Development of a TMDL to Reduce NonPoint Source Sediment Pollution in Deep Creek, Montana

Report to Montana Department of Environmental Quality

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I. BACKGROUND

Deep Creek, located south of Townsend, Montana, in Broadwater County, is a major tributary of the Missouri river (Figure 1). It provides spawning and rearing habitat for a blue ribbon rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) fishery in the Missouri River and for the nearby Canyon Ferry Reservoir, one of the most heavily fished bodies of water in Montana. The Deep Creek watershed and surrounding streams are severely degraded by sedimentation and dewatering and recruitment of wild trout is limited. Due to construction of Toston Dam on the Missouri River, Deep Creek is one of the few spawning streams available between Toston dam and Canyon Ferry Reservoir. In addition to use by spawning trout migrating from Canyon Ferry Reservoir, Deep Creek supports a resident population of trout in its upper reaches. With remediation of habitat degradation, Deep Creek has excellent potential to provide spawning habitat and a high quality resident fishery along its entire length.

Deep Creek has been the focus of substantial efforts to address the decline in the Missouri River/Canyon Ferry Reservoir trout fishery. Landowner and agency interest and involvement has been high and has resulted in cooperative efforts to improve conditions in the watershed. Two sections of riparian corridor have been fenced to exclude livestock, one funded by Montana Department of Fish Wildlife and Parks (MDFWP) and the other initiated by the landowner. A major sediment source from the Broadwater-Missouri Canal has been eliminated by improving canal practices through assistance with annual start-up and shutdown practices since 1992. Irrigators

Figure 1. Map of Deep Creek Watershed. Water sampling sites are designated with triangles.

Figure 2. Map of reaches on Deep Creek.

have also delivered surplus irrigation water to the lower 3 miles of Deep Creek to improve summer stream flows. In 1991, a seasonal barrier to spawning brown and rainbow trout was eliminated using over $200,000 of Toston Dam mitigation funds. Montana Ditch, which previously intercepted Deep Creek about 1/2 mile above the mouth of the stream, was routed under Deep Creek with a siphon. Considering the large investment to provide spawning access to Deep Creek, it is important to further address issues of habitat quality to maximize spawning success.

A significant amount of information has been collected to help guide solutions to erosion and sedimentation problems in the watershed. This information includes aerial photos, stream bank inventory, water quality data, substrate cores, and information on fish and macroinvertebrate communities. The Natural Resource Conservation Service (NRCS, formerly Soil Conservation Service), U.S. Forest Service, Montana Department of Environmental Quality (DEQ), MDFWP and numerous landowners have all contributed to the data collection process.

Because of sedimentation problems and limited recruitment of trout to the Missouri River and Canyon Ferry Reservoir, Deep Creek has been identified as a candidate stream for the development of a TMDL (total maximum daily load). The TMDL process is established by section 303(d) of the federal Clean Water Act and by EPA's Water Quality and Planning and Management Regulations (40 CFR Part 130) as a tool for implementing state water quality standards. A TMDL is based on the relationship between pollution sources and instream water quality conditions and establishes allowable loading of a pollutant or other quantifiable parameters for a body of water. This provides the basis for States to establish water quality based controls to provide the pollution reduction necessary to meet water quality standards.

Several TMDL's have been established in the U.S. to address non-point source sediment pollution (USEPA 1994). A TMDL was designed for Sycamore Creek, Michigan to address non-point source (NPS) sediment primarily from agricultural activities. The TMDL was established to reduce sediment loading from a variety of sources through the use of agricultural best management practices (BMP's). Another TMDL was designed for South Fork of the Salmon River, Idaho, to address NPS fine sediment from logging activities. Montana and Idaho do not have numeric standards for sediment load or concentration. Therefore, numeric goals for instream conditions in the Salmon River were established in terms of cobble embeddedness and surface fines. Methods by which goals were to be attained included silvicultural BMP's, a moratorium on ground-disturbing activities, and a number of rehabilitation projects including: dragline removal of sediment from pools, instream gravel cleaning, revegetation of streambanks, and road closures and reclamation.

This document has three major objectives: 1) describe water quality, bank conditions and stream habitat conditions that define/describe NPS sources of fine sediment and limitations to the fishery of Deep Creek; 2) identify remedial actions and TMDL targets for reducing fine sediment and increasing trout recruitment; and 3) outline monitoring activities to assess the efficacy of remediation efforts.

II. WATERSHED DESCRIPTION

A watershed inventory was performed on Deep Creek by the NRCS (Oestreich 1992) which provides information on geology, topography, soils and landuses. The Deep Creek watershed has a drainage area of 87.7 square miles. The length of Deep Creek from the Meagher County line to the confluence with the Missouri River is 24 miles. Topography ranges from steeply wooded slopes in the Helena National Forest portion of the watershed to near level in the Missouri River floodplain. Soils in the valley were formed from weathered marine deposits and alluvium from sedimentary rocks in the mountains. A variety of landuses are found in the watershed. Timber harvest and grazing occurs within the Helena National Forest. The lower portions of the watershed are used as rangeland and cropland (irrigated and dry).

Deep Creek has previously been divided into 11 reaches varying from 0.75 miles to over 5 miles in length. Reach boundaries have been generally delineated by roads or property lines (Table 1 and Figure 2). Reach numbers start near the mouth and progress upstream. The following reach descriptions include present physical conditions of each reach in addition to past and potential areas of channel loss as identified through examination of the time series of aerial photographs (Bergantine 1993). Descriptions of channel slope and sinuosity as high, medium or low are based on Rosgen classification of natural rivers (Table 1).

Table 1. Sinuosity ratings (Rosgen 1991).

	Low	Medium	High
Sinuosity	<1.2	1.2 - 1.4	>1.4

Reach 1

This reach begins near the confluence with the Missouri River at the Montana Ditch siphon and lies within the Missouri River floodplain. The section is characterized by low to moderate sinuosity and low channel slope. This section has lost about 300 feet of channel length since 1980 through cut-off of channel meanders (Bergantine 1993). Cultivation of hay and alfalfa occurs in the uplands. The entire riparian zone was fenced to exclude livestock in 1991 and dramatic recovery of the riparian shrub community has occurred since the 1991 aerial photographs (R.Spoon, MDFWP, Townsend, personal communication).

Reach 2

This reach flows through the Missouri River floodplain and is characterized by low to moderate sinuosity and channel slope. Examination of 1991 aerial photographs indicates that the riparian zone on the north side of the stream is narrow with low density of shrubs. Land use practices along this reach include hay cultivation and livestock grazing. This section has lost about 400 feet of channel length due to cut-off of channel meanders since 1980 and two more meanders are at risk of being lost.

Reach 3

This is the last reach to lie entirely within the Missouri River floodplain. It is characterized by low to moderate sinuosity, and steeper slope than the previous reaches. A major feature of this reach is a long channelized section which was mechanically straightened prior to 1955. Channelization resulted in loss of approximately 1,350 feet of stream channel. An additional 500 feet of channel was lost when Deep Creek abandoned its normal channel downstream of Lightning Barn Road sometime between 1955 and 1976. The creek now occupies what was formerly an irrigation ditch for about one-third of its length. Riparian shrub communities are negligible along much of this reach. Landuse practices include cultivation of hay and grain and livestock grazing.

Reach 4

This reach is bordered by foothills on both sides of the stream. The stream is relatively straight while channel slope is steep. The 1991 aerial photographs indicate a narrow riparian corridor. Landuse practices along the reach include grain production and livestock grazing.

Reach 5

This reach is characterized by varied stream habitat and riparian conditions along its length. Overall, the reach is characterized by low sinuosity and high channel slope. A wide buffer of riparian vegetation (30 -50 ft) occurs along much of its length.

Reach 6

This reach is characterized by higher sinuosity and lower channel slope than the previous reach. One meander bend in this reach is at risk of cutoff. In 1988, twelve heavily-eroded outer banks of channel bends were stabilized with tree revetments or riprap. This bank stabilization was part of a study to compare trout densities following riprap and tree revetment stabilization techniques (McClure 1991). The main source of stream bank erosion observed in this reach was mass wasting fracture caused by attached ice shelves during spring thaw. This section is not subjected to livestock grazing within the riparian zone.

Reach 7

This reach is characterized by meandering channel and low channel slope. Four meanders have been identified as being at risk of cutoff in this section. Much of this reach has a wide riparian zone (+ 50 feet) and dense cover of riparian vegetation.

Reach 8

This is a long reach with a range of conditions. Sinuosity varies widely with from low to high. Much of the reach has a wide riparian zone (+ 50 feet) and dense canopy cover of riparian shrubs. Livestock are excluded from some sections of stream by riparian fencing. Significant channel loss has occurred since 1955, totaling 3500 feet. Additional loss of channel length is possible with potential cutoff of 2 meanders.

Table 2. Description of reaches on Deep Creek

Reach	Boundaries	Length (miles)	Average Sinuosity	Channel Slope (%)	Length of Channel Loss since 1955 (ft)
1	MT ditch to Hwy 287	0.78	1.28	0.005	300
2	Hwy 287 to Carson Ln.	0.93	1.59	0.005	400
3	Carson Ln. To Lt.Barn Ln.	1.14	1.22	0.008	1850
4	Lt. Barn Ln. To BM siphon	0.68	1.20	0.015	
5	BM siphon to McArthur/ Shipman (l)	0.97	1.17	0.015	
6	McArthur/ Shipman (l) to Shipman/ McArthur (u)	0.90	1.41	0.011	
7	Shipman/ McArthur (u) to Plymale's bridge	2.01	1.95	0.011/0.009	
8	Plymales bridge to lower Jepson's	3.99	2.07	0.009/0.011	3500
9	Lower Jepson's to upper Jepson's	0.76	1.52	0.011	800
10	Upper Jepson's to lower Dagnall's	1.75	1.91	0.009	
11	Lower Dagnall's to Hwy 12 bridge	5.34	1.78	0.010	

Reach 9.

This reach has moderate sinuosity and channel slope. Channel loss is estimated at 800 feet, although there is indication that the stream is now attempting to re-establish meanders (Bergantine 1993).

Reach 10

A wide riparian buffer (+50 feet) occurs between cultivation and the stream for much of this reach. The stream has been re-establishing meanders in this section (Bergantine 1993).

Reach 11

The stream flows through a narrow floodplain with timbered uplands in this reach. Sinuosity is moderate in this section and the channel slope relatively steep. The first half of this reach has a narrow riparian zone. The upper half, however, has a broad riparian buffer with dense cover of riparian woody vegetation. The stream in this reach has been re-establishing meanders in some places since 1955 (Bergantine 1993). One meander is at risk of cutoff in this reach.

III. ASSESSING AND CHARACTERIZING THE PROBLEM

Examination of data on Deep Creek indicates a number of constraints to water quality and aquatic life. These conditions vary throughout the watershed and the purpose of this section is to identify areas and sources of degradation on a watershed level.

Loss of Channel Length

Low level aerial photographs are an important source of information regarding past and current conditions on Deep Creek. Deep Creek channel configurations have been compared over time using aerial photographs taken in 1955, 1980 and 1991 and areas of channel loss and potential channel loss have been identified (Bergantine 1993). Channel losses are attributed to intentional straightening of the stream by humans or loss of meanders due to bank erosion. Based on this photo series, it is estimated that since 1955, approximately 9,100 feet of channel length has been lost out of the original 106,000 feet for a 9% loss of stream channel length. Loss of channel on a reach basis is described in Watershed Description section. Efforts are currently underway to digitize the aerial photograph series to compare channel lengths and riparian widths over time.

Aerial photos also indicate areas of potential channel loss (Bergantine 1993). Potential loss of channel length can occur with cut-off of stream meanders through soil erosion during high water events. Further loss of channel length will result in increased local stream energy during high flows, increased bank erosion and sedimentation, and reduction fish habitat quality. Reaches 2, 6, 8 and 11 have meanders which are at risk of cut-off without intervention to increase bank stability.

Water Quality

Water quality data exists for several points along the mainstem and at the mouth of some tributaries in the headwaters (Figure 1). Parameters tested and years in which sampling occurred varied among sites (Table 3). Generally, sampling effort was concentrated during periods of spring peak flow and decreased as flows diminished in the summer months. Total phosphorus, nitrate, and suspended sediment are identified as potentially harmful to aquatic life by the Montana Numeric Water Quality Standards, however, numeric standards do not currently exist for the state (MDEQ 1995). Therefore, concentrations of nitrate, total phosphorus, and total suspended sediment will be compared to ranges measured in Montana valley and foothill prairies reference streams (Table 3, Bahls et al. 1992). These streams were typically spring creeks with a relatively few observations made, however, it is assumed they are suitable for limited qualitative comparison. Potential contribution of nitrogen to eutrophication on Montana Valley and Foothill Prairies reference streams was determined by measuring total inorganic nitrogen (TIN). This is a measure of nitrate, nitrite and ammonia. Typically in surface waters, the majority of TIN is in the form of nitrate-nitrogen, it is assumed that it is valid to compare this with nitrate-nitrogen from Deep Creek. Total phosphorus is a measure of phosphorus in all forms and includes phosphorus molecules adsorbed onto soil particles that may not be biologically available. Therefore, TP is not a direct measure of nutrient enrichment, and will increase under conditions of soil erosion.

Nutrients

Total phosphorus (TP) data was available at three water sampling sites and compared with Montana Valley and Foothill Prairies reference streams (Figure 3). Total phosphorus at the Lippert Gulch and Broadwater-Missouri Ditch sites do not exceed values of the reference streams. The upper limits of TP at Montana Ditch, however, exceeded maximum levels in the reference streams. The relationship between soil erosion and TP was investigated with regression analysis for Montana Ditch (Figure 4). Total phosphorus was highly correlated with TSS suggesting soil erosion as a source of TP. However, this is confounded by discharge. Increased surface run-off from agricultural activities may also be a factor. Comparison of total nitrogen concentrations among water sampling sites (Figure 5) and Montana reference streams indicates nitrogen concentrations in Deep Creek to be well under reference stream values. Based on this information, nutrient enrichment does not appear to be significant in Deep Creek.

Temperature

Temperature data was collected at water sampling sites during spring run-off. Water temperatures did not exceed thermal threshold for trout (73 °F) during this sampling period (Figure 6); however, these data were likely to have missed conditions that were unfavorable to trout as the summer and irrigation season progressed. Temperature has been monitored at a permanent thermograph located near the Montana Ditch siphon. Data from 1993 and 1994, extremely wet and dry years, respectively, indicate that water temperatures can often exceed 73 °F during hot, dry summers (Figure 7). Water from Broadwater-Missouri Ditch may also be a significant source of thermal input to Deep Creek. However, spot temperatures during summer months indicate that water in the canal is somewhat cooler during hot, dry periods than water in Deep Creek (R. Spoon MDFWP, Townsend, personal communication).

Table 3. Comparison of water quality parameters sampled and years in which sampling occurred on Deep Creek. (+ = data available; - = data not collected).

Site/Reach	Years	Discharge	TSS	Temp.	Total Phosphate	Turbidity	pH	Conductivity	Suspended Load	Nitrates (NO_3 and NO_2)
Mainstem										
MT Ditch /Reach 1	'92-'93	+	+	+	+	-	-	-	-	+
Carson Ln./Reach 2	'92-'93	-	+	-	-	-	-	-	-	-
BM Ditch/ Reach 5	'92-'93	+	+	+	+	-	-	-	-	+
Below Clopton Ln./ Reach 9	'92-'93	-	+	-	-	-	-	-	-	-
Above Clopton Ln./ Reach 10	'93	-	+	-	-	-	-	-	-	-
Horse Pasture (USFS)	'91-'93	+	+	+	-	+	+	+	+	-
Upper Deep Creek (USFS)	'91-'93	+	+	+	-	+	+	+	+	-
Tributaries										
Cabin Gulch	'78-'93	+	+	+	-	+	-	-	+	-
Lippert Gulch	'92-'93	+	+	+	+	-	-	-	-	+
Carl Creek	'88-'90	+	+	+	-	+	+	+	-	-
Cedar Bar		+	+	+	-	+	+	+	-	-
Sulphur Bar	'91-'93	+	+	+	-	+	+	+	+	-

Table 4. Approximate levels of nutrients measured at Montana Valley and Foothill Prairies reference streams (Bahls et al. 1992).

Pollutant	Mean Concentration	Maximum Concentration	Minimum Concentration
Total Phosphorus (mg/L)	0.08	0.18	0.01
Total Inorganic Nitrogen (mg/L)	0.41	0.75	0.15

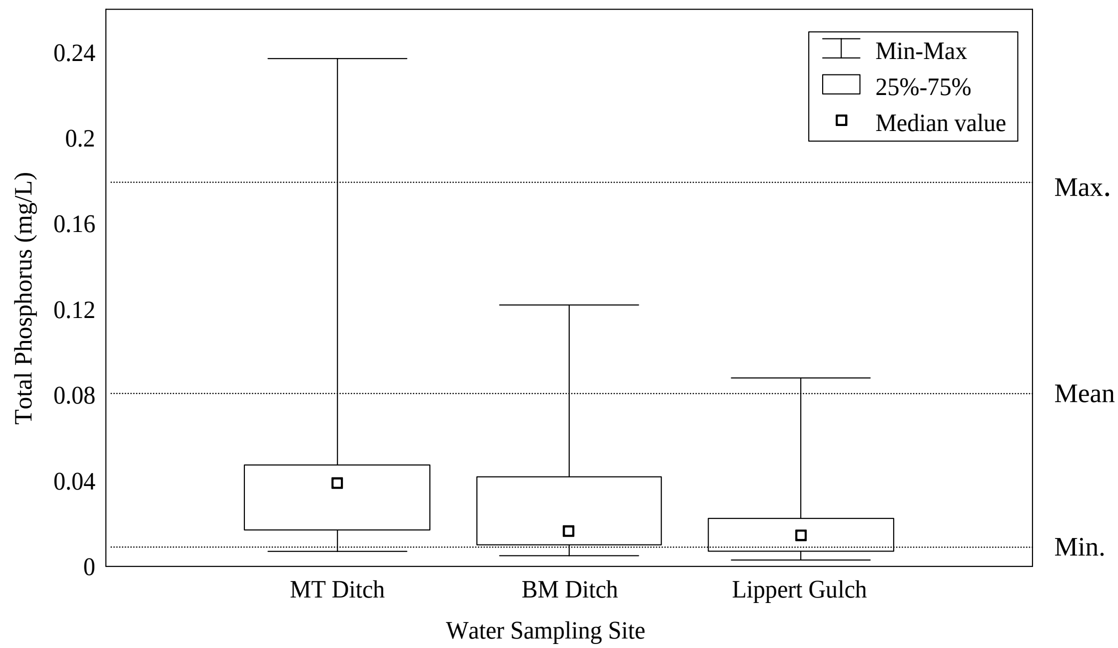

Figure 3. Total phosphorus concentration per water sampling site. Horizontal lines represent minimum, mean and maximum concentrations measured at Montana Valley and Foothill Prairies reference streams (Bahls et al. 1992).

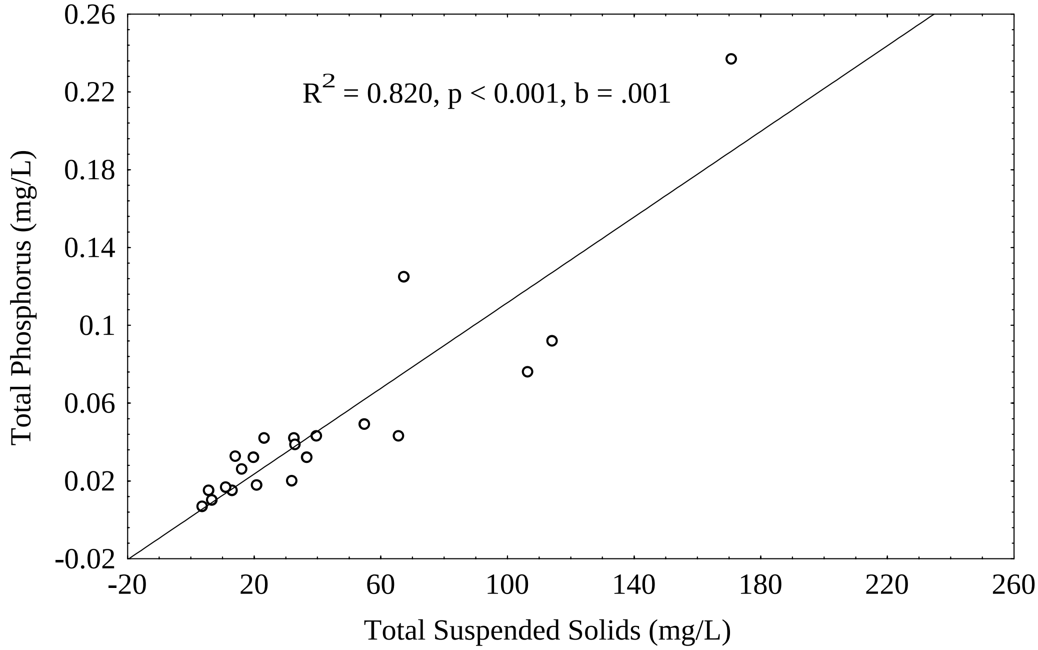

Figure 4. Relationship between total phosphorus concentration and TSS concentration at Montana Ditch.

