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Tobacco River Stream Assessment and Restoration Recommendations

by

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Tobacco River Stream Assessment and Restoration Recommendations

Advisor: Dr. Vicki J. Watson VW

The Tobacco River flows through the town of Eureka in northwestern Montana. Historically, Eureka applied treated wastewater to a privately owned hay field beside the river. Recently, the town of Eureka obtained a permit to discharge directly to the river, and wastewater was discharged into the river in May and June of 2001 and again in March and April of 2002. Wastewater is stored in a lagoon at other times.

The Tobacco Valley Resource Group is a local non-profit organization concerned about the impacts of discharging wastewater to the river. Additionally, the owner of the land application site is interested in reducing streambank erosion at the site. This study reports on current stream morphology, riparian conditions, and late summer instream nutrient levels along the Tobacco River and provides some recommendations for streambank stabilization at the land application site.

Water samples were taken in July and August 2001, when discharge was not occurring. Sampling sites bracketed the land application site and the discharge pipe. At the time of sampling, nutrient levels were at or below standards and targets adopted for the Clark Fork River and Flathead Lake. The ratio of nitrogen to phosphorus suggests that phosphorus is in shorter supply than nitrogen and likely limits the growth of river bottom algae. Since phosphorus is better trapped by land application than nitrogen, discharging wastewater to the river will likely increase the amount of phosphorus in the Tobacco River. This may result in an unacceptable increase in algae levels, especially if discharge continues throughout the growing season. Hence, the decision to abandon land application should be reconsidered. Wastewater could be stored or land applied during the growing season, and direct discharged only during winter and/or spring high flows.

Based on the width of the riparian zone in less disturbed reaches, I propose that the riparian corridor along the land application site be revegetated with native woody species to a width of 60 meters. This should reduce the rate of streambank erosion and the loss of nutrients from the land application site to the river.

ADDENDUM to Jeff Dunn thesis

Regarding the reference to the Tobacco Valley Resource Group on page one of this thesis-- while the group did contact the clinic for assistance, on later consultation it was determined that the nature of the study they needed was beyond the time frame and budget possible for this unfunded one year master's project. Hence the TVRG was not involved in the design or execution of this study and are not connected with its conclusions in any way.

Acknowledgements

Thanks to Dr. Vicki Watson at the University of Montana for guidance and support, Kirk Sullivan of the Natural Resource Conservation Service, Dr. Paul Hansen for guidance with riparian topics, Dr. Sarah Halvorson, Tom Roy, Karl Kassler for interest in the project and access to his property, John Lhotak for field and lab assistance, the Flathead Lake Biological Station for analyzing the water samples, and Sara Anderson with the Tobacco Valley Resource Group. Field and lab work were partially supported by a grant from the B. and B. Dawson Fund, while the Watershed Health Clinic provided additional funding.

Table of Contents

List of Tables

List of Figures

List of Appendices

Introduction

The Tobacco River of northwest Montana drains a watershed dominated by evergreen forest and by private and Forest Service lands. The town of Eureka, Montana, historically applied its treated municipal wastewater to a 40-acre hay field located beside the Tobacco River. The wastewater receives secondary treatment using an activated sludge process. At the request of the landowner of the field, the town applied to the Montana Department of Environmental Quality for a permit to discharge the wastewater directly to the Tobacco River. The town obtained a permit and discharged to the river in May and June of 2001 and again in March and April of 2002 (T. Reid, pers. comm.). The wastewater is stored in a lagoon at other times.

The Tobacco Valley Resource Group, a local non-profit group in Eureka, requested assistance from the University of Montana Watershed Health Clinic in gathering information about water quality in the Tobacco River. The group is concerned about possible negative impacts of discharging treated municipal wastewater directly to the Tobacco River. Additionally, the Natural Resource Conservation Service and the owner of the hay field that served as Eureka's land application site are interested in reducing streambank erosion along the site and revegetating some of the area with riparian vegetation.

To address these concerns, a study was designed with the following goals:

1) to assess and report on current channel conditions, riparian health, and summer nutrient levels along the Tobacco River; and 2) develop a restoration plan for the Tobacco River along the land application site. The goals were accomplished through

fulfilling the following objectives: 1) during the summer of 2001, measure nutrients and attached algae levels along the Tobacco River at sites selected to bracket the land application site and direct discharge site; 2) assess the health of the riparian vegetation and the condition of the river channel along the reach of the Tobacco River that includes the land application site; 3) use the results of the study to develop recommendations for improving and maintaining water quality, riparian health and channel conditions along the Tobacco River.

Study Area

The Tobacco River is located in northwestern Montana and flows through the town of Eureka, population 1017 (Figure 1). The Tobacco River watershed, which drains 707 square kilometers, is part of the Columbia River Basin. The official length of the Tobacco River is 21.7 kilometers. However, the overall length varies seasonably depending on the level of Lake Koocanusa, which is regulated by Libby Dam on the Kootenai River. Full pool elevation is 746.6 meters, while low pool elevation is 695.2 meters. The difference between the two is 5.1 river kilometers. The Tobacco River begins at the confluence of Grave Creek and Fortine Creek. Grave Creek is 25.6 kilometers long and Fortine Creek is 49.4 kilometers long. There is an average of 38 centimeters of precipitation per year at the Eureka Ranger Station and 43 centimeters at Fortine, while Snotel sites in the Tobacco River headwaters record an average of 122 centimeters of precipitation per year at the Grave Creek site and 152 centimeters at the Stahl Peak site (Western Regional Climate Center, 2002).

The Tobacco River watershed is comprised of public and private lands, while its riparian corridor is mainly privately owned. The Kootenai National Forest surrounds the headwaters of both Fortine Creek and Grave Creek. The Tobacco River is protected under the Northwest Power Planning Council Protected Areas Program. Streams in this program are protected from future hydroelectric development. Protected areas contain fish and wildlife resources that are of critical importance to the region. For example, the Tobacco River is an important migratory route for bull trout seeking spawning grounds in Grave Creek and Fortine Creek. The bull trout is listed under the Endangered Species Act as a threatened species in the Columbia River Basin.

Land-use practices within the Tobacco River watershed have degraded the river. The federal Clean Water Act (Section 303d) and the Montana Water Quality Act require surface waters to be monitored, assessed and identified as impaired if they exceed water quality standards. The Tobacco River and its major tributaries, Fortine Creek and Grave Creek, are listed as impaired on the 2002 Montana 303(d) list by the Montana Department of Environmental Quality (DEQ, 2002). Aquatic life and cold water fishery are only partially supported, and DEQ has identified the probable causes of impairment to be siltation, bank erosion, and habitat alteration, while grazing and agriculture are the probable sources of impairment. The DEQ plans to develop a water quality restoration plan, also known as a Total Maximum Daily Load (TMDL) plan, for the Tobacco River watershed by 2011 (DEQ, 2002).

Study Design

The three main parameters looked at in this study are channel morphology, riparian vegetation, and instream nutrient and algae levels. Meaningful study design requires an understanding of the processes that shape stream channels, riparian communities, and water quality. For a discussion of these processes, see Appendix A.

Channel morphology was investigated along a 1.98 kilometer study reach of the river. This reach was divided into three sub-reaches (hereafter referred to as polygons). The polygons were selected based on three criteria: altering riparian conditions, the extent of anthropogenic modification, and changing land-use practices. Polygon 1 is located above the land application site, Polygon 2 is located beside the site, and Polygon 3 is downstream of the site (Figure 2). The condition of riparian vegetation was assessed within each polygon.

In-stream assessments included water samples and periphyton (attached algae) samples. The water samples were taken at six points along the Tobacco River extending from the confluence of Grave Creek and Fortine Creek to the top of the reservoir in an attempt to document downstream variation (Figure 1, Table 1). Periphyton samples were collected at three sites: above (site 3) and below (site 4) the land application site and below the new effluent discharge site (site 5). Sites were chosen in an attempt to document the impact of the land application site on instream nutrient levels and to provide an assessment of instream nutrient levels when direct discharge was not occurring. Algae levels reflect the influence of both the land application site and the 2 months of direct discharge that occurred earlier that year.

Methods

Channel Morphology

Channel characteristics were measured using techniques described in the Environmental Monitoring and Assessment Program-Surface Waters: Western Pilot

Study Field Operations Manual for Wadeable Streams (EMAP-WP, 2000). The EMAP-WP procedures represent a rapid assessment protocol that employs a systematic spatial sampling design geared toward minimizing bias in the placement of measurements (Peck, *et al.*, 2001). Measurements of wetted width, bankfull width, bankfull depth, channel substrate, bank angle, canopy cover, channel slope, and compass bearing were made at each transect using the EMAP-WP protocol.

Channel measurements were made at 34 transects placed at 60 meter intervals along the study site, which extends 780 meters above the land application site and 480 meters below it (Figure 1). The land application site extends along 720 meters of the Tobacco River. Transect 1 is located at an old railroad tie sticking vertically out of the water along the left bank where the railroad track abuts the river channel. Transect 34 is located near the osprey nest on the right side of the river along the meander bend upstream of the effluent discharge pipe. Each transect was georeferenced using a Global Positioning Unit (GPS) (Appendix B). Channel measurements from each transect were analyzed corresponding to the three polygons. The upper and lower boundaries of each polygon, as well as interesting features, were recorded with digital photographs (Figure 3).

Cross-section Measurements

Channel measurements perpendicular to the flow were made at each transect. Wetted width and bankfull width were measured in meters using a line level and a measuring tape. The bankfull width was identified by the presence of recently deposited alluvial materials, changes in the angle of the bank, and the presence of perennial vegetation (Olsen *et al.*, 1997). The bankfull depth was measured at 1 meter intervals across the channel using a stadia rod. A laser level was used to measure the channel cross-section in a riffle section below Transect 14. Laser level measurements extended onto the floodplain beyond the bankfull zone. Channel substrate was sampled at five points across each transect by measuring the first particle contacted when reaching into the water. Substrate was classified based on the size of the particle along the b-axis, which is the axis of intermediate length (Kondolf, 1997). Bank angle was recorded at each transect along the wetted margin of the river using a clinometer. Canopy cover was measured at the wetted margin, as well as in the middle of the river facing upstream, toward river right, downstream, and toward river left (Peck *et al.*, 2001).

Longitudinal Profile

Stream channels contain pools and riffles that interact with the substrate and bank materials as a function of flow velocity to create the channel morphology (Knighton, 1998). The length of pools, riffles, and glides was measured between each pair of transects at a flow of approximately 100 cubic feet per second (CFS). Pool length was measured from the steep drop off at the tail end of a riffle until coarse gravels again dominated the bed. The mean pool spacing was determined for the reach by dividing the reach length by both the number of pools and the reach average bankfull channel width as described by Montgomery *et al.* (1995). This yielded a pool-to-pool spacing in units of channel width. Riffles were considered as moving water with small ripples and waves that were not breaking, while glides were considered as slow moving water with a smooth unbroken surface (Peck *et al*, 2001). The total number of large woody debris pieces greater than 1 meter in length and 10cm in diameter located within the bankfull channel were recorded between each pair of transects (Montgomery *et al.*, 1995). The surface water slope and sinuosity were measured between each transect using a clinometer, compass, and stadia rod. The amount of eroding bank was also quantified between each transect.

The channel stage was determined using the Lotic Health Assessment Short Form for Small Streams and Rivers (Bitterroot Restoration, 2001). The channel stage describes the ability of the river to access the floodplain, which is related to the amount of downcutting. Stage A-2 describes a fairly stable, wide, unincised valley bottom channel with defined meanders and a well-developed floodplain. Bankfull flows are able to access a floodplain that is at least twice the bankfull width in Stage A-2 streams. Bankfull flows in Stage B channels can only access a narrow floodplain that is often less than twice the bankfull channel width. Stage C occurs when flows less than a 5-10 year event access a floodplain that is less than twice the bankfull width (Rosgen, 1996).

Stream Classification

Channel measurements recorded with the laser level along with data gathered from the longitudinal profile were used to determine the Rosgen channel type. The Rosgen Classification System assigns a channel type based on the slope, sinuosity, width-to-depth ratio, and the entrenchment ratio (Rosgen, 1996).

Discharge

The USGS maintains a gauging station on the Tobacco River located downstream of the study site with an unbroken record extending 42 years. Analysis of long-term flow patterns was conducted using daily discharge data. Discharge was measured in the field at two sites (Transect 6 and Transect 32), which correspond with water quality and algae Sample Sites 3 and 4 (Figure 2). A Marsh-McBirney Portable Water Current Meter

(Model 201D) was used to measure flow velocity and the depth at regular intervals. Velocity was measured with a top setting rod at 60% of the depth. Field measurements were used to calculate discharge, which was correlated with the USGS gauging station data. Bankfull flow was determined from analysis of long-term flow patterns and the WinXSPRO channel cross-section analyzer.

Riparian Assessment

A riparian assessment was conducted along each transect. Both the current riparian community and the potential natural community were determined along each transect. The extent of the riparian zone was determined by a conversion from riparian vegetation to upland vegetation or a conversion to cultivated crop land. The condition of the riparian vegetation was assessed using the Lotic Wetland Health Assessment for Streams and Small Rivers (Bitterroot Restoration, 2001). This procedure was developed at the University of Montana in conjunction with the Bureau of Land Management and the Fish and Wildlife Service (Hansen *et al.*, 2000). This assessment indicates the overall condition of a riparian site based on vegetation, soil, and hydrologic conditions. This assessment emphasizes vegetative characteristics to determine the "health" of a riparian site. The term "health" is used to describe the ability of a riparian or wetland area to perform certain functions. Plants provide a good indicator of riparian health since they are more visible than soil or hydrologic characteristics and provide an indicator of successional trend (Hansen *et al.*, 2000).

The Lotic Wetland Health Assessment Field Score Sheet rates stream health based on 11 criteria: 1) vegetative cover of floodplain and stream banks, 2) invasive plant species, 3) disturbance-caused undesirable species, 4) preferred tree and shrub establishment and regeneration, 5) utilization of preferred trees and shrubs, 6) standing decadent and dead woody material, 7) streambank root mass protection, 8) human-caused bare ground, 9) streambank structurally altered by human activity, 10) pugging and/or hummocking (caused by ungulate hoof action), and 11) stream channel incisement (Appendix C). Categories 1-6 represent vegetative factors, while categories 7-11 represent soil/hydrology factors. There are 57 possible points, with 27 points for vegetative factors and 30 points for soil/hydrology factors. An NA (not applicable) is assigned to categories that do not apply to a given site. A health rating is determined using the field score sheet. Health scores from the individual transects were averaged to give an overall health score for each polygon.

The riparian vegetation at the study site was classified into community and habitat types using *Classification and Management of Montana's Riparian and Wetland Sites* (Hansen *et al.*, 1995). The width of the riparian zone was measured perpendicular to the channel along both sides of the river at each transect. Changes in plant community and habitat types progressing from the edge of the stream channel out to the upland interface were recorded along these riparian cross-sections. An inventory of plant species found on the site was also conducted.

Instream Analyses

Water Samples

Water samples were collected at six sites extending from the confluence of Grave Creek and Fortine Creek down to Lake Koocanusa (Table 1, Figure 1). Sample sites were chosen based on changing land-use activities, the influence of tributary streams, and available access. Each sample site was georeferenced using a GPS unit (Appendix B).

Samples were collected in July and August, 2001. Water clarity was measured with a 100cm transparency tube at each water quality sample site in July and August, 2001.

Samples were collected by wading into flowing knee-deep water and collecting water upstream of the sampler. Two bottles were rinsed with river water three times each. The bottles were filled by pointing upstream and moving them vertically up and down from the top of the water column to the bottom. Unfiltered samples were frozen immediately. Filtered samples were prepared by filtering 30-50ml from the sample bottle into a clean bottle to first rinse the bottle with this water. The sample was then filtered into the rinsed bottle. Samples were frozen at the time of collection using dry ice. To check for contamination in handling, a filter blank was prepared on both sampling trips by filtering de-ionized water. Unfiltered samples were analyzed for total phosphorus and total per-sulfate nitrogen. Filtered samples were analyzed for soluble reactive phosphorus and nitrates/nitrites. The Freshwater Lab at the Flathead Lake Biological Station performed all water quality analyses. Total phosphorus, soluble reactive phosphorus, and nitrates/nitrites were analyzed using the standard methods of the American Public Health Association (1998). Total per-sulfate nitrogen was analyzed using methods described by D'Elia *et al.* (1977).

Water sampling equipment was acid washed at the Watershed Health Clinic Lab at the University of Montana prior to use in the field. Rubber gloves were worn during all lab work. Filter holders, syringe tubes, and syringe plungers were soaked for 1 hour in a bath of 10% HCL and 90% de-ionized water. The rubber stoppers for the syringes and the rubber O-rings from the filters were dipped in this bath. Water bottles were rinsed with this solution. Everything was then rinsed three times in de-ionized water.

The syringes were assembled on a clean tray and stored in a clean bag. Clean equipment was then stored in zip-lock bags for use in the field.

