STREAM RESTORATION DESIGN FOR NORTH FORK, INDIAN CREEK, ELKHORN MOUNTAINS, MONTANA [1]

by

Karen Kennedy[2]

Abstract. The North Fork of Indian Creek, a stream located in the Elkhorn Mountains, approximately 10 miles northwest of Townsend, Montana, has been selected for restoration. The stream, 4.5 miles long, is damaged by severe flood events and fluvially deposited streamside tailings from breached tailings impoundments. The stream is characterized by downcutting, incisement, vertical, unvegetated banks, and dysfunctional riparian areas. Prior to stream restoration, streamside tailings and remnants of the tailings impoundments will be removed to a repository. Subsequent restoration activities have been delineated into two types. The stream reaches through the two impoundments will be completely reconstructed. In total, roughly 550 ft.of new stream will be constructed. These reaches are located near the stream headwaters as well as in high gradient (8-10%) valley areas. Channel and floodplain reconstruction was based upon analysis of basin hydrology, (i.e.; determination of the bankfull discharge) and analysis of channel planform and profile. Meander planform and profile was selected to minimize the work done by the stream.The result was a Rosgen type "B3a" stream. The remainder of the restoration will be the stabilization and re-shaping of streambanks and floodplain areas. The purpose of the bank treatments is to either restore the connection between the stream and the floodplain, or create a new floodplain at the current stream elevation. Bank treatments were designed to provide channel carrying capacity for the bankfull discharge.

Additional Key Words: stream restoration, streamside tailings, hydrology.

Introduction

Indian Creek, a tributary of the Missouri River, is located in the Elkhorn Mountains, approximately 10 miles northwest of Townsend, Montana. The Indian Creek drainage encompasses roughly 13 500 acres, and consists of a main stem, and two forks, the West Fork and North Fork. The main stem is 5 miles long, the West Fork is 2 miles long, and the North Fork is 4.5 miles long, (Figure 1).

Indian Creek was placer mined by conventional and hydraulic methods along the main stem and West Fork in the 1860s and 1870s, and as recently as the 1940s. Lode mining for gold occurred sporadically at the headwaters of the North Fork (Park Mine) from the early 1900's through the 1950's. At the West and North Fork confluence, mining continues today (Pegasus Gold Diamond Hill Mine).

At the Park Mine, waste rock was deposited adjacent to the shaft openings. Analysis of waste rock material reveals high metal content (e.g., 1-2% arsenic). Mill waste (tailings) were collected in at least 2 impoundments constructed as berms across the valley floor, (Figure 2). Analysis of the tailings materials reveals high levels of arsenic, lead, cadmium, and zinc. Concentrations of these metals are such that disposal in a RCRA-approved (Resource Conservation Recovery Act) repository is required.

Flood events in the 1980s breached the impoundments and caused the tailings to be fluvially deposited streamside (Figure 3). Beaver ponds along the North Fork were also filled with tailings and subsequently breached. As the beaver ponds were breached, the stream downcut in response to the sharp change in water elevation (Figure 4). The deposition of these tailings has also impaired the establishment of bank-building vegetation, as well as riparian vegetation. Streamside tailings are visible as far as

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[2] Karen Kennedy is Environmental Engineer for the Bureau of Land Management, Butte District Office, and graduate student in Environmental Engineering, Mine Waste Technology Program, Montana Tech, Butte, MT, 59701.

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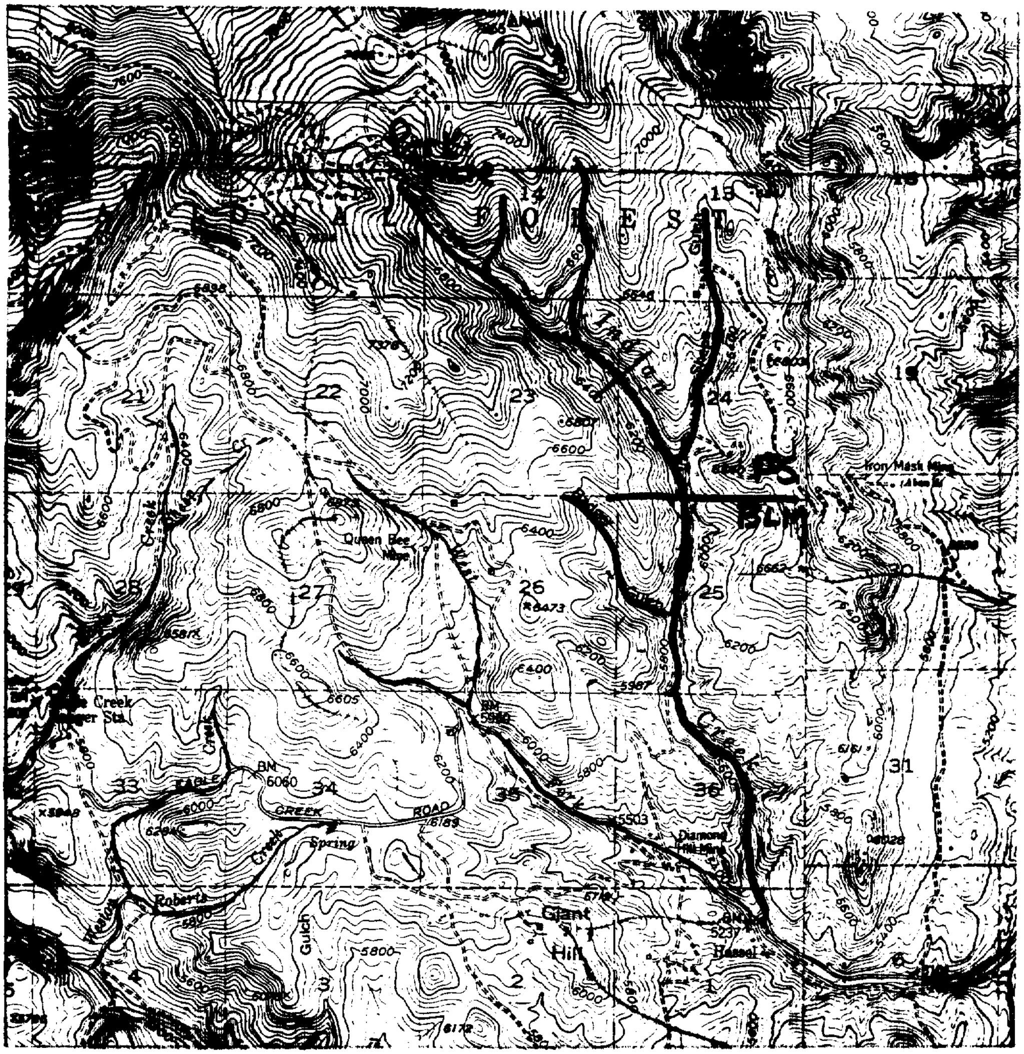


