TECHNICAL SERVICE CENTER
DENVER, COLORADO

WILLOW CREEK FEEDER SYSTEM

GAME RANGE REACH EROSION CONTROL AND BANK STABILIZATION PLAN

PREPARED BY

RODNEY WITTLER
WILL GONZALES
JOHN ENGLAND

US Department of the Interior
U.S. Bureau of Reclamation

MAY 15, 2000

Jimmy

1. **Receipt for last statement (Walgreen's $25.64 rubbing alcohol)**
2. **This month's statement signed w/Family Dollar receipt (I have)**
3. **Receipts for Phoenix and Dillon (Idaho Falls - $28.00- Gas?)**
4. **Sign Albuquerque, Reno, Sacramento vouchers (Immediately)**
5. **Obtain receipts for Phoenix / Dillon and Albuquerque trips**
6. **Create vouchers for Phoenix / Dillon and Albuquerque trips and sign**
7. **Switch timesheet WOID from UC547 to OPECD**

Job/WOID: CCS77
Person for whom this work is being performed (First and Last Name): Bobby Rinehart
Cost center of the group for whom this work is being done (e.g., 8668460):
Craftsman: JBlack
Date:

Soil Sample Boxes 16" x 16" x 16"

Date	Material ID (from list of materials in database) *	Quantity	Units	Craftsman
8/25/17	Plywood, Perma Ply 3/4" x 8'	5	Sheets	JB

For Admin Use Only

Date Entered Into Database	
Transaction I.D. Number	

* Please supply unit costs if you are using a material that is not already in the database.

** For miscellaneous materials, enter the dollar cost in the "Units" column

Job/WOID	CCST7
Person for whom this work is being performed (First and Last Name)	Bobby Rinehart
Cost center of the group for whom this work is being done (e.g., 8668460)	
Craftsman	JBlack
Date	

Soil Sample Boxes 16"x16"x16"

Date	Material ID (from list of materials in database) *	Quantity	Units	Craftsman
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7-1654 (11-94)
Bureau of Reclamation

COMPUTATION SHEET

BY	DATE	PROJECT	SHEET ___ OF ___
CHKD BY	DATE	FEATURE	
DETAILS Soil Sample boxes for Bobby Rinehart			

X2395

woid: CCST7

- qty 12
- 16" x 16" x 16" boxes
- 3/4" perma-ply
- 2 handles
- lids attach w/ screws
- need by 9/6

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RECLAMATION'S MISSION

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

DEPARTMENT OF THE INTERIOR'S MISSION

The mission of the Department of Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

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ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

GAME RANGE REACH EROSION CONTROL AND BANK STABILIZATION PLAN

INTRODUCTION

This report presents a plan for controlling the erosion and stabilizing the banks of a reach of the Willow Creek Feeder System within the Sun River Wildlife Management Area. Greenfields Irrigation District of Fairfield, Montana administers the feeder system, part of the Sun River Project. Montana Fish, Wildlife and Parks administer the Sun River Wildlife Management Area.

This plan describes the location of the subject reach. Next, a description of equipment and procedures for gathering field data. Then an explanation of the types of bank and bed stabilization that this plans. The following section presents the flood frequency estimates for the feeder system and Willow Creek. An inventory of both banks of the reach follows including detailed photographic documentation. Then an analysis of the hydraulics of representative channel sections, as well as an estimate of available rock. The final section presents a plan for controlling the erosion and stabilizing the banks of the reach.

The subject reach, hereafter referred to as the "Game Range Reach," is a deeply incised channel, formed by water deliveries of the Willow Creek Feeder System. The lower portion of the roughly 1.2 mile long reach is not as deeply incised, however it meanders at a high sinuosity eroding banks on the order of 5-20 feet in height. The middle and upper portions of the reach are deeply incised down to bedrock in some locations, and have begun to migrate laterally within the channel. The middle and upper portions are roughly 20 feet or more in depth. The upper portions have undergone dramatic geotechnical failures of the banks, creating vast unstable areas adjacent to the channel and significant sediment sources for further erosion.

This plan will recommend three types of erosion control and bank stabilization:

1. Longitudinal peaked stone toe protection
2. Barb
3. Headcut stabilization

The plan calls for utilization of two sources of rock, an existing stockpile on-site at the upper end of the reach, and the other at the Willow Creek dam site. Bedrock in the channel will also be useful for stabilizing selected portions of the reach.

LOCATION

Figure 2 shows the upper portions of the Sun River project in northwest Montana. Willow Creek reservoir is located 15 miles southeast of Gibson Dam. The Willow Creek Feeder System stems from Pishkun Supply Canal a short distance below the Sun River Diversion Dam. The Willow Creek Feeder System has a design capacity of 350 ft^3/s and is 7.3 miles long where it enters a natural channel to Willow Creek and then Willow Creek Reservoir. The natural channel reach is within T21N, R8W, SW¼ section 12, NE¼ section 13. At present, the Greenfield Irrigation District limits the operational flows of the feeder system to 75 ft^3/s. The intent of the self-imposed limitation is to reduce and control erosion and sedimentation in the natural portion of the Game Range Reach. Greenfield Irrigation District imposed the 75 ft^3/s limitation in the feeder system in 1993 following a qualitative analysis of water quality in the system. Casual observations of the clarity of the water entering Willow Creek reservoir indicated that flows above 75 ft^3/s produced increased erosion and quantities of sediment.

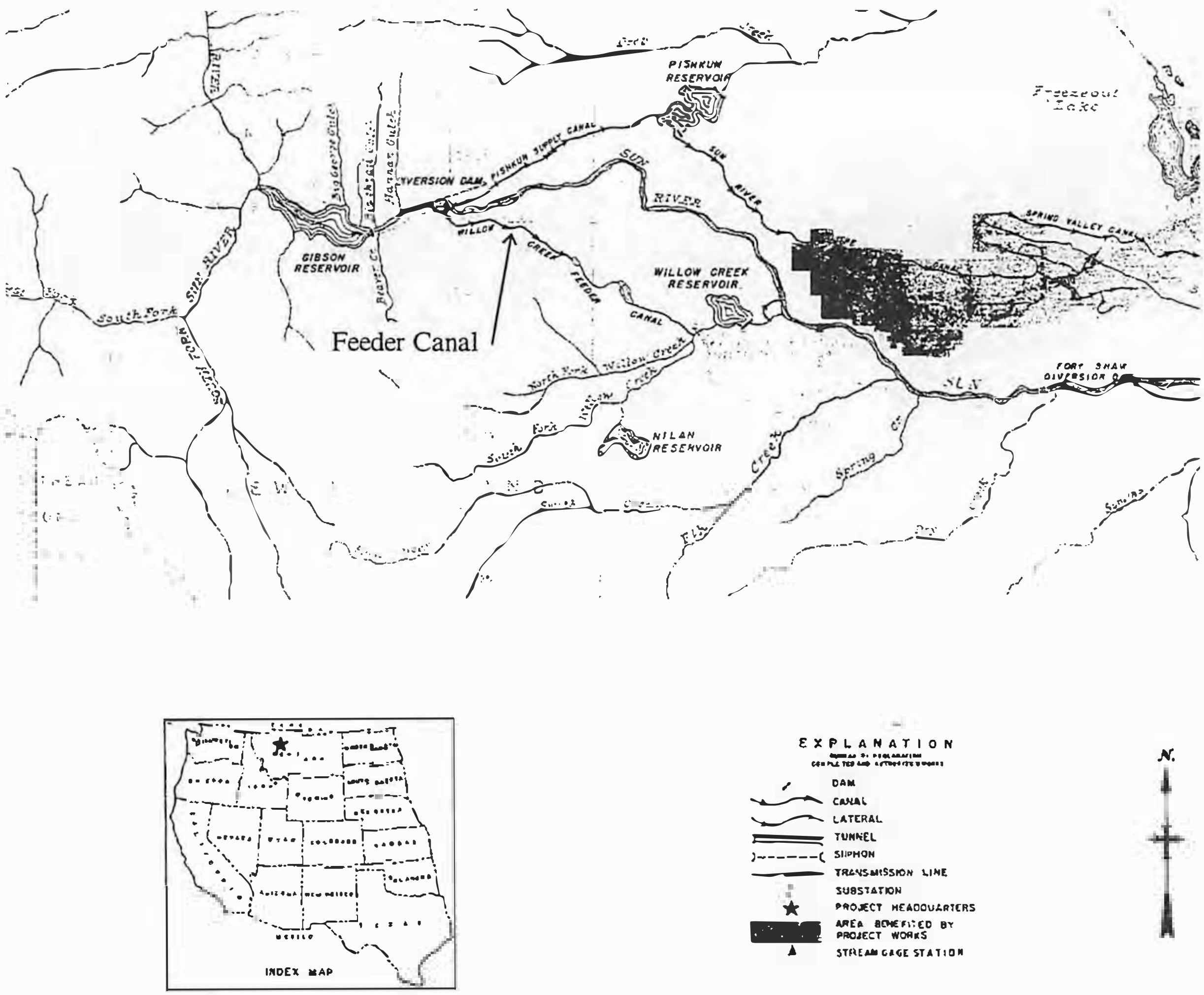


Figure 2. Location of Willow Creek Feeder System in northwest Montana.

FIELD DATA PROCEDURES

This section describes the field data procedures for future reference and repetition. A Real-Time Kinematic Global Positioning System (RTK-GPS) was the primary tool in measuring the geography of the reach. Photographs record an inventory of the channel and both the left and right bank. Field observations by Wittler and Gonzales complete the field data.

SURVEYING EQUIPMENT

The Trimble GPS Total Station® 4800 packages real-time kinematic (RTK) GPS survey technology in a lightweight system that has no external cables, batteries or antennae. The system's dual-frequency receiver, Micro-centered™ GPS antennae, data radio, power supply and cables are integrated into a Trimble PowerLiTE™ GPS pole with a total weight of 8.5 pounds. The system does not need a backpack or waistpack and there are no cables connecting the surveyor to the pole. The GPS Total Station 4800 provides superior mobility and RTK accuracy, providing an ideal solution for surveying.

The TSC1™ with Trimble Survey Controller™ provides the functionality and seamless link between Trimble's GPS Total Stations and conventional surveying instruments as well as conventional instruments from other leading manufacturers. Conventional and GPS data collected from any of these systems can be downloaded to Trimble Geomatics Office™ processing software for integration, processing and export to popular survey, CAD, and design software.

The 4800 is ideal for a broad range of surveys, where mobility and ease of movement are vital. Using the 4800, surveyors can collect and stakeout centimeter-level measurements in seconds. Data transfer from the data logger to office to design software and back to the data collector is seamless. Moving data between the 4800, other Total Stations and conventional instruments is equally simple.

SPECIFICATIONS

- 9-channel, dual-frequency GPS receiver with integrated radio modem
- RTCM SC104 input/output and NMEA-0183 output
- On-the-Fly initialization for RTK survey

Technical Specifications

Physical

- Size: 23 cm (9") W x 17.8 cm (7") H
- Receiver weight: 2.1 kg (4.6 lbs.) with internal radio
- 3.9 kg (8.5 lbs.) as full RTK rover
- Receiving power: 6 Watts receiver only
- 7 watts as full RTK rover
- 10.5 to 20 VDC
- Battery life (typical): >4 hours as full RTK rover including internal radio and TSC1, with one Li-Ion battery.

Environmental

- Operating temp: -40°C to +55°C (-40°F to +131°F)
- Storage temp: -20°C to +75°C (-40°F to +167°F)
- Humidity: 100%, fully sealed. Buoyant
- Shock: 2 m (6 ft) accidental pole drop

Performance Specifications

Static Survey Performance

- Modes: Quick-start, Static survey, FastStatic survey
- Accuracy: Horizontal: ±5 mm + 0.5 PPM
- Vertical: ±5 mm + 1 PPM
- Azimuth: ±1 arc second + 5/baseline length in kilometers

Kinematic Survey Performance (Postprocessed)

- (Requires TSC`™ data collector with Trimble Survey Controller™ software at rover.)
- Modes: Continuous, Stop & go
- Accuracy: Horizontal: ±1 cm + 1 PPM
- Vertical: ±2 cm + 1 PPM
- Occupation: Continuous: 1 measurement
- Stop & go: 2 epochs (min) with 5 satellites
- Fastest datalogging Rate: Continuous: 1 Hz

Real-time Survey Performance

- Modes: Real-time Kinematic (RTK)
- Real-time Differential (DGPS)
- Real-time
- DGPS accuracy: 0.2 m + 1 PPM RMS

- RTK accuracy:

	Mode	Latency	Accuracy
Horizontal:	1 Hz fine	0.4 second	±1 cm + 1 PPM
	5 Hz fine	0.1 second	±3 cm + 2 PPM
Vertical:	1 Hz fine	0.4 second	±2 cm + 1 PPM
	5 Hz fine	0.1 second	±5 cm + 2 PPM

- Range: Range varies depending on radios used, local terrain and operating conditions. Multiple radio repeaters may be used to extend range, depending on type used.

Photograph 0570-25 shows the RTK-GPS set up over a USGS benchmark near the bottom of the Game Range Reach. We did not determine the position of this benchmark with respect to any coordinate system. The basis of the data is a relative coordinate system with its origin at this benchmark, and orientation determined by the RTK-GPS unit. We collected roughly 1600 points during the course of 12 hours of data collection over a two-day period, using one rover transmitting to one base. We exceeded the coverage area near the head cut at the upstream end of the reach.

More than 130 35-mm color slide photographs record the vicinity of the reach as well as the channel, left, and right banks. The section "Bank Inventory" presents most of those photographs later in this report. Weather conditions during the surveying on the first two days was mild with temperatures in the low 30°s (F) and gusty winds roughly 5-20 mph. Conditions deteriorated dramatically on the third day with sustained wind speed greater than 70 mph. Parking the vehicle in a way that blocked the wind helped secure the base station and antennae from vibration and overturning.

Photographs 0570-24 & 25. Trimble GPS rig at USGS Bench Mark (BM). Will Gonzales.

LONGITUDINAL PEAKED STONE TOE PROTECTION

Longitudinal Peaked Stone Toe Protection (LPSTP) is a continuous stone dike placed longitudinally at, or slightly streamward of, the toe of the eroding bank. The cross-section is triangular. The LPSTP does not necessarily follow the bank toe exactly. It can form an improved or "smoothed" alignment through the bend. Figure 3 shows a typical cross-section of longitudinal peaked stone toe protection.

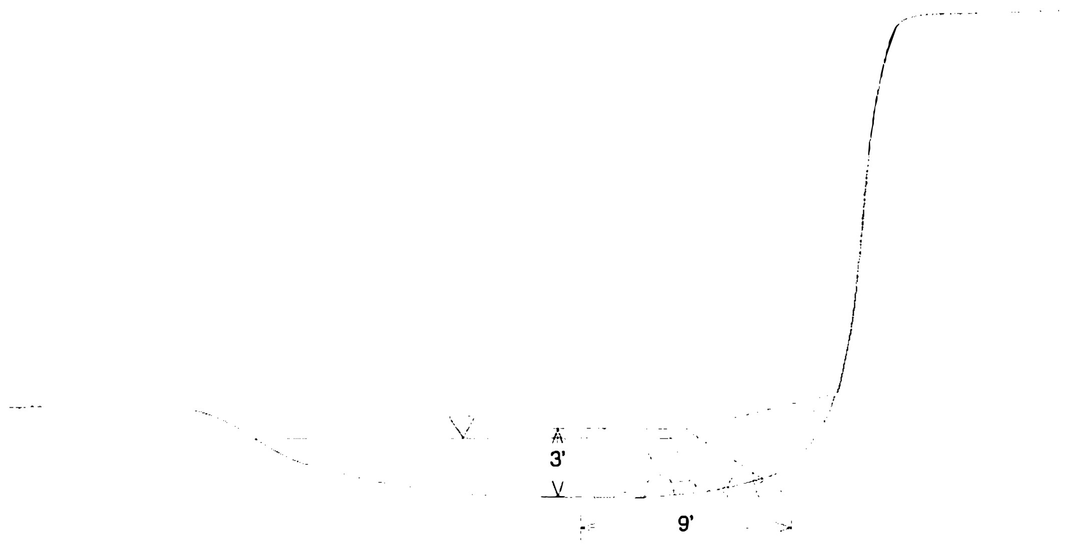


Figure 3. Typical section of Longitudinal Peaked Stone Toe Protection. 0.68 tons/foot.

According to Biedenharn, Elliot, and Watson (Biedenharn, Elliot, Watson, 1998) longitudinal peaked stone toe protection...

> *...is another form of windrow revetment, with the stone placed along the existing streambed rather than on top bank. The longitudinal stone toe is placed with the crown well below top bank, and either against the eroding bank line or a distance riverward of the high bank. Typical crown elevations may vary, but are commonly between 1/3 and 2/3 of the height to top bank.*
>
> *The success of longitudinal stone toe protection is based on the premise that as the toe of the bank is stabilized, upper bank failure will continue until a stable slope is attained and the bank stabilized. This stability is usually assisted by establishment of vegetation along the bank.*

Figure 4 and Figure 5 picture two applications of longitudinal peaked stone toe protection on an incised sand-bed stream in northern Mississippi. In small streams like the Willow Creek Feeder system one-half to one ton per foot of rock is sufficient to protect or establish the toe of a sub-reach. We won't attempt to overly "smooth" the alignment, or shorten the thalweg length. We will offset the stone toe from the foot of the vertical banks a few feet to provide a base area for calving bank material. Only in the sharpest bends will the alignment change. The short offset negates the need for tiebacks, though the use of tiebacks is allowable based upon the construction engineer's judgement at the time of construction.

The LPSTP must be keyed into the bank at the upstream and downstream ends and at regular intervals along its entire length. Tie-backs are short dikes connecting the LPSTP to the bank at regular intervals. They are only used in areas where the LPSTP does not follow the toe of the bank. All tie-backs are keyed into the bank. Tie-backs are usually constructed to the same height as the LPSTP, or sloped slightly higher toward the bank end.

Figure 4. One ton per foot immediately after construction. (from Biedenharn, Elliot, & Watson. 1998)

This continuous bank protection technique resists the erosive flow of the stream, thereby stabilizing the toe of the bank. The "smoothed" longitudinal alignment results in improved stream flow near the toe of the eroding bank. Success of this method depends on the ability of stone to self adjust, or "launch", into the scour hole formed on the stream side of the LPSTP. The stone must be well graded so as to launch properly. The weight of the stone (loading of toe) also resists geotechnical bank failure and mass wasting. The LPSTP captures alluvium and up-slope failed material (colluvium) on the bank side of the structure, thus providing a foundation for vegetation to become established. If the mid-to upper bank is left untreated these areas will fail to a stable slope (at the angle of repose of the bank material), and usually within a short period of time will be invaded and naturally revegetated by native plants. Over time this vegetation strengthens and further stabilizes the bank and bend.

APPLICABILITY

LPSTP is well suited for many situations where a continuous bank protection method is needed, and particularly applicable for ephemeral, narrow, and small to medium sized streams. LPSTP is also well suited for areas where the toe is suffering erosion but the mid and upper bank areas are fairly stable due to cohesive materials, vegetation, infrequent short duration inundation, or relatively slow flow velocities.

LPSTP can be applied in some situations where the bank line needs to be built back out into the stream, where the existing stream channel needs to be completely realigned, where flow force needs to be redirected (bridge or pipeline protection, etc.), where the outer bank alignment makes abrupt changes (scallops, coves, or elbows), or where the stream is not smoothly aligned. However, in the aforementioned situations the crest should be high enough so that it is not overtopped frequently.

ADVANTAGES

Bank grading, reshaping, or sloping is usually not needed (existing bank and overbank vegetation is not disturbed or cleared), and a filter cloth or gravel filter layer is usually not needed. LPSTP works well in zoned and blended configurations (with bio-engineering in mid to upper bank areas). In some instances the LPSTP itself has been invaded by herbaceous plants and trees, resulting in a more aesthetically pleasing (barely visible) project. LPSTP is relatively simple to design and specify and is a thoroughly tested method that has been used in a wide variety situations and has been monitored extensively.

Figure 5. Typical longitudinal peaked stone toe protection with tie-backs (from Biedenharn, Elliot, & Watson. 1998)

DISADVANTAGES

By definition LPSTP only provides toe protection and does not protect mid- and upper bank areas. Some erosion of these areas should be anticipated during long-duration, high energy flows, especially before these areas stabilize and become vegetated.

In areas of deep scour LPSTP might not provide sufficient rock to launch into the scour hole. If excessive scour occurs, the over-launching of rock will result in a lowering of the crest elevation of the LPSTP. If excessive scour is anticipated, a Longitudinal Fill Stone Toe Protection (LFSTP), instead of LPSTP, should be applied.

DESIGN CONSIDERATIONS

The LPSTP should provide as smooth of an outer bank alignment as possible. The amount of stone required depends on a number of factors, including stream and flow alignment into the project reach, depth of scour at the toe, height of bank in relation to stage duration, and estimated stream forces (impinging flow) on the outer bank. Stone for LPSTP should be well graded and properly sized.

LPSTP can be specified either by weight or volume, or to a specific crest elevation. Typically LPSTP applied at the rate of 1 ton of stone per lineal ft of protected bank will have a height of roughly 3-ft (measured from the bed of the stream where the stone was placed). Two tons per ft of LPSTP is 5 to 5.5 ft tall, whereas 0.5 tons per ft is approximately 2-ft tall.

In areas where the bed of the stream is uneven, or deep scour holes are evident, the crest of the LPSTP should be constructed to a specified elevation. This elevation can be referenced to an established datum, or specified as a certain height above the base flow or typical low-flow water surface elevation.

LPSTP might not launch effectively in areas where the bank is composed of layers of cohesive and non-cohesive materials, in which case the LPSTP could become "perched" on a cohesive layer.

In a situation where clay outcrops or sections of the bank are cohesive and other areas are composed of non-cohesive materials the differential erosion rates could result in discontinuities (scour and eddies) between launched sections of LPSTP and the erosive resistant in-situ materials.

For any application the LPSTP must be keyed deeply into the bank at both the upstream and downstream ends and at regular intervals along its entire length. On small streams 75-100 ft spacing between keys is typical, while on larger streams and smaller rivers one to two multiples of the channel width can be used as a spacing guide. If tie-backs are required, the same spacing guidelines developed for keys can be used. The minimum key recommendation for small to medium sized streams is a Type C key (excavated into the bank and back-filled with stone) constructed to a height equal to top bank elevation or the Q-2 water surface elevation (whichever height is less). On larger streams and smaller rivers with banks less than 25 ft tall Type D keys are recommended. Type D keys are excavated from the LPSTP to top bank with an excavated section (called a bankhead or root) going into the bank. A rule-of-thumb to determine the length of the bankhead section of the Type D key would be to add the maximum height of the outer bank of the bend to the maximum scour depth. On larger streams and smaller rivers with banks greater than 25 ft tall an analysis of the Q-2, Q-5, and Q-10 water surface elevations follows. After analyzing this information an informed choice between a Type D or Type C key can be made, and if the Type C key is chosen, determine the key height.

CONSTRUCTION TECHNIQUES

All LPSTP should be constructed in an upstream to downstream sequence. LPSTP generally requires heavy equipment for excavation of keys and efficient hauling and placement of the stone. LPSTP can be constructed from within the stream, from construction roads built along the lower section of the stream bank itself, or from top bank. The preferred method is from the bar side of the stream, as this results in the least disturbance of existing bank vegetation. The least preferred method is from top bank since this typically disturbs or destroys the most bank vegetation and the machine operator's vision is limited (resulting in longer construction times). Usually the keyways are excavated first and the rock is dumped into the key. The rock is then formed into tie-backs (if needed) and finally the LPSTP is constructed along a "smoothed" alignment, preferably with a uniform radius of curvature throughout the bend if possible. In a multi-radius bend, smooth transitions between dissimilar radii are preferred.

Prior to construction, the alignment that the LPSTP is to be placed on should be marked, along with the locations of all tie-backs, keys, rock staging (short term storage) areas, and haul roads. The locations of the keys can usually be moved slightly upstream or downstream so as to avoid disturbing valuable bank vegetation. Design, bidding, and supervision of construction is relatively simple.

ENVIRONMENTAL BENEFITS

The stone the LPSTP is constructed from will increase available habitat in streams where rocky habitat is limited. Studies show that a well graded stone has many aquatic habitat benefits. Scour along the streamside toe of the LPSTP provides some aquatic habitat benefits (diversity of depth and hiding areas for juveniles in the interstices of the rock). The rock used for the LPSTP provides a stable substrate for benthic invertebrates. Volunteer vegetation usually becomes established on mid to upper bank areas (and in some instances grows through the LPSTP itself) which can improve terrestrial habitat and provide canopy cover and a supply of carbon based debris to the stream.

COST ESTIMATES

Costs are dependant on cost of stone and amount of stone used. Counting keys and tie-backs, typically 90 to 110 tons of stone will be used for each 100 ft length of LPSTP when placed at a rate of 0.68 ton/per lineal ft of protected bank. In many parts of the country cost of stone delivered and placed in the stream ranges from $14.00 to $25.00 per ton, therefore costs for LPSTP placed at a rate of 0.68 ton/ft ranges from $12.60 to $27.50 per lineal ft of protected bank.

MAINTENANCE AND MONITORING

As with all bank protection projects, periodic inspection and analysis is necessary. Scour near the LPSTP and keys, and on the bank immediately above the crest elevation of the LPSTP should receive attention.

BARBS

Barbs are rock jetties, triangular in plan, placed on the outside bends, displacing the thalweg away from the bank. Barbs build stream banks and create riparian areas by trapping bed load and suspended sediments. Other names of barbs include jetties, toe dikes, groins, habitat sills, and bendway weirs. Barbs slope from the bank to the stream and angle upstream to cause a weak back eddy next to the bank, creating a flood plain. Barbs vary in size depending upon channel size, shape and flow levels. Typical barb construction uses rock whose size primarily depends on stream velocity. Barb elevation is near the normal high water elevation or the top-of-bank. The elevation of the point of a barb is usually the bed or low water elevation.

Eddies between barbs cause sediment deposition. Bank collapse slows as the banks reach a threshold slope. Sediment accumulation between barbs eventually results in riparian development. Over time the barbs become less visible as sediment accumulates, the high banks collapse, and vegetation grows.

Figure 6 and Figure 7 show the plan and section of a barb. The section shows the barb keyed into the bank. Keying is a recommended procedure if economics allow. Figure 8 shows a series of barbs. In this case, the barbs all angle upstream. Flow passing a barb must first go around the point. Flow over the barb tends to align its primary velocity component perpendicular to the axis of the barb, away from the bank. Some flow, deflected by the barb towards the bank, forms a gentle eddy. Sediment fed into the eddy eventually drops out, forming a bar between the barbs. The barbs shelter material caving onto or between the barbs, from the high velocity of the main portion of the stream, and adds to the bar.

The Bendway Weir Design Guidance from the US Army Corps of Engineers (USACE, 1995) provides specifications for barb length and spacing. Although created for bendway weirs, recent experience with the Colorado Department of Transportation indicates that the design guidance applies to barbs. Equation 1 specifies the maximum length, L_{max}, of the bendway weir sills in terms of the channel width, W.

$$L_{\max} = W/3 \text{ and typically } W/10 \le L \le W/4 \qquad (1)$$

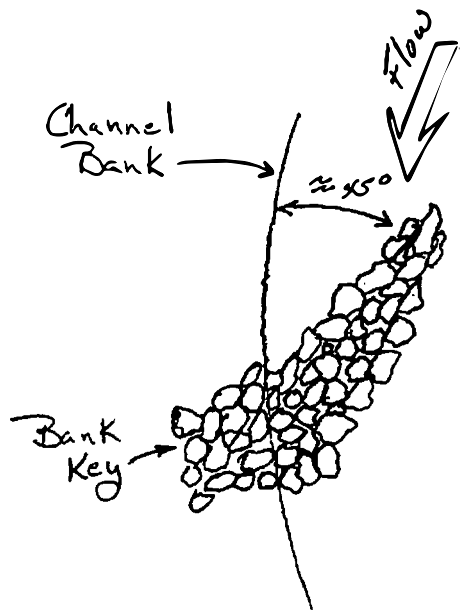


Figure 6. Plan of typical barb, perpendicular orientation.

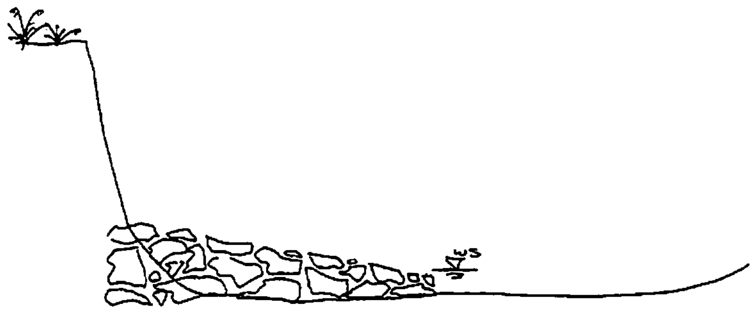


Figure 7. Section of typical barb.

