5.0 - 8.0	floodplain
Prunus virginiana	chokecherry	*Rosaceae*	P	N	5.2 - 8.4	floodplain
Ribes inerme	white-stemmed gooseberry	*Grossulariaceae*	P	N	6.0 - 7.5	floodplain
Ribes wolfii	Wolf's currant	*Grossulariaceae*	P	N	NA	floodplain
Rosa woodsii	Woods' rose	*Rosaceae*	P	N	5.0 - 8.0	floodplain
Salix bebbiana	Bebb willow	*Salicaceae*	P	N	5.5 - 7.5	floodplain
Salix drummondiana	Drummond's willow	*Salicaceae*	P	N	5.2 - 7.4	floodplain
Salix exigua	narrowleaf willow	*Salicaceae*	P	N	6.0 - 8.5	floodplain
Salix geyeriana	Geyer's willow	*Salicaceae*	P	N	6.5 - 7.5	floodplain
Salix interior	sandbar willow	*Salicaceae*	P	N	NA	floodplain
Salix ligulifolia	strapleaf willow	*Salicaceae*	P	N	5.5 - 7.5	floodplain
Salix monticola	mountain willow	*Salicaceae*	P	N	5.0 - 7.0	floodplain
Salix planifolia	planeleaf willow	*Salicaceae*	P	N	4.5 - 6.0	floodplain
Cercocarpus montanus	mountain-mahogany	*Rosaceae*	P	N	6.0 - 8.0	upland
Rhus aromatica	skunkbrush	*Anacardiaceae*	P	N	NA	upland
Ribes cereum	wax currant	*Grossulariaceae*	P	N	6.5 - 7.5	upland
Trees						
Alnus tenuifolia	thinleaf alder	*Betulaceae*	P	N	NA	floodplain
Picea pungens	Colorado blue spruce	*Pinaceae*	P	N	5.5 - 7.8	floodplain
Populus angustifolia	narrowleaf cottonwood	*Salicaceae*	P	N	6.0 - 7.5	floodplain
Populus trichocarpa	black cottonwood	*Salicaceae*	P	N	5.0 - 7.0	floodplain
Salix amygdaloides	peachleaf willow	*Salicaceae*	P	N	6.0 - 8.0	floodplain
Picea engelmannii	Engelmann spruce	*Pinaceae*	P	N	6.0 - 8.0	upland
Pinus contorta	lodgepole pine	*Pinaceae*	P	N	6.2 - 7.5	upland
Pinus ponderosa	ponderosa pine	*Pinaceae*	P	N	5.0 - 9.0	upland
Populus tremuloides	quaking aspen	*Salicaceae*	P	N		upland
Pseudotsuga menziesii	Douglas-fir	*Pinaceae*	P	N	5.0 - 7.5	upland

A- Annual, P- Perennial
N- Native, I- Introduced

The seeding of the project areas needs to be accomplished during the dormant season [after October 15] unless there is adequate soil moisture for germination and establishment during the growing season.

A range grass drill and auger for planting trees and shrubs can be obtained from the Colorado Division of Wildlife at no cost. The grass drill could be towed, although at very low speeds.

If livestock will be used for maintaining the health of the landscape (improve soil hydrology, improve grass health, weed control), a grazing plan must be developed and implemented. Grazing should be deferred from the site during establishment and at least for 3 years following construction; to allow for good shrub development. If grazing is planned, fencing (temporary or permanent) and water facilities will be necessary considerations.

Plant Materials

Plant materials for revegetation can be acquired through several methods: collecting seed on-site for several years prior to the beginning of construction or purchasing seed; collecting willow and shrub cuttings and clumps on or offsite; collecting cottonwood poles offsite; collecting grass and wetland plugs on or offsite; and purchasing bareroot stock and/or container stock. The advantages of purchasing nursery stock are: good root development, good carbohydrate storage, generally few pest problems, and many plant species are readily available (Hoag 1993b). Disadvantages of purchasing nursery stock include: expense, plants may not be acclimated to the elevation, and plants desired may not be available.

Cuttings are used to establish woody riparian vegetation such as willows and cottonwoods. The first step is to collect or purchase cuttings of species recommended. If gathering from the wild, the cuttings need to be taken prior to leafing out, from sites close to the area reclaimed. Cut the specimens at a 45 degree angle, then plant directly or store in buckets of water for 5-7 days. If storing in buckets of water, survival will be increased by adding root stimulants. The length of the cutting is determined by the depth to water table where it will be planted. Eight to fifteen inches are added to the cutting length to determine length above ground (Smith & Prichard, 1992). When planting the cutting, place the cut end of the plant into the water table. The terminal end of the plant can be pruned to prevent flowering to direct energy to root growth. If pruned, paint the top of the plant to prevent excess loss of moisture.

Cuttings can be collected any time during the dormant season, from leaf fall to just before the buds begin to break in the spring. Cuttings can also be collected during the growing season if all leaves are removed from the stem prior to planting, although establishment success will be lower (Hoag 1993b). Procedures and techniques for collecting, preparing, and planting willow cuttings are described by McClusky et al. (1983) and Smith & Prichard (1992). Cottonwood pole cuttings can be from tree or shrub species and typically range in diameter from ½ to 3 inches. Post plantings are from tree species and range from 3 to 6 inches in diameter (Hoag 1993b). Former NRCS District Conservationist Steve Russell found when cottonwood bark begin to get “corky” (rough and ridged), survival rates for poles drop off. Hence, three inch diameter is a critical threshold.

Hoag (1993b) found that establishment success of cuttings is significantly increased if cuttings are taken from live, dormant willows in late fall, winter, or very early spring before buds start to break. Cuttings should generally be ¾ inch diameter or larger. Larger diameter cuttings have more energy reserves than smaller diameter cuttings.

Cuttings and pole plantings, which are taken from species that sprout readily and planted in high densities, are more resistant to erosion than plantings from bareroot and container stock (Federal Interagency Stream Restoration Working Group 1998).

Steps for Successful Pole Plantings

The following steps, from USDA-NRCS (2006), are recommended when using pole plantings:

- Select collection sites as close to the area as possible to conserve genetic diversity.
- Try to match donor site and revegetation site in terms of soils, elevation, hydro-dynamics, permanent groundwater table, and soil salinity.
- Select willow cuttings from a local, native stand in healthy condition.
- Prune no more than 2/3 of plants in an area.
- Willow cuttings for pole plantings should generally be at least 1/2 inch in diameter or larger.
- Select the longest, straightest poles available
- Use only two to four-year old wood.
- Cut poles while dormant.
- Remove all side branches except the top two or three.
- The total length of the poles needed depends upon the water table depth.
- Prepare cuttings by trimming off the top to remove the terminal bud, allowing a majority of the energy in the stem to be sent to the lateral buds for root and shot development.
- Soak poles in water for at least 5 to 7 days before planting.
- Dig holes to the depth of the lowest anticipated water table.
- Sites where the water table will be within one foot of the ground surface during the growing season are better suited for willows than cottonwoods.
- The cuttings should extend several inches into the permanent water table to ensure adequate moisture for sprouting.
- At least 1/2 to 2/3's of the cutting should be below ground to prevent the cutting from being ripped out during high flows.
- Usually, at least 2 to 3 feet should be below ground.

- It should also be long enough to emerge above adjacent vegetation such that it will not be shaded out.
- Place the cuttings in the holes the same day they were removed from the soak treatment.
- Set the butt as close to the lowest annual water table elevation as possible.

Electric hammer drills (DeWalt model DW530) fitted with one-inch diameter, 3-foot bits were used to plant thousands of willows in New Mexico. With one drill, two people installed 500 willow cuttings per day to a 3-foot depth. A power auger or a punch bar can also be used.

Willow pole cuttings were generally planted on 10 to 20 foot centers in New Mexico. Areas with a shallow water table (4-6 feet) were generally planted with a higher number of pole cuttings to enhance overall survival. Often understory species were planted under the canopy of pre-existing overstory (cottonwoods, tree willows), since they are often observed occupying this niche.

It is critical to ensure that the soil is packed around the cutting to prevent air pockets. "Mudding" (filling the hole with water and then adding soil to make mud slurry) can remove air pockets.

When necessary, install tree guards around the poles to protect from beavers, other rodents, or rabbits. As buds begin to swell (usually in April or May), remove them from the lower two-thirds of the pole. This will reduce evapotranspiration water loss and stimulate root growth.

Exclude the planting area from livestock grazing for at least two to three growing seasons.

Transplanting Willow Root Wads

Willow root wads (willow clumps) are an assemblage of living stems, root crown, roots, and attached soil, excavated as a contiguous unit to be transplanted to another site. Recommendations and steps for transplanting, from USDA-NRCS, 2006, are provided below.

In general, willows that are considered for harvesting are preferably shrub-like, mature, healthy, and have multiple stems emerging from the root crown. Select willow **species** that are native, non-invasive, or have multiple beneficial values such as; wildlife habitat, forage value, aesthetics, biomass, limited water uptake, and root mass to stabilize streambanks.

Soil properties are critical for a successful and sustainable willow transplant. The best willow growth occurs on sites with a large rooting volume and good aeration, water, and nutrient availability. Soil pH should be above 5.5 and below 8.0 (Hoag. 2001). Soil texture ranging from sandy loam to silt or clay loams.

Fertilizer is generally not needed, or recommended, for wetland or riparian willow plantings (Hoag. 2001). Soil tests must be preformed and an evaluation of environmental effects completed before fertilizer application. Polymers and other moisture-retaining soil additives may be used. However, the soil moisture in plantings sites should be adequate to maintain native wetland species.

The **planting density** at which willows are planted will affect the rate at which the plants cover the area. Rapid vegetation coverage, which will require a higher planting density, may be critical in the following instances:

- Replacement site has invasive plant species and native revegetation will be utilized to control the spread.
- Areas where an abundance of wildlife may be damaging to the newly planted willows, i.e. beaver, elk, moose.
- Sites where erosion control is needed.
- The function of the planting requires dense coverage to meet wildlife habitat goals.
- Where survival rate of the newly planted willows is expected to be low.

With respect to **timing**, transplant willows while the plant is dormant. Dormancy typically lasts from late fall (early October) to early spring (late April). This increases the survival rate, putting less stress on the plant. If transplanting must be done during active growing periods, factor in an increased mortality and plant in higher density rates.

Collect willows from areas which will be destroyed by construction on-site. If collection from the impacted areas is inappropriate or not feasible, then collect from a "donor" site. Utilize suitable plant materials that are available from a nearby location with similar soils, hydrology, and elevation.

Obtain any necessary authorizations, permits, or permissions for removal of willows.

Minimize harvest impact to the donor site. **Never collect in such a way that your actions change the composition of the donor community.** Harvest from the edge of a willow patch to minimize heavy equipment damage to other plants. Take only a few plants from each donor site to disperse the impact.

The following steps are provided for transplanting willow root wads:

- Cut the stems of the willow to be transplanted 12-18 inches above the root crown, leaving at least two stems with live buds. This allows the newly transplanted willow to use nutrient reserves for producing new root mass.
- Transplants can be accomplished by backhoe, hand, excavator, or tree spade. Due to the weight of the root wad, a backhoe or excavator is the preferred means of excavating and lifting the plant.
    - The backhoe or excavator should have a bucket width of 24 inches or greater.
    - Minimum excavated surface area should be 24"x 24", with a minimum depth of 18 inches.
    - The plant should be lifted in a manner as to minimize the disturbance of the soil bound by the roots. It's important to retain the soils attached to

the roots; it protects the fragile root system and maintains the soil microorganisms.

- If long-distance transportation or storage is needed, the root wad is to be wrapped in a single layer of wetted burlap immediately after harvest to prevent damage to the root system.
    - Store in a location sheltered from the wind, sun, or freezing.
    - Store root wads so they are "roots down", placed snuggly next to each other; they should not be stacked on top of each other.
    - Re-wet the burlap as needed.
    - Do not store for more than 72 hours.
- Spacing between planted root wads should be determined by their intended function.
    - For streambank protection, root wads should be placed along the entire radius of either inside or outside curves, above the high water mark of the stream, or at the top of the bank where seasonal overbank flows are expected.
    - Spacing of the willows should also be determined by the size of the willow at maturity.
- The excavated root wad should be placed in a prepared planting hole.
    - The sides of the planting hole should be vertical, lightly scarified, and the bottom loosened to an additional depth of 6 inches.
    - The planting hole should be filled with water at least one hour but not more than 2 hours before final root wad placement.
    - The highest success rate will occur when the root wad is planted within 30 minutes of harvest.
- Place the root wad, with burlap removed, into the prepared hole and adjust to the fill grade.
    - Plant the willow wad erect, any lean greater than 10º will need to be straightened.
    - Backfill the hole halfway, tamp the soil lightly, and fill the remainder with water to eliminate air pockets.
    - Continue to add soil and water until the saturated backfill material covers the top of the root crown.
    - After the free water has drained, backfill the planting hole to finish grade. Plant roots do not develop through pockets of air, and may cause plant mortality.
- Water new transplants, twice a month, throughout the first growing season to reduce plant shock and to assist in soil compaction in the planting hole.

Seeding

Seasonal growth of plants is an important consideration for diversity of a site. Cool season plants typically begin their growth in late winter and early spring, blooming in early summer. They typically enter dormancy period in the summer heat and may resume growth or bloom again in late summer/early fall if there's enough moisture available. Warm season plants begin their growth in late spring or early summer, blooming in late summer.

Use native species or mixes (recommendations included) that are adapted to the site. The NRCS recommends using adapted improved varieties and cultivars in the following order of preference, when available:

1. <u>Certified Named Varieties (blue tagged)</u>- meets minimum requirements and standards of the Association of Official Seed Certification Agencies.
2. <u>Named Varieties</u>- has not been certified, but is sold by seed companies. A named variety is the variety name that has been assigned to a particular species, for example: slender wheatgrass "San Luis" or western wheatgrass "Arriba".
3. <u>Common Seed</u>- This is non-certified seed, which may be a named variety but not grown under the certification program. This term is also applied to seed that cannot be identified as to a variety; sometimes denotes local strains resulting from natural selection.

Quality seed is a critical component to success. The ideal method to assure quality is to specify "certified" seed. Certified seed has been approved by a certifying agency; the seed must meet minimum requirements and standards for germination and purity; also certification provides some assurance of genetic quality (Hoag, St. John, and Ogle 2001). Some native seed species are not available as certified seed. Seed quality can still be ascertained by examining percent germination and percent purity. True cost of seed can be determined by multiplying percent germination by the percent purity which equals Pure Live Seed (PLS). PLS is then divided into the price per pound to determine actual cost of good seed. These calculations can increase the accuracy of bid comparisons. Seed must be free of noxious weeds; this is also noted on seed tags along with germination and purity.

The seed mixes presented in this document have been carefully developed and are based on research and NRCS recommendations. Seeding recommendations were planned using species native to the site; species that were observed on reference reaches; and species that function similarly to plants native to the site. Deviations from the recommendations need careful consideration.

If soils in the project area have insufficient depth or physical characteristics unsuitable for development of vegetative cover, spread 3" of topsoil or soil material having the capability of supporting the planned vegetation over the deficient areas. Apply the material uniformly and in sufficient depth to support the type and quality of vegetative cover for the site. The seedbed shall be well settled and firm, although friable enough that seed can be placed at the seeding depths specified.

The best type of seeding equipment is a grass drill with 7-12 inch spacing and capable of planting fluffy seeds, equipped with a seedbox agitator, small seedbox, double disc furrow openers with depth bands, and packer wheels. Drills used will be capable of dropping the seed between the double disk openers and not behind them when planting light, fluffy seed. Fluffy and free-flowing grass seeds will be planted directly into the cover crop residue without additional seedbed preparation. The grass drill should be operated as near to the contour as practical. Grass drills will be adjusted to plant the seed to a depth of not less than ½ inch and not more than 1 inch. To accurately maintain seeding depth, drilling speed is limited to 4 to 4.5 mph. (USDA, NRCS. 1991).

Protect planted sites from trampling, grazing, rodents, and browsing animals until plants are well established. In heavy use areas, protect critical area plantings with fencing or barriers.

Timing of Planting

Willows and other shrubs need to be planted along the streambanks and bends as rock drop construction is being completed. Trees and shrubs can be successfully planted throughout the growing season beginning in May on through the end of September, although cuttings and poles installed during dormancy have the highest survival rate (Federal Interagency Stream Restoration Working Group 1998). Late fall planting of trees and shrubs can be a risky prospect and is not recommended. Trees and shrubs that are in bud and are brought in from lower elevations are subject to severe damage if they experience a hard frost.

According to NRCS Standards, grass seeding for cool season grasses in this area can be conducted in the dormant season from October 25 to April 15; during the growing season from July 15 to August 31. Grass seeding for warm season grasses in this area can be conducted in the dormant season from October 25 to April 15; during the growing season from June 15 to July 15.

Operation and Maintenance

The following actions shall be carried out to insure that this practice functions as intended.

- Replacement of dead plantings will be required until the intended functions of the practice are accomplished. Depending on the function of the root wad, replacement may be accomplished by other willow planting techniques.
- The riparian planting will be protected from adverse impacts such as excessive vehicular and pedestrian traffic, pest infestation, pesticides, livestock or wildlife damage and fire.
- Any use of fertilizers, pesticides, or other chemicals shall not compromise the intended purpose.
- Effective weed control is critical for the successful establishment of willow plantings. Willow clones do not compete well with weeds during the establishment year, or during the first part of the second growing season. Once trees close canopy, completely occupying the site, weeds are unable to compete.

Monitoring

Once established, vegetation is generally self-sustaining although initially, some maintenance may be required. A long-term monitoring program is recommended to document changes in land and plant condition; a short-term program is recommended as an annual use/management record. Vegetation should be evaluated and monitored annually for the first five years after establishment; then once every other year or two.

Monitoring of the vegetation along the corridor should include:

- photo points
- visual estimation of vegetative cover
- plant height
- percent survival

Annual monitoring will reveal any replanting or trimming that needs to be performed, determine successes and failures of construction and revegetation, highlight exposed areas that need maintenance such as clearing debris around plantings, indicate the need for weed control, and provide insight into stream stabilization process (Bentrup and Hoag, 1998)

Local Plant Sources

Potential local sources of plant material are provided in this section, from both private and commercial sources.

Private Plant Sources

Potential private land sources of plant material, with contacts, are provided below:

Miners Creek	Bob Deacon	505-266-2559
Rio Oxbow Ranch	Dale Pizel	719-658-2484
Soward Ranch	Scott Lamb	719-658-2295
Upper Wright' Ranch	Cindy Villa	719-588-4155

Other Mineral County landowners may be amiable towards providing plant material at the time of the project construction. The NRCS field office should be worked with during the design process to develop such options.

Commercial Plant Sources

Colorado State Forest Service
P.O. Box 1137
Alamosa, CO 81101
Phone: (719) 587-0915
Fax: (719) 587-0916
Specialize in potted trees, seedling trees and shrubs, supplies, and services.

La Garita Mountain Nursery LLC
Phil and Peggy Varoz
45030 Road L

Center, CO 81125
Phone: (719) 754-3630
588-1380
Specialize in annuals, perennials, trees, and shrubs for the San Luis Valley. Trees and shrubs are generally over-wintered prior to selling.