Figure 1. North Fork of Indian Creek. Detail of USGS 7.5"Quad Giant Hill

Figure 2. Breached Tailings Impoundment (TP4)

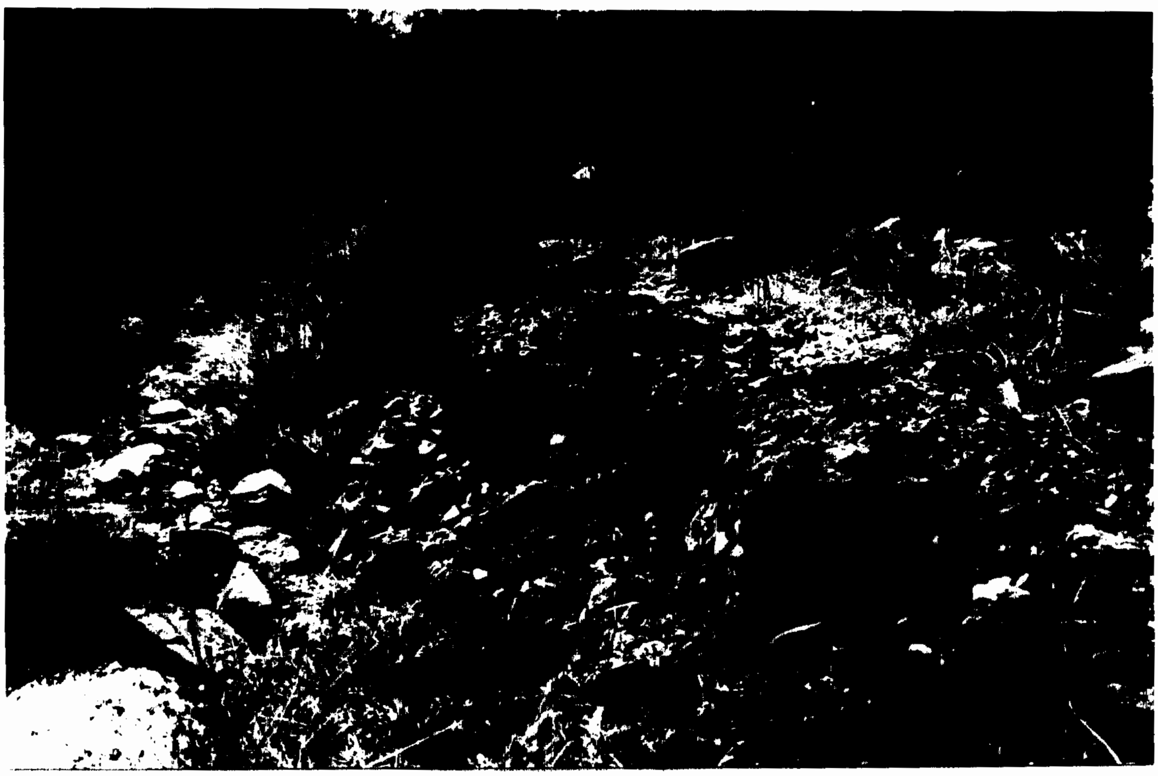


Figure 3. Streamside Tailings. North Fork Indian Creek.

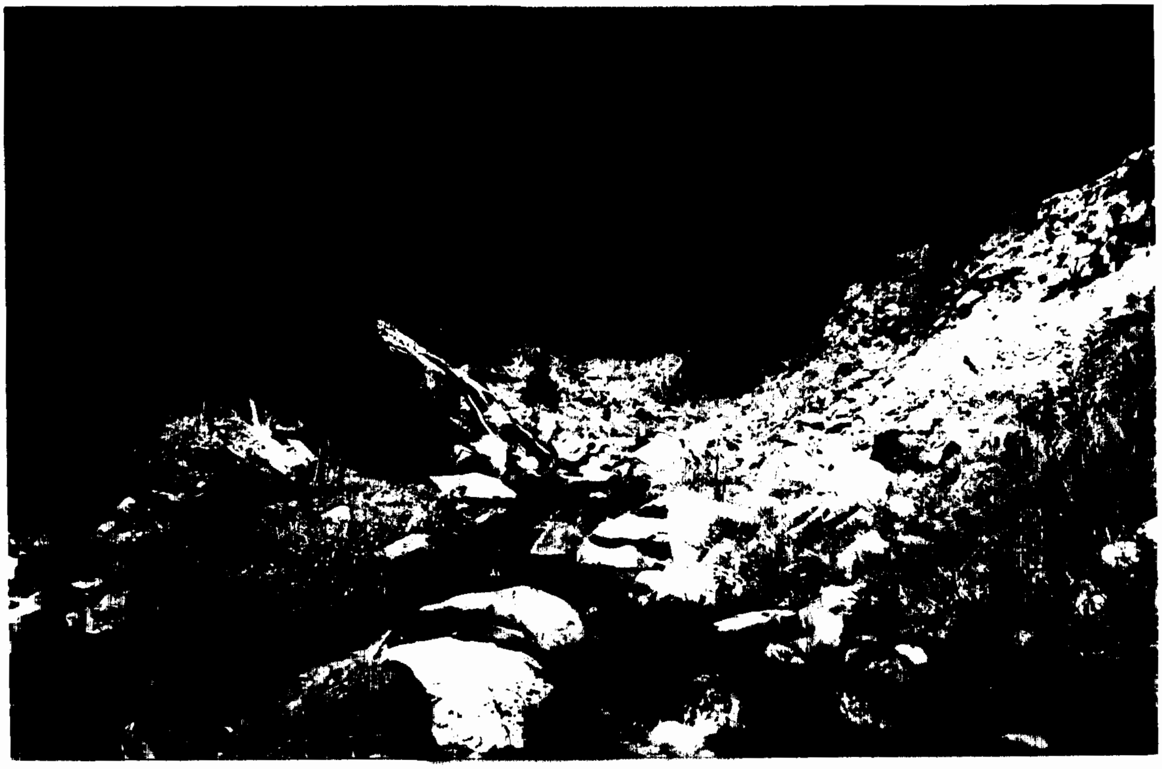


Figure 4. Stream Downcut Through Beaver Pond

four miles downstream of the impoundments. As a result of this disturbance, the stream is characterized by eroding, unvegetated vertical banks, an entrenched channel, poor channel geometry, and poor water quality.