Spacing, S, the channel distance between weirs, is a function of the length of the sill, the channel width, and the channel radius of curvature, R.

$$S = 1.5L(R/W)^{0.8}(L/W)^{0.3} \tag{2}$$

The maximum spacing, S_{max} is a function of the intersection of the tangent flow line with the bank line.

$$S_{\max} = R\left[1-(1-L/R)^2\right]^{0.5} \tag{3}$$

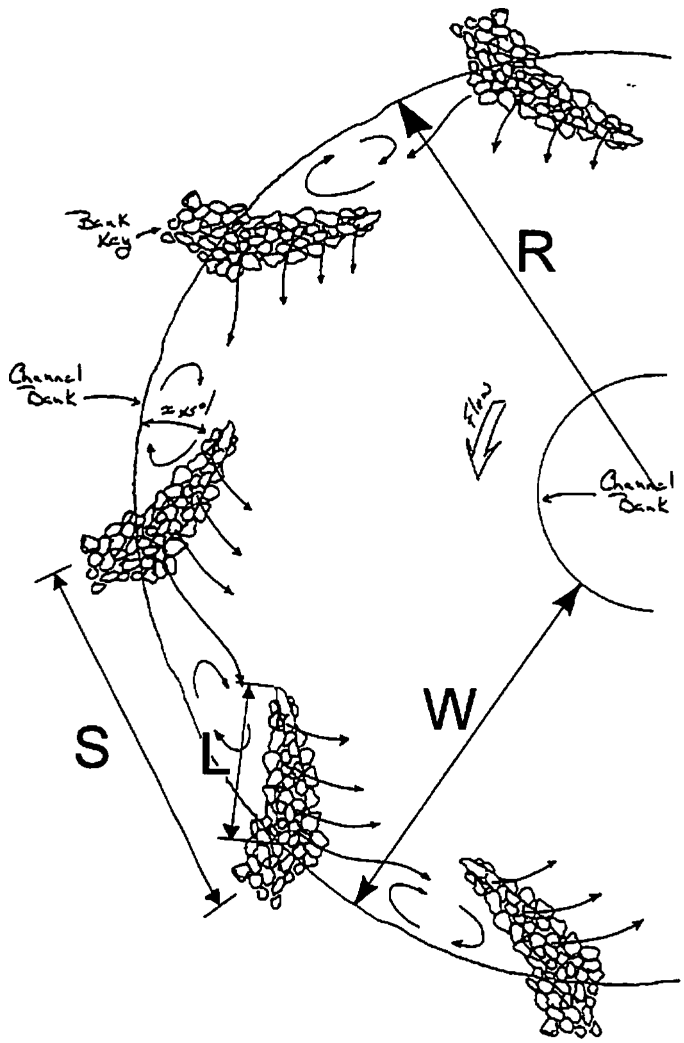


Figure 8. Plan of barbs in series.

HEADCUT STABILIZATION STRUCTURES

Headcut stabilization structures may occasionally be known as grade control or drop structures. Since Willow Creek Feeder Canal is bedrock controlled in most locations, and we are not proposing any hydraulic drop, the appropriate moniker for the bed stabilization measures is Headcut Stabilization Structures. There are several head cuts migrating in the Game Range Reach. Along with a few zones of temporary bed material storage, some bed stabilization is necessary to found the bank stabilization in adjoining areas. We propose a rock sill type of headcut stabilization structure. The sill is installed at current bed elevation, just upstream of a headcut knickpoint. As the headcut advances upstream it encounters the rock sill. Rock from the sill "launches" into the scour hole until a stable slope forms, and permanently stops the advance of the headcut. Figure 9 and Figure 10 show typical sections of a headcut stabilization structure before arresting a headcut and after arresting a headcut.

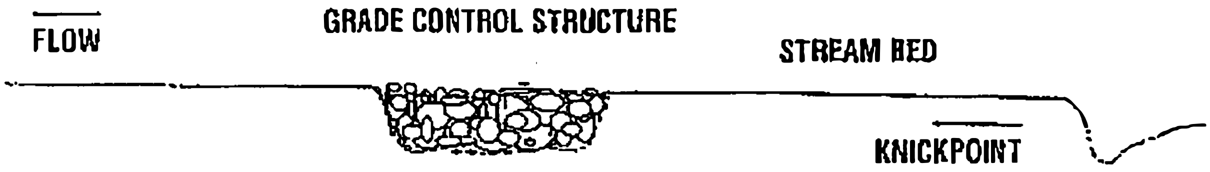


Figure 9. Typical section of headcut stabilization structure before degradation arrives at toe.

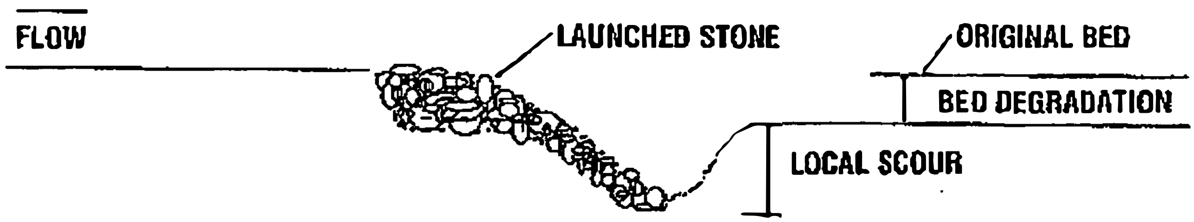


Figure 10. Typical section of mature headcut stabilization structure following degradation at toe.

The depth of the rock sill is one to two times the D_{100}, or in this case up to 84 inches. Most of the existing headcuts appear to be roughly three to five feet in height. We will excavate the toe of the headcuts and key into the bed roughly one to three feet to place the rock sill. The sill shall extend into the banks a sufficient distance as to ward off flanking of the structure.

FLOOD FREQUENCY ESTIMATES

This section summarizes flood frequency estimates for the Willow Creek Feeder System. The primary basis for the flood frequency estimates are peak discharge records from U.S. Geological Survey gaging stations. These data and results are appropriate for construction planning and rehabilitation activities along the Game Range Reach of the Willow Creek Feeder System.

BACKGROUND

This part of the plan prepares flood frequency estimates for construction planning and rehabilitation activities for the Willow Creek Feeder System. This section describes peak discharge frequency estimates and associated uncertainty for the 2-, 5-, 10-, 25-, 50-, and 100-year flows. The assumptions and limitations to this study include, but are not limited to three major factors: regional transfer of flood information is appropriate (regional regression equations are applicable); natural, unregulated flood frequency estimates do not include canal flows; and any reduction of peak flows due to storage in several small ponds, especially "Neal Pond", at downstream locations are not considered.

The Willow Creek Feeder System entrance is located at the Sun River crossing on the Pishkun Supply Canal, approximately ¾ mile southeast of the Pishkun Supply Canal Diversion Dam. Elevations in the canal basin range from 4,150 feet near the entrance to Willow Creek Reservoir to 8,135 feet (Buttolph Creek watershed) along the Sawtooth Ridge. Water and Power Resources Service (1981) presents a project description and list of pertinent data for the Willow Creek Feeder System. A summary includes:

Construction Date	1938
Total Drainage Area	23.6 mi^2
Maximum Diversion Capacity	350 ft^3/s
Total Constructed Length	7.5 mi.
Bottom width	14 ft.
Side slopes	1.5:1
Water depth	4.5 ft.

Drainage areas to Willow Creek Reservoir were estimated as part of Reclamation Probable Maximum Flood (PMF) studies (USBR, 1986). Figure 11 shows the sub-watershed boundaries estimated from U.S. Geological Survey 7½ minute topographic maps. In addition, Land & Water (1998) estimated the total drainage area of the Willow Creek Feeder System at Willow Creek Reservoir. Drainage areas were estimated at five locations as part of this study (Table 1). The watershed points "C" through "F" that are listed in Table 1 are discussed in some detail in Land & Water (1998).

Figure 11. Drainage area and subareas.

Table 1. Willow Creek Feeder System Drainage Area and Mean Basin Elevation Summary.

Area No.	Description	Incremental Area (mi^2)	Cumulative Area (mi^2)	Estimated Mean Basin Elevation (ft)
2	Buttolph Creek	4.26	4.26	---
3	East of Buttolph Creek to former natural divide of Willow Creek	6.06	10.32	---
4	Top of natural divide to near eastern boundary of Game Range Reach(point "C")	1.31	11.63	4450
5	Eastern boundary of Game Range Reach ("C" to "D")	0.32	11.95	4400
6	Floodplain reach to Neal's pond ("D" to "F")	0.69	12.64	4350
---	Total drainage area of Willow Creek Feeder System upstream of Willow Creek Reservoir	---	23.6	4200

A difference in the total drainage area of the Willow Creek Feeder System to Willow Creek Reservoir was noted between the Land & Water (1998) study (25.7 mi^2) and USBR (1986) (23.6 mi^2). This difference is about 9 percent, and is not significant for this study. Drainage area is the major factor (explanatory variable) for estimating flood peak discharge, this difference in drainage area estimates is within the typical accuracy (8 to 25%) of maximum peak discharge estimates (e.g., Benson and Dalrymple, 1967).

DATA SOURCES AND DESCRIPTION OF REGIONAL FLOOD POTENTIAL

The precipitation source for the Willow Creek basin and vicinity is predominately from Gulf and subtropical Atlantic moisture from the southeast, with some Pacific moisture (Caprino, 1991). A review of an extreme storm catalog (McKee and Doesken, 1997) indicated that most flood-producing rainstorms in the region occur in April through October. The largest magnitude rainstorm that was observed in the region around Willow Creek and that caused flooding with widespread damage and deaths is the June 7-8, 1964 Gibson Dam storm. This flood was caused by moisture from the Gulf of Mexico that was carried northward and then westward over the mountains in Montana. Details of this rainstorm and flood are in Boner and Stermitz (1967) and Hansen et al. (1988).

Three data sources from the U.S. Geological Survey were used to characterize streamflow in the foothills and northeast plains regions of Montana:

- Annual peak discharge estimates at gaging stations and crest-stage stations;
- Indirect discharge measurement estimates at gaging stations and miscellaneous sites; and
- Qualitative information from Water-Supply Papers.

Instantaneous, annual maximum streamflow (peak discharge) is a strong indicator of flood potential and seasonality. Regional streamflow data indicate the flood potential is high from spring (late April) to summer (late July). The largest peaks in the region, at basin scales comparable to the Willow Creek Feeder System, have typically occurred in May through July and result from either snowmelt runoff combined with rainfall, or thunderstorms.

HYDROLOGIC METHODS

Two techniques were utilized for this flood frequency report: (1) an envelope curve of peak discharge estimates and (2) regional frequency analysis of annual peak discharges. A brief description of each method follows.

Figure 12 shows an envelope curve prepared from the regional records of annual peak discharge estimates from gaging station and indirect measurement data, based on techniques presented in Cudworth (1989). The region was first based on the northwest foothills and northeast plains regions defined by Omang (1992). This region was extended to include peak discharge data from the Missouri River basin in Montana, from the Continental Divide to the Montana state line, to include a larger sample of runoff from small drainage basins (e.g., less than 50 mi²).

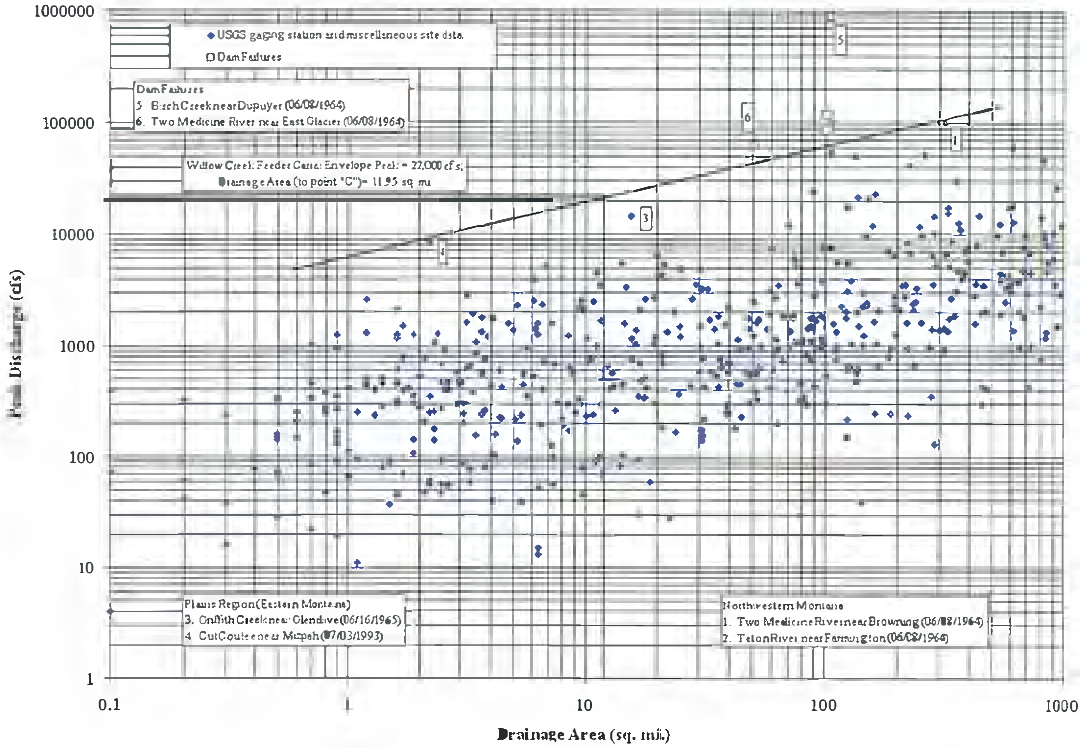


Figure 12. Montana annual peak discharge observations, small drainage basins in Upper Missouri River Watershed.

Because there are few streamflow estimates from hill slopes in the Willow Creek Feeder System basin, flood frequency estimates for the Willow Creek Feeder System were obtained from regional frequency equations developed by Omang (1992). These equations were developed using multiple regression techniques to obtain the T-year flood at specific return periods (2-, 5-, 10-, 25-, 50-, 100-, and 500-years). The basin characteristics used in the multiple regression are drainage area (mi²) and mean basin elevation (feet). A U.S. Geological Survey computer program (Jennings et. al., 1994) was used to obtain frequency estimates and standard errors. Approximate 67-percent (one standard deviation) confidence estimates for each specific return period were estimated using approaches outlined in Hardinson (1969, 1971) (also see Omang, 1992 p. 11). These are based on a normal approximation to the logarithm of the standard error of prediction (standard deviation).

RESULTS AND DISCUSSION

ENVELOPE CURVE

Figure 12 shows an envelope curve prepared to assess the potential for extreme floods in the Willow Creek Feeder System watershed. Records from 526 locations, encompassing the Missouri River basin in Montana, were used to define peak estimates for small basins (i.e. less than 50 mi²) (attached as Appendix B). The data from this large region were used to increase the peak discharge spatial sampling from these small basins.

A precise determination of the maximum, instantaneous peak discharge observed historically for a basin in northwestern Montana with a comparable sized drainage area to the Willow Creek Feeder System near the eastern boundary of the Game Range Reach (point "C") (11.95 mi^2) is subject to large uncertainties. Regional values range from about 8,000 to 35,000 ft^3/s for large rainfall-dominated events, for drainage areas between 2 and 30 mi^2 (Figure 12). The observed, regional peak estimates are about forty times as large as the design capacity of Willow Creek Feeder System.

Four peak discharge estimates control the position of the envelope curve: the Two Medicine River near Browning, Teton River near Farmington, Griffith Creek near Glendive and Cut Coulee near Mizpah (Figure 12). The first two peaks are from the June, 1964 flood in northwest Montana. The second two observations are from the eastern plains region and result from intense, local convective precipitation. In particular, the peak on Cut Coulee is substantially larger than any other small basin (≤10 mi^2) observation in the state. This observation might be the sixth largest small basin peak in the United States in terms of unit discharge (3909 $ft^3/s/mi^2$) according to Table 2 from Crippen (1982). Currently, there is a lack of USGS published information for this flood; however the USGS Montana District indicated that an indirect measurement was performed (C. Parrett, pers. commun., 1998). Some plains peak discharge estimates most likely are unrepresentative of conditions in the local region around the Willow Creek Feeder System, but provide highly conservative estimates of observed peak discharge at this site. This envelope curve (Figure 12) is similar to others for the Missouri River basin presented by Crippen (1982).

In addition to large magnitude peak discharge estimates on the eastern plains, peaks in the USGS archives that were affected somewhat by dam failures and/or debris, are highlighted on Figure 12. Three peak discharges from the June, 1964 flood are affected by dam failures and debris and are not utilized to construct the envelope curve. Boner and Stermitz (1967) document these sites; Hadley (1967) describes the erosion and deposition effects of the flood.

The regional envelope curve is considered an upper limit to floods in the region and has an unknown probability of exceedance associated with it. Further work is required to assess the quality and accuracy of the four peak discharge estimates that control the position of the envelope curve, and to gain a better understanding of floods in small drainage basins in this region.

FLOOD FREQUENCY ESTIMATES

Flood frequency estimates were made for four locations along the Willow Creek Feeder System:

- Top of natural divide to near eastern boundary of Game Range Reach (point "C");
- Eastern boundary of Game Range Reach (point "D");
- Floodplain reach to Neal's pond (point "F"); and
- Total drainage area of Willow Creek Feeder System upstream of Willow Creek Reservoir.

The major input variables to the flood frequency analysis are selection of the region, drainage area, and mean basin elevation. Drainage areas and mean basin elevations for the four locations are listed in Table 1. The Northeast Plains region was selected as a representative region for the Willow Creek Feeder System watershed for three reasons: (1) to eliminate the effect of the 1964 flood on the regression equations; (2) the watershed is very close to the boundary between the two regions; and (3) the Northeast Foothills region has a greater number of gaging stations of similar drainage area size to the Willow Creek Feeder System watershed. Although the watershed is located entirely within the Northwest Foothills region, Omang (1992, p. 11) states that the regression equations are not valid for determining Q50, Q100 and Q500 in the Northwest Foothills region for any stream that originates in this region. The Northwest Foothills region equations for these return periods are dominated by the June 1964 Gibson Dam flood.

Table 2 through Table 5 and Figures 2 through 4 summarized the flood frequency results The results indicate the frequency of floods equal to design canal capacity (350 ft^3/s) are subject to some uncertainties (20 to about a 500-year event) near the Game Range Reach (Figure 2). Peak discharge estimates for the 50-year flood range from 283 to 765 ft³/s near the eastern boundary of the Game Range Reach (Table 2, Figure 2). In contrast, the 50-year flood estimates are twice as large for the entire Willow Creek Feeder System drainage basin, and range from 568 to 1,610 ft³/s (Table 5, Figure 3). There is little difference between flood frequency estimates near the eastern boundary of the Game Range Reach (point "C"), at the eastern boundary (point "D"), and at the floodplain reach to Neal's Pond (point "F") (Figure 4). The flood frequency curve for the drainage area is substantially larger than at these three locations.

Figure 2

Flood Frequency Estimates

Willow Creek Feeder Canal, Montana

Top of natural divide to near eastern boundary of Game Range Reach (point "C")

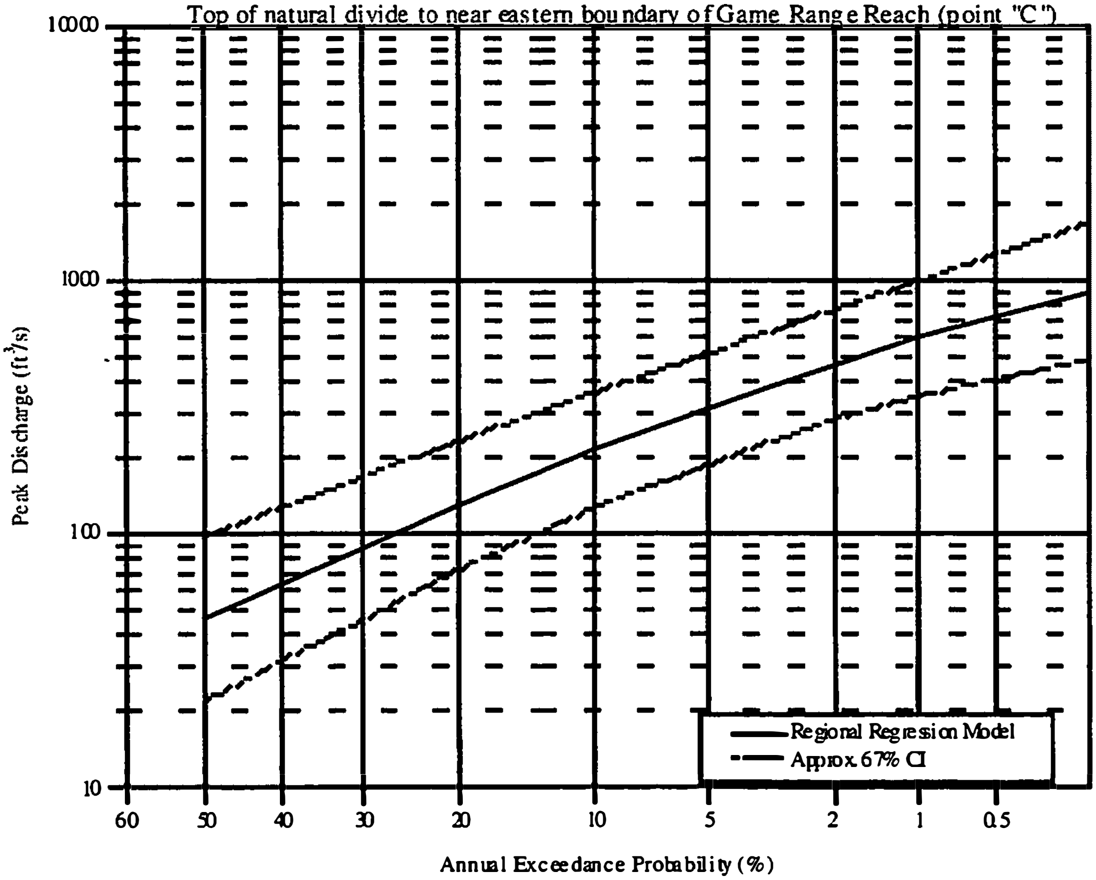


Table 2. Flood Frequency Estimates, Willow Creek Feeder System, Montana. Top of natural divide to near eastern boundary of Game Range Reach (point "C").

Annual Exceedance Probability (percent)	Return Period (years)	Peak Discharge (ft³/s)		
		33% Confidence Limit (- one standard deviation)	Regression Model Estimate	67% Confidence Limit (+ one standard deviation)
50	2	22	47	98
20	5	73	131	234
10	10	128	216	364
4	25	209	344	566
2	50	283	465	765
1	100	349	589	993

Figure 3
Flood Frequency Estimates
Willow Creek Feeder Canal, Montana

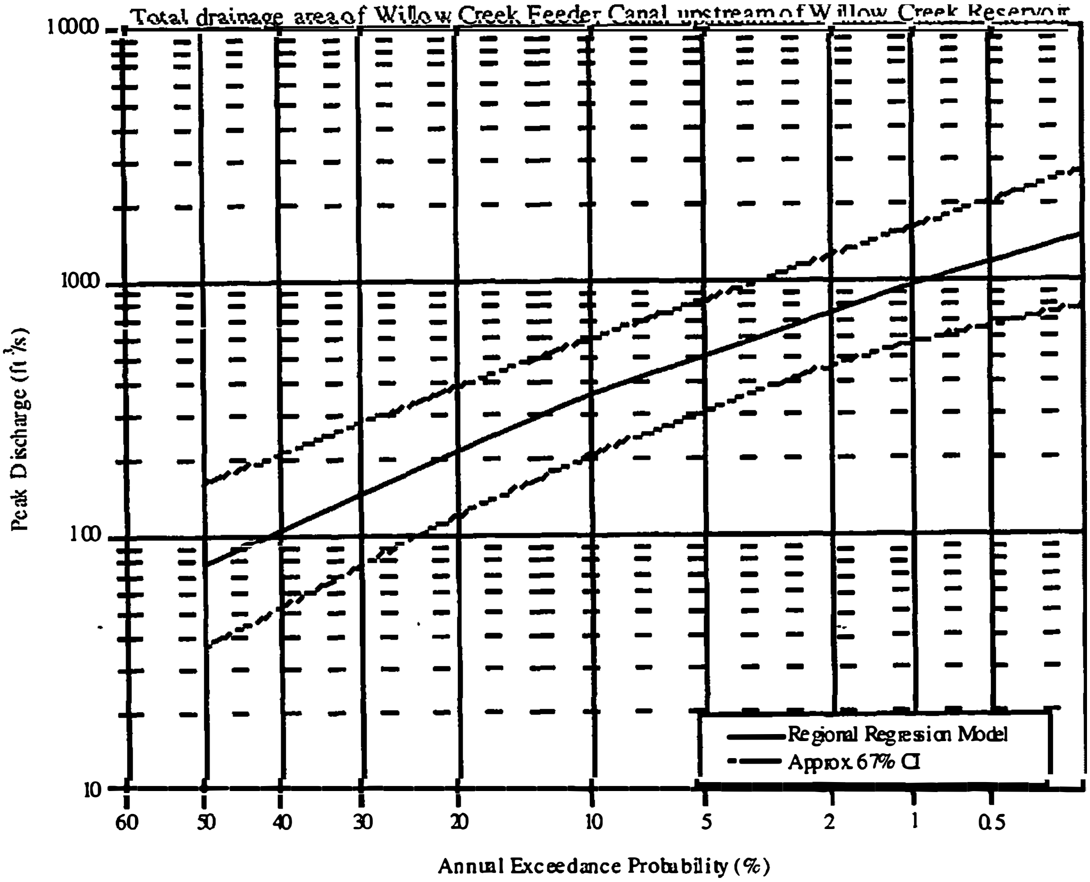


Table 3. Flood Frequency Estimates, Willow Creek Feeder System, Montana. Eastern boundary of Game Range Reach (point "D").

Annual Exceedance Probability (percent)	Return Period (years)	Peak Discharge (ft^3/s): 33% Confidence Limit (- one standard deviation)	Regression Model Estimate	67% Confidence Limit (+ one standard deviation)
50	2	23	48	100
20	5	76	135	241
10	10	131	221	373
4	25	215	354	582
2	50	291	478	786
1	100	359	606	1020

Figure 4
Comparison of Flood Frequency Estimates at four locations
Willow Creek Feeder Canal, Montana

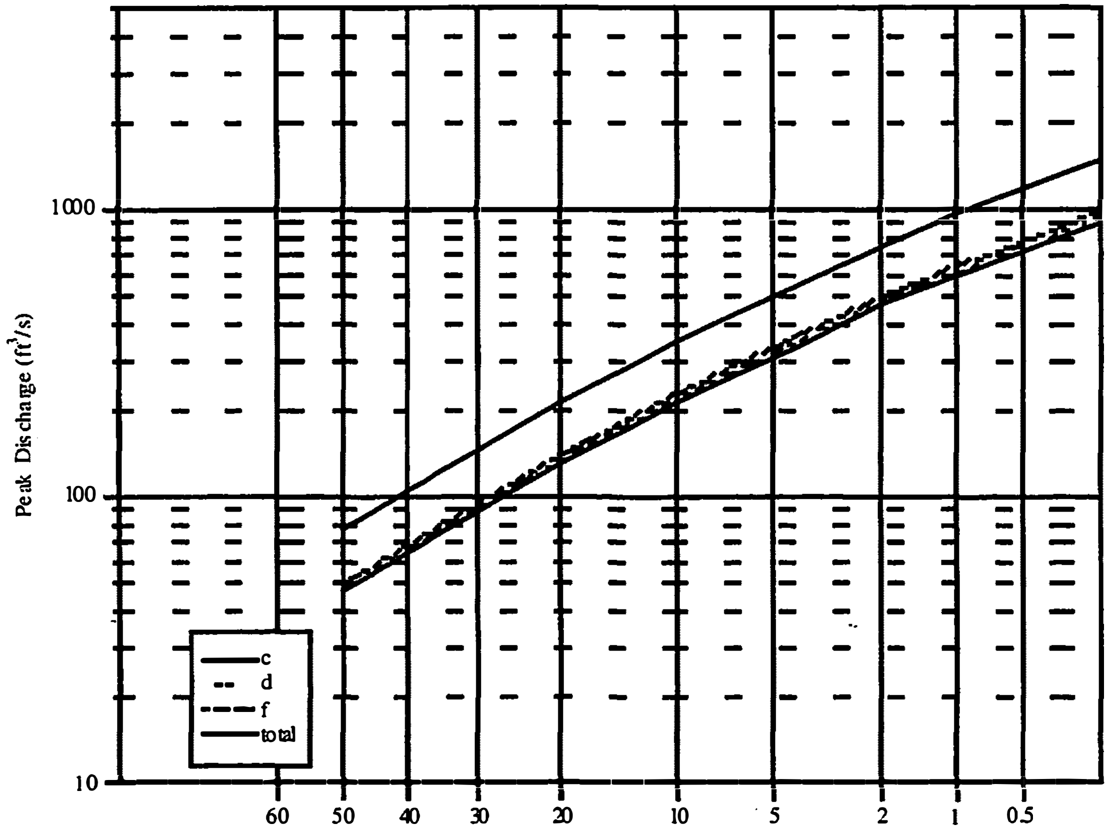


Table 4. Flood Frequency Estimates, Willow Creek Feeder System, Montana. Floodplain reach to Neal's pond (point "F").