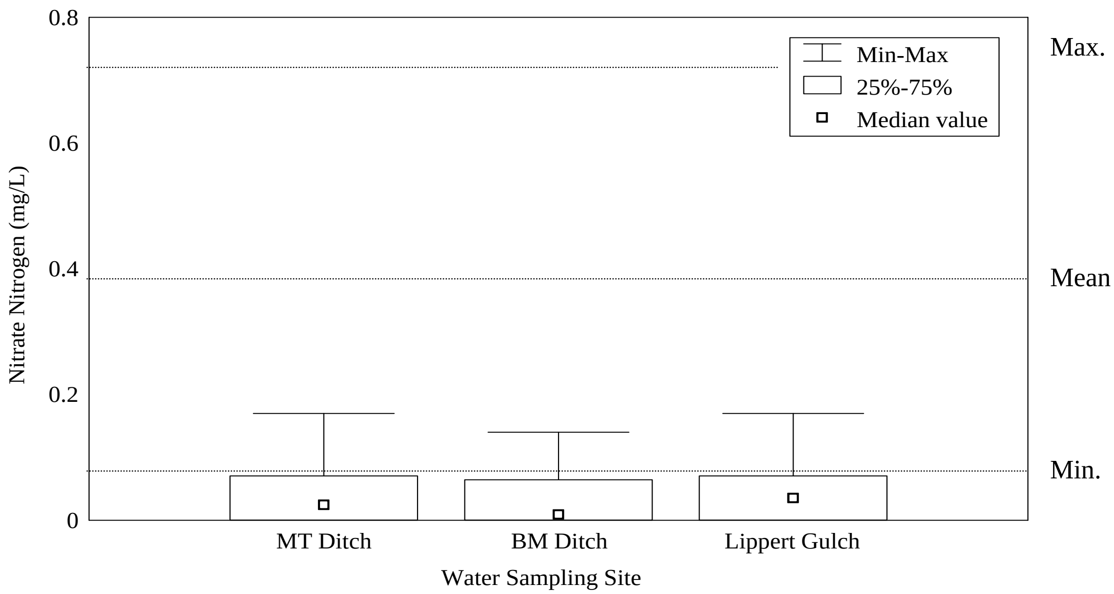

Figure 5. Nitrate-nitrogen per water sampling site. Horizontal lines represent minimum. mean, and maximum concentrations measured on Montana Valley and Foothill Prairies reference streams (Bahls et al. 1992).

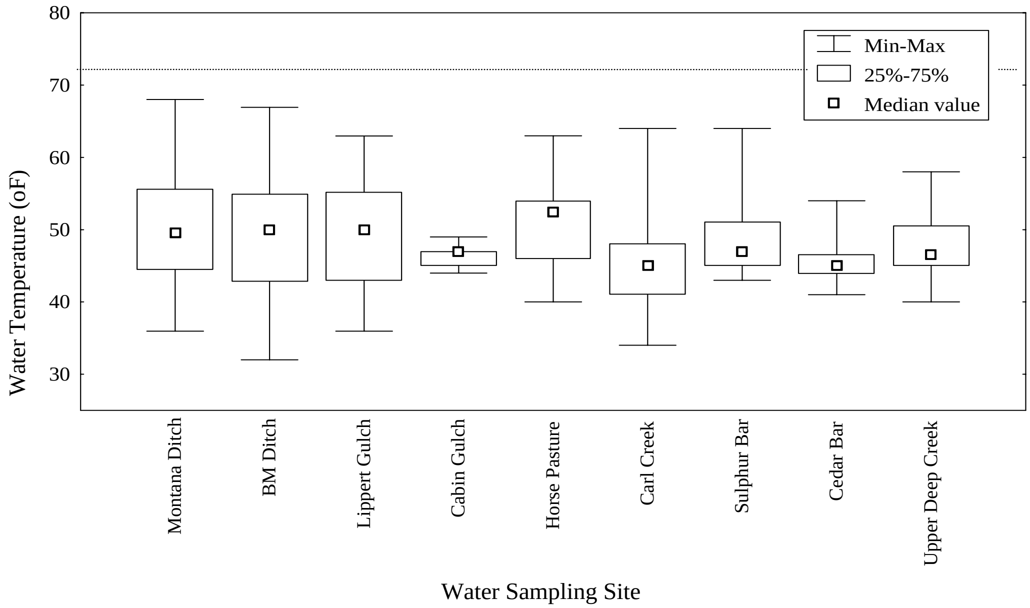

Figure 6. Water temperature during spring run-off (April through June). Horizontal line indicates thermal threshold for trout (Bell 1986).

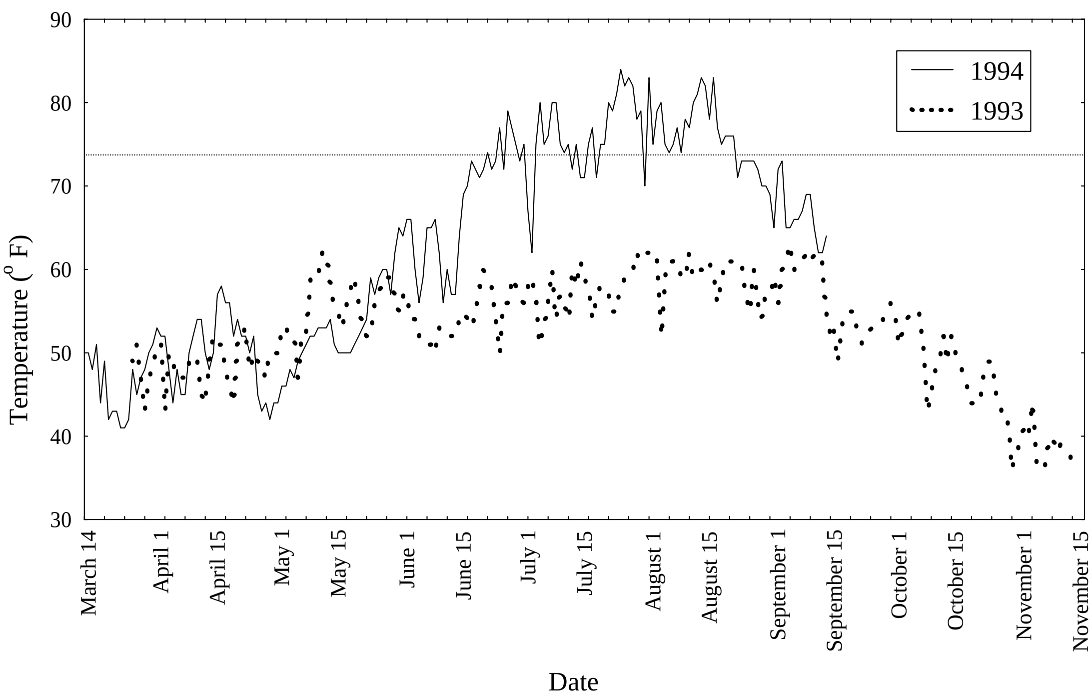

Figure 7. Maximum daily temperatures at Montana Ditch thermograph for 1993 and 1994. Horizontal line represents threshold for thermal tolerance of trout (Bell 1986).

Suspended Sediment

The rationale for assessing suspended sediment is threefold. First, suspended sediment directly impacts aquatic organisms resulting in reduced reproduction, tissue damage, reduction of foraging efficiency, increased susceptibility to disease, dislodgement, and death (Newcombe and MacDonald 1991). Second, total suspended solids (TSS) levels measured throughout a watershed can indicate reaches of stream which are experiencing high levels of erosion and thus are a significant source of fine sediment to the system. Third, in the absence of sufficient data on substrate composition and sedimentation, suspended sediment levels can be used to infer constraints to reproduction of salmonids related to reduction of permeability of spawning gravels.

Comparison of TSS levels encountered in Deep Creek (Figure 8) among water sampling sites illustrates the relative level of degradation in the watershed. Upper Deep Creek water sampling site has lowest TSS levels. Other upper tributaries (Carl Creek and Cedar Bar) had comparably low maximum concentrations (< 50 mg/L maximum). The tributary contributing the highest TSS was Sulphur Bar. This indicates that most headwater tributaries are not contributing much to the total TSS in the mainstem. TSS concentration increased markedly between the Horse Pasture sampling site (median = 6 mg/L; max. = 51 mg/L) and the lower four mainstem water sampling sites (median = 38 mg/L; max. = 402 mg/L at Montana Ditch). This indicates that the much of the TSS increase is associated with the lower reaches.

Sources of fine sediment from bank erosion throughout the watershed can be inferred by comparing TSS load among water sampling sites (Figure 9). Daily load was calculated for water sampling sites by multiplying TSS concentration by daily discharge.

TSS load in Upper Deep Creek and upper tributaries indicates a small amount of sediment (i.e. maximum 2 tons/day at Sulphur Bar) compared to the lower portions of the watershed (between 40 and 70 tons/day at Montana Ditch and Broadwater-Missouri Ditch). Total sediment load is mostly from sources below Horse Pasture sampling. During peak flows, Deep Creek can transport 67 tons of sediment per day to the Missouri River.

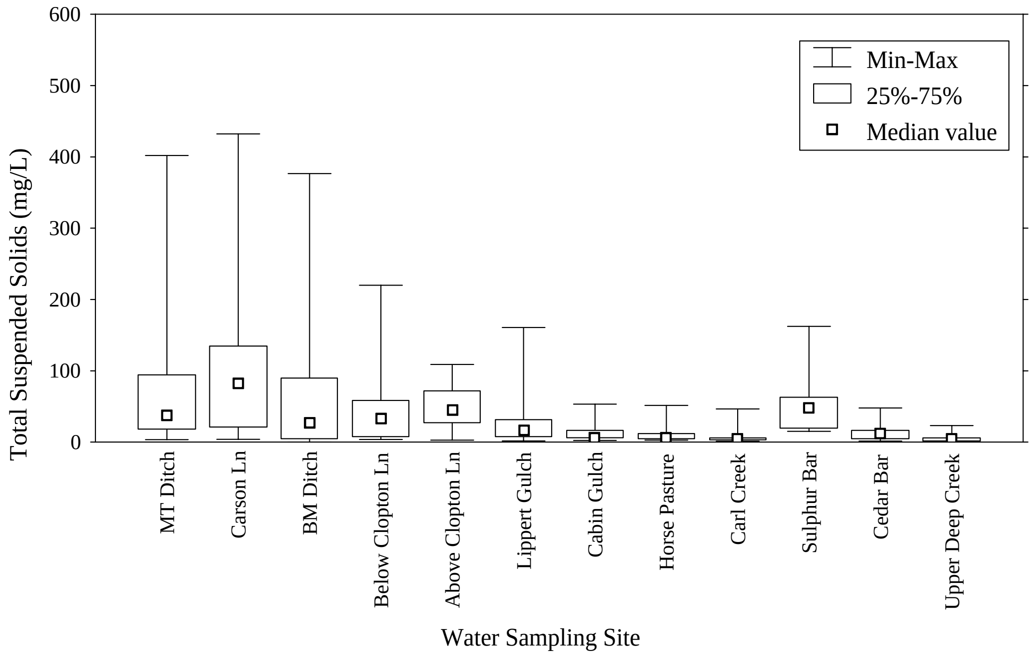

Figure 8. Total suspended solids concentration at each water sampling site.

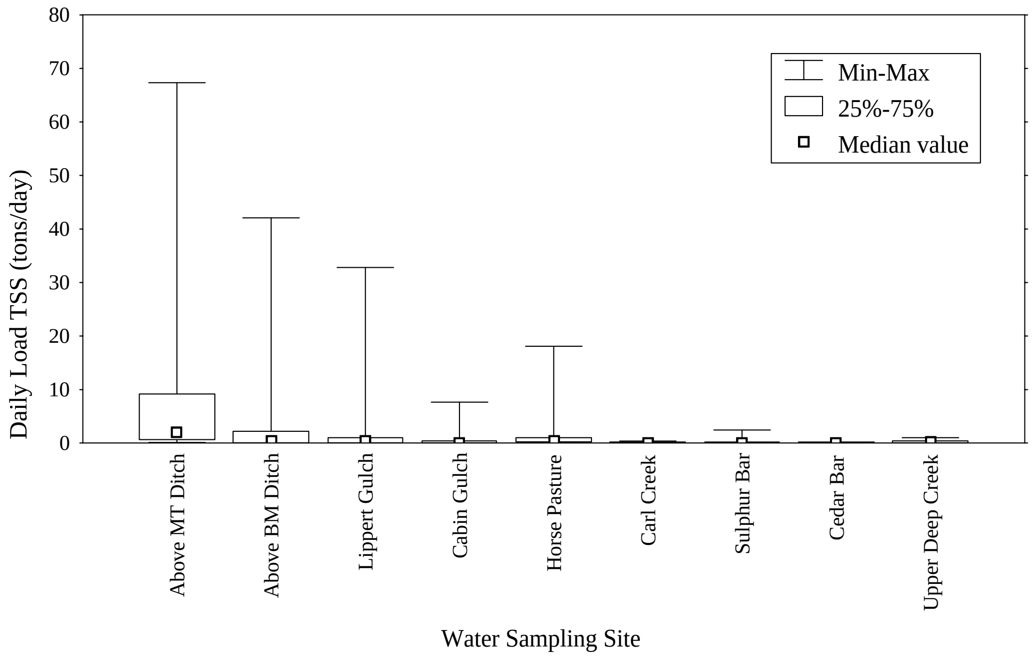

Figure 9. Daily load of total suspended solids per water sampling site.

Histograms of TSS concentration and load over time were generated to compare TSS levels within and among years (Appendices B and C). For most stations, data collection occurred in 1992 and 1993; extremely dry and wet years, respectively. Comparison of TSS concentration and discharge among the 4 major mainstem water sampling sites (Montana Ditch, Broadwater-Missouri Ditch, Horse Pasture and Upper Deep Creek) indicate that TSS increases markedly with increased flows at the 2 lower sites but not at the upper sites. For example, the Montana Ditch and Broadwater-Missouri Ditch sites showed substantially greater TSS levels in response to greater discharge in 1993 compared to 1992. Discharge increased at the Horse Pasture station at a similar level, but the increase in TSS was much lower. This indicates that stream banks above this site are more stable than banks in the lower portions of Deep Creek. At the

Upper Deep Creek station, neither discharge nor TSS concentration showed much fluctuation between years.

Comparison of TSS load over time yielded similar results (Appendix C). Daily sediment load was greatest at the Montana Ditch and Broadwater-Missouri Ditch water sampling sites with over 60 tons of sediment transported per day during peak flows. Daily sediment load transported at these sites was considerably higher than at Horse Pasture indicating major sediment sources between these sampling sites. Among tributaries, Lippert Gulch transported the highest sediment load. Headwater tributaries and Upper Deep Creek water sampling site transported small loads of suspended sediment. Comparison of TSS load for a given day among Horse Pasture and Montana Ditch stations shows that bank erosion below Horse Pasture station is responsible for the majority of the sediment yield. On May 24, 1993, TSS load estimated at Horse Pasture was 3 tons/day and at Montana Ditch, 67 tons/day. This suggests that 96 % of the sediment in transport originated below Horse Pasture.

The association between TSS and discharge was explored by correlation analysis to test predictability of TSS concentration based on discharge at each station. The ability to predict TSS concentration based on discharge would be valuable in estimating annual sediment yield. In addition, changes in the relationship between TSS and discharge offers a potential monitoring tool to assess the success of remediation activities. Of the 9 stations, only Montana Ditch showed a high correlation between TSS concentration and discharge (Figure 10). Thus, using the gauging station located at Montana Ditch will be useful in estimating annual sediment loads at the mouth of Deep Creek.

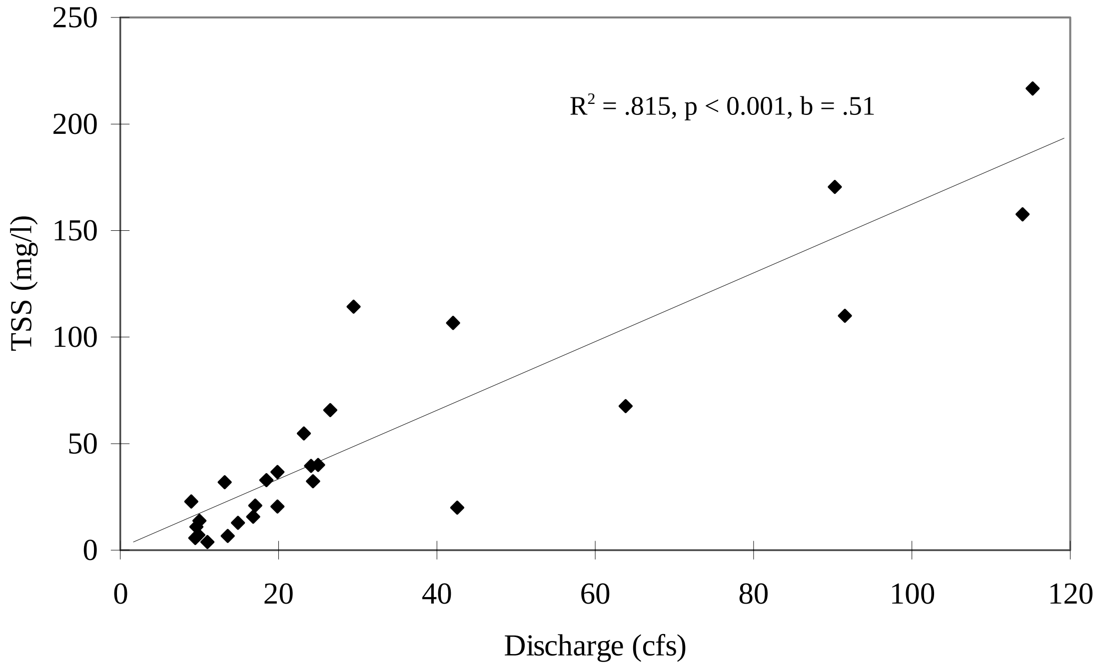

Figure 10. Relationship between TSS concentration and discharge at Montana Ditch.

Streambank and Channel Conditions.

In 1991, a streambank inventory was performed for the 11 reaches. This was an interagency effort by MDFWP, Montana Department of Environmental Quality, USFS, NRCS and local landowners. The inventory identified direct bank manipulations by humans, beaver dams and other features such as debris jams, irrigation diversions, and riprap. For each eroding bank, measurements were made on its length, height and overall stability. Stability of eroding banks was ranked as high, medium or low based on the amount vegetative and/or rock cover (Table 5). Stream banks with greater than 75 % vegetative and/or rock cover were considered to be stable and not included in the survey. Total length of erosive bank (left and right banks) was divided by twice the stream length to derive percent of the reach with erosive banks. To aid in determination of priority banks for stabilization, data on erosive banks per reach was ranked by total area of erosive bank, bank height and stability rating (data listed in Appendix A). Identification numbers correspond to numbers on the 1991 aerial photographs.

Additional information on stream characteristics included channel slope and sinuosity. Stream channel slope was obtained from topographical maps. Sinuosity was measured from the aerial photographs using a planimeter.

Streambank erosion and channel conditions were compared among reaches to identify the type and degree of degradation. In most streams, channel slope is generally highest in the upper portions of the watershed and gradually decreases downstream. Likewise, sinuosity should increase downstream as channel slope decreases and the stream becomes more meandering (Rosgen 1994). However, Deep Creek deviates from this general pattern with Reaches 4 and 5 exhibiting relatively high channel slope and low sinuosity (Figure 11). This steeper channel slope is not the result of topographical variation in landform but due to channelization; however, all channel slopes are within ranges expected in F and C channel types (Rosgen 1994). This artificially induced increase in slope in the valley has likely accelerated bank erosion and increased TSS loads and concentrations measured at Montana Ditch.

Table 5. Stream bank stability rating criteria used in 1991 Deep Creek survey.

Qualitative Rating	Numeric Rating	Criteria
High	3	50-74% of the streambank surface are covered by vegetation or by gravel or larger material. Those areas not covered by vegetation are protected by materials that allow only minor erosion.
Medium	2	25-49% of the streambank surfaces are covered by vegetation oar gravel or larger material. Those areas not covered by vegetation are covered by materials that give limited protection.
Low	1	<25% of the streambank surfaces are covered by vegetation or gravel or larger material. That area not covered by vegetation provides little or no control over erosion and the banks are usually eroded each year by high water flows.

Percent erosive bank data are shown in Figure 12. Reaches 2 and 10 show less than 10 percent eroding bank per reach. Reach 3 shows the greatest percentage eroding bank at about 20 %. Reach 1 showed the next greatest percent erosive bank; however, this section has been excluded from livestock grazing since the streambank inventory and marked recovery of riparian vegetation and bank stability has occurred since the time of the bank survey (R. Spoon MDFWP, Townsend, personal communication). Reaches 4, 6 and 8 also have greater than average percentage of eroding bank. Bank stability ratings (Figure 13) further supported these findings. Upper reaches had the highest mean bank stability. Bank stability decreases in reaches 7 through 5 to about 1.2 indicating that the majority of the erosive banks had less than 25 % vegetative cover. Bank stability rating shows modest increase in the lowest 4 reaches, although these ratings are still low compared to reaches 8 through 11. Low bank stability ratings measured in reaches 1 - 7 could be contributing to high TSS levels measured at Montana Ditch.

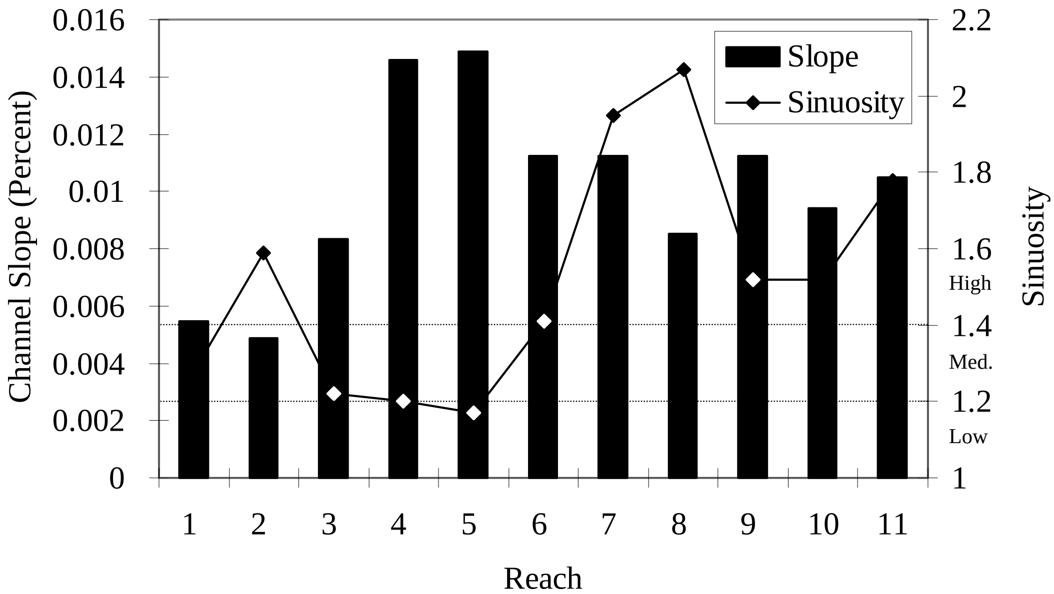

Figure 11. Channel slope and sinuosity by reach. Horizontal lines designate boundaries for low, medium and high sinuosity ratings (Rosgen 1994).