High Country Gardens
2902 Rufina St
Santa Fe, NM 87507-2929
Phone: 1-800-925-9387
http://www.highcountrygardens.com/
Retail and mail order specializing in high elevation xeric garden and landscape plants.

Pagosa Nursery Company
166 Bastille Drive
Pagosa Springs, CO
Phone: (970) 731-4126
Fax: (970) 731-5195
Email: durk@pagosa.net
www.pagosanursery.com
Specialize in retail, contract propagation, and landscaping. Specialize in montane and alpine plant materials; trees, shrubs, grasses in containers, ball & burlap, seeds.

Rocky Mountain Native Plants
3780 Silt Mesa Road
Rifle, CO 81650
Phone: (970) 625-4769
Fax: (970) 625-3276
Email: native@rmnativeplants.com
http://www.rmnativeplants.com/index.htm
Specialize in wholesale, propagation, contract propagation, and installation of native wetland and upland plant materials. Contract grow grass and grass-like species in 5.5 cu. inch, 3 cu. inch, and smaller containers.

Seed sources

Colorado Seed Solutions
Perry DiCamillo
195 N. Washington
P.O. Box 68
Monte Vista, CO 81144
Phone: (719) 852-3505
Fax: (719) 852-4942
Email: pdicamillo@seedsolutions.com
Specialize in grass and wildflower seed.

Granite Seed
1697 West 2100 North
Lehi, UT 84043
Phone: (801) 762-4422
Fax: (801) 768-3967
Email: granite@graniteseed.com
http://www.graniteseed.com
Specialize in grass and wildflower seed, erosion control products, and reclamation technical guidelines and services.

Pawnee Buttes Seed Inc.
PO Box 100
605 25th Street
Greeley, CO. 80632
(800) 782-5947
(970) 356-7002
Fax (970) 356-7263
Email: info@pawneebuttesseed.com
http://www.pawneebuttesseed.com/index.htm
Specialize in grass and wildflower seed and soil amendments.

Upper Colorado Environmental Plant Center
PO Box 448
Meeker, CO
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CULTURAL RESOURCES

Marsha Sims, *Archeologist*

This chapter outlines an intensive inventory for cultural resources south of Creede, Colorado, in Mineral County. The object of the inventory is to locate potential cultural resources, determine eligibility of these resources, provide historic and prehistoric background of the area, outline methodology of the inventory, make recommendations regarding the resources, and consult with the Colorado Historic Preservation Officer (SHPO) and other interested parties. Cultural resources were not located during the survey. The report meets the requirements set forth in National Historic Preservation Act of 1966 (NHPA) (16 U.S.C. 470f, as amended, Section 301(7)) and the Council's implementing regulations for Section 106 of the Act, "Protection of Historic Properties" (36 CFR Part 800) may affect cultural resources (historic properties) as defined in 800.16(l) and 36 CFR 800.2(c)(1) and 800.2(c)(2). Some of the activities outlined in this report may be considered undertakings (as defined in 36 CFR 800.16(y)) and have the potential to impact cultural resources. The scope of work, environment, and APE are described and recommendations for avoidance or mitigation are included in the following.

The area of potential effect (APE) is along Willow Creek from the town of Creede to the Rio Grande River. The location is:

Township 42 North Range R1W Unsectioned

Township 42 North Range R1E Unsectioned

Township 41 North Range R1E Section 6

Prehistory

Archeologists and others recognize the product of human culture known as artifacts. Artifacts are often the only items remaining at locations that humans have occupied. Cultural resources include artifacts and features such as dwellings and fire pits/hearths that were once built by humans. The order assigned in the southwest corner of Colorado is based on dates using a sequence of layers in the soil (stratigraphy) or some form of dating that measures the composition of the remains from cultural resources. This area would support a settled human community or hunter/gatherers with varying degrees of success, and the following addresses the estimated periods of occupation (Lipe et al. 1999, calibrated to Before Present—B.P. as of 2000):

Paleoindian Period 10,800-7,650 B.P.
Archaic Period
- Early 8,600-5,600 B.P.
- Middle 5,600-3,600 B.P.
- Late 3,600 B.P.-A.D. 500

Basketmaker II (Basketmaker-Puebloan cultural tradition) 2,999 B.P.-A.D. 500
Basketmaker III A.D. 1600-1350 B.P.
Pueblo I A.D. 1250-1250 B.P.
Pueblo II A.D. 1100-50 B.P.
Pueblo III A.D. 850-700 B.P.

Early Pueblo III A.D. 850-775 B.P.
Late Pueblo III A.D. 775-700 B.P.
Post-Puebloan Occupation A.D. 700-160 B.P.

In 1958 Erik Reed provided a chronology for the Mancos Canyon determining the sequence for Pueblo I-III and Basketmaker III as follows (Cassells 1997):

Mesa Verde Focus 1300-1200 B.P.
McElmo Focus (?) 1200-1125 B.P.
Mancos Focus 1125-900 B.P.
Piedra Focus 900-750 B.P.
LaPlata Focus 750-550 B.P.

Martorano et al. (1999) base a chronology on their own report, Black (1991), Guthrie et al. (1984), Duke (1997), and Irwin-Williams (1973). Several headings are listed and they are Rio Grande Basin, Mountain Tradition, Mountain Context, San Juan NF, and Oshara Tradition. The burn area is within the San Juan subarea of the Rio Grande Basin and is within the San Juan National Forest. Martorano et al. (1999) list the following:

Paleoindian 14,000 - 7,000 B.P.
Archaic 7,000 B.P. - A.D. 0
BM - II A.D. 1000 to present
BM - III
PI - III
Ute

The Paleoindian Period is represented by projectile points from Angostura, Great Basin Stemmed, Eden, Hell Gap, Agate Basin, Concave-Based Stemmed, Pryor Stemmed, and Jimmy Allen types. The tool kit includes large fluted points, scrapers, blades, hammer stones, flake knives, choppers, and bone tools utilized for animal kill sites. Kill sites involve mammoth, horse, bison, camel, and other fauna (Cassels 1997, Lipe et al. 1999).

The Archaic includes a greater use of grinding tools in the form of hand stones (manos), grinding slabs (metates); introduction of baskets and cordage woven into nets and fishing lines; and use of bone fish hooks. Other technology introduced during the Archaic is special processing of wild crops. Forms of projectile points change from the smooth lanceolate stem to notched points. Colorado provided varied climate and biology due to topography. A great number of ecological zones were available because mountains and plains environments were accessible from most locations in Colorado. So what Colorado lacked in quantity compared to other areas of the country, it made up for in the variety of ecological zones. The Archaic peoples took advantage of this diversity and many of their artifacts contest to this broad spectrum of usage. Jacal construction for houses may have been introduced at this time (Cassels 1997).

The western portion of Colorado provides a Post Archaic cultural sequence that includes the Anasazi/Fremont/Gateway groups. In the timeline, these are the Basketmaker and Pueblo designations. Representative of these groups is a reliance on cultigens, substantial masonry housing complexes, pottery, and characteristic rock art in some cases.

The Ute Tribe maintained control of this portion of Colorado from A.D. 1200 to well after historic contact in 1881. This Tribe practiced hunting and gathering across

Colorado, Utah, Arizona, and New Mexico (Crum 1996, Pettit 1990). Artifacts associated with these people might consist of tanned buffalo hides, cradle boards, moccasins, arrows, spears, guns, baskets, riding gear for horses, and tipi material.

Pottery vessels are used for preparing food, cooking, and storage (Cordell 1997; Crawford 1992, Dennell 1992, Miller 1992, Harlan 1992, McClung de Tapia 1992, Pearsall 1992, Smith 1992, Sinpoli 1991). Use of pottery implies added efforts for the community in gathering supplies such as firewood, water, and other raw materials. Supplies are necessary in order to manufacture the pottery unless the pottery is a trade item. An increase in numbers of vessels implies modification in food storage and processing (Crown and Wills 1995). The residue remaining in the pottery can be analyzed in order to discern the storage material.

Early people in the southwest traded and interacted so a mixing of the cultural materials is apparent in some cases. These people are known as the Anasazi, the Hohokam, the Mogollon, the Patayan, and the Fremont. The study area is associated with the Anasazi, and population estimates of the area are found in Wilshusen and Ortman (1999). Traits of the Salado people, Mogollon or Anasazi, are a blend of those of the Anasazi and the Hohokam. These people resided in the upper Salt River drainage. Their potter is polychrome known as Pinto, which is the earliest; Gila; and Tonto polychrome. The use of red slip is prevalent, and black and white designs are painted on the vessels. The Hohokam heartland displays Hohokam buffware (Colton and Hargrave 1937 and Crown 1994 cited in Cordell 1997).

A distinct chronology is presented for pottery of the Southwest. Characteristics of pottery from different periods of development are listed in Lister and Lister (1996).

Agricultural investigations have followed the “model of necessity” (Barker 1985; Binford 1968; Cohen 1977; Flannery 1973, Glassow 1972, 1980; Rindos 1984) and the “model of opportunity” (Le Blanc 1982, Minnis 1992).

Historic Background

The portion along the western boundary of Colorado has been referred to as the Plateau Country (Husband n.d.). La Plata County and those areas west of the Rocky Mountain range are contained in the Plateau Country historic context. The following summarizes information from Husband (n.d.) unless otherwise referenced.

Many Tribes were already established when the English, Spanish, and French people saw a new land to explore during the 1500’s. In the 1600’s pressures from the colonies in eastern North America and settlements in what is now Canada, Mexico, California, and New Mexico escalated change for the American Indians of North America. Cultures of the agrarian people were impacted and predominantly pedestrian mobility was enhanced. The Spanish brought horses to the Americas, and, although the American Indians were forbidden to acquire horses, these beautiful animals were incorporated into the way of life of these people. Some Apache Tribes and Ute Tribes embraced this new mobility and became part of the “New-Rich of the Plains” and western portions of Colorado. Territory for these Tribes included the southwestern portion of Colorado (Crum 1996, Pettit 1990, Underhill 1971). Hopi, Zuni, Navajo, and Pueblo Tribes and some of the Apache Tribes inhabited the southwest and were traditionally agrarian. These groups resisted Spanish conquest and influence for many years; however, the eastern Pueblos paid taxes of cloth, corn, or labor. Churches were built within the Pueblo area in order to convert the people. Traditional ceremonies were forbidden. The following points out some of the traits of these people in prehistoric and early historic times that would relate them to characteristics that are prevalent in the study area.

Spanish trade with the Ute Indians of Colorado stimulated expeditions into southwestern Colorado. Expeditions were by de Rivera in 1761-1765; Mora, Sandoval, and Muniz in 1775; and Dominquez and Escalante in 1776. Mexico gained independence from Spain in 1821, and this opened the area to the mountain men era.

Early people in the southwest were referred to as Mogollon, Hohokam, and Anasazi (Early Puebloan) people. These early people relied on growing plants, using stone hoes, and digging canals in order to survive. Villages were pit-houses near the gardens or stone structures in cliff overhangs. Prehistoric Anasazi people known by the Navajo name that means “old people” lived to the southest. The cultural affiliation is represented in the section entitled “Prehistory” and is Basket Maker II through Pueblo III. The style of building in the Basket Maker period first relied on a pit house having a wooden superstructure, and then they built a structure of poles and mud in a rectangle. Fremont and Gateway are people who illustrated Anasazi traits and lived to the north of the study area (Cassells 1997, Dutton 1975).

Tribal affiliations have been attributed to the areas of the southwest that involve the study area. The Anasazi are most closely affiliated with the modern day Rio Grande Puebloans of New Mexico, from Albuquerque to Taos, and the Hopi of northern Arizona (Cassells 1997: 145). Consultation with all of the tribes listed above is recommended in order to determine what Tribes are interested. The cultural resources of the study area are outlined in this report. The Tribes termed Athabascan are included in this study because their antiquity has not been definitively determined.

Forts and American expeditions into the area in 1836 to 1843/45 increased interest in Colorado, and Colorado became part of an American territory in 1848 following the Mexican War. Americans mounted expeditions through the territory. Among them were Fremont and Beal and Gunnison in 1853, Marcy in 1857-58, Colonel Loring in 1858, Berthoud/Bridger in 1861, Powell in 1869, King in 1871-1873, Wheeler in 1873, and Hayden in 1873-1876.

Treaties with the Ute Indians took more and more of Colorado away from these Indians and finally the Hunt Treaty of 1868 reduced their reservation to 1/3 of Colorado. Incidents that assisted in taking more land were the Meeker massacre and the Thornburgh battle on Milk Creek. Soldiers at Fort Lewis near Hesperus protected the settlers from forays of the Ute Indians in 1880. By 1881 the Tabeguache and White River Ute Indians were sent to Utah and the Southern Ute and Ute Mountain Ute were confined to the southwestern corner of the State of Colorado in 1889. Fort Lewis was converted into an Indian School and later into an agricultural college.

The discovery of gold in 1859 acted as the impetus to the greed for the Ute Land. The need for agricultural land in the 1870’s also added fuel to the desire for Indian confinement in order to take more land. The Brunot Agreement of 1873 denied access of the Ute Indians to the San Juan area. Rail transportation and roads that increased wagon and stage access into the area in the late 1800's brought more and more people from the east. The industry of smelting and refining ores provided jobs for many entering into the area. Coal, uranium, and oil provided a boon as well as gold and silver. Much of this activity was confined north of Durango leaving the study area relatively on the fringes.

An early prospector in the area was a man named S.B. Kellogg, and he founded Animas City near the present location of Durango in 1861. A town named Baker's Park was 50 miles away. A gold rush was launched in 1873 in this area. A trail connected Durango to Silverton along the present route of 550. In 1880 Denver and Royal Gorge Railroad (D & RG) staff staked out the site of Durango City 1 and ½ miles to the south (McTighe 1984). Previously, in 1874, Parrott & Company founded Parrott City 14 miles to the west. A few months after founding, the residents of Parrot City and Animas City moved to Durango City. The San Juan & New York and the American Smelting & Refining Company smelters were built in the area McTighe 1984).

Ranching was one of the areas that impacted to the south of the study area. Fruit growing reached the southwest corner of Colorado by the turn of the century. Irrigation projects such as canals/ditches increased the growing/grazing capacity of the four corners area.

Railroads provided a network for the urban centers. The Denver and Rio Grande Railway became Denver and Rio Grande Railroad (D&RG) in 1885. Construction of this railroad to the southwestern corner of Colorado made Durango a large center. The Rio Grande Southern railroad provided increased settlement in Mineral, Montezuma, Rio Grande, and Dolores Counties, and a diverse work group was enlisted the southern towns in order to build the railroads. Hispanic ranchers and farmers moved into the area in the 1870's. Populations increased to a few hundred for such towns as Mancos, Cortez, and Dolores by 1900. William J. Palmer built a unique railroad west of the Mississippi. It was narrow gauge. That means that the rails could be 30 pounds in weight and the rails could be laid 3 feet apart. Palmer bought English steam engines that were small and light weight. This combination provided tighter turns to navigate the mountain curves.

The Ute Reservations in this portion of Colorado established an American Indian presence and then white settlers were enabled to buy land in the area in 1895 through the Hunter Act (Wycoff 1999).

The town of South Fork incorporated May 19, 1892. Creede, Colorado is to the northwest. Highway 149 to the west and north of South Fork is the Silver Tread Byway. It was designated a National Forest Service and Colorado Scenic and Historic Byway in 1990. Most of the area along this byway is federal land. Silver Thread and Creede and Lake City to the west are historic mining camps. The route to these areas would take you through South Fork. The Old Spanish Trail ran through the San Juan Mountains and followed the Rio Grande River in the upper Rio Grande Valley in the 1500's to the 1800's. The ski area at Wolf Creek and Pagosa Springs, as well as Creede, provide tourist attractions.

The Ute Indians or "Nuche," as they call themselves, reside on the Ute Mountain and Southern Ute Indian Reservations in southwestern Colorado and northern New Mexico and on the Uintah and Ouray Indian Reservation in Utah. They speak a language that is associated with Shoshonean. They inhabited most of Colorado when the Spanish expeditions recorded the area in the 1500's. Ethnographic records (Baker 1926, Buckles

1971, Crum 1996, Delaney 1974, Pettit 1990, Underhill 1971) indicate that these hunter and gatherer groups were very mobile before confinement on reservations. Please see the references listed for a complete inventory of cultural resources. Some of the cultural resources associated with this tribe are hearths, manos, bone awls, hammersones, stone flakes, points, knives, scrapers, and hunted animals. Baskets and pottery were used for storing and carrying various items. Digging sticks were common. Roasting pits were used. More information regarding cultural resources is available (Dutton 1975).

Local History

The Denver and Rio Grande Railroad was constructed from Derrick (known as South Fork today) to Wagon Wheel Gap in 1882 to 1883 and connected to the line from Alamosa in the San Luis Valley to the east. This historic line is now called the Creede Branch, Denver & Rio Grande Railroad (5ML.273 and 5RN.515). The tracks were set down between Wagon Wheel Gap and Creede in 1891 as part of the Rio Grande Gunnison Railway (RGG) that became the D&RG by lease and then was purchased under the name Denver & Rio Grande Western. Under a merger in 1996, the Union Pacific Railroad Company owned the railroad and sold a 21.7-mile portion of right-of-way to the Denver & Rio Grande Railway Historical Foundation (DRGHF). The line runs along the bank of the Rio Grande River between South Fork and turns north along Willow Creek to Creede. A bridge for the D&RG (319A) crosses Willow Creek at Mile Post 319.97. It is 45 feet long and is “a three-panel flat deck pile trestle of all wood construction” built in 1901 (Liestman 2002).

The D&RG line built to Creede was originally a narrow gauge railroad. That means that it was 3 feet between the rails and the rails used were 30 pounds per yard. The railroad was built on “a roadbed of native earth.” Light-weight locomotives and wooden cars were used on the narrow gauge track. The track was converted to standard gauge between 1901 and 1902 and 65 pound rails replaced the lighter weight rails. The line immediately south of Creede is abandoned (Liestman 2002).

Near Creede, the Wye track at Mile Post 320.23, built in 1891, was removed in the 1950’s (Liestman 2002). A rail yard and depot were built in Creede in 1892.

Mining in the mountains in Colorado started with a gold rush in California. Gold was found by members of the Cherokee Nation in Colorado and recorded by John Lowrey Brown on June 22, 1850. The members of the Cherokee Nation followed the corridor that is now I-25 to Fort Collins then proceeded up the Cache la Poudre and the route of Fremont’s party. They turned west on Laramie plain and stopped for camp #44 on what they called Ralston Creek where they discovered gold. Cherokee Indians returned to the vicinity in 1858 with William Green Russell of Auraria, Lumpkin County, Georgia and the gold rush in Colorado began (McTighe 1989). Mining was first centralized in Clear Creek, Gilpin, and Boulder Counties, and mining soon spread throughout the mountains of Colorado. Remains associated with mining are facilities for processing gold and coal, mines, miner’s lamps, dynamite, black powder, airshafts (adit), boarding houses, boilers, coke ovens, head frames, scales, washing plants, wash houses, company towns, and railroads. Other items are pumps, siphons, fans, square timbers, concentrators, and bellows. Important people and events will be associated with mining. The history of the area will be associated with the coal industry. The two major coal companies in Colorado were Colorado Fuel and Iron Company (CF&I) and Rocky Mountain Fuel Company. Rocky Mountain Fuel Company had a center in Walden. Numerous small companies abound (Mehls 1984). The largest placer was the Independence Mountain group in North Park that was 160 acres in size and was discovered in 1875 (Athearn 1977). Lode or underground mining involved tunneling along veins of precious minerals underground (Husband n.d.).