Annual Exceedance Probability (percent)	Return Period (years)	Peak Discharge (ft^3/s) 33% Confidence Limit (- one standard deviation)	Regression Model Estimate	67% Confidence Limit (+ one standard deviation)
50	2	24	50	1 Photograph 05
20	5	79	141	251
10	10	138	232	391
4	25	226	371	610
2	50	3 Photograph 05	501	824
1	100	377	635	1070

The curves on Figures 2, 3, and 4, and values in Table 2 through Table 5 summarize our interpretation of the existing flood frequency information. The curves are based on the information presented herein and our engineering and scientific judgment. These estimates summarize our current understanding of the limited data available for making frequency estimates for floods of interest along the Willow Creek Feeder System.

Table 5. Flood Frequency Estimates, Willow Creek Feeder System, Montana. Total drainage area of Willow Creek Feeder System upstream of Willow Creek Reservoir.

		Peak Discharge (ft³/s)		
Annual Exceedance Probability (percent)	Return Period (years)	33% Confidence Limit (- one standard deviation)	Regression Model Estimate	67% Confidence Limit (+ one standard deviation)
50	2	37	78	163
20	5	122	217	387
10	10	209	353	595
4	25	342	562	924
2	50	460	757	1250
1	100	568	957	1610

FLOOD FREQUENCY CONCLUSIONS

1. Regional peak discharge estimates range from 8,000 ft^3/s to about 35,000 ft^3/s for a basin of comparable size to the Willow Creek Feeder System, and are subject to large uncertainties. The observed, regional peak magnitudes are about forty times as large as the design capacity of Willow Creek Feeder System.

2. Peak discharge estimates for the 50-year flood are about 465 ft^3/s near the eastern boundary of the Game Range Reach, and 757 ft^3/s for the entire Willow Creek Feeder System drainage basin.

3. The flood frequency relations, based on regional regression equations, indicates a peak discharge equal to the canal design capacity (350 ft^3/s) might have a return period in the range of 20- to 500-years near the eastern end of the Game Range Reach.

This characterization of flood frequency is based on the application of regional regression equations to the Willow Creek Feeder System drainage basin. No site-specific data were obtained or utilized to make flood frequency estimates for this study.

BANK INVENTORY

This section inventories the left and right banks of the Willow Creek Feeder System in the Game Range Reach. The purpose is to identify bank sub-reaches requiring erosion control or bank stabilization treatment. Figure 13 shows a plan view of the Game Range Reach including the thalweg and stationing as well as the rim of the incised channel. Stationing begins at the boundary fence at the downstream end of the Game Range Reach and continues upstream. The photographic record shows each overlapping sub-reach from the opposite bank. The photograph station is perpendicular to the adjacent thalweg station.

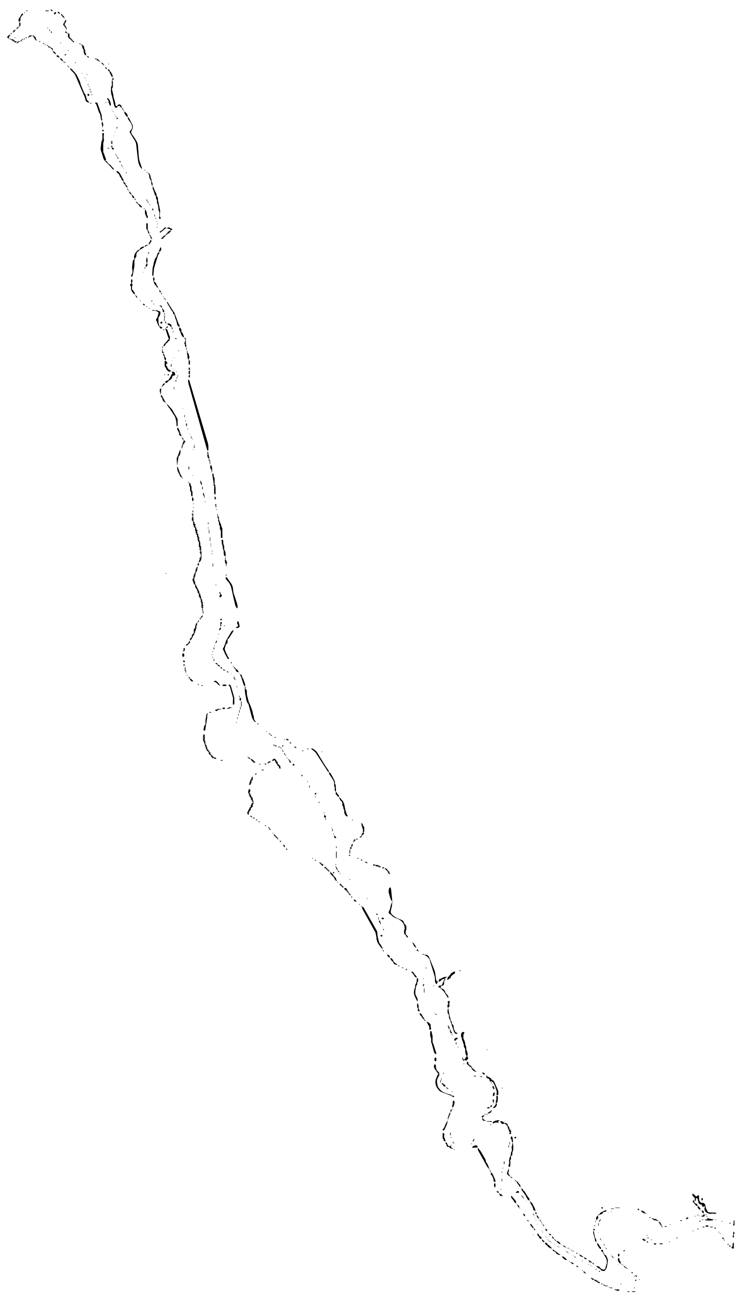


Figure 13. Thalweg and rim of Game Range Reach.

Plate 1 shows the Game Range Reach and the layout of Plate 2, Plate 3, and Plate 4. Those plates show in detail the locations and bearings of each photograph, as well as the thalweg stationing, and overall plan view of the Game Range Reach. Figure 21 through Figure 31 detail the photograph locations and channel characteristics. Sub-reaches have been given names such as "Straight Reach #1," "Bend #3," and "Gully #1." The photograph captions reflect this naming scheme to provide reference from the visual record to the geographic record and vice versa. Each photograph references the treatment or refers to a corresponding photograph.

Estimates of the Photo Station, perpendicular to the adjacent thalweg station, and Upstream and Downstream stations of the photographic reach included in the picture follow each photograph. Lastly, recommendations for erosion control or bank stabilization treatment in the photographic reach follow each photograph. Table 6 summarizes and tabulates the bank inventory data.

LEFT BANK

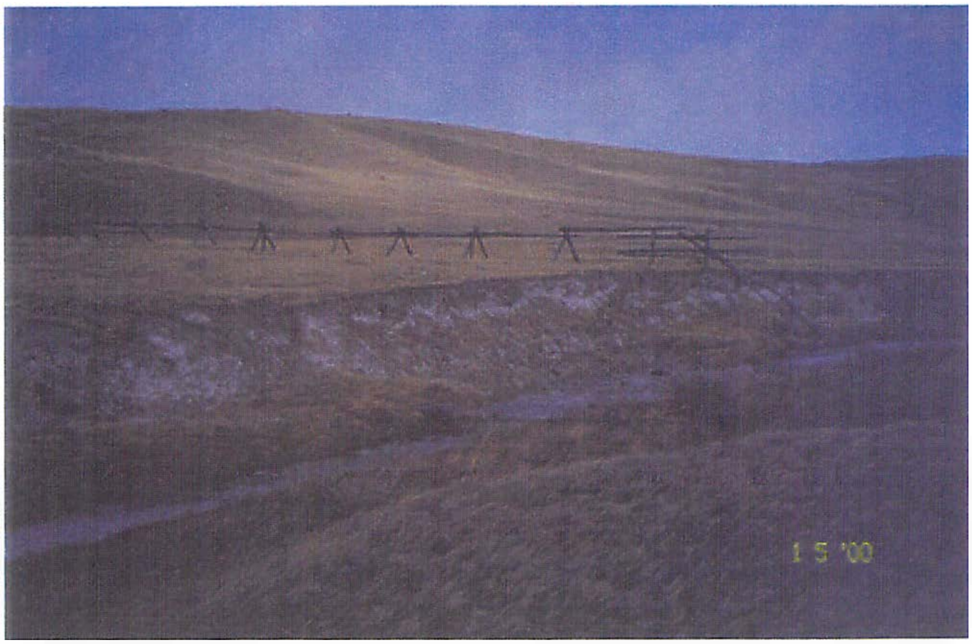
The left bank inventory begins at the downstream end of the Game Range Reach. In most instances, Wittler posed the photographs from the opposite bank. References in the captions indicate the direction of the view of the photograph; either upstream, downstream, or across the channel. Each caption contains a reference to a local name given to identify the general vicinity of the photograph and to correlate with the figures, maps, and plates. Where possible, the caption references overlapping photographs or corresponding photographs from other locations. There are three levels of priority assigned to each bank stabilization recommendation. One, high; two, medium; and three, low. Unless otherwise noted, priority is high with respect to the recommendation for Bank Stabilization. We assigned priority on the potential for erosion and the resulting volume of bank material contributed to the stream. A low bank that is relatively stable has a low priority. A high bank that is relatively unstable has high priority. Continuity of bank treatment between reaches increases the priority.

Photograph 0570-23. Gully #1 on left bank near fence at Bottom Reach.

Photo Station : 1+60
Bank Stabilization : None

Photograph 0570-22. View from DS looking US at Bottom Reach.

Photo Station	: 0-50 (estimate)
Bank Stabilization	: Low priority longitudinal peaked stone toe protection on both banks.
Upstream Station	: 0+00
Downstream Station	: 2+00



Photograph 0570-21. Left bank looking slightly DS.

Photo Station	: 1+00
Bank Stabilization	: See Photograph 0570-22.

Photograph 0570-20. Left bank from opposite bank. Panned left from Photograph 0570-21.

Photo Station : 1+00
Bank Stabilization : See Photograph 0570-22.

Photograph 0570-19. Left bank from opposite bank. Panned left from Photograph 0570-20

Photo Station : 1+00
Bank Stabilization : See Photograph 0570-22.

Photograph 0570-18. Left bank looking slightly US from Bottom Reach. Panned left from Photograph 0570-19.

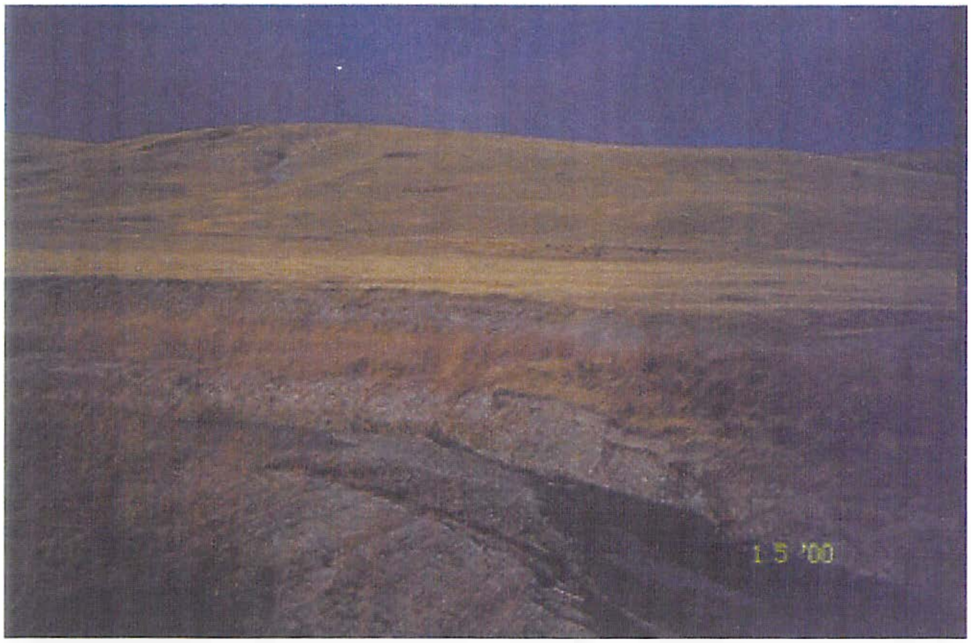
Photo Station : 1+00
Bank Stabilization : See Photograph 0570-22.

Photograph 0570-17. Left bank looking more US. Panned left from Photograph 0570-18.

Photo Station : 1+00
Bank Stabilization : See Photograph 0570-22.

Photograph 0570-16. Left bank looking DS from bottom of Loop #1.

Photo Station : 4+00
Bank Stabilization : None.

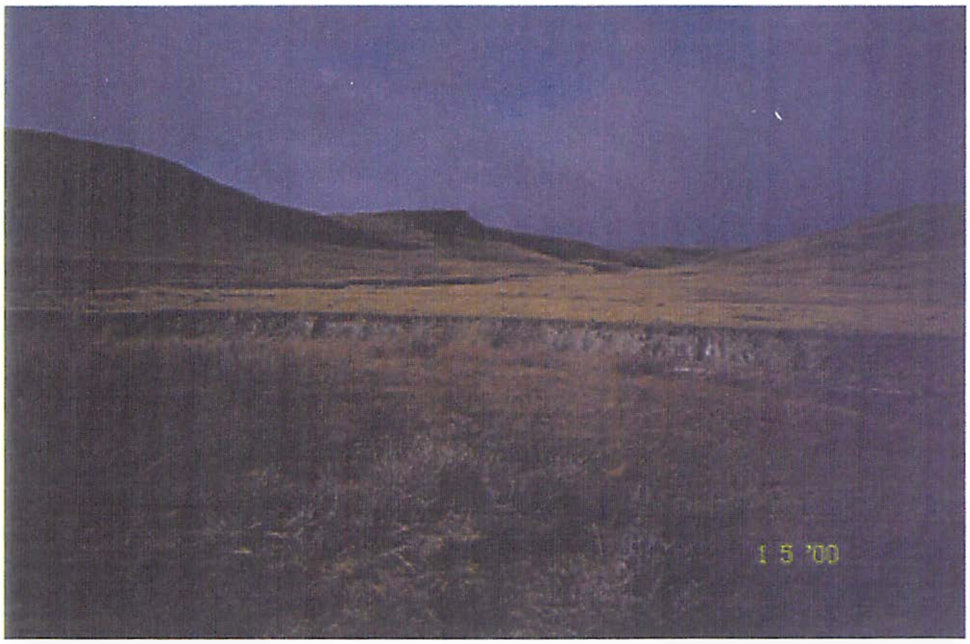


Photograph 0570-13. Left bank looking US at Loop #1. Panned left from Photograph 0570-16.

Photo Station : 4+00
Bank Stabilization : See Photo 0570-11.

Photograph 0570-12. Left bank looking US of Loop #1. Panned left from Photograph 0570-13.

Photo Station : 4+00
Bank Stabilization : See Photo 0570-11.



Photograph 0570-11. Left bank looking slightly US at upper Loop #1. Panned left from Photograph 0570-12.

Photo Station : 4+00
Upstream Station : 8+00
Downstream Station : 5+40
Bank Stabilization : Medium priority barbs or longitudinal peaked stone toe protection on left bank
: Bend Diameter: 160 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 16.3 – 33.8 ft; No. of Barbs: 16 - 8

Photograph 0570-10. Left bank looking at chute of Loop #1. Panned left from Photograph 0570-11.

Photo Station : 4+00
Bank Stabilization : See Photo 0570-11.

Photograph 0570-08. Left bank looking DS at upper Loop #1.

Photo Station : 9+00
Bank Stabilization : See Photo 0570-11.

Photograph 0570-07. Both banks looking DS from Loop #2.

Photo Station	: 10+00
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank in Loop #2.
Upstream Station	: 10+75
Downstream Station	: 9+90

Photograph 0570-06. Looking US from Loop #2. Note riffle.

Photo Station	: 10+40
Bank Stabilization	: None

Photograph 0570-05. Looking US opposite riffle in Straight Reach #1.

Photo Station : 11+50
Bank Stabilization : None

Photograph 0570-04. Looking DS at Straight Reach #1 in Photograph 0570-05 and Photograph 0570-06.

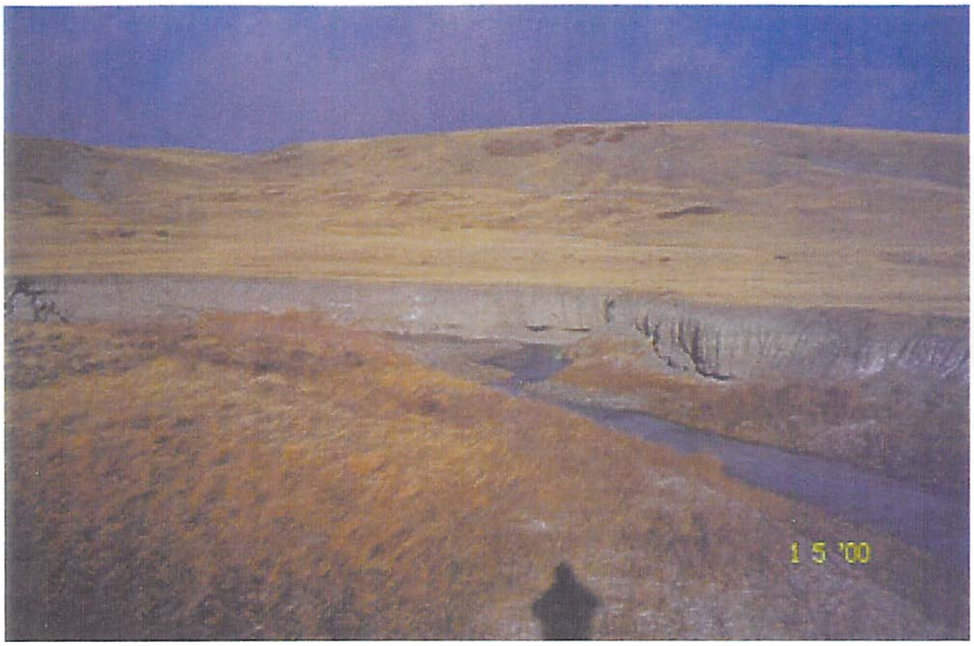
Photo Station : 15+25
Bank Stabilization : None

Photograph 0570-02. Left bank, looking US from head of Straight Reach #1 on Loop #3. Note vehicle next to BM.

Photo Station : 17+00
Bank Stabilization : See Photograph 0898-02. Barbs on outside (Right Bank) of Loop #3.

Photograph 0570-01. Left bank, looking US at Loop #4. Will Gonzales.

Photo Station : 17+60
Bank Stabilization : None. See Photograph 0570-26 and Photograph 0570-27.



Photograph 0570-26. Left bank, looking US at lower Loop #4.

Photo Station	: 18+30
Upstream Station	: 21+20
Downstream Station	: 19+70
Bank Stabilization	: Barbs on left bank.; Bend Diameter : 124 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 7.9 – 20.8 ft; No. of Barbs: 12 - 6

Photograph 0570-27. Left bank, looking DS at upper Loop #4.

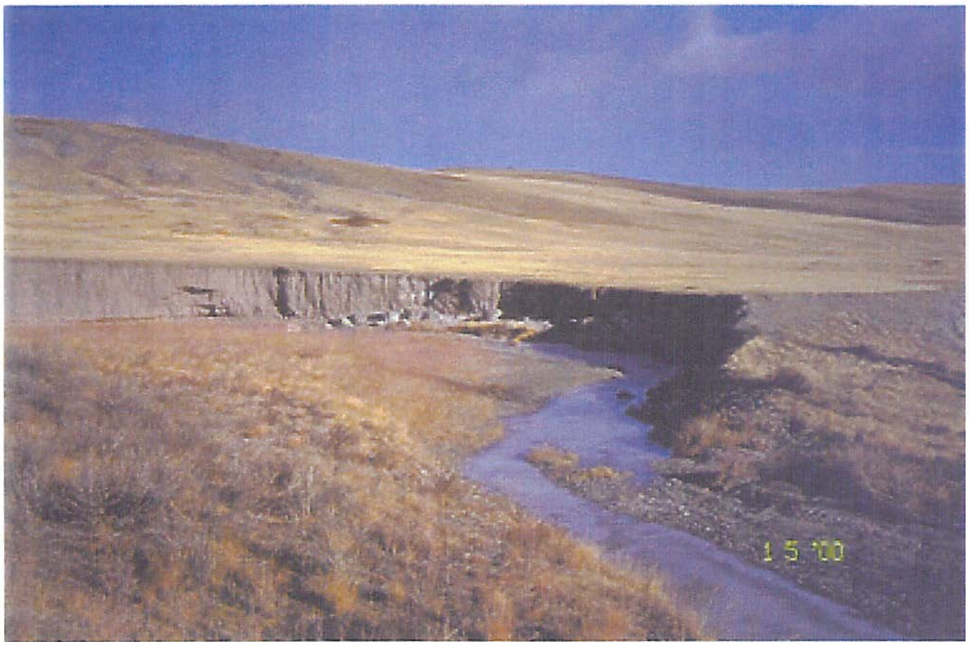
Photo Station	: 22+00
Bank Stabilization	: See Photograph 0570-26.

Photograph 0570-28. Left bank, opposite "point," from Loop #5. Panned left from Photograph 0570-27.

Photo Station : 22+00
Bank Stabilization : See Photograph 0570-26

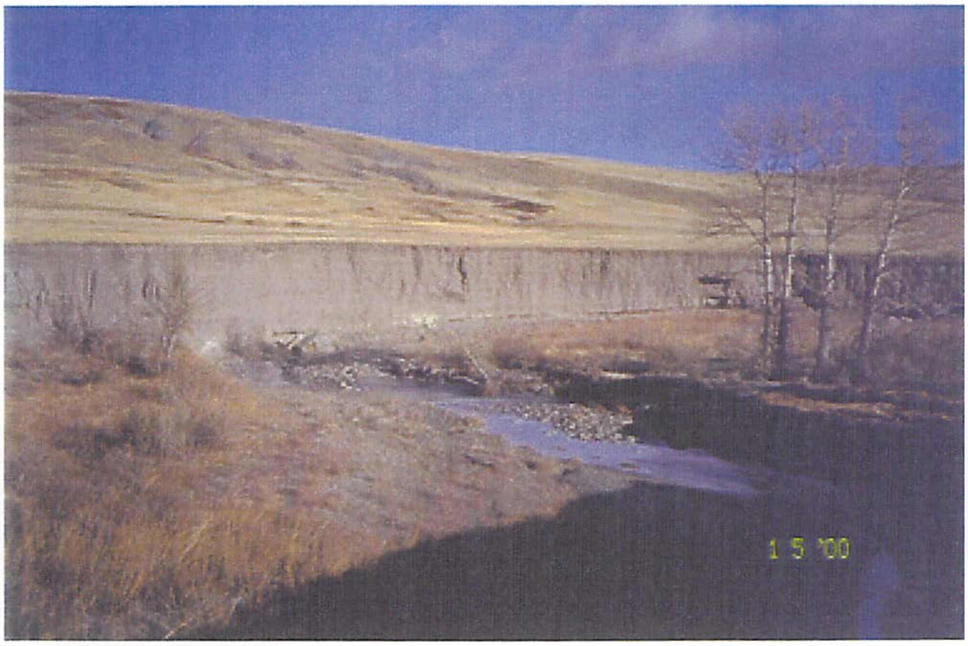
Photograph 0570-30. Left bank and point bar, looking slightly US at lower Loop #6.

Photo Station : 23+60
Bank Stabilization : Barbs below on right bank of Loop #5. See Photograph 0898-03.



Photograph 0570-31. Left bank looking US at Loop #6.

Photo Station	: 24+30
Upstream Station	: 27+70
Downstream Station	: 25+60
Bank Stabilization	: Barbs on left bank of Loop #6; possible Headcut stabilization at lower end of Loop #6; Bend Diameter: 141 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 14.7 – 31.6 ft; No. of Barbs: 15 - 7



Photograph 0570-32. Left bank looking DS at Loop #6.

Photo Station	: 30+20
Bank Stabilization	: See Photograph 0570-31.

Photograph 0570-33. Left bank looking US at Loop #8 from Loop #7 bank. Panned left from Photograph 0570-32.

Photo Station	: 30+20
Upstream Station	: 32+00
Downstream Station	: 31+20
Bank Stabilization	: Longitudinal peaked stone toe protection or barbs on left bank of Loop #8; possible headcut stabilization structure at bottom of Loop #8. Bend Diameter: 72 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 8.6 – 22.0 ft; No. of Barbs: 10 - 4

Photograph 0570-34. Left bank looking slightly DS at upper Loop #8.

Photo Station	: 32+10
Bank Stabilization	: Medium priority longitudinal peaked stone toe protection on left bank.
Upstream Station	: 34+00
Downstream Station	: 32+00

Photograph 0570-35. Left bank opposite Straight Reach #2 above Loop #8.

Photo Station : 33+50
Bank Stabilization : See Photograph 0570-34.

Photograph 0570-36. Left bank looking slightly US from Straight Reach #2 above Loop #8. Panned left from Photograph 0570-35.

Photo Station : 33+50
Bank Stabilization : See Photograph 0570-34.

Photograph 0570-37. Left bank, even more US than Photograph 0570-36. Note Gully #2.

Photo Station : 34+20
Bank Stabilization : Low priority longitudinal peaked stone toe protection on left bank. (Note gully destabilization of left bank.)

Photograph 0570-38. Looking US at left bank of Bend #1. Panned left and zoomed from Photograph 0570-37. Note Gully #2.

Photo Station : 34+20
Bank Stabilization : Low priority longitudinal peaked stone toe protection on left bank.

Photograph 0570-39. Looking US at Bend #0, foreground, Bend #1 at top.

Photo Station : 34+60
Bank Stabilization : Low priority longitudinal peaked stone toe protection on left bank Bend #0; Med. priority longitudinal peaked stone toe protection on left bank Bend #1.

Photograph 0570-40. Right bank, looking DS at Bend #0.

Photo Station : 35+50
Upstream Station : 35+50
Downstream Station : 33+50
Bank Stabilization : Barbs or longitudinal peaked stone toe protection on right bank of Bend #0. Bend Diameter: 200 ft; Channel Width: ~30 ft; Barb Length: 15.0 ft; Barb Spacing: 47.9 – 52.7 ft; No. of Barbs: 4 - 3

Photograph 0570-41. Left bank, looking DS of Bend #0 point bar & Gully #2. Panned left from Photograph 0570-40.

Photo Station : 35+50
Bank Stabilization : None or low priority longitudinal peaked stone toe protection on left bank. (Note gully destabilization and sediment source that may compliment a stone toe on left bank.)

Photograph 0570-42. Both banks looking US at Bend #2. Panned left from Photograph 0570-41.

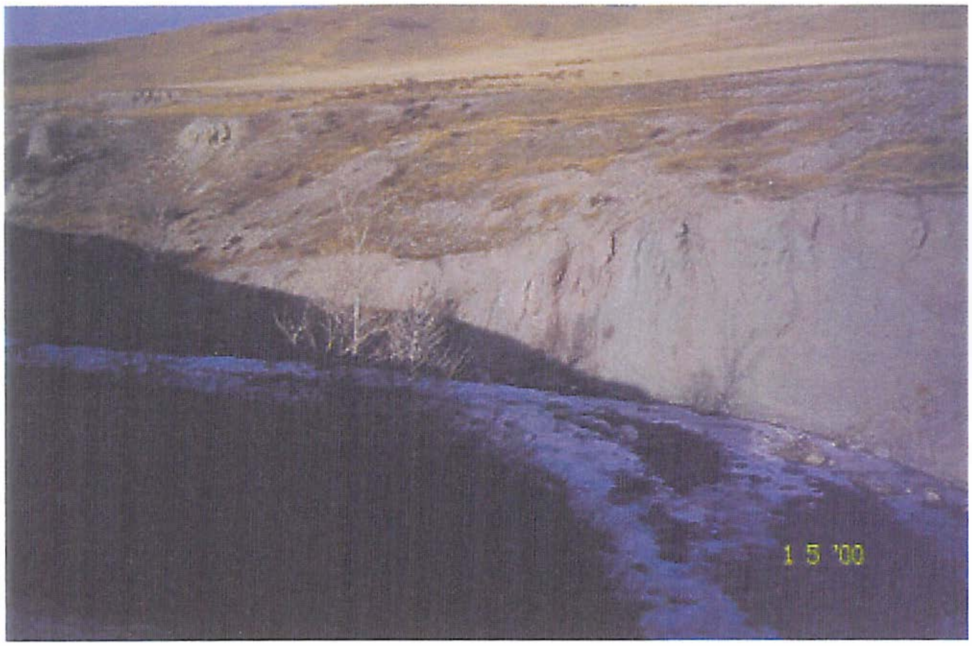
Photo Station : 35+50
Bank Stabilization : Longitudinal peaked stone toe protection on right bank. Low priority longitudinal peaked stone protection toe on left bank.
Upstream Station : 38+00
Downstream Station : 35+50

Photograph 0570-43. Left bank looking DS at Bend #1.

Photo Station	: 37+30
Bank Stabilization	: See Photograph 0570-42 – right bank; Longitudinal peaked stone toe protection on left bank. See Photograph 0570-39.
Upstream Station	: Left bank: 36+20 or higher
Downstream Station	: Left bank: 35+00

Photograph 0570-44. Both banks, looking US at Bend #3 from Bend #2. Panned left from Photograph 0570-43.

Photo Station	: 37+30
Bank Stabilization	: Longitudinal peaked stone toe protection on left bank.
Upstream Station	: 40+00
Downstream Station	: 38+40



Photograph 0570-45. Left bank, looking US at Bend #3.