Comparison of mean length of individual eroding banks (Figure 14) identifies reaches with long expanses of eroding bank. Extended areas of erosive bank may be significant sediment sources during high flows. Reach 6 shows the longest eroding banks followed by reaches 11, 8, 3 and 1. Because of the potential contribution of sediment from these banks, they are a priority for restoration activities.

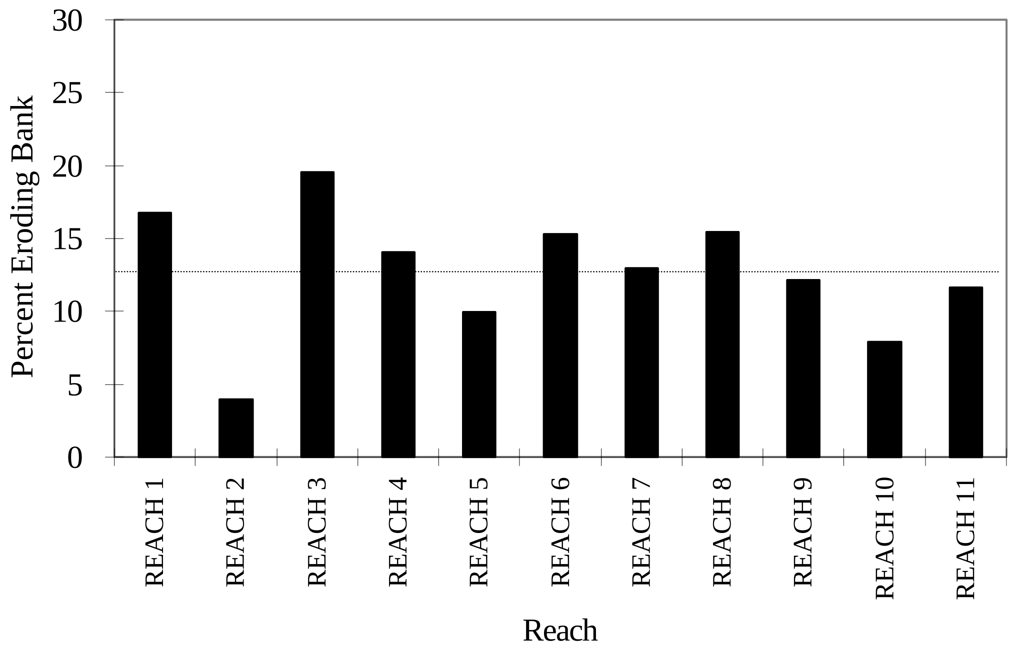

Figure 12. Percent length of reach consisting of erosive bank. Horizontal line designates mean percent of reach consisting of erosive banks for all 11 reaches.

Bank height is informative in terms of entrenchment of the stream and how easily the stream can access its floodplain in order to dissipate energy during high flows. Upper reaches show the greatest bank heights (Figure 14). This is predictable given the foothills topography through which the stream flows. The narrow floodplain increases the probability that the stream will encounter a terrace, resulting in increased bank heights. Erosive terraces can be significant sources of sediment. The relatively high banks in the lower 3 reaches indicate the channel may be making vertical adjustments resulting in incisement of banks. These adjustments result in increased entrenchment and disassociation of the stream from its floodplain.

Bank stability and channel information indicates types and degree of channel and bank degradation among the 11 reaches. The upper 4 reaches (8 -11) show a relatively small proportion of erosive bank and the stability of these banks is relatively high. However, examination of bank height information indicates that the stream is currently eroding terraces at numerous locations. These high vertical banks experience great boundary stress during high flows and are probably a significant source of sediment. Reach 7 shows a moderate amount of erosive bank; however, stability ratings are low. In addition, there in places, the stream is eroding a terrace and bank heights exceed 20 feet (Appendix A). Reach 6 shows above average percentage of erosive bank, relatively low bank stability rating and numerous long (≥ 150 feet) expanses of erosive bank which likely contribute large amounts of sediment during spring run-off. Reaches 4 and 5 show low percentage of erosive bank and bank heights and lengths are relatively low; however, most erosive banks show low stability with less than 25 % vegetative cover. The relatively high gradient and low sinuosity in these reaches may contribute to the low stability of banks. Reach 3 shows a large percentage of erosive bank. In addition, examination of bank data (Appendix A) indicates this reach has several long banks (≥ 250 feet) which are deeply incised. Low sinuosity may contribute to the problems of erosive banks. Reach 2 shows relatively "good" conditions in terms of channel and bank conditions. Less than 5 percent of the reach consists of erosive banks. Sinuosity is high, channel slope is relatively low. Finally, Reach 1 shows a high percentage of erosive bank based on the 1991 data. Conditions have improved within this reach since exclusion of livestock, making this an inaccurate estimate of current conditions. However, the stream is eroding a terrace which results in high, vertical banks. Even with rest from livestock pressures, it is difficult for vegetation to become established under these conditions.

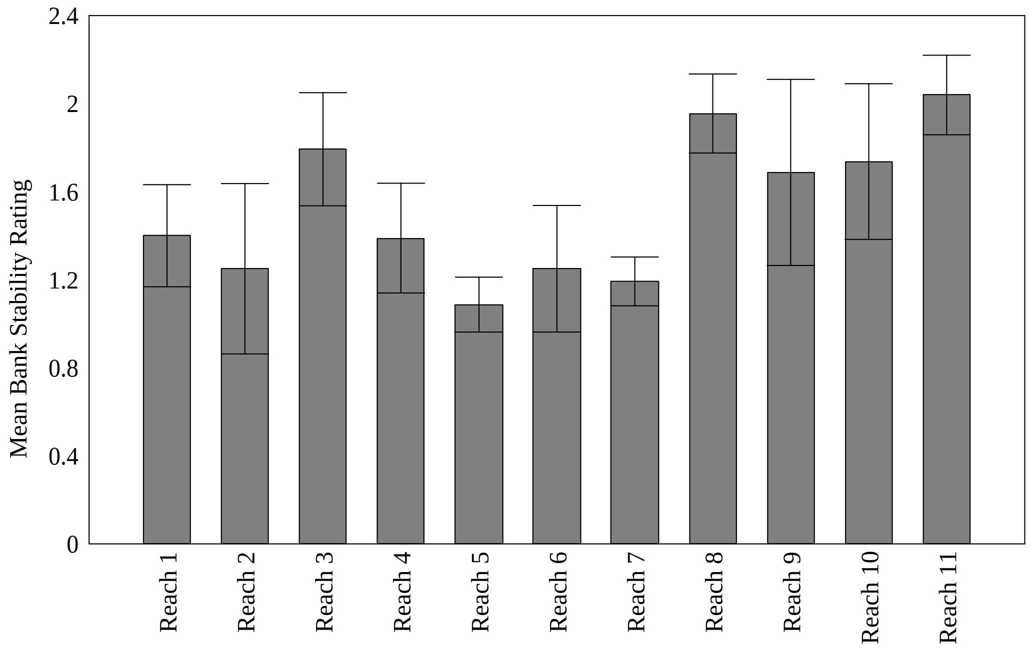

Figure 13. Mean bank stability rating per reach. Error bars illustrate 95 % confidence intervals.

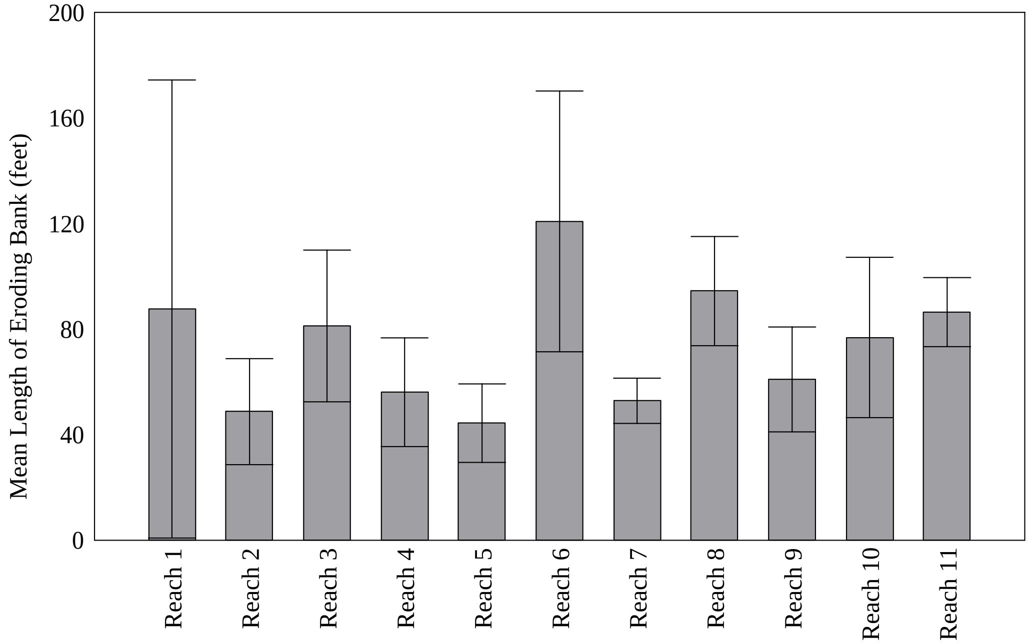

Figure 14. Mean length of eroding banks per reach.

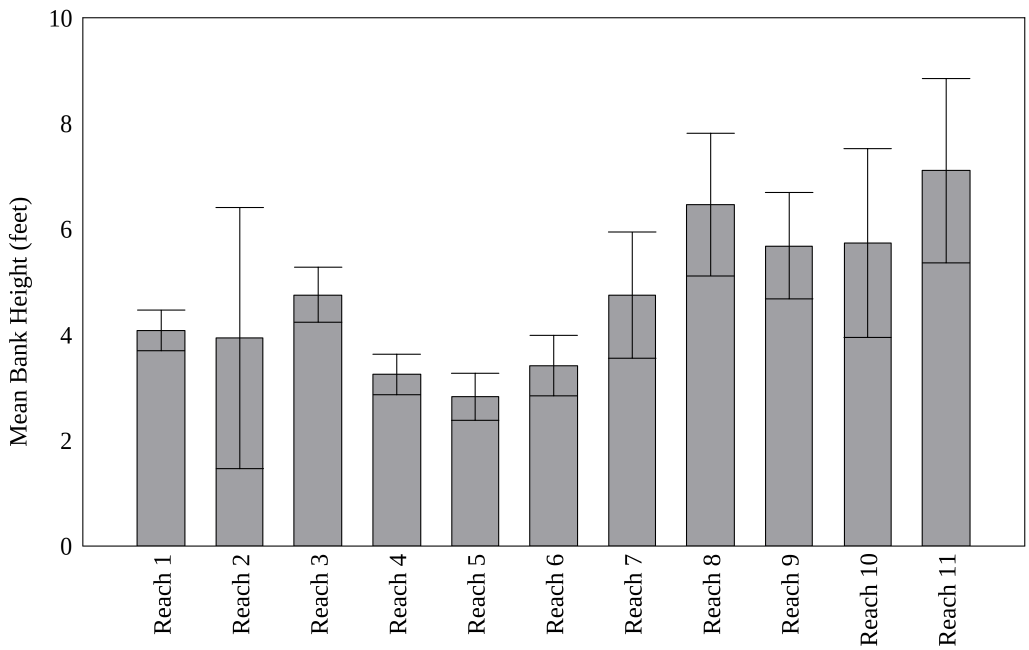

Figure 15. Mean bank height per reach. Error bars illustrate 95% confidence intervals.

Substrate

Limited information is available on substrate composition and sedimentation of streambed surfaces. Five substrate core samples were collected in 1991 from one riffle in reaches 3 and 9 using a McNeil sampler. Core samples were sorted by sieves of varying mesh size. For this report, reaches were compared by mean percent weight of particles passing through each mesh size. Proportions of fine sediment less than 0.85 mm and less than 6.35 mm were compared with fine sediment collected via McNeil sampler in westslope cutthroat trout (*Oncorhynchus clarki lewisi*) redds in the Taylor Fork drainage, Montana, a sediment-rich basin (Magee et al, in press). Fine sediment levels in redds in the Taylor Fork drainage are the highest reported in egg pockets of salmonid redds in the Rocky Mountain region. Such high sediment levels resulted in very low estimated embryo survival (< 8.5%).

Comparison of core samples among Reaches 3 and 11 does not indicate any striking differences in substrate composition (Figure 16). However, data is limited to 2 riffles and is not sufficient for broad inference to conditions throughout Deep Creek. Proportions of fine sediments in Deep Creek were slightly higher than proportions of fine sediments in redds in the Taylor Fork (Figure 17). Inference regarding these samples is limited by numerous factors including sample size and collection protocol, however, it does indicate that sedimentation on Deep Creek is possibly similar to sedimentation on the Taylor Fork.

Although there were no striking differences in substrate conditions in Reaches 3 and 11, overall, riffles contained a very high proportion of fine sediments. In both reaches, particles < 6.35 comprised about 50% and < 0.85 mm comprised about 20% of total sediments by weight (Figure 17). These values are equal to or greater than those observed in Taylor Fork spawning redds. Emergence success of redds constructed in this substrate (proportion < 6.35 = 50 %) was estimated using the equation developed by Weaver and Fraley for cutthroat trout (1993):

Emergence success (%) = -0.7512 (arcsin transformed percent substrate particles < 6.35 mm) + 39.67.

which yields an estimate of 6 %. Although redds and non-redd areas in riffles are not always equivalent (Chapman 1988), these data do indicate low potential of redds in Deep Creek for successful egg-fry survival.

Substrate conditions were also estimated during application of Rapid Bioassessment Protocol (RBP) in Deep Creek. RBP was performed in Reaches 3 and 9 in 1991 (McGuire 1992). A Broadwater-Missouri Ditch sampling site was added in 1992 (Brooks 1993). RBP is a tool to assess the biological integrity of a stream (see below). The streambed condition assessment portion of RBP involves assigning a score between 1 and 20 based on visual estimation of substrate composition and embeddedness using criteria provided in Table 5..

Comparison of substrate quality information gathered for RBP assessment shows substrate composition to be optimal at the 3 sampling sites for both years. In terms of

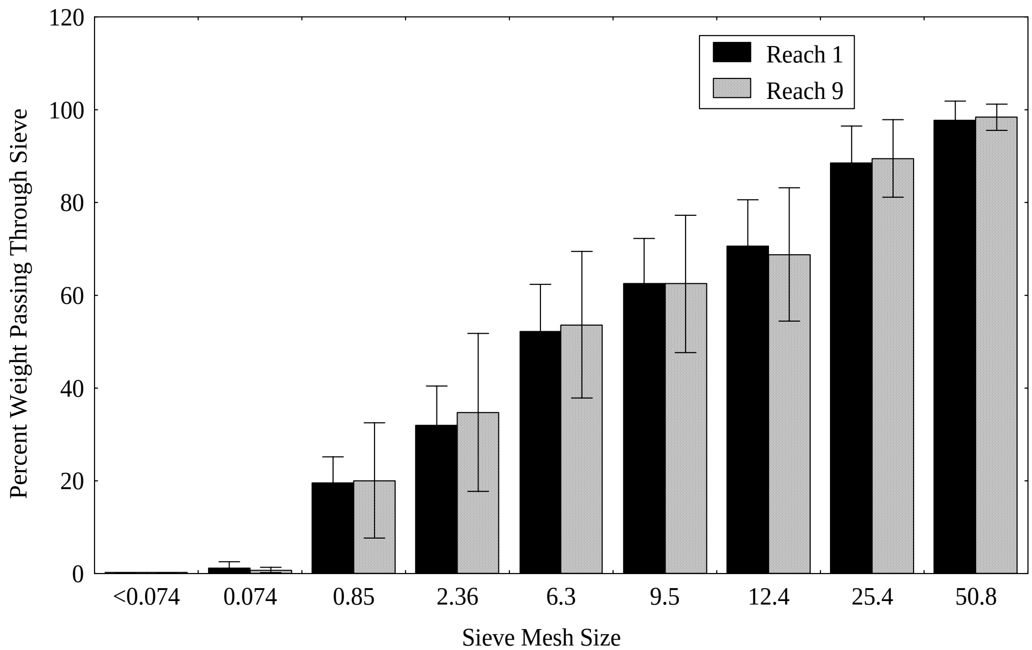

Figure 16. Mean percent weight of substrate particles passing through sieves of varying mesh size of core samples collected on Reaches 3 and 9 on Deep Creek. Error bars illustrate 95% confidence intervals.

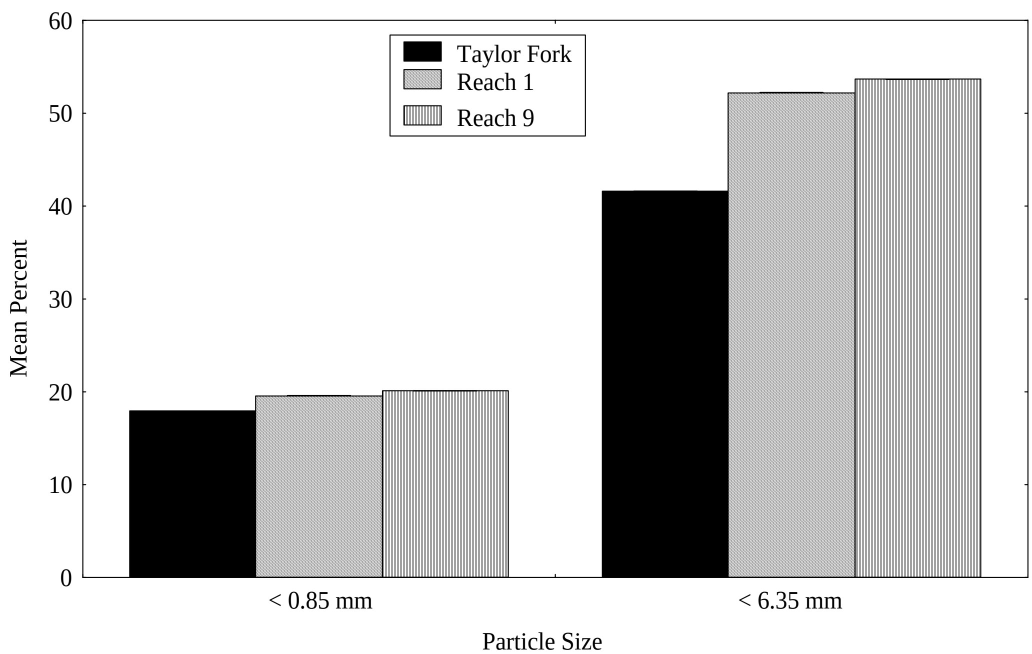

Figure 17. Comparison of proportion of fine sediment particles from Reaches 1 and 9 on Deep Creek and within redds in the Taylor Fork drainage (Magee et al., in press).

embeddedness, however, Reach 3 shows marginal to sub-optimal conditions indicating a greater degree of embeddeness than the other 2 sampling sites.

Table 6. Criteria for rating of substrate quality and embeddedness used in Rapid Bioassessment Protocol (Bukantis 1995).

Substrate Parameter	Category			
	Optimal	Sub-Optimal	Marginal	Poor
Substrate Composition	Diverse substrate dominated by cobble.	Substrate diverse, with abundant cobble and boulder; fine gravel or sand prevalent.	Substrate dominated by bedrock, boulders, fine gravel, sand or silt, cobble present	Monotonous fine gravel, sand, silt, or bedrock substrate
Score	16-20	11-15	6-10	0-5
Embeddeness	Gravel, cobble or boulder particles are between 0-25% surrounded by fine sediment particles less than 0.25 in.	Gravel, cobble, or boulder particles are between 25-50% surrounded by fine sediment.	Gravel, cobble, or boulder particles are between 50-75% surrounded by fine sediment.	Gravel, cobble, or boulder particles are over 75% surrounded by fine sediment.
Score	16-20	11-15	6-10	0-5

Table 7. Substrate conditions ratings from RBP on Deep Creek (McGuire 1992; Brooks 1993).

	Reach 3		Reach 11		Broadwater-Missouri Ditch
Parameter (Range)	1991	1992	1991	1992	1992
Substrate Composition (0-20)	19	19	18	16	18
Embeddeness (0-20)	12	10	20	18	16

Dewatering

Another stress on aquatic life in Deep Creek are low flows experienced during the summer irrigation season. The gauging station located near the Montana Ditch siphon provides a record of daily discharge near the mouth of Deep Creek. Dewatering has been addressed through cooperation between irrigators and MDFWP and available data represents improvement from past conditions. Flows are available from 1993 and 1994, again representing extremely wet and dry years respectively. Data are not available for the most severely dewatered portions of Deep Creek (Reaches 5 through 9).

Comparison of hydrographs for available years illustrates the range of flows that can occur on Deep Creek (Figure 18). During 1993, flows remained elevated throughout much of the summer due to above normal precipitation. However, lack of rainfall, compounded by irrigation withdrawals resulted in extremely low flows during the summer of 1994.