Periphyton Samples

Periphyton samples were collected at Sites 3, 4, and 5 in conjunction with the water quality samples (Figure 1). Periphyton samples were collected from 10-20cm cobbles found in 30cm of flowing water. Twenty rocks were randomly sampled at each site. To obtain periphyton samples a 5.08 by 5.08cm (2 inch by 2 inch) area was scraped clean on each rock using a single edge razor blade. The peripyton sample scraped from each rock was placed in a separate snap-shut petri dish and immediately put in a cooler containing dry ice. Samples were frozen and kept in the dark until thawed for analysis. Periphyton samples were analyzed for chlorophyll a and phaeophytin in the Watershed Health Clinic lab at the University of Montana. Twenty samples collected at each site were arranged from smallest to largest and every other sample was processed. Thus, 10 samples were analyzed for each site. The other 10 samples were saved for possible future analysis if the original 10 samples exhibited unacceptably high variability. Samples were allowed to thaw at room temperature and then placed in a mortar. The samples were then ground for 1 minute in 95% alcohol using a mortar and pestle. Just enough solvent was used to achieve a light green color. The solvent was then drained into a small graduated cylinder, measured, and placed into a vial with the sample. The sample vials were then warmed to 75°C and held there for 2 minutes. A 3ml aliquot of extract was removed from the vial, placed in a glass cuvette, and read in a split beam, 2nm spectrophotometer at 664, 665, and 750nm. The extract in the cuvette was then acidified to 0.003M HCl (0.1ml of 0.1N HCl), mixed, held for 90 seconds and read again at the same wavelengths.

The amount of pigment in each sample was calculated using the formulae:

$$\text{Chlorophyll a in mg} = [(A664b - A750b) - (A665a - A750a)] \times V \times [R/(R-1)] \times k/L$$

$$\text{Phaeophytin in mg} = R[(A665a - A750b) - (A664b - A750a)] \times V \times [R/(R-1)] \times k/L$$

Where A664b = absorbance at 664nm before acidification
A665a = absorbance at 665nm after acidification
A750b = absorbance at 750nm before acidification
A750a = absorbance at 750nm after acidification
R = acid correction ratio (maximum ration of A664b:A665a)
k = absorbance coefficient of chlorophyll a at 664nm in 95% alcohol = 11.99
V = total volume of the extract in liters

The amount of pigment in the sample was divided by the area sampled to give the amount of pigment per square meter of stream bottom.

The samples were then placed in aluminum weigh boats and dried to constant weight for ash free dry weight (AFDW) analysis. Boats were weighed on an analytical balance. The samples were then ashed at 500°C for 1 hour, cooled to room temperature, rehydrated by spritzing with water, dried and reweighed. Ash free dry weight is determined by the equation:

$$\text{AFDW} = \text{dry weight} - \text{ashed weight}$$

The ash free dry weight was divided by the area sampled to give the biomass per square meter of stream bottom.

Maps

The CartaLinx program was used to digitize maps representing channel width, riparian vegetation, erosion, and proposed restoration sites. Maps were drawn in meters using a T-square, triangle, and engineering ruler. Maps were created using field measurements of wetted width, bankfull width, riparian zone width, and the vegetation type for each transect. Paper maps were then digitized on a digitizing tablet using

Cartalinx. Distance was measured in meters. The digitizing tablet was registered to a user-defined coordinate system with the coordinates (0,0), (0,1080), (1540, 1080), and (1540,0). The reference system was set to State Plane coordinates and the reference units were set to meters. The digitized maps represent an area of 1,663,200 square meters (410.8 acres). The strategy for digitizing was to first digitize the external boundary, then add the boundary points, the internal arcs, and finally build the polygons. Polygons were created for map features and the attribute information was added to the geographic database in CartaLinx. The individual layers were exported from CartaLinx as Shapefiles that could be incorporated into ArcView 3.2 to create maps and perform analysis. The Query Builder tool was used to determine the amount of acreage covered by the various riparian vegetation types along the study site as well as the amount of acreage required for the restoration project.

Results and Discussion

Channel Morphology

Polygon Descriptions

Polygon 1 extends from the upstream end of the study site to the top of the land application site (Figure2). Polygon 1 includes Transects 1-13. This polygon has well-developed meanders with alternating gravel bars on the inside of the meander bends and vertical eroding banks on the outside of meander bends. Riparian vegetation is confined by the railroad along the left side of the river and by a bedrock outcrop along the right side of the river. The riparian vegetation is well developed within this corridor. The railroad truncates the outside of the meander curve along the left side of the river in two locations where steep banks are lined with rock riprap. Transects 3, 4, and 5, along with transects 11, 12, and 13 represent the reference condition for the study area due to the low degree of anthropogenic impacts (Figure 3).

Polygon 2 extends from the upstream end to the downstream end of the land application site, which is located along the left side of the river (Figure 2). Polygon 2 includes Transects 14-25. There is relatively little riparian vegetation along the left side of the river due to the presence of the land application site, while a large rock outcrop that ends just above the bridge confines the right side of the river. The channel is confined by rock riprap at the bridge along with autobody riprap both above and below the bridge resulting in a channelized condition. Erosion upstream of the bridge may be the result of channelization at the bridge, where the width of the river is constricted to 11 meters. There is an autobody in the channel above the bridge attached to a point bar along the right side of the river, while the left side of the river is a tall eroding bank. The removal of the autobody riprap from the left bank below the bridge has increased the rate of erosion, while the bank below this section of erosion is maintained by additional autobodies (Figure 3). A natural meander pattern appears to be developing within the confined channel below the bridge. There is also a smaller field along the right side of the river below the bridge along with an irrigation intake pump.

Channelization with riprap leads to morphological changes both upstream and downstream of a channelized reach (Knighton, 1998). Increases in flow velocity due to river straightening can cause channel downcutting and bank erosion both in the channelized reach and upstream (Brooks, 1985). Bed erosion precedes channel widening in streams with cohesive banks, which leads to a deeper channel capable of confining larger flows. Thus, the shear stress is increased on the bed and the toe of the banks until the banks reach a critical height for failure, which leads to channel widening (Bledsoe and Watson, 2000). Eroding banks upstream of the bridge in Polygon 2 may have attained the critical height for failure, and it is only a matter of time until these banks collapse and the river cuts around the bridge (Figure 2). Aggradation tends to occur downstream of channelized sections due to the increased sediment load provided by upstream erosion. This is evident in Polygon 3.

Polygon 3 begins below the land application site and extends from Transect 26 to Transect 34 (Figure 2). There is autobody riprap on both sides of the river in the top 10 meters of the polygon, though none downstream. The channel splits around a large gravel bar island with a side channel forming along the right bank. In time, this gravel bar may become attached to the right bank as sediment fills in the side channel, thereby returning the channel to a meandering pattern (Nelson, 1996). An extensive riparian zone extends along the left site of the river below the land application site, while the size of the riparian zone along the right side of the river also increases. Cattle belonging to a downstream landowner have accessed this portion of the reach and heavy browsing on the riparian vegetation is evident (Figure 3).

Cross-section Measurements

Cross-sectional channel form results from interactions between the flow of water and sediment through the system and the composition of the stream banks. Bank material controls the strength and stability of banks, which, in turn, influences the adjustment of channel width. The cross-sectional form of stream channels tends to be irregular with abundant local variations. Thus, the width and shape of the stream channel is expected to be variable. The cross-sectional form is a highly adjustable channel characteristic

(Knighton, 1998).

Wetted width was analyzed for each polygon during low flow (approximately 100 CFS according to the USGS gauge). The mean wetted width was 17 meters in Polygon 1, 19.2 meters in Polygon 2, and 18 meters in Polygon 3 (Figure 4). The greater wetted width in Polygon 2 may result from the lack of riparian vegetation, which can influence cross-sectional form (Ikeda and Izumi, 1990), as well as from channel alterations resulting from extensive riprap. Dense vegetation gives rise to deeper and narrower channels (Knighton, 1998). Dense vegetation is present along the banks of both Polygons 1 and 3, coinciding with narrower channel widths. Polygon 2 lacks dense riparian vegetation along the left side of the river, while both sides of the river have some degree of riprap.

Bankfull width represents the capacity of the channel to transport water and sediments. Bankfull width is determined by bankfull stage, which is the discharge at which a river begins to overflow its banks. The bankfull stage plays an important role in shaping the stream channel by moving sediment, creating and destroying bars, and altering meander bends (Dunne and Leopold, 1978; Olsen *et al.*, 1997). The mean bankfull width was 24.7 meters in Polygon 1, 24.9 meters in Polygon 2, and 29.4 meters in Polygon 3 (Figure 5). While the mean bankfull widths are similar for Polygons 1 and 2, the maximum bankfull width is substantially lower in Polygon 2. This is a direct result of channelization due to rock and autobody riprap along Polygon 2, which prevents the stream from spreading out onto the floodplain. The increase in mean bankfull width experienced in Polygon 3 may be related to the lack of riprap confining the river, which allows the river to expend energy that was not dissipated in the confines of Polygon 2.

Figure 6 represents the mean wetted width and mean bankfull width along the entire reach.

Width-to-depth ratio of the stream channels is a fundamental aspect of channel morphology (Beshcta and Platts, 1986). Cross-section measurements with the laser level below transect 14 indicate the maximum bankfull depth is 1.1 meters, while the mean depth is 0.7 meters and the overall cross-sectional area is 68.4 square meters. The bankfull width was 27.7 meters. Thus, the width-to-depth ratio is 39. The width-to-depth ratio is commonly used to described channel dimensions, though it gives no indication of the overall channel shape (Knighton, 1998). The land application site is approximately 1 meter higher in elevation than the bankfull stage at this cross-section.

Channel substrate influences the rate of sediment transport, provides hydraulic resistance, and affects the biological function of rivers. Substrate size influences the channel morphology as smaller particles are mobilized at lower velocity flows while high velocity flows are required to move larger particles (Beschta and Platts, 1986). Channel substrate was sampled at five points across each transect, totalling170 samples for the entire 1980 meter study reach. Substrate samples indicate the distribution of grain sizes on the surface of the bed. The EMAP-WP sampling method achieves a composite grain size for the whole reach, with samples from distinct bed features (Peck *et al.*, 2001). However, there is a large amount of spatial variability in bed material size. Thus, this method may not be as accurate as the Wolman pebble count, which measures grain size at a single point and represents a single population (Kondolf, 1997). The channel substrate is comprised of 2% fine gravels (>2-16mm), 60% coarse gravel (>16-64mm), 34% cobbles (>64-250mm), and 4% boulders (>250-4000mm) (Figure 7). Since gravels make up the majority of the substrate, the Tobacco River can be considered a gravel-bed stream.

Bank angle and canopy cover measurements were highly dependent on the location of the transect. Therefore, the results will be qualitatively described for the entire reach. Bank angles approached and sometimes exceeded 90 degrees along the outside of meander bends and were in the single digits along point bars at the insides of meander bends. Canopy cover was generally dense along the outside of meander bends and sparse along point bars and eroding banks. Canopy cover measurements from the center of the river were generally zero indicating that the center of the river is exposed to full sunlight. A summary of physical measurements made at each transect is presented in Appendix D.

Longitudinal Profile

Riffle-pool channels are characterized by a series of bars, pools, and riffles that occur along an undulating bed (Leopold *et al.*, 1964). These features are clearly evident in the Tobacco River. Point bars are formed as erosion along the outside of the curve is deposited along the inside of the curve, extending toward the stream and increasing in height as sediment is deposited during higher flows. As the height of the gravel bar increases, flooding becomes less frequent and finer sediments are deposited, forming a floodplain along the inside of the bend composed of a fine layer of sediments overlaying a coarser layer (Knighton, 1998). Pools are depressions within the channel and bars are the high points in the channel. The deepest location in the channel tends to occur at the tip of a point bar along the opposite bank, which is the apex of the bend. Riffles occur in the shallow zones between apex points and act as the major storage location for bed material within the stream channel (Leopold, 1994; Beschta and Platts, 1986). Riffles tend to be wider, shallower, and contain coarser bed material than pools (Knighton, 1998).

Riffle-pool sequences develop through the processes of scour and deposition. Pools result from localized scour during moderate to high flows, while riffles represent areas of gravel accumulation below pools where coarse sediment is deposited (Knighton, 1998). Measurements of pools, riffles, and glides were used to determine the riffle-pool sequence along with the size and number of pools for each individual polygon and the overall study reach. There are 20 pools in the study reach. Polygon 1 had 14 pools along a 780 meter reach, Polygon 2 had 5 pools along a 720 meter reach, and Polygon 3 had 2 pools along a 480 meter reach. The boundary between Polygons 1 and 2 contained a pool that was counted for both polygons (Figure 8).

Polygon 1, which represents a reference condition as the least impacted reach in the study, contains a higher number of pools than Polygon 2, which is channelized and lacks riparian vegetation. Polygon 1 contains a high number of small pools, averaging 8 meters in length, while Polygon 2 has a few large pools, averaging 21 meters in length (Table 2). However, the overall area occupied by pools is comparable, with 15% of the reach occupied by pools in both Polygons. Polygon 3, on the other hand, has only 2 pools occupying 6% of the reach. The numerous smaller pools in Polygon 1 are formed primarily at the outside of meander bends and by naturally occurring large woody debris, while the pools in Polygon 2 are associated with rock and autobody riprap.

Large woody debris is a major factor in pool formation in small forested streams (Richmond and Fausch, 1995). There are 85 pieces of large woody debris in Polygon 1, 41 in Polygon 2, and 45 in Polygon 3. A greater quantity of large woody debris in

Polygon 1 has resulted in more frequent pools. The pools of Polygon 1 are primarily naturally formed, while the pools in Polygon 2 results from anthropogenic alterations of the channel. The 50 meter pool in Polygon 2 is found along the rock-lined section associated with the bridge (Figure 8).

There is a similar percent of the stream reach occupied by both riffles and glides in Polygons 1 and 2 at a flow of approximately 100 CFS, while Polygon 3 has a slightly greater percent of glides. Polygons 1, 2, and 3 contain 43%, 44%, and 44% of stream length in riffles and 42%, 41%, and 50% in glides respectively (Table 2). Polygon 1 is made up of a greater number of riffles and glides than Polygons 2 and 3. While the overall length of the stream reach occupied by pools, riffles, and glides is the same in all three polygons, these features tend to occur at more frequent intervals in the relatively undisturbed conditions of Polygon 1 than in areas where anthropogenic disturbance has been greater. Thus, anthropogenic disturbance to the streambanks and riparian zone appear to reduce heterogeneity of in-stream habitat features by reducing the number of pools, riffles, and glides, while increasing their size.

Pool spacing is a fundamental aspect of channel morphology (Montgomery *et al.*, 1995). The amount of channel widths per pool was determined for each polygon and over the entire study reach. Polygon 1 has 2.3 channel widths per pool, with an average of 56 meters between each pool. Polygon 2 has 5.8 channel widths per pool, with an average of 144 meters between each pool. Polygon 3 has 8.2 channel widths per pool and an average spacing of 241 meters between each pool. Overall the study reach has 3.8 channel widths per pool and an average of 100 meters between each pool. While Leopold *et al.* (1964) found an average pool spacing of 5-7 channel widths in free-formed riffle-pool reaches, Keller and Melhorn (1978) found that average pool-to-pool spacing ranging from 1.5-23.3 channel widths, with a mean of 5.9. Montgomery *et al.* (1995) found riffle-pool channels to exhibit a mean pool spacing of 2-4 channel widths. Thus, a spacing of 3.8 channel widths per pool along the study reach is generally more frequent than average pool spacing in free-formed riffle-pool channels. In addition, pools occur more frequently in Polygon 1 where the channel is relatively undisturbed than in Polygons 2 and 3, which have been dramatically altered (Figure 8).

<u>Eroding banks</u> that appeared to be the result of anthropogenic disturbance were measured, while natural erosion along the outside of well-vegetated meanders bends was not measured. Bank stability is controlled primarily by vegetation and the nature of the bank materials (Beschta and Platts, 1986). I measured 109 meters of anthopogenically induced erosion along the right side of the river and 313 meters of erosion along the left side of the river for a total of 422 meters of erosion along 3960 meters of bank. Accelerated rates of erosion are therefore occurring on 11% of the study reach. The majority of the erosion occurs above and below the bridge along the left side of the river. Erosion above the bridge is in the form of an active headcut, while erosion below the bridge is related to the removal of autobody riprap. Erosion above the bridge is occurring along a vertical bank that is approximately 2 meters above the surface water at low flow and 1 meter above the bankfull level, while erosion below the bridge is occurring along a loosely consolidated bank sloped at a 2:1 ratio (Figure 3). Erosion near the downstream end of the study site is occurring along banks that lack extensive woody vegetation (Figure 3). Cattle that access the site from downstream are consuming woody vegetation along the study site. Cattle were witnessed on the site during fieldwork in July.

Channel stage, which describes the amount of entrenchment, was determined between each transect. The channel stage describes the ability of the river to access the floodplain, which is related to the amount of downcutting. Polygon 1 has 420 meters (54%) in Stage A-2 and 360 meters (46%) in Stage B (Figure 9). Thus, bankfull flows (1.5 year event) are able to access a floodplain ranging from one bankfull width to greater than two bankfull widths in Polygon 1. In Polygon 2 there are 60 meters (8%) in Stage A-2, 180 meters (25%) in Stage B, and 480 meters (67%) in Stage C, indicating that the majority of this reach is downcut (Figure 9). Thus, the river is unable to access the majority of the floodplain with flows less than the 5-10 year event. Polygon 3 has 120 meters (25%) in Stage A-2 and 360 meters (75%) in Stage B (Figure 9). Bankfull flows are able to access a floodplain in Polygon 3 that ranges from one bankfull width to greater than two bankfull widths.