Photo Station : 39+70
Bank Stabilization : See Photograph 0570-44.

Photograph 0570-46. Left bank, looking US at Bend #4.

Photo Station : 40+80
Bank Stabilization : Longitudinal peaked stone toe protection on right bank. See Photograph 0898-06; low priority longitudinal peaked stone toe protection on left bank.
Upstream Station : Left bank: 42+00
Downstream Station : Left bank: 41+00

Photograph 0570-47. Both banks, looking US at island in Bend #4.

Photo Station : 41+20
Bank Stabilization : Right bank – See Photograph 0898-06 (Right bank).

Photograph 0570-48. Left bank looking US at Bend #5.

Photo Station : 41+80
Bank Stabilization : Longitudinal peaked stone toe protection on left bank.
Upstream Station : 47+00
Downstream Station : 43+00

Photograph 0570-49. Left bank, looking DS at Bend #6.

Photo Station	: 46+90
Bank Stabilization	: Longitudinal peaked stone toe protection on left bank.
Upstream Station	: 50+50 (bottom of Kayak)
Downstream Station	: 47+00 (Abuts Photograph 0570-48)

Photograph 0570-50. Left bank, looking DS at Straight Reach #4. Panned left and down from Photograph 0570-49.

Photo Station	: 46+90
Bank Stabilization	: See Photograph 0570-49.

Photograph 0570-52. Same as Photograph 0570-50. After changing film rolls.

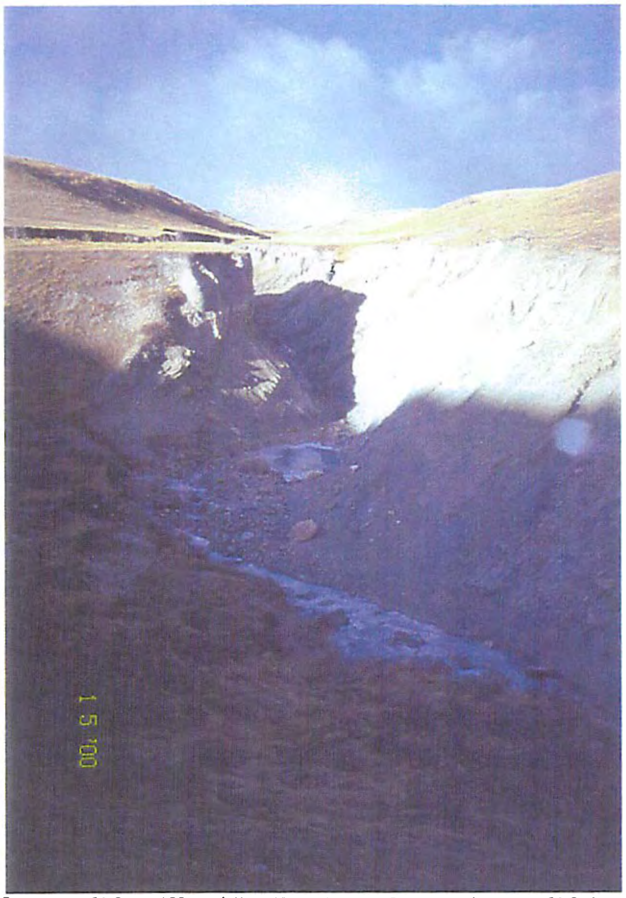
Photo Station	: 46+90
Bank Stabilization	: See Photograph 0570-49.

Photograph 0570-53. Looking US at Bend #8, exit of "Kayak" chute.

Photo Station	: 47+20
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank. Left bank see Photographs 0570-49 to 52.
Upstream Station	: 50+50
Downstream Station	: 49+00

Photograph 0570-54. Looking DS at Bend #8.

Photo Station : 48+80
Bank Stabilization : See Photographs 0570-49 to 53.

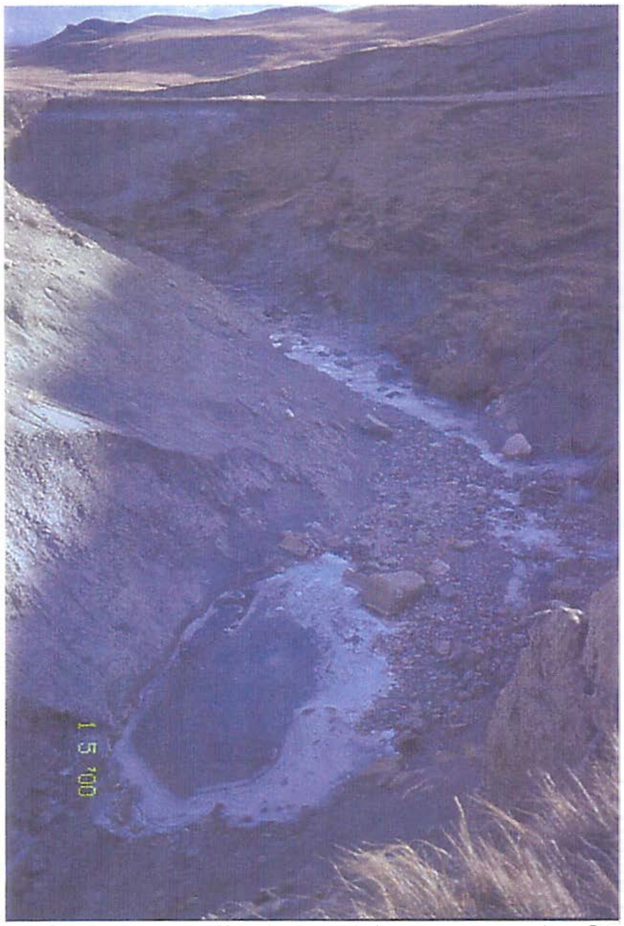


Photograph 0570-55. Looking US at "Kayak" stilling basin. Panned left and US from Photograph 0570-54.

Photo Station	: 48+80
Bank Stabilization	: See Photographs 0570-49 to 54.
Note	: Longitudinal peaked stone toe protection on both banks downstream of "Kayak." No treatment in "Kayak" with the possible exception of headcut stabilization or stilling basin at the foot of "Kayak."

Photograph 0570-57. Looking DS at Straight Reach #4 below "Kayak" stilling basin.

Photo Station	: 50+80
Bank Stabilization	: See Photographs 0570-49 to 56.



Photograph 0570-58. Looking DS at "Kayak" scour hole. Panned down from Photograph 0570-57.

Photo Station	: 50+80
Bank Stabilization	: See Photographs 0570-49 to 57.

Photograph 0570-59. Looking DS at "Kayak" chute.

Photo Station	: 51+70
Bank Stabilization	: See Photographs 0570-49 to 58.

Photograph 0570-60. Left bank US of "Kayak." Panned left and US from Photograph 0570-59.

Photo Station	: 51+70
Bank Stabilization	: Longitudinal peaked stone toe protection on left bank.
Upstream Station	: 53+70
Downstream Station	: 51+80

Photograph 0570-61. Left bank entrance to "Kayak."

Photo Station	: 53+70
Bank Stabilization	: See Photograph 0570-60.

Photograph 0570-62. Left bank. Panned left from Photograph 0570-61.

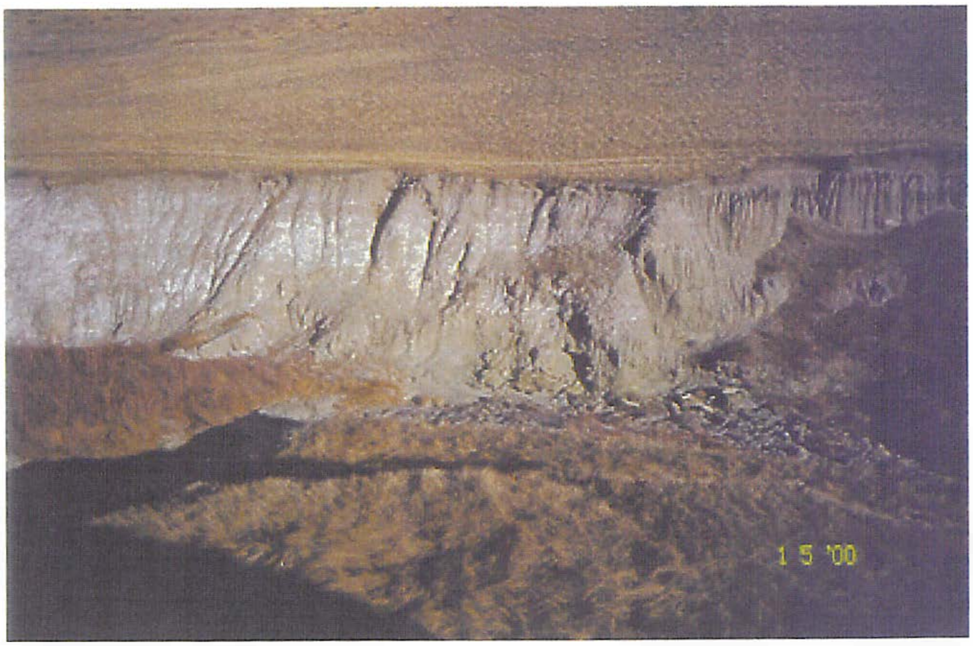
Photo Station : 53+70
Bank Stabilization : See Photograph 0570-60.

Photograph 0570-63. Left bank. Panned left from Photograph 0570-62.

Photo Station : 53+70
Bank Stabilization : See Photograph 0570-60 for downstream left bank in this photograph.

Photograph 0570-64. Left bank. Panned left from Photograph 0570-63.

Photo Station	: 53+70
Bank Stabilization	: Low priority longitudinal peaked stone toe protection on left bank
Upstream Station	: 56+00
Downstream Station	: 54+00



Photograph 0570-65. Left bank opposite Bend #14.

Photo Station	: 56+90
Bank Stabilization	: Medium priority longitudinal peaked stone toe protection on left bank.
Upstream Station	: 57+20
Downstream Station	: 56+80

Photograph 0570-66. Left bank. Panned left from Photograph 0570-65.

Photo Station : 56+90
Bank Stabilization : None.

Photograph 0570-67. Left bank looking into Straight Reach #5. Panned left from Photograph 0570-66.

Photo Station : 56+90
Bank Stabilization : None.

Photograph 0570-70. Left bank, looking US into Straight Reach #5.

Photo Station : 59+40
Bank Stabilization : None.

Photograph 0570-71. Left bank looking US into Straight Reach #5.

Photo Station : 60+10
Bank Stabilization : None.

Photograph 0570-72. Left bank looking US. Panned US and left from Photograph 0570-71. Lower chute of Bend #15. Note vehicle tracks on left bank.

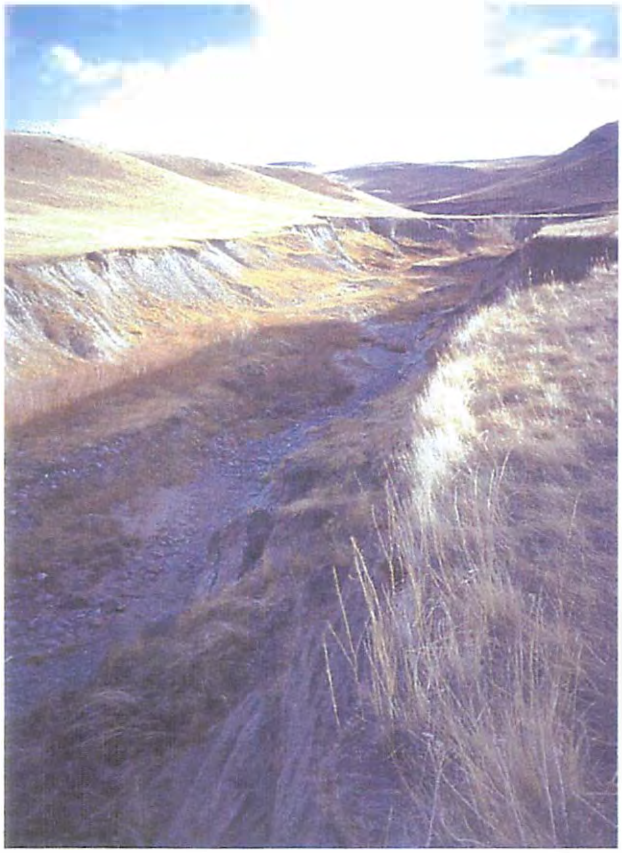
Photo Station : 60+10
Bank Stabilization : None.

Photograph 0570-74. Right bank in Bend #15 and left bank US of Bend #15.

Photo Station : 61+30
Bank Stabilization : Longitudinal peaked stone toe protection on left bank opposite of Bend #15.
Upstream Station : 62+00
Downstream Station : 61+50

Photograph 0570-75. Left bank US of Bend #15.

Photo Station : 61+00
Bank Stabilization : See Photograph 0570-74.



Photograph 0570-51. Panoramic looking DS. Out of sequence. Good perspective of "no-man's-land."

Photo Station : 67+50 (Our best guess)
Bank Stabilization : None on left bank between 62+00 and 67+50. (Visible left bank in photo.)

RIGHT BANK

Photograph 0898-01. Right bank looking US at bottom of Loop #1.

Photo Station	: 1+00
Bank Stabilization	: Medium priority longitudinal peaked stone toe protection on right bank.
Upstream Station	: 4+00
Downstream Station	: 3+00

Photograph 0898-02. Right bank looking US at Loop #3.

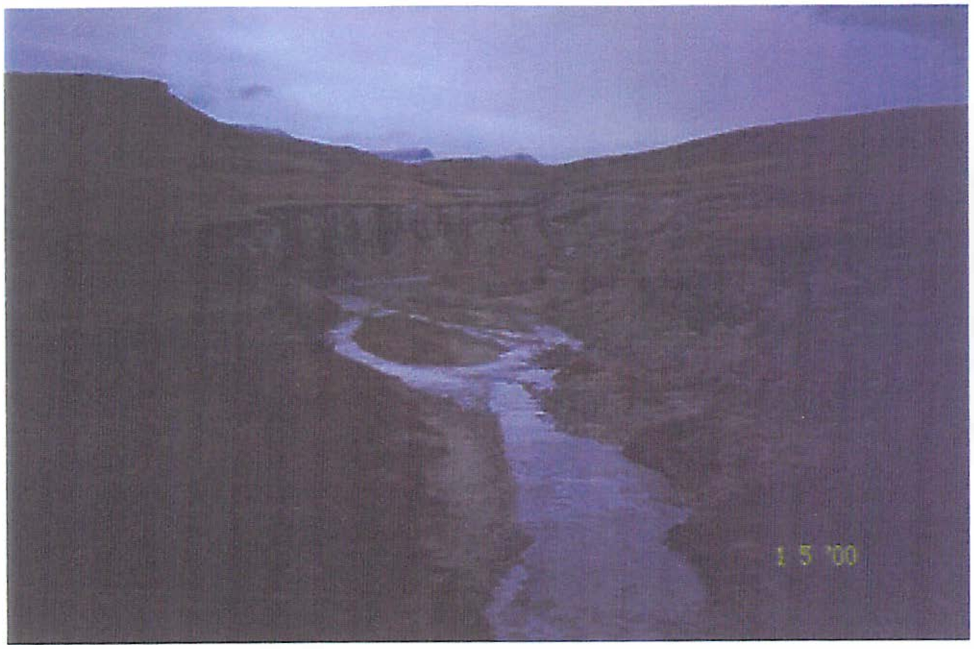
Photo Station	: 16+70
Upstream Station	: 18+00
Downstream Station	: 17+30
Bank Stabilization	: Medium priority longitudinal peaked stone toe protection or barbs on right bank (outside of Loop #3). Bend Diameter: 65 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 7.9 – 20.8 ft; No. of Barbs: 9 - 4

Photograph 0898-03. Right bank looking US at Loop #5.

Photo Station	: 20+60
Upstream Station	: 24+50
Downstream Station	: 22+50
Bank Stabilization	: Barbs on right bank (Loop #5). Bend Diameter: 113 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 12.3 – 28.1 ft No. of Barbs: 17 - 8

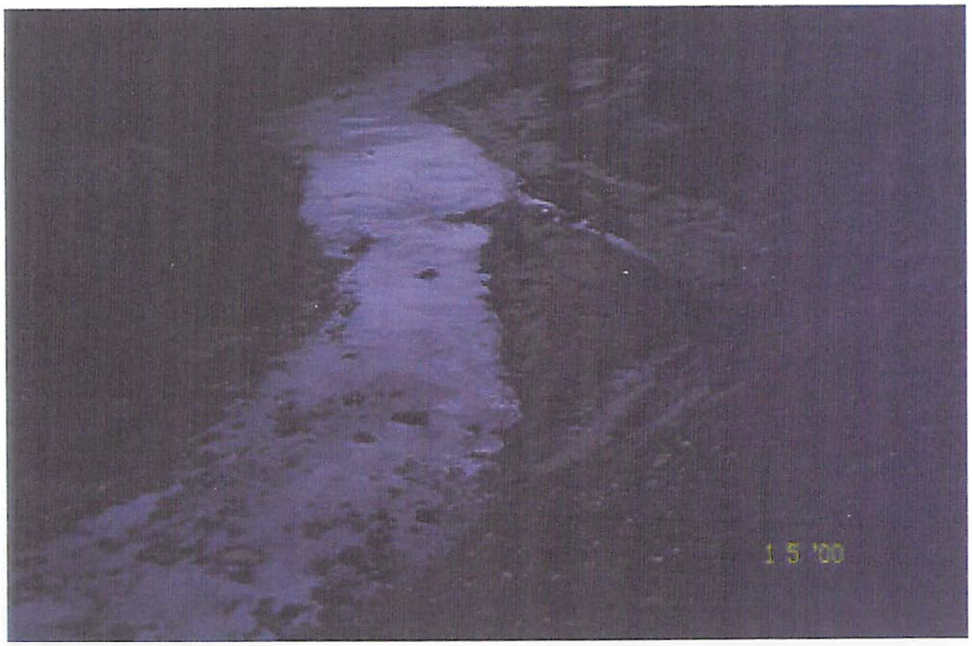
Photograph 0898-04. Right bank looking US at Loop #7.

Photo Station	: 27+60
Upstream Station	: 30+20
Downstream Station	: 29+00
Bank Stabilization	: Barbs on right bank (Loop #7). Bend Diameter: 100 ft; Channel Width: ~30 ft; Barb Length: 7.5 ft; Barb Spacing: 11.2 – 26.3 ft; No. of Barbs: 11 - 5



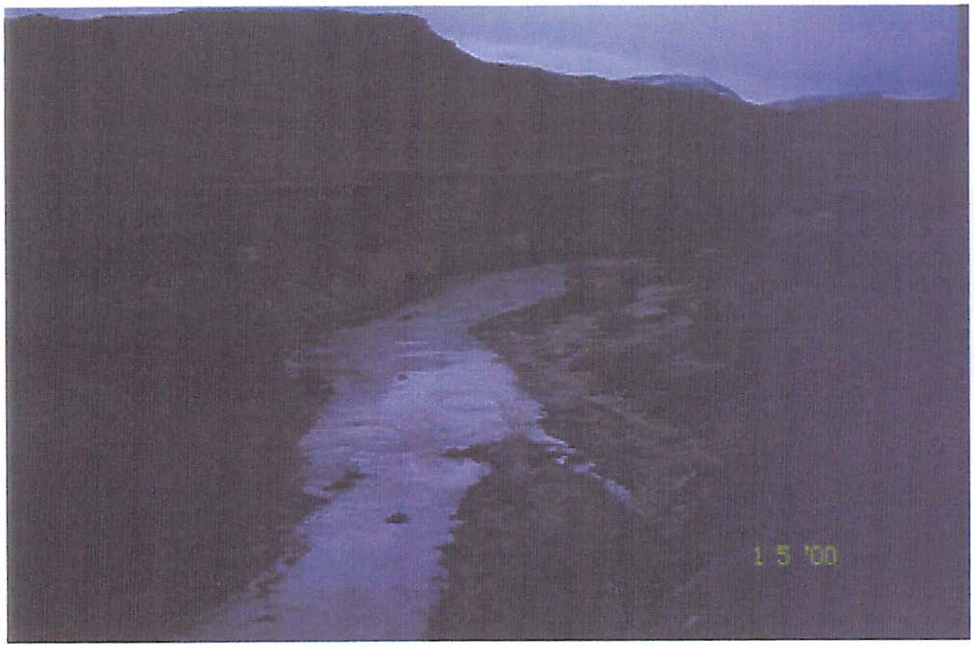
Photograph 0898-05. Looking US at Straight Reach #2, above benchmark.

Photo Station : 31+40
Bank Stabilization : Right bank, see Photograph 0570-40.



Photograph 0898-06. Right bank looking US at Bend #4.

Photo Station : 38+90
Bank Stabilization : Longitudinal peaked stone toe protection on right bank.
Upstream Station : 41+50
Downstream Station : 38+90



Photograph 0898-07. Right bank looking US at Bend #4. Panned up from Photograph 0898-06.

Photo Station	: 38+90
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank. See Photograph 0570-43 and Photograph 0898-06.

Photograph 0898-08. Right bank looking US at riparian area in Bend #5.

Photo Station	: 40+30
Bank Stabilization	: Low priority longitudinal peaked stone toe protection on right bank.
Upstream Station	: 42+50
Downstream Station	: 41+50

Photograph 0898-09. Right bank looking US at upper Bend #5.

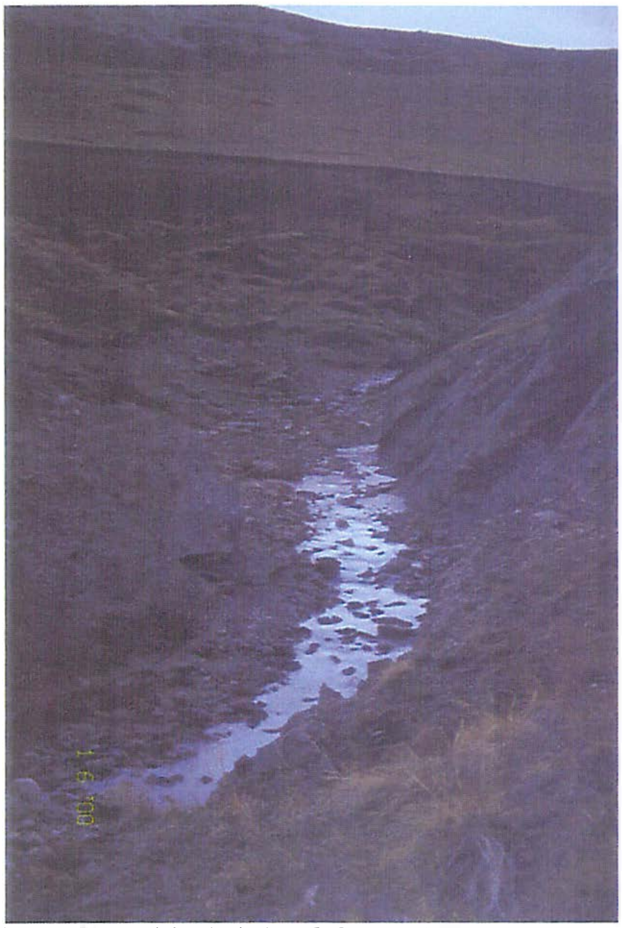
Photo Station	: 42+20
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank.
Upstream Station	: 43+50
Downstream Station	: 42+50

Photograph 0898-10. Both banks looking US at Straight Reach #3. Will Gonzales.

Photo Station	: 43+70
Bank Stabilization	: None.

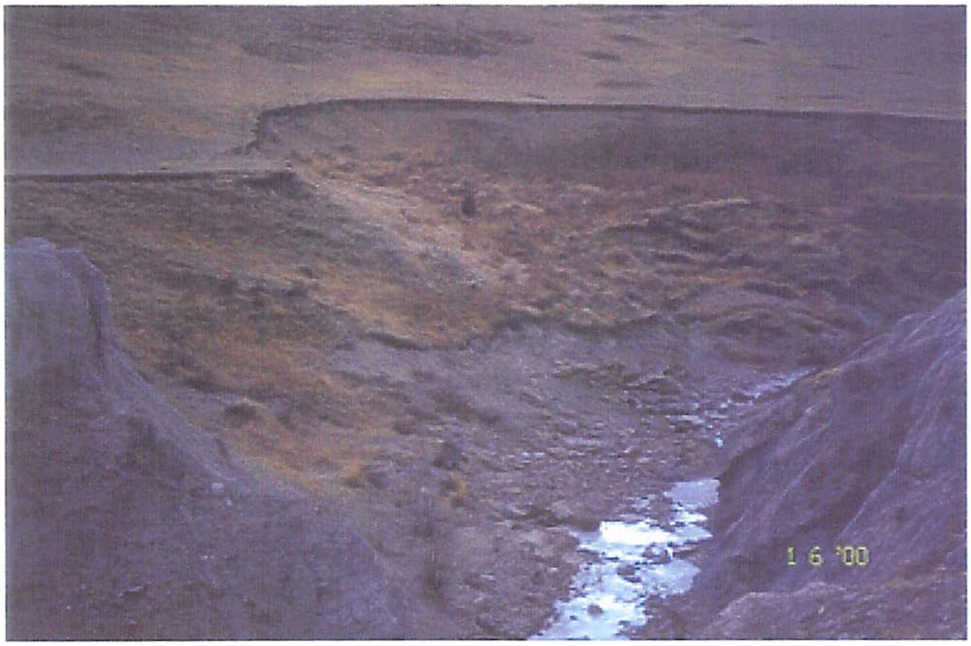
Photograph 0898-12. Right bank looking US at Bend #6. Downstream slide on left.

Photo Station	: 42+70
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank. Left bank see Photograph 0570-48.
Upstream Station	: Right bank: 45+00
Downstream Station	: Right bank: 44+50



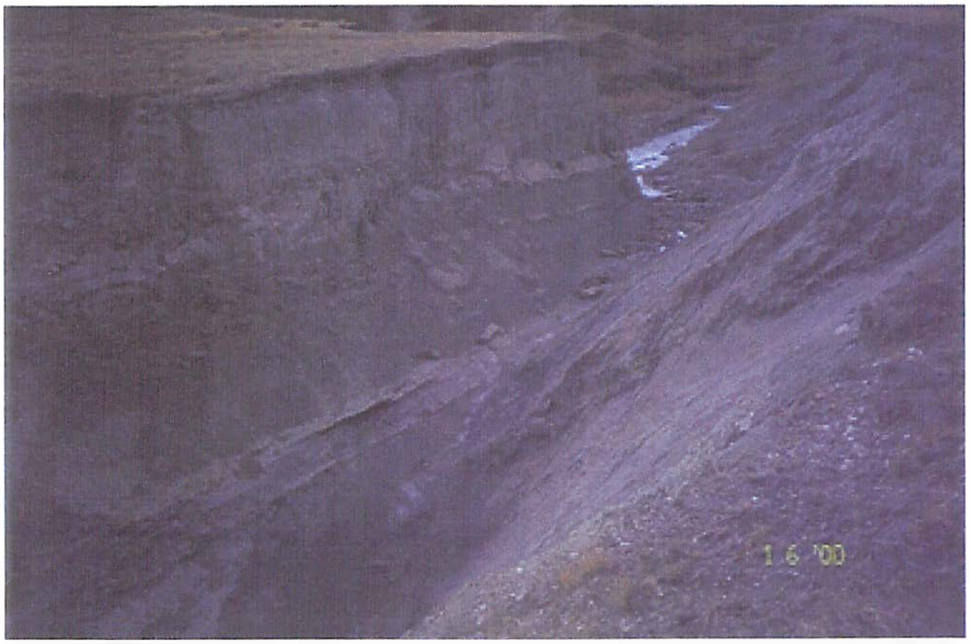
Photograph 0898-15. Both banks looking US at Bend #6. Downstream slide on left.

Photo Station : 46+50
Bank Stabilization : None, except mine rock from channel and revet both banks.



Photograph 0898-18. Right bank Bend #8, in middle slide.

Photo Station : 47+00
Bank Stabilization : See Photograph 0898-15.



Photograph 0898-19. "Kayak."

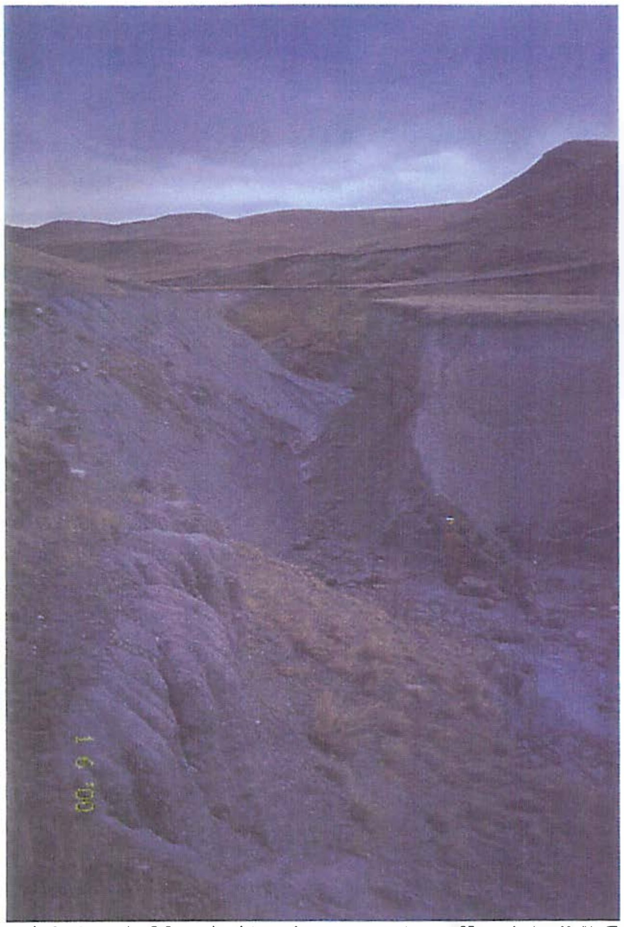
Photo Station : 50+00
Bank Stabilization : None.