The combination of high air temperatures and low flows results in increased water temperatures. During the hot summer of 1994, water temperatures increased concurrently with decreased flows and maximum temperatures were above the tolerable levels for trout for 50 days (Figure 19). During 1993, flows remained elevated throughout the summer and water temperatures remained within tolerable levels for trout (Figure 20). It should be noted, however, that although high temperatures were not a stress on aquatic life, high sediment levels accompanied increased discharge in 1993.

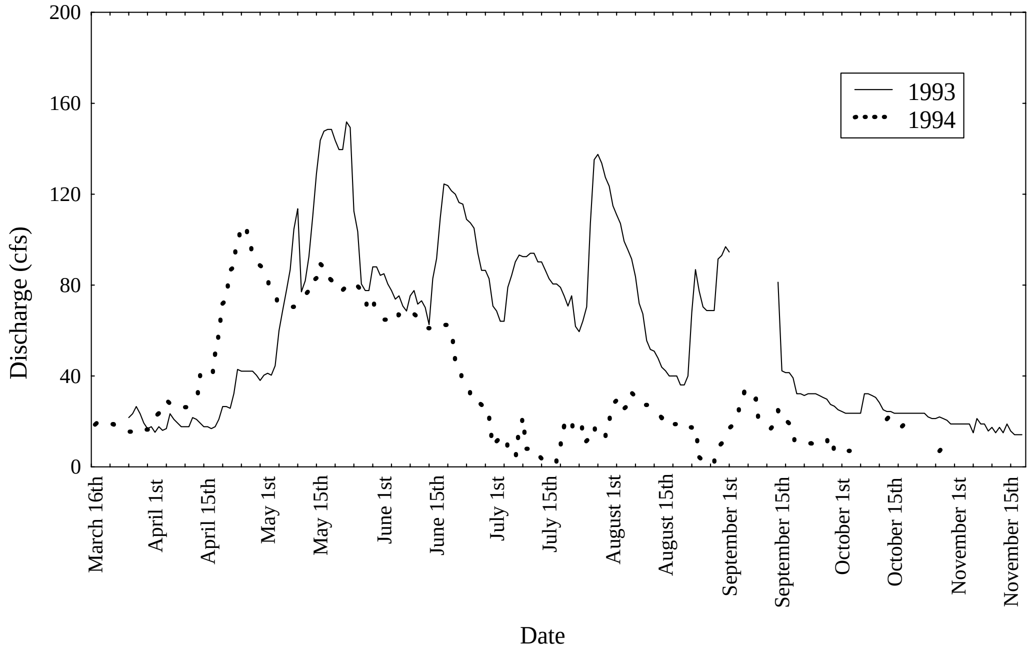

Figure 18. Daily flows monitored at Montana Ditch gauging station during 1993 and 1994.

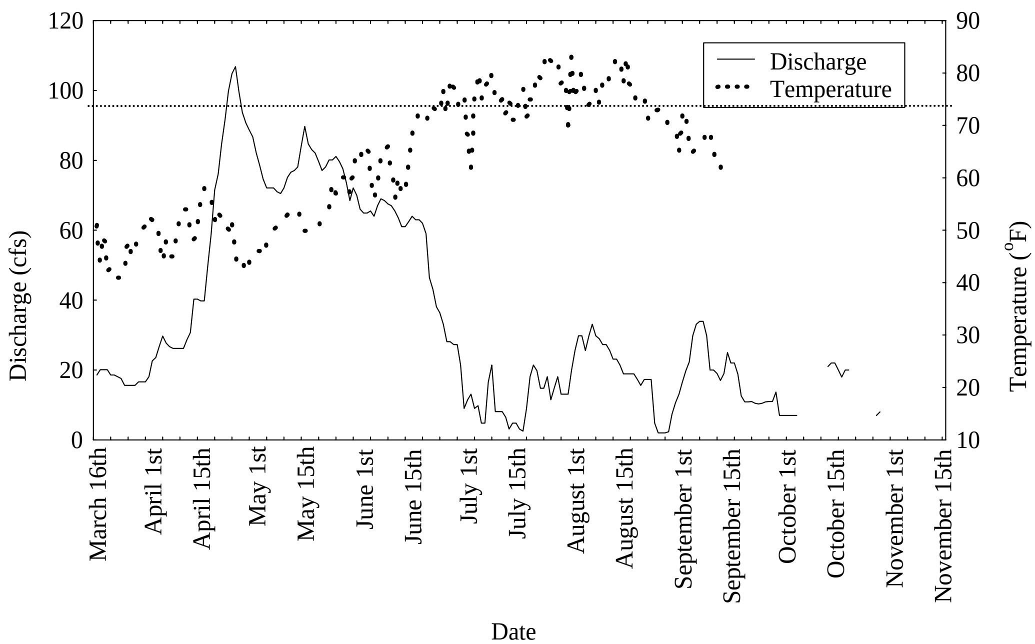

Figure 19. Discharge and water temperature measured at Montana Ditch gauging station and thermograph during 1994. Horizontal line represents thermal threshold for trout (Bell 1986).

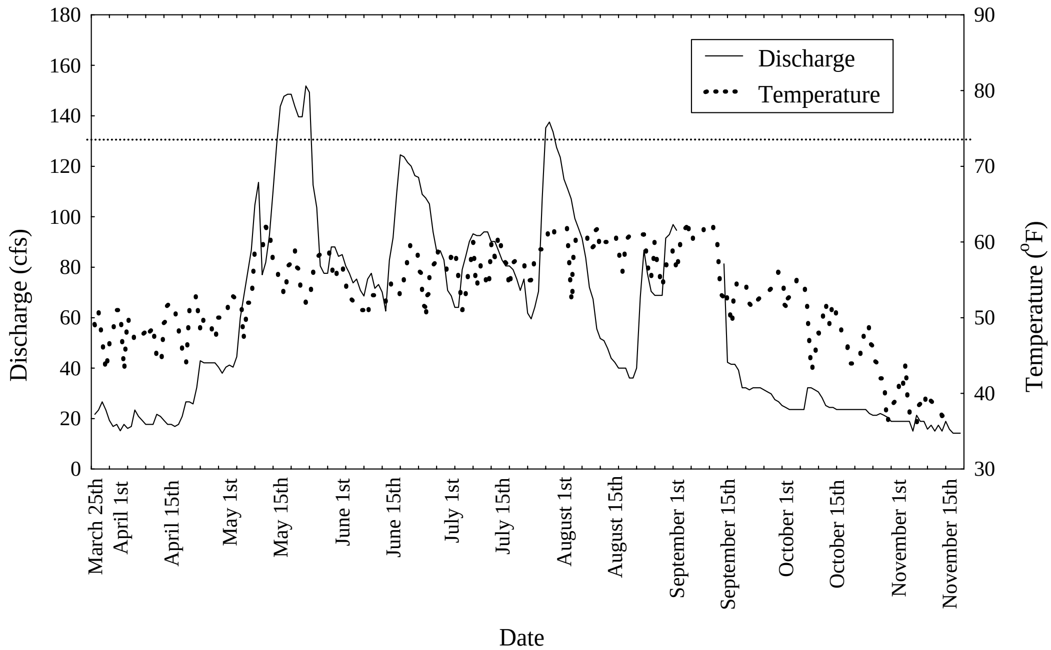

Figure 20. Discharge and water temperature measured at Montana Ditch gauging station and thermograph during 1993. Horizontal line represents thermal threshold for trout (Bell 1986).

Trout Fishery

In addition to a resident trout populations, Deep Creek is used by adult trout from the Missouri River/Canyon Ferry Reservoir for spawning. Their progeny are believed to rear in Deep Creek for one year prior to migration to the Missouri River (R. Spoon, MDFWP, personal communication). Canyon Ferry reservoir has been planted with several stocks of rainbow trout. Recently, efforts have been made to promote natural reproduction of rainbow trout by stocking wild strains.

Trout use of Deep Creek has been monitored since the construction of the Montana Ditch siphon. A weir has been operated at the siphon to monitor movement of trout in and out of Deep Creek. Adult trout from the Missouri river entering Deep Creek to spawn are trapped in addition to juveniles migrating to the Missouri River after rearing in Deep Creek. The proportion of fish captured in the weir varies with flow. During periods of low flow, approximately 100% of the fish moving through this weir are captured. During spring run-off, only a portion of the flow is sampled with the weir allowing fish to elude capture. Data on young of the year (YOY) and age1+ trout (brown trout and rainbow trout) passing through the weir towards the Missouri River were sampled daily from March to August 1994 as part of a graduate student study (Snelson, in press). For each sampling date, the proportion of flow sampled by the weir was visually estimated and rated as an approximate percent of the water column sampled. The number of trout trapped per day was recorded and extrapolated to percent of water column sampled by the weir. Because capture probability at high flows is unknown, these estimates may not be valid.

Based on data from the weir, 3,000 adult trout migrate to Deep Creek from the Missouri River/Canyon Ferry fishery to spawn (R. Spoon, MDFWP, Townsend, personal communication). Assuming a 1:1 sex ratio and an average fecundity of 2,000 eggs/female, an estimated 3,000,000 eggs are laid by the 1,500 females. Using egg to swim up fry survival estimates of about 40-50% for over a range of substrate conditions (Shepard et al. 1984; Weaver and Fraley 1993), an estimated survival for “average” substrate conditions yields 1.5 million fry.

Information on survival from emergence to age 1 is limited, but usual estimates for this period is 5 % (Bjorn and Johnson 1977, cited in Rieman and Apperson 1989). Thus, expected recruitment of trout to the Missouri River/Canyon Ferry Reservoir from Deep Creek is 75,000 age +1 juveniles. The estimated number of juveniles produced based on weir data (approximately 1,000) is a small fraction of the potential recruitment (Table 8). This estimate of juveniles produced has to be balanced with several unknown factors such as how many fish remain in Deep Creek beyond age +1 and sampling efficiency problems of juveniles when they migrate from the stream during spring run-off. Nevertheless, the high proportion of fines in spawning riffles (50%), low estimated emergence success (6 %), plus the relatively few juveniles observed, strongly suggest that actual juvenile recruitment is well below that of potential.

Weir data has been supplemented with redd counts. Data on brown trout redd counts are available for Reaches 1 - 11 and above Reach 11 to the Deep Creek rest area (Figure 1) from 1991 to 1993. Rainbow trout redd counts are not available as high flows and turbidity preclude location of redds during much of the spring spawning period. However, it is believed that rainbow trout utilize the same spawning areas as brown trout (R. Spoon, MDFWP, Townsend, personal communication) and thus brown trout redds may be used as an index of where rainbow trout spawning is likely to occur in Deep Creek.

Redd surveys indicated that few redds occur in the lower reaches where sedimentation, as measured by TSS and bank erosion is very high (Figure 21). The occurrence of brown trout redds increased markedly in the upper, less sedimented reaches. While it is unclear how many of these redds were produced by resident or adfluvial fish, marked brown trout trapped at the weir have been observed spawning above Reach 11 (R. Spoon, MDFWP, Townsend, personal communication).

Table 8. Juvenile trout trapped at weir near Montana Ditch siphon in 1994.

Species	Total Number of Age 1+ Trout Trapped	Estimated Number of Age 1+ Trout Moving Past Weir	Number of Young of Year Trout Trapped
Rainbow Trout	235	949	40
Brown Trout	87	347	0

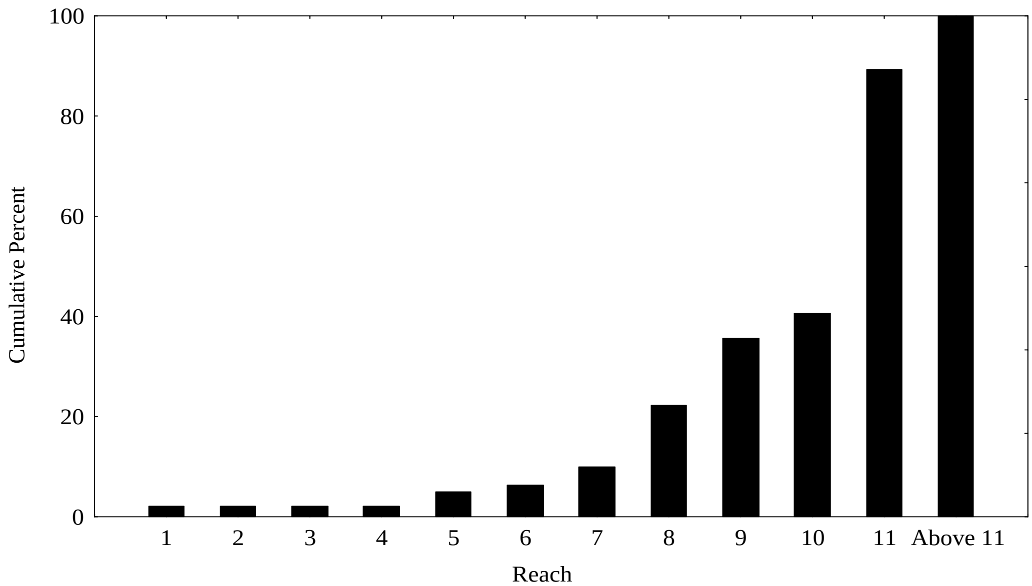

Figure 21. Cumulative percent of brown trout redds counted on Deep Creek.

Rapid Bioassessment Protocol (RBP)

RBP was also employed to assess biotic impairment. RBP was developed by the EPA as a tool to assess the biological integrity of aquatic systems (Plafkin et al. 1989). Supporting information is gathered on habitat condition in addition to community composition and functional feeding group composition of benthic macroinvertebrates. Macroinvertebrate assessments of biological health were done on Deep Creek using RBPIII (Plafkin, Bukantis 1995) This procedure was conducted during 1991 (McGuire 1992) and 1992 (Brooks 1993). In 1991, RBP was performed at Reach 3, and Reach 11, above the most impacted sections. In 1992, a third site near Broadwater-Missouri Ditch was added (Reach 5). Results of RBP were compared among years, among sites and with Montana Valley and Foothill Reference data (Wisseman 1992). This analysis indicates degree, location and type of impairment of water and habitat conditions.

Results of RBP assessment indicate decreased habitat quality and changes in macroinvertebrate community composition between Reach 11 and Reach 3. Habitat quality was rated as sub-optimal at both locations, the lower reach had a lower score due to increased substrate embeddedness. Results of the 1991 assessment (McGuire 1992) indicate that the benthic fauna at Reach 11 was comprised of species intolerant of stream dewatering, fine sediment deposition, nutrient enrichment, and elevated water temperatures. This assemblage was largely replaced by more tolerant species at Reach 1. Comparison of communities against the Montana Valley and Foothills Stream Reference Community (Wisseman 1992) indicate that biological integrity appeared to be unimpaired at the upper reach and slightly impaired at Reach 1. In the 1992 analysis, habitat conditions improved in Reach 1, perhaps due to riparian improvement; however, biological conditions remained unchanged, indicating water quality conditions related to soil erosion and dewatering continued to impact biota.

Conclusions

Based on the above information, aquatic life in Deep Creek is impaired by several types of habitat degradation. Degraded instream habitat and water quality on Deep Creek is the result of degradation of riparian vegetation communities and dewatering. Bank stability is poor throughout the lower reaches resulting in bank collapse, loss of meander bends, stream entrenchment and high suspended and deposited fine sediment. Water temperatures become elevated due to limited riparian shading and dewatering. Dewatering may also impair migration of juvenile salmonids to the Missouri River. The combined effects of degradation on Deep Creek result in impacts on aquatic life which can be seen in the low production of juvenile trout and alteration in communities of benthic macroinvertebrates in Reach 1. Priorities for remediation on Deep Creek include prevention of additional channel length loss and stabilization of stream banks that are significant sources of sediment, primarily in Reaches 1 through 8 plus 11; and maintenance of adequate flows throughout the summer months.

IV. REMEDIATION

Overview

A variety of stream restoration activities can be implemented along Deep Creek that would increase bank stability, decrease erosion, and increase the health of the fishery by reducing sediment stresses and improving fish habitat. Three general categories of restoration procedures could be applied on Deep Creek. These categories are: 1) riparian best management practices (BMP's), 2) direct stabilization of banks through installation of tree revetments, and 3) mechanical alteration of the shape of the channel to more stable channel configurations. Each category varies in terms of labor, materials, equipment, and cost.

Although these three stream restoration approaches are used widely throughout the western United States, little is known regarding how these methods compare in terms of relative cost and effectiveness. Therefore, it is proposed that remediation activities on Deep Creek be planned under the guidelines of adaptive management (Halbert 1993) in order to compare the effectiveness of the various proposed remediation methods. Monitoring, therefore, is a critical component of remediation. Determination of cost-effectiveness of these procedures can guide future restoration projects in Deep Creek and other watersheds having excessive sedimentation.

The first and least intensive category of treatment involves implementing riparian best management plans (BMP's) to promote the health and vigor of riparian vegetation communities and hence promote bank stabilization. Riparian BMP's are recommended for the entire stream, regardless of other remediation activities. Implementation of appropriate riparian management through BMP's will ensure the long-term success of more intensive streambank alterations.

Riparian BMP's can be related to both livestock management and cultivation practices. Grazing practices along riparian areas vary in terms of compatibility with riparian vegetation and fisheries needs (Platts 1991, Kovalchick and Elmore 1991). Possible grazing management strategies that may be employed range from rest-rotation grazing systems to temporary (e.g. 5 to 10 years) exclusion of livestock from severely degraded sections. Along other stretches of Deep Creek, increasing the width of the riparian buffer by not cultivating as close to the stream could show a positive effect on riparian, bank, and stream conditions. Deep rooted shrubs provide more structural support to stream banks than shallow rooted herbaceous crops. Planting of willow cuttings can be used to promote regeneration of shrubs in conjunction with both these approaches.

The second type of remediation is to add riprap or tree revetments to protect banks and prevent further soil erosion (McClure 1991). Tree revetments on Deep Creek have used Rocky Mountain juniper trees (*Juniperus scopulorum*) overlapped (1/3 to 1/2 of tree length) along the inside bend of an erosive bank (Figure 22). Riprap construction involves sloping incised banks with a backhoe then installing rocks of about 1 m diameter overlain by rocks of smaller diameter (ca. 20 - 80 cm). Both riprap and tree revetments can be used to promote the structural integrity of banks and reduce soil erosion.

Tree revetments are recommended over riprap for bank stabilization on Deep Creek. In a comparison of riprap with tree revetments on Deep Creek, McClure (1991) concluded that tree revetments have several advantages. Tree revetments immediately increase instream cover for trout and decompose over time allowing restoration of more natural and functional streambanks. Revetments allow for the establishment of vegetation, particularly shrubs which promote long-term bank stability. In some locations, banks stabilized with tree revetments are virtually indistinguishable from natural, pristine streambanks within 5 years after installation (Endicott, personal observation). Another advantage of juniper revetments over riprap is cost as they do not require large machinery to install. Finally, a key feature of revetments is that they function to trap sediment which provides soil for re-establishment of riparian vegetation. Trapping of sediment is a desirable characteristic in a sediment rich stream like Deep Creek.

Reach Specific Recommendations

Based on existing data, a number of reach specific recommendations for remediation on Deep Creek are proposed. Because data on erosive banks is several years old, it is advisable to repeat the bank survey prior to remediation efforts due to possible changes in conditions since the 1991 survey. Additional parameters could be measured to assess channel entrenchment. The use of global positioning system (GPS) technology would improve the efficiency. Priority banks for mechanical alteration are identified as those stretches of erosive bank with an length of greater than 100 ft and/or with bank heights of greater than 5 feet (i.e. erosive terraces or highly entrenched areas; Appendix A). Riparian BMP’s are recommended for the entire stream and may be sufficient for erosive banks with lengths of 100 ft or less. A priority for remediation on Deep Creek is to prevent additional loss of the channel length by loss of meander bends. Therefore, erosive banks associated with meanders at risk of cut-off should be the focus of intensive remediation efforts.

Figure 21. Diagram of juniper revetment for stabilizing outer meander bend.

Reach Specific Remediations

Reach 1. Although bank conditions in this reach have improved since exclusion of livestock, additional bank protection is recommended. A potential source of sediment occurs where the stream has been eroding a terrace. Either Rosgen type channel modifications or tree revetment is recommended for stabilization of erosive terraces.

Reach 2. This section shows the lowest percentage of erosive bank among the 11 reaches, but several banks that exceed 8 feet in height appear to be significant sources of sediment. Either channel modifications or juniper revetment are recommended on these banks. In addition, this reach has 2 meanders which are at risk of being cutoff. These areas of potential channel loss are high priorities for remediation effort. Increasing the riparian belt through riparian BMP's and willow plantings, particularly on the right side of the stream that shows limited riparian shrub communities should be a priority for this reach.

Reach 3. A large proportion of this reach consists of deeply incised, erosive banks. Therefore, either channel modification or tree revetments are recommended for bank stabilization. Another recommendation involves conducting a feasibility study to re-activate the abandoned channel below Lightning Barn Lane. Spring flow could be distributed between two channels, thereby reducing erosion, providing trout spawning habitat, and addressing landowner concerns regarding loss of croplands due to bank erosion. In addition, continuation of assistance to the Broadwater-Missouri Ditch Company in its annual start-up and shut-down practices is recommended to decrease sediment pulses from operation of the ditch.

Reach 4. Impairment in this reach is due to a combination of low sinuosity, high gradient, a narrow riparian zone, and high bank erosion. Improving riparian conditions through riparian BMP's, willow transplants, and widening of riparian zone width is recommended. In addition, reactivation of abandoned channel meanders is recommended to improve fish habitat and dissipate flow energies and hence reduce erosion. Banks can be stabilized using either tree revetments or channel modification. With increased riparian width, stream type can be converted to C4 configuration which provide better fish habitat. Otherwise, conversion to B4 channel type would be possible given the narrow floodplain available.