Slope and sinuosity were analyzed for each polygon as well as the entire reach. The surface water slope has a strong influence on stream power, which has a direct impact on channel morphology. The mean slope over the entire reach was 0.87%. The mean slope for each polygon was 0.80%, 0.75%, and 1.16% respectively (Table 3). Sinuosity is the ratio of stream length to the valley length. The sinuosity over the entire reach was 1.14, while the sinuosity for each polygon was 1.01, 1.10, and 1.23 respectively (Table 3). Thus, the Tobacco River has a meandering channel pattern along the study reach. Channel patterns are influenced by stream power, which is determined by the slope and the discharge. Meanders reduce the gradient relative to a straight reach, which, in turn, reduces stream power. As water flows through a meander bend, it is raised against the outside bank creating a zone of maximum boundary sheer stress along the outer bank just below the apex of the bend. The maximum velocity current moves from the inner bank at the bend entrance to the outer bank at the bend exit (Knighton, 1998).

Stream Classification

The study reach along the Tobacco River is a Rosgen C4 stream type based on the valley type and the size of channel materials, the slope and sinuosity of the channel, and the width-to-depth ratio. Rosgen C4 streams occur in broad, gentle gradient alluvial valleys with channel materials composed primarily of gravel. Slopes are less than 2%, sinuosity is greater than 1.2, the width-to-depth ratio is greater than 12, and the entrenchment ratio is greater than 2.2 (Rosgen, 1996). The Rosgen Classification System was developed for rivers in their natural state. While this reach of the Tobacco River has been extensively altered by land-use activities, the Rosgen Classification System provides insights into the rivers natural condition. Overall, the study site along the Tobacco River has a slope of 0.87%, a sinuosity of 1.14, and a width-to-depth ratio of 39. The entrenchment ratio was not determined.

Rosgen C4 streams are slightly entrenched, gravel-dominated, riffle-pool channels characterized by meanders and point bars with a well-developed floodplain. The riffle-pool sequence averages 5-7 bankfull channel widths (Rosgen, 1996). Riffle-pool channels occur at moderate to low gradients, with slopes generally less than 1.5%. Substrate in riffle-pool channels is typically comprised of gravel, though it can range from sand to cobbles (Montgomery and Buffington, 1997). These types of streams are susceptible to accelerated rates of bank erosion and lateral adjustment is related to the presence and condition of the riparian vegetation. There is a moderate to high sediment supply in C4 streams. These streams are influenced laterally and vertically by direct streambank disturbance as well as by changes in the supply of sediment and the flow regime of the watershed (Rosgen, 1996).

Discharge

Stream power results from a combination of discharge and slope. Daily discharge data covering a 25-year period (USGS, 2002) was used to plot a Flow Duration Curve (Figure 10). Daily discharge data represents the amount of discharge over time. There is an annual spring runoff followed by flows averaging 100 CFS throughout the rest of the year. The Flow Duration Curve measures the cumulative probability of a given discharge occurring or being exceeded on any given day. A flow exceeding 1500 CFS has a 0.5% chance of occurring, while a flow over 1000 CFS has a 3.7% chance of happening, a flow over 500 CFS has a 16% chance, a flow over 100 CFS has a 69% chance, and a flow over 50 CFS has a 96% chance of happening.

Long-term data from the gauging station (USGS, 2002) were used to determine the peak flows over a 42-year period (Figure 11). A Flood Frequency Curve was plotted using this data. Peak flows occur from mid-April through June and range from 591 CFS in 1977 to 3,180 CFS in 1991. The Flood Frequency Curve describes the probability that a given peak flow will be exceeded. Thus, a peak flow over 2500 CFS has a 7% chance of occurring on a given year, while the peak flow will exceed 2000 CFS 26% of the time, 1500 CFS 45% of the time, and a peak flow over 1000 CFS will occur 81% of the time.

Bankfull discharge was determined using the Flood Frequency Curve. The bankfull discharge is the flow that fills the channel to the top of the bank (Williams, 1978). The bankfull discharge is defined as the flow that occurs every 1.5 years (Dunne and Leopold, 1978). Thus, the bankfull flow has a 75% chance of occurring in a single year. The bankfull flow for the Tobacco River is 1,070 CFS, while analysis of the cross-section measurements made with the laser level that suggest bankfull discharge is equal to 1,207 CFS.

Discharge was measured at Transects 6 and 32 on both July 11, 2001 and August 15, 2001. The summer of 2001 was an extremely low flow year that was preceded by a low flow year. The peak flow in 2000 was 1,080 CFS on April 22, while the peak flow in 2001 was 596 CFS on April 29, which is the second lowest peak flow in 40 years of record (USGS, 2002). A flow of 105 CFS at Transect 6 and 137 CFS at Transect 32 was obtained on July 11, 2001 using the Marsh-McBirney Portable Water Current Meter. The discrepancy of flow between the two transects may be a result of measurement error or due to the input of groundwater. The USGS gauge recorded a flow of 116 CFS on July 11, 2001. A flow of 51 CFS at Transect 6 and 49 CFS at Transect 32 on August 15, 2001 was obtained using the Marsh-McBirney Portable Water Current Meter. The USGS gauging station was not recording on that day, though a flow of 45 CFS was reported for August 14, 2001.

Riparian Assessment

Community and Habitat Types

There are five different riparian vegetation types covering 25.3 acres along the study reach: the *Alnus incana* (Mountain alder) community type, *Populous trichocarpa*/recent alluvial bar (Black cottonwood/recent alluvial bar) community type, *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type, *Populous trichocarpa/Symphoricarpos occidentalis* (Black cottonwood/Western snowberry) community type, and the *Picea/Cornus stolonifera* (Spruce/Red-osier dogwood) habitat type as described in *Classification and Management of Montana's Riparian and Wetland Sites* (Hansen *et al.*, 1995). The location of various riparian vegetation types depends on soil structure, soil texture, and the level of the watertable (Kovalchik and Chitwood, 1990).

Habitat types represent the "climax" vegetation that a given piece of land has the potential of supporting, while community types are seral stages currently present. Climax vegetation has attained a steady state with its environment and the population is self-maintaining, while seral vegetation has not yet reached a steady state and some species are being replaced by other species. A given piece of land has a potential for certain climax vegetation, known as the habitat type or the potential natural community, which is an ecological site classification that uses plant communities as indicators of environmental factors. The potential of a site can change with time as environmental factors, such as soil and water characteristics, change in response to erosion and deposition (Kovalchik and Chitwood, 1990).

The *Alnus incana* (Mountain alder) community type is found on streambanks and alluvial terraces of swift moving mountain and foothill streams. This is an early-to-mid seral disturbance community type that establishes following severe disturbance and is currently present on 10 sites covering 7.8 acres of the study area (Table 4, Figure 12). This type is often found along streams that were used to transport logs to mills through the use of splash dams, which has historically occurred on the Tobacco River. This type may persist for a long time before being replaced by willows or conifers. Soils on these sites remain moist throughout the growing season. The *Alnus incana* (Mountain alder) community type helps to stabilized streambanks, reduce erosion, and provide fish with cover, food, spawning sites, and cool temperatures (Hansen *et al.* 1995).

Study sites covered with the *Alnus incana* (Mountain alder) community type contain a dense overstory of *Alnus incana* (Mountain alder) with an understory comprised primarily of *Phalaris arundinacea* (Reed canarygrass) along the Tobacco River. *Phalaris arundinacea* (Reed canarygrass) is a native plant in Montana with a rhizomatous root system that tends to form dense, monotypic stands. This plant is difficult to remove once established. *Phalaris arundinacea* (Reed canarygrass) helps to stabilize streambanks and reduce erosion, though it also displaces more desirable riparian plants and reduces the overall diversity of the site (Hansen *et al.*, 1995). The *Alnus incana* (Mountain alder) community type comprises 26%, 54%, and 30% of the riparian community in Polygons 1, 2, and 3, respectively (Figure 13). Thus, this type makes up a major portion of the riparian zone, especially in Polygon 2, which has experienced the greatest amount of anthropogenic disturbance.

The *Populous trichocarpa*/recent alluvial bar (Black cottonwood/recent alluvial bar) community type, which is found on 9 sites covering 3.8 acres, is made up of seedlings and saplings of cottonwoods, which are a pioneering species that require a seed source and freshly deposited alluvium that is moist and exposed to full sunlight (Table 4, Figure 12). This is an early seral stage of primary succession that occurs on new point bars and other features formed during flood events that deposit new sediment. *Populous trichocarpa* (Black cottonwood) is a seral species that does not represent a climax community. Mature stands may appear to be regenerating in open areas, though it is likely through asexual reproduction. Climax communities on these sites are often dominated by conifers (Hansen *et al.*, 1995).

There are several nice examples of the *Populous trichocarpa*/recent alluvial bar (Black cottonwood/recent alluvial bar) community type along the study reach. *Populous trichocarpa* (Black cottonwood) seedlings along the study reach occur primarily on point bars and tend to be interspersed with *Centurea camulosa* (Spotted knapweed). The *Populous trichocarpa*/recent alluvial bar (Black cottonwood/recent alluvial bar) community type makes up 18%, 3%, and 15% of the riparian community in Polygons 1, 2, and 3 respectively (Figure 13). While this type is nicely established on point bars in Polygons 1 and 3, there is little room for the development of point bars in Polygon 2 due to the channelized condition and lack of floodplain. Thus, it is not surprising to find little evidence of this community type in Polygon 2.

The *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type is a mid-seral stage of primary succession along streams and covers 6.3 acres on 7 different sites (Table 4, Figure 12). This type is characterized by an overstory of cottonwoods and a dense understory containing an array of shrubs and herbaceous plants. The water table usually drops below 1 meter from the surface in the summer. This community type stabilizes streambanks and provides thermal cover for fish, as well as a source for large woody debris. *Cornus stolonifera* (Red-osier dogwood) and other shrubs help to control erosion (Hansen *et al.*, 1995).

The *Populous trichocarpa/Symphoricarpos occidentalis* (Black cottonwood/Western snowberry) community type is a moderately disturbed secondary successional stage of the *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type. This type is found on 3 sites covering

5.1 acres of the study area (Table 4, Figure 12). Moderate levels of grazing and/or browsing by wildlife will reduce the amount of *Cornus stolonifera* (Red-osier dogwood), *Amelancheir alnifolia* (Western serviceberry), *Prunus virginina* (Common chokecherry) found in the *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type, and increase the amount of *Rosa* species (Rose) and *Symphoricarpos occidentalis* (Western snowberry). The conversion from a dense shrub understory to a more open herbaceous understory opens up the stand, leading to a drier site with widely spaced decadent cottonwoods (Hansen *et al.*, 1995).

There are three stands representing the *Populous trichocarpa/Symphoricarpos occidentalis* (Black cottonwood/Western snowberry) community type along the study reach, the largest of which is located at the downstream end of the study reach along the right side of the river. While the *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type makes up 35%, 4%, and 16% of the riparian community in Polygons 1, 2, and 3, the *Populous trichocarpa/Symphoricarpos occidentalis* (Black cottonwood/Western snowberry) community type makes up 10%, 5%, and 39% of the riparian community in each of the respective polygons (Figure 13). Polygon 1, which represents the reference condition has a high amount of the *Populous trichocarpa/Cornus stolonifera* (Black cottonwood/Red-osier dogwood) community type, while the *Populous trichocarpa/Symphoricarpos occidentalis* (Black cottonwood/Western snowberry) community type, which is a disturbance stage covers more area in Polygon 3, where land-use practices have altered the composition of the riparian zone.

The *Picea/Cornus stolonifera* (Spruce/Red-osier dogwood) habitat type occurs on moist flat alluvial benches along streams and covers 2.4 acres on a total of 6 sites (Table 4, Figure 12). The water table is usually within 1 meter of the surface throughout the growing season. *Picea* (spruce) re-establishes quickly on disturbed sites, though it matures slowly. *Populous trichocarpa* (Black cottonwood) can comprise a major portion of the overstory (Hansen *et al.*, 1995). This type was found only in Polygon 1. Mature stands occurred along the right side of the river and were confined by the bedrock outcrop. Young stands occurred along both sides of the river along the upper margin of the gravel bars. These stands are comprised primarily of *Picea Gluaca* (White Spruce), reaching 5 meters in height, and *Populous trichocarpa* (Black cottonwood), reaching 4 meters in height, with an understory of *Centurea camulosa* (Spotted knapweed). *Cornus stolonifera* (Red-osier dogwood) and *Alnus incana* (Mountain alder) are located along the margins. The *Picea/Cornus stolonifera* (Spruce/Red-osier dogwood) habitat type comprises 11%, 31%, and 0% of the riparian community in Polygons 1, 2, and 3, respectively (Figure 13).

The amount of land covered by the different riparian communities varies widely between the three polygons as does the overall area cover by riparian vegetation, with 13.1 acres in Polygon 1, 2.9 acres in Polygon 2, and 9.3 acres in Polygon 3 (Table 4). The conversion of the riparian zone into an agricultural area in Polygon 2 is clear from these results.

Riparian Cross-sections

The mean width of the riparian zone for each polygon was determined by combining the width of the riparian zone on the right and left sides of the river and then averaging the total wide for all the transects within a polygon. The riparian zone width averages 88 meters in Polygon 1, 21 meters in Polygon 2, and 119 meters in Polygon 3 (Figure 14). Thus, the width of the riparian corridor has been greatly reduced by the clearing of the land application site for agricultural purposes.

Health Scores

Health scores determined at each transect were averaged to provide an overall health score for each polygon. A score of 80-100% indicates a "proper functioning condition" ("healthy"), while a score of 60-79% indicates the site is "functional at risk" ("healthy, but with problems"), and a score below 60% represents a "nonfunctional" condition ("unhealthy") (Bitterroot Restoration, 2001). Scores were calculated for factors representing key vegetative functions and for factors representing key soil/hydrology functions. These were combined to give the overall health score for each polygon. Scores are presented along with the highest score possible, which is used to develop the health rating. Polygon 1 and Polygon 3 had scores indicating that the stream reach is performing most assessed functions adequately (Table 5). Polygon 2, on the other hand, has problems performing many functions associated with healthy riparian areas (Table 5).

The three polygons have widely ranging scores, though many of the same problems are experienced in each. Polygon 1, which is located upstream of the land application site, is generally "healthy", though it has some problems resulting from noxious weeds, reduced streambank root mass protection, structural alterations of the streambank in the form of rip-rap along the railroad track, and places where past channel incisement appears to be healing. Polygon 2, which extends the length of the land application site, is "unhealthy", with severely reduced vegetative cover of the streambanks and floodplain, noxious weeds, only a minimal amount of preferred tree and shrub regeneration, a low amount of streambank root mass protection, and extensive structural alterations to the streambank that has led to an incised channel along the majority of the polygon. Polygon 3, which is below the land application site, is generally "healthy", though it has problems similar to Polygon 1. While this polygon is not influenced by the railroad, the downstream portion appears to be aggrading, possibly due to the input of sediment from bank erosion upstream. There is a large cottonwood gallery on the right side of the river in which most of the trees are old and decadent. This polygon is also the only section of the study reach that appears to be affected by grazing. Cattle, which appear to access this polygon from downstream, have reduced the shrub cover along the banks, leaving *Phalaris arundinacea* (Reed canarygrass) as the only stabilizer along the outside of the meander bend (Figure 3). A breakdown of the health scores into each of the 11 categories is presented in Table 6.

Biodiversity

Riparian zones are highly productive areas that tend to have a high level of biodiversity. Total species richness in riparian areas is correlated with substrate heterogeneity, which is created by the natural processes of erosion and deposition. Natural flood regimes create a high level of substrate heterogeneity, which, in turn, provides for a higher level of species richness than would otherwise occur in tightly regulated systems. High levels of biodiversity are also associated with intermediate substrate particle sizes (Nilsson *et al.*, 1989). In the study area there are 7 species of trees, 15 species of shrubs, 7 graminoids, 10 forbs, and 4 species of ferns and fern allies for a total of 43 different plant species (Table 7). Six of these species are considered noxious weeds.

Noxious Weeds

The six different species of noxious weeds found along the study reach are found in varying distributions and different locations within the riparian ecosystem. The majority of the noxious weeds are found primarily in disturbed areas and young community types, which agrees with the findings of Planty-Tabacchi *et al.*, (1996). *Centurea camulosa* (Spotted knapweed) is found primarily on the recent alluvial bars where they are densely intermingled with *Populous trichocarpa* (Black cottonwood) seedlings, which appeared to be thriving in competition with the noxious weed. *Centurea camulosa* (Spotted knapweed) is also pervasive on disturbed upland sites in the area. *Cirsium arvense* (Canada thistle), on the other hand, is found dispersed throughout the mature riparian forest, as is *Cynoglossum officinale* (Common hound's tongue). *Chysanthemum leucanthemum* (Oxeye daisy) and *Verbascum thapsus* (Common mullein) are found primarily along side-channel and mid-channel bars that appear to be covered at most flows. Low flows during the past two years of drought may have lead to increased colonization. *Melilotus alba* (White sweet clover) is the dominant noxious weed on side and mid-channel bars but does not appear anywhere else in the riparian ecosystem.