The Alpha-Corsair fault two miles southwest of Creede was mined first in this area in the 1870's (Huston 2005). Mr. Gay, J.C. McKensie, John Bernitt, James Wilson and Mr. Jackson set up camp in 1876 along the banks of Deep Creek (reported 1892a). Gold was discovered in the Creede district in 1887. Mining began in earnest in 1888 at Bachelor Mountain. In 1891 the Holy Moses mine opened. The Amethyst vein system dominated the Bachelor Mountain producing silver ore (Davis and Streufert 1990, Eimon 1988). Davis and Streufert (1990) provide a map of the district ion p. 71 showing mines, adits, occurrences, veins, and gravel pits of the district surrounding Creede. Shown are Solomon-Holy Moses, Alpha-Corsair, OH, and Amethyst Veins and Phoenix, Holy Moses, Solomon, Bachelor, Bulldog Mountain, Monon Hill, Monte Carlo, Equity, Captive Inca, Corsair, Commodore, and Alpha Mines. Many of these mines date to very recent time. These veins and mines are concentrated on the north, northwest, and west sides of the town of Creede (Davis and Streufert 1990, Steven and Ratte 1960).

Huston (2005) begins his story with early transportation. Finding routes through the mountains began with trails. Wagon roads carried travelers along the Rio Grande from Del Norte to Antelope Springs. The area was known as Hinsdale County and the first county seat was San Juan City. A company of business men in Del Norte built the Del Norte and San Juan Toll Road in 1873. The road went from Del Norte, over Stony Pass, to Howardsville. The Antelope Park and Lake City Toll Road was built in 1875 by another company of Del Norte and extended from Del Norte, over Spring Creek and Slumgullion Passes, to Lake City.

In 1964 the Homestake Mining Company developed Bulldog Mountain Mine 4,000 feet northwest of Creede proper. In 1983 they began explorations in the northern portion of the Creede district. The district stretches approximately 18,000 feet to the northwest of Creede proper (Davis and Streufert 1990).

The Creede district has produced most of the silver in Colorado and produced a significant amount of the gold. Lead and zinc production amounted to 9 and 1.2 percent respectively. Waters in the area are meteoric and flow through a fossil geothermal system. Salts, metals, and sulfur have risen on this water flow and surfaced through faults in the system. Mineralization occurred under the Creede system in this area producing the ores. A cap of sericite-illite-smectite formed above these ores because of boiling and loss of acidic material. The ores deposit in the fractures of the Creede graben, and ratios of gold to silver vary in different portions of the district (Barton et al. 1977, Caddey and Byington 1988, Davis and Streufert 1990, Steven and Eaton 1975).

The mining Act of 1872 promoted mineral extraction in the U.S. It was signed by President Ulysses Grant on May 10. The Law allowed free and open "exploration and purchase" of "all Federal lands valuable for their mineral content. . . ." This law outlined the claim system. Several mining companies are associated with the town of Creede.

They are Cleopatra Mining Company, Del Monte Mining Company, Park Regent Consolidated Mining Company, Nelson Tunnel & Mining Company, Las Chance Mining & Milling Company, Kreutzer Sonata Consolidated Mining Company, Eunice Mining Company, Amethyst Mining Company, Inc., Stanhope Mining Company, 400 Acre Diamond Drill Consolidated Mining Company, New York Chance Mining Company, Bristol Head Mining Company, White Star Mining Company, Creedmoor Mining Company, and Golden Eagle Consolidated Mining Company. Investors were Ralph Granger, Charles F. Nelson, David H. Moffat, Lafayette E. Campbell, Albert E. Reynolds, Albert E. Humphreys, and the Wallaces (Huston 2005).

Mineral County was established March 27, 1893, and the county seat was Wason. By popular vote on November 7, 1893, the county seat was changed from Wason to Creede. A one-story frame building at Wason served as the county courthouse. It had been built by Major Martin Van Buren Wason along Wason Road. The Mineral County Commissioners purchased this small building and it was moved to Creede on January 10, 1895. Fire destroyed the building December 12, 1946 (Huston 2005).

The town of Creede is named for Nicholas C. Creede. Nicholas moved from Pueblo, Colorado, to Custer County in 1873 to mine the Bassic Mine. He founded the Monarch Mine and camp west of Poncha Springs in 1878. He also located the Bonanza and Twin Mines in the Cochetopa Hills, and in the 1880's, he moved to Spring Creek north of Creede. He staked the first claim of record in the Spring Creek Mining District in 1887, and followed an ore vein to the Creede area where he prospected the Campbell Mountain area north of Creede where he established the Holy Moses claim in 1889. The actual founder of Creede was Charles F. Nelson who began a camp in 1890-1891 on what is now the town of Creede. Several other men are associated with mining in the Creede area. They are Charles Born, S.D. Coffin, Julius Haase, Eric Von Buddenbock, Ralph Granger, and David H. Moffat. The Denver and Rio Grande Railroad (D&RG) accessed Creede in 1892 (Huston 2005). For more information see Henderson (1926) and Canfield (1893).

A toll road named the Wason Toll Road extended from the Wason ranch house south of Creede to Holy Moses Mine at the junction of East and West Willow Creeks. The Wason Toll Road Company, formed on December 30, 1890, built the toll road in 1891 and 1892. The company consisted of Martin Van Buren, Harriet L., and Edith Wason. It is drawn in dotted line on the "Map of Creede and Surrounding Country Based on maps printed in the Creede Candle, April 15, 1892 and the Creede Chronicle, March 22, 1892 (Huston 2005 p. 107). It runs to the southeast of the D&RG line recorded by Hand (2002). The toll road was purchased for $10,000 and became a public highway on April 3, 1899. Noted on the map is the "Town site of Wason" just northeast of the Wason Ranch (Huston 2005 p. 107). This is clearly vacant land now, because the building was moved in 1895 and the area was surveyed by Hand in 2002. Willow Creek is also noted on this map and the area surrounding the creek south of Creede is vacant as of 1892.

The area south of Creede is noted as unoccupied land in 1892 (Huston 2005 p. 113 and reporter 1892b). A map of the Creede fire area was published and the Wason is depicted as the first landmark south of town. This area has remained unoccupied due to the flooding of the area.

The Nelson-Wooster-Humphreys Tunnel was a series of branched tunnels carrying water from mine to mine in order to provide access to all of these ventures. The Nelson Tunnel and Mining Company, incorporated in 1892, ran a tunnel at an elevation of 9,175 feet above sea level from West Willow Creek. The size of the tunnel is 8 feet wide by 8 feet high with double track, lighted with electricity, and powered by electric motors (Huston 2005)

> *The tunnel reached a point where connections with the shaft were to be made and, after cutting a station, a raise was started to meet the shaft, which was accomplished in about 50 feet, and when the two came together with great exactness* (Lakes 1903).

The tunnel was closed in 1918 and has caved in several portions beginning in 1934 as all of the lines were abandoned and the machinery taken. Huston (2005) provides several photographs of this tunnel.

In the early 1950's, the U.S. Army Corps of Engineers diverted Willow Creek into a masonry channel for a distance of approximately one mile through the town of Creede (Liestman 2002).

Previous Work in and Near the Area

Fraser and Strand (1997) and Hand (2002) provide information regarding railroads of Colorado and intensive inventory that include the Creede Branch of the D&RG in Mineral County (5ML.273.8). Segments of the D&RG are listed on the NRHP (Liestman (2002). Others have recorded portions of the railroad (Fraser 1998, Robinson and Wharton 2001, Wharton 2000, Wharton and Baker 2001, Unknown 2001). Spero and Frye (1999) and Spero (1995) inventoried Creede Landfill. Several reports and inventories of the area are available (Unknown 1966, 1991, 1994a, 1994b; Davis Engineering 1994; Fraser and Strand (1997); Hand 2002; Hartley and Schneck 1995; Denver and Rio Grande Historical Foundation 2002; Reed and Nickens 1981; Spero 1992, 1998; and Angulski 1990; Rottman 1981.

Survey Methods

The archeologist surveyed the APE in transects of 20 feet increments. The survey was pedestrian. Isolated finds are considered four or fewer artifacts lacking indications of a locus of activity. A site is five or more artifacts or items that provide a locus of activity.

Results

The survey produced no cultural resources.

The literature search produced the following results. The Creede Branch of the Denver & Rio Grande Railroad in Mineral County is listed on the National Register of Historic Places. Fraser and Strand (1997) and Hand (2002) address the Creede Branch of the D&RG (5ML.273.8). This railroad runs outside the APE. It was built in 1882. The district of the railroad extends 22.8 miles from South Fork to Creede. The line runs along the Rio Grande River and turns north along Willow Creek. The nomination boundary for the historic right-of-way is 50 feet from the center of the railroad grade to either side. The abandoned track was converted to a standard gauge line between 1901 and 1902. This involved replacing the 30 pound per year rail with 65 pound rail and widening from 3 feet (narrow gauge) to 4 feet 8 ½ inches (standard gauge) between rails. William J. Palmer originally selected the narrow-gauge railroad for the Denver and Rio Grande Railroad in 1871. He built the first "north-south railroad west of the Mississippi River and it began to snake its way into the mountains to reach the new mining camps" (King 1984). Care shall be taken to avoid impact to these tracks. A buffer of 65 feet is recommended and this will maintain a safe distance for construction activities.

The Wason Ditch, a privately owned ditch, runs outside the APE on the east side.

The Emperius Mill and tailing pond are outside of the APE and date to 1934. Emperius Mining owns a portion of the land of the APE; however, none of the mining or milling was conducted on this portion of the property. The Creede Camp required approximately 182 miles of tunnels, adits, drifts, shafts, raises, and winzes, none of which are located in the APE. Emperius Mine produced $115,154 from cadmium from 1965 to 1972. The tailings pond was south of Creede at the town edge, east of Emperius Mill, and west of the railroad. It was approximately 200 acres of agricultural land. The tailings were spread across this area and structures were not used for confinement. A flume made of wood, U shaped, and two feet wide and one foot high carried the tailings from the mill to the pond. This structure has been removed. The flume leaked quartz and chlorite. The tailings pond could still produce gold so at least one man set about recovering what remained in the pond. Mineral Engineering ran the old Emerius Mine from 1972 to 1976. Tyrus and Ben Poxson founded the Emperius Mining Company that owned Emperius Mine. Minerals Engineering, CoCa, and then Hecla Mining Company (and subsidiary, Creede Resources) owned the mill site. Mineral Engineering broadened activities at the Emperius Mine in 1973 so that production was 300 ton per day. The Mill Superintendent was Miller, from Carlin Nevada, and Tony Mastrovich was the general manager for Mineral Engineering at Creede. Mining discontinued on August 9, 1976, but the mill continued until the roof collapsed in 1976 from heavy snow. *The Pueblo Star Journal* reported on October 31, 1976, that the mill closed due to "marginal economics involved in processing lower grade ores from surface dumps and burdensome mine and mill royalties which combined to exceed 25 per cent of the mill's monthly smelter income." Anton Faust became president of Mineral Engineering. Underground and surface diamond drilling continued under control of Houston Oil & Minerals Corporation. Mineral Engineering leased Emperius Mining Company and Creede Mines in June 1977 and relinquished options December 2, 1977. In 1978, Chevron Resources Company optioned the Minerals Engineering holdings and commenced sampling, but in 1981, Chevron discontinued this avenue and could not justify large "open pit" mines. Silver was shipped from the Emperius Mine until 1985 by Pioneer Nuclear Inc. Mesa Limited Partnership of Amarillo, Texas and run by T. Boone Pickens purchased Pioneer Nuclear Inc in 1986 and drilled north of Emperius Mine and was the last mining for the Emperius Mine at the Amethyst Vein. The mill site was cleaned, the tailing pond was reclaimed, and the tailings were capped in 2000 by San Luis Valley Earthmovers of Monte Vista, Colorado. The mill was dismantled at that time (Clark 1934, Huston 2005). Tailings extended across the APE; however, due to flooding and the reclamation efforts this area does not exhibit in situ mine tailings.

The first court case regarding contamination downstream occurred in 1905 (Records 1905). Anton F. Frank filed a lawsuit against Humphreys Tunnel and Mining Company regarding dumping tailings into Willow Creek. This served to stop dumping of mine tailings into creeks (Smith 1987). The land in question was a quarter section of the original homestead of Julius H. Weiss “on the lower end of Willow Creek where it joins the Rio Grande River” (LaFont 1971). The lawsuit was filed in Colorado’s Twelfth Judicial District Court, Alamosa, Colorado, in Costilla County. The complaint was that dumping in the creek had affected the ranch, livestock, and hay (Records 1905). Damages were assessed at $1,072 by Judge Charles C. Holbrook. The Humphreys Mill tailings pond is the one described above and a settling dam was built in order to discontinue dumping into the creek (Huston 2005).

Emperius Mine

Emperious mine tailings have been studied and the United States Army Corps of Engineers collected a core from the tailings in 2002. A 4 ½ inch auger was used to take samples at 3, 7, 10, and 15 feet. The results are that cadmium, magnesium, manganese, and zinc were in the samples and the greatest quantities of these were at the 15 foot level. This indicates that leaching from modern mine tailings may be a possibility for contamination noted downstream. Another possibility is that leaching is from the older mine tailings underneath (Willow Creek Reclamation Committee, 2004a).

The Emperius Mill and tailing pond are outside of the APE and date to 1934. Emperius Mining owns a portion of the land of the APE; however, none of the mining or milling was conducted on this portion of the property. Emperius Mine produced $115,154 from cadmium from 1965 to 1972. The tailings pond was south of Creede at the town edge, east of Emperius Mill, and west of the railroad. It was approximately 200 acres of agricultural land. The tailings were spread across this area and structures were not used for confinement. A flume made of wood, U shaped, and two feet wide and one foot high carried the tailings from the mill to the pond. This structure has been removed. The flume leaked quartz and chlorite.

The mine tailings have been cleaned and capped. The survey of the APE produced no cultural resources. The APE contains no structures or intact mine tailings. The walking survey indicated no cultural resources in the APE. Reconstructing this stream in this location will not impact cultural resources. Chemical runoff from mining has been evident in the area since 1905 in the court case of that time.

SUMMARY OF CONDITIONS

Historic mining activities have negatively impacted the natural resources of the watershed surrounding the community of Creede, most visibly within the Willow Creek floodplain. Willow Creek is currently in a braided form, an unsightly and locally atypical geomorphic condition that, in combination with the water and soil contamination, has led to poor ecosystem function. The substantial water-quality impairments and poor morphologic conditions are preventing significant invertebrate and fish populations. Additional problems in this floodplain stem for poor grass and willow populations due to physical disturbance from the braiding, mechanized manipulation, and contaminated soils. A large quantity of what is apparently cobble-size waste rock, from the mining activities, has been dumped throughout the floodplain, preventing substantial vegetation growth over most of the floodplain.

The Creede Mining district is in the central part of the San Juan Volcanic Field. Between 27.8 and 26.4 Ma (million years ago), a sequence of large calderas formed in the central part of the San Juan Volcanic Field. The town of Creede is located on the northern edge of the **Creede caldera**. The San Luis and the Creede calderas formed between 26.7 and 26.4 Ma. Deep circulation in a convecting hydrothermal system above the magma produced the mineralization in the open spaces between fault and fracture surfaces and within fault breccia. The mineralization has been dated by the K-Ar method at 24.6 ± 0.6 Ma, approximately 2 million years after the youngest volcanism in the area. The principal metals produced in the Creede district are silver (Ag), lead (Pb), zinc (Zn), copper (Cu), gold (Au) found in veins in a system of open faults and fractures that strike generally north to northwest.

Historic Aerial photography of the Willow Creek floodplain was obtained from the U.S. Forest Service for the years 1939, 1958, 1964, 1973, and 1985. This photography indicates that Willow Creek has been in a braided form since at least 1939, and multiple-generations of mine waste structures and deposits have been located in and adjacent to the floodplain (Figure 83). The extensive floodplain vegetation that used to envelope the floodplain, as illustrated in Figure 66, was covered by mine waste or removed before 1939. Between 1939 to 2006, little change in floodplain vegetation has occurred, indicating that the floodplain and stream will take a substantial amount of time (greater than 100 years) to naturally transform itself into a properly functioning stream system.

The Humphreys mill was located north of Creede and used a flume to carry tailings to the south, discharging just north of the airport property. **Humphrey mill tailings** were also collected in an impoundment south of Creede in the area west of the **Emperius tailings impoundment**, in the middle of the floodplain. The first mill on the Creede Resources property was a 100-ton per day flotation mill built in 1937. A new 150-ton per day mill was constructed on the south side of the Property in June 1956 and operated until October 1976. The process at the mill from 1937 to 1976 included flotation milling of rock ore into concentrates that were shipped to offsite smelters. Deposition to the tailings impoundment, on the north-eastern portion of the floodplain, continued until October 1976. The impoundment consisted of three containment ponds, plus three smaller evaporation ponds located immediately downstream of the main tailings impoundment.