Reach 5. The combination of high channel slope, low sinuosity, and low bank stability ratings indicates that this section contributes a significant amount of sediment during high flows. Restoration activities should focus on increasing channel length and riparian width. Because of similarities between Reaches 4 and 5 in terms of channel slope, sinuosity, and bank height, as well as their proximity, these reaches provide an opportunity to employ adaptive management to test the effectiveness of the various restoration methods. Alternating stretches can be subjected to conversion to C4 and B4 channel configurations, tree revetment, rest from grazing, riparian BMP's, or no treatment. Monitoring activities will aid in the assessment of the success of the respective remediation activities in promoting desirable conditions for reducing bank erosion, and, improving water quality and fish habitat.

Reach 6. Re-evaluation of meander bends stabilized in 1988 with tree revetments or rip-rap would be valuable to assess long-term conditions after stabilization. Several long stretches of eroded stream bank should be stabilized using channel modifications or tree revetments (See Appendix A, Table 6a). Preservation of channel length through protection of a meander bend at risk of cut-off should be addressed through bank stabilization procedures. Finally, riparian willow transplants should be used to reduce erosion of banks during winter by providing insulation of banks and reducing build-up of ice shelves (Platts and Nelson 1989).

Reach 7. Priority management for this reach is preservation of channel length by protection of 4 meanders bends threatened by loss by a combination of riparian vegetation plantings, channel modifications, and tree revetments. In addition, there are several places where the stream is actively eroding a terrace (see eroding banks no. 96 and 96, Appendix A, Table 7a) that likely contribute significant amounts of sediment and require channel modifications and/or tree revetments.

Reach 8. First, assistance is recommended to a landowner who has expressed interest in fencing a 5 mile stretch of Deep Creek to exclude livestock from the stream and riparian areas. Second, channel length should be protected by preservation of 2 meanders at risk of cut-off through re-establishment of vegetation and/or channel modifications or tree revetment. Third, examination of erosive bank data (Appendix A, Table 8a) indicates several erosive terraces that are a priority for stabilization. Finally, this section has lost about 3,000 feet of channel since 1955. Increasing channel length through re-establishment of abandoned meanders should be considered.

Reach 9. Several banks in this reach appear to be significant sources of sediment (Appendix A, Table 9a) and should be stabilized with channel modifications and/or tree revetments. Overall, though, there is limited degradation apparent in this reach.

Reach 10. While riparian and stream conditions appear to be generally good in this section, there are several incised and eroded banks which may be a significant source of sediment (see Appendix A, Table 10a). Employment of channel modification procedures or tree revetment is recommended to reduce erosion of these stream banks.

Reach 11. Riparian and stream conditions are generally good in the upper portion of this section. However, the lower half of this reach has significant bank and terrace erosion resulting in significant loss of irrigated hay fields annually (R. Spoon MDFWP, Townsend, personal communication). It would be valuable to compare techniques used in stabilization of erosive terraces between this reach and Reach 10.

V. DEEP CREEK TMDL

Deep Creek has been identified as a candidate stream for the development of a TMDL. The first step in the development of a TMDL is identification of existing constraints to instream communities. Examination of existing data in this document indicates that aquatic life in Deep Creek is impaired due to several stressors. These stressors are: 1) high total suspended solids, 2) degraded stream habitat (i.e. loss of bank overhang and meander bends), 3) excessive substrate embeddedness, 4) high water temperatures, and 5) excessive dewatering. This results in limited recruitment of trout and poor water quality.

The next step in TMDL development is the ranking of identified stressors. On Deep Creek, stressors are inter-related, yet ultimately tied to high erosion, excessive sedimentation and dewatering. Most of the constraints on biota are the function of channel adjustments which are likely the result of riparian degradation and channel straightening, which have resulted in bank erosion, loss of undercut bank, widening of the channel, increased concentrations of suspended sediments, and sedimentation of substrate surfaces. High levels of total phosphorus may be related to phosphorus adsorbed to soil particles (as suggested by regression analysis, Figure 4) or disruption of riparian areas ability to filter agricultural run-off (Lowrance et al. 1984). High summer water temperatures are probably related to channel widening, loss of vegetation, and excessive dewatering.

The third step in the development of the TMDL is to identify sources of degradation. On Deep Creek, sources of degradation include landuse practices that promote bank erosion via loss of riparian vegetation buffer and channel straightening. Irrigation withdrawals in the lower portion of the watershed also result in dewatering during the summer months. Dewatering is most severe in Reaches 5 through 9 (R. Spoon, MDFWP, Townsend, personal communication). These causal factors result in sources of degradation that vary throughout 11 reaches.

The next step in the TMDL process is to propose a remediation plan that involves establishing quantifiable targets for successful remediation. While the title “TMDL” implies that these goals are expressed in terms of concentrations or levels of a given pollutant, a TMDL can be phrased in terms of any quantifiable goal related to the aquatic system. For example, a TMDL can be defined as established decreases in percent eroding bank or measured increases in trout recruitment.

A general guideline for remediation on Deep Creek is provided above. More specific remediation plans will be designed based on landowner participation and preliminary construction design drawings of existing channel configurations and determination of appropriate channel geometry.

A number of TMDL targets are proposed here to meet the goal of reducing impairment on Deep Creek (Table 9). First, is the establishment of a numeric goal for suspended sediment load. Meeting a State numeric standard for suspended sediment is an obvious goal, but Montana lacks such a standard for suspended sediment. In addition, because of the relationship between discharge and TSS, it is difficult to set a specific target because these targets could be met in low water years and exceeded in unusually wet years. One proposed goal, then, is to decrease the slope of the regression between discharge vs. TSS by half in 4 out of 5 years (from 0.51 to 0.26).

Another TMDL target to measure reduction in suspended sediment load is to compare sediment loading with a neighboring watershed in which excessive bank erosion or suspended sediment levels are not a problem. Sixteen Mile Creek is a candidate for this approach. The numeric goal could be that sediment load during spring run-off does not differ significantly between Deep Creek and the reference stream in 4 out of 5 years.

A second TMDL target is based on a quantifiable reduction in the amount of erosive banks. By decreasing the contribution of sediment and increasing channel stability, this would address several of the identified stressors including high TSS, high total phosphorus, and high substrate embeddeness. One approach to this would be to identify priority stream banks per reach (i.e. banks that are a significant source of sediment or are implicated in potential loss of stream length). Priority banks are identified in this report as eroding banks with a length of greater than 100 ft and or height of greater than 5 feet (Appendix A). An overall target is to decrease the percentage of eroding banks by 50% over the next 10 years, with particular emphasis on reaches 1 - 8 and 11, the sources of most sediment.

A third TMDL target is to replace stream channel lost by reducing the 9,100 feet of channel lost by 25 % over the next 5 years. By re-establishing meanders, flow velocities will be dissipated during high water events, resulting in decreased erosion and increased channel stability. In addition, habitat conditions for fish will be improved with return to a more natural channel configuration that includes undercut banks. This approach requires determining proper channel geometry configuration based on additional field data.

A fourth TMDL target is to reduce substrate fines < 6.35 mm in substrate cores from 50% to 30% in spawning riffles over the next 5 years. Such a reduction could potentially increase egg-fry survival threefold from the estimated 6 percent to 15 percent. In addition, a reduction in surface fines would be an indicator of improvements in channel and bank stability. Available data on substrate composition and percent surface fines, however, is limited. Establishing a TMDL based on substrate conditions would require collection of data on substrate conditions such as a Wolman pebble count (Wolman 1954) and/or percent fines grid.

Setting TMDL targets is also possible for biotic conditions in the watershed. Given capture efficiency problems with juvenile fish, a TMDL targeting adult spawners from the Missouri River/Canyon Ferry Reservoir may be more desirable. Therefore, I suggest a numeric target for number of spawning wild trout entering Deep Creek of 3,000 females/year over the next 10 years which is about double current numbers. Increased recruitment would result in greater numbers of adult trout imprinted on Deep Creek returning to spawn.

A sixth TMDL target is to address thermal problems in Deep Creek. The target is that temperatures not exceed 73 ^{o}F for more than 10 days per year along the length of Deep Creek. This would be a substantial improvement over 1994, when temperatures exceeded 73 ^{o}F on 50 days.

Finally, a TMDL target addressing dewatering is set at not less than 9 cfs in the lower four and upper two reaches, and, not less than 3 cfs in Reaches 5 through 9. These targets are based on requests by MDFWP from the Upper Missouri Basin Water Reservation. These flows allow for fry migration and represent a significant improvement of past flow conditions (R.Spoon MDFWP, Townsend, personal communication).

The final and vital component of the TMDL development is design of a monitoring protocol. The purpose of monitoring is to assess the success of restoration activities at meeting TMDL targets and providing information about which restoration activities are most cost-effective for future restoration efforts.

Table 9. TMDL targets for Deep Creek. Targets are to be achieved within 5 years of implementation of restoration activities.

Parameter	Baseline Condition	Target Condition
Slope of discharge vs. TSS regression at Montana Ditch	0.51	0.26 in 4 of 5 years
Comparison of daily TSS load during spring run-off on Deep Creek with reference stream (i.e. Sixteen Mile Creek)	unknown	not significantly different in 4 of 5 years
Percent of reach consisting of erosive banks		
Reach 1	17	8.5

Reach 2	4	2
Reach 3	20	10
Reach 4	14	7
Reach 5	10	5
Reach 6	15	7.5
Reach 7	13	6.5
Reach 8	16	8
Reach 9	12	6
Reach 10	8	4
Reach 11	12	6
Re-establishment of lost channel length	9,100 feet lost since 1955	add 2275 feet
Fine sediments < 6.35 mm in substrate cores	50 %	30 %
Number of rainbow trout captured at weir	1,500 females	3,000 females*
Maximum daily temperatures exceeding 73 ^{o}F	50 days (1994)	≤ 10 days in 4 of 5 years
Lowest flows measured on Reaches 1-4, 10-11	Not available	9 cfs
Lowest flows measured on Reaches 5-9.	Not available	3 cfs

* within 10 years

VI. MONITORING

Monitoring is a crucial, although frequently neglected component of restoration activities. If restoration activities on Deep Creek are designed under adaptive management, extensive monitoring will be essential.

A variety of potential monitoring tools are available to assess restoration activities on Deep Creek, each varying in terms of labor and cost. The following proposed monitoring tools cover aspects of water quality, channel morphology, substrate characteristics, and aquatic biota. Monitoring protocols should be applied yearly for between 5 and 10 years (Hunter 1991) following treatment. While not all the proposed monitoring procedures outlined below need to be implemented, it is important to design a monitoring protocol for each of the TMDL targets. In addition, because landowner involvement is so important to the success of this, monitoring tools that can be implemented by landowners should be considered.

Riparian Conditions

A general monitoring tool that can be applied by landowners along Deep Creek is the riparian monitoring questionnaire developed by the Montana Riparian Association. This questionnaire addresses conditions and changes in fish habitat parameters, stream banks, riparian vegetation community, and stream substrate composition. This tool is recommended for implementation by landowners along Deep Creek, regardless of restoration activities that occur on their property, to assess the effects of land management on riparian and stream conditions and troubleshoot problems such as excessive soil erosion.

Water Quality

Total suspended Sediment.

Monitoring of sediment concentration and load is required for assessment of TMDL targets. Continued measurement of TSS concentrations and discharge through spring run-off is recommended. Correlation analysis of discharge and TSS at Montana Ditch should be performed yearly to test whether the slope of the regression is meeting the TMDL target. In addition, yearly load of suspended sediment contributed to the Missouri River could be calculated based on the discharge/TSS relationship and daily flow data from the Montana Ditch gauging station. Additional sampling sites located at reach boundaries would be valuable in assessing TSS contributed per reach. An alternative method to assess sediment load would be to monitor sedimentation of known sediment traps. The weirs located near the Montana ditch siphon serves as a sediment trap and must be periodically flushed to prevent filling in. A very simple procedure would be to gauge the time it takes to accumulate a determined level of sediment.

Temperature

Monitoring water temperatures on Deep Creek is required to assess progress towards temperature TMDL targets. In addition to the thermograph at Montana Ditch, thermographs should be installed throughout the 11 reaches. This temperature data would identify where temperature problems are most severe, and assess improvement with riparian recovery and increased summer base flows.

Sedimentation

Measurement of substrate sedimentation is another way to monitor conditions on Deep Creek. Analysis of substrate cores is required for assessment of meeting TMDL targets. At least 3 core samples should be collected in 3 riffles per reach. In addition, substrate composition and surface fines can be monitored by Wolman pebble counts and percent fines grids. Another approach to monitoring sediment is taking a photo series of the substrate. Transects should be established at points along the stream channel. Potential sites for transects are within stream sections subjected to mechanical alteration. Baseline photographs should be taken prior to initiation of restoration procedures. Using a percent fines grid and a modified PVC tube (Appendix H), photographs of the substrate can be taken and compared over time. This visual comparison has the advantage of being an educational tool for future restoration projects.

Channel Morphology

Measurement of channel morphology changes is another potential monitoring tool. This involves establishing transects along reaches that have undergone remediation. Hunter (1991) provides a good description of how to establish transects to measure cross-sectional channel changes. Transects should be established at 10 to 30 meter intervals along treated or control reaches of stream. Transects are marked with rebar stakes above the active channel (Appendix H). A measuring tape is stretched between the metal stakes. Data collected at these cross-sections is width of wetted channel, width of active channel and flow data. In addition, distance below the tape to channel bed should be taken at regular intervals to determine the cross-section channel shape. Flow data should be taken in conjunction with this data. Fish habitat data can also be collected at these transects. This includes data on bank angle, bank undercut, overhanging vegetation, amount of instream cover and substrate composition.

Photopoints

Another method to monitor fluvial and habitat changes following restoration activities is a photographic record. This involves establishing photo points which can be found in subsequent years. Hunter (1991) provides a description of the procedure. First, find a reference point that can be located in subsequent years such as a rock, tree, fence post or other relatively permanent feature. Photographs taken over the years using the same reference point can be compared for changes in stream and riparian conditions. As with all monitoring procedures, pretreatment photographs are essential to determine effectiveness of treatments. It is important to take the photos at the same time every year to avoid a seasonal bias in vegetation features.

Fish

Permanent weirs located at the Montana Ditch siphon facilitate trapping of fish to determine use of Deep Creek by spawning adults from the Missouri River. Monitoring returns of wild trout is required for the TMDL target of doubling number of female spawners returning to Deep Creek. The weirs can also be applied to determine the success of spawning in Deep Creek by adfluvial populations by trapping juveniles migrating to the Missouri River.

The use of artificial redds may be useful in recording changes in inter-gravel oxygen levels and success of incubation of eggs and emergence of fry (Maret et al. 1993). This involves installing baskets with substrate particles and trout eggs. Prior to emergence, baskets would be pulled and number of live eggs and fry counted. Dissolved oxygen meters can be used in conjunction with artificial redds to assess permeability of the substrate. Comparisons should be made between a number of treatment sections. Treatments should include the upper, less impacted parts of Deep Creek, sections subjected to various remediation activities and controls. At least three artificial redds should be installed per treatment.

Little is known regarding the resident trout fishery on Deep Creek. Therefore, a basin fish and fish habitat survey (i.e. Hankin and Reeves 1989) is recommended to determine fish abundance patterns throughout the Deep Creek watershed.

Rapid Bioassessment

Continued use of RBP is recommended to assess changes in habitat conditions and benthic macroinvertebrate communities. Periodic application of RBP could be compared to baseline data (1991 and 1992).

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APPENDIX A. EROSIVE BANK DATA PER REACH ON DEEP CREEK

Table 1a. Reach 1 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID No.	River-mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length (ft)	Height (ft)	Area (ft^2)	Stab. Rating
029	0.60	127	18.8	1.20	LF	200.0	5.0	1000.0	High
037	0.70	127	18.8	1.20	LF	200.0	4.0	800.0	Med.
001	0.19	125	18.8	1.08	LF	150.0	4.0	600.0	High
035	0.67	127	18.8	1.20	LF	80.0	6.0	480.0	Med.
003	0.23	125	18.8	1.08	LF	75.0	6.0	450.0	Med.
025	0.55	127	18.8	1.20	LF	75.0	4.0	300.0	High
039	0.73	127	18.8	1.20	LF	60.0	5.0	300.0	Med.
040	0.74	127	18.8	1.20	RT	45.0	5.0	225.0	High
031	0.62	127	18.8	1.20	LF	35.0	5.0	175.0	High
016	0.44	127	18.8	1.20	RT	40.0	4.0	160.0	High
022	0.51	127	18.8	1.20	LF	30.0	5.0	150.0	Med.
020	0.48	127	18.8	1.20	LF	35.0	4.0	140.0	Med.
038	0.71	127	18.8	1.20	RT	30.0	4.0	120.0	High
006	0.30	125	18.8	1.08	LF	20.0	6.0	120.0	High
015	0.44	127	18.8	1.20	LF	35.0	3.0	105.0	High
034	0.65	127	18.8	1.20	RT	25.0	4.0	100.0	High
010	0.40	125	18.8	1.08	RT	25.0	4.0	100.0	Med.
028	0.59	127	18.8	1.20	RT	20.0	5.0	100.0	High
007	0.35	125	18.8	1.08	LF	30.0	3.0	90.0	High
012	0.41	125	18.8	1.20	LF	25.0	3.5	87.5	High
014	0.44	127	18.8	1.20	RT	20.0	4.0	80.0	High
033	0.65	127	18.8	1.20	LF	30.0	2.0	60.0	Med.
021	0.50	127	18.8	1.20	LF	10.0	5.0	50.0	High
026	0.58	127	18.8	1.20	LF	12.0	4.0	48.0	High
018	0.45	127	18.8	1.20	LF	15.0	3.0	45.0	High
009	0.38	125	18.8	1.08	RT	10.0	4.0	40.0	High
019	0.45	127	18.8	1.20	LF	12.0	3.0	36.0	High
032	0.63	127	18.8	1.20	RT	15.0	2.0	30.0	High
011	0.40	125	18.8	1.08	LF	10.0	3.0	30.0	High
008	0.36	125	18.8	1.08	RT	10.0	3.0	30.0	High

Table 2a. Reach 2 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID No.	River-mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
060	1.59	129	16.7	1.31	LF	50.0	8.0	400.0	Med.
043	0.79	127	16.7	1.74	LF	75.0	4.0	300.0	Low
059	1.58	129	16.7	1.31	RT	85.0	3.0	255.0	Med.
049	0.94	127	16.7	1.74	LF	20.0	9.0	180.0	Low
058	1.55	129	16.7	1.31	RT	65.0	2.0	130.0	Low
057	1.49	129	16.7	1.31	RT	35.0	2.0	70.0	Low
047	0.88	127	16.7	1.74	LF	25.0	2.5	62.5	Low
048	0.90	127	16.7	1.74	RT	35.0	1.0	35.0	Low

Table 3a. Reach 3 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID. No.	River-mile	Photo No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
113	2.45	131	28.9	1.33	LF	300.0	8.0	2400.0	High
114	2.42	131	28.9	1.33	RT	250.0	8.0	2000.0	Med.
095	2.72	131	28.9	1.33	RT	290.0	5.0	1450.0	High
118	2.34	131	18.8	1.33	LF	95.0	7.0	665.0	Med.
109	2.51	131	28.9	1.33	RT	140.0	4.0	560.0	Med.
100	2.63	131	28.9	1.33	LF	125.0	4.0	500.0	Med.
099	2.64	131	28.9	1.33	RT	90.0	5.0	450.0	High
115	2.39	131	28.9	1.33	LF	110.0	4.0	440.0	Med.
112	2.46	131	28.9	1.33	RT	80.0	5.0	400.0	Med.
105	2.57	131	28.9	1.33	RT	70.0	5.0	350.0	Med.
096	2.71	131	28.9	1.33	RT	75.0	4.0	300.0	Med.
111	2.47	131	28.9	1.33	LF	50.0	6.0	300.0	Med.
116	2.39	131	28.9	1.33	RT	45.0	6.0	270.0	Low
103	2.59	131	28.9	1.33	RT	45.0	6.0	270.0	High
101	2.61	131	28.9	1.33	RT	60.0	4.0	240.0	Med.
094	2.75	131	28.9	1.33	LF	75.0	3.0	225.0	Med.
098	2.66	131	28.9	1.33	LF	50.0	4.5	225.0	Low
108	2.53	131	28.9	1.33	LF	55.0	4.0	220.0	Low
091	2.81	131	28.9	1.33	RT	40.0	5.0	200.0	Med.
097	2.68	131	28.9	1.33	LF	45.0	4.0	180.0	Low
102	2.61	131	28.9	1.33	LF	45.0	4.0	180.0	Med.
110	2.48	131	28.9	1.33	RT	35.0	5.0	175.0	Med.
092	2.79	131	28.9	1.33	LF	30.0	5.0	150.0	Med.
104	2.57	131	28.9	1.33	LF	35.0	4.0	140.0	Low
093	2.76	131	28.9	1.33	RT	25.0	5.0	125.0	Low
106	2.55	131	28.9	1.33	LF	20.0	5.0	100.0	Low

Table 3a. (continued)

ID. No.	Rivermile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
119	2.32	131	28.9	1.33	LF	35.0	2.0	70.0	Low
090	2.83	131	28.9	1.33	LF	25.0	2.5	62.5	Low
107	2.54	131	28.9	1.33	RT	15.0	4.0	60.0	Low