Instream Analyses

Water Samples

Water samples were analyzed for total per-sulfate nitrogen, total phosphorus, soluble nitrogen (nitrates and nitrites only), and soluble reactive phosphorus. Nutrient levels in the Tobacco River will be discussed relative to targets developed for the Clark Fork River Voluntary Nutrient Reduction Program (VNRP) by the Tri-State Implementation Council (TSIC), as well as the targets suggested by Stanford *et al.* (1997)

and adopted by the Flathead Basin Commission (FBC) for Flathead Lake (FBC, 1998). Studies on the Clark Fork River in west-central Montana suggest that the standing crop of attached diatom communities continue to increase in response to nutrient additions up to 250 parts per billion (ppb) for soluble nitrogen and 30ppb for soluble phosphorus (TSIC, 1998). Based on studies by Watson (1990), Bothwell (1989), and Dodds *et al.* (1997), the VNRP document proposes the following summer target nutrient levels for the upper Clark Fork River, which is similar in size to the Tobacco River: 300ppb for total nitrogen, 20ppb for total phosphorus, 30ppb for soluble nitrogen, and 6ppb for soluble reactive phosphorus (TSCI, 1998). The target nutrient levels for Flathead Lake are 95ppb for total nitrogen, 5ppb for total phosphorus, 30ppb for soluble nitrogen, and <0.5ppb for soluble reactive phosphorus (Stanford *et al.*, 1997). Thus, the nutrient target levels set for Flathead Lake are much lower than those set for the Clark Fork River for total nitrogen, total phosphorus, and soluble reactive phosphorus, while the soluble nitrogen target level is the same.

Total per-sulfate nitrogen analysis measures all forms of nitrogen present, including inorganic nitrogen (nitrates, nitrites, and ammonia) that is currently available, and organic nitrogen, which is soon to be available to the algae. Total per-sulfate nitrogen was higher at all sites in August than in July (Figure 15) possibly due to algal sloughing and greater dominance by groundwater during lower flows. Values range from 39ppb at Site 2 to 104ppb at Site 6 in July. August values, which are slightly higher, range from 53ppb at Site 3 to 202ppb at Site 6. The farthest downstream site contained the highest level of total per-sulfate nitrogen, though this level is still well below the Clark Fork River standard of 300 ppb. All sites also fall below the FBC nutrient target level for Flathead Lake, except for Site 6, which was 104ppb in July and 202ppb in August.

Total phosphorus measurements from unfiltered samples include dissolved phosphorus that is currently available to algae, organic phosphorus that is soon to become available, and sediment bound phosphorus that is relatively unavailable. Total phosphorus ranged from 5ppb to 6ppb at all study sites between July and August (Figure 16). Thus, all Tobacco River sites are currently well below the 20ppb level set to protect uses on the Upper Clark Fork, though they are right at the 5ppb level set for Flathead Lake.

Soluble nitrogen values reported here include only nitrates and nitrites found in filtered samples. Sites 1, 5, and 6, which are located at the upstream and downstream ends of the Tobacco River, exceeded the 30ppb level during one or both sampling periods (Figure 17). Site 1 was at 39ppb in July and 34ppb in August, Site 5 was at 34ppb in August, and Site 6 was at 51ppb in July and 169ppb in August. Thus, soluble nitrogen levels exceeded the 30ppb level at the confluence of Grave and Fortine Creeks, as well as at the downstream end of the Tobacco River. Sites 2, 3, and 4, which are located along the middle reaches of the river, along with Site 5 in July, fall below the soluble nitrogen targets of the Clark Fork River and the Flathead Lake, with values ranging from 0.6ppb to 7.7ppb.

Soluble reactive phosphorus is the most available form of phosphorus. Levels of soluble reactive phosphorus generally decreased from July to August, with one outlier recording of 3ppb at site 5 in July (Figure 18). Overall, soluble reactive phosphorus levels ranged from 0.8ppb to 1ppb, which exceeds the soluble reactive phosphorus target level of <0.5ppb set for Flathead Lake.

The relation of nitrogen and phosphorus in the water column appears to influence the species composition of the algal community. The filamentous green *Cladophora* dominates those parts of the Clark Fork River with low nitrogen:phosphorus (N:P) ratios. Hence, targets developed by the Clark Fork VNRP allow for a N:P ratio of 15:1 to discourage *Cladophora* growth. Watson (1990) suggests that an N:P ratio in the water column less than 5:1 indicates nitrogen limitation and a ratio greater than 10:1 indicates phosphorus limitation, with values falling in-between representing a balance between nitrogen and phosphorus. The mean ratio of total nitrogen to total phosphorus was 10 in July and 17 in August. The N:P ratio in the Tobacco River ranges from 10:1 to 17:1, indicating that phosphorus is the nutrient currently limiting the growth of algae in the Tobacco River. Since the algae are usually starved for phosphorus, they are not able to use all the nitrogen available.

The concentration of total nitrogen and soluble nitrogen increase downstream of the land application site, while phosphorus levels remain fairly constant along the entire Tobacco River. Nitrogen is primarily transported in groundwater, while phosphorus is primarily transported attached to sediment particles in surface runoff (Peterjohn and Correl, 1984). Reduced levels of phosphorus may be related to the fact that soil holds onto phosphorus during the land application of effluent, while the nitrogen is flushed through the system more easily. Thus, discharging the waste water plant effluent directly into the river may increase the amount of phosphorus reaching the river, which would reduce the N:P ratios and possibly shift algal communities toward the more problematic filamentous green algae.

Water clarity was measured on July 11 and August 15, 2001, with a transparency tube. The tube bottom was visible through 100cm of water.

Periphyton Samples

Benthic chlorophyll a levels were measured to determine the amount of attached algae that accumulated during the sample period. The amount of chlorophyll a pigment in each algae sample was divided by the area sampled to give the amount of pigment per square meter of stream bottom. Standards developed for the Clark Fork River set levels for chlorophyll a at 100mg/square meter for the summer average (June 21-September 21) and 150mg/square meter for a peak value (Watson and Gestring, 1996). The amount of chlorophyll a increased in a downstream direction during both sampling periods. The July samples ranged from 9.6-26mg per square meter, while the August samples ranged from 13-23mg per square meter (Figure 20). While the chlorophyll a levels significantly increased at Site 3 from July to August, chlorophyll a levels dropped at Sites 4 and 5. This may be related to the lower flow during the August samples and the associated alterations in groundwater interactions. Overall, the amount of chlorophyll a per square meter of stream bottom is well below the Clark Fork River target levels. However, target levels have not yet been defined for the Tobacco River.

Benthic attached algae samples were also analyzed for their ash free dry weight (AFDW) as another measure of the amount of biomass found on a square meter of stream bottom (Figure 20). In July there was 15, 26, and 36 grams of AFDW per square meter at sites 3, 4, and 5 respectively. The amount of benthic biomass increased slightly at sites 3 and 4 during August, with 19 and 28 grams of AFDW per square meter of stream bottom, while the AFDW decreased at site 5, with only 26 grams per square meter. The ratio of

AFDW to chlorophyll a ranged from 1300-1600 during July and 1200-2200 during August, which indicates most of the biomass was not living algae.

Conclusions and Recommendations

Channel Morphology

Riparian vegetation can be managed to stabilize stream banks, which reduces erosion, improves fish habitat, and restores natural channel morphology (Osborne and Kovacic, 1993). Channel widening and lateral instability brought about by land-use practices are reversible (Millar, 2000). Restoration projects that impose unnatural conditions on the stream system lead to unstable channels (Hey, 1996), while projects that complement natural processes will attain success with less effort and lower costs (Heede, 1986). Re-establishing vegetation on the banks and in the riparian zone with species that grow densely and have deep-binding root-masses should lead to narrower channels. The creation of well-vegetated banks, which allow for erosion and lateral channel migration to occur at natural rates, is a fundamental aspect of successful stream restoration projects (Miller, 1999). Various natural streambank stabilization techniques, such as willow poles, brush mats comprised of bundles of willows, and fiberscine roles appropriate for this site can be found in *The Practical Streambank Bioengineering Guide* (Bentrup and Hoag, 1998). Specifically, willow pole plantings of *Salix Exigua* (Sandbar Willow) along the base of the eroding bank may help reduce the rate of erosion along the land application site.

Streambank stabilization techniques should be focused primarily on preventing erosion upstream of the bridge, while it may be beneficial in the long run to allow erosion downstream of the bridge to proceed. The channel appears to be re-establishing a meandering pattern downstream of the bridge. Beginning the restoration project above the bridge allows the work to be completed in phases, while, at the same time, providing an opportunity to test various restoration techniques. This also reduces the cost of the original project and would limit the amount of loss due to failures related to natural events and/or improper installation techniques. There are 133 meters of eroding bank above the bridge between Transect 18 and Transect 21 that would benefit from streambank stabilization efforts, while there are 83 meters of eroding bank below the bridge from Transect 21 to Transect 23 leading down to the autobody riprap (Figure 21). The autobody should be removed from the center of the stream in the reach above the bridge, while autobody riprap along the left bank below the bridge should only be removed if the river is going to be allowed to continue meandering. If the decision is made to stabilize the streambank below the bridge, then the autobody riprap should not be removed until dense growth of vegetation is established along the bank. Vegetated streambanks and restored riparian forests should reduce streambank erosion and the rate of lateral migration along this reach of the Tobacco River, which will decrease sedimentation rates and improve fish habitat.

Riparian Vegetation

Maintaining existing riparian vegetation and re-establishing natural riparian vegetation is an important tool for restoring natural channel stability (Beeson and Doyle, 1995). Restored stream reaches improve the health of the stream ecosystem and the watershed as a whole. Based on the findings of this study, it is proposed that riparian communities be restored to a width of 60 meters along the left side of the river in Polygon 2 upstream of the bridge and 60 meters along both sides of the river downstream of the bridge. This plan calls for vegetative plantings extending 420 meters upstream of the bridge and 380 meters downstream of the bridge on the left side of the river, along with 240 meters along the right side of the river downstream of the bridge (Figure 22). Restoration would increase the width of the riparian zone in Polygon 2 so that it would more closely resemble the width of less disturbed upstream and downstream riparian areas. Restoring 60 meters of vegetation along the land application site would add an additional 3.1 acres of riparian vegetation to the left side of the river above the bridge and 2.8 acres below the bridge, while an additional 1.6 acres would be restored along the right side of the river below the bridge (Figure 22). Thus, 7.5 acres of crop land would be converted back into riparian vegetation, including 5.9 acres of land application site.

Restoration of this site will require the active planting of vegetation and protection of the vegetation from grazing until it becomes established. Since this site is well above the water table, it will require species adapted to drier conditions. Appropriate shrub species adapted to drier conditions include *Amelanchier alnifolia* (Western serviceberry) and *Prunus Virginina* (Common chokecherry), while appropriate tree species include *Populous Tremuloides* (Quaking aspen), *Pinus Pondrosa* (Ponderosa pine), and *Pseudotsuga menziesii* (Douglas fir). Planting vegetation along the stream channel will increase the size of the riparian corridor while reducing the amount of nutrients that enter the river from the land application site. Thus, both terrestrial and aquatic ecosystems will benefit from the restoration project.

Nutrients and Algae Levels

The original intent of this study was to document nutrient and algae levels in the Tobacco River before direct discharge commenced. Unfortunately, direct discharge began in the spring of 2001, earlier than expected, so it was not possible to obtain the intended baseline data. Fortunately, discharge occurred for only two months, May and June. Thus the water samples collected during July and August, 2001, provide a reasonable indication of nutrient levels in the river without direct discharge during those months. However, July and August algal levels were likely influenced by the spring discharge. Although not the ideal situation for assessing the effects of the new direct discharge on the river, it is still possible to gain some insight from these observations.

At the time of this study, Tobacco River nutrient levels were well below Clark Fork River nutrient standards, and were at or below target values for Flathead Lake (except for soluble reactive phosphorus, which was slightly above the target level). While phosphorus (P) levels were fairly uniform at all sample sites, nitrogen (N) levels increased downstream of the land application site, suggesting N loading from that site.

Given the low levels of nutrients and algae observed in July and August when direct discharge was not occurring, it seems likely that direct discharge of nutrient-rich wastewater throughout the summer would increase attached algae levels. Higher levels of nutrients and algae downstream of the land application and direct discharge sites are also suggestive that algae levels would respond to increased nutrients.

Low levels of P and high N:P ratios suggest that P probably limits the growth of benthic algae in the Tobacco River when direct discharge is not occurring. Although benthic chlorophyll a levels are well below Clark Fork River standards, they increase significantly downstream of the land application site. At first glance, this might suggest that algal levels are responding to higher N levels, but recall that higher P levels probably occurred earlier during direct discharge, and the higher algae levels probably accumulated at that time.

Discharging wastewater directly into the river, rather than land applying it, will likely increase the amount of P in the river. If direct discharge takes place throughout the summer, higher algae levels are likely. Hence the decision to abandon land application should be reconsidered. Wastewater could be stored or land applied during the growing season, and direct discharged only when the ground is frozen or perhaps during spring high flows. Such a strategy would reduce the load on the land application site while protecting the river at the most sensitive time. Impacts of the increased nutrient load to Lake Koocanusa should also be considered.

Additional land application sites may be needed to rest the existing site and to accommodate growth in Eureka. To avoid overapplication of wastewater, consult EPA's Design Manual for Land Treatment of Municipal Wastewater (EPA 625/1-81-013).

Table 1. Water quality sample sites proceeding downstream.

Site	*Description*
1	10m below the bridge that crosses the Tobacco River directly downstream of the confluence of Grave Creek and Fortine Creek
2	10m above the bridge crossing the Tobacco River near the Historic Village in Eureka directly above the confluence with Sinclair Creek
3	Located above the field where sewage effluent has been land applied, accessed at the last mender bend that is truncated by rip-rap protecting the railroad track
4	Below the field and slightly upstream of the osprey nest in the power pole, just upstream of the new effluent discharge pipe
5	Located at the USGS gauging station 600m below the new effluent discharge pipe, which allows for a mixing zone of 40 times the channel width (considered to be 15m since this was the average wetted width at approximately 100 CFS)
6	Slightly upstream of the remnants of the old railroad bridge, at the Forest Service fishing access

Table 2. Pools, riffles, and glides (length in meters).

	Amount	Percent of Reach Length	Total Length	Mean Length	Maximum Length	Minimum Length
Pools						
Polygon 1	14	15	115	8.2	15	4
Polygon 2	5	15	104	21	50	7
Polygon 3	2	6	29	15	15	14
Riffles						
Polygon 1	12	43	344	29	105	3
Polygon 2	7	44	319	46	102	10
Polygon 3	6	44	216	36	88	12
Glides						
Polygon 1	17	42	321	19	51	5
Polygon 2	8	41	296	37	78	15
Polygon 3	5	50	235	47	75	21

Table 3. Slope and sinuosity.

	Polygon 1	Polygon 2	Polygon 3	Overall
Slope	0.80	0.75	1.16	0.87
Sinuosity	1.01	1.1	1.23	1.14

Table 4. Land coverage of riparian vegetation.

Community or Habitat Type	***Acres***			
	Polygon 1	Polygon 2	Polygon 3	*Total*
Mountain alder	3.4	1.6	2.8	7.8
Black cottonwood/recent alluvial bar	2.3	0.1	1.4	3.8
Black cottonwood/Red-osier dogwood	4.6	0.1	1.5	6.2
Black cottonwood/Western snowberry	1.3	0.2	3.6	5.1
Spruce/Red-osier dogwood	1.5	0.9	0	2.4
Total	13.1	2.9	9.3	25.3

Table 5. Lotic Wetland Health Assessment.

	Vegetation	Rating	Soil/Hydrology	Rating	Overall	Rating	Description
Polygon 1	21/27	77%	21/27	77%	42/54	77%	Functional at Risk
Polygon 2	14/27	51%	13/27	48%	27/54	50%	Nonfunctioning
Polygon 3	18/27	66%	23/30	77%	41/57	72%	Functional at Risk

Table 6. Health scores for each transect derived from the Lotic Wetland Health Assessment Field Score Sheet.