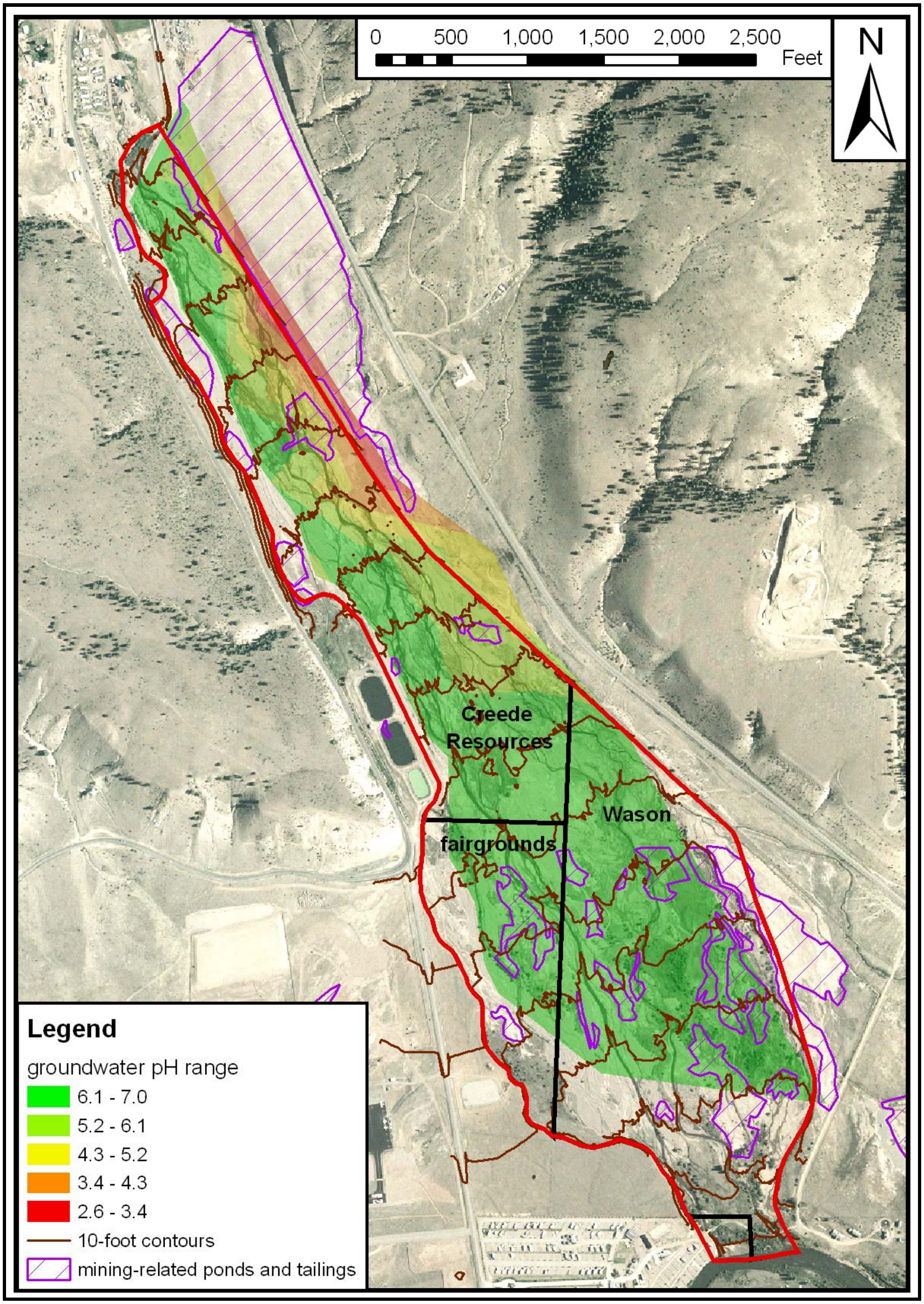

Figure 83: Groundwater contamination, with locations of historic mining ponds and likely tailings and 10-foot contours.

Extremely fine mill waste streams were directed to a concrete pond, at the mill, and several "**duck ponds**", located on the north-west portion of the floodplain. The footprints of these impoundments and ponds are illustrated in Figure 83.

Analyses of **water quality samples** collected in 1965 and 1966 from the surface effluent out from the **Emperius tailings impoundment** indicates pH ranging from 4.0 to 5.7, lead concentration from *not detected* to 7200 ug/l, zinc concentrations from 10,500 to 1,200,000 ug/l and cyanide concentrations from 550 to 1000 ug/l. Analyses of samples collected in 1965 and 1966 from the surface effluent out from a smaller pond located between the stream and the railroad tracks, at the location of the old Humphrey's tailings pond, indicates pH ranging from 3.2 to 4.2, lead concentration from *not detected* to 2600 ug/l, zinc concentrations from 800 to 540,000 ug/l and cyanide concentrations from 40 to 100 ug/l. These lead and zinc concentrations are similar to concentrations currently found in the contamination plume at these former pond locations. Analyses of samples collected from the effluent from the mill to the "duck pond", on the west side of the floodplain, indicates pH ranging from 3.6 to 10.2, lead concentration from *not detected* to 7200 ug/l, zinc concentrations from *not detected* to 67,000 ug/l and cyanide concentrations from 550 to 600 ug/l.

An extensive **topographic survey** of the floodplain was conducted in the autumn of 2005. The survey was completed using a Trimble survey-grade GPS system. Breaklines were created for the survey. The breaklines and survey points were used to develop a Triangular Irregular Network (TIN), from which the 2-foot contours were developed. The results of the survey are provided in Figure 16, with higher-resolution results provided in Figures A-6 and A-7. Electronic files from this survey are provided as supplemental data to accompany this document.

The **flood frequency** of the floodplain was developed by merging the results of both a streamgage analysis and a regional flood-frequency analysis. A streamgage was operated by the U.S. Geological Survey on Willow Creek at Creede from 1951 to 1982, collecting both annual peak flow and average daily flow readings. A log-Pearson statistical analysis of these data was performed. The frequent flood results (up to 2-year) of this analysis were merged with the results for larger, less frequent events from a regional analysis that developed multiple linear regression equations and error bars for the Willow Creek watershed. The recommended flows for Willow Creek at the Rio Grande are 1210 cfs for the 100-year event and 190 cfs for the (1.5-year) bankfull event.

Groundwater surface levels in the wells and pits were measured from 8/9 to 8/11/2005. Combined with water surface elevations in the stream segments, these data provided points to construct 2-foot contour map of the **water table**. Figures 30 and A-8 illustrate these contours. These results were interpreted to indicate which sections of stream are giving, receiving or neutral, with respect to groundwater. Results indicate that the stream segment on the eastern portion of the floodplain is essentially an irrigation ditch, delivering water to the Wason Diversion while being perched, providing flow to groundwater, and acting as a groundwater divide, possibly impacting potential movement of the groundwater contamination plume (Figure 46). Additionally, the seasonal variability in water table level measurements were observed in most wells for 14 months. Well level fluctution ranged from 0.5 feet (MW-3) to up to 7.1 feet (MW-1). Finally, the depth to groundwater was computed for most of the project area and presented in Figures 40 and A-9.

There are two **stream diversions** within the floodplain, specifically the Wason and Zimmerman ditches. Structures for each of these diversions will need to be included in the stream restoration. The Wason Ditch has a decreed capacity of 6.0 cfs, while the Zimmerman Ditch has a decreed capacity of 1.2 cfs. The Zimmerman ditch is infrequently used and is in disrepair. The Wason ditch essentially starts at approximately 1/3 of the distance from the upper end of the floodplain and is diked along the eastern edge of the floodplain, appearing at first glance to be a branch of the stream. Excess flows in this uncontrolled portion of the ditch are wasted from two locations to the south-east portion of the floodplain, providing water to wetlands that are interspersed with mine tailings on the Wason property. The ditch is perched with respect to groundwater, losing flow over its entire length (Figure 31).

Groundwater quality in the floodplain has been previously monitored by and documented by the Willow Creek Reclamation Committee. These data have been combined with the results of additional sampling and field parameter collection. Locations of monitoring wells and pits are provided in Figure 41. The elevated contaminants found in groundwater of the floodplain are zinc, manganese, magnesium, and cadmium. The most contaminated wells are MW8, MW9, MW10, MW11, MW16, MW18, MW19 and MW20. Dissolved zinc levels in all the wells range from <5 to 679,250 ug/l. Dissolved cadmium levels in the wells range from <0.1 to 1539 ug/l. Dissolved lead levels in the wells range from <1 to 149 ug/l. The Colorado Department of Public Health and Environment (CDPHE), in cooperation with the EPA, sets **table value standards** for contaminants for agricultural and human use. For zinc, a 2000 ug/l standard has been set for agricultural purposes while 5000 ug/l has been set for drinking water. For cadmium, a 10 ug/l standard has been set for agricultural purposes while 5.0 ug/l has been set for drinking water. For lead, a 100 ug/l standard has been set for agricultural purposes while 50 ug/l has been set for drinking water (EPA 2006). It was found that pH can be a good indicator for groundwater contamination in the floodplain. Figure 46 illustrates the pH variability of the floodplain groundwater, highlighting the groundwater contamination plume. The link between low pH and groundwater contamination can be used for early detection of groundwater contamination plume movement, without the expense of water quality analyses.

Surface water quality in the Willow Creek floodplain and watershed has also been previously monitored. The data have been combined with additional data to perform interpretations. Water quality in the two upper branches of Willow Creek, specifically West Willow and East Willow Creeks, as well as mainstem Willow Creek, have been documented to exceed Colorado Table Value Standards for zinc, cadmium and lead. In **East Willow Creek**, point sources of metal loading to the stream include Solomon Mine adit and the Solomon Wetlands. In **West Willow Creek** documented point sources of metal loading include Nelson Creek, a seep at the Commodore and the Nelson Tunnel. The Nelson tunnel is the largest contributor of metals in the Willow Creek watershed. To assess the impact of potential Nelson Tunnel water treatment, an analysis was performed to determine potential impacts of such proposals. During the water quality synoptics, Nelson tunnel total cadmium load was found to range from 23 to 63 percent of the total cadmium load in mainstem Willow Creek just upstream of the flume, with an average of 42 percent. Nelson total lead load ranged from 15 to 68 percent of the total load in Willow Creek, with an average of 49 percent. Nelson total zinc load ranged from 35 to 69 percent of the total load in Willow Creek, with an average of 61 percent. This analysis indicates that, if Nelson water is treated, a substantial portion of the metal loading will be eliminated. However, metal concentrations in Willow Creek would still be above chronic TVS unless other contaminant reduction projects are performed. In mainstem **Willow Creek** two floodplain seeps adjacent to the groundwater contamination plume have been documented. Measurements of these seeps have shown pH as low as 2.95, with aluminum, cadmium, copper, lead and zinc concentrations as high as 120,000 ug/l, 2100 ug/l, 2400 ug/l, 3000 ug/l and 420,000 ug/l. Though discharge from these seeps is low, there is a direct link between the groundwater contamination plume and Willow Creek. The stream restoration should preserve similar water surface elevations to deny potentially steeper gradients and additional discharge to Willow Creek.

A **snowmelt-related flood** occurred in late May of 2005. This flood caused extensive damage on **West Willow Creek**, causing the failure of a large culvert and eroding mine waste and tailings and other mining-related material. Much of this debris, including large woody debris, was deposited in the Willow Creek floodplain, downstream of Creede within the proposed stream restoration area. As of late 2006, this reach on West Willow Creek has yet to be stabilized. A logging multi-parameter probe was deployed during the beginning of this event, indicating pH is West Willow creek dropping to 4.8. Grab sampling of the flood waters on West Willow during the event indicate very high metal concentrations, with aluminum, cadmium, copper, lead and zinc concentrations of 946, 384, 492, 2600 and 53,200 ug/l, respectively. In addition to the debris, a large load of metals was transported through the Willow Creek floodplain, partially depositing within the floodplain.

Due to the threat of potential deposition of substantially contaminated material onto the floodplain and the threat of debris from West Willow Creek potentially causing an avulsion and failure of the stream restoration, especially in the early period before vegetation has stabilized the channel, **the stabilization of West Willow Creek is strongly recommended before construction of the Willow Creek stream restoration**.

A **biological assessment** of the Willow Creek watershed was previously performed using data collected from 1999 to 2001. The results were published in WCRC (2004c), from which these results have been drawn. In **East Willow Creek** the assessment indicates a self-sustaining population of brook trout. Most size classes were found at every sample site on the creek, despite chronic Table Value Standards being exceeded on lower portions. Invertebrate tissue are below concentrations that should effect fish. Macroinvertebrates in East Willow Creek consisted of metals-tolerant taxa, such as caddisflies (Hydropsychidae), mayflies (Baetidae) and true flies (Orthoclasiimae). Taxa that tend to be intolerant of metals, such as Heptageniid mayflies and Rhyacophilid caddisflies, generally decrease from upstream to downstream. In **West Willow Creek** brook trout were captured at most sites. Additionally, some brown trout were captured. Downstream of the mining-impacted areas, the sampled sites provided fewer captured fish with the populations not likely being self sustaining. No fish were found at the bottom limit of West Willow Creek. Invertebrate tissue analyzed from West Willow

Creek indicate concentrations less than benchmark values for upper sites and no invertebrates were not found just above the confluence with East Willow. Macroinvertebrates in West Willow Creek consisted of metals-tolerant taxa, such as mayflies (Baetidae) and true flies (Orthoclasiimae chironomids). Taxa that tend to be intolerant of metals, such as Heptageniid mayflies, Chloroperlid stoneflies, and Rhyacophilid caddisflies, generally decreased from upstream to downstream. In mainstem **Willow Creek** only two fish were collected, just above the confluence with the Rio Grande. They were likely from the Rio Grande. Invertebrate tissue samples generally indicate metal concentrations for arsenic, copper and zinc that exceed dietary exposure concentrations for fish. Lower sites have substantially higher concentrations of arsenic, cadmium, copper, lead and zinc in macroinvertebrate tissues. Metals in the Willow Creek floodplain are biologically available and being accumulated by invertebrates. Macroinvertebrate communities in the mainstem Willow Creek consisted of metals-tolerant taxa such as mayflies (Baetidae), and true flies (Orthocladiinae chironomids). Taxa that are less tolerant of metals were at low abundance.

The water quality of Willow Creek has a substantial impact on the ultimate success of the stream restoration. It is commonly the case for the success of stream restoration projects to be judged on increases in population of aquatic life. Impairment is due to both current physical and chemical condition of Willow Creek below Creede. The reconstruction of the stream will greatly increase the quality of the physical habitat, but water quality will still be issue until additional improvements are implemented upstream. **Substantial water quality improvements need to be performed in the Willow Creek watershed before the full potential of a stream restoration can be realized.** Additionally, **the legacy of mine waste processing and storage in the Willow Creek floodplain may provide biologically available metals from within this stream segment itself**, possibly reducing the effects of water-quality improvements in the watershed and reducing the potential for creating a self-sustaining fish population within the restored stream. Stream channel construction from the current braided form will decrease the surface area of interaction with the floodplain material, potentially decreasing the collection of any biologically-available metals.

The pebble-count method was used to characterize the **bed material size** of the existing braided channel. Two reaches were samples, one in the upper floodplain and another near the midpoint of the floodplain. For the upper reach the D_{50} and D_{84} were 47 mm (very coarse gravel) and 103 mm, respectively. For the middle reach the D_{50} and D_{84} were 15 mm (medium gravel) and 62 mm, respectively. The D_{100} of both reaches was 180 mm.

Soil samples were collected at 10 sites in the floodplain. Soils were found to be primarily coarse-textured with clay mineralogy. For sampled soils, the pH for surface materials ranges from 5.4 to 6.8 (strongly acid to neutral), with the exception of a sample on the fairgrounds site with an extremely acidic pH of 4.6. Soil pH is a good indicator of the relative availability of plant nutrients. The highest and lowest amounts of soil Pb are found in adjacent sampling sites, on the fairgrounds property. Denuded Mound and Sedge Mound sites, respectively. Additionally, the lowest and greatest amounts of trace elements in the soils are found in these same two sites. These differences help to explain the stark difference in appearance from vegetated versus barren sites, for these two sites.

Additionally, these data suggest that a correlation may exist between metal levels in soils and/or associated water with vegetation or lack there of within the floodplain. Soil pH can be used as a useful indicator of potential availability of these metals.

The Willow Creek floodplain has the potential for substantial **visual resources**. Lower Willow Creek is highly visible to a large number of viewers, regardless of whether they are looking at the valley from Creede, or approaching town from Colorado State Road 149. Few mine reclamation activities have been implemented and, as a result, the floodplain remains a highly unstable and unsightly. The scenery adjacent to the project area helps enhance the overall impression of the project's setting. The landforms are distinctive, with massive mountain tops that serve as a backdrop for Creede. The visual diversity of this setting is striking and is dominated by very prominent geomorphology. Given the many natural features present on this project's site, and the amazing natural features surrounding it, consideration of the landscape architectural components should be a significant factor during a restoration design.

Due to the poor soil conditions combined with poor water quality, plant diversity throughout the site is extremely low for a riparian area. The **vegetation** along this corridor is primarily found along the water courses and areas that are sub-irrigated. The vegetation of these areas is dominated by graminoids with some wetlands and bands of willows found on the Wason Property and a band of willows found on Mineral County Fairground property to the south of the property, as well as scattered willows towards the north boundary. High density mass planting using hardwood cuttings, willow clumps, bareroot plants, rooted cuttings and container transplants on streambanks is necessary to provide adequate bank stabilization after stream reconstruction. Riparian plantings using on-site willow clumps provide quick establishment. Willow clump transplants along the outside of the channel bends is preferred, if available, otherwise container transplants may be best. Establishment of high density vegetation on the outside of the meander bends is a high priority, to establish root density and cohesion within to the alluvial material in this high stress zone. If substantial vegetation density is not established along the outside bends within a relatively short period of time, project failure may result.

An inventory of cultural resources on the Willow Creek floodplain was performed. Cultural resources were not located during the survey. Reconstructing this stream in this location will not impact cultural resources. Interestingly, it was found that a court case regarding contamination downstream occurred in 1905. Anton F. Frank filed a lawsuit against Humphreys Tunnel and Mining Company regarding dumping tailings into Willow Creek. The land in question was a quarter section of the original homestead of Julius H. Weiss "on the lower end of Willow Creek where it joins the Rio Grande River". The lawsuit was filed in Colorado's Twelfth Judicial District Court, Alamosa, Colorado, in Costilla County. The complaint was that dumping in the creek had affected the ranch, livestock, and hay. Damages were assessed at $1,072.

It is recommended that the stream restoration be constructed as a **single-thread stream preferentially on the west side of the floodplain**. A single thread stream is recommended since developing a stable morphology for splitting the flow would be difficult to properly size, substantially increasing the risk of failure and loss of capital. Designing the stream to flow primarily on the west side of the floodplain avoids dangers imposed by the Emperius tailings impoundment, remnants of other historic ponds, the groundwater contamination plume and a substantial quantity of probable tailings on the Wason property. Additionally, a western stream alignment respects the current topography, which is slightly lower in elevation on the western side of the floodplain. Non-flood flow on the eastern portion of the lower floodplain is almost exclusively irrigation waste flow from the Wason diversion.

PRELIMINARY MORPHOLOGICAL DESIGN

Steven Yochum, *Hydrologist*

Proper stream dimension, pattern and profile need to be predicted in a stream restoration. Dimension refers to the cross-sectional area of the stream. Pattern refers to the plan-form of the stream. Profile refers to the bed profile of the stream. Preliminary recommendations for dimension, pattern and profile of a restored Willow Creek are provided in this section. The regional bankfull characteristics study (Yochum 2003), discussed previously, is helpful in determining the form of a single-thread stream. However, that study only provides general guidance for developing the proper geometry. Many more variables are needed to properly define the stream geometry - the use of appropriate reference reaches will be necessary for the final restoration design. **Hence, these results are preliminary and are intended for this restoration plan only - additional data collection and analysis will be needed for the Willow Creek restoration design.**

Dimension

The regional bankfull study (Yochum 2003) can be used as a base point for determining the preliminary stream cross section geometry. Since this study collected its geometric data at the head of riffle, these preliminary geometry values are also for the head of riffle. The estimates are a bankfull area of 25 square feet, with a bankfull width of 18.3, average depth of 1.35 feet and a width/depth ratio of 13.4.

To fine tune these regional results, the geometry was modified to the following criteria: the geometric section must pass the approximate bankfull discharge, as computed using a normal depth (Manning) computation; and the section must move the D_{100} size bed material of the existing braided channel.

As revealed by the survey, the valley slope of the Willow Creek floodplain ranges from 0.0179 to 0.0222 ft/ft. An average valley slope of 0.020 ft/ft was used in this analysis. As discussed below, a sinuosity of 1.4 is recommend at this planning level. With the average valley slope, this translates to an estimated 0.014 ft/ft average water surface slope (S).

The D_{100} size channel material of the two pebble counts performed in the floodplain was 180 mm. This material size needs to be transported by the bankfull channel. According to a compilation of data provided in Leopold et. al. (1964), to move this size of material approximately 1.3 pounds per square foot of critical shear stress (τ_c) is needed.