Table 4a. Reach 4 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID. No.	River mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
067	3.39	133	50.8	1.20	LF	130.0	4.0	520.0	med
071	3.31	133	50.8	1.20	LF	130.0	3.0	390.0	med
080	3.10	133	50.8	1.20	LF	120.0	3.0	360.0	low
065	3.44	133	50.8	1.20	RT	100.0	3.0	300.0	med
077	3.17	133	50.8	1.20	LF	65.0	4.0	260.0	low
086	2.98	133	50.8	1.20	RT	60.0	4.0	240.0	med
075	3.23	133	50.8	1.20	RT	90.0	2.0	180.0	low
070	3.33	133	50.8	1.20	RT	65.0	2.5	162.5	med
088	2.93	133	50.8	1.20	LF	35.0	4.0	140.0	low
073	3.24	133	50.8	1.20	LF	35.0	4.0	140.0	low
072	3.29	133	50.8	1.20	LF	40.0	3.0	120.0	low
087	2.96	133	50.8	1.20	LF	25.0	4.0	100.0	low
078	3.16	133	50.8	1.20	RT	20.0	4.0	80.0	low
089	2.90	133	50.8	1.20	LF	20.0	4.0	80.0	med
085	2.98	133	50.8	1.20	LF	35.0	2.0	70.0	low
082	3.06	133	50.8	1.20	LF	25.0	2.0	50.0	low
064	3.47	133	50.8	1.20	LF	10.0	3.0	30.0	med
066	3.42	133	50.8	1.20	RT	5.0	3.0	15.0	low

Table 5a. Reach 5 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID. No.	River-mile	Photo No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stab.
011	3.80	135	52.0	1.19	RT	150.0	3.0	450.0	Low
026	4.11	135	52.0	1.19	RT	110.0	4.0	440.0	Low
027	4.24	137	52.0	1.14	RT	80.0	3.5	280.0	Med.
010	3.76	135	52.0	1.19	LF	90.0	3.0	270.0	Low
028	4.29	137	52.0	1.14	RT	70.0	3.0	210.0	Low
024	4.09	135	52.0	1.19	RT	35.0	5.0	175.0	Low
012	3.84	135	52.0	1.19	LF	40.0	4.0	160.0	Low

Table 5a (continued)

ID. No.	River-mile	Photo No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stab.
031	4.39	137	52.0	1.14	LF	40.0	4.0	160.0	Low
032	4.41	137	52.0	1.14	LF	40.0	4.0	160.0	Low
005	3.70	135	52.0	1.19	LF	50.0	3.0	150.0	Low
029	4.34	137	52.0	1.14	LF	40.0	3.0	120.0	Med.
007	3.72	135	52.0	1.19	LF	25.0	3.0	75.0	Low
006	3.71	135	52.0	1.19	LF	25.0	2.5	62.5	Low
015	3.90	135	52.0	1.19	LF	30.0	2.0	60.0	Low
018	3.96	135	52.0	1.19	RT	30.0	2.0	60.0	Low
008	3.73	135	52.0	1.19	RT	15.0	3.0	45.0	Low
019	3.97	135	52.0	1.19	RT	15.0	3.0	45.0	Low
021	3.98	135	52.0	1.19	RT	15.0	3.0	45.0	Low
016	3.90	135	52.0	1.19	RT	30.0	1.5	45.0	Low
025	4.10	135	52.0	1.19	LF	40.0	1.0	40.0	Low
013	3.88	135	52.0	1.19	LF	20.0	1.5	30.0	Low
002	3.64	135	52.0	1.19	LF	10.0	2.0	20.0	Low
022	4.08	135	52.0	1.19	LF	20.0	1.0	20.0	Low

Table 6c. Reach 6 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID. No.	River mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft2)	Stability
050	4.96	137	39.3	1.32	RT	300.0	4.0	1200.0	Med.
062	5.30	139	39.3	1.61	LF	200.0	4.0	800.0	Med.
063	5.35	139	39.3	1.61	LF	140.0	4.0	560.0	Med.
059	5.23	139	39.3	1.61	LF	130.0	4.0	520.0	Low
043	4.82	137	39.3	1.32	LF	120.0	4.0	480.0	Low
052	5.01	137	39.3	1.32	LF	150.0	3.0	450.0	Low
053	5.02	139	39.3	1.61	RT	150.0	3.0	450.0	Low
064	5.37	139	39.3	1.61	RT	60.0	5.0	300.0	Low
055	5.12	139	39.3	1.61	LF	90.0	3.0	270.0	Low
035	4.53	137	39.3	1.14	LF	40.0	3.0	120.0	Low
046	4.90	137	39.3	1.32	LF	40.0	2.0	80.0	Low
048	4.92	137	39.3	1.32	RT	30.0	2.0	60.0	Low

Table 7c. Reach 7 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID No.	River-mile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
096	6.22	141	29.4	1.52	RT	60.0	25.0	1500.0	Low
098	6.27	141	29.4	1.52	RT	60.0	25.0	1500.0	Low
116	6.76	141	29.4	2.17	RT	80.0	8.0	640.0	Med.
105	6.40	141	29.4	2.17	LF	150.0	4.0	600.0	Low
120	6.87	141	29.4	2.17	LF	90.0	6.0	540.0	Med.
095	6.20	141	29.4	1.52	RT	80.0	6.0	480.0	Low
092	6.06	141	29.4	1.52	LF	110.0	4.0	440.0	Med.
094	6.14	141	29.4	1.52	LF	110.0	4.0	440.0	Med.
103	6.34	141	29.4	1.52	LF	80.0	5.0	400.0	Low
073	5.59	139	39.3	2.18	LF	90.0	4.0	360.0	Low
118	6.84	141	29.4	2.17	LF	110.0	3.0	330.0	Low
119	6.86	141	29.4	2.17	LF	110.0	3.0	330.0	Low
129	7.09	141	29.4	2.17	LF	80.0	4.0	320.0	Med.
119	6.86	141	29.4	2.17	RT	70.0	4.0	280.0	Low
068	5.50	139	39.3	2.18	LF	50.0	5.0	250.0	Low
083	5.87	139	39.3	2.18	LF	50.0	5.0	250.0	Low
110	6.60	141	29.4	2.17	LF	60.0	4.0	240.0	Low
090	6.04	141	29.4	1.52	RT	60.0	4.0	240.0	Med.
080	5.81	139	39.3	2.18	LF	80.0	3.0	240.0	Low
070	5.52	139	39.3	2.18	LF	45.0	5.0	225.0	Low
066	5.46	139	39.3	2.18	LF	40.0	5.0	200.0	Low
101	6.31	141	29.4	1.52	LF	40.0	5.0	200.0	Low
124	6.98	141	29.4	2.17	RT	40.0	5.0	200.0	Low
123	6.94	141	29.4	2.17	RT	50.0	4.0	200.0	Med.
107	6.50	141	29.4	2.17	RT	40.0	4.0	160.0	Low
122	6.92	141	29.4	2.17	LF	40.0	4.0	160.0	Med.
104	6.38	141	29.4	2.17	RT	25.0	6.0	150.0	Med.
072	5.57	139	39.3	2.18	LF	50.0	3.0	150.0	Low
085	5.91	139	29.4	1.52	LF	50.0	3.0	150.0	Low
089	5.99	139	29.4	1.52	LF	50.0	3.0	150.0	Low
121	6.90	141	29.4	2.17	RT	50.0	3.0	150.0	Low
077	5.71	139	39.3	2.18	LF	35.0	4.0	140.0	Low
076	5.66	139	39.3	2.18	RT	25.0	5.0	125.0	Low
117	6.80	141	29.4	2.17	LF	40.0	3.0	120.0	Low
137	7.32	143	29.4	1.60	RT	40.0	3.0	120.0	Low
099	6.29	141	29.4	1.52	LF	40.0	3.0	120.0	Med.
127	7.01	141	29.4	2.17	RT	80.0	1.5	120.0	Low
086	5.93	139	29.4	1.52	RT	70.0	1.5	105.0	Low
067	5.49	139	39.3	2.18	RT	20.0	5.0	100.0	Low

Table 7a. (continued)

ID. No.	River-	Photo	Gradient	Sinuosity	Bank	Length	Height	Area	Stab.

	mile	No.	(ft/mile)					(ft^2)	
071	5.54	139	39.3	2.18	RT	20.0	5.0	100.0	Low
065	5.40	139	39.3	1.61	RT	25.0	4.0	100.0	Low
069	5.51	139	39.3	2.18	RT	20.0	4.0	80.0	Low
106	6.46	141	29.4	2.17	RT	20.0	4.0	80.0	Low
078	5.76	139	39.3	2.18	RT	40.0	2.0	80.0	Low
097	6.25	141	29.4	1.52	LF	40.0	2.0	80.0	Low
135	7.25	143	29.4	1.60	LF	40.0	2.0	80.0	Low
093	6.11	141	29.4	1.52	RT	15.0	5.0	75.0	Low
126	7.00	141	29.4	2.17	LF	40.0	1.5	60.0	Low
100	6.29	141	29.4	1.52	RT	15.0	3.0	45.0	Low
112	6.66	141	29.4	2.17	LF	5.0	6.0	30.0	Low
074	5.62	139	39.3	2.18	RT	12.0	2.5	30.0	Low
107	6.50	141	29.4	2.17	LF	6.0	4.0	24.0	Low

Table 8c. Reach 8 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

ID No.	Rivermile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
075	9.99	147	39.3	1.86	RT	320.0	18.0	5760.0	High
131	7.97	143	39.3	3.61	RT	200.0	25.0	5000.0	Low
053	10.68	147	39.3	1.91	LF	200.0	25.0	5000.0	High
041	11.16	149	39.3	1.76	RT	300.0	8.0	2400.0	Low
083	9.78	147	39.3	1.86	RT	90.0	25.0	2250.0	Med.
042	11.10	149	39.3	1.76	LF	420.0	5.0	2100.0	Med.
055	10.66	147	39.3	1.91	LF	100.0	20.0	2000.0	Med.
046	11.00	149	39.3	1.76	LF	220.0	9.0	1980.0	Low
089	9.55	145	39.3	1.77	LF	240.0	8.0	1920.0	Med.
035	11.35	149	39.3	1.52	RT	300.0	6.0	1800.0	Med.
045	11.04	149	39.3	1.76	RT	220.0	7.0	1540.0	High
068	10.20	147	39.3	1.86	RT	175.0	8.0	1400.0	Med.
104	9.13	145	39.3	1.30	LF	220.0	6.0	1320.0	High
037	11.30	149	39.3	1.76	LF	165.0	8.0	1320.0	High
099	9.31	145	39.3	1.30	LF	200.0	5.0	1000.0	High
078	9.92	147	39.3	1.86	RT	150.0	6.0	900.0	Med.
039	11.20	149	39.3	1.76	RT	80.0	11.0	880.0	High
086	9.66	147	39.3	1.86	LF	45.0	19.0	855.0	High
095	9.41	145	39.3	1.77	LF	160.0	5.0	800.0	High

Table 8c. (continued)

ID No.	Rivermile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability

133	7.90	143	39.3	3.61	RT	40.0	20.0	800.0	Low
085	9.71	147	39.3	1.86	LF	125.0	6.0	750.0	High
070	10.15	147	39.3	1.86	RT	100.0	6.0	600.0	High
069	10.18	147	39.3	1.86	LF	100.0	6.0	600.0	High
065	10.25	147	39.3	1.86	RT	140.0	4.0	560.0	High
076	9.96	147	39.3	1.86	LF	80.0	7.0	560.0	Med.
057	10.61	147	39.3	1.91	RT	110.0	5.0	550.0	Med.
101	9.26	145	39.3	1.30	RT	120.0	4.0	480.0	Low
051	10.77	147	39.3	1.91	LF	90.0	5.0	450.0	Med.
080	9.90	147	39.3	1.86	LF	100.0	4.0	400.0	Low
040	11.19	149	39.3	1.76	LF	50.0	8.0	400.0	Med.
048	10.85	149	39.3	1.76	RT	55.0	7.0	385.0	Med.
034	11.38	149	39.3	1.52	RT	55.0	7.0	385.0	Med.
036	11.35	149	39.3	1.52	RT	90.0	4.0	360.0	Med.
087	9.63	145	39.3	1.77	LF	85.0	4.0	340.0	High
044	11.06	149	39.3	1.76	RT	55.0	6.0	330.0	Med.
058	10.45	147	39.3	1.91	RT	40.0	8.0	320.0	Med.
109	8.97	145	39.3	1.30	RT	150.0	2.0	300.0	Low
049	10.84	149	39.3	1.76	LF	50.0	6.0	300.0	Low
043	11.08	149	39.3	1.76	RT	50.0	6.0	300.0	Med.
097	9.37	145	39.3	1.77	RT	50.0	5.0	250.0	High
072	10.09	147	39.3	1.86	LF	40.0	6.0	240.0	High
060	10.37	147	39.3	1.91	RT	70.0	3.0	210.0	Low
056	10.62	147	39.3	1.91	LF	65.0	3.0	195.0	High
073	10.05	147	39.3	1.86	RT	45.0	4.0	180.0	Med.
038	11.21	149	39.3	1.76	RT	30.0	6.0	180.0	Med.
092	9.52	145	39.3	1.77	RT	40.0	4.0	160.0	Med.
128	8.17	143	39.3	3.61	LF	75.0	2.0	150.0	Low
138	7.64	143	29.4	1.60	RT	30.0	5.0	150.0	Low
129	8.10	143	39.3	3.61	LF	40.0	3.0	120.0	Med.
081	9.88	147	39.3	1.86	RT	40.0	3.0	120.0	Low
091	9.53	145	39.3	1.77	RT	40.0	3.0	120.0	Med.
079	9.91	147	39.3	1.86	LF	30.0	4.0	120.0	Low
047	10.97	149	39.3	1.76	LF	25.0	4.5	112.5	Med.
082	9.83	147	39.3	1.86	LF	35.0	3.0	105.0	Low
132	7.93	143	39.3	3.61	LF	30.0	3.0	90.0	Low
130	8.09	143	39.3	3.61	LF	30.0	3.0	90.0	Med.
094	9.49	145	39.3	1.77	LF	30.0	3.0	90.0	Med.
074	10.04	147	39.3	1.86	LF	20.0	4.0	80.0	Med.
090	9.58	145	39.3	1.77	RT	25.0	3.0	75.0	Med.

Table 8c. (continued)

ID No.	Rivermile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
052	10.74	147	39.3	1.91	RT	30.0	2.0	60.0	Med.
105	9.11	145	39.3	1.30	RT	30.0	2.0	60.0	Low

137	7.67	143	29.4	1.60	LF	20.0	3.0	60.0	Low
136	7.69	143	29.4	1.60	RT	20.0	3.0	60.0	Low
062	10.32	147	39.3	1.86	RT	15.0	3.0	45.0	Low
118	8.71	145	39.3	1.30	LF	20.0	2.0	40.0	Low
112	8.87	145	39.3	1.30	RT	10.0	4.0	40.0	Med.
113	8.84	145	39.3	1.30	LF	25.0	1.5	37.5	Med.
084	9.75	147	39.3	1.86	LF	15.0	2.0	30.0	Med.

Table 9c. Reach 9 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

Id. No.	River-mile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
003	11.44	149	39.3	1.52	RT	120.0	7.0	840.0	High
009	11.52	149	39.3	1.52	RT	150.0	5.0	750.0	Med.
015	11.64	149	39.3	1.52	RT	80.0	8.0	640.0	Med.
019	11.68	149	39.3	1.52	RT	70.0	8.0	560.0	Med.
030	11.69	149	39.3	1.52	LF	85.0	6.0	510.0	High
025	11.73	149	39.3	1.52	LF	50.0	8.0	400.0	Low
018	11.80	149	39.3	1.52	RT	45.0	8.0	360.0	High
022	11.83	149	39.3	1.52	LF	60.0	6.0	360.0	Low
026	11.87	149	39.3	1.52	RT	40.0	5.0	200.0	Med.
007	11.98	149	39.3	1.52	RT	30.0	6.0	180.0	Med.
032	12.01	149	39.3	1.52	LF	30.0	5.0	150.0	Low
027	12.04	149	39.3	1.52	LF	30.0	5.0	150.0	Low
002	12.08	149	39.3	1.52	LF	25.0	5.0	125.0	Low
012	12.10	149	39.3	1.52	RT	30.0	4.0	120.0	Low
004	12.13	149	39.3	1.52	LF	30.0	4.0	120.0	Low
011	12.13	149	39.3	1.52	LF	100.0	1.0	100.0	Low

Table 10c. Reach 10 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

Id. No.	River-mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft2)	Stability
052	13.72	153	32.5	2.41	LF	220.0	15.0	3300.0	Low
085	12.29	151	32.5	1.79	RT	150.0	12.0	1800.0	Med.
078	12.47	151	32.5	1.79	RT	130.0	10.0	1300.0	High

077	12.58	151	32.5	1.79	LF	220.0	5.0	1100.0	Med.
057	13.46	153	32.5	1.79	RT	90.0	4.0	360.0	Low
071	12.86	153	32.5	1.79	LF	70.0	5.0	350.0	Low
059	13.38	153	32.5	1.79	LF	50.0	5.0	250.0	High
086	12.26	151	32.5	1.79	LF	30.0	8.0	240.0	Low
069	12.93	153	32.5	1.79	LF	120.0	2.0	240.0	Med.
062	13.25	153	32.5	1.79	LF	70.0	3.0	210.0	Med.
079	12.43	151	32.5	1.79	LF	20.0	10.0	200.0	High
058	13.44	153	32.5	1.79	LF	45.0	4.0	180.0	Med.
076	12.69	151	32.5	1.79	LF	40.0	4.0	160.0	Low
082	12.36	151	32.5	1.79	LF	20.0	7.0	140.0	Med
072	12.84	153	32.5	1.79	RT	35.0	4.0	140.0	Med.
064	13.20	153	32.5	1.79	LF	40.0	3.0	120.0	Med.
056	13.54	153	32.5	1.79	RT	20.0	5.0	100.0	Med.
060	13.36	153	32.5	1.79	RT	55.0	1.5	82.5	Low
074	12.76	151	32.5	1.79	LF	35.0	1.5	52.5	Low

Table 11c. Reach 11 erosive bank data. Identification numbers correspond with numbers from 1991 aerial photographs.

Id. Num.	River-mile	Photo. No.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft2)	Stability
019	16.84	159	36.2	1.44	LF	250.0	25.0	6250.0	Med.
001	15.74	157	36.2	2.56	RT	220.0	5.0	1100.0	High
045	14.13	153	32.5	2.41	RT	200.0	15.0	3000.0	Low
004	15.90	157	36.2	2.56	RT	200.0	5.0	1000.0	High
010	16.11	157	36.2	2.56	RT	200.0	4.0	800.0	High
008	15.58	157	36.2	2.56	LF	200.0	3.5	700.0	High
022	17.00	159	37.0	1.44	LF	175.0	9.0	1575.0	Med.
046	14.09	153	32.5	2.41	LF	170.0	20.0	3400.0	High
040	14.46	155	32.5	1.94	LF	160.0	20.0	3200.0	Med.
031	17.65	161	37.0	2.03	RT	150.0	30.0	4500.0	High
040	18.50	161	37.0	2.03	RT	150.0	12.0	1800.0	Med.
035	18.18	161	37.0	2.03	LF	150.0	7.0	1050.0	High

Table 11a. (continued)

ID No.	Rivermile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
013	16.34	157	36.2	1.62	RT	150.0	5.0	750.0	High
016	16.60	157	36.2	1.62	RT	150.0	4.0	600.0	High
001	15.77	157	36.2	2.56	RT	150.0	3.0	450.0	Med.
016	15.34	157	36.2	1.39	LF	150.0	1.5	225.0	High
004	15.70	157	36.2	2.56	RT	140.0	5.0	700.0	High
009	15.55	157	36.2	1.39	RT	130.0	4.0	520.0	High

007	15.62	157	36.2	2.56	RT	130.0	4.0	520.0	High
017	15.28	157	36.2	1.39	RT	120.0	40.0	4800.0	High
032	17.71	161	37.0	2.03	LF	120.0	20.0	2400.0	High
008	16.04	157	36.2	2.56	RT	120.0	3.0	360.0	Med.
039	14.55	155	32.5	1.94	RT	120.0	2.0	240.0	Med.
018	16.80	159	36.2	1.44	RT	100.0	7.0	700.0	High
003	15.86	157	36.2	2.56	LF	100.0	3.0	300.0	Med.
013	15.42	157	36.2	1.39	LF	100.0	3.0	300.0	High
036	14.63	155	32.5	1.94	RT	100.0	2.0	200.0	Med.
021	15.22	157	36.2	1.39	LF	90.0	40.0	3600.0	Med.
043	14.27	155	32.5	1.94	LF	90.0	2.0	180.0	High
018	16.80	159	36.2	1.44	RT	80.0	8.0	640.0	Med.
038	18.38	161	37.0	2.03	LF	80.0	6.0	480.0	Low
043	18.70	161	37.0	1.74	RT	80.0	6.0	480.0	Low
012	16.20	157	36.2	1.62	RT	80.0	5.0	400.0	Med.
006	15.98	157	36.2	2.56	LF	80.0	4.0	320.0	Med.
037	14.61	155	32.5	1.94	LF	80.0	3.0	240.0	Low
011	16.17	157	36.2	2.56	RT	80.0	3.0	240.0	Low
011	15.50	157	36.2	1.39	LF	80.0	2.5	200.0	Med.
041	18.56	161	37.0	2.03	LF	70.0	10.0	700.0	Low
045	18.92	163	37.0	1.74	RT	70.0	5.0	350.0	Low
020	15.24	157	36.2	1.39	RT	70.0	2.5	175.0	Low
005	15.95	157	36.2	2.56	RT	70.0	2.0	140.0	Med.
024	15.12	155	36.2	1.07	LF	60.0	10.0	600.0	High
005	15.68	157	36.2	2.56	LF	60.0	5.0	300.0	High
022	15.18	157	36.2	1.39	RT	60.0	4.0	240.0	Med.
025	17.31	159	37.0	1.38	RT	60.0	3.0	180.0	Low
035	14.72	155	32.5	1.03	RT	60.0	1.5	90.0	Med.
047	14.06	153	32.5	2.41	RT	55.0	6.0	330.0	Low
038	14.60	155	32.5	1.94	RT	55.0	1.5	82.5	Med.
019	15.27	157	36.2	1.39	LF	50.0	12.0	600.0	High
026	17.40	159	37.0	1.38	LF	50.0	8.0	400.0	Low
034	18.03	161	37.0	2.03	LF	50.0	7.0	350.0	Low

Table 11a. (continued)

ID No.	Rivermile	Photo. Num.	Gradient (ft/mile)	Sinuosity	Bank	Length	Height	Area (ft^2)	Stability
025	15.09	155	36.2	1.07	LF	50.0	6.0	300.0	High
044	14.21	153	32.5	2.41	LF	50.0	4.0	200.0	Med.
007	16.01	157	36.2	2.56	RT	50.0	3.0	150.0	Low
023	15.14	155	36.2	1.07	LF	50.0	3.0	150.0	High
006	15.66	157	36.2	2.56	RT	50.0	2.0	100.0	Med.
048	19.24	163	37.0	1.74	RT	40.0	7.0	280.0	Med.
026	15.03	155	36.2	1.07	LF	40.0	6.0	240.0	Med.
017	16.75	159	36.2	1.44	LF	40.0	6.0	240.0	High

044	18.77	161	37.0	1.74	LF	40.0	5.0	200.0	Low
002	15.83	157	36.2	2.56	RT	40.0	3.0	120.0	Med.
042	14.33	155	32.5	1.94	LF	40.0	2.0	80.0	High
015	15.37	157	36.2	1.39	LF	40.0	1.5	60.0	Med.
028	17.52	159	37.0	1.38	RT	30.0	10.0	300.0	Low
033	17.88	161	37.0	2.03	RT	30.0	6.0	180.0	Low
042	18.66	161	37.0	1.74	LF	30.0	4.0	120.0	Low
028	14.93	155	36.2	1.03	LF	30.0	4.0	120.0	Med.
014	15.41	157	36.2	1.39	LF	30.0	1.5	45.0	Med.
029	17.57	159	37.0	1.38	LF	20.0	10.0	200.0	Low
030	17.62	161	37.0	2.03	RT	20.0	6.0	120.0	Low
010	15.55	157	36.2	1.39	LF	20.0	3.0	60.0	Med.
046	19.13	163	37.0	1.74	LF	15.0	8.0	120.0	Low
021	16.95	159	36.2	1.44	RT	15.0	5.0	75.0	Med.
014	16.42	157	36.2	1.62	LF	15.0	4.0	60.0	Low
047	19.19	163	37.0	1.74	RT	10.0	8.0	80.0	Low
018	15.30	157	36.2	1.39	LF	10.0	3.0	30.0	Med.