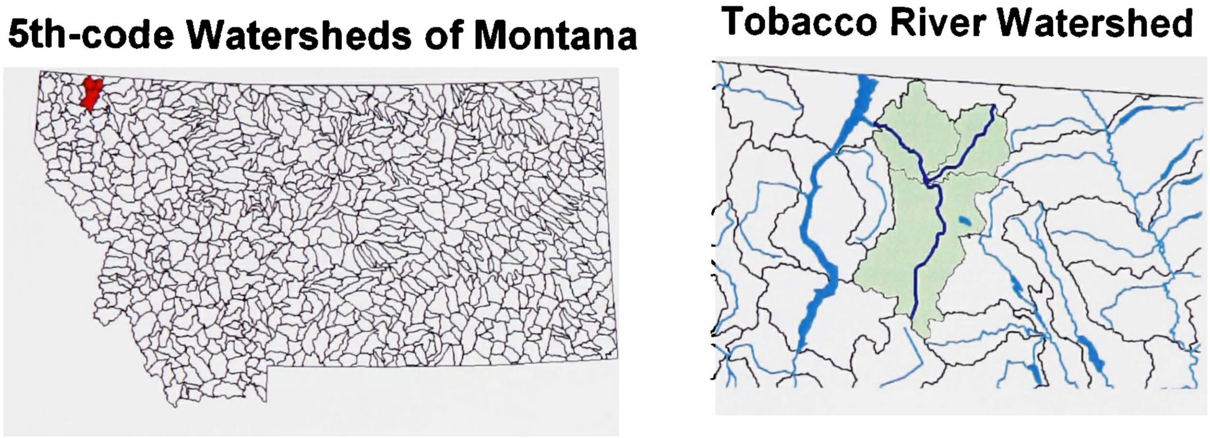
	Description	Polygon 1	Polygon 2	Polygon 3	Possible
1	vegetative cover of floodplain and streambanks	6	4	6	6
2	invasive plant species	0	0	0	6
3	disturbance-caused undesirable species	3	3	3	3
4	preferred tree and shrub establishment and regeneration	6	2	6	6
5	utilization of preferred trees and shrubs	3	2	1	3
6	standing decadent and dead woody material	3	3	2	3
7	streambank root mass protection	4	2	4	6
8	human-caused bare ground	6	6	6	6
9	streambank structurally altered by human acitivity	4	2	4	6
10	pugging and/or hummocking	NA	NA	2	3
11	stream channel incisement (vertical stability)	7	3	7	9

Table 7. Plants species present along the study reach (*noxious weed).

Trees	
Larix occidentalis	Western Larch
Picea glauca	White Spruce
Pinus ponderosa	Ponderosa Pine
Populous tremuloides	Quaking Aspen
Populous trichocarpa	Black Cottonwood
Pseudotsuga menziesii	Douglas Fir
Thuja plicata	Western Redcedar
Shrubs	
Alnus incana	Mountain Alder
Amelanchier alnifolia	Serviceberry
Betula occidentalis	Water Birch
Cornus stolonifera	Red-osier Dogwood
Crataegus douglasii	Black Hawthorn
Lonicera involucrata	Black Twinberry
Prunus virginiana	Common Chokecherry
Ribes spp.	Currant
Salix drummondiana	Drummond Willow
Salix exigua	Sandbar Willow
Salix geyeriana	Geyer Willow
Salix lutea	Yellow Willow
Salix planifolia	Planeleaf Willow
Symphoricarpos albus	Common Snowberry
Symphoricarpos occidentalis	Western Snowberry
Graminoids	
Agrostis stolonifera	Redtop
Bromis inermis	Smooth Brome
Carex raynoldsii	Raynold's Sedge
Carex rostrata	Beaked Sedge
Descampsia cespitosa	Tufted Hairgrass
Phalaris arundinacea	Reed Canarygrass
Poa pratensis	Kentucky Bluegrass
Forbs	
Aralia nudicaulis	Wild Sarsaparilla
*Centaurea camulosa**	Spotted Knapweed*
*Cirsium arvense**	Canada Thistle*
*Chryanthemum leucanthemum**	Oxeye Daisy*
Clematis ligusticifolia	White Virgin's Bower
*Cynoglossum officinale**	Common Hound's Tongue*
Dodecatheon jeffreyi	Tall Mountain Shootingstar
*Melilotus alba**	White Sweet Clover*
Mentha arvense	Field Mint
*Verbascum thapsus**	Common Mullein*

Ferns and Allies	
Elocharsis palustris	Creeping Spikerush
Equisetum arvense	Field Horsetail
Equisetum hyemale	Common Scouring-rush
Scirpus tabernaemontani	Common Great Bulrush

Figure 1. The Tobacco River Watershed and an overview of the sample sites (Natural Resource Information System, 2002).



Overview of Water Quality Sample Sites and the Land Application Site

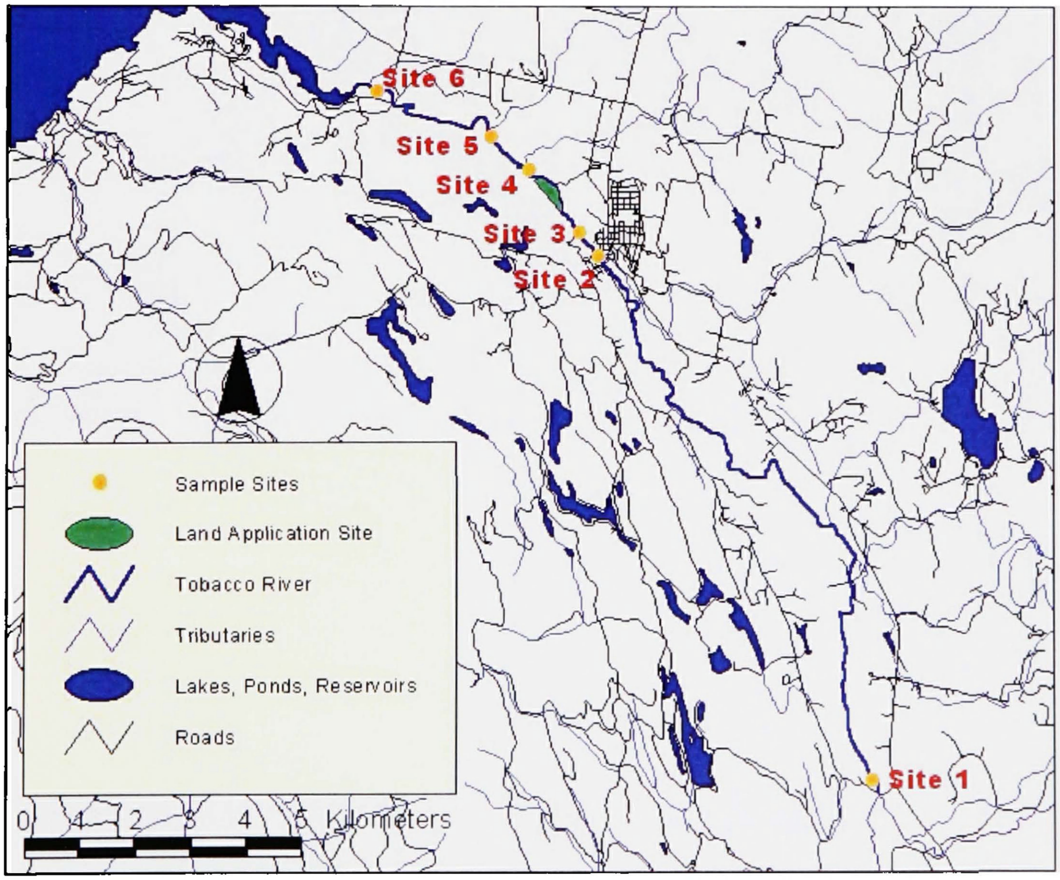


Figure 2. Overview of the Tobacco River study reach showing polygons, transects, and sample sites presented at bankfull flow.

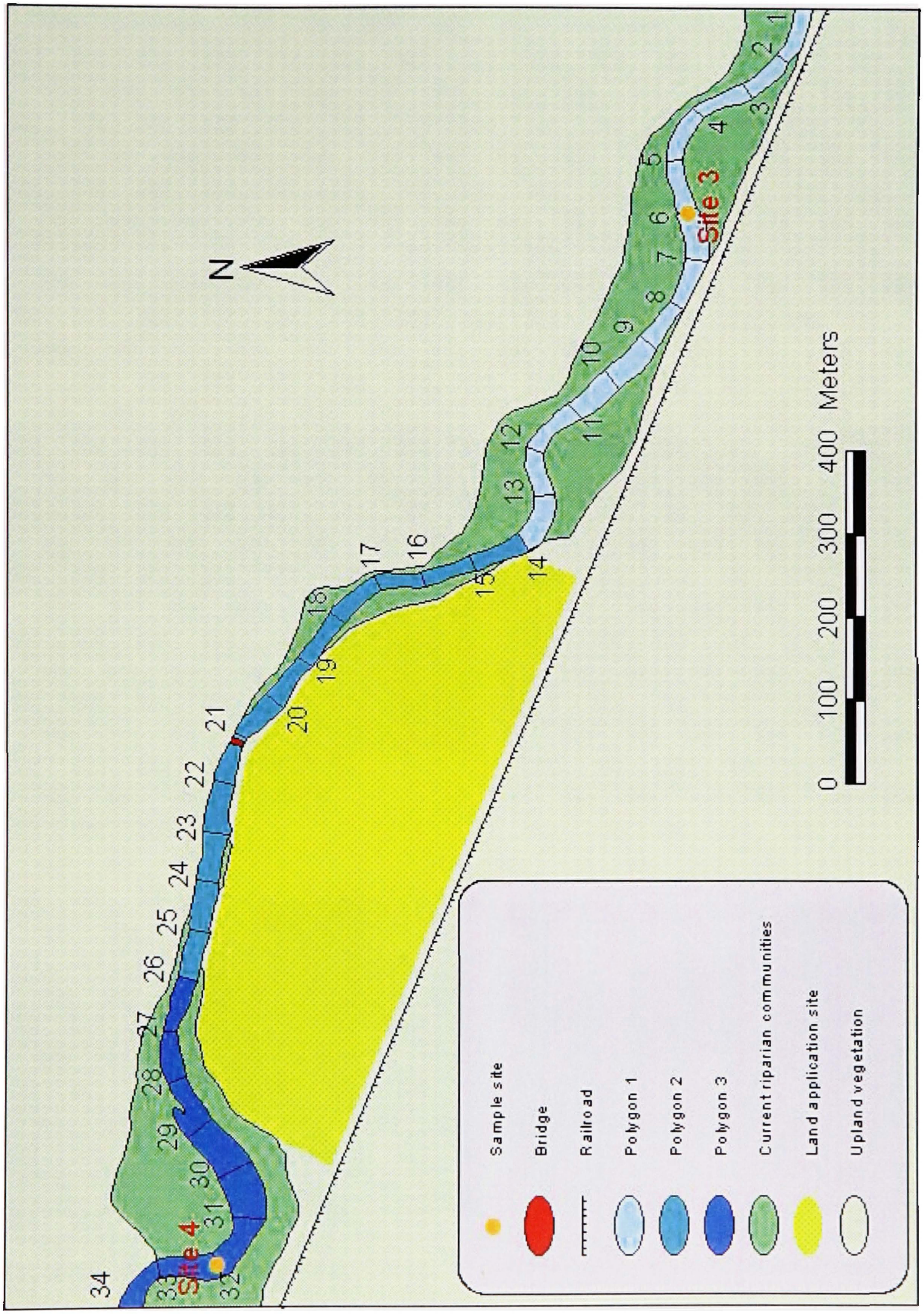


Figure 3. Photographs for each of the polygons along with other interesting features.

Photo 1: Polygon 1, Transect 1, upstream upstream view.

Photo 2: Polygon 1, Transect 1, downstream view.

Photo 3: Polygon 1, Transect 10, downstream view showing the "reference condition."

Photo 4: Polygon 1, Transect 12, upstream view showing the "reference condition."

Photo 5: End of Polygon 1, start of Polygon 2, Transect 14, upstream view.

Photo 6: End of Polygon 1, start of Polygon 2, Transect 14, downstream view.

Photo 7 (series): Polygon 2, Transects 19-23, showing an overview of the land application site along with erosion upstream and downstream of the bridge.

Photo 8: Erosion below Transect 20.

Photo 9: Deep pool at Transect 20 formed by LWD and autobody rip-rap.

Photo 10: Erosion above Transect 23.

Photo 11: Autobody rip-rap “stabilizing” the streambank below Transect 23.

Photo 12: End of Polygon 2, Start of Polygon 3, Transect 26, upstream view.

Photo 13: End of Polygon 2, start of Polygon 3, Transect 26, downstream view.

Photo 14: Polygon 3, Transect 31, eroding Reed Canarygrass.

Photo 15: Outlet of effluent discharge pipe, around the bend from Transect 34.

Photo 16: End of Polygon 3, Transect 34, upstream view.

Photo 17: End of Polygon 3, Transect 34, downstream view.

Photo 18: Algae at Transect 6, July 11, 2001.

Photo 19: Algae below Transect 20, August 15, 2001.

Figure 4. Tobacco River, MT, wetted widths measured on July 8, 2001 (mean, maximum, minimum).

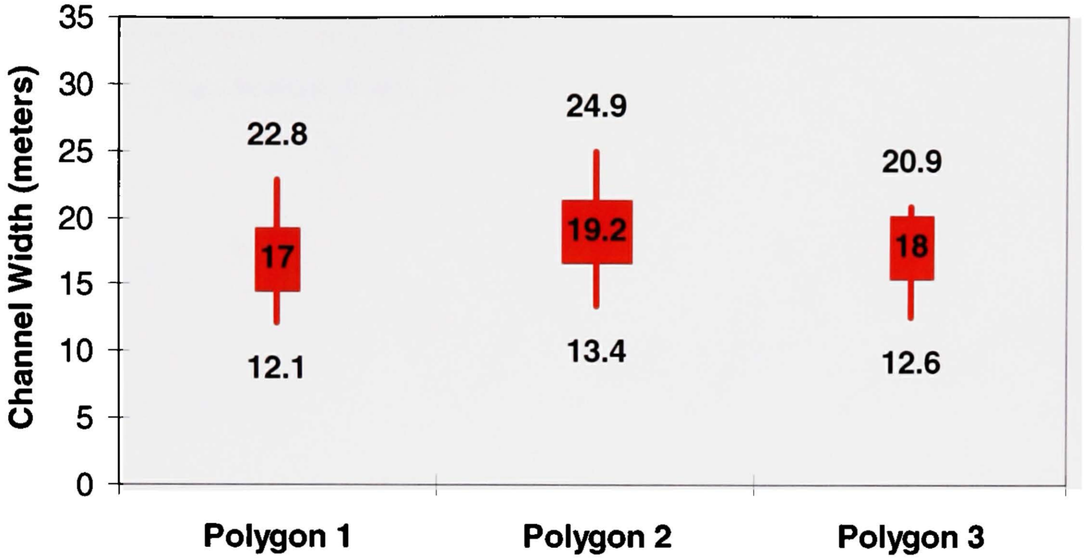


Figure 5. Tobacco River, MT, bankfull widths measured on July 8, 2001 (mean, maximum, minimum).

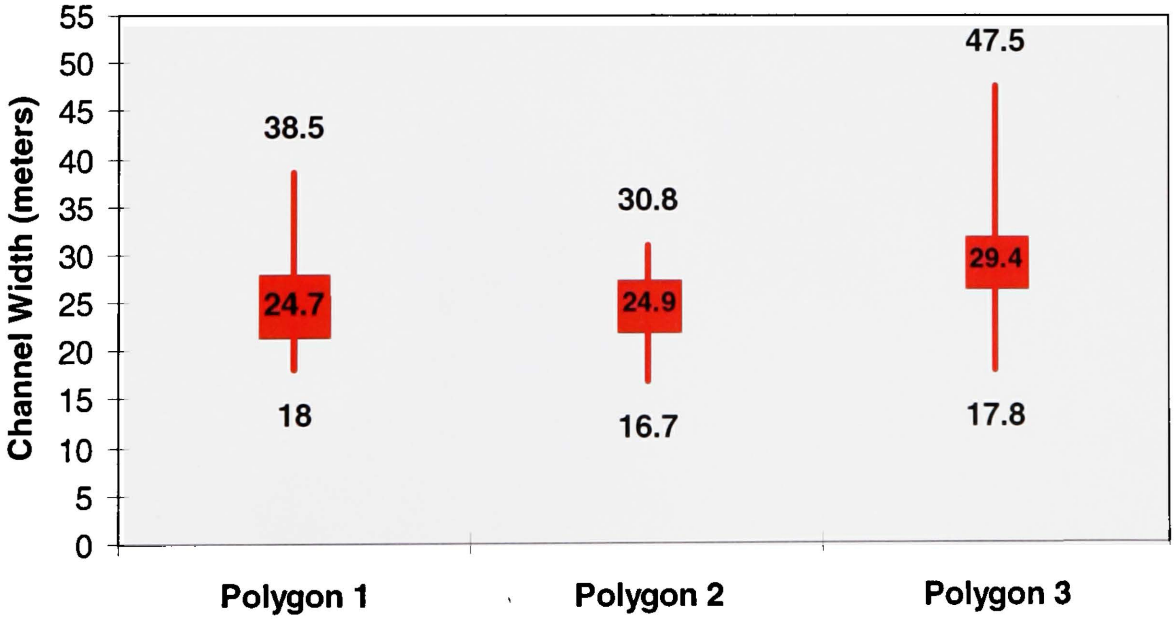


Figure 6. Tobacco River, MT, bankfull width and wetted width along the study reach measured on July 8, 2001.