Assuming normal flow, mean boundary shear stress (τ_o) can be approximated by

$$\tau_o = \gamma R S_f \qquad (12)$$

where γ is the specific weight of water, S_f is the energy slope, and R is the hydraulic radius, defined as A/P_w where A is the cross sectional area P_w is the wetted perimeter. Using this equation with the previous critical sheer stress required indicates that a hydraulic radius of 1.5 feet is needed to convey the D_{100}. If a wide, shallow channel is assumed, which is reasonable, then the hydraulic radius is approximately equal to the depth – 1.5 feet. Considering the substantial-size material that may be transported through the flume during a large flood event, a slightly higher average depth is advisable. An average depth of 1.6 feet is recommended for Willow Creek.

The median return period for bankfull flow for the drier watersheds used to develop the regional regression work was 1.5 years. In Willow Creek at the Rio Grande, the 1.5-year event corresponds to an estimated flow of 190 cfs (Table 7).

The roughness (Manning's *n*) of the channel section can be computed using a number of methods. The use of a standard visual selection methodology, with guidance provided by Chow (1959), Arcement and Schneider (1989), and Brunner (2002), was implemented. These sources, and the experience of the author, suggest that *n* ranges from 0.035 to 0.045. Additionally, relationships have been developed relating a dimensionless friction factor with Manning's *n*. The dimensionless friction factor, u/u* has been graphically related by Rosgen (1996) to relative roughness, the average depth divided by the D_{84} of the bed material. With a recommended average depth of 1.6 feet and a measured D_{84} of 62 mm, the relative roughness is 7.8. Using a Rosgen (1996) relationship, this corresponds to a u/u* of 7.9. Using a relationship in Leopold (1994), this dimensionless friction factor corresponds to a Manning's *n* of 0.039. Additionally, the methods developed by Limerinos (1970) and Hey (1979) were implemented. Using the Limerinos prediction, *n* was estimated as 0.040 for the upper portion of the floodplain and 0.034 for the middle portion. Using the Hey equation, *n* was estimated as 0.041 for the upper portion of the floodplain and 0.034 for the middle portion. From these estimates, a Manning's *n* of 0.040 was chosen for this analysis.

The Manning equation is:

$$Q = \frac{1.49}{n} AR^{2/3} S^{0.5} \qquad (13)$$

Where *Q* is discharge (cfs), *n* is the Manning's roughness, *A* is the cross sectional area (ft2), *S* is the frictional slope and *R* is the hydraulic radius.

Using this equation with the variables computed above indicates that the bankfull area should be approximately 31.5 ft^2, a bit more than the regionally-computed initial estimate. An area of 32 ft^2 is used in this analysis.

The preliminary recommended geometric form of the riffle sections is provided in Table 22.

Table 22: Recommended preliminary geometric form of the restored Willow Creek's riffle section.

cross section area (ft^2)	32
average depth (ft)	1.6
bankfull width (ft)	20
width/depth ratio	12.5
average velocity at bankfull (ft/s)	5.9

This is a preliminary, planning -level estimate for the section geometry. In the design process sediment transport calculations should be performed while determining the final dimension, pattern and profile of the restored stream. Other checks of the hydraulic design will also be necessary.

Pattern

The regional bankfull study (Yochum 2003) can be used as a base point for determining appropriate sinuosity of the restored Willow Creek. Sinuosity (*P*) is defined as:

$$P = \frac{streamlength}{valleylength} = \frac{valleyslope}{streamslope} \tag{14}$$

This study developed a plot of sinuosity versus valley slope (Figure 69). Using this plot and the average valley slope of 0.020, and the knowledge that limited floodplain width is available for the lateral migration portion of the sinuosity, a sinuosity of 1.4 is recommended for this plan.

To make planning-level predictions on the plan form of the restored stream, the river meander and channel size equations of Williams (1986) have been implemented. The results of this method alone are not appropriate for a restoration design - additional analysis will be needed during the design phase of the Willow Creek Stream Restoration to determine the proper pattern of restored Willow Creek.

From Williams (1986), the following equations have been developed to predict the plan form geometry of a natural stream:

$$L_m = 30A^{0.65} \tag{15}$$

$$L_b = 22A^{0.65} \tag{16}$$

$$B = 18A^{0.65} \tag{17}$$

$$R_c = 5.8A^{0.65} \tag{18}$$

$$L_m = 7.5W^{1.12} \tag{19}$$

$$L_b = 5.1W^{1.12} \tag{20}$$

$$B = 4.3W^{1.12} \tag{21}$$

$$R_c = 1.5W^{1.12} \tag{22}$$

$$L_m = 240D^{1.52} \tag{23}$$

$$L_b = 160D^{1.52} \tag{24}$$

$$B = 148D^{1.52} \tag{25}$$

$$R_c = 42D^{1.52} \tag{26}$$

where L_m is the meander wavelength, L_b is the along-channel bend length, *B* is the meander belt width, R_c is the radius of curvature, *A* is the bankfull section area, *W* is the bankfull width and *D* is the average bankfull depth. **All variables are in meters.** A definition sketch of the relevant plan-form variables are provided in Figure 84.

Using an *A* of 3.0 meters^2 (32 feet^2), a *W* of 6.10 meters (20.0 feet) a *D* of 0.49 meters (1.6 feet), the use of equations 15 through 26 suggest that L_m can range from 56.8 to 81.2 meters (186 to 266 feet), L_b should range from 38.6 to 54.1 (127 to 177), *B* should range from 32.6 to 50.0 meters (107 to 164 feet) and R_c should range from 11.4 to 14.2 meters (37.3 to 46.6 feet). Higher values within the range allow larger features and less rock structures – this has been done. The variables for the recommended planning-level design are provided in Table 23.

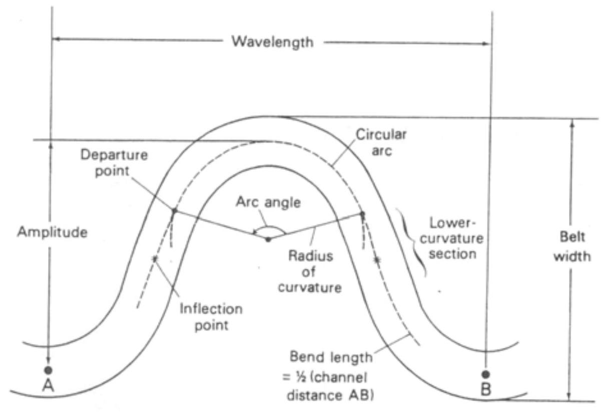

Figure 84: Definition sketch of plan-form variables (Williams 1986).

Table 23: Recommended plan-form characteristics.

meander wavelength, L_m (feet)	260
along-channel bend length, L_b (feet)	165
meander belt width, B (feet)	120
radius of curvature, R_c (feet)	45

Profile

In mountain settings bed profile typically fall into a category of cascade, step-pool, plane-bed, riffle-pool and dune-riffle (Montgomery and Buffington 1997). With the valley type and slope of Willow Creek, a riffle-pool bed form is expected. Such a bed shows a sequential bed form of riffle, run, pool and glide throughout the stream profile, with the pool typically being located in the cut bank-section at the apex of the curve of the meander (the middle of the stream segment sketched in Figure 84) and the riffle typically located between the meander curves in what Figure 84 refers as the "lower curvature section." This form should be predicted in a restoration design and constructed into the channel. A recommended profile form has not yet been computed and is not provided in this planning document – this is left to the restoration design.

Floodplain Section

A relatively-smooth, flat floodplain surface needs to be constructed, with the channel section dug into this freshly-graded section. Constructing a smooth, flat surface from the current braided form will require grading of the surface, to cut aggregated areas and fill channel sections. The reconstructed channel, with riffles, runs, pools and glides, is then cut into this surface. This is illustrated in Figure 85. The grading is necessary to eliminate flow concentration points that can cause excessive erosion, with potential channel avulsion and project failure. Additionally, it will be cost prohibitive to truck in soils to cover the entire floodplain. A flat, vegetated floodplain will promote sediment deposition during flood flow to develop soils on the graded, cobble-size material. Vegetation will be promoted in selective areas to slow down flood flows, provide stability, and provide seed sources for germination on new, deposited soils.

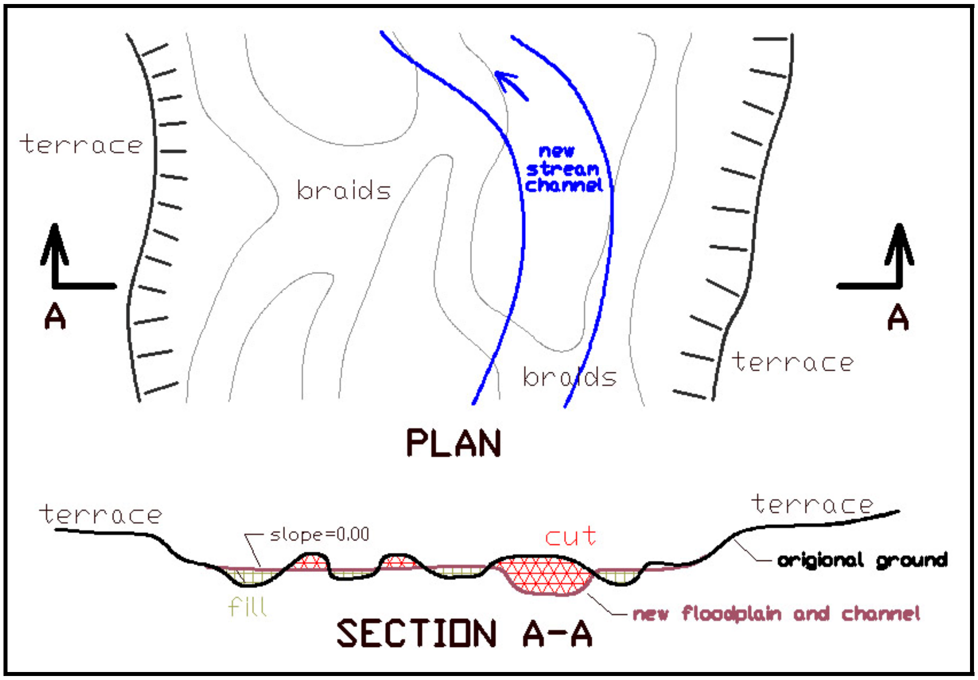

Figure 85: Typical floodplain plan and section.

Rock Features

Rock features are not a natural form in riffle-pool stream systems. Natural stream of this type rely primarily on vegetation to minimize bank instabilities and the rate of meander migration, preventing a braided condition. However, rock features can be necessary for a stream reconstruction to buy time until vegetation is reestablished. With the mining legacy of Willow Creek, the challenges in reestablishing vegetation argue for the necessity of rock features.

Hence, cross-vanes and J-hooks will very likely be necessary in this project. The cross-vanes are necessary to provide nick points for grade control. The J-hooks are necessary to provide bank protection of the channel bends until vegetation has been reestablished. Additionally, two stream diversions are necessary – a rock diversion structure is recommended for both of these diversions.

It is theorized that before settlement large woody debris commonly occurred in streams in the Inner-Mountain West. Though it is not known if this actually was the case, such large woody debris has been shown to offer substantial benefits to aquatic life. As an alternative to rock features, log structures may be substituted for the rock J-hooks. Such wood structures may be more esthetically pleasing and could better mimic natural processes since they can be common in C-type pool-riffle streams. It is essential that such structures be appropriately designed and constructed, so that they can fulfill the function of rock structures.

The restoration plan has assumed that three J-hooks will be necessary on most stream bends. However, some research indicates that bends suffer from excessive bank shear stress only towards the end of the bend. If this hypothesis can be substantiated through a literature search, it is recommended that the numbers of J-hooks implemented on the bends for bank protection be reduced.

Cross-Vanes

Cross-vanes are designed to redirect higher velocities from the edge to the center of a channel, reducing near-bank stress. Energy is dissipated in pools located away from the stream bank. Such pools function as fish habitat. Cross-vanes provide grade control, to prevent downcutting. An example of a cross vane, with both a plan and section view, is provided in Figures 86 and 87. The provided dimensions are approximate and need to be adjusted for the restoration design.

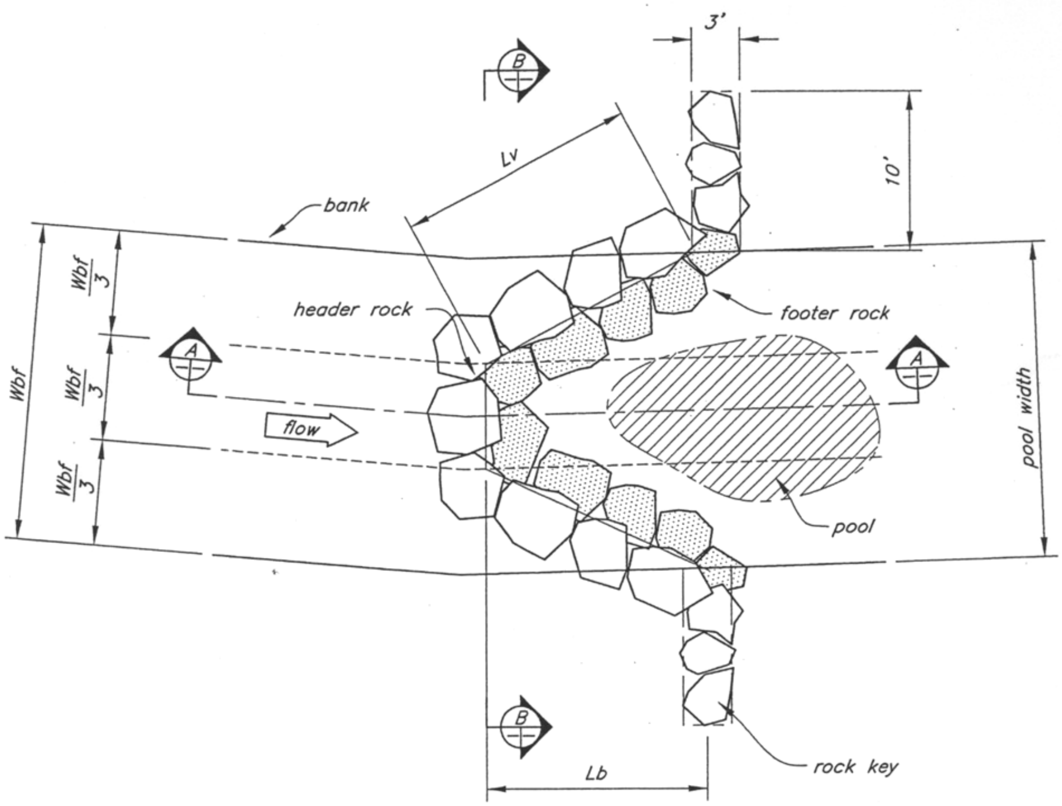

Figure 86: Cross vane example, plan view.

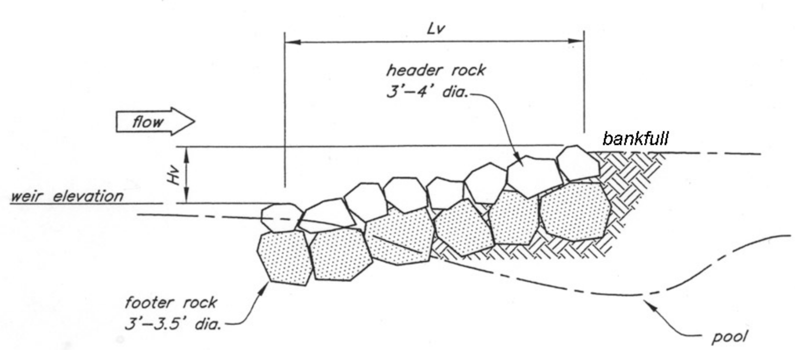

Figure 87: Cross vane example, section A.

J-Hooks

J-hooks are designed to redirect higher velocities on the outside of stream curves further into the channel, inducing subcritical flow near the erosive banks and reducing near-bank stress. Energy is dissipated in pools located away from the stream bank. Such pools also function as fish habitat. Wood and free-floating plant material and seed are commonly recruited in the subcritical zone between the vane structure and the streambank. Vanes are often used to address potential avulsion (meander cutoff) in constructed floodplains.

An example of a rock J-hook, with both a plan and section view, is provided in Figures 88 and 89. The provided dimensions are approximate and need to be adjusted for the restoration design.

As an alternative to rock features, log J-vane structures may be an effective alternative for the rock J-hooks.

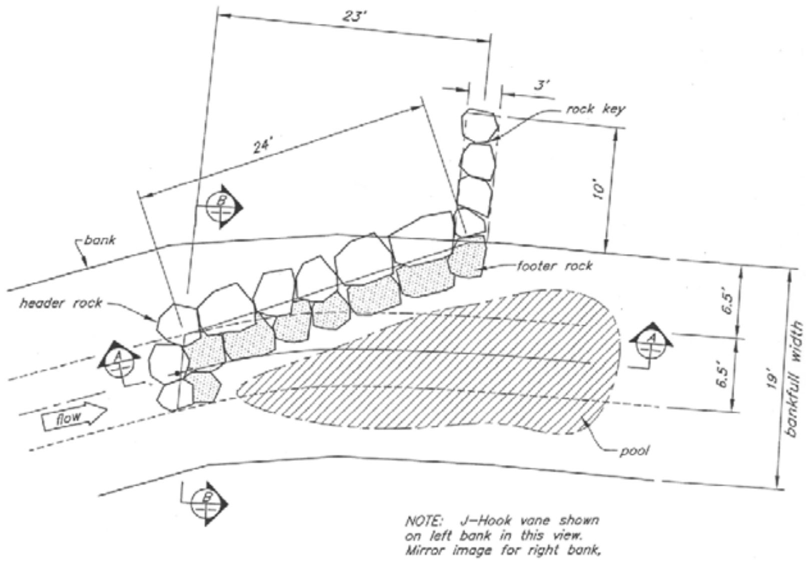

Figure 88: J-hook example, plan view.

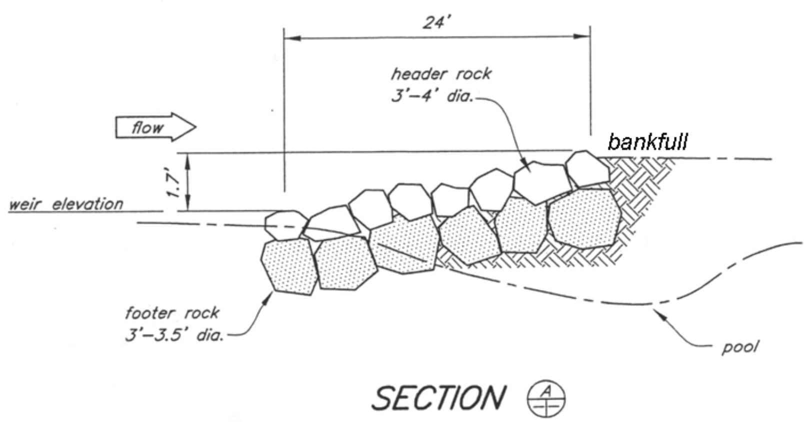

Figure 89: J-hook example, section A.