Under the auspices of the Clean Water Act, the Bureau of Land Management Abandoned Mine Land (BLM AML) Program has been directed to reclaim mine lands on a priority watershed basis. The Indian Creek watershed is the third highest priority watershed on Montana BLM lands. Additionally, one of the stated goals of the BLM *Riparian-Wetland Initiative for the 1990s* is to restore 75% of riparian-wetland areas to proper functioning condition by 1997.

This stream was selected for restoration based upon its proximity to the Missouri River and its location in the Elkhorn Mountains, a sensitive wildlife management unit, managed for elk winter range. Streams within the Elkhorns are also now managed for native trout reintroduction. Because of its proximity to the Missouri River, Indian Creek also provides critical riparian habitat for migratory and perennial avian and terrestrial wildlife.

The Park Mine and adjacent land is privately held, and roughly half of the North Fork is within National Forest land. For these reasons, restoration of the North Fork is a collaborative effort between the BLM, Forest Service, and State of Montana Department of Environmental Quality Mine Waste Cleanup Bureau (DEQ MWQB). The DEQ will reclaim the Park Mine area during the upcoming 1997 field season. This reclamation will consist of slope re-contouring and revegetation, stream reconstruction, and the construction of a repository for waste rock and tailings. Projected cost is $1.2 million. The federal agencies, under a joint contract, will remove fluvially deposited tailings on federal lands and reconstruct and restore selected reaches of the stream during the upcoming field season. Under agreement with the DEQ, removed tailings will be placed in the Park Mine repository. The BLM is the lead agency for the stream restoration design; providing channel and bank designs for all federal lands.

Restoration Objectives

Indian Creek has responded to flood events and fluvially deposited tailings by downcutting (to bedrock in some places) to achieve elevation equilibrium; and by lateral degradation manifested as erosion of channel banks. The consequences of the stream's response include a disconnection of the stream from the floodplain, degraded streamside and riparian vegetation communities, and subsequent increased sedimentation. In short, the stream and riparian system is dysfunctional throughout the drainage. The objective of the reclamation is to restore the functionality of the stream and riparian system. Healthy and functional stream and riparian systems provide: sediment filtering, streambank building, water storage and aquifer recharge, stream energy dissipation, and wildlife habitat (Hansen 1995). Each facet of the reclamation objective is achieved by specific actions.

Sediment filtering is the means by which sediment carried by overland flow is trapped before it is entrained in the stream. This sediment loading to the stream aggrades pools and runs and impacts macroinvertebrate and sac fry habitat. Available sediment is reduced by creating vegetated banks and riparian areas which hold sediment in their root mass. Remaining available sediment is captured by the same vegetation.

Streambank building is the process of creating banks consisting of a deep and binding root mass. These banks are resistant to erosion and lateral degradation because the soil constituents are bound in the roots of the vegetation. Banks are built when streamflows carry and deposit fine soil particles on to the floodplain adjacent to the stream. These depositional areas provide favorable conditions for streamside vegetation. This process is disrupted when the stream is disconnected from the floodplain, (i.e; the stream is entrenched or incised). To re-connect the stream and floodplain, banks are re-contoured to create a floodplain or a floodplain is constructed at the toe of the vertical bank.

Water storage is also facilitated by connecting the floodplain and channel. Streamside vegetation acts as a sponge to capture and store water. Where the stream and floodplain are disconnected, water has no opportunity for storage. Aquifer recharge can also occur where water is slowed in a pool or run. By slowing water, pools and runs also dissipate energy which might otherwise be expended as shear stress on the bed and banks. Establishment of an appropriate pool/riffle/run sequence is needed to optimize water storage.

The final objective of stream and riparian functionality, as well its test of the integration of the prior aspects, is the formation of favorable wildlife habitat. The creation of favorable wildlife habitat is the successful establishment of appropriate streamside and riparian vegetation communities to meet the forage, cover, and breeding requirements of terrestrial and avian wildlife; and the establishment of appropriate feeding, spawning, cover, and resting habitat for fish and macroinvertebrates.

Restoration of each of these aspects of stream and riparian functionality will constitute restoration of Indian Creek. This restoration occurs on a reach by reach basis, but the same methodology applies. This methodology consists of a series of analyses performed sequentially, using the results of each analysis in subsequent steps. The methodology followed for Indian Creek was:

- basin hydrology
- fluvial geomorphology
- wildlife habitat

The importance and substance of each step is discussed in successive paragraphs.

Basin Hydrology

Basin hydrology is the prediction of the magnitude of flood events in a drainage, at varying recurrence intervals. These predicted flood events vary from the 2 year flood to the 100 year flood. For stream reconstruction, the 1.5 to 2 year flood defines the bankfull discharge. The bankfull discharge is "the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels" (Leopold 1994). The magnitude of the bankfull discharge is the fundamental parameter in the design of a stream channel. The channel design must contain the bankfull discharge, and permit greater flows to dissipate on the floodplain. An underestimated channel cross-section can result in lateral degradation or bed scour. An overestimated cross-section can result in disconnection of the stream from the floodplain. Bank treatments and channel modifications are designed such that the flow capacity of the channel is the bankfull discharge.