Photograph 0898-20. Right bank US of "Kayak" entrance, lower Bend #10.

Photo Station : 51+50
Bank Stabilization : None. Rebuild headcut stabilization structure at entrance to "Kayak" with rock from channel and right bank. This protects right bank (cupola) immediately to the right at upstream of "Kayak." See Photograph 0898-22.
Station : 52+10

Photograph 0898-21. Right bank, Bend #11. Upper slide.

Photo Station : 52+10
Bank Stabilization : See Photograph 0898-20.



Photograph 0898-22. View looking downstream into "Kayak." Will Gonzales.

Photo Station : 53+70
Bank Stabilization : Headcut stabilization structure at entrance to "Kayak." See Photograph 0898-20.

Photograph 0898-24. Both banks looking US at Bend #12 then Straight Reach #5. Note view upstream showing potential access along left bank for construction equipment. Probability low that vehicles could access along upper bank. Access in channel adequate for tracked vehicles only.

Photo Station : 54+60
Bank Stabilization : None.

Photograph 0898-25. Right bank opposite Bend #13 & #14.

Photo Station : 55+90
Bank Stabilization : Medium priority longitudinal peaked stone toe protection on right bank. High priority headcut stabilization structure at 56+00.
Upstream Station : 61+10
Downstream Station : 56+00

Photograph 0898-27. Closer view of Photograph 0898-25. Will Gonzales.

Photo Station : 56+00
Bank Stabilization : Headcut stabilization structure where Will is walking. See Photograph 0898-25.

Photograph 0898-28. View looking DS of Photograph 0898-25 and Photograph 0898-26.

Photo Station : 57+10
Bank Stabilization : See Photographs 0898-25 and 27.

Photograph 0898-29. Right bank looking US at Straight Reach #5. Panned right from Photograph 0898-28.

Photo Station : 57+10
Bank Stabilization : Medium priority longitudinal peaked stone toe protection on right bank. See Photograph 0898-25.

Photograph 0898-30. Right bank looking US at Straight Reach #5.

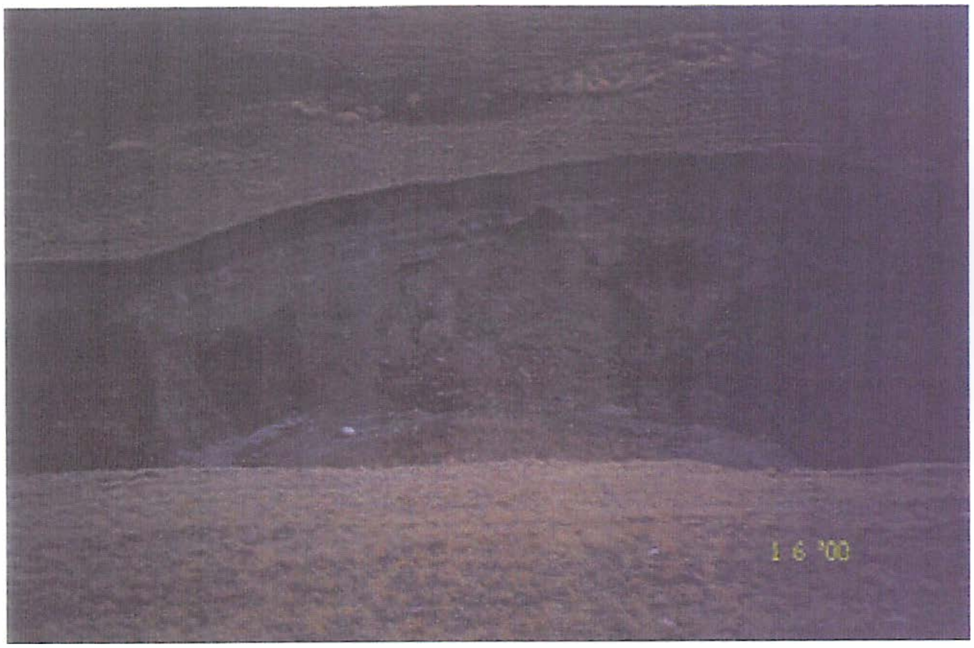
Photo Station : 59+10
Bank Stabilization : See Photograph 0898-25.

Photograph 0898-31. Right bank looking US at Bend #15.

Photo Station : 60+90
Bank Stabilization : See Photograph 0898-25.

Photograph 0898-32. Right bank of Bend #15.

Photo Station : 61+10
Bank Stabilization : Longitudinal peaked stone toe protection on right bank.
Upstream Station : 62+20
Downstream Station : 61+10



Photograph 0898-33. Right bank of Bend #15.

Photo Station : 62+00
Bank Stabilization : See Photograph 0898-32.

Photograph 0898-34. Right bank looking US at Straight Reach #6 and Bend #16.

Photo Station : 62+50
Bank Stabilization : Paired barbs using available rock in channel for energy dissipation.
Upstream Station : 66+30
Downstream Station : 62+20

Photograph 0898-35. Right bank looking US from Straight Reach #6 to Bend #16.

Photo Station : 63+00
Bank Stabilization : See Photograph 0898-34.

Photograph 0898-51. Right bank looking DS at Bend #15. (Overlaps)

Photo Station : 63+00
Bank Stabilization : See Photograph 0898-34.

Photograph 0898-52. Right bank looking US at Bend #16. (Similar to Photograph 0898-35)

Photo Station : 63+50
Bank Stabilization : See Photograph 0898-34.

Photograph 0898-53. Right bank looking US at Bend #18.

Photo Station : 66+30
Bank Stabilization : Longitudinal peaked stone toe protection on right bank. Potential headcut stabilization structure at 66+30.
Upstream Station : 68+00
Downstream Station : 66+30

Photograph 0898-54. Right bank panned right from Photograph 0898-53 looking US at Bend #19.

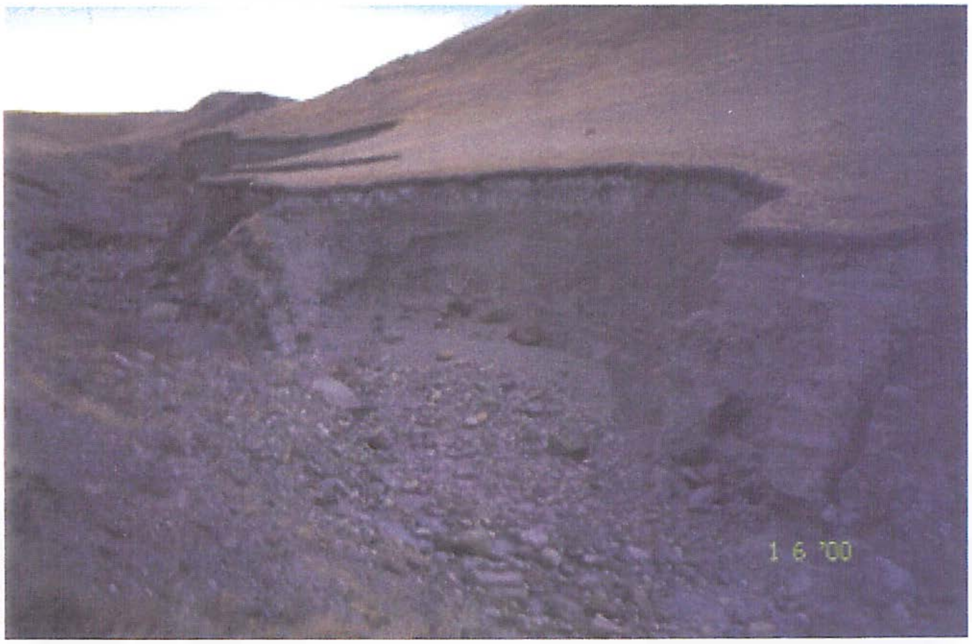
Photo Station	: 66+30
Bank Stabilization	: See Photograph 0898-53.

Photograph 0898-55. Right bank looking US at Bend #19 (foreground) and Bend #20 (middle).

Photo Station	: 67+90
Bank Stabilization	: See Photograph 0898-53. Potential headcut stabilization structure.
Upstream Station	: 68+75
Downstream Station	: 68+00

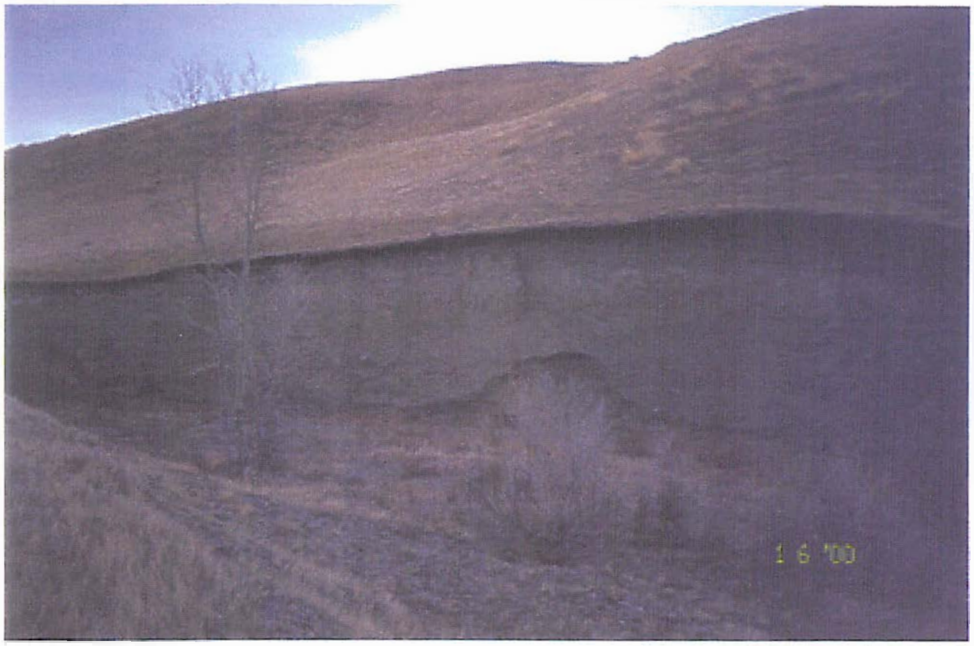
Photograph 0898-56. Right bank looking US at Bend #21.

Photo Station : 69+00
Bank Stabilization : High priority longitudinal peaked stone toe protection on right bank.
Upstream Station : 72+00
Downstream Station : 69+40



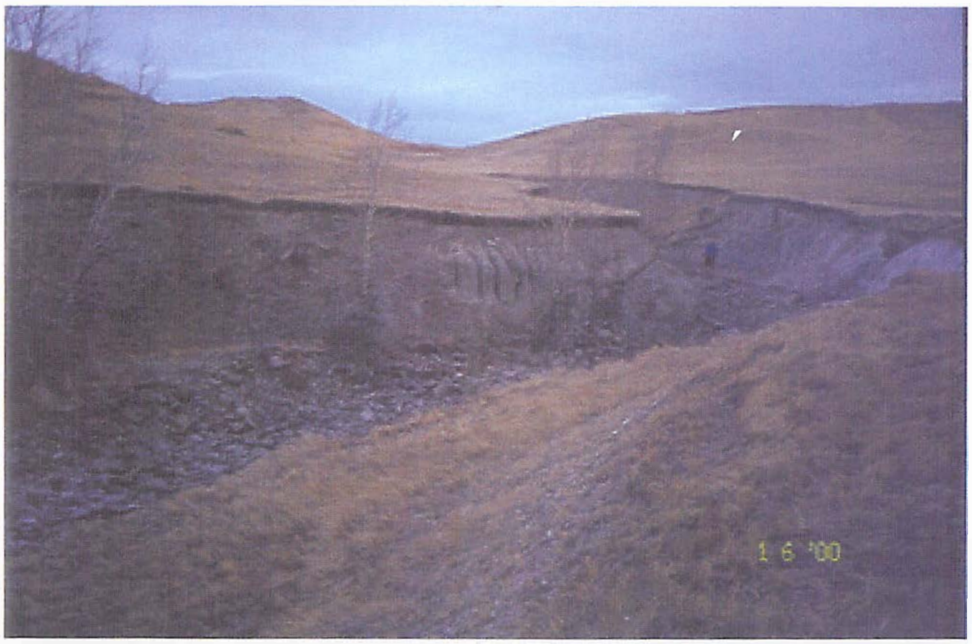
Photograph 0898-57. Right bank looking DS into Bend #20.

Photo Station : 69+00
Bank Stabilization : See Photograph 0898-53.



Photograph 0898-58. Right bank looking DS into middle of Bend #21.

Photo Station	: 72+70
Bank Stabilization	: Photograph 0898-56.



Photograph 0898-59. Right bank looking US into upper Bend #21. Panned right from Photograph 0898-58.

Photo Station	: 72+70
Bank Stabilization	: None. Potential longitudinal peaked stone toe protection using rock in channel.

Photograph 0898-60. Both banks looking US at upper end of Bend #21, into Straight Reach #7. Will Gonzales.

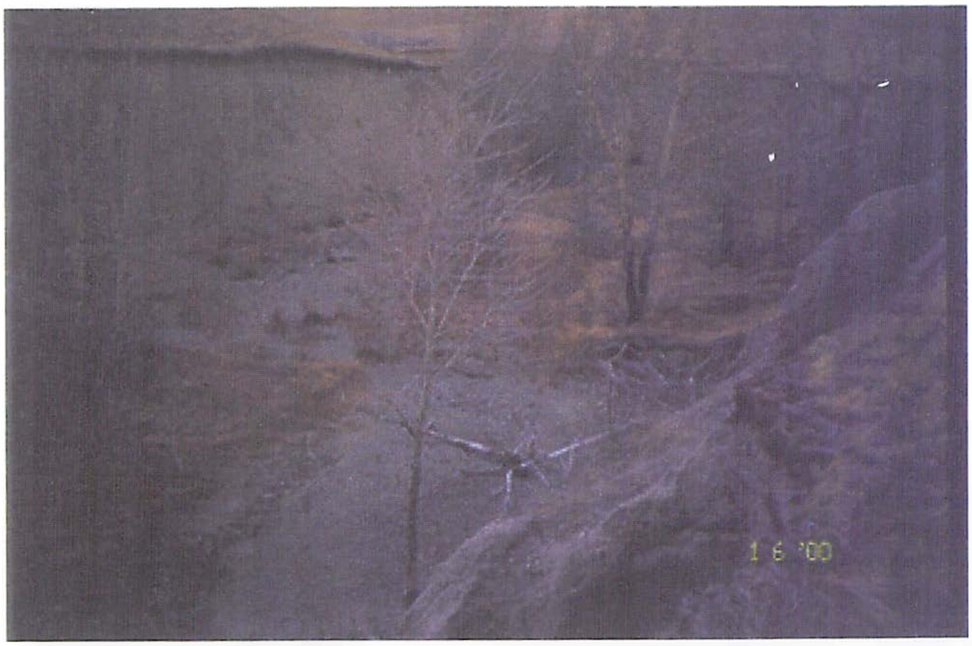
Photo Station	: 73+00
Bank Stabilization	: None – right bank.
	: Longitudinal peaked stone toe protection on left bank.
Upstream Station	: 73+80
Downstream Station	: 73+00

Photograph 0898-61. Right bank looking US into Bend #22.

Photo Station	: 74+40
Bank Stabilization	: Low priority longitudinal peaked stone toe protection on right bank.
Upstream Station	: 77+00
Downstream Station	: 74+40

Photograph 0898-62. Right bank looking US into Bend #22.

Photo Station	: 78+50
Bank Stabilization	: Longitudinal peaked stone toe protection on right bank.
Upstream Station	: 78+00
Downstream Station	: 77+00 (Abuts Photograph 0898-61)



Photograph 0898-63. Left bank looking US into Bend #23.

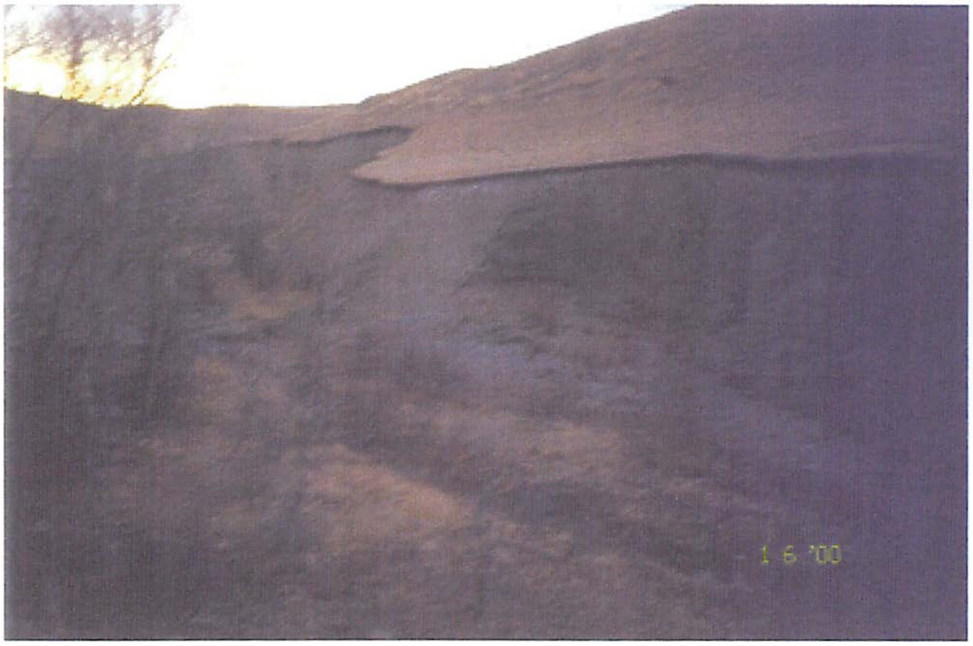
Photo Station	: 79+20
Bank Stabilization	: Longitudinal peaked stone toe protection on left bank. Longitudinal peaked stone toe protection on right bank. Medium priority headcut stabilization structure at 80+00.
Upstream Station	: Left bank: 80+00; Right bank: 80+20
Downstream Station	: Left bank: 79+20; Right bank: 81+20

Photograph 0898-64. Right bank looking US into Bend #24.

Photo Station : 80+90
Bank Stabilization : See Photograph 0898-63.

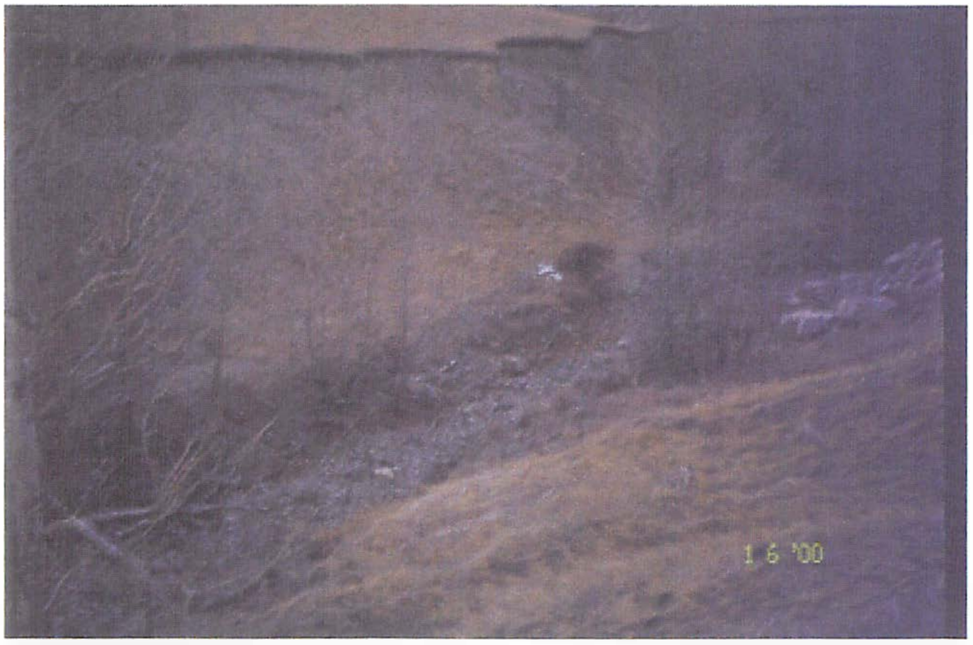
Photograph 0898-65. Riparian area on left bank US of Bend #24. Panned right from Photograph 0898-64.

Photo Station : 80+90
Bank Stabilization : None.



Photograph 0898-66. Right bank looking DS into Bend #24.

Photo Station : 82+80
Bank Stabilization : See Photograph 0898-63.



Photograph 0898-67. Both banks looking into Straight Reach #8. Panned right from Photograph 0898-66.

Photo Station : 82+80
Bank Stabilization : None.

Photograph 0898-68. Both banks into Bend #26. Panned right from Photograph 0898-67.

Photo Station : 82+80
Bank Stabilization : None. Salvage rock on left bank.

Photograph 0898-69. Left bank longitudinal peaked stone toe protection in Bend #26.

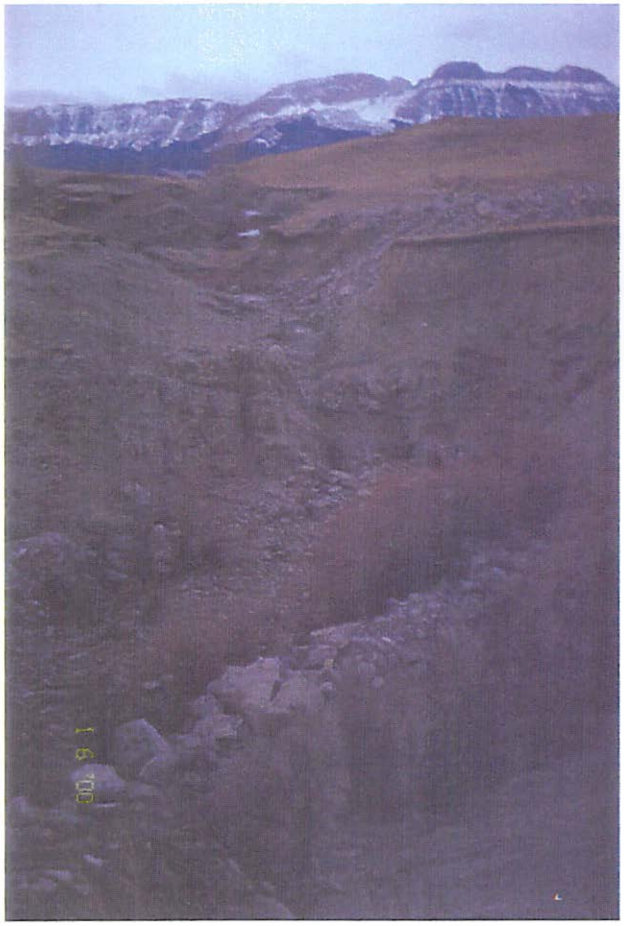
Photo Station : 84+20
Bank Stabilization : None. Repairs to existing longitudinal peaked stone toe protection.

Photograph 0898-70. Both banks, looking US into Bend #26, DS of headcut. Panned up and US from Photograph 0898-69.

Photo Station : 84+20
Bank Stabilization : Repair existing longitudinal peaked stone toe protection.

Photograph 0898-71. Left bank and riparian area created behind longitudinal peaked stone toe protection. Panned up from Photograph 0898-70.

Photo Station : 84+20
Bank Stabilization : See Photograph 0898-70.



Photograph 0898-72. Headcut.

Photo Station	: 85+00 (Estimated)
Bank Stabilization	: None.

TOTAL ERODED MATERIAL

The estimate of the total volume of earth material eroded in the Game Range Reach is 442,700 cubic yards. The estimate is from GPS surveying digital terrain model.

HYDRAULIC ANALYSIS

Figure 14 and Figure 15 picture the "Kayak" reach and Loop #5 in 1997. The flow in these pictures is unknown. An estimate of the depth in these two pictures is roughly 2-3 feet at an unknown discharge.

Figure 14. The "Kayak" chute. Note relative position of head cut in this photograph from July 2, 1997.

The primary factor in the design of the longitudinal peaked stone toe protection is the normal high water depth. The design capacity of the feeder system is 350 ft^3. According to Land & Water Consulting, and their Final Report, Willow Creek, Hydrologic Analysis and Engineering Feasibility Study (Land & Water Consulting, 1998, Fig. E6b) flow depth at three hundred cubic feet per second is roughly 2.35 feet in the reach upstream of the lower boundary of the Game Range Reach. For the basis of this plan, the design height of the longitudinal peaked stone toe protection for a normal high water flow of 350 ft^3 is three feet. This plan also assumes a stable channel width of roughly 30 feet. The basis of all alignments of bank treatments is a thirty-foot bottom width.

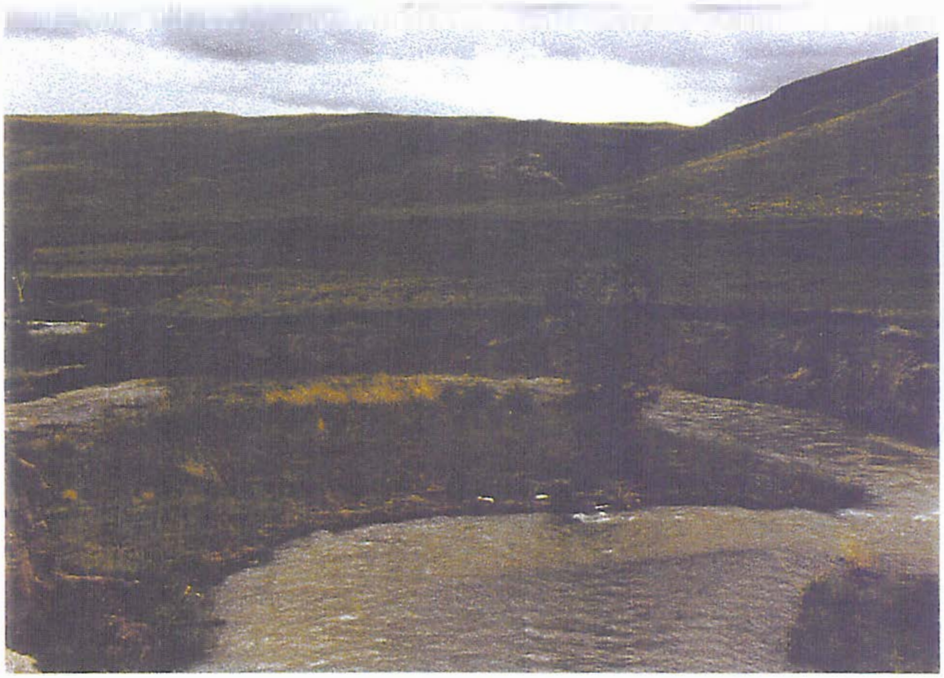


Figure 15. Feeder system with flows eroding outside of Loop #5 on July 2, 1997.

Figure 16 shows a plan view of the thalweg location in the Game Range Reach. The horizontal and vertical scales in this figure are roughly the same. There are two distinct sub-reaches in the Game Range Reach. The upper reach, beginning roughly at station 32+00 is very steep, has low sinuosity, and has eroded to bedrock in most locations. Figure 17 shows the profile of the Game Range Reach. The horizontal and vertical scales differ substantially. However, the relative "shape" of the profile indicates the significant difference in slope between the upper and lower reaches.

Upper Reach: >32+00

Sinuosity ~1.10
Slope ~ 1.80%

The lower reach, below station 32+00 is less steep, has high sinuosity, and has a gravel or sand bed in most locations.

Lower Reach: <32+00

Sinuosity ~1.92
Slope ~ 0.38%

Figure 14 and Figure 15 illustrate these differences. Accordingly, stabilization measures differ in the two reaches. In the lower reach, the primary mode of bank stabilization is barbs in concert with some headcut stabilization. In the upper reach, the primary mode of stabilization is longitudinal peaked stone toe protection in concert with some headcut stabilization. There is one sub-reach in the upper reach between stations 62+20 and 66+30 where paired barbs are the primary mode of bank stabilization. Paired barbs are a recent innovation adapted from stream restoration to fish passage and now back to bank stabilization. Paired barbs are simply a pair of barbs, at the same channel station, one on each bank, pointing in the upstream direction, forcing flow between the tips. The barbs do not meet in mid-channel. A scour hole may form immediately downstream of the paired tips resulting in an artificial pool-riffle sequence. In straight reaches paired barbs appear to be a realistic choice for avoiding revetment or channel lining. Paired barbs are very effective at preventing bank scour while dissipating energy. Alternating barbs conversely are very effective at meandering the stream and incurring a great deal of bank scour and energy dissipation while creating fish habitat.