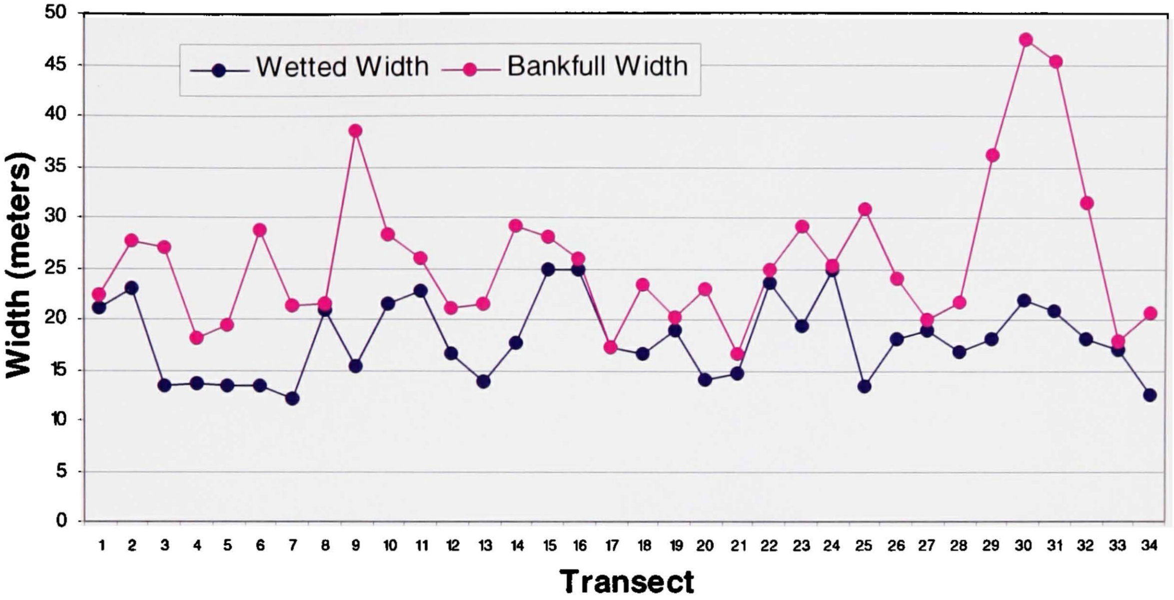


Figure 7. Tobacco River, MT, channel substrate average over the entire study reach on July 8, 2001.

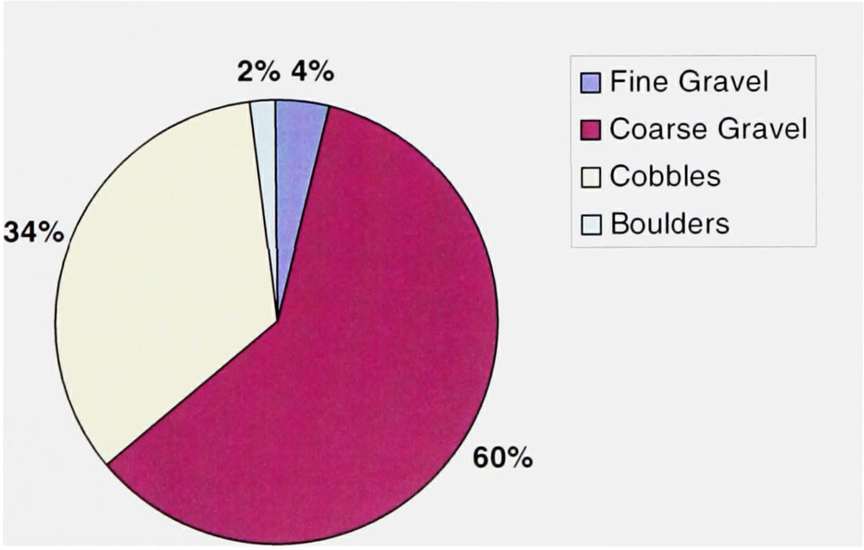


Figure 8. Pool spacing along the Tobacco River study reach at low flow.

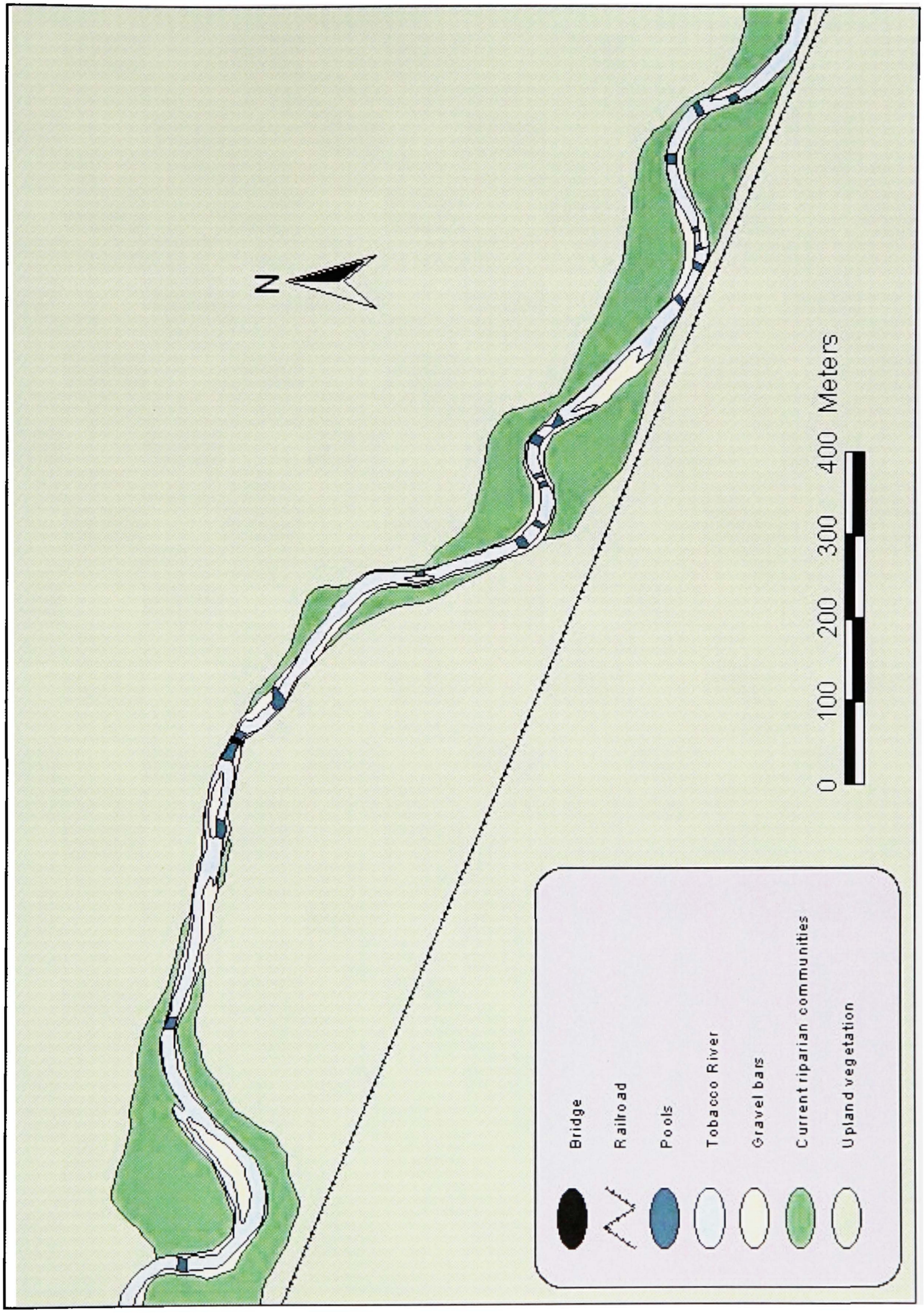


Figure 9. Channel stage along the Tobacco River study reach presented at bankfull flow.

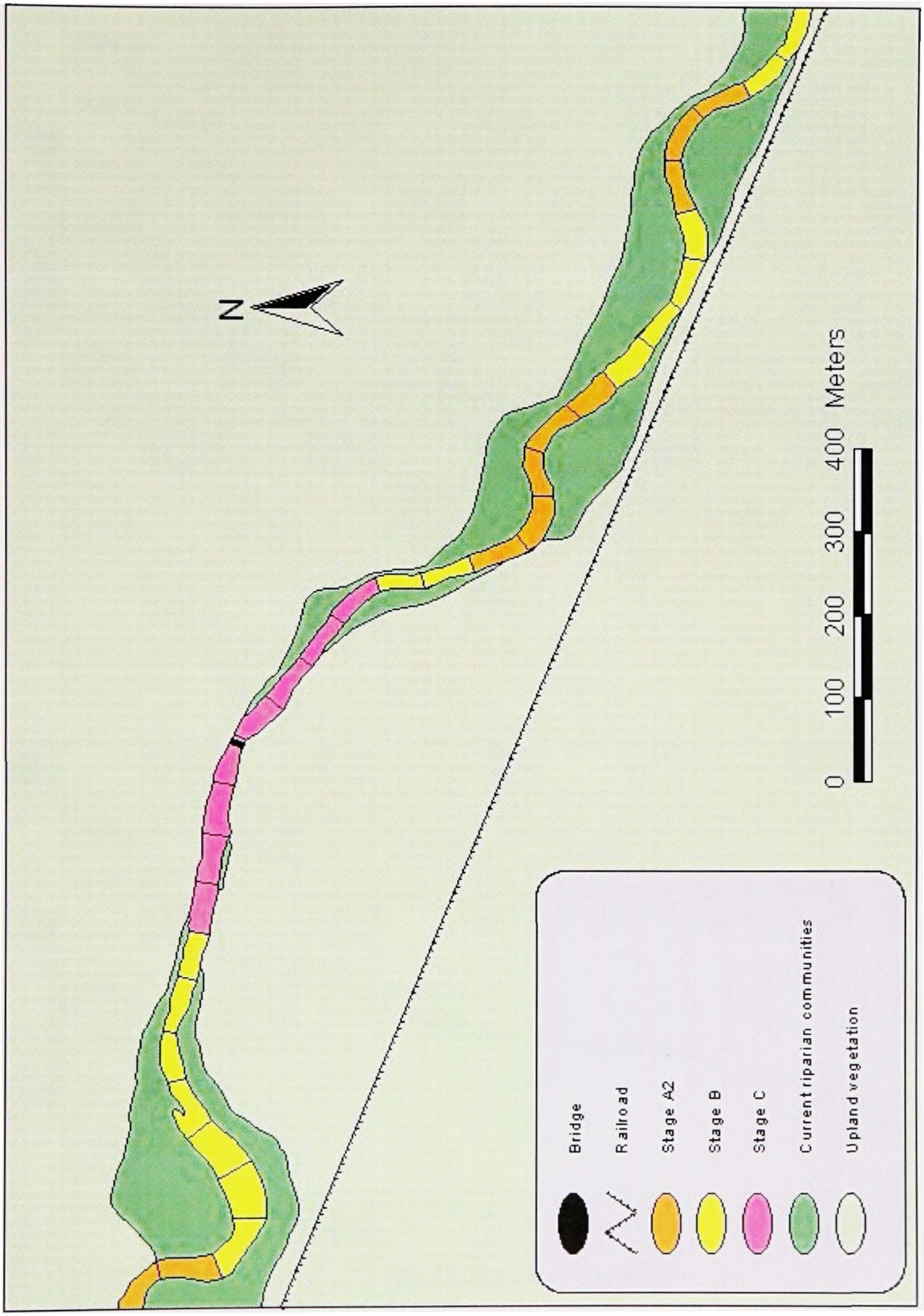


Figure 10. Flow duration curve for the Tobacco River using 25 years of data (USGS, 2001).

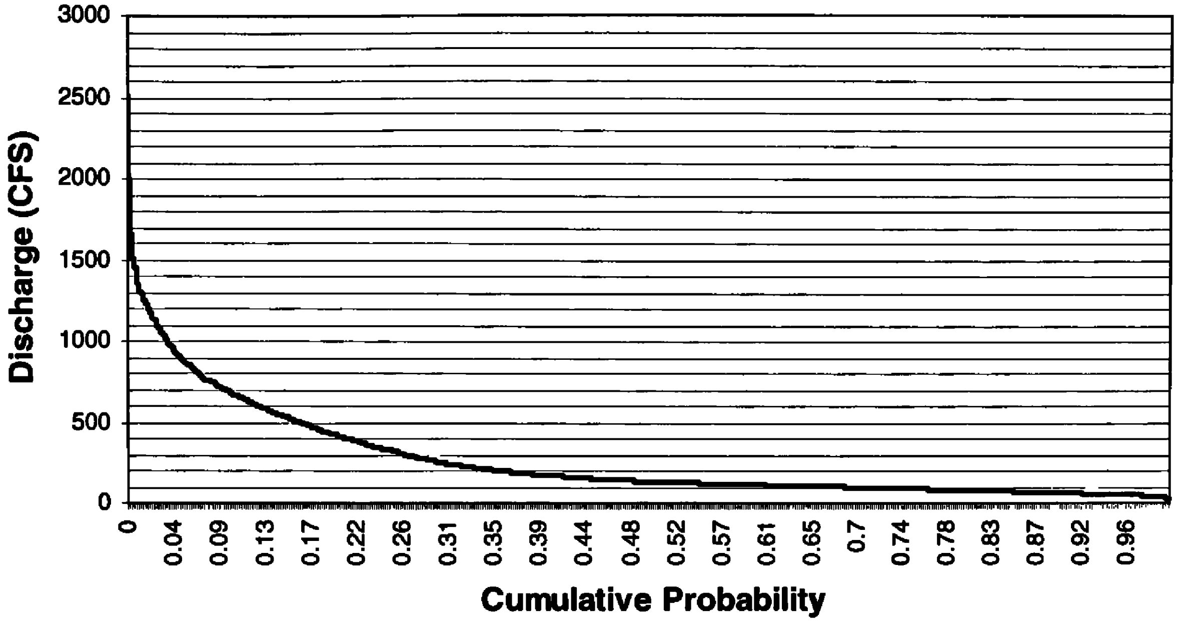


Figure 11. Flood frequency curve for the Tobacco River using 42 years of data (USGS, 2001).

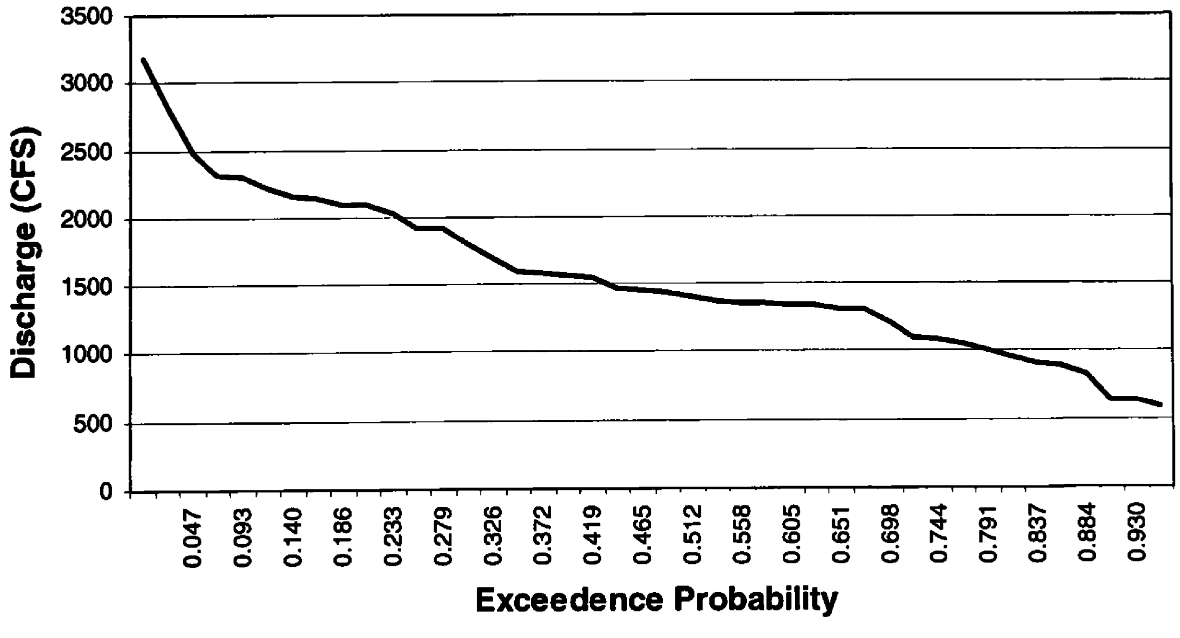


Figure 12. Riparian vegetation community and habitat types along the Tobacco River study reach presented at low flow.