IX. APPENDIX B DAILY TSS LOAD AND DISCHARGE PER SAMPLING DATE GRAPHS

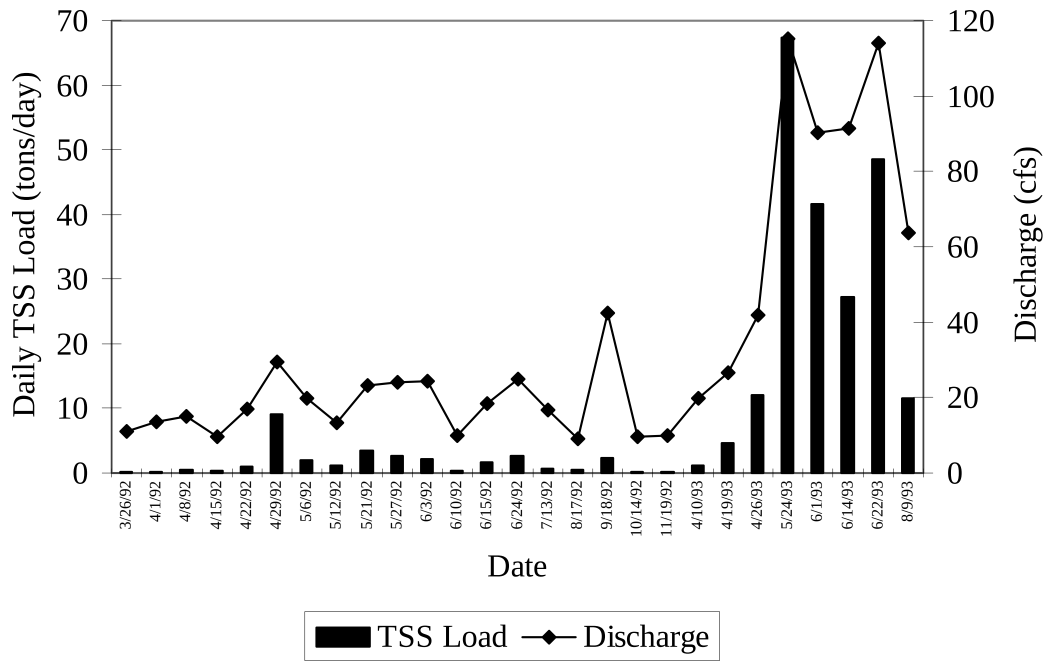

Figure 1b. Daily TSS load and discharge per sampling date for above Montana Ditch water sampling site.

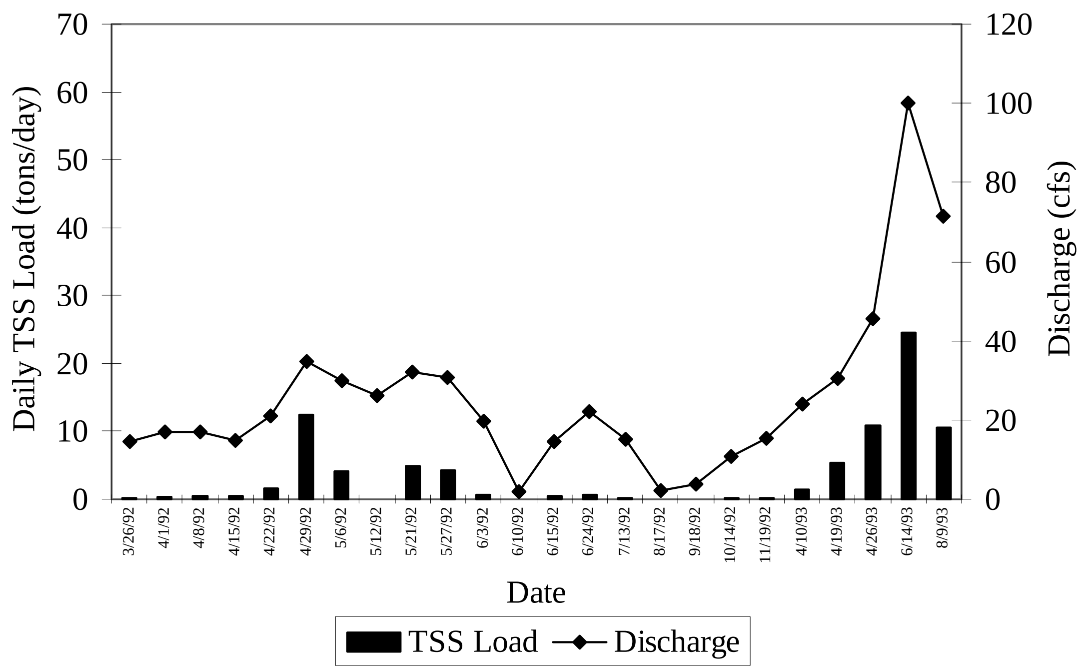

Figure 2b. Daily TSS load and discharge pre sampling date for above Broadwater-Missouri ditch water sampling site.

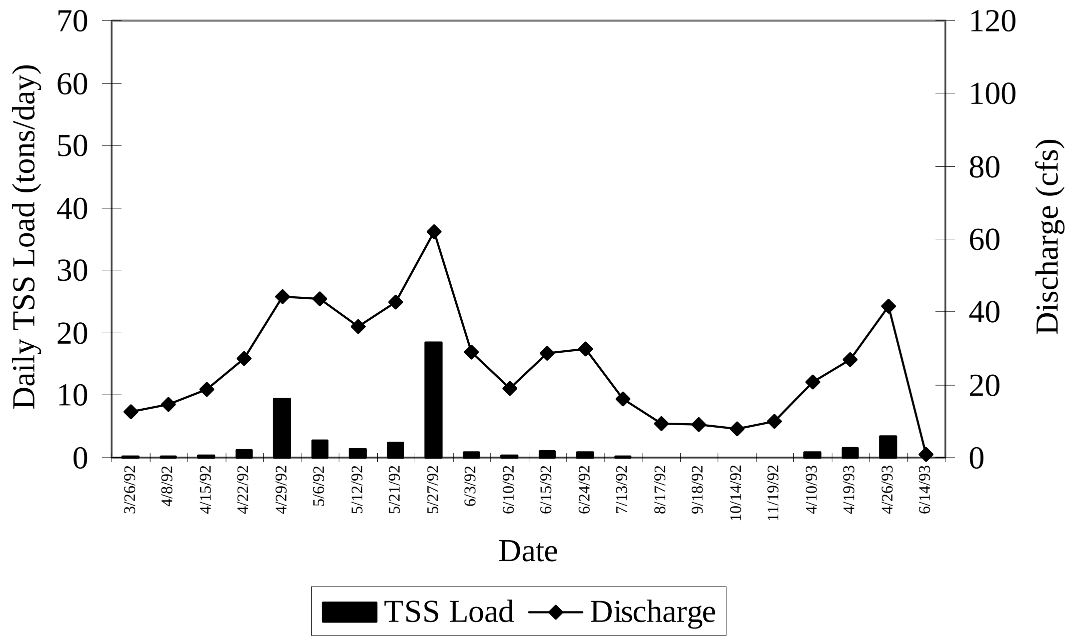

Figure 3b. Daily TSS load and discharge per sampling date at Lippert Gulch water sampling site.

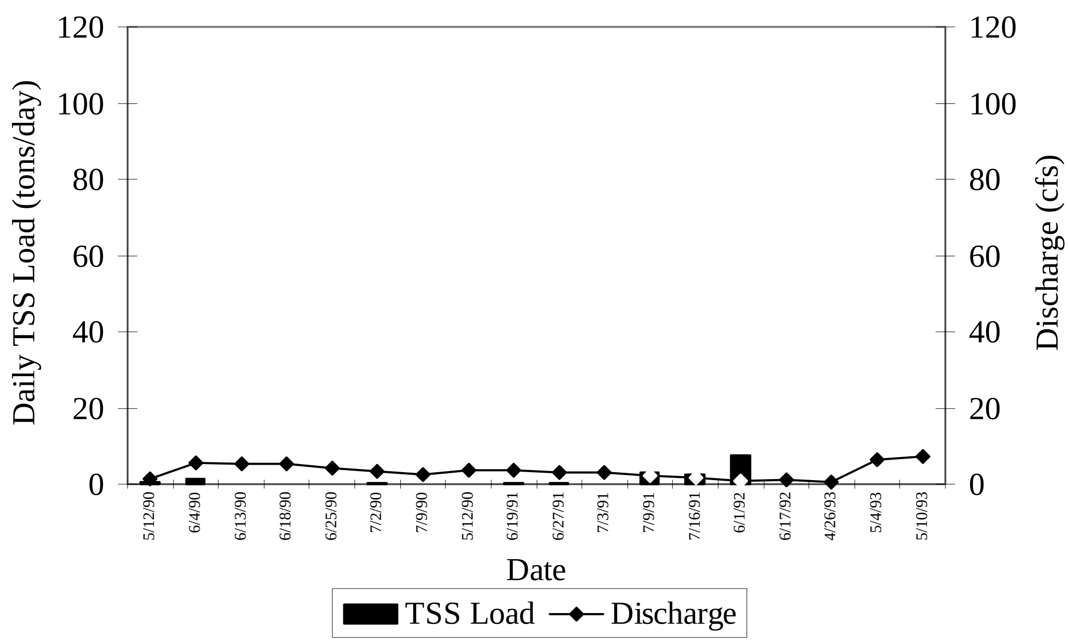

Figure 4b. Daily TSS load and discharge per sampling date at Cabin Gulch water sampling site.

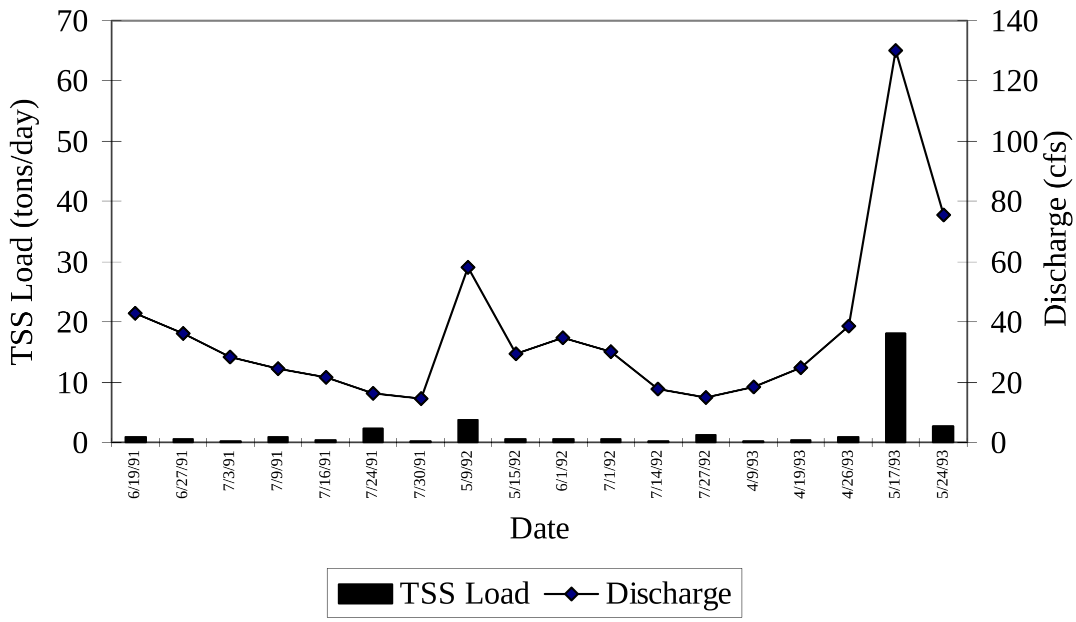

Figure 5b. Daily TSS load and discharge per sampling date at Horse pasture water sampling site.

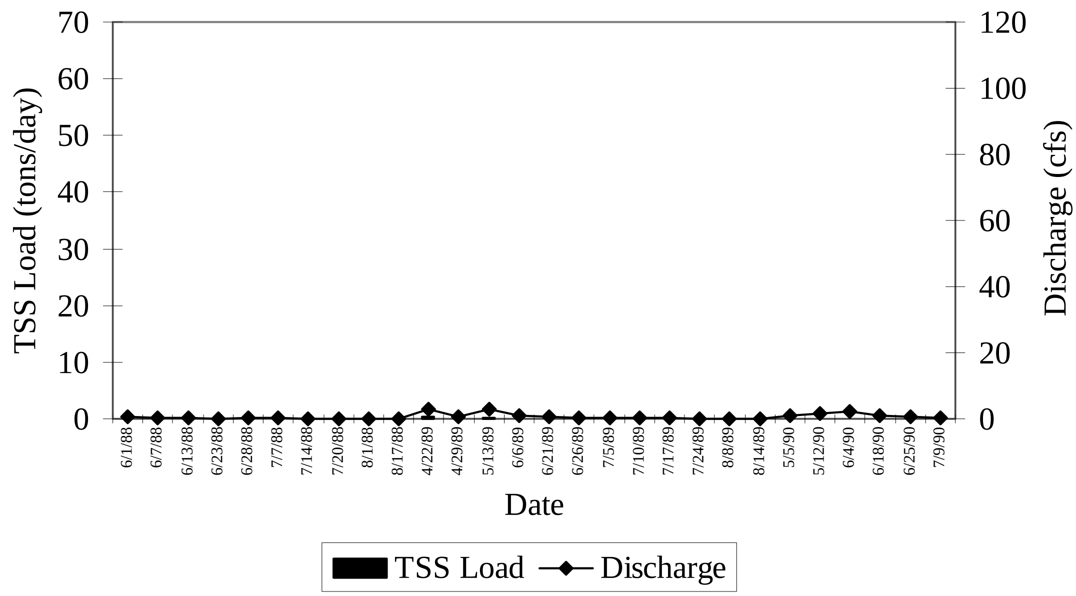

Figure 6b. Daily TSS load and discharge per sampling date at Carl Creek water sampling site.

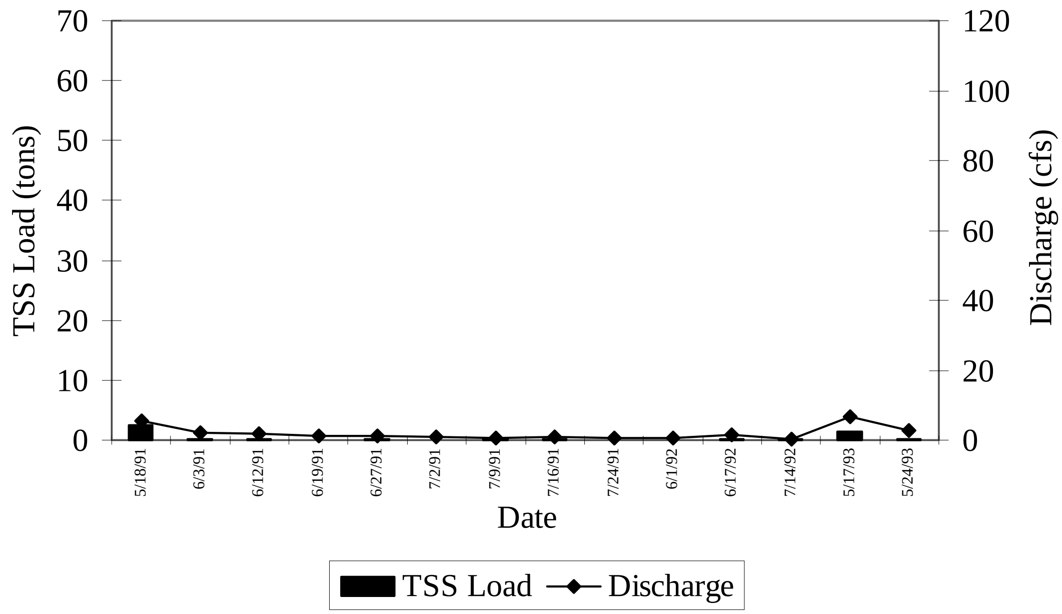

Figure 7b. Daily TSS load and discharge per water sampling date at Sulphur Bar water sampling site.

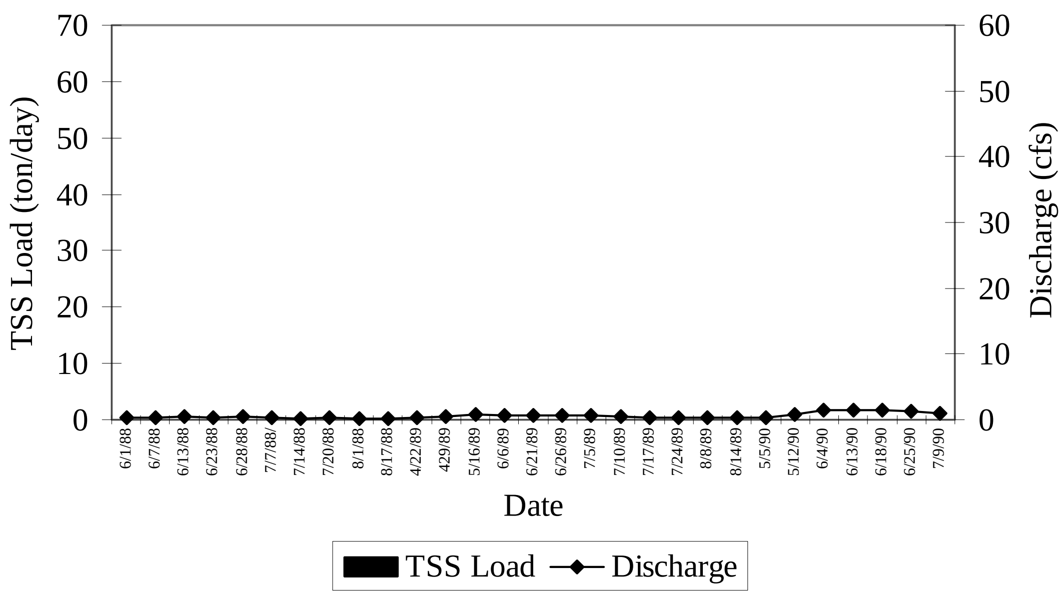

Figure 8b. Daily TSS load and discharge per sampling date at Cedar Bar water sampling site.

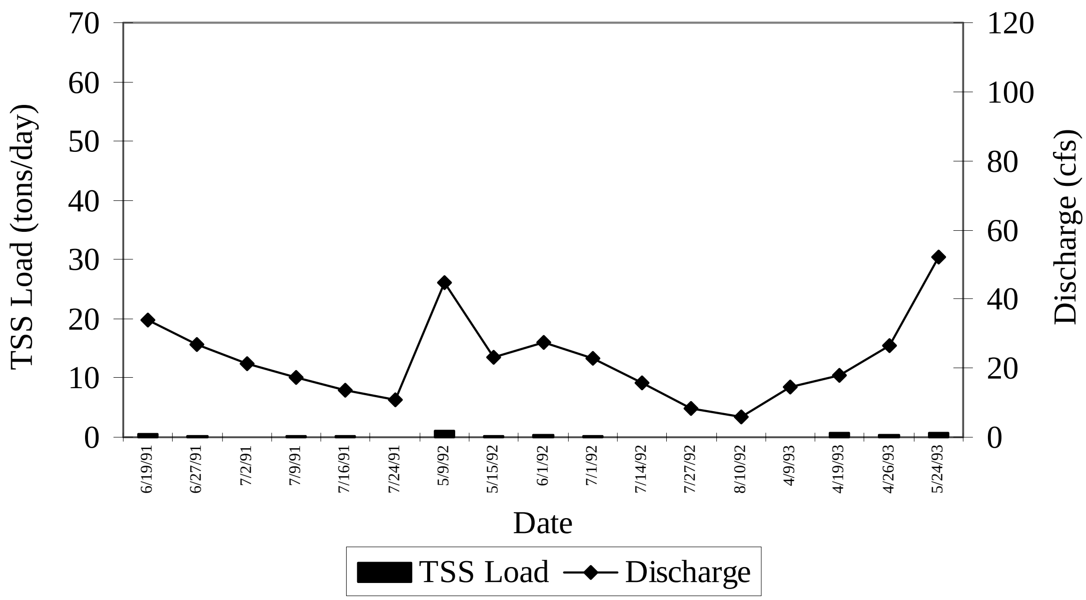

FIGURE 9B. DAILY TSS LOAD AND DISCHARGE PER SAMPLING DATE AT UPPER DEEP CREEK WATER SAMPLING SITE.