Because the stream is ungaged, estimates of bankfull discharge were made by four methods:

1) Channel width: from "Revised Techniques for Estimating Peak Discharges from Channel Width in Montana" (Parrett, Hull, Omang, 1987, USGS 87-4121).
2) Regional curves of channel width vs. bankfull discharge for streams in the Elkhorn Mountains
3) Basin area and elevation: from "Revised Techniques for Estimating Magnitude and Frequency of Floods in Montana" (Parrett, Omang, 1981, USGS 81-917).
4) Regional curves of basin area vs. bankfull discharge for streams in the Elkhorn Mountains

These methods use simple regression equations to estimate discharge. The first method utilizes channel width and a regional coefficient. Measurements of the bankfull width were made at thirty locations along the stream. Ideally, measurements would be taken at pristine locations. However, due to the pervasiveness of the disturbance, most measurements reflect entrenchment or a similar morphologic distortion. This method yielded a bankfull discharge of 5 cubic feet per second (cfs).

The second method utilizes channel widths from four gaged streams in the Elkhorn Mountains, as well as channel widths from the North Fork and main stem of Indian Creek. This method was considered suspect because the channel widths were measured at the site of the gaging station, rather than at optimal locations representative of bankfull width. This method yielded a bankfull discharge of 102 cfs.

The third method is based upon basin area, basin area above 6000 ft., and a regional coefficient. This method yielded a bankfull discharge of 22 cfs.

The fourth method utilizes the basin areas of the same gaged Elkhorn streams, as well as the basin areas of the North Fork and main stem. A regression analysis based upon area alone yielded a bankfull discharge of 26 cfs. Given the good agreement between methods 2 and 3, a bankfull discharge of 25 cfs was selected.

However, the reaches of the stream requiring a new channel are located about one-half mile from the headwaters. The area drained by the stream at these reaches is about 1.88 square miles. To determine the appropriate bankfull discharge for these reaches, the percent area drained by these reaches is multiplied by the bankfull discharge. In other words, the bankfull discharge is apportioned by fraction of area drained. This approach resulted in a bankfull discharge for the new reaches of 6.5 cfs.

Fluvial Geomorphology

This portion of the stream design addresses the physical features of the reconstructed stream and banks. The channel geometry and planform must be appropriate for the valley slope and morphology basin relief, depositional load, and hydrologic forces (Rosgen 1996). Geomorphic parameters to be specified include: channel geometry, sinuosity, entrenchment ratio, and radius of curvature. These features will determine how well the channel can transport its sediment load and maintain its flow conveyance.

Modification of the physical features of Indian Creek is delineated into two types of activity. The most prevalent activity is bank stabilization and reconstruction. The second activity involves reconstruction of the entire channel.

Two stream reaches within one-half mile of the headwaters require complete reconstruction. Two tailings impoundments, about 1300 ft. apart, were located near the headwaters. Behind each breached impoundment, tailings cover the valley bottom, and are in contact with the water's edge. These two reaches are roughly 200 ft. in length. Fluvially deposited cobble-size rock is also pervasive across the valley in these reaches. The removal of these tailings will require diversion of live water while new channels are constructed. The new channels were designed to convey bankfull discharge within the context of a valley slope of roughly 10% and a valley width of 150-200 ft. Valley slope and width were determined by USGS 7.5" topographic map and onsite measurements.

Based upon the valley slope, a Rosgen "A" type stream would normally apply. However, the risk of instability associated with successfully constructing an "A" channel was considered unacceptable. An "A" type stream was considered risky because of its inherent high energy (high stream power and shear stress values). Additionally, unless the streambed and banks are controlled by boulders or bedrock, the bed and banks will contribute large amounts of sediment when under shear stress. For this reason, the design channel is a Rosgen "B3a", with some tendency towards characteristics of an "A" channel. A "B3a" channel is characterized by a predominantly cobble substrate, width/depth ratio greater than 12, sinuosity greater than 1.2, and entrenchment ratio 1.4 - 2.2. A "B3a" typically occurs in narrow, moderately steep valleys having colluvium and/or alluvium based soil (Rosgen 1996).

A channel cross-section analysis package (XSPRO, version 1.1) was used to evaluate the conveyance of the design channel and ensure appropriate cross-section geometry. The design channel should contain the bankfull discharge, exhibit a width to depth ratio consistent with the design Rosgen type of "B3a", and show similarity to existing upstream and downstream reaches.

The XSPRO program uses Manning's equation to calculate velocity, and then discharge for a given cross-section, stage, and water surface slope. Manning's roughness coefficient, n, was calculated by the Jarrett equation, which relates roughness to slope and hydraulic radius. Manning's coefficient may also be calculated as a function of bed substrate size (d_{84}) using the Hey equation. Visual inspection indicates a bed substrate d_{50} of roughly 3 -5 inch, intermediate axis. This estimate will be verified by Wolman pebble count, and used to cross-check discharge values predicted by XSPRO.

A channel slope of 9% was used to run iterations of width and depth. Selection of width and depth were driven by the width to depth ratio of a "B3a" channel (>12). However, the most appropriate channel geometry, which also conveyed the bankfull discharge, yielded a width to depth ratio of 10.3. This ratio shows the tendency of the channel towards an "A" type (<12). At bankfull, the channel width is 6.2 ft. and the average depth is 0.6 ft. Figure 5 shows the channel cross-section. Because a "B3a" channel is a riffle-dominated stream, the typical channel cross-section represents a riffle.

To aid in energy dissipation and provide aquatic species habitat, pools are interspersed throughout the reach. "B" type streams are riffle dominated. Pool spacing is typically 4 bankfull widths. However, higher gradient streams, e.g., "A" and "B+" types can have pool spacing of 3.5 bankfull widths. To accommodate this spacing, roughly eight or nine pools 2.5 ft. in length will be placed in each new reach. Pools will be placed at the concave bank of meander bends to take advanatge of the natural erosion which occurs at these locations. The cross-section side adjacent to the convex bank of a bend is less steep to allow for bar development and subsequent streamside vegetation. A pool cross-section is slightly narrower than a riffle cross-section. Figure 6 shows the pool cross-section.