Irrigation Withdraws

Two stream diversions needed to be constructed within the floodplain, for the Wason and Zimmerman ditches, which divert flow to the east and west of the Willow Creek floodplain, respectively. These diversions are discussed in the irrigation diversion section. The Wason ditch has a decreed capacity of 6.0 cfs while the Zimmerman ditch has a decreed capacity of 1.2 cfs.

It is recommended that these diversions be a made using a cross-vane diversion structure, as illustrated in Figure 90.

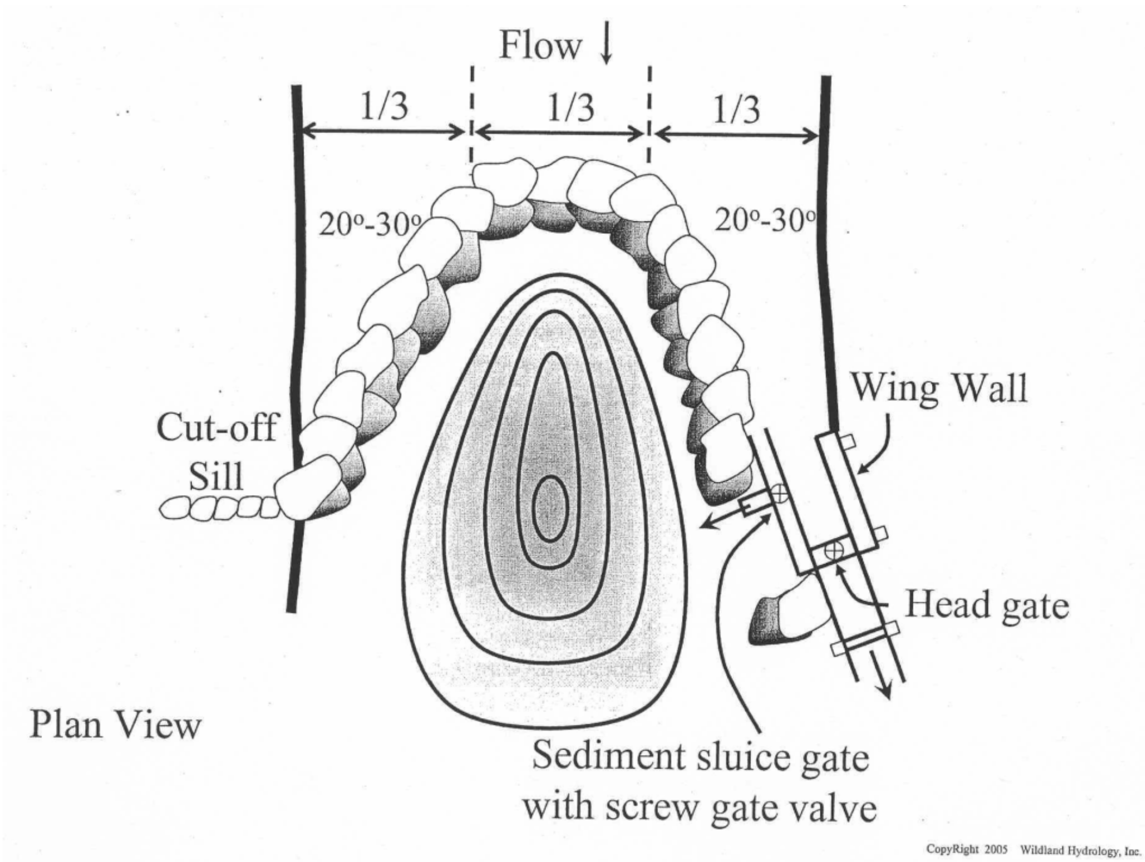

Figure 90: Illustration of cross-vane stream diversion. Reprinted with permission from Wildland Hydrology.

PROJECT MONITORING

Steven Yochum, *Hydrologist*

Project monitoring for a substantial period is strongly recommended. Such monitoring should be performed to assess the long-term success of this specific restoration and to serve as a learning tool for stream reconstruction and mine rehabilitation projects.

The monitoring should consist of at least the following data collection:

- Installation of photo locations, with specific points and azimuths (directions) set up before construction and monitored every year, at the same time of year. Initial photos should be taken immediately before construction. Eight to 12 photo locations are recommended.
- Installation of bank pins in at least three locations on the stream reconstruction. Bank pins are horizontal lengths of rebar pounded into the bank to measure lateral erosion rated. The bank pins should be measured once a year, at the same time of year.
- Detailed cross-sections measurements are recommended at the locations of the bank pins. These measurements should be taken once a year, at the same time of year. The cross section should be tied to a permanent benchmark located outside of the floodplain.
- Macroinvertebrate sampling at a number of points along the stream restoration. Sampling should occur once a year or once every-other year, at the same time of year. An initial monitoring event should be performed during the year before project construction, to establish a baseline condition.
- Fish count at a number of points along the stream restoration. Sampling should occur once a year or once every-other year, at the same time of year. An initial monitoring event should be performed during the year before project construction, to establish a baseline condition.
- Vegetation should be evaluated and monitored annually for the first five years after establishment; then once every other year or two. Monitoring of the vegetation along the corridor should include:
    - photo points
    - visual estimation of vegetative cover
    - plant height
    - percent survival

RESTORATION ALTERNATIVES

Steven Yochum, *Hydrologist*

Overviews and schematics of restoration alternatives, with quantities and cost estimates, are provided in this section. All quantities and costs are approximate. Costs are in 2006 dollars.

A substantial portion of the Wason property is intermittently covered with a fine, unvegetated material that appears to be tailings. All alternatives do not plan for restoring the Wason property where mine tailings appear to be prevalent. This area of exclusion is illustrated in Figure 91. The fine material has not been characterized - a restoration plan for this area can not be developed at this time. Additional and extensive site evaluation is needed on this portion of the floodplain before any plan can be developed for remediation.

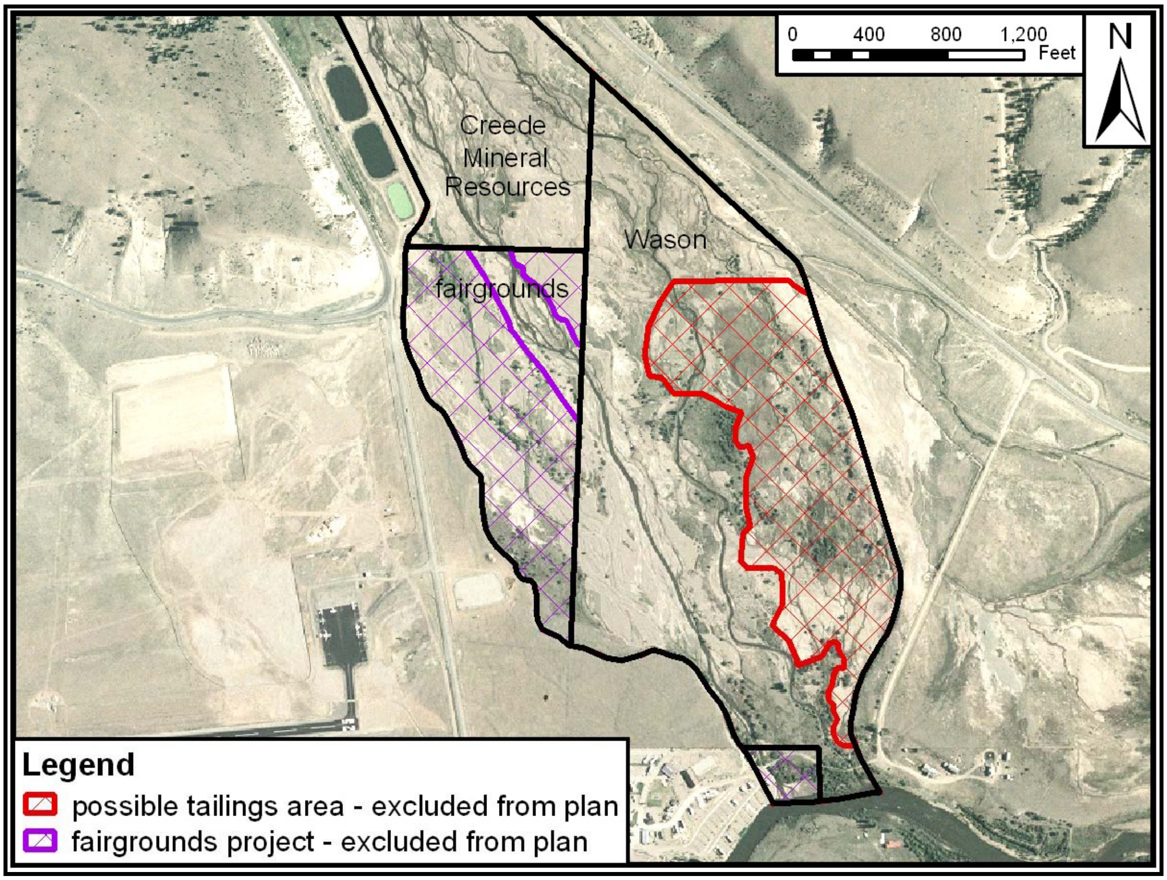

Figure 91: Excluded portions of the floodplain.

The fairgrounds plan is addressing restoration of their portion of the floodplain, as a part of the Mineral County fairgrounds construction. All areas not immediately adjacent to the stream will be addressed by this plan and do not need top be included in the Willow Creek stream restoration plan. This area is also shown in Figure 91. The restoration of the stream itself, with its adjacent active floodplain, is not currently planned for by the fairgrounds and is included in this restoration plan.

Additionally, a portion of the historic floodplain that lies east of the railroad tracks, in the vicinity of the Emperious tailing pile, is in the need of restoration. However, this area is beyond the limits of the proposed project and was not considered in the restoration plan.

It is NRCS policy that all planning and design recommendations are made in accordance with criteria in applicable practice standards. Table 24 lists the practice standards believed to be applicable to this project. It is believed that the planning recommendations comply with the requirements of these standards.

Table 24: NRCS practice standards applicable to project.

Practice Name (and unit)	Practice Code
Channel Bank Vegetation (ac)	322
Channel Stabilization (ft)	584
Critical Area Planting (ac)	342
Dam, Diversion (no)	348
Open Channel (ft)	582
Streambank and Shoreline Protection (ft)	580
Stream Crossing (no)	578
Stream Habitat Improvement and Management (ac)	395
Wetland Creation (ac)	658

Alternatives

The alternatives proposed for the Willow Creek Stream Restoration are as follows:

(1) Do nothing.

(2) Single-thread stream to downstream limit of the fairgrounds property, with restored floodplain.+

(2a) Option 2, plus restored upland terraces.

(3) Single-thread stream to downstream limit of the fairgrounds property, with restored floodplain and constructed wetlands.

(3a) Option 3, plus restored upland terraces.

(4) Single-thread stream to Rio Grande, with restored floodplain.

(4a) Option 4, plus restored upland terraces.

(5) Single-thread stream to Rio Grande, with restored floodplain and constructed wetlands.

(5a) Option 5, plus restored upland terraces.

To help illustrate the features and limits of each alternative, Table 25 is provided to illustrate what each alternative accomplishes with respect to the restoration objectives. The restoration objectives, listed at the beginning of this document, are provided again below:

A. Construct a geomorphically stable, meandering stream channel from the end of the existing flume to the Rio Grande.

B. Vegetate the riparian corridor with regionally appropriate herbaceous and woody vegetation.

C. Provide physical conditions so that, when water-quality improvements have been made within the watershed, proper biologic function of riparian corridor can be attained.

D. Monitor the channel morphology, vegetation success, and biologic re-colonization following construction.

E. Produce data, maps, and reports for dissemination of information regarding the approach to stream restoration and success.

Table 25: Project objectives versus restoration options.

Objective	Restoration Alternative								
	1	2	2a	3	3a	4	4a	5	5a
A. Stable stream to Rio Grande						X	X	X	X
B. Vegetated floodplain			X		X		X		X
C. Proper stream physical conditions		X	X	X	X	X	X	X	X
D. Project monitoring		X	X	X	X	X	X	X	X
E. Project documentation		X	X	X	X	X	X	X	X

Cost Estimates

General costs per unit for performing the construction, in 2006 dollars, are provided below. The cost estimates are approximate, with not all costs considered. For example, not all of the labor for material placement and material transportation costs are accounted for at this planning level since the necessary variables for making these estimates are not yet known. At the same time, earth work estimates may be a bit high. Hence, cost estimates provided may be a bit high in some regards in a bit low in other regards. The bottom line estimates should be a reasonable representation of the costs to perform the required work.

- ***Earth Movement*** Earth movement quantities used in the analysis consisted of \$240 per acre for grading of the floodplain surface and \$4.25 per cubic yard for moving volumes of material on-site.

- ***Rock*** Previous stream projects where rocks of an appropriate size were used in the Upper Rio Grande watershed has a cost range of \$45 to \$65 per cubic yard, depending upon contractor. A value of \$55 per cubic yard was used in this cost estimate. Specific gravity of rocks in the San Juans typically range 2.2 to 2.5. Using a specific gravity of 2.4, this translates to approximately \$27 per ton.
    - The J-hooks are estimated to have a volume of 35 to 40 cubic yards. Using an estimate of 40 cubic yards or 81 tons per structure, each J-hook is estimated to cost \$2200.
    - The cross vanes are estimated to have a volume of 60 cubic yards. Using this estimate, which equates to 120 tons per structure, each cross vane is estimated to cost \$3300.

- ***Soil*** Numerous potential suppliers of topsoil and mulch were contacted regarding the cost of providing material. The costs of topsoil ranged from \$10 to \$25 per cubic yard. The cost of mulch ranged from \$20 to \$25 per cubic yard. For this work, a topsoil cost of \$18 is assumed while a mulch cost of \$25 is assumed.

Assuming a soil depth of 3 inches in restored areas, the $18 per cubic yards of soil is equivalent to $7300 per acre.

Importantly, it has been mentioned that several reservoirs in the Upper Rio Grande may be dredged in the coming years. Examples include Humphries Lake, Browns Lake and Rio Grande Reservoir. Dredging material from these reservoirs, if deemed clean and of appropriate composition, may provide a source of cheaper soils for the floodplain.

The floodplain is not entirely denuded of soil – some wet areas have existing soil. It has been assumed that one quarter of the wet areas of the Creede Resources property have recoverable soil to cover an equal area. This amounts to approximately 5.8 acres of potential available on-site soil to be used in all alternatives.

- ***Vegetation*** Proposed vegetation for the stream and floodplain includes grasses and willows.
  - Grass seed recommendations for the floodplain for wetland and upland areas, with species as shown in Table D-2, are as follows:
    - Floodplain: $51/acre
    - Wetland: $524/acre
    - Upland: $57/acre
  - Willow costs are estimated assuming the use of containers from an offsite nursery, since currently few willows are available on site. **This is not the preferred option, since more mature willows are preferred to provide greater stability in less time.** Also, excavation cost is not included. Developing an on-site willow nursery in the years before construction may be an excellent option, to reduce costs and provide better material for construction. Also, bringing in willows from local properties would be another good option. Such scenarios will change the cost estimates.
    - Dense line (6 foot spacing), for along channel bends, with a cost per pot of $11.50: $1.90/ linear foot.
    - Broadly-spaced line (12 foot spacing), for such places as along irrigation ditches, with a cost per pot of $11.50: $0.95/ linear foot.
    - Willow area (20 foot spacing), with a cost per pot of $11.50: $1150/acre.

With the wide-ranging issues to be addressed, Willow Creek is a relatively difficult project to achieve success. Due to this risk, substantial **operation and maintenance (O&M) costs** should be initially set aside to address project needs over the long term. It is recommended that O&M costs of 15 to 20 percent of the project cost be set aside. An O&M value of 15 percent has been used in this analysis.

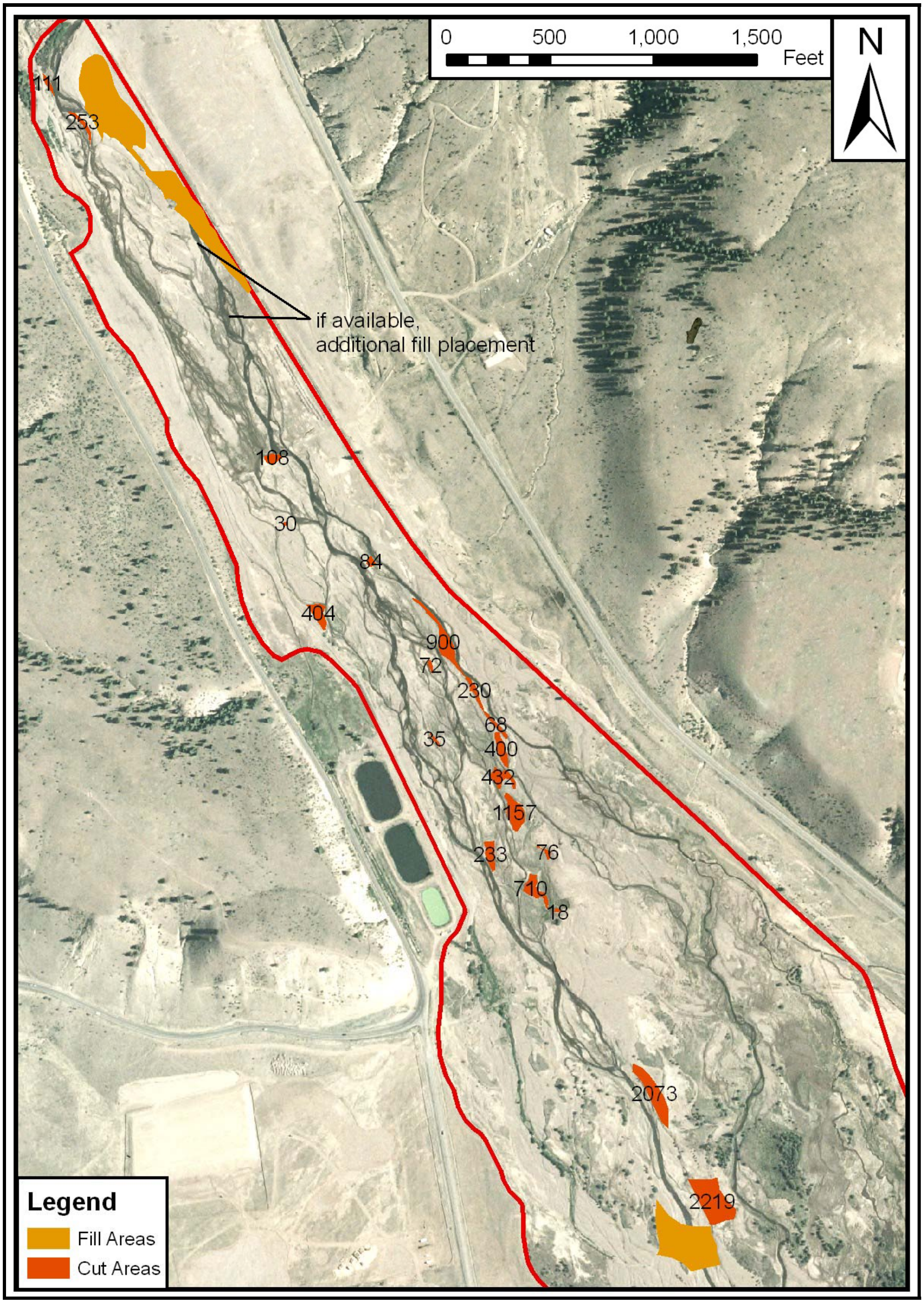

Figure 92: Cut and fill areas of the stream restoration, with volumes in cubic yards. The substantial cut of the stream channel has not been illustrated.