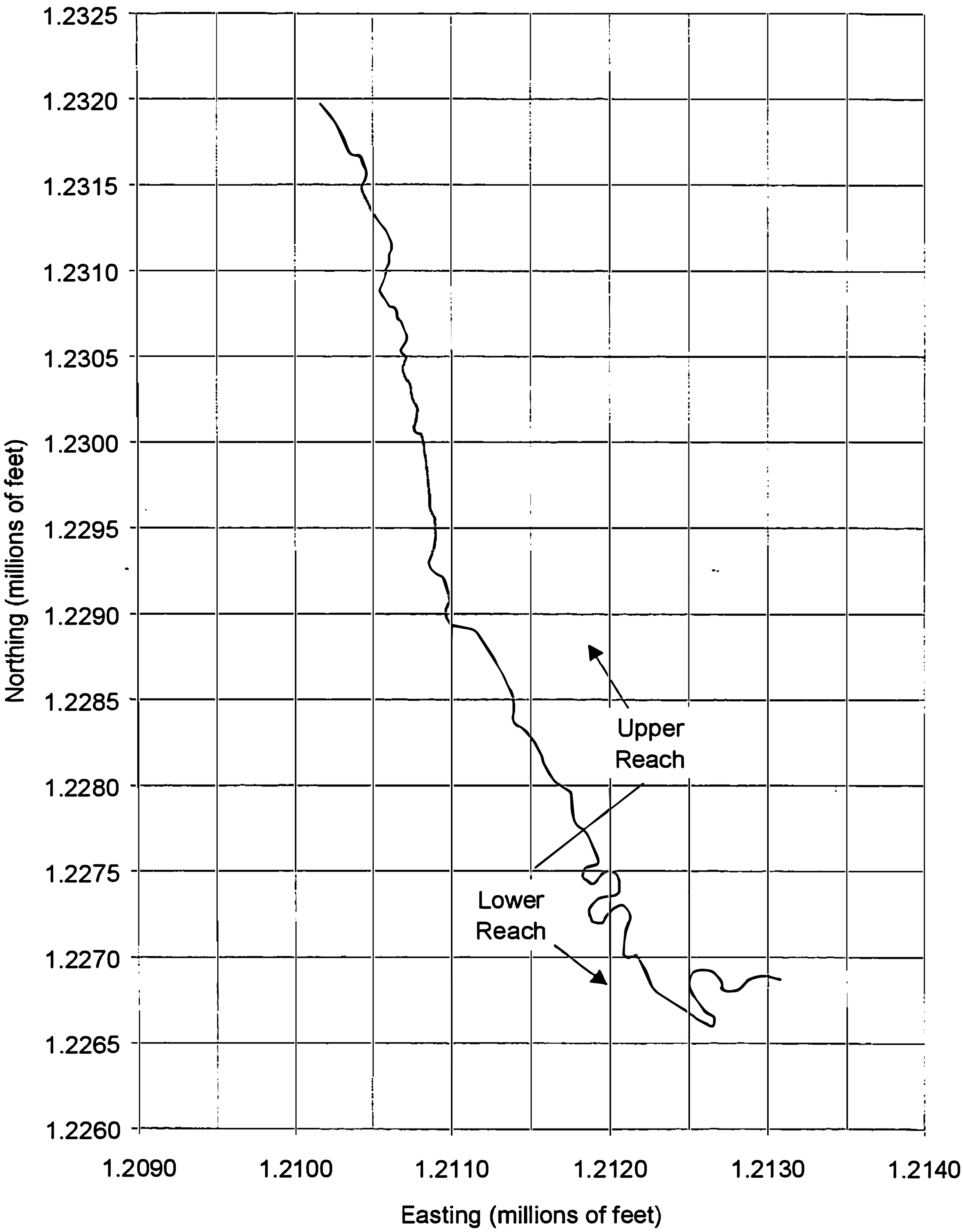


Figure 16. Plan view of thalweg in Game Range Reach. Vertical and horizontal scales differ slightly. (See Figure 13 and Plate 1 for plan views at correct scale.)

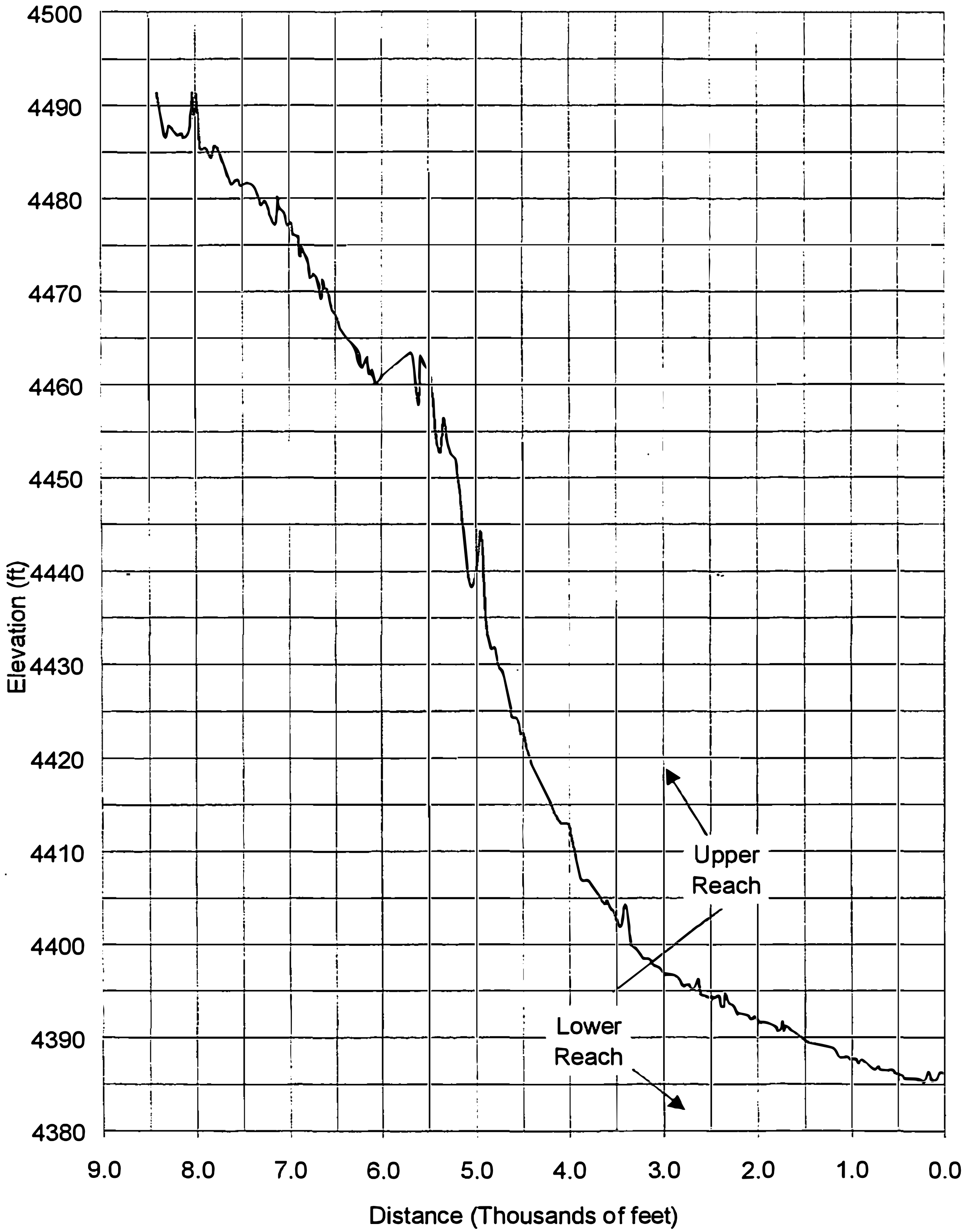


Figure 17. Profile of thalweg in Game Range Reach.

Figure 18 shows a combination "moving" average of the slope in the Game Range Reach. Each point on the graph indicates a 3-point, central point moving average. The line on the graph is a 5-point moving average trend line. On average, the steepest slope occurs in the reach around station 50+00 and averages greater than five percent. In the lower reach the slope averages less than one percent.

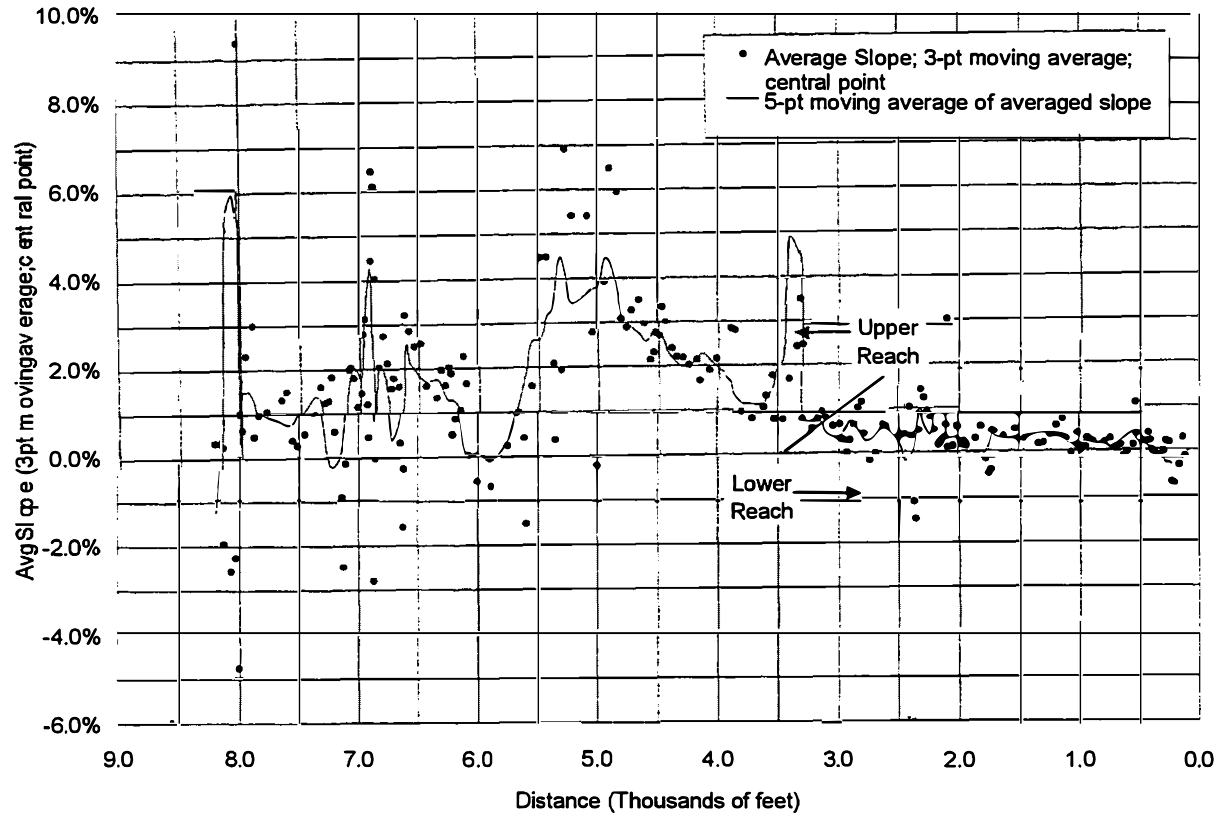


Figure 18. Moving average thalweg slope of the Game Range Reach of the feeder system.

ROCK VOLUME ESTIMATE

The bank inventory specifies types of treatment for bank and headcut stabilization. This section summarizes the types of treatment, and estimates the volume of rock necessary for each treatment. Table 6 tabulates the reference location, photographs, bank (left or right), beginning and ending station, length, priority, type, and volume estimate for each sub-reach of bank treatment. Frequent reference to the maps and figures is necessary to understand and implement the recommendations in Table 6. Stationing begins at the boundary fence at the downstream end of the Game Range Reach and continues upstream. Reference names are arbitrary. Bank references include R-right, L-left, B-both, and X-across. Length is simply the straight-line distance between thalweg stations. Priority increases as potential sediment production in a sub-reach versus relative cost to stabilize the sub-reach increases. Type references include LPSTP-Longitudinal peaked stone toe protection, Barbs, Paired Barbs, and HSS-Headcut Stabilization Structure. The last column sub-totals volume, in tons, according to priority. First priority volume is 2,575 tons. First and second priority volume is 3,412 tons. First, second, and third priority volume is 4,165 tons. With a 15% contingency, the tonnage's are respectively, 3,000 tons, 3,900 tons, and 4,800 tons. The estimate includes 102 barbs, 8 headcut stabilization structures, and 4,665 lineal feet of longitudinal peaked stone toe protection at 0.68 tons per foot. Table 7 contains calculations of barb volumes.

Estimates use the US Army Corps of Engineers Bendway Weir Design Guidance (USACE, 1995) criteria. Bend diameter is an estimate by the CAD operator. In the cases where the spacing/length ratio is less than 1.5, it is probably more economical to use longitudinal peaked stone toe protection over barbs. The table indicates the consideration of that option. This estimate counts the maximum number and volume of rock for the barbs. The judgement of the construction engineer will determine the exact number during construction.

Table 6. Summary of bank inventory data and information.
LPSTP – Longitudinal Peaked Stone Toe Protection
HSS – Headcut Stabilization Structure

Reference	Photo(s)	Bank	Begin Sta.	End Sta.	Length ft	Priority	Type	No.	Volume (Tons)
Loop #2	0570-07	R	9+90	10+75	85	1	LPSTP		58
Loop #4	0570-26, 27, 28	L	19+70	21+20	150	1	Barbs	12	53
Loop #5	0898-03; 0570-30	R	22+50	24+50	200	1	Barbs	17	75
Loop #6	0570-31, 32	L	25+60	27+70	210	1	Barbs	15	66
Loop #7	0898-04	R	29+00	30+20	120	1	Barbs	11	48
Loop #8	0570-33, 34, 35, 36	L	31+20	32+00	80	1	LPSTP		54
Bend #0	0570-39,40	R	33+50	35+50	200	1	Barbs	4	30
Bend #1	0570-38, 39, 43	L	35+00	36+20	120	1	LPSTP		82
Bend #2	0570-42, 44	R	35+50	38+00	250	1	LPSTP		170
Bend #3	0570-44, 45	L	38+40	40+00	160	1	LPSTP		109
Bend #4	0898-06, 07; 0570-46, 47	R	38+90	41+50	260	1	LPSTP		177
Bend #5	0898-09	R	42+50	43+50	100	1	LPSTP		68
Bend #5	0570-48; 0898-12	L	43+00	47+00	400	1	LPSTP		272
Bend #6	0898-12	R	44+50	45+00	50	1	LPSTP		34
Bend #6	0570-49, 50, 52, 53	L	47+00	50+50	350	1	LPSTP		238
Reach #4	0570-53, 54, 55, 56, 57, 58	R	49+00	50+50	150	1	LPSTP		102
Kayak (US)	0898-20,21,22	X	52+10			1	HSS		50
Bend #13 (DS)	0898-25,27,28	X	56+00			1	HSS		50
Bend #15	0898-32,33	R	61+10	62+20	110	1	LPSTP		75
Bend #15	0570-74, 75	L	61+50	62+00	50	1	LPSTP		34
Reach #6 & Bend #16	0898-34,35,51,52	L	62+20	66+30	410	1	Paired Barbs	9	72
Reach #6 & Bend #16	0898-34,35,51,52	R	62+20	66+30	410	1	Paired Barbs	9	72
Bend #18	0898-53, 54, 55, 57	R	66+30	68+00	170	1	LPSTP		116
Bend #18 (DS)	0898-53	X	66+30			1	HSS		50
Bend #21	0898-56,58	R	69+40	72+00	260	1	LPSTP		177
Reach #7	0898-60	L	73+00	73+80	80	1	LPSTP		54
Bend #22	0898-62	R	77+00	78+00	100	1	LPSTP		68
Bend #23	0898-63,66	L	79+20	80+00	80	1	LPSTP		54
Bend #23	0898-63,64, 66	R	80+20	81+20	100	1	LPSTP		68
Bend #26	0898-69,70,71	B	84+00	85+00	100	1	LPSTP repairs		0
				Subtotal	2955		Subtotal	77	2575
Loop #1	0898-01	R	3+00	4+00	100	2	LPSTP		68
Loop #1	0570-8, 9, 10, 11, 12, 13	L	5+40	8+00	260	2	Barbs	16	70
Loop #3	0898-02; 0570-02	R	17+30	18+00	70	2	Barbs	9	39
Loop #6	0570-31, 32	X	27+70			2	HSS		50
Loop #8	0570-33, 34, 35, 36	X	31+00			2	HSS		50
Loop #8	0570-33, 34, 35, 36	L	32+00	34+00	200	2	LPSTP		136
Bend #13 & #14	0898-25,27,28,29,30,31	R	56+00	61+10	510	2	LPSTP		347
Bend #14	0570-65	L	56+80	57+20	40	2	LPSTP		27
Bend #23 (DS)	0898-63	X	80+00			2	HSS		50
				Subtotal	850		Subtotal	25	838
Bottom Reach	0570-17, 18, 19, 20, 21, 22	L	0+0	2+00	200	3	LPSTP		136
Bend #0	0570-37, 39, 40	L	34+00	35+00	100	3	LPSTP		68
Bend #4	0570-46	L	41+00	42+00	100	3	LPSTP		68
Bend #5	0898-08	R	41+50	42+50	100	3	LPSTP		68
Kayak (DS)	0570-55	X	50+90			3	HSS		50
Bend #13	0570-64	L	54+00	56+00	200	3	LPSTP		136
Bend #20 (DS)	0898-55	X	68+75			3	HSS		50
Bend #22	0898-61	R	74+40	77+00	260	3	LPSTP		177
				Subtotal	960		Subtotal	0	753
				Total	4765		Total	102	4165

Table 7. Barb and optional longitudinal peaked stone toe protection volume estimates.

Reference	Bend Diameter	Channel Width	Barb Length	Barb Spacing	Spacing/ Length	Maximum Spacing	Bend Length	Number of Barbs	Minimum Number	Barb Height	Barb Volume	Maximum Volume	Minimum Volume	LPSTP Volume
Loop #1	160	30	7.50	16.3	2.2	33.8	260	16	8	3.75	4.4	70	35	176.8
Loop #2	56	30	7.50	7.0	0.9	19.1	85	13	5	3.75	4.4	57	22	57.8
Loop #3	65	30	7.50	7.9	1.1	20.8	70	9	4	3.75	4.4	39	18	47.6
Loop #4	124	30	7.50	13.3	1.6	29.6	150	12	6	3.75	4.4	53	26	102
Loop #5	113	30	7.50	12.3	1.6	28.1	200	17	8	3.75	4.4	75	35	136
Loop #6	141	30	7.50	14.7	2.0	31.6	210	15	7	3.75	4.4	66	31	142.8
Loop #7	100	30	7.50	11.2	1.5	26.3	120	11	5	3.75	4.4	48	22	81.6
Loop #8	72	30	7.50	8.6	1.1	22.0	80	10	4	3.75	4.4	44	18	54.4
Bend #0	200	30	15.00	47.9	3.2	52.7	150	4	3	3.75	7.5	30	23	102
								103	47		Yards	482	229	160
											Tons	651	309	216
										With Optional LPSTP				
										Barbs	Yards	342	172	
											Tons	461	232	
										LPSTP	Yards	160	160	
											Tons	216	216	
										Total	Yards	501	332	
											Tons	677	448	

Barb Slope	S_b	2.0
Flank Slope	S	1.5
Key Depth (ft)	K_d	1.0
Key Length (ft)	K_L	1.0
Channel Width		30.0
Length as a Proportion of Width		4.0
Optional LPSTP		
LPSTP	ton/ft	0.68

AVAILABLE ROCK VOLUME

There is an existing stockpile, Stockpile Site #1, of minus-36 inch angular rock, acceptable for longitudinal peaked stone toe protection, barbs, and headcut stabilization at the upper end of the Game Range Reach. Figure 19 shows the stockpile. The surface area of the stockpile, measured by GPS, is roughly 10,400 ft^2. The height of the stockpile is roughly 3.5 feet. The estimated volume of the stockpile is 1,350 cubic yards or roughly 1,800 tons. The LPSTP, barbs, and headcut stabilization structures require roughly the same size and gradation of rock. The maximum, or D_{100}, size is 42 inches. The median, or D_{50}, size is 30 inches. The practical minimum size, or D_{10}, is two inches. This gradation is well-graded yet massive, and is similar to rock designs on Muddy Creek, Montana, Blue River, Colorado, Sun River, Montana, Hilton Creek, California, and others.

Figure 19. Rock stockpile at upper end of Game Range Reach.

Supplemental rock is available from the Willow Creek Dam site. That rock is smaller and rounder than that in stockpile #1. Mixing the rock from stockpile #1 and Willow Creek Dam site makes a larger volume available without resorting to purchasing large quantities of additional rock. Mixing at 1:1 results in a well-graded rock material and a total volume of roughly 2,700 cubic yards or 3,600 tons. A second stockpile, Stockpile Site #2, will be established at the downstream end of the Game Range Reach to service construction sites below the "Kayak" location.

CONSTRUCTION PLAN

This construction plan describes the basic steps required to implement the bank stabilization recommendations shown in Table 6. All steps are subject to revision and input from Greenfields Irrigation District, Montana Fish, Wildlife & Parks, Reclamation, reviewers, and the contractor.

The construction plan describes work on the Sun River Game Range managed by Montana Fish, Wildlife & Parks (MFW&P). Rock may be available at the Willow Creek dam site as part of on-going construction on that Reclamation owned and managed land.

1. Construct one NEW road (bladed in)
   – New road installed along fence at downstream end of game range reach (Route on advice of MFW&P)
   – Use existing entrances along road on south and middle of game range (With permission)
   – Roads are bladed from main road to rock stockpiles, and 2-tracked path from rock to work sites

2. Establish one new stock rock pile
   – Site 1 is the existing site at the upstream end of the game range reach (See Figure 19)
   – Locate the new site, Site 2, on the saline seep flats located on bottom of coulee at south end of game range reach (See Photograph 0570-20)
   – If mixing rock from Site 1 and Willow Creek dam site, transport rock from Site 1 to Site 2 and mix there. Transport mixed rock from Site 2 directly to work sites, not back to Site 1.
   – Trucks delivering rock to excavator would parallel gorge or travel in the gorge
   – Reclaim and revegetate all rock stockpile areas

3. Construct ramps from the bottom of gorge to the top of bank for construction access in two to four locations. Blade the ramps from the top of the bank with bulldozer or excavator
   – Re-contour and revegetate following construction

4. Transport rock to individual sites and construct longitudinal peaked stone toe protection, barbs, and headcut stabilization structures.

5. Reclaim available rock from channel bottom.

6. Avoid disturbing all vegetation along channel banks by traversing the channel bottom only.

7. The best tactic is to use rubber-wheeled trucks or loaders on the top bank to deliver rock to a tracked excavator(s) in the channel by dumping over the bank into the channel.

ACCESS

From a construction access point-of-view, there are three areas within the Game Range Reach, an upper area, a lower area, and a middle area. In the lower area, serviced from the south end of the Game Range

Reach, the terrain is relatively flat, with good access on both banks and in the channel. In the upper area, serviced from the north end of the Game Range Reach, the terrain is rolling and becomes increasingly steep as you go downstream. However, access is good along the rim of the left bank. In the middle reach access is poor, with service difficult from either the upstream or downstream directions.

UPPER REACH

Photograph 0898-49 pictures the view looking downstream along the Game Range Reach. The road pictured in the right side of the photograph originates at the county road along the north end of the Game Range Reach of the feeder system. Construction access on this road along the left bank is good from Station 85+00 downstream to roughly Station 69+00. Rubber wheeled and tracked vehicles could use this existing road to dump rock over the bank to the construction sites. The terrain becomes too steep below roughly 69+00 (maybe as low as 65+00) to safely traverse loaded trucks. The road is partially graded, and near 69+00 reduces to two wheel tracks.

Photograph 0898-49. Panoramic view looking downstream from knoll.

LOWER REACH

Photograph 0898-75 shows gate at lower end of Game Range Reach for access to lower portions of construction area. It is roughly 0.75 miles from this gate to the USGS Benchmark at Station 31+50. There is no existing roads or tracks past the entrance. We traversed this path in January of 2000 during the field collection of data. The first part is relatively flat, if not smooth, followed by a rather steep drop into the canal valley along the log fence at the downstream boundary of the Game Range Reach. Some grading work would be necessary to establish the construction road. Access along both banks is good from Station 0+00 to roughly Station 54+00. The left bank is preferred, and a temporary crossing would be necessary to access the right bank. This access route would also service rock stockpile Site #2.

AREA AROUND "KAYAK"

Photograph 0898-24, taken at roughly Station 54+60, shows the middle area, around the "Kayak" feature. From roughly Station 54+00 to 69+00, 1,500 feet, access will be very difficult from both the top-of-bank and within the channel. Rubber wheeled vehicles will not be able to traverse the left bank because the terrain is too steep. Tracked vehicles can traverse the channel up-to or down-to the "Kayak" location.

However, transporting the required volumes of rock material will be difficult. We advise receiving construction advice from the Greenfields Irrigation District or another contractor, in coordination with Montana Fish, Wildlife & Parks on access in the middle area of the Game Range Reach.

Photograph 0898-75. Lower entrance into game range.

Photograph 0898-24 (54+60). Both banks looking US at Bend #12 and Straight Reach #5. Note view upstream showing potential access along left bank for construction equipment. Low probability that those vehicles could traverse upper left bank. Access in channel adequate for tracked vehicles only.

Figure 20 shows the existing and proposed access routes to the Game Range Reach. The reach extends from "B" to "C." Stockpiles are at "S1" and "S2." Existing two-wheel track extends from "B" to "E." Proposed new two-wheeled track extends from "F" along the boundary along the downstream end of the

Game Range Reach to the county road. Area between "E" and "F" slopes towards the canal, making it very difficult to traverse without extensive grading. There may be other preferable routes that can be determined in cooperation with Greenfields Irrigation District and Montana Fish, Wildlife, and Parks.

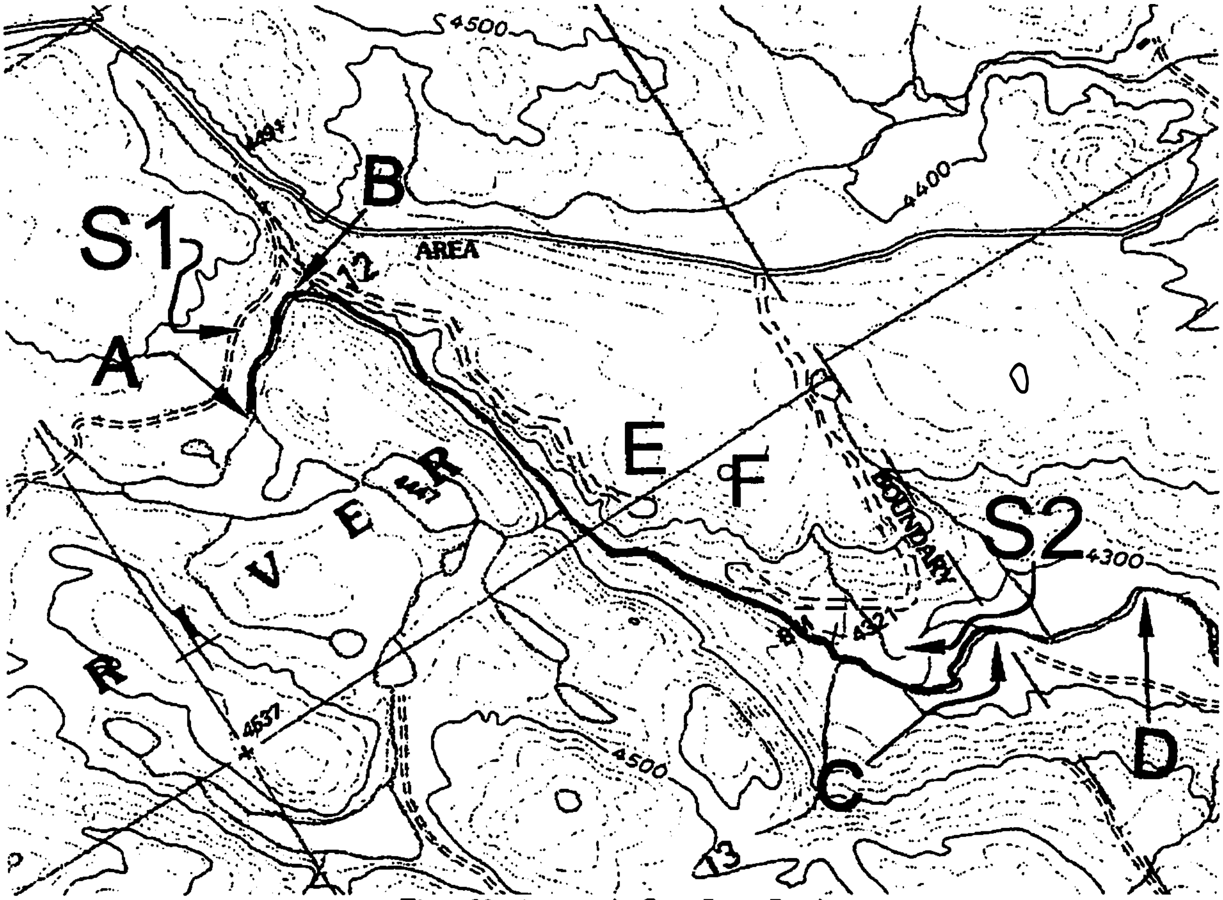


Figure 20. Access to the Game Range Reach.