IX. APPENDIX C. DAILY TSS LOAD AND DISCHARGE PER SAMPLING DATE GRAPHS

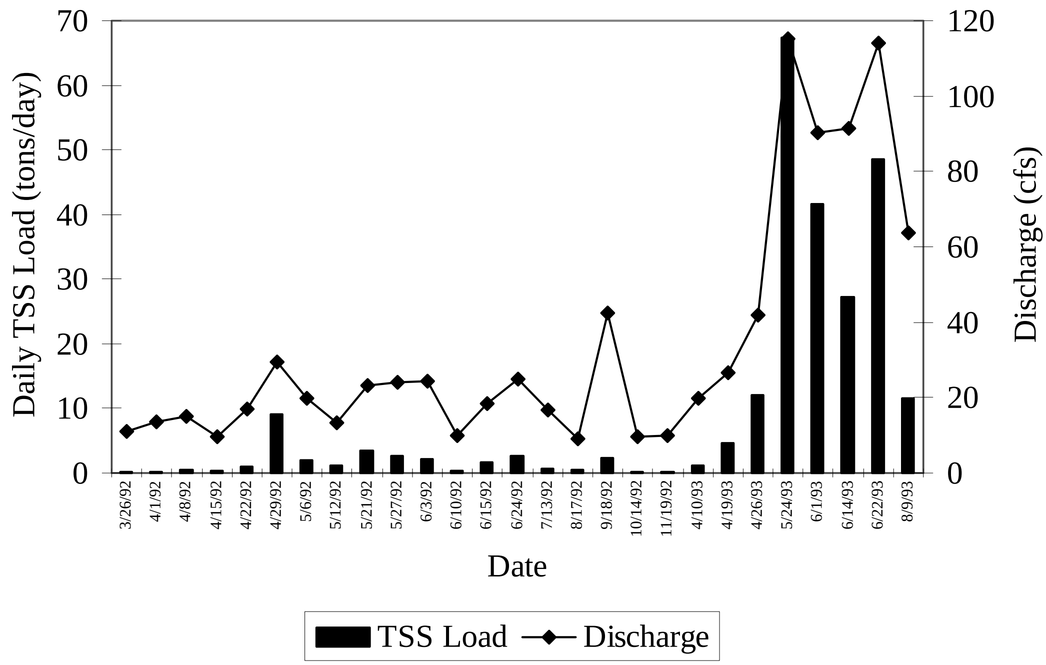

Figure 1c. Daily TSS load and discharge per sampling date for above Montana Ditch water sampling site.

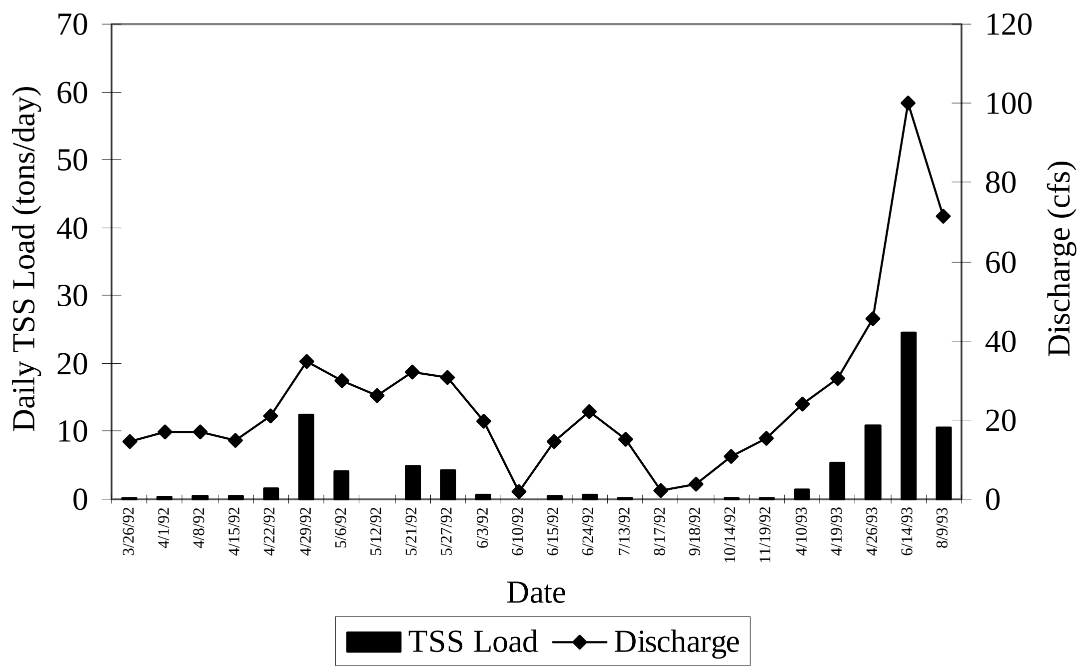

Figure 2c. Daily TSS load and discharge pre sampling date for above Broadwater-Missouri ditch water sampling site.

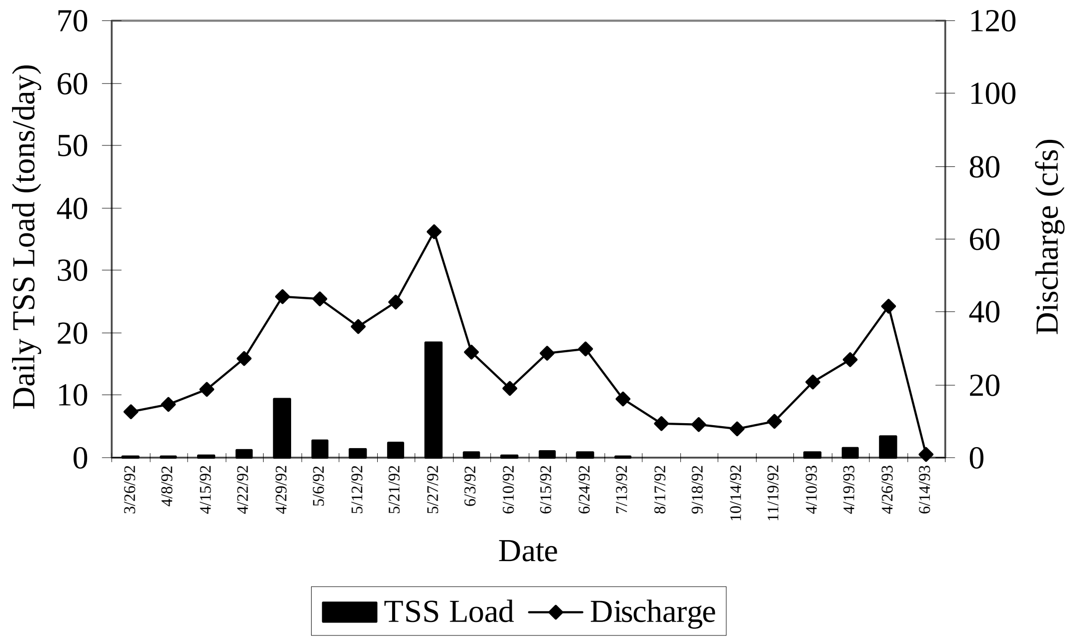

Figure 3c. Daily TSS load and discharge per sampling date at Lippert Gulch water sampling site.

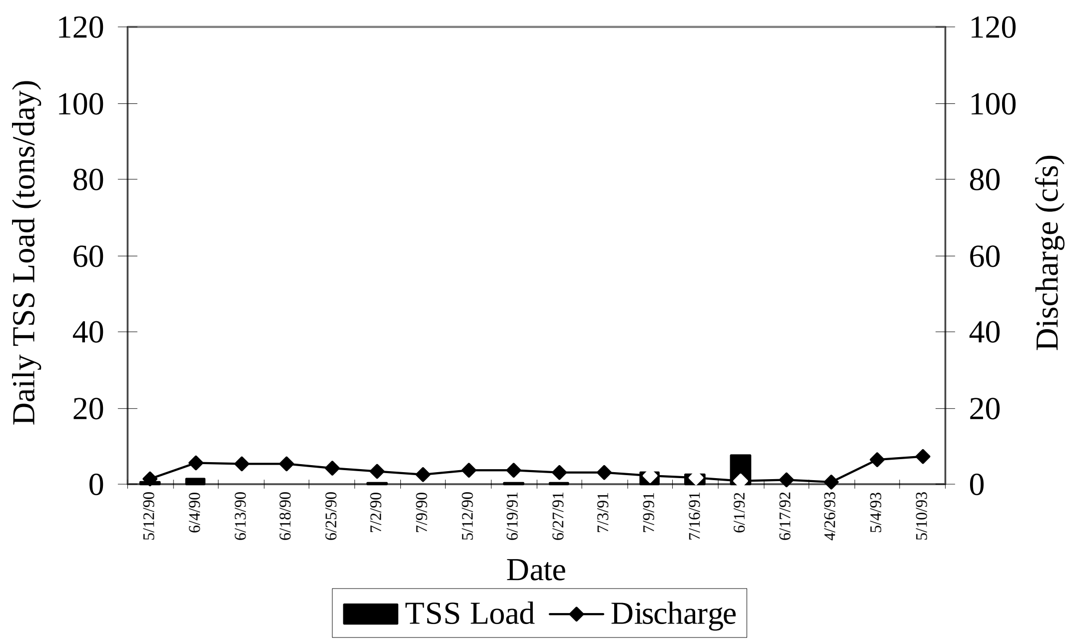

Figure 4c. Daily TSS load and discharge per sampling date at Cabin Gulch water sampling site.

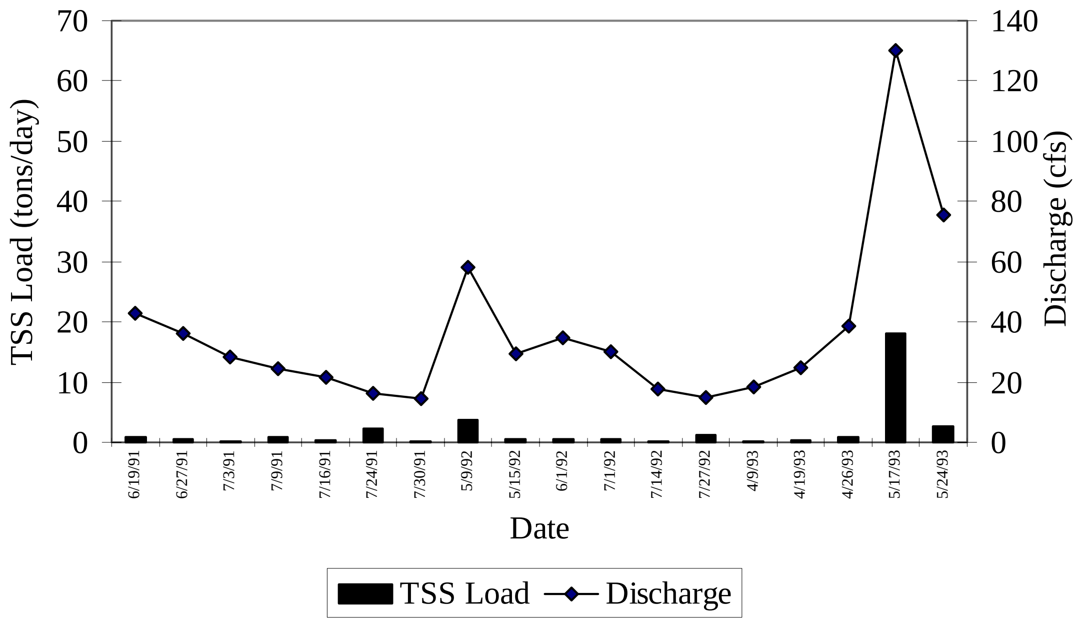

Figure 5c. Daily TSS load and discharge per sampling date at Horse pasture water sampling site.

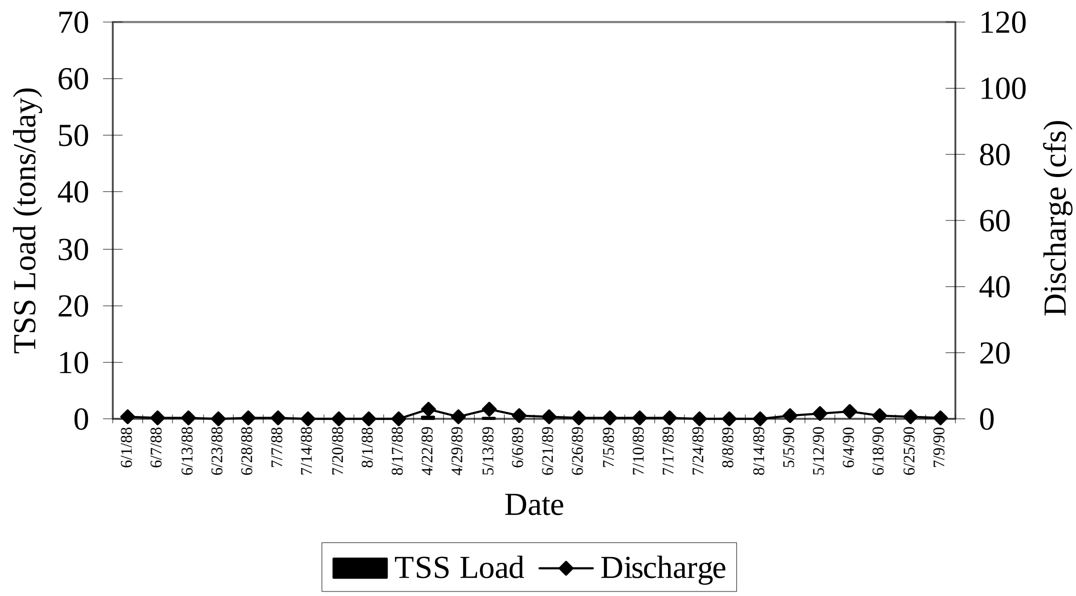

Figure 6c. Daily TSS load and discharge per sampling date at Carl Creek water sampling site.

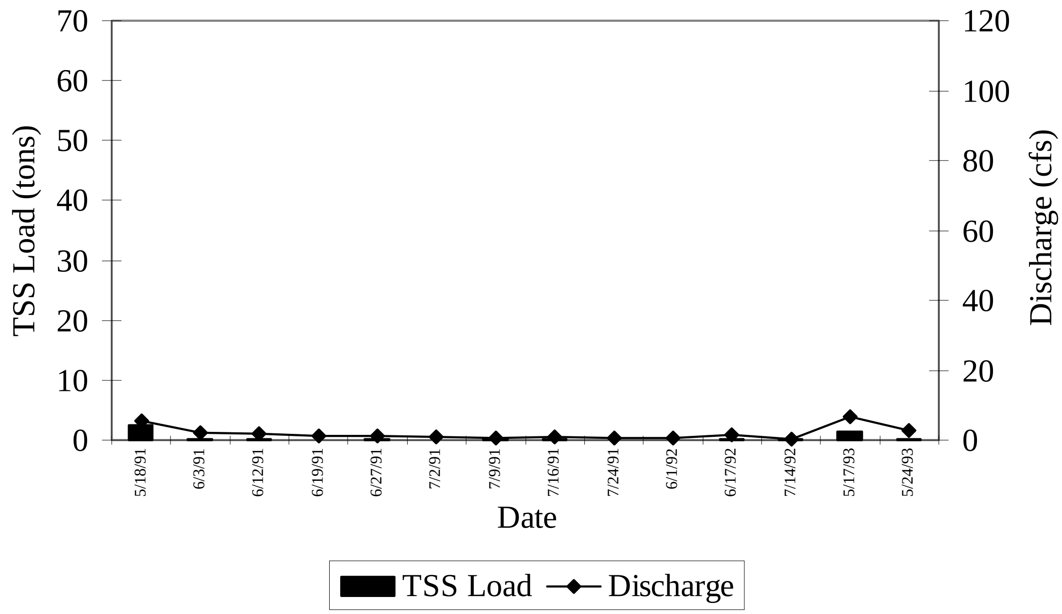

Figure 7c. Daily TSS load and discharge per water sampling date at Sulphur Bar water sampling site.

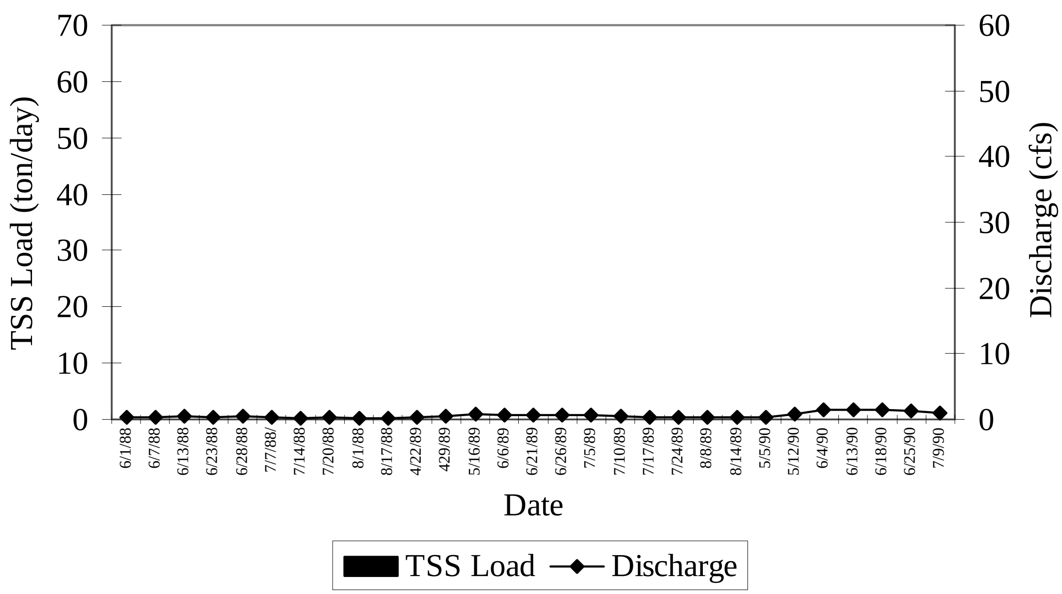

Figure 8c. Daily TSS load and discharge per sampling date at Cedar Bar water sampling site.

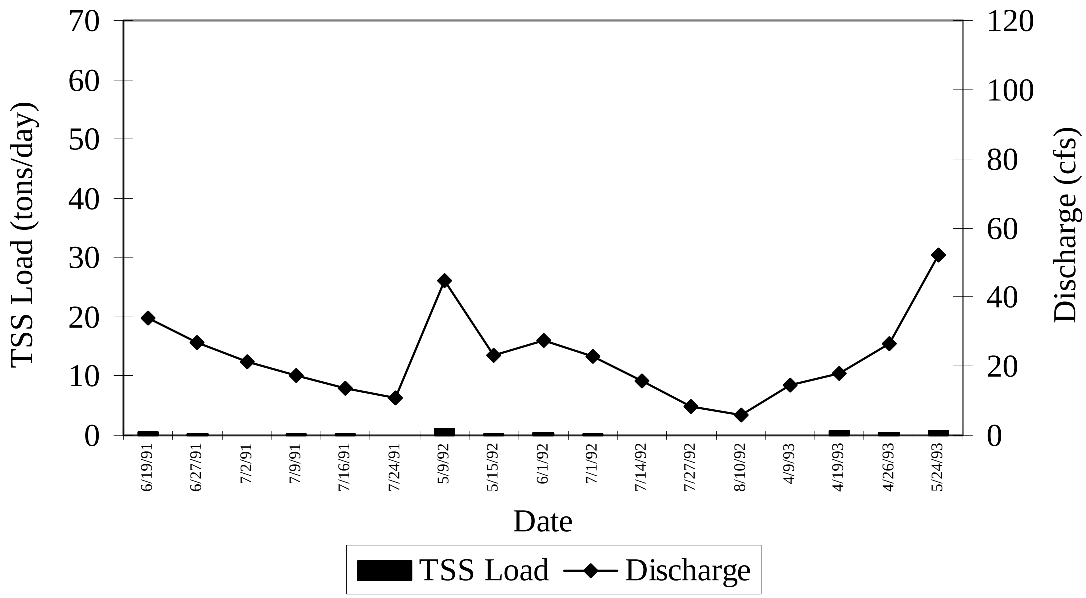

Figure 9c. Daily TSS load and discharge per sampling date at Upper Deep Creek water sampling site.

APPENDIX D. TYPICAL STREAMBANK DEGRADATION ON DEEP CREEK

APPENDIX E. DESCRIPTION OF ROSGEN RIVER CLASSIFICATION CHANNEL TYPES RELEVANT TO REMEDIATION ON DEEP CREEK (MODIFIED FROM ROSGEN 1992).

Appendix F. Proposed Streambank Alterations on Deep Creek

(Modified from Rosgen 1992)

APPENDIX G. MONITORING TOOLS TO BE USED ON DEEP CREEK