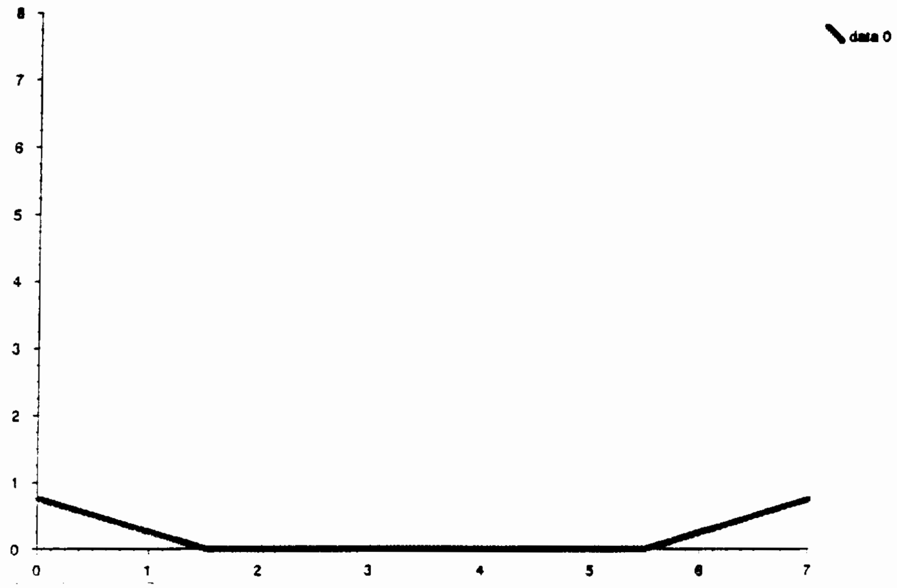


Figure 5. Riffle Cross-section

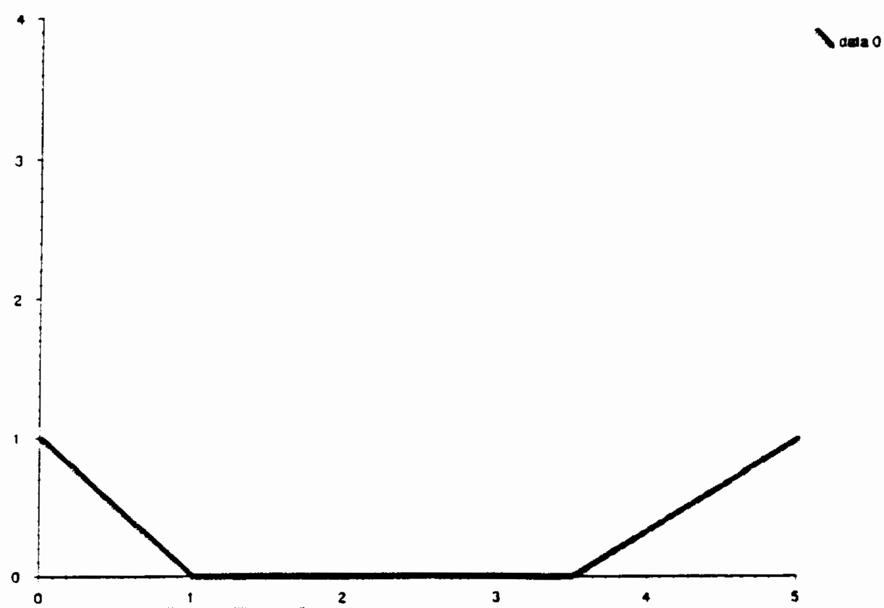


Figure 6. Pool Cross-section

Channel sinuosity was derived from the valley slope and sinuosity relationship:

$$\text{sinuosity} = Sv/Ss \qquad (1)$$

Sv = valley slope = 10%
Ss = stream slope = 9%

or

$$\text{sinuosity} = Ls/Lv \qquad (2)$$

L s = stream length
Lv = valley length

From equation (1), a channel sinuosity of 1.1 was calculated for the channel planform. Reaches downstream exhibit sinuosities of 1.1 to 1.2.

In general, steep gradient streams are relatively straight (low sinuosity). Energy is dissipated in a series of steps and pools, rather than meander bends. Sinuosity is also lower in streams having low silt/clay content (Rosgen, 1996). Given the estimated downstream sinuosities and the known soil composition, the lower (calculated) sinuosity value was used. A sinuosity of 1.1 is expected to minimize the potential for meander cutoffs and subsequent downcutting.

To design the channel with this sinuosity, the meander length is determined, and the appropriate valley length extrapolated from equation (2). The meander length is a function of the bankfull width (Leopold 1994):

$$L = 10.9 * (W_{bf})^{1.01} \qquad (3)$$

L = meander length
W_{bf} = bankfull width

Using this relation, a meander length of 72 ft. was used, yielding a valley length of 65 ft. The total valley length per reach is roughly 200 ft. Therefore, three meanders of 72 ft. are needed per reach.

The shape of the meander channel can be defined by two methods: radius of curvature and sine-generated curve. The radius of curvature is the radius of the circle which forms the central portion of a meander bend (Leopold 1994). Radius of curvature as a function of cross-sectional area and width are given by (Williams 1986):

$$Rc = 5.8\ A^{0.65} \qquad (4)$$
$$Rc = 1.5\ W_{bf}^{1.12} \qquad (5)$$

Rc = radius of curvature
A = cross-sectional area

Based on these relations, radius of curvature values of 13.6 ft. and 11.6 ft. were calculated.

The second method utilizes the relation between the deviation angle, θ, and the path length, S. The deviation angle is the angle between the direction measured at a given point along the curve and the mean downstream distance. ω, is the maximum deviation angle. Using the relation,

$$\theta = \sin (S/M) * 2 \qquad (6)$$

M = meander length

the meander amplitude as a function of downstream distance was plotted, Figure 7. This sine-generated curve represnts the channel shape which minimizes the work of erosion on the banks, and the average path of random walks of a given length between two fixed points (Leopold 1994). Figure 7 shows a single meander. Three of these meanders will be joined to form each of the two new reaches. The planform and profile views of the new reach design is shown in Figure 8.

The final design parameter for channel morphology is the entrenchment ratio. Entrenchment ratio is an index used to describe the degree of vertical containment of a channel at an elevation twice the maximum bankfull depth. Currently, the stream is moderately to severely entrenched, i.e.; incised such that flows greater than bankfull do not inundate the floodplain. Design of the channel will ensure that the flows greater than bankfull inundate the floodprone area and deposit fines.