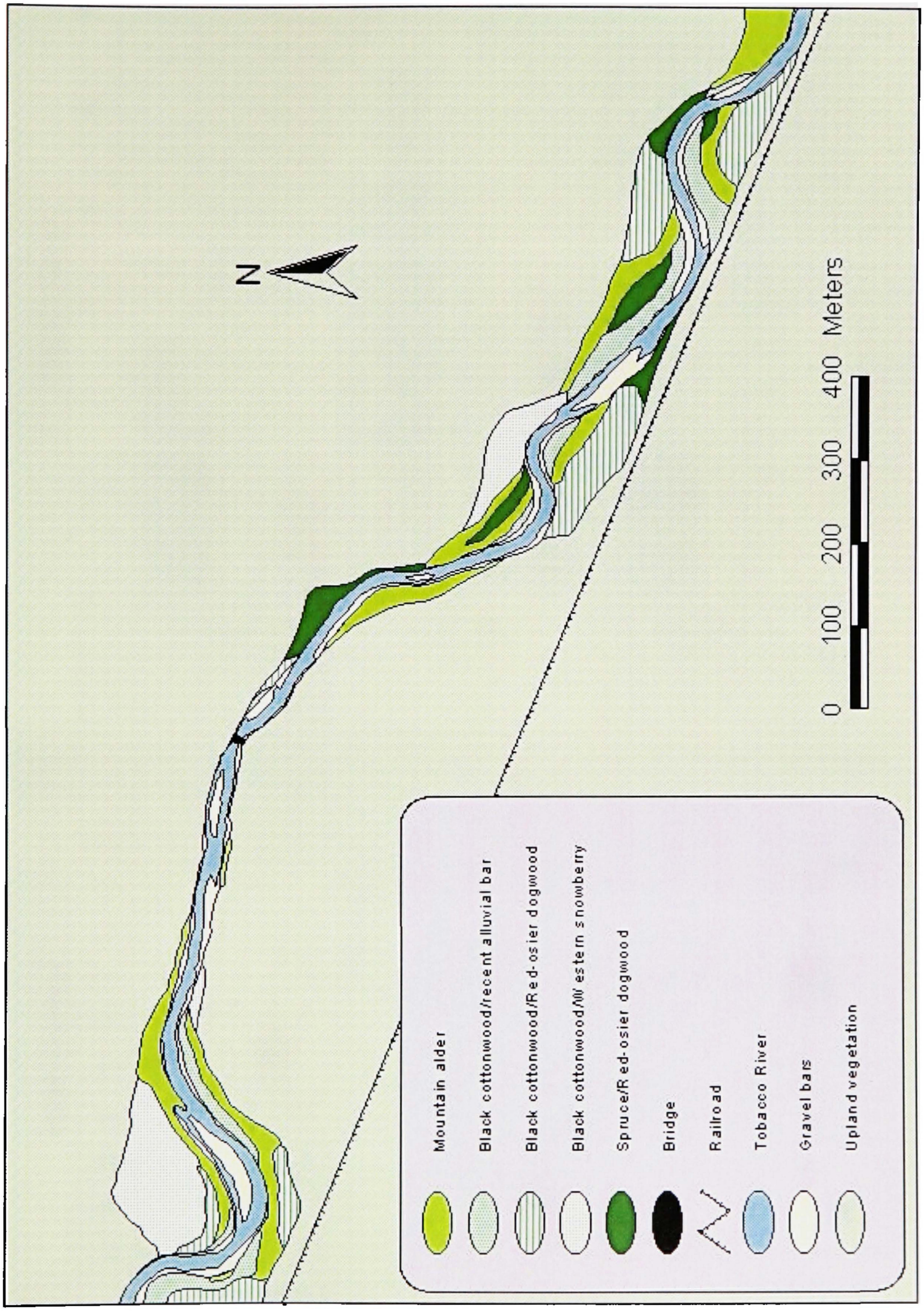


Figure 13. Tobacco River, MT, riparian communities in each study polygon (percent cover).

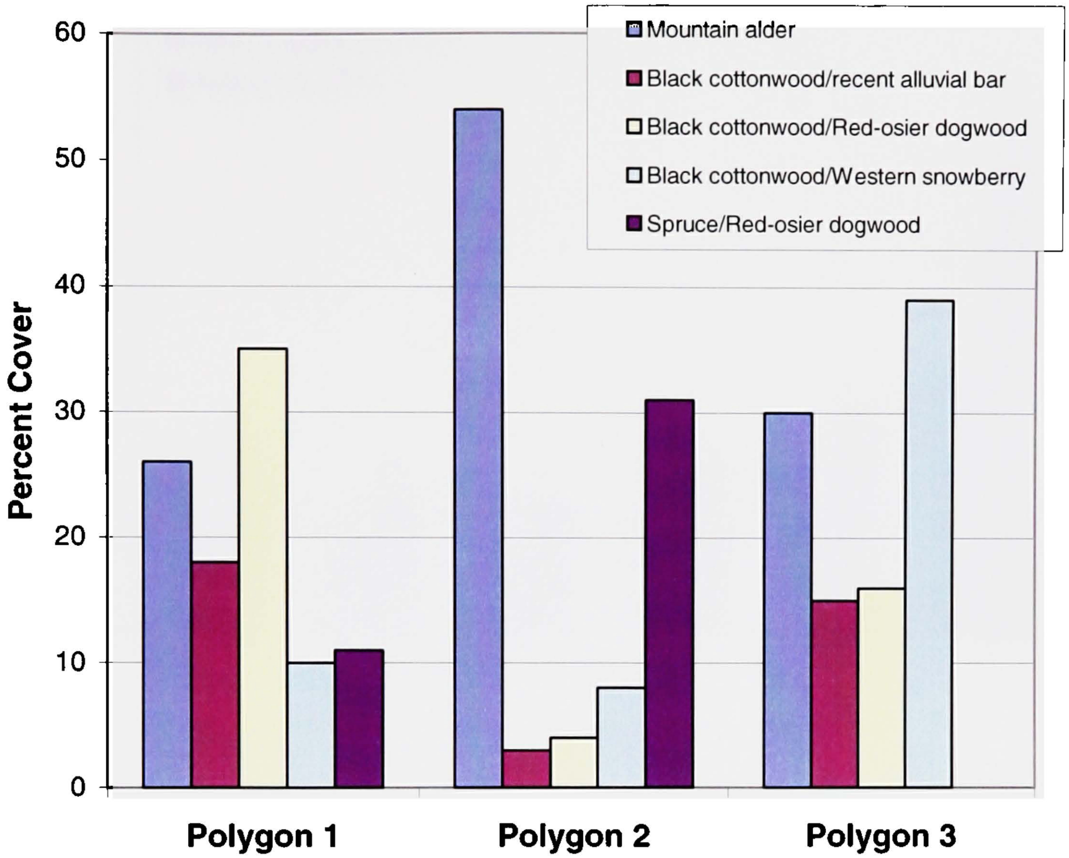


Figure14. Tobacco River, MT, riparian zone widths (mean, maximum, minimum) measured on August 14, 2001.

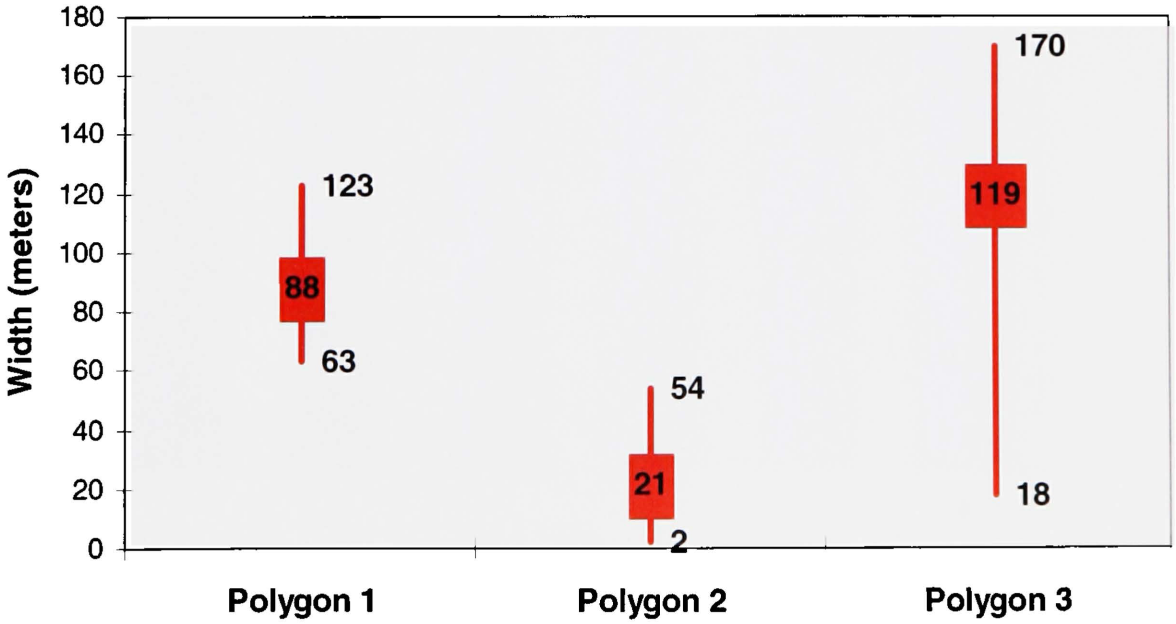


Figure 15. Tobacco River, MT, total per-sulfate nitrogen.

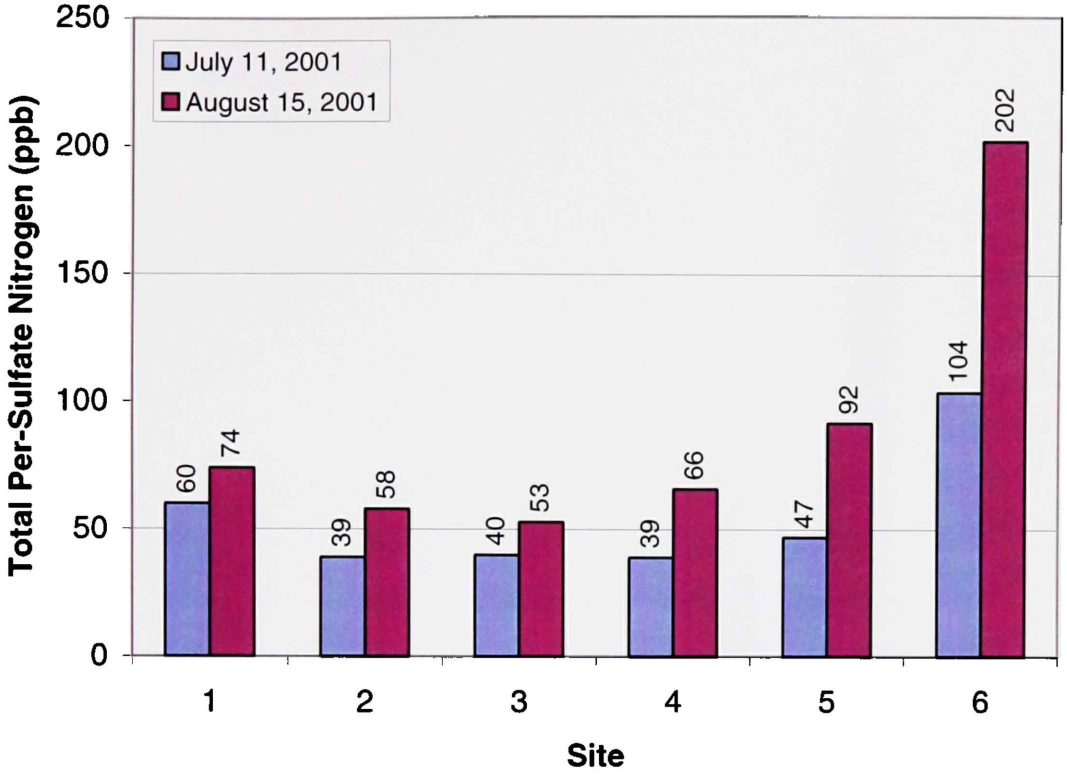


Figure 16. Tobacco River, MT, total phosphorus.

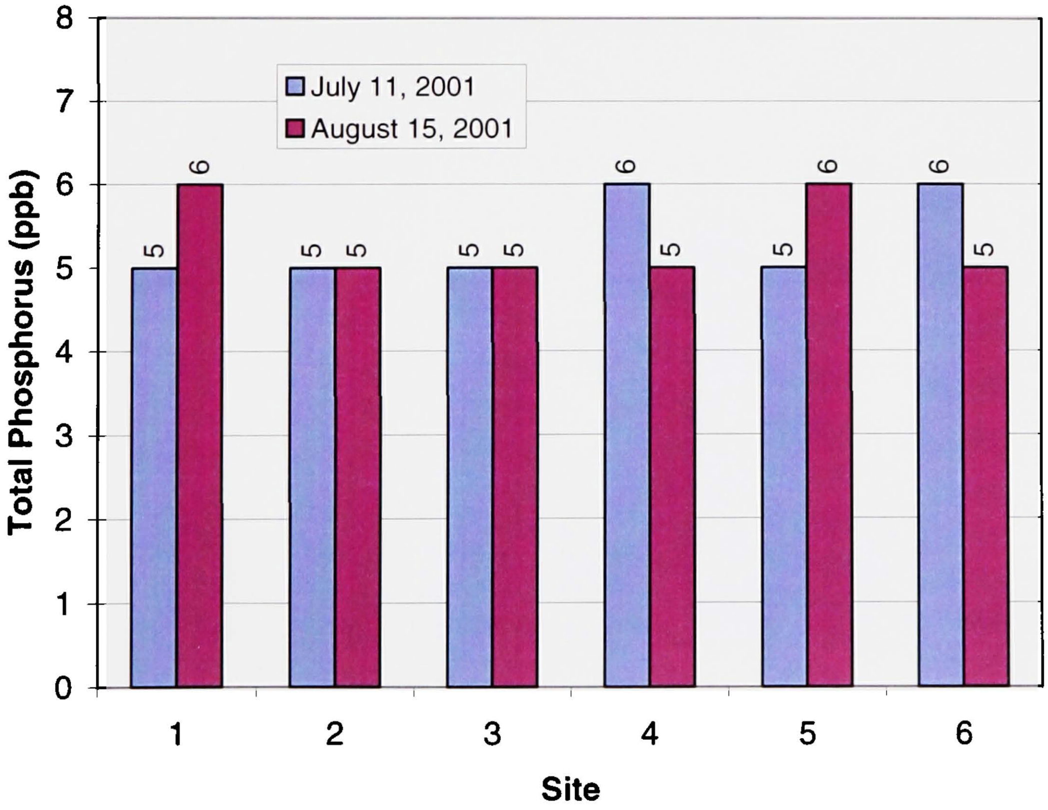


Figure 17. Tobacco River, MT, nitrates/nitrites (soluble nitrogen).

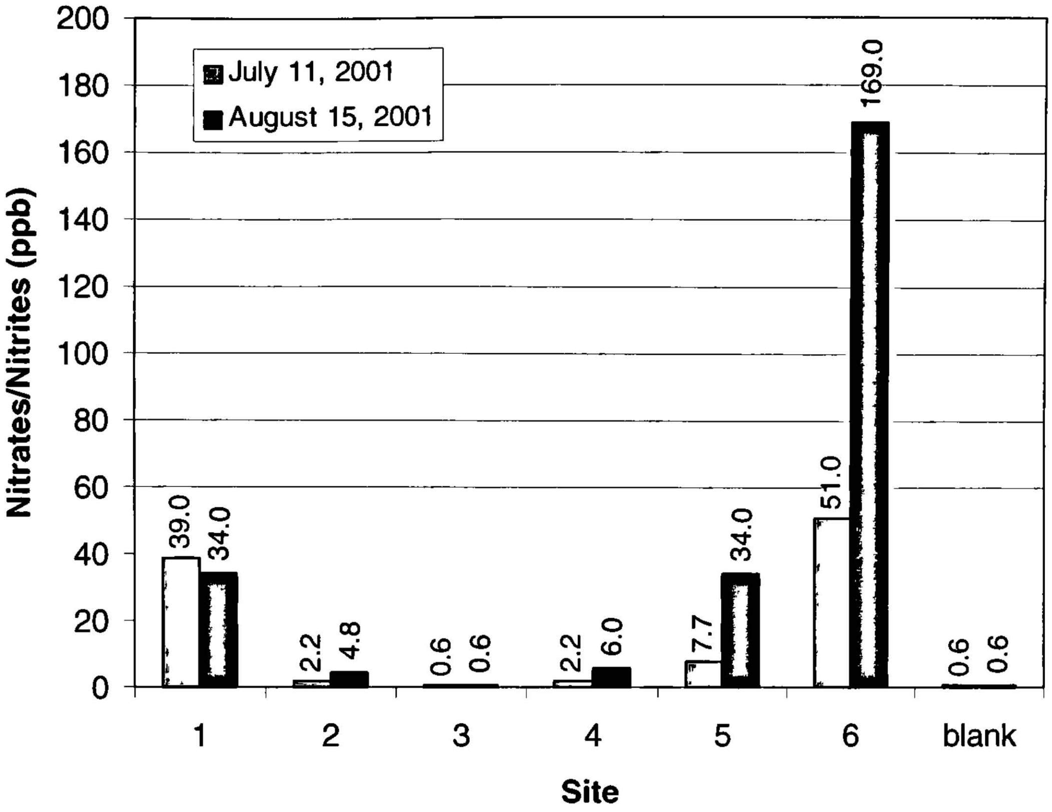


Figure 18. Tobacco River, MT, soluble reactive phosphorus.