Photograph 0898-49 shows a view facing downstream from roughly the location of the "S1" label on Figure 20. Photograph 0898-75 shows the gate along the county road at the downstream boundary of the Game Range Reach, just above the "F" label on Figure 20.

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FIGURES & PLATES

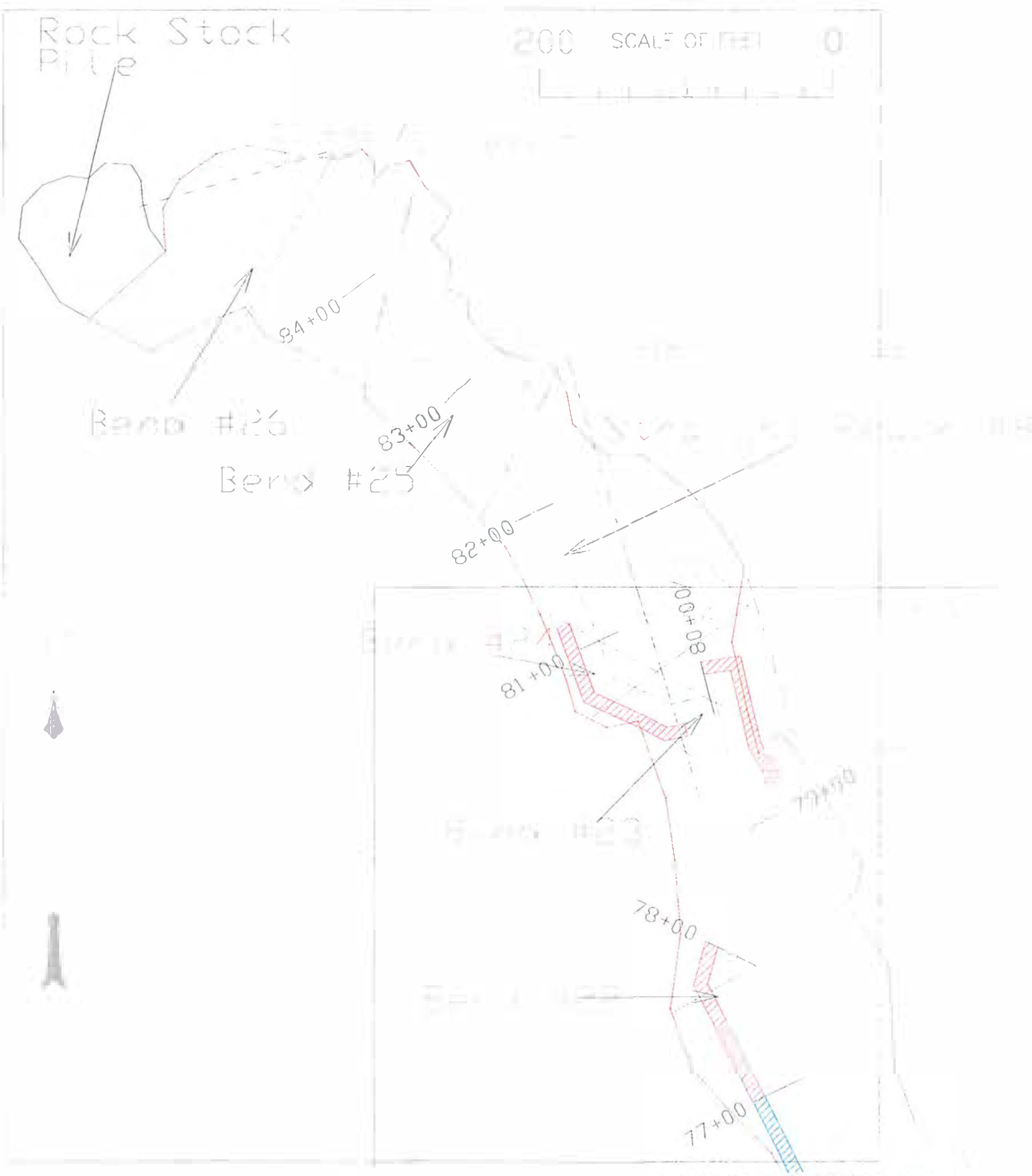


Figure 21. Station 76+50 to 85+00. Features Bends 22-26, rock stockpile #1, and LPSTP treatment.

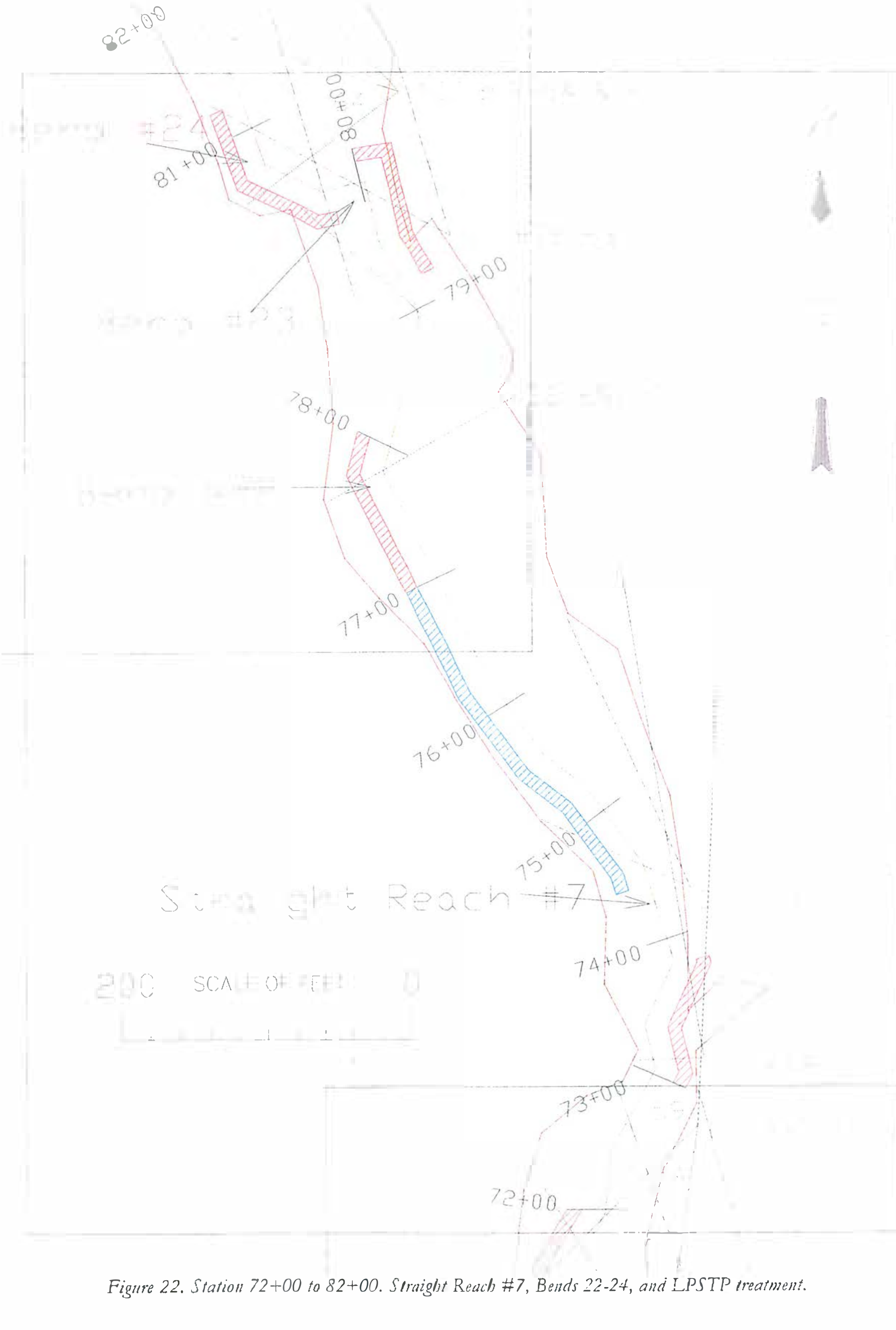


Figure 22. Station 72+00 to 82+00. Straight Reach #7, Bends 22-24, and LPSTP treatment.

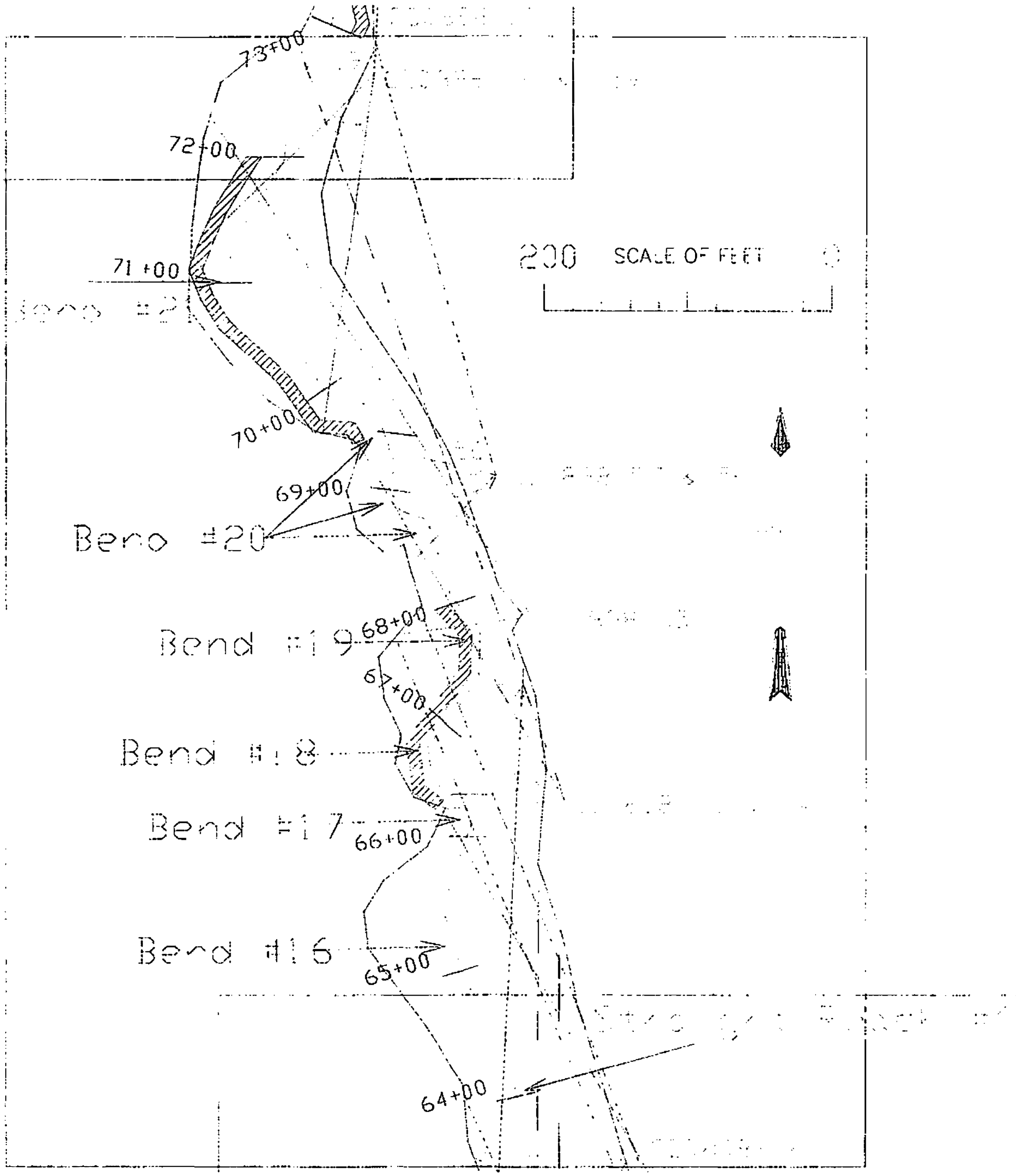


Figure 23. Station 64+00 to 73+00. Features Straight Reach #6, Bends 16-21.

Figure 24. Station 56+50 to 64+50. Features Bends 14 & 15, Straight Reaches 5 & 6, and LPSTP treatment.

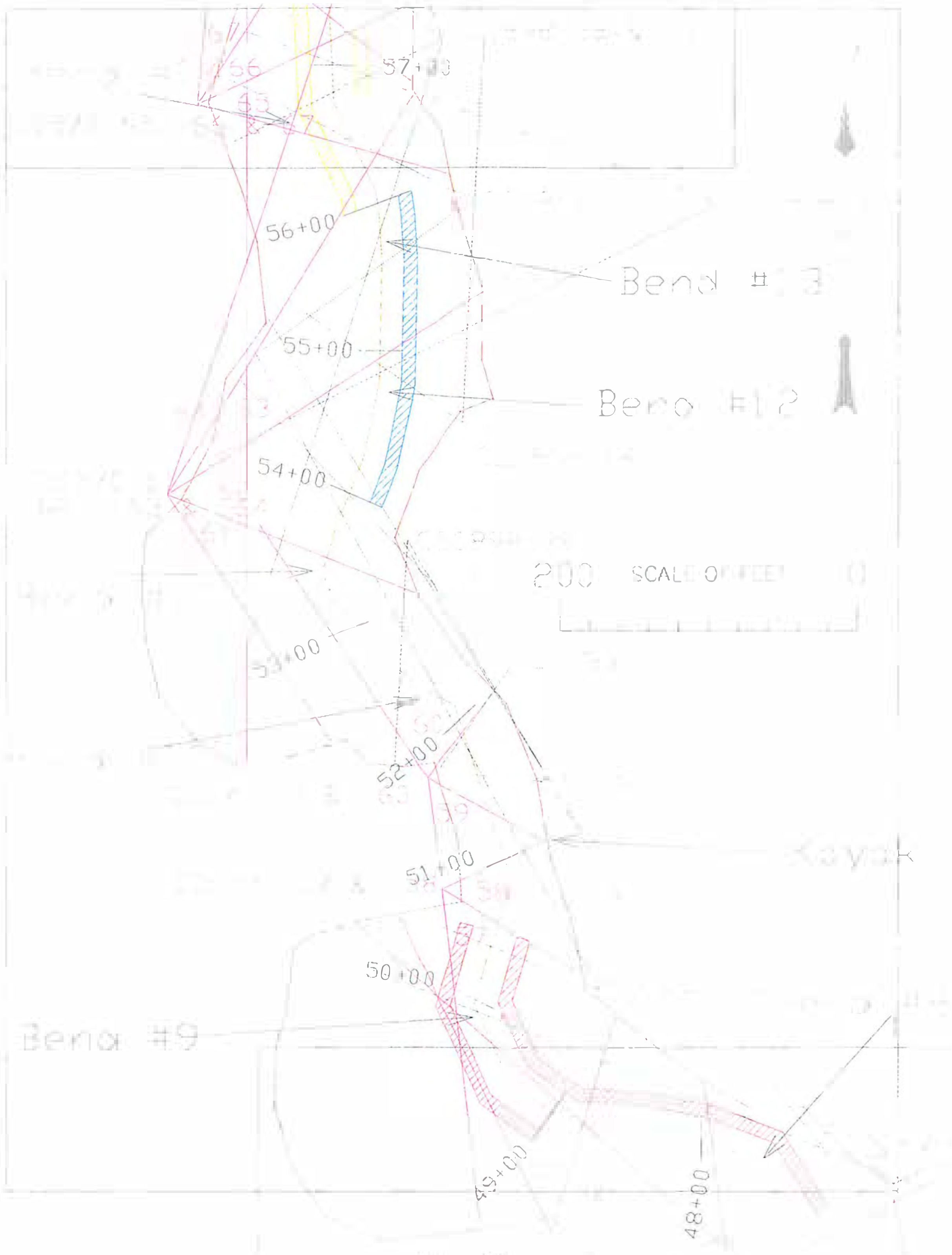


Figure 25. Station 48+00 to 57+00. Features Bends 8-14, Kayak, and LPSTP treatment.

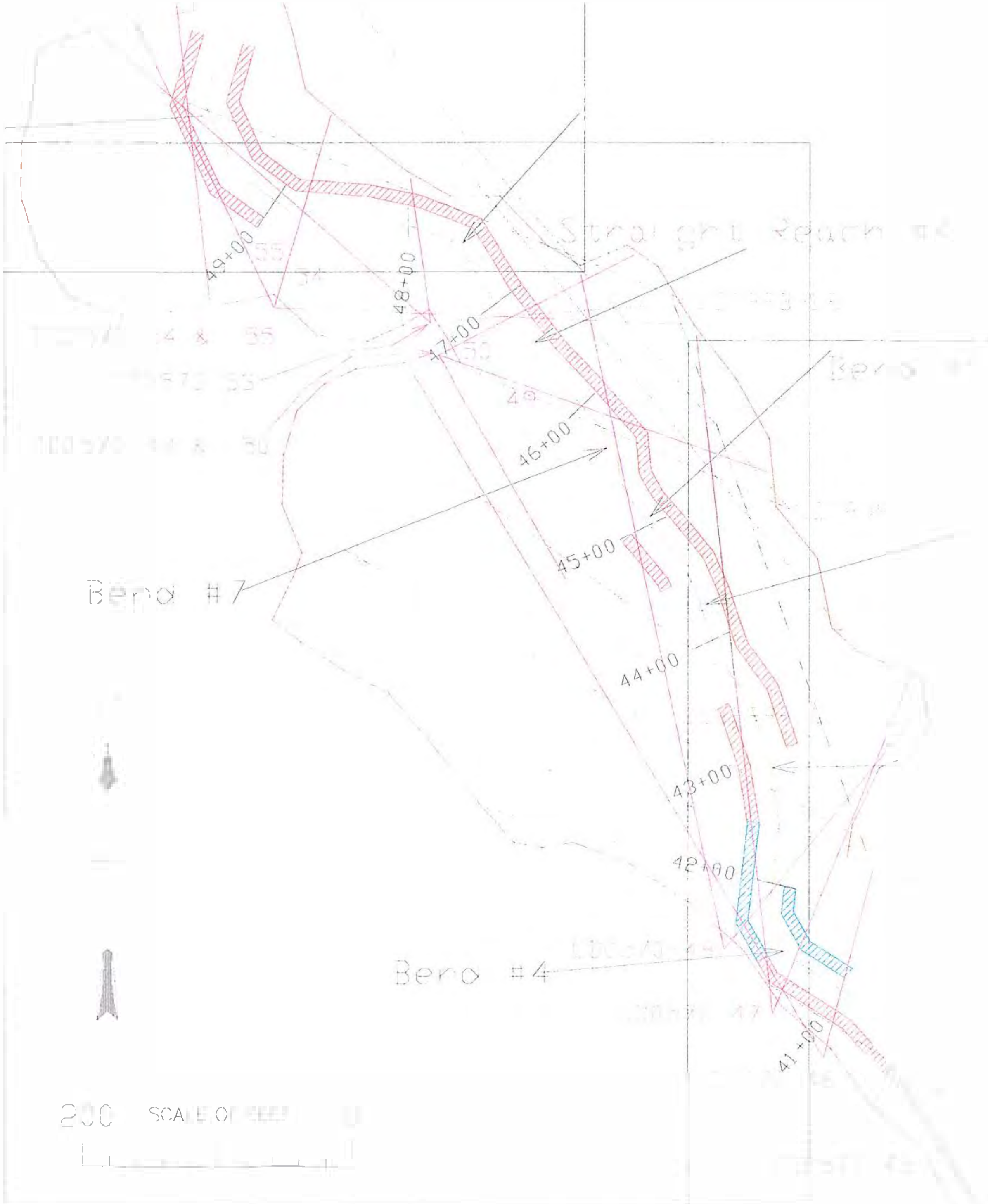


Figure 26. Station 41+00 to 49+00. Features Bends 4-7, Straight Reach 4, and LPSTP treatment.

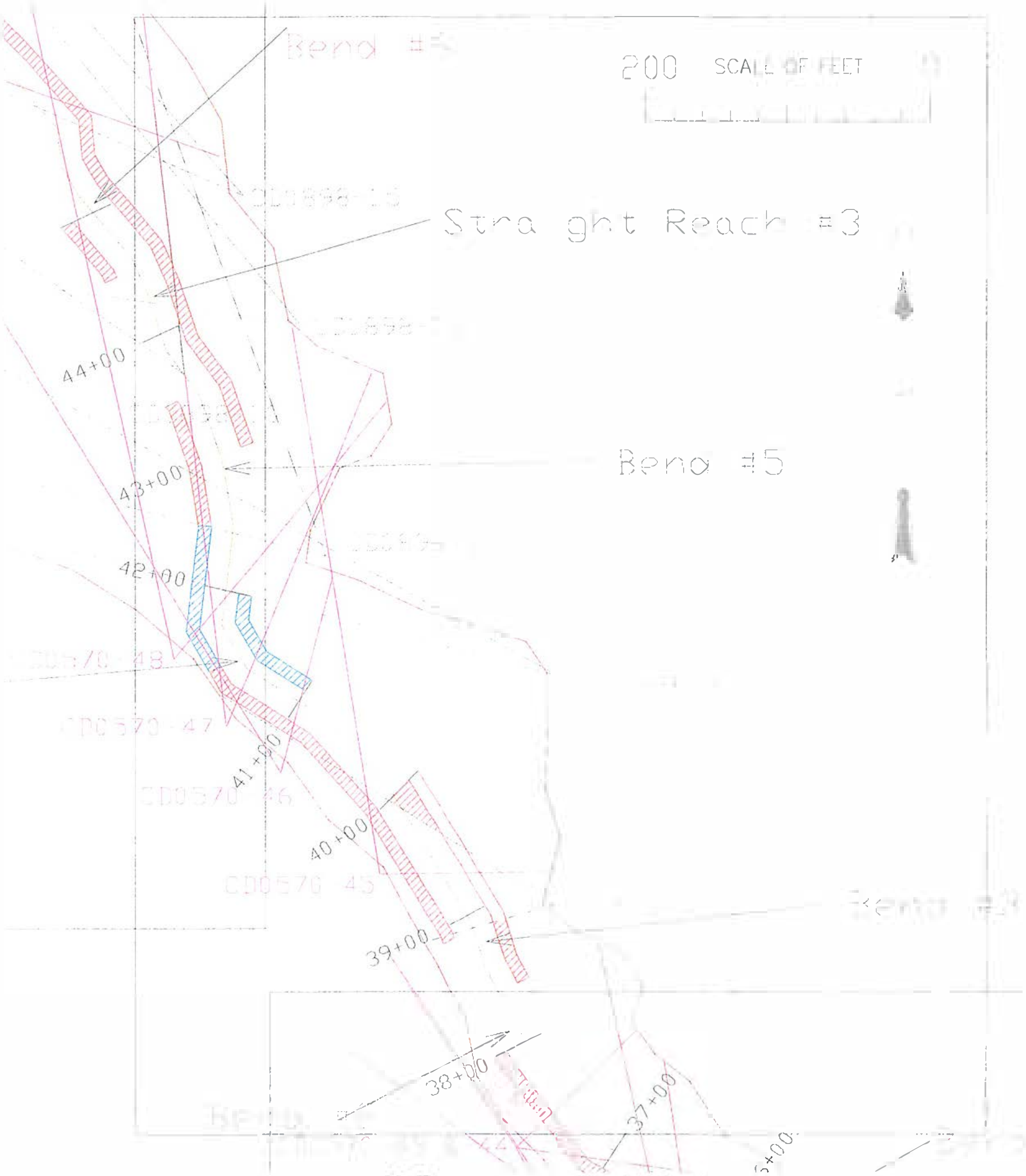


Figure 27. Station 37+00 to 44+00. Features Bends 3-6, Straight Reach #3, and LPSTP treatment.

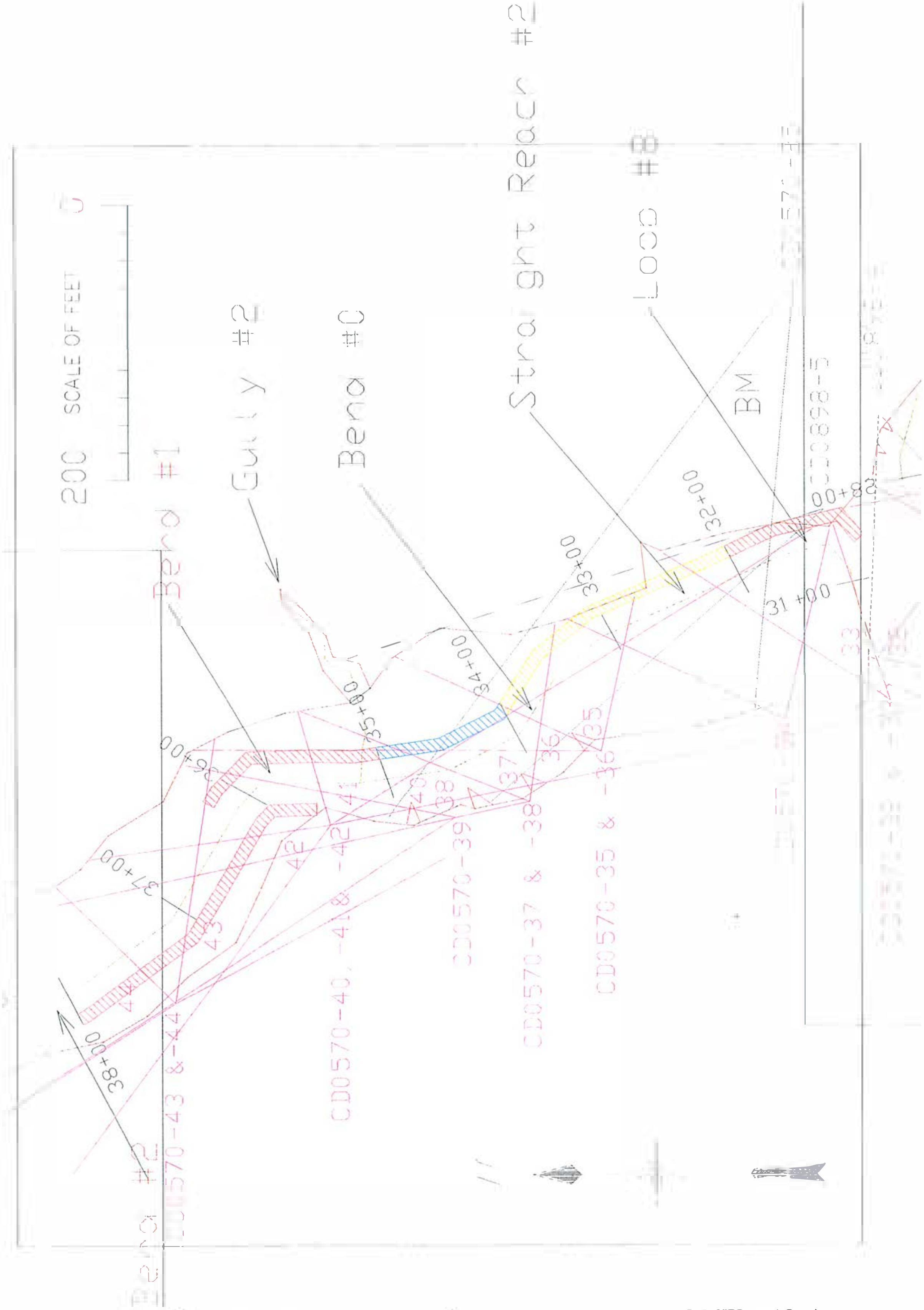


Figure 28. Station 31+00 to 38+00. Features Loops 8-10, Bends 0-1, Gully #2, BM, LPSTP and Barb treatments.