The entrenchment ratio is the primary design variable for the remaining portions of the creek where bank stabilization and reconstruction is needed. Where the stream elevation is well below the elevation of the floodplain, banks and side slopes are re-contoured, where feasible, to provide the entrenchment ratio appropriate to a "B" type stream

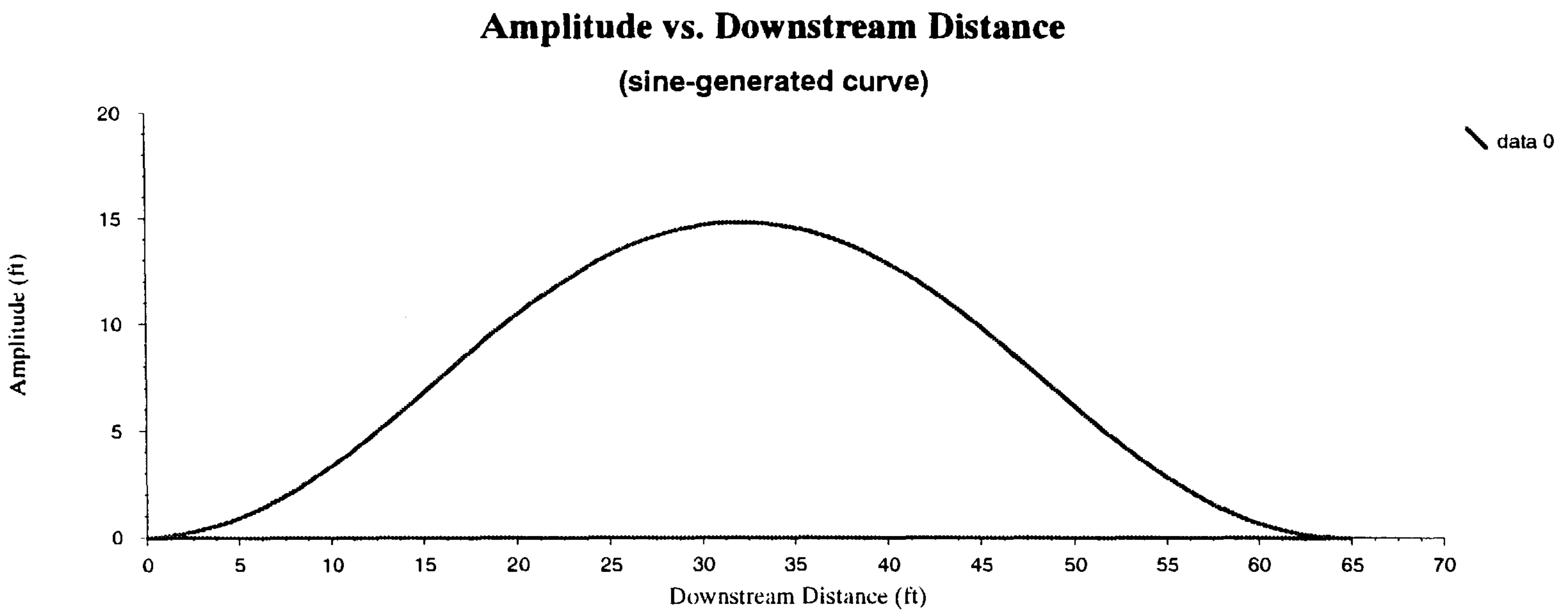


Figure 7. Stream Meander Curve

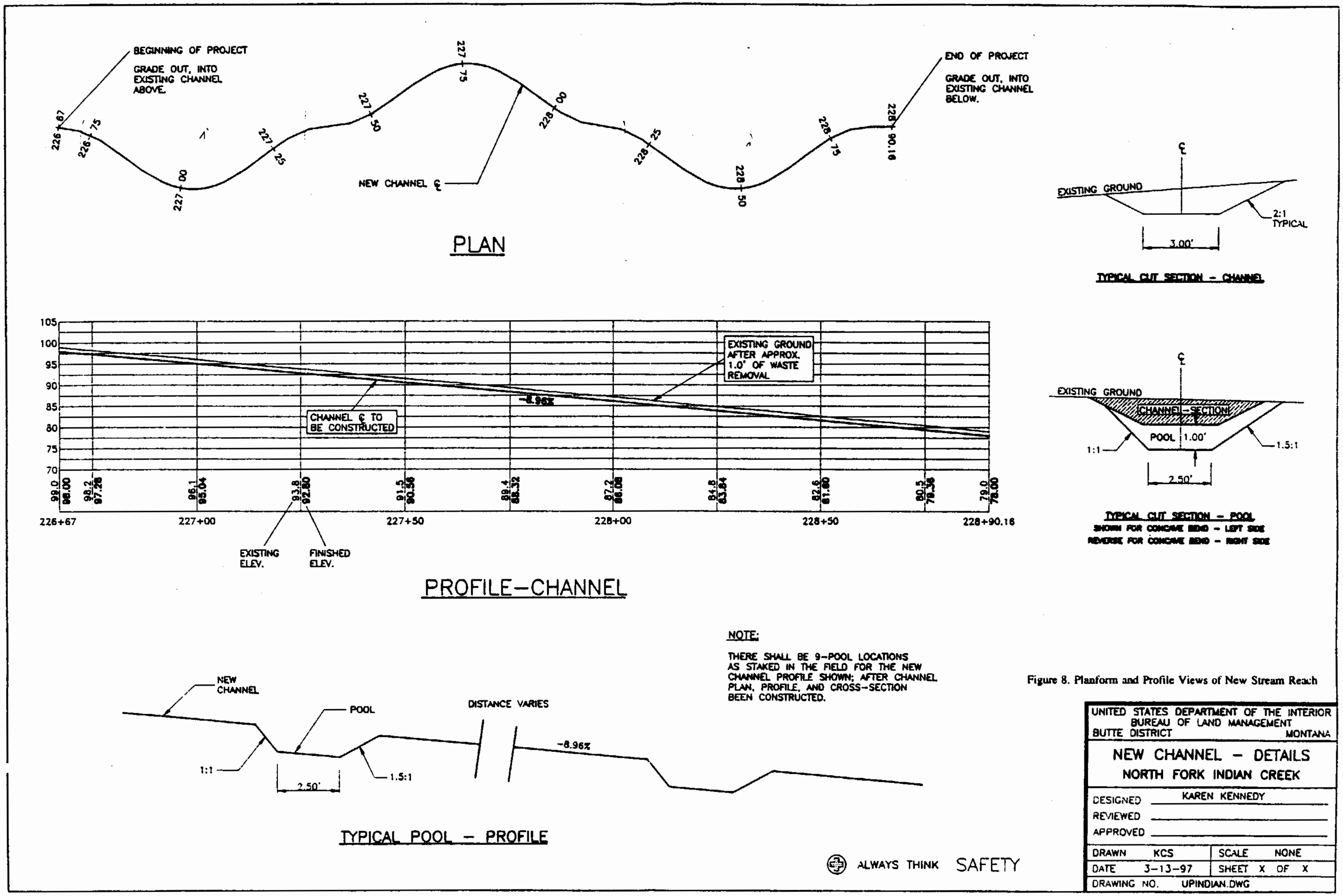


Figure 8. Planform and Profile Views of New Stream Reach

and maintain bankfull conveyance of the channel.