Cut Quantities

Quantities of earth cut for areas other than the stream channel are provided in Figure 92. Fill areas are also shown. Approximately 9600 cubic yards of material are recommended to be moved as a part of the project. An additional volume of material will need to be moved for the stream channel, diversion channels and wetlands. In addition, the entire floodplain is to be graded to smooth the channel braids.

Alternative Details

Each restoration alternative is detailed in this section. A plan view schematic of each proposal is provided. The plan layouts are preliminary – the design will fine tune the pattern geometry and lay out the final form. Approximate quantities and costs are also provided.

Alternative (1): Do nothing.

The historic aerial photography has noted little to no change in the form of the stream and the extent of the vegetation within the will Creek Floodplain between 1939 and 2006. It is estimated that letting the stream and floodplain naturally restore itself will take at least 100 years and possibly much longer.

Alternative (2): Single-thread stream to downstream limit of the fairgrounds property.

In this alternative it is assumed that Wason Ranch does not participate in the stream restoration. The stream restoration is planned through the Creede Resources and Fairgrounds properties, to the Wason property line. A layout of this alternative is shown in Figure 93, with a higher-resolution schematic provided in Figure A-10.

In alternative 2 the surface of the floodplain for the entire project extent is to be graded, to eliminate braiding and provide a relatively smooth surface. Additional waste-rock material currently located in piles throughout the floodplain is to be moved to the noted fill areas. Impact on existing wetlands will need to be assessed. On the relatively smooth new floodplain surface a sinuous channel is to be excavated and J-hooks and cross vanes installed to provide stability until vegetation has been restored. Possible irrigation diversion locations are indicated on the map – the Wason diversion can be shifted upstream if deemed necessary to reduce the potential of groundwater contamination plume movement. A substantial quantity of soil is to be deposed on the floodplain (alternative 2) or both the floodplain and upland terraces (in alternative 2a) to allow vegetation growth. Healthy vegetation within the floodplain is a necessary part of the project – the roots are highly effective in holding streambanks together. Dense willow lines, with soil, are to be installed along the outside bend of the constructed channel and this area is to be seeded. Additionally, willow areas with soil are to be installed with wider spacing in a number of noted areas within the floodplain, with additional seeding provided.

The estimated cost of alternative 2 is $570,000. A breakdown of the quantities and costs is provided in Table 26. The estimated cost of Alternative 2a, with restored upland terraces, is $840,000. If a less expensive source for soil can be located, then the costs for alternative 2 will decrease a bit and 2a will decrease substantially.

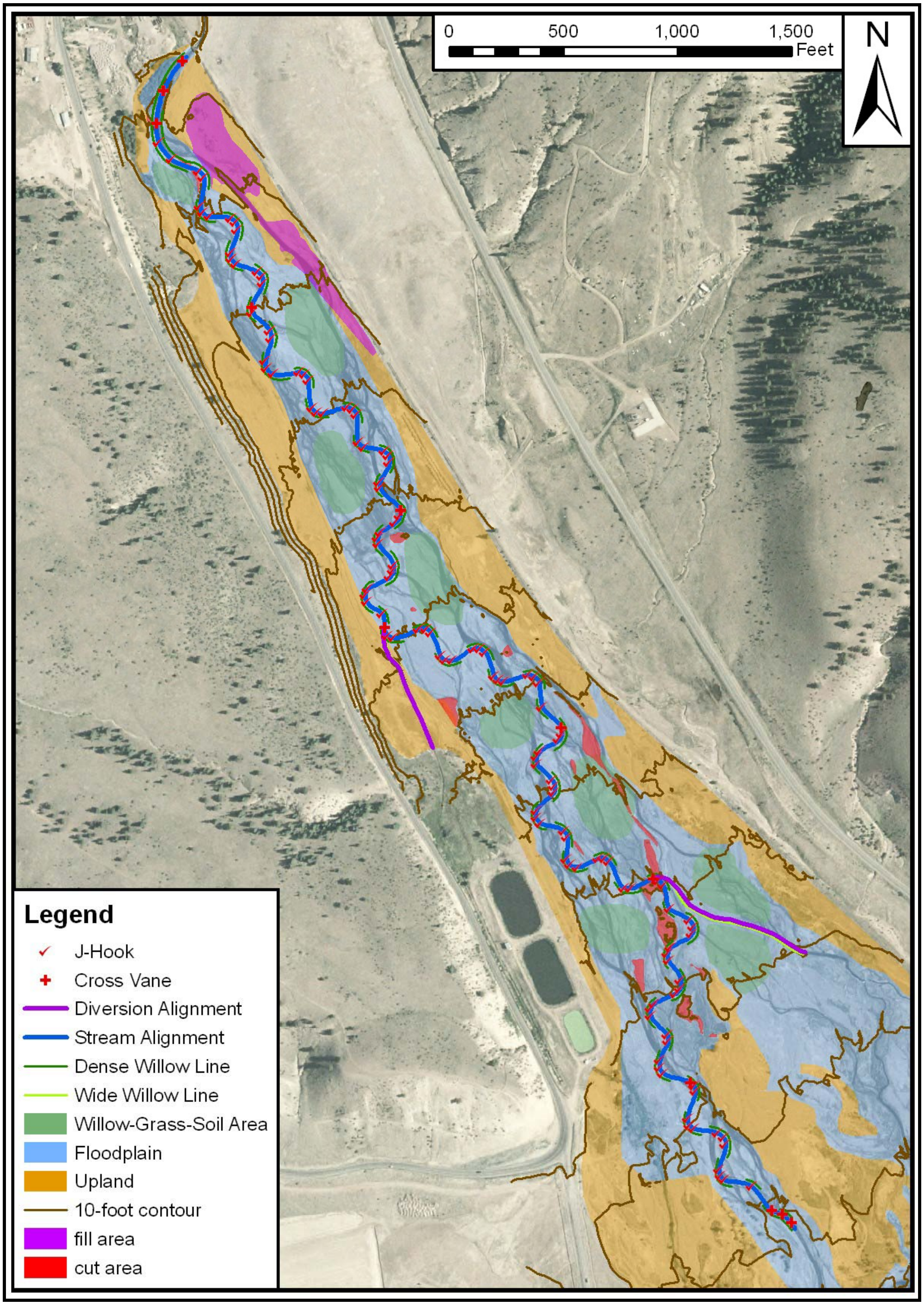

Figure 93: Restoration layout, Alternative 2.

Table 26: Cost estimates, alternative 2 and 2a.

cost per acre of graded surface:	$240
cost per cubic yard of moved material:	$4.25
cost per J-hook:	$2,200
cost per Cross-Vane:	$3,300
soil, per acre at 3" depth:	$7,300
floodplain seed mixture, per acre:	$51
wetland seed mixture, per acre:	$524
upland seed mixture, per acre:	$57
dense willow line, per foot:	$1.90
broad willow line, per foot:	$0.95
willow area, per acre:	$1,150

Channels

length of reconstructed stream (feet):	*8230*
average excavation width (feet):	*20*
average excavation depth (feet):	*1.8*
excavation volume (yd3):	*10973*
cost for excavating channel:	*$46,637*
length of diversion ditch (feet):	*910*
average excavation width (feet):	*10*
average excavation depth (feet):	*3*
excavation volume (yd3):	*1011*
cost for excavating divesion channels:	*$4,297*
subtotal, channels:	*$50,934*

General Earth Movement

area to be graded (acres):	*58.3*
cost for floodplain grading:	*$13,992*
volume moved a distance (yards3):	*5321*
cost for moving material:	*$22,614*
subtotal, earth movement:	*$36,606*

Soil

willow area, acres:	*12.2*
wetland area, acres:	*0*
floodplain area needing soil, acres:	*12.2*
length of dense willows:	*8036*
dense willow soil width:	*6*
area of soil, with dense willows:	*1.1*
soil area potentially available:	*5.8*
additional soil area needed, acres:	*7.5*
floodplain soil cost:	*$54,800*
upland area in need of soil, acres:	*31.64*
upland soil cost:	*$230,972*

Structures

number of J-hooks:	*120*
cost for J-hooks:	*$264,000*
number of cross vanes:	*11*
cost for cross vanes:	*$36,300*
subtotal, structures:	*$300,300*

Vegetation

length of dense willows, feet:	*8036*
cost of dense willow line:	*$15,268*
length of broad willow line, feet:	*932*
cost of broad willow line:	*$885*
willow area, acres:	*12.2*
cost for willow area:	*$14,030*
floodplain grass seed area, acres:	*13.3*
floodplain seed costs:	*$679*
upland grass seed area, acres:	*31.6*
upland seed costs:	*$1,803*
wetland seed area, acres:	*0*
wetland seed costs:	*$0*
subtotal, vegetation:	*$32,666*

Miscellaneous

diversion quantity:	*2*
cost per headgate:	*1000*
cost per parshall flume:	*$1,500*
diversion costs:	*$5,000*
O&M costs, alternative 2:	$71,775
O&M costs, alternative 2a:	$106,692
Total, Alternative 2:	***$550,278***
Total, Alternative 2a:	***$817,970***

Alternative (3): Single-thread stream to downstream limit of the fairgrounds property, with constructed wetlands

This alternative is essentially alternative 2 with the addition of constructed wetlands. Alternative 3 also assumes that Wason Ranch does not participate in the stream restoration. The stream restoration is planned through the Creede Resources and Fairgrounds properties, to the Wason property line. A layout of this alternative is shown in Figure 94, with a higher-resolution schematic provided in Figure A-11.

In alternative 3 the surface of the floodplain for the entire project extent is to be graded, to eliminate braiding and provide a relatively smooth surface. Additional waste-rock material currently located in piles throughout the floodplain is to be moved to the noted fill areas. On the relatively smooth new floodplain surface a sinuous channel is to be excavated and J-hooks and cross vanes installed to provide stability until vegetation has been restored. Possible irrigation diversion locations are indicated on the layout map – the Wason diversion can be shifted upstream if deemed necessary to reduce the potential of groundwater contamination plume movement. Constructed wetlands are to be installed by excavating the cobble and gravels of the floodplain to just below the expected constructed water table surface and soils and wetland-appropriate vegetation added. A portion of the excavation from the wetlands may need to be deposited in an unknown location, though additional fill can be placed in the floodplain in the vicinity of the contamination plume (Figure 92). It is possible that additional fill can be added to the floodplain surface, raising the surface in an even manner. A substantial additional quantity of soil is to be deposed on the floodplain (alternative 3) or both the floodplain and upland terraces (in alternative 3a) to allow vegetation growth. Healthy vegetation within the floodplain is a necessary part of the project – the roots are highly effective in holding streambanks together. Dense willow lines, with soil, are to be installed along the outside bend of the constructed channel and this area is to be seeded. Additionally, willow areas with soil are to be installed with wider spacing in a number of noted areas within the floodplain, with additional seeding provided.

The estimated cost of alternative 3 is $730,000. A breakdown of the quantities and costs is provided in Table 27. The estimated cost of Alternative 3a, with restored upland terraces, is $990,000. If a less expensive source for soil can be located, then the costs for both alternative 3 and 3a will decrease substantially.

Alternative (4): Single-thread stream to Rio Grande.

Alternative 4 assumes that Wason Ranch will participate in the stream restoration. The stream restoration is planned through the Creede Resources and Fairgrounds properties, and through Wason Ranch property to the Rio Grande. A layout of this alternative is shown in Figure 95, with a higher-resolution schematic provided in Figure A-12.

In alternative 4 the surface of the floodplain for the entire project extent is to be graded, to eliminate braiding and provide a relatively smooth surface. Additional waste-rock material currently located in piles throughout the floodplain is to be moved to the noted fill areas. Impact on existing wetlands will need to be assessed. On the relatively smooth new floodplain surface a sinuous channel is to be excavated and J-hooks and cross vanes installed to provide stability until vegetation has been restored. Possible irrigation diversion locations are indicated on the layout map – the Wason diversion can be shifted

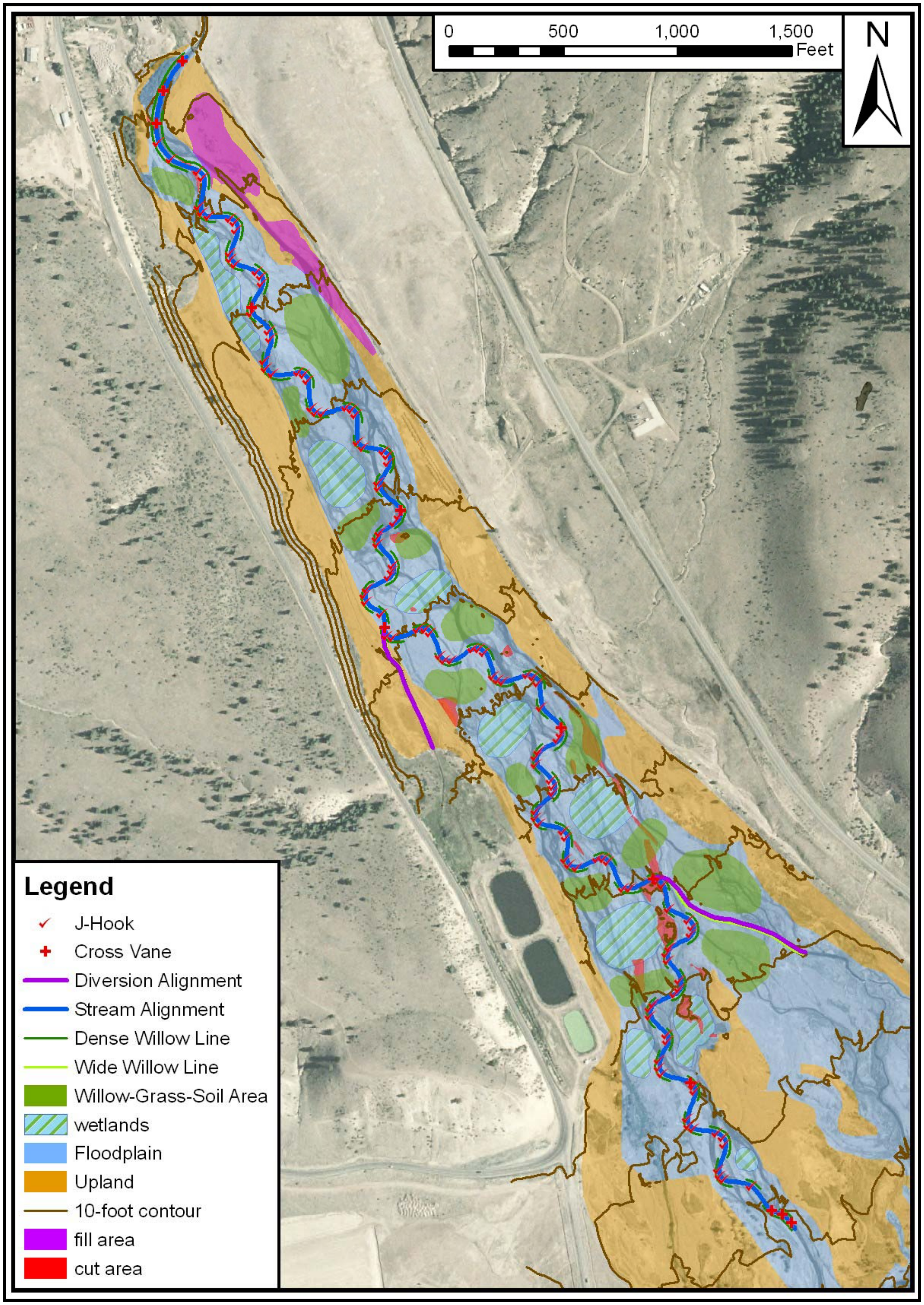

Figure 94: Restoration layout, Alternative 3.

Table 27: Cost estimates, alternative 3 and 3a.

cost per acre of graded surface:	$240
cost per cubic yard of moved material:	$4.25
cost per J-hook:	$2,200
cost per Cross-Vane:	$3,300
soil, per acre at 3" depth:	$7,300
floodplain seed mixture, per acre:	$51
wetland seed mixture, per acre:	$524
upland seed mixture, per acre:	$57
dense willow line, per foot:	$1.90
broad willow line, per foot:	$0.95
willow area, per acre:	$1,150

Channels

length of reconstructed stream (feet):	*8230*
average excavation width (feet):	*20*
average excavation depth (feet):	*1.8*
excavation volume (yd3):	*10973*
cost for excavating channel:	*$46,637*
length of diversion ditch (feet):	*910*
average excavation width (feet):	*10*
average excavation depth (feet):	*3*
excavation volume (yd3):	*1011*
cost for excavating divesion channels:	*$4,297*
subtotal, channels:	*$50,934*

General Earth Movement

area to be graded (acres):	*58.3*
cost for floodplain grading:	*$13,992*
volume moved a distance (yards3):	*25649*
cost for moving material:	*$109,008*
subtotal, earth movement:	*$123,000*

Soil

willow area, acres:	*11.1*
wetland area, acres:	*8.4*
floodplain area needing soil, acres:	*19.5*
length of dense willows:	*8036*
dense willow soil width:	*6*
area of soil, with dense willows:	*1.1*
soil area potentially available:	*5.8*
additional soil area needed, acres:	*14.8*
floodplain soil cost:	*$108,090*
upland area in need of soil, acres:	*31.64*
upland soil cost:	*$230,972*

Structures

number of J-hooks:	*120*
cost for J-hooks:	*$264,000*
number of cross vanes:	*11*
cost for cross vanes:	*$36,300*
subtotal, structures:	*$300,300*

Vegetation

length of dense willows, feet:	*8036*
cost of dense willow line:	*$15,268*
length of broad willow line, feet:	*932*
cost of broad willow line:	*$885*
willow area, acres:	*19.5*
cost for willow area:	*$22,425*
floodplain grass seed area, acres:	*20.6*
floodplain seed costs:	*$1,051*
upland grass seed area, acres:	*31.6*
upland seed costs:	*$1,803*
wetland seed area, acres:	*8.4*
wetland seed costs:	*$4,402*
subtotal, vegetation:	*$45,835*

Miscellaneous

diversion quantity:	*2*
cost per headgate:	*1000*
cost per parshall flume:	*$1,500*
diversion costs:	*$5,000*
O&M costs, alternative 3:	$94,703
O&M costs, alternative 3a:	$129,620
Total, Alternative 3:	***$726,059***
Total, Alternative 3a:	***$993,751***