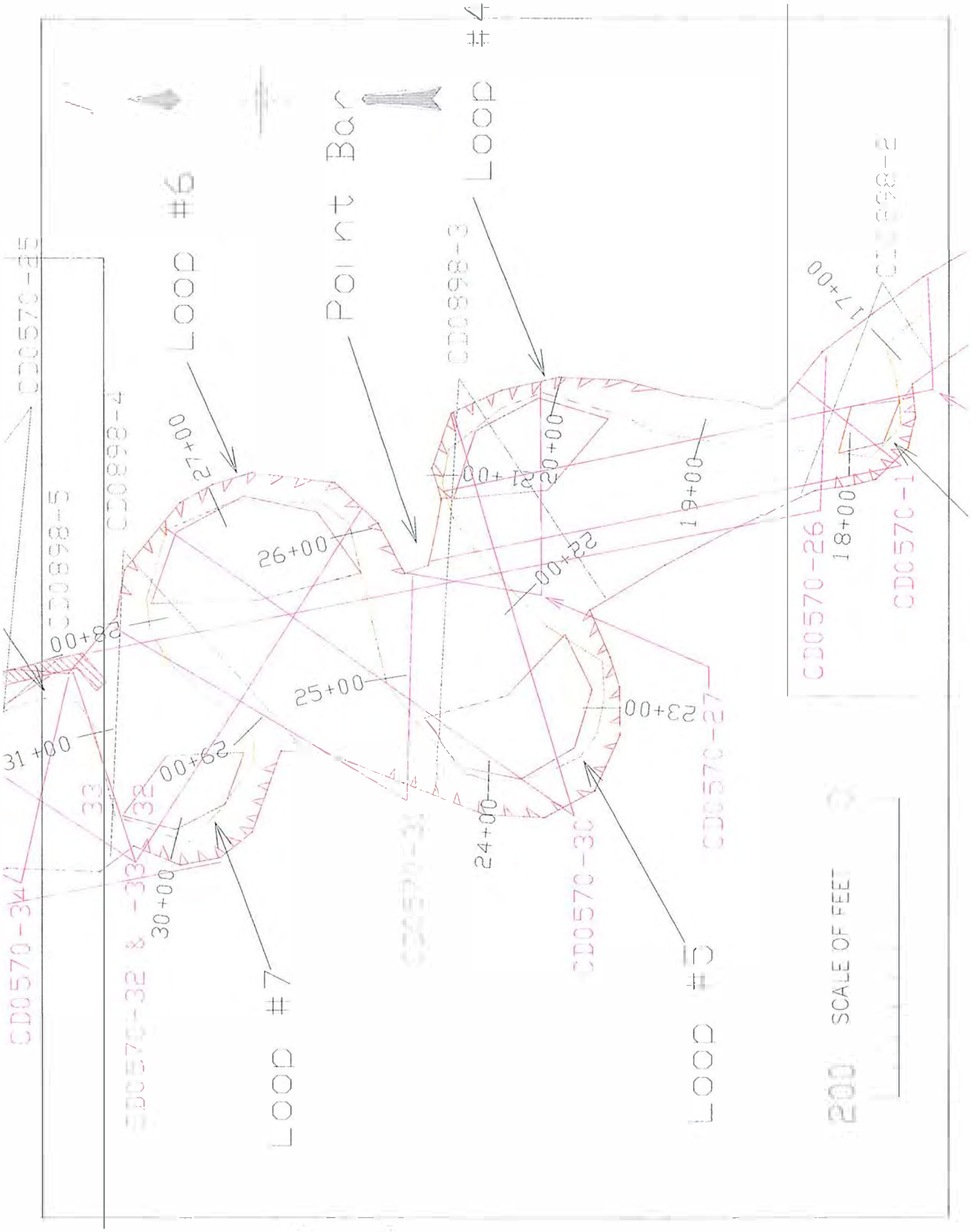


Figure 29. Station 17+00 to 31+00. Features Loops 4-7, LPSTP and Barb treatments.

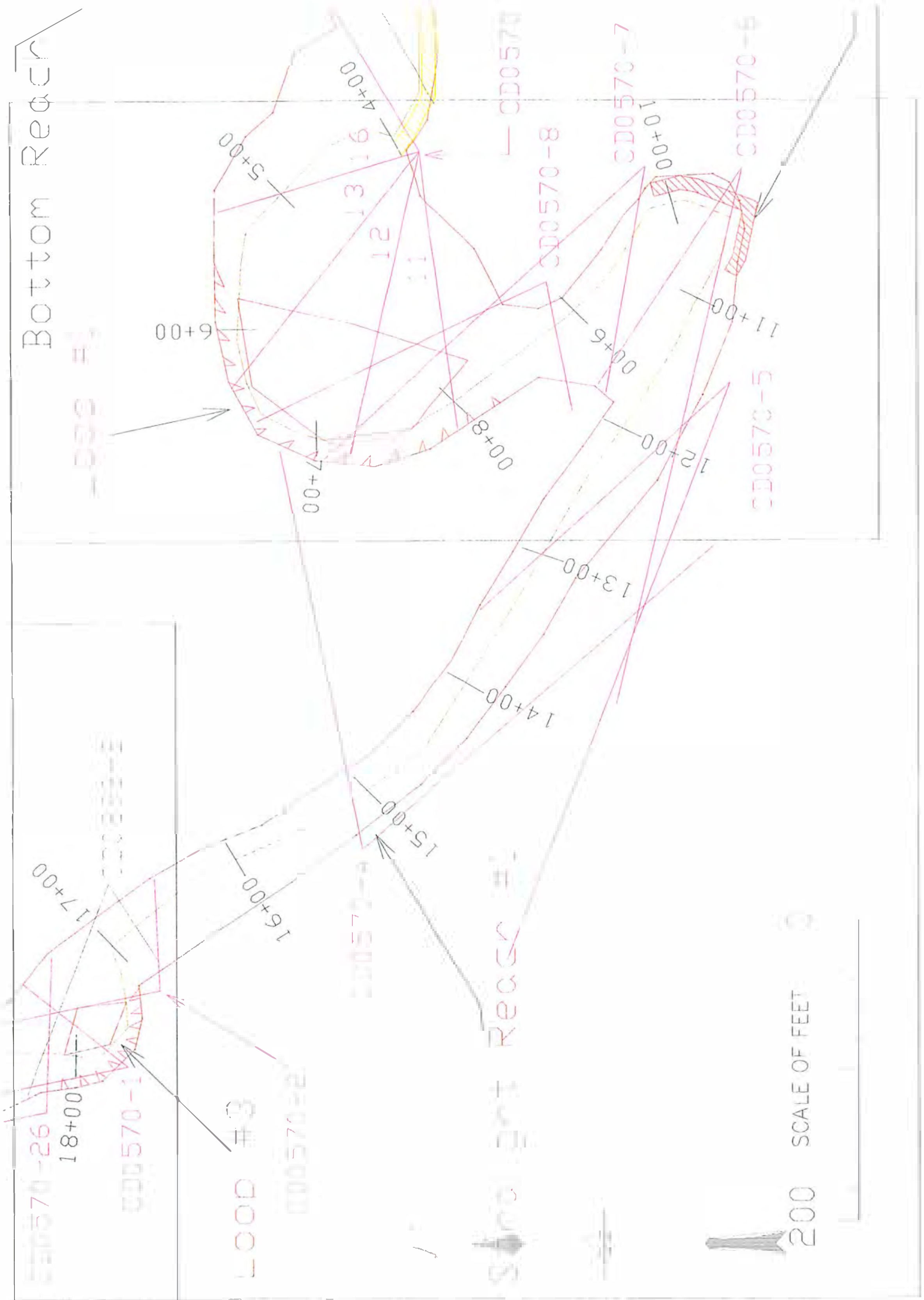


Figure 30. Station 4+00 to 18+00. Features Loops 1-3, Straight Reach #1, LPSTP and Barb treatments.

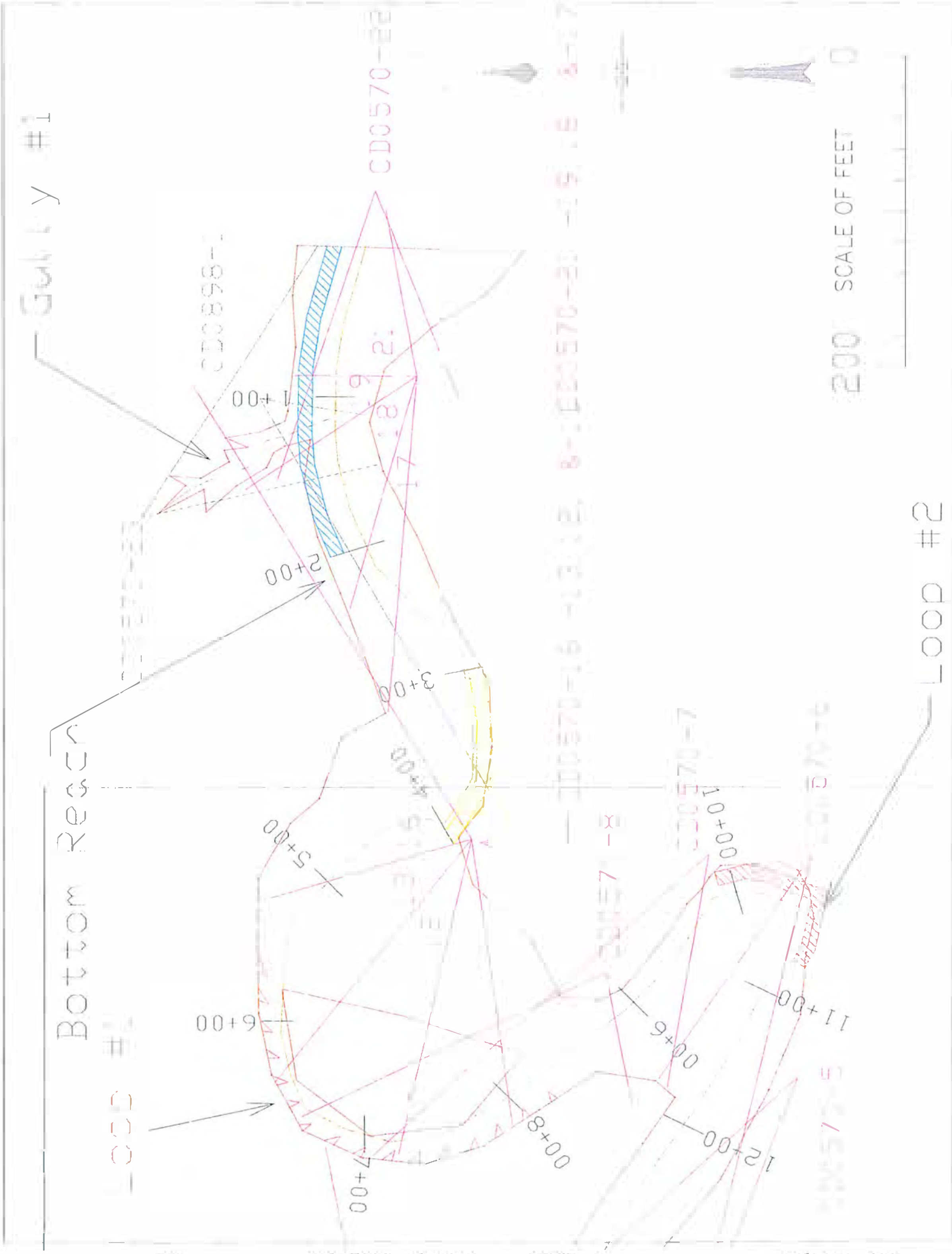


Figure 31. Station 0+00 to 12+00. Features Loops 1 & 2, Gully #1, Fence, LPSTP and Barb treatments.

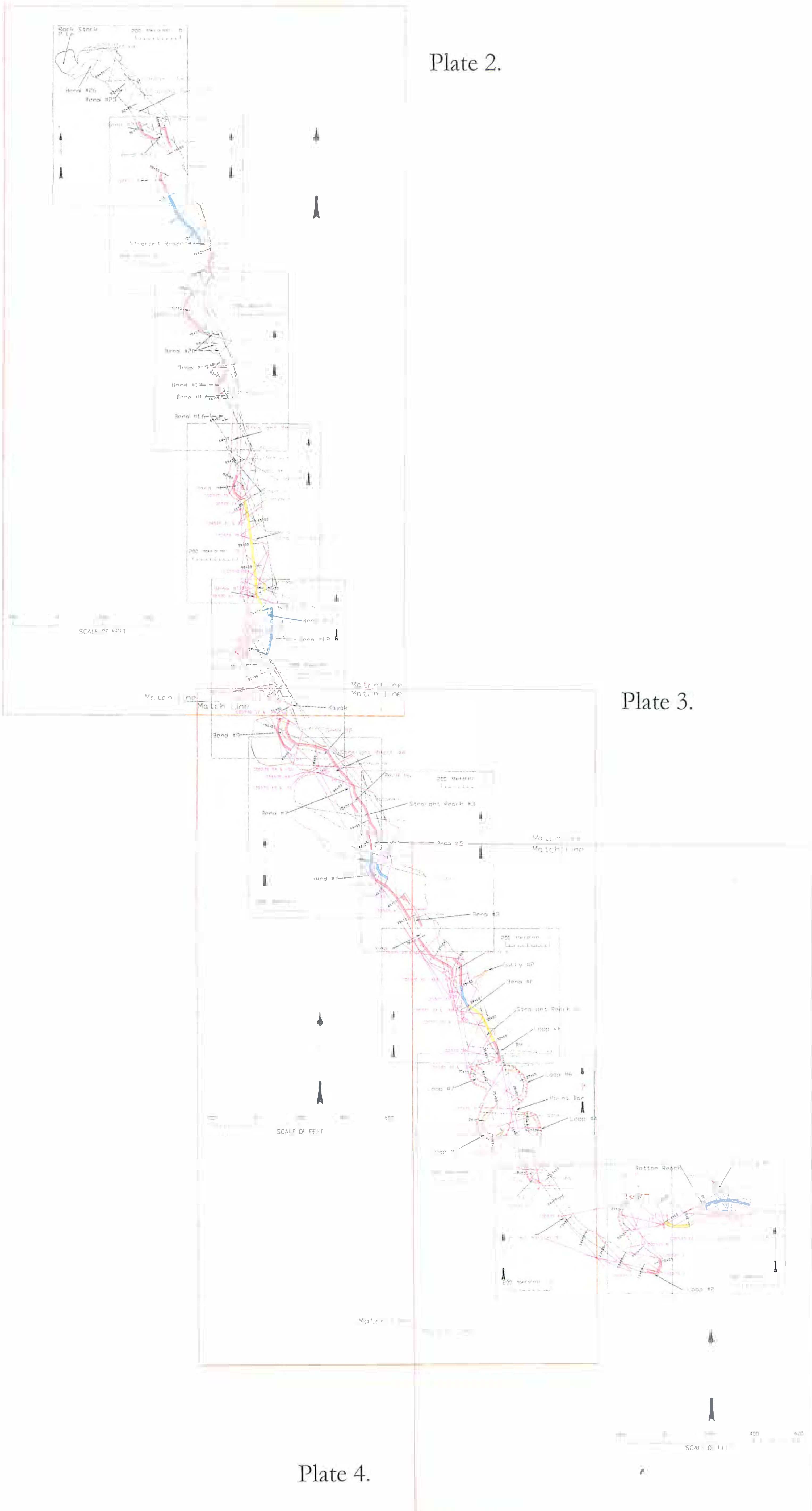


Plate 1. Game Range Reach of Willow Creek Feeder system.

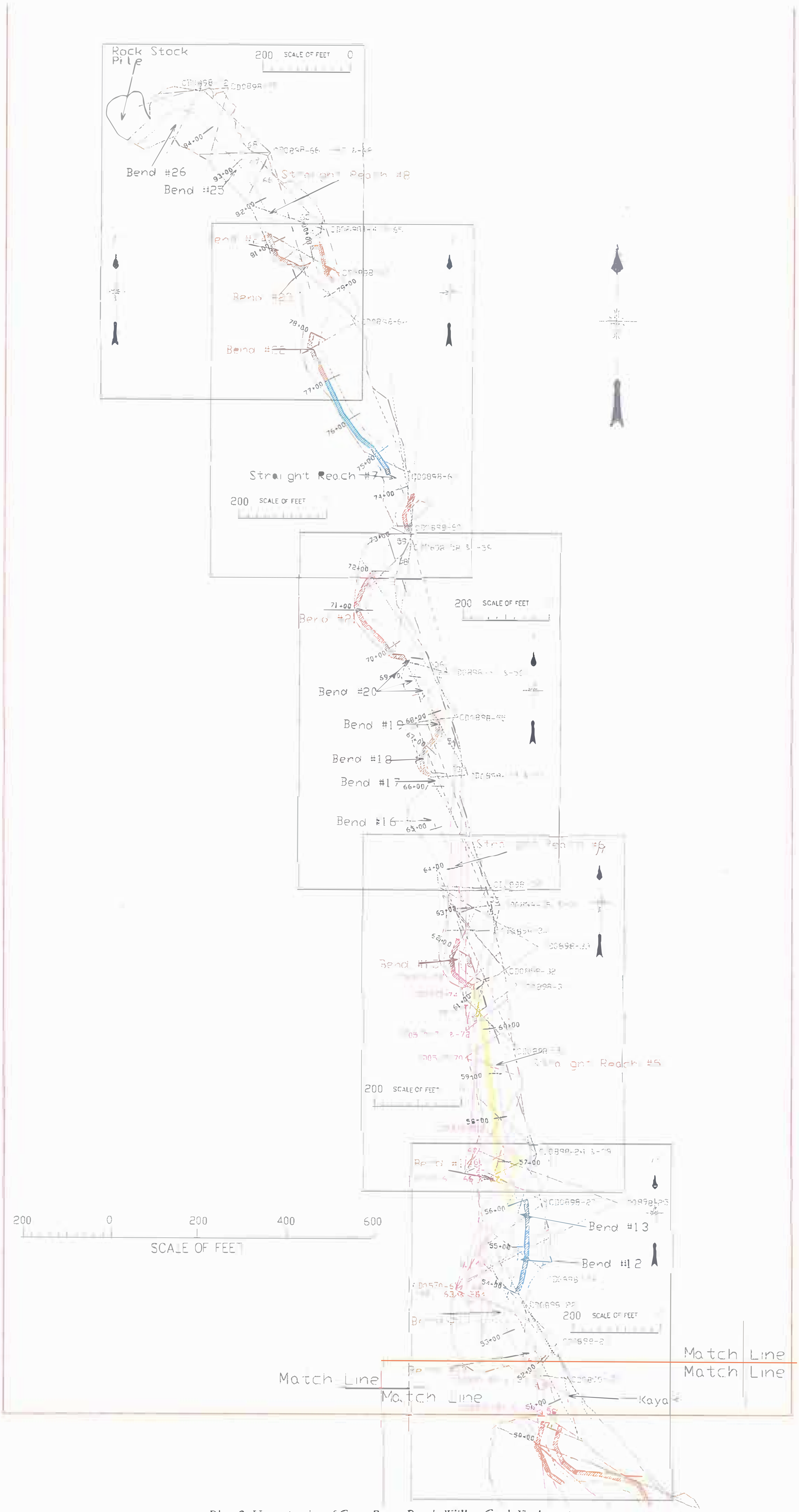


Plate 2. Upper portion of Game Range Reach. Willow Creek Feeder system.

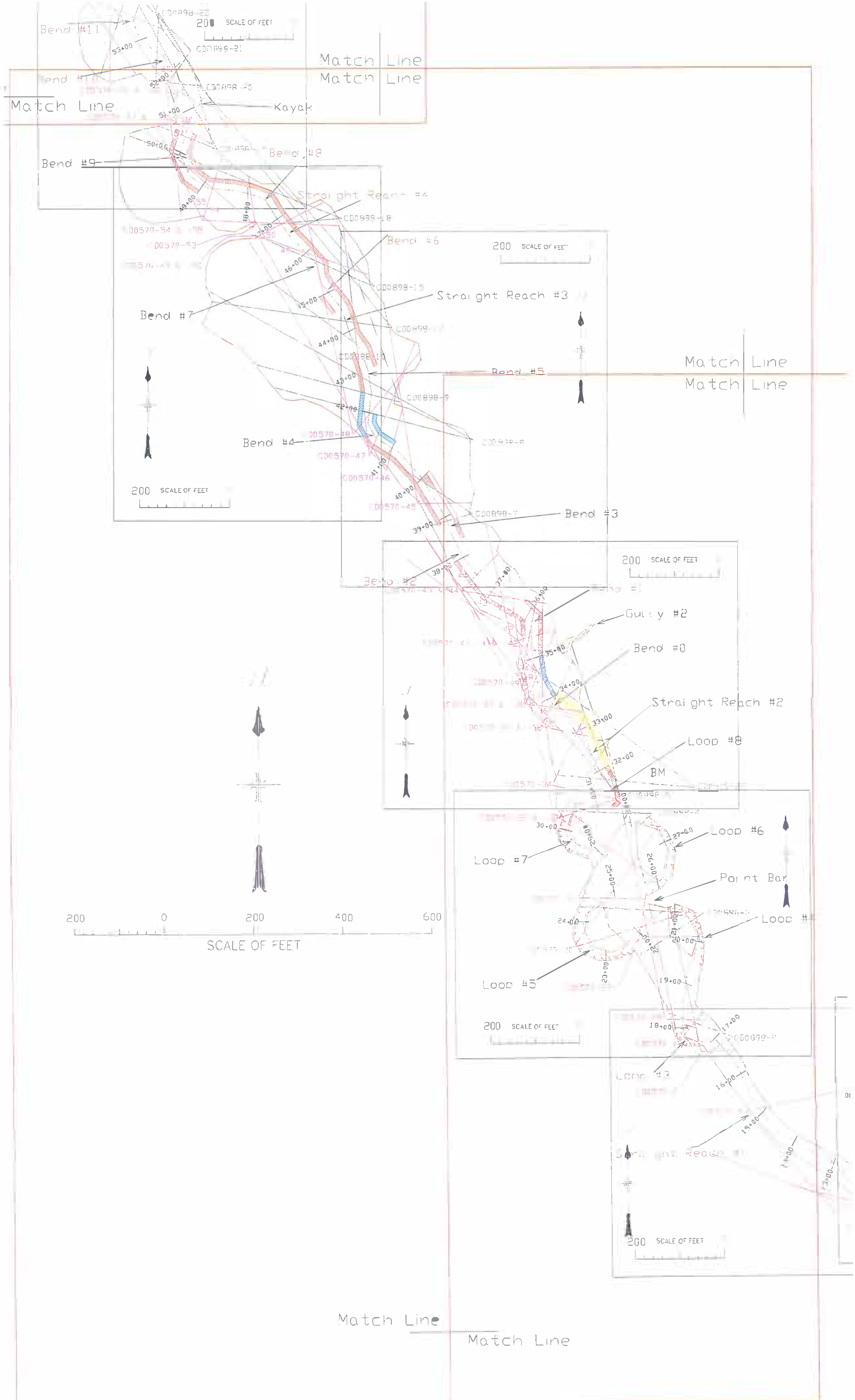


Plate 3. Middle and lower portions of Game Range Reach, Willow Creek Feeder system.

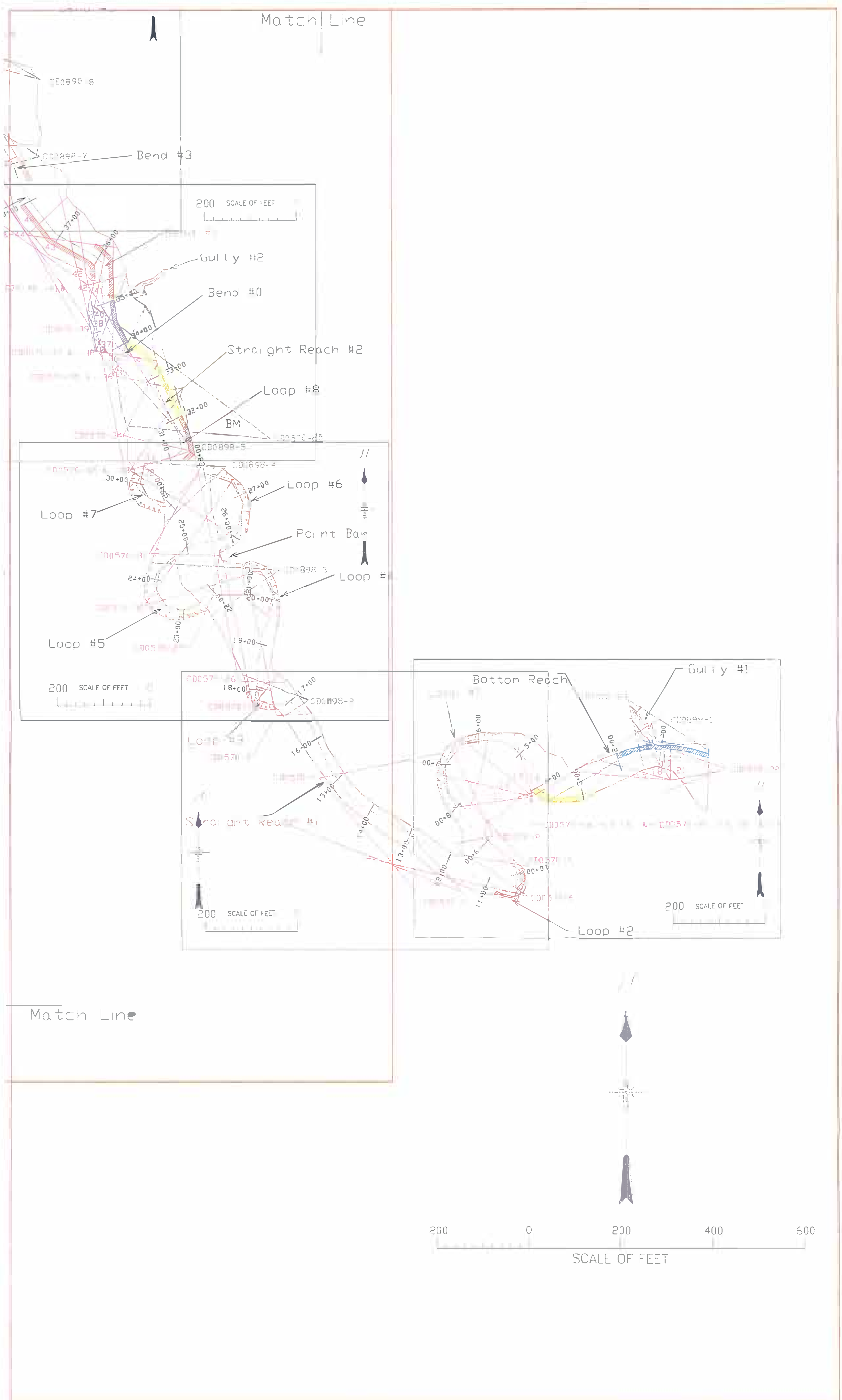
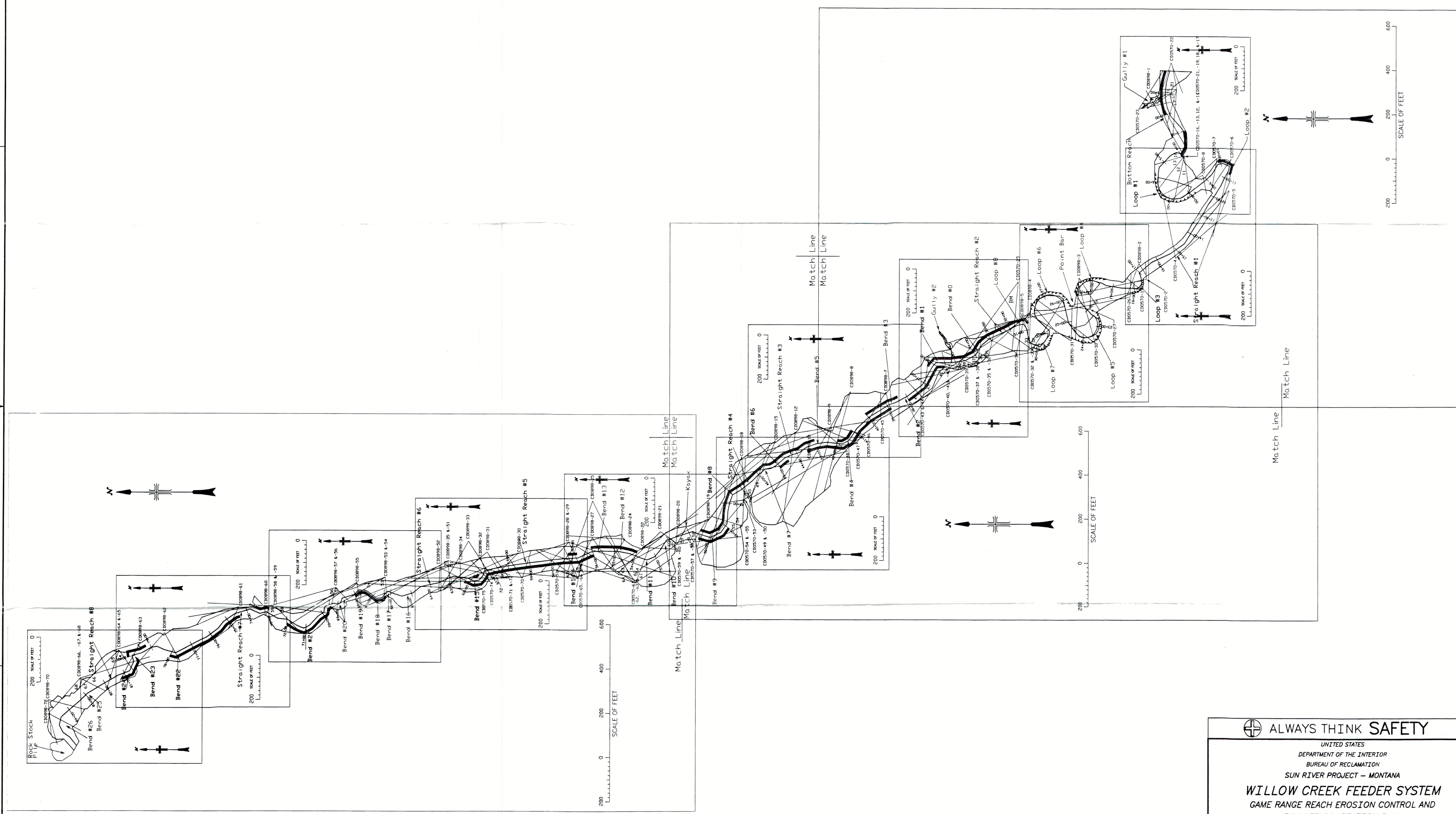


Plate 4 . Lower portion of Game Range Reach, Willow Creek Feeder system.



ALWAYS THINK **SAFETY**

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT – MONTANA

WILLOW CREEK FEEDER SYSTEM

GAME RANGE REACH EROSION CONTROL AND BANK STABILIZATION PLAN

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DRAWN [signature]
CHECKED [signature] APPROVED
HYDRAULIC ENGINEER

CADD SYSTEM	CADD FILENAME	DATE AND TIME PLOTTED
AutoCAD	Unknown	Not Plotted
DENVER, COLORADO	MAY 5, 2000	

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