Due to the pervasive entrenchment of the stream and its length, criteria have been developed to determine when to modify banks. Where entrenched banks contain high rock content and do not exhibit erosion at the toe, banks are not modified. Banks are also not modified where heavy equipment access is difficult. Where the toe of the banks is eroding, banks are re-contoured to a grade appropriate for a "B" type stream and favorable to vegetative success, (e.g., 3H:1V), or the eroding toe is protected. In areas where streamside vegetation has established at the toe of vertical banks, a floodplain will be established, rather than re-contouring the entire slope. Bank treatments are checked reach by reach to ensure that the stream conveyance of bankfull discharge is maintained. Examples of these treatments are shown in Fig. 9. The stream was GPS surveyed to locate reaches requiring bank treatment, and identified by stations and bank treatment type. These locations are shown in Figure 10.

Wildlife Habitat

The final aspect of the stream restoration is the creation of wildlife habitat. For the cover, feeding, and breeding requirements of terrestrial and avian wildlife, creation of wildlife habitat is simply the establishment of native, diverse riparian grass, forb, and woody species. In short, representation of species needed to facilitate the growth and succession of the potential climax community. As previously emphasized, access of vegetation to water is critical.

Meeting the breeding, feeding, and cover requirements of aquatic life, particularly fish, is inextricably linked to the stream design. Currently, the stream supports isolated populations of eastern brook trout. It is thought that the stream was historically populated by indigenous Westslope cutthroat trout (personal communication, Harper, Helena National Forest).

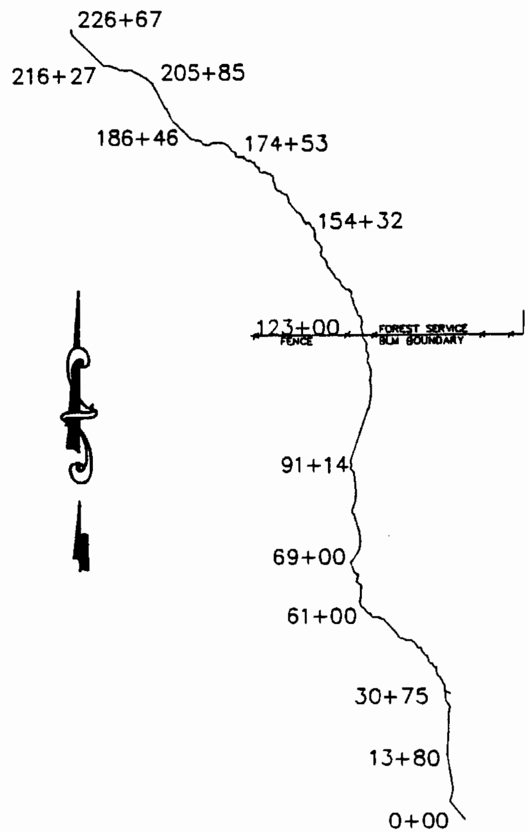
Each life activity of the trout requires a different kind of environment. Feeding often occurs in riffles, resting occurs in pools and runs, and egg laying occurs in relatively quiet gravel beds. Ideally, the stream design is both hydraulically stable and provides favorable conditions for fish habitat. These conditions include appropriate size and number of pools, appropriate pool/riffle/run sequence, and appropriate substrate size for both eggs and macroinvertebrate habitat. In addition to morphologic features, minimal sedimentation is also required for productive trout habitat. Fine materials entrained from either streamside sources or bed and bank erosion reduce incubation success, rearing space, cover, and macroinvertebrate production (Harper). In this stream design, sedimentation via erosion is minimized by the design of the meander curve, (discussed earlier), and the use of protective construction materials such as coconut matting and appropriate-sized bed substrate and bank materials.

Pools for resting and energy dissipation can be implemented as exterior structures such as logs and weirs. Exterior features are initially minimal to allow the stream to find its natural equilibrium after the first few years of restoration. Because of the high gradients found throughout the stream, structures keyed into banks will be avoided. However, exterior features are added to meet specific habitat needs. Exterior structure additions will be limited to rock structures such as vortex rock weirs. A vortex rock weir consists of a series of rocks anchored in the streambed between footer rocks, also anchored in the streambed. The uppermost rocks breach the water surface, providing grade control in steep reaches and creating "quiet" areas on the upstream side. Ideally, the stream water quality and morphological features will ultimately allow reintroduction of native trout (Westslope cutthroat).

Summary and Conclusions

The stream restoration of the North Fork of Indian Creek is designed to provide both hydraulic stability and favorable conditions for the resident avian, terrestrial, and aquatic wildlife. In short, provide all the components of a healthy and functional riparian system. Hydraulic stability is ensured by conveying the bankfull discharge within the confines of the channel, dissipating stream energy within pools, and minimizing erosion. Wildlife habitat is enhanced by providing access of water to the floodplain or reestablishment of the floodplain, removal of streamside tailings, revegetation of riparian areas, and inclusion of key aquatic habitat features in the stream design. Post construction monitoring of water quality and morphologic channel features is tentatively planned to evaluate the efficacy of the restoration. Restoration to pristine, pre-mining conditions is not feasible, but the hope is to restore the water quality, wildlife, and aesthetic features which once graced this corner of the mountains.