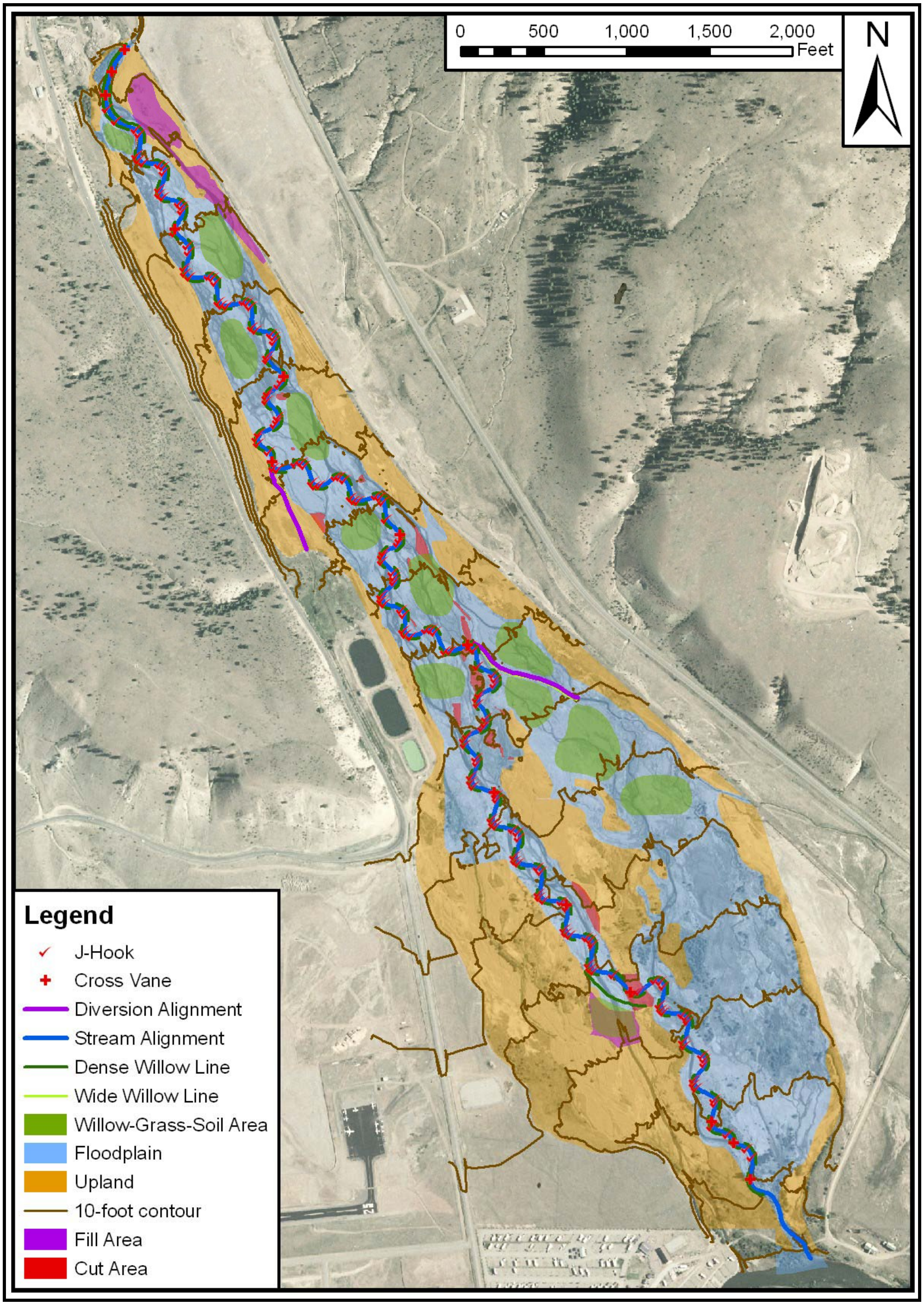

Figure 95: Restoration layout, Alternative 4.

Table 28: Cost estimates, alternative 4 and 4a.

cost per acre of graded surface:	$240
cost per cubic yard of moved material:	$4.25
cost per J-hook:	$2,200
cost per Cross-Vane:	$3,300
soil, per acre at 3" depth:	$7,300

Channels

length of reconstructed stream (feet):	*11600*
average excavation width (feet):	*20*
average excavation depth (feet):	*1.8*
excavation volume (yd3):	*15467*
cost for excavating channel:	*$65,733*
length of diversion ditch (feet):	*910*
average excavation width (feet):	*10*
average excavation depth (feet):	*3*
excavation volume (yd3):	*1011*
cost for excavating divesion channels:	*$4,297*
subtotal, channels:	*$70,031*

General Earth Movement

area to be graded (acres):	*85.7*
cost for floodplain grading:	*$20,568*
volume moved a distance (yards3):	*9613*
cost for moving material:	*$40,855*
subtotal, earth movement:	*$61,423*

Soil

willow area, acres:	*18.4*
wetland area, acres:	*0*
floodplain area needing soil, acres:	*18.4*
length of dense willows:	*10970*
dense willow soil width:	*6*
area of soil, with dense willows:	*1.5*
soil area potentially available:	*5.8*
additional soil area needed, acres:	*14.1*
floodplain soil cost:	*$103,010*
upland area in need of soil, acres:	*59.76*
upland soil cost:	*$436,248*

floodplain seed mixture, per acre:	$51
wetland seed mixture, per acre:	$524
upland seed mixture, per acre:	$57
dense willow line, per foot:	$1.90
broad willow line, per foot:	$0.95
willow area, per acre:	$1,150

Structures

number of J-hooks:	*161*
cost for J-hooks:	*$354,200*
number of cross vanes:	*13*
cost for cross vanes:	*$42,900*
subtotal, structures:	*$397,100*

Vegetation

length of dense willows, feet:	*10970*
cost of dense willow line:	*$20,843*
length of broad willow line, feet:	*932*
cost of broad willow line:	*$885*
willow area, acres:	*18.4*
cost for willow area:	*$21,160*
floodplain grass seed area, acres:	*19.9*
floodplain seed costs:	*$1,015*
upland grass seed area, acres:	*59.8*
upland seed costs:	*$3,406*
wetland seed area, acres:	*0*
wetland seed costs:	*$0*
subtotal, vegetation:	*$47,310*

Miscellaneous

diversion quantity:	*2*
cost per headgate:	*1000*
cost per parshall flume:	*$1,500*
diversion costs:	*$5,000*
O&M costs, alternative 4:	$102,070
O&M costs, alternative 4a:	$168,018
Total, Alternative 4:	***$782,538***
Total, Alternative 4a:	***$1,288,141***

upstream if deemed necessary to reduce the potential of groundwater contamination plume movement. A substantial quantity of soil is to be deposed on the floodplain (alternative 4) or both the floodplain and upland terraces (in alternative 4a) to allow vegetation growth. Healthy vegetation within the floodplain is a necessary part of the project – the roots are highly effective in holding streambanks together. Dense willow lines, with soil, are to be installed along the outside bend of the constructed channel and this area is to be seeded. Additionally, willow areas with soil are to be installed with wider spacing in a number of noted areas within the floodplain, with additional seeding provided.

The estimated cost of alternative 4 is $780,000. A breakdown of the quantities and costs is provided in Table 28. The estimated cost of Alternative 4a, with restored upland terraces, is $1,290,000. If a less expensive source for soil can be located, then the costs for alternative 4 will decrease a bit and 4a will decrease substantially.

Alternative (5): Single-thread stream to Rio Grande, with constructed wetlands.

This alternative is essentially alternative 4 with the addition of constructed wetlands. Alternative 5 assumes that Wason Ranch will participate in the stream restoration. The stream restoration is planned through the Creede Resources and Fairgrounds properties, and through Wason Ranch property to the Rio Grande. A layout of this alternative is shown in Figure 96, with a higher-resolution schematic provided in Figure A-13.

In alternative 5 the surface of the floodplain for the entire project extent is to be graded, to eliminate braiding and provide a relatively smooth surface. Additional waste-rock material currently located in piles throughout the floodplain is to be moved to the noted fill areas. On the relatively smooth new floodplain surface a sinuous channel is to be excavated and J-hooks and cross vanes installed to provide stability until vegetation has been restored. Possible irrigation diversion locations are indicated on the layout map – the Wason diversion can be shifted upstream if deemed necessary to reduce the potential of groundwater contamination plume movement. Constructed wetlands are to be installed by excavating the cobble and gravels of the floodplain to just below the expected constructed water table surface and soils and wetland-appropriate vegetation added. A portion of the excavation from the wetlands may need to be deposited in an unknown location, though additional fill can be placed in the floodplain in the vicinity of the contamination plume (Figure 92). It is possible that additional fill can be added to the floodplain surface, raising the surface in an even manner. A substantial additional quantity of soil is to be deposed on the floodplain (alternative 5) or both the floodplain and upland terraces (in alternative 5a) to allow vegetation growth. Healthy vegetation within the floodplain is a necessary part of the project – the roots are highly effective in holding streambanks together. Dense willow lines, with soil, are to be installed along the outside bend of the constructed channel and this area is to be seeded. Additionally, willow areas with soil are to be installed with wider spacing in a number of noted areas within the floodplain, with additional seeding provided.

The estimated cost of alternative 5 is $970,000. A breakdown of the quantities and costs is provided in Table 29. The estimated cost of Alternative 5a, with restored upland terraces, is $1,470,000. If a less expensive source for soil can be located, then the costs for both alternative 5 and 5a will decrease substantially.

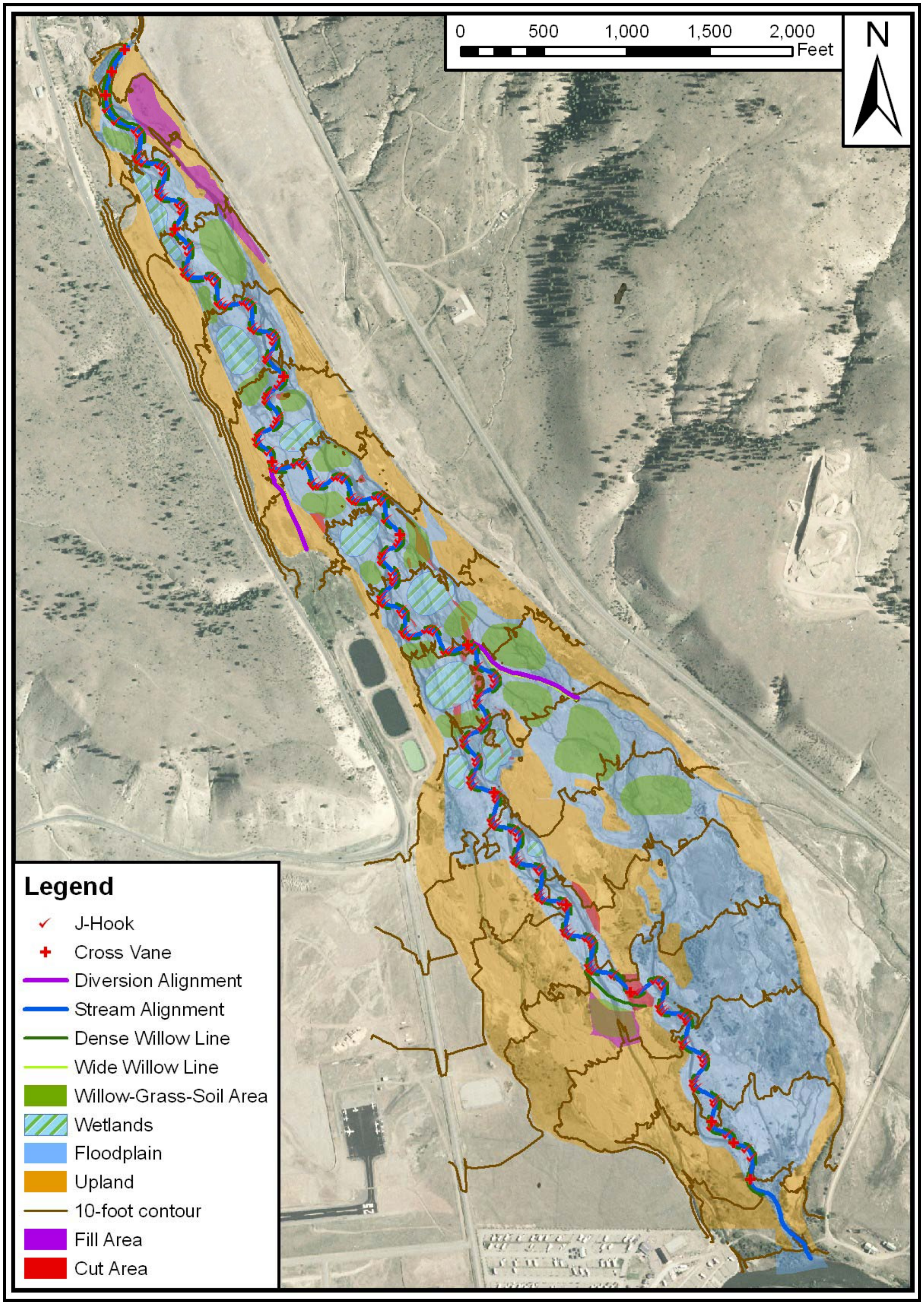

Figure 96: Restoration layout, Alternative 5.

Table 29: Cost estimates, alternative 5 and 5a.

cost per acre of graded surface:	$240
cost per cubic yard of moved material:	$4.25
cost per J-hook:	$2,200
cost per Cross-Vane:	$3,300
soil, per acre at 3" depth:	$7,300

Channels

length of reconstructed stream (feet):	*11600*
average excavation width (feet):	*20*
average excavation depth (feet):	*1.8*
excavation volume (yd3):	*15467*
cost for excavating channel:	*$65,733*
length of diversion ditch (feet):	*910*
average excavation width (feet):	*10*
average excavation depth (feet):	*3*
excavation volume (yd3):	*1011*
cost for excavating divesion channels:	*$4,297*
subtotal, channels:	*$70,031*

General Earth Movement

area to be graded (acres):	*85.7*
cost for floodplain grading:	*$20,568*
volume moved a distance (yards3):	*29941*
cost for moving material:	*$127,249*
subtotal, earth movement:	*$147,817*

Soil

willow area, acres:	*18.4*
wetland area, acres:	*8.4*
floodplain area needing soil, acres:	*26.8*
length of dense willows:	*10970*
dense willow soil width:	*6*
area of soil, with dense willows:	*1.5*
soil area potentially available:	*5.8*
additional soil area needed, acres:	*22.5*
floodplain soil cost:	*$164,330*
upland area in need of soil, acres:	*59.76*
upland soil cost:	*$436,248*

floodplain seed mixture, per acre:	$51
wetland seed mixture, per acre:	$524
upland seed mixture, per acre:	$57
dense willow line, per foot:	$1.90
broad willow line, per foot:	$0.95
willow area, per acre:	$1,150

Structures

number of J-hooks:	*161*
cost for J-hooks:	*$354,200*
number of cross vanes:	*13*
cost for cross vanes:	*$42,900*
subtotal, structures:	*$397,100*

Vegetation

length of dense willows, feet:	*10970*
cost of dense willow line:	*$20,843*
length of broad willow line, feet:	*932*
cost of broad willow line:	*$885*
willow area, acres:	*26.8*
cost for willow area:	*$30,820*
floodplain grass seed area, acres:	*28.3*
floodplain seed costs:	*$1,444*
upland grass seed area, acres:	*59.8*
upland seed costs:	*$3,406*
wetland seed area, acres:	*8.4*
wetland seed costs:	*$4,402*
subtotal, vegetation:	*$61,800*

Miscellaneous

diversion quantity:	*2*
cost per headgate:	*1000*
cost per parshall flume:	*$1,500*
diversion costs:	*$5,000*
O&M costs, alternative 5:	$126,401
O&M costs, alternative 5a:	$192,349
Total, Alternative 5:	***$969,073***
Total, Alternative 5a:	***$1,474,675***

RESTORATION SUMMARY AND RECOMENDATIONS

The Willow Creek floodplains suffers from a great deal of impairment due to historic mining practices. The condition of this floodplain has been poor for more than a century, with current condition being similar to conditions as far back to at least 1939. Due to the high degree of destruction and neglect of the floodplain by the mining activities, the challenges of this project are substantial – the costs of a reconstruction will also be substantial.

Restoring the upland terraces is recommended. Otherwise, these areas will not grow substantial beneficial vegetation.

The Wason property appears to have an extensive quantity of tailings on their portion of the floodplain. These areas need additional analysis and have been not included in this restoration plan.

It is strongly recommended that a single thread stream be designed and constructed. Attempting to divert streamflow into two active bankfull channels will increase the probability of project failure.

Four restoration alternatives, with four additional sub-alternatives, have been provided in this restoration plan. The costs of the restoration alternatives are estimated to range from $550,000 to 1,470,000. The alternatives vary in both restored length and restored extent. The restored length varies to reflect the unknown willingness of the Wason Ranch to participate in the restoration, due to their lack of participation and coordination with other Willow Creek Restoration Committee activities. The restored extent varies due to the inclusion or exclusion of the upland-terrace areas. Restoring these areas will require a great deal of imported soil, contributing up to a third of the estimated project cost. These areas will not restore without intervention – soil and seeding will be necessary. Additionally, the inclusion or exclusion of wetlands in the restoration substantially adds to the cost of the project. Additional funding may be available for a project that includes wetlands.

To reduce the possibility of restoration failure due to the project unraveling from the downstream up, it is recommended that the entire project length be restored and that alternative 4 or 5 be implemented. If additional funding can be secured for the inclusion of wetlands, option 5 is recommended. Restoration of the upland areas should also be performed to address what currently has the appearance of a wasteland. Such an appearance does not support Creede’s wish to make this stream corridor into a park setting. Restoration of this upland area can be delayed and implemented in a phased approach if additional funds can not be immediately located.

Only preliminary, planning -level estimates have been provided in this document for the hydraulic geometry of the restored stream. In the design process, a reference reach should be implemented in the hydraulic design. Also, sediment transport calculations and other more advanced methods should be performed while determining the final dimension, pattern and profile of the restored stream. Other checks of the hydraulic design will likely also be necessary.

Due to the substantial challenges of this project, the restoration designer should have a number of successful braided-to-sinuous stream reconstructions in their portfolio before being considered for this project. The choice of construction company for this job is also critical. A company that typically constructs roadways would not be appropriate for this job, for example. Only construction companies with extensive experience constructing riffle-pool stream channels, with rock features, should be considered for this project.

Finally, a list of issues to be resolved **before** construction of the stream restoration is provided in bulleted form below:

- Install long-term stabilization measures in West Willow Creek.
- Restore the groundwater contamination plume within and immediately adjacent to the floodplain. If this is not possible, develop and implement a long-term monitoring plan of the groundwater contamination plume, to measure movement and to ensure the stream restoration does not impact and increase discharge from the plume.
- Develop a plant nursery, to grow the substantial plant material needed for the project.
- Obtain project funding, for design and construction.
- While assessing and incorporating the community vision of the floodplain, develop landscape architecture priorities and objectives and develop a landscape architectural design.
- Hire a competent and appropriate design firm.
- Have the project design performed, using reference reach information, sediment transport modeling and other more advanced analysis that were not implemented in the restoration plan to develop the most appropriate dimension, pattern and profile of the restored stream.
- Locate additional sources of plant material and soil material.
- Complete final design.
- Hire a suitable construction firm that has experience with stream reconstruction projects.

Additionally, for full realization of stream potential, the following issue will need to be addressed:

- Restore the watershed's water quality impairments to such a point so that water-quality improvements in the mainstem Willow Creek will allow aquatic life and, ultimately, a fishery.

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