NORTH FORK INDIAN CREEK



WORK SUMMARY CHART

STATION	TOTAL LENGTH	BANK TREATMENT	COMMENTS
5+60–6+60	100	tails removal; C	thin skiff of tails covers cobles, no veg
11+50–13+20	170	B or C	steep, unveg side slopes; B or C is a function of depth
13+80–14+30	50	remove culvert, C	"new" channel at culvert site; vert unveg short slopes
30+75		**** started GPS logging ****	
38+00–38+75	75	C	incised
42+00–43+20	120	B	this reach is just d/s of J. tails #1
43+20–46+40	320	tail removal; B	J. tails #1
51+60–52+60	100	A or B	
61+00–63+14	214	tails removal; B	J. tails #2
69+00–69+50	50	A	10 stamp mill
91+14–101+50	1036	combination of A,B, and C	Fr. Badger Gulch to u/s
101+50–102+50	100	A or B	remove downed trees in creek
111+53–112+90	137	A or B	
114+80–117+00	220	A or B	
123+00			locked gate; BLM/FS boundary
154+32–154+62	30	replace roadbed with creekbed	
154+62–155+32	70	A or B	
160+50–165+55	505	tails removal from aspen grove; B or C	
165+55–168+55	300	combination of A,B, and C	
169+64–173+64	400	tails removal; combination of A, B, or C	
174+53–176+03	150	A or B	
178+81–186+46	765	tails removal; no stream work	Ribedeaux Gulch
186+46–199+13	1267		length of road on rt side (looking u/s)
205+85–226+85	2100		length of reappearing road on rt side
216+27–218+61	234	new channel	length of TP4
226+67–228+90	223	new channel	length of TP3

Figure 10. Plan View of North Fork and Locations of Channel Construction and Bank Treatments

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
BUTTE DISTRICT MONTANA

WORK LOCATION PLAN
NORTH FORK INDIAN CREEK

DESIGNED
REVIEWED
APPROVED

DRAWN	LW	SCALE	NONE
DATE	3-19-97	SHEET	X OF X
DRAWING NO.	KENNEDY.DWG		

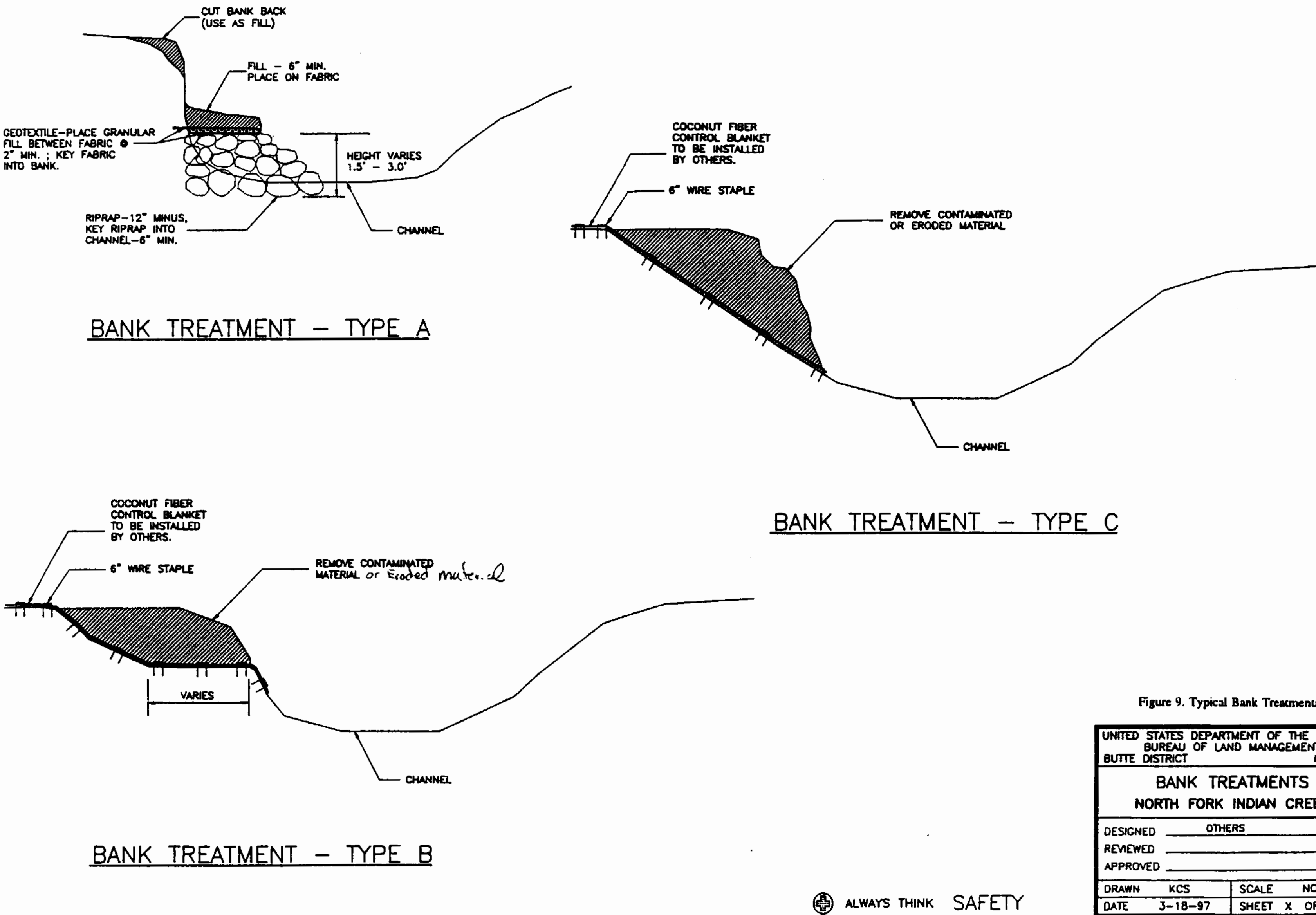


Figure 9. Typical Bank Treatments

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT
BUTTE DISTRICT MONTANA

BANK TREATMENTS
NORTH FORK INDIAN CREEK

DESIGNED OTHERS
REVIEWED
APPROVED

DRAWN	KCS	SCALE	NONE
DATE	3-18-97	SHEET	X OF X
DRAWING NO.	BANKTRET.DWG		

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