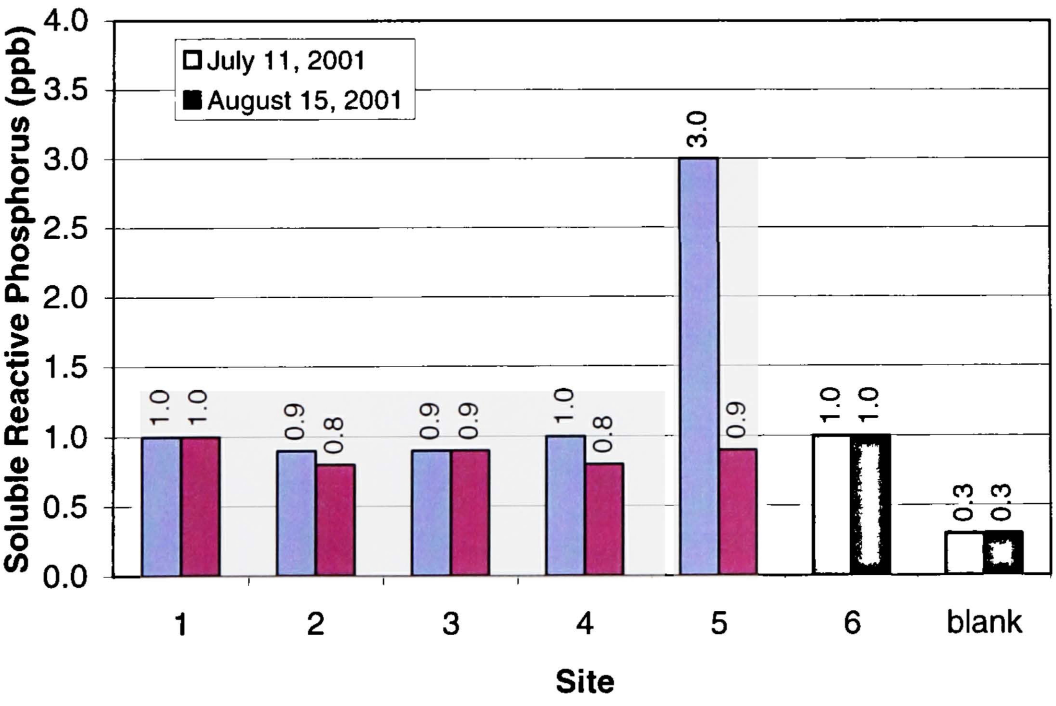


Figure 19. Tobacco River, MT, attached benthic algae levels measured on July 11 and August 15, 2001.

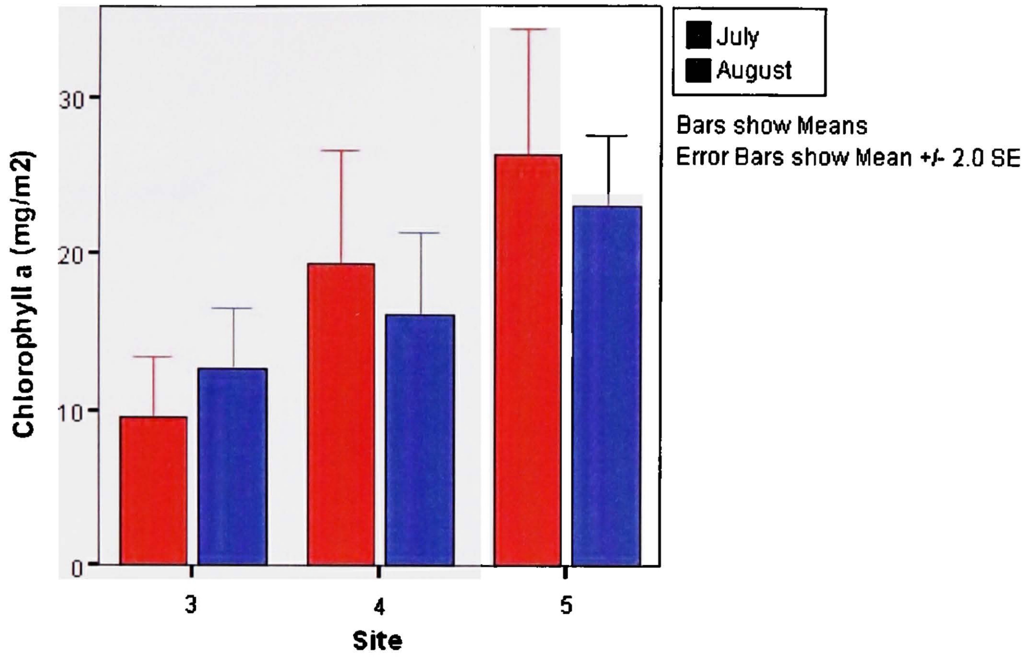


Figure 20. Tobacco River, MT, ash free dry weight of attached benthic algae measured on July 11 and August 15, 2001.

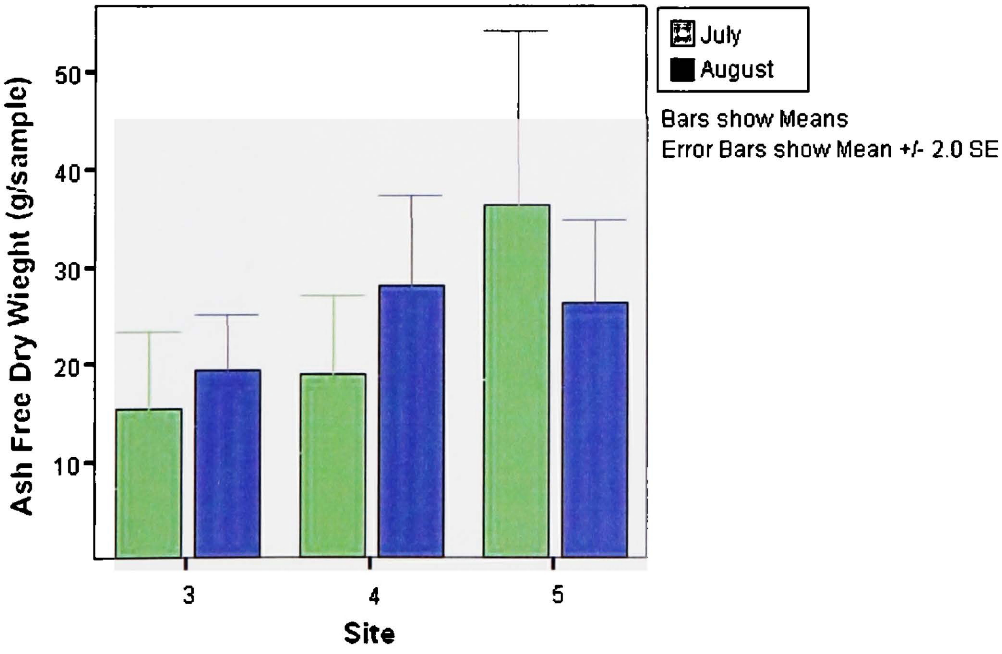


Figure 21. Streambanks along the Tobacco River study reach that would benefit from bank stabilization using willow plantings.

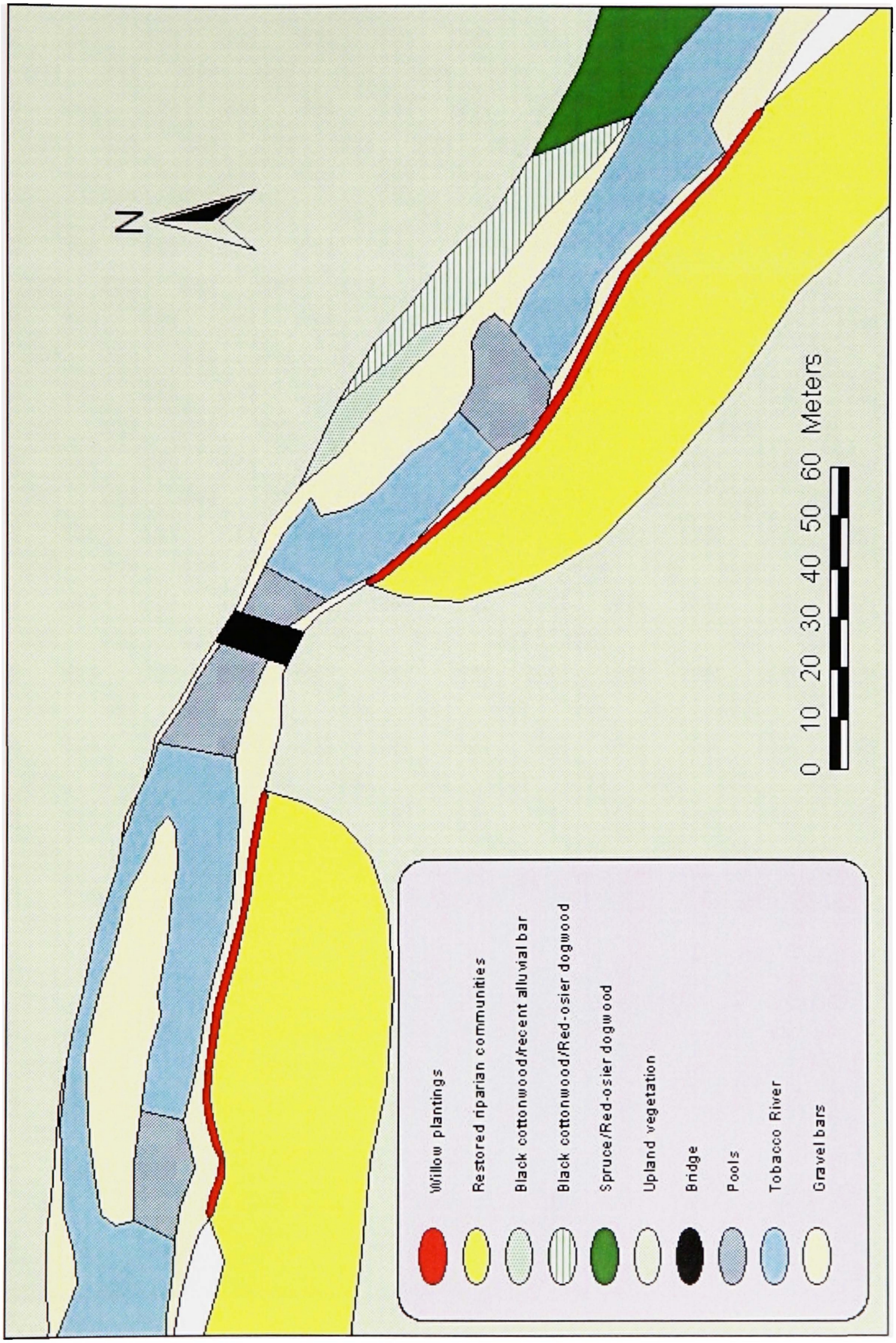
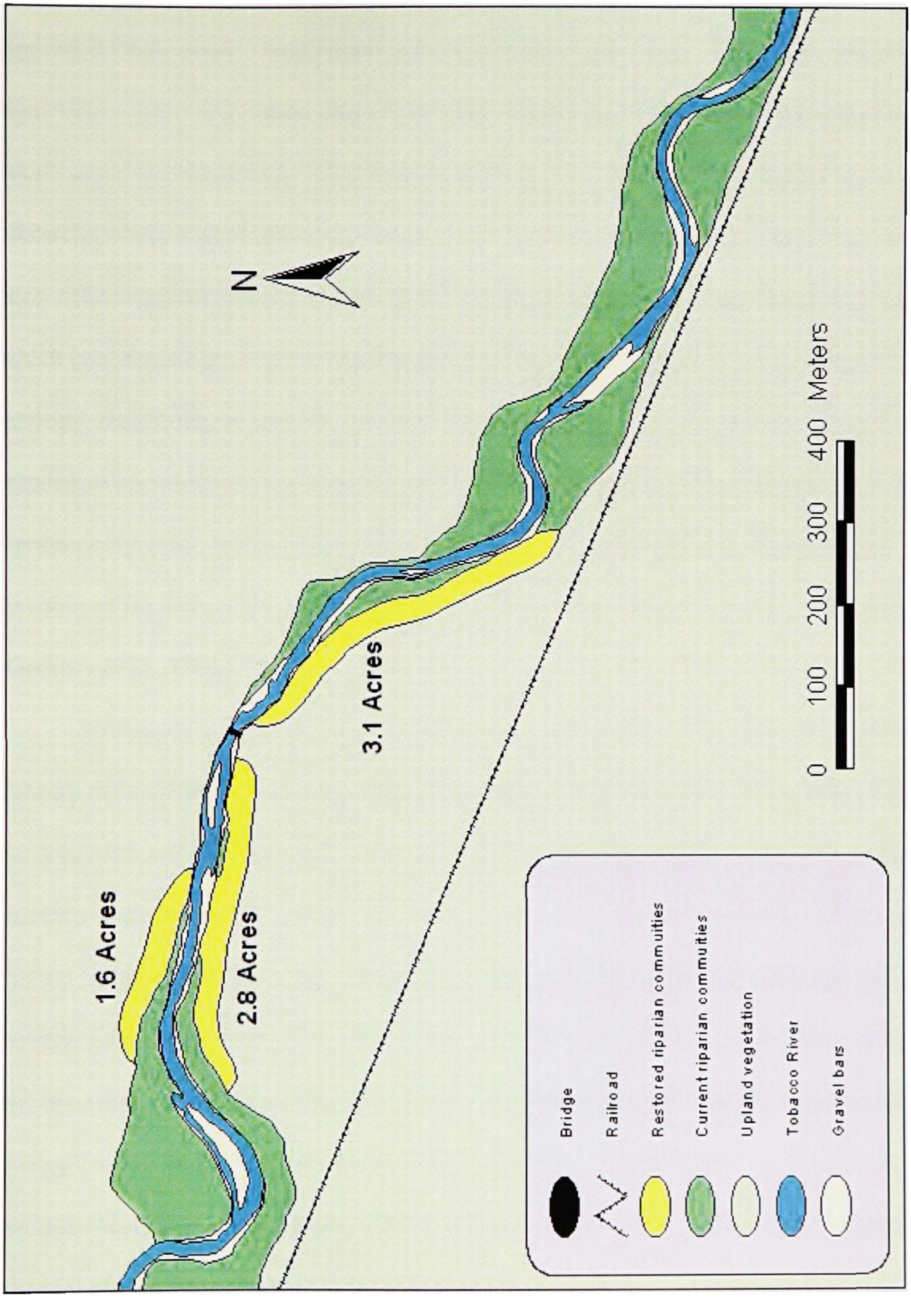


Figure 22. Proposal for the restoration of riparian vegetation along the Tobacco River study reach presented at low flow.



Appendix A. Literature review.

Stream restoration projects designed to alter channel morphology and improve riparian habitat should complement natural watershed processes. Therefore, designing successful stream restoration projects involves an understanding of the processes that create and maintain stream ecosystems (Goodwin *et al.*, 1997). Watersheds consist of a hierarchy of ecological units progressing from in-stream microhabitat, upward to the pool-riffle sequence, the stream reach, the stream segment, and finally the stream system, which contains all the surface water within the watershed (Frissell *et al.*, 1986). Climate, geology, landforms, vegetation, land-use patterns and stream flow patterns throughout the watershed operate along the stream network to influence the structure and function of the stream ecosystem. Watershed processes acting at one scale affect the structure and function of the stream ecosystem at other scales through stream corridor connectivity (Gregory *et al.*, 1991).

Stream channels and fluvial surfaces that support riparian vegetation are formed through the contribution of water and sediment from the watershed. Thus, hydrology and the supply of sediment are the driving processes influencing stream restoration projects geared toward modifying channel morphology and restoring riparian habitat (Toth *et al.*, 1995). Morphologically stable channels exist in a state of dynamic equilibrium that is maintained through the fluvial processes of scour, fill, aggradation, degradation, erosion, and deposition (Beschta and Platts, 1986). A stream in dynamic equilibrium is at an energy level in which the amount of sediment entering a reach equals the amount of sediment leaving a reach (Heede, 1986). When rivers are in equilibrium, the amount of material eroded from the banks along the outside of meander bends will equal the amount of material deposited on the point bars (Madej *et al.*, 1994). Newly deposited fluvial surfaces support developing riparian communities. Morphological channel types and fluvial processes provide a basis for the design of stream restoration projects (Beschta and Platts, 1986). The restoration of riparian vegetation leads to self-regulating naturally stable channels.

The Development of Fluvial Landforms and Riparian Vegetation

Landforms shaped by fluvial processes include the channel bed, channel bars, channel banks, floodplain, and terraces. Features formed at different elevations above the channel bed are inundated by flows of varying magnitude. Sites that are flooded frequently and for long periods of time are more likely to be closer to the water table than sites inundated less frequently (Auble *et al.*, 1994). The portion of streambed covered by stream flows less than the mean annual discharge is referred to as the active channel bed. Channel bars that develop along meandering rivers are the lowest geomorphic feature above the active channel bed. The height of channel bars usually corresponds to the low flow stage of the river. The average discharge of a river reaches the channel banks, which occur between the steep bank and the lower limit of persistent woody vegetation. Water reaches the flat surface of the floodplain when bankfull discharge is exceeded every 1-3 years. Terraces are former floodplains now located above the level of the bankfull discharge. Terraces are inundated at intervals greater than every three years (Hupp and Osterkamp, 1996). Hupp and Osterkamp (1996) suggest that stream gradient is the most important variable affecting the development of the various fluvial landforms that comprise the riparian zone.

The riparian zone includes both the fluvial landforms and the associated riparian plant communities (Osterkamp and Hupp, 1984). The riparian zone encompasses the stream channel between the low and high water marks, as well as the portion of the terrestrial landscape above the high water mark that is influenced by elevated water tables, flooding, and the ability of the soil to hold water (Naiman *et al.*, 1993). Different riparian communities are associated with specific fluvial landforms (Hupp and Osterkamp, 1996). Riparian plant communities represent associations of native species occurring on a fluvial surface. The potential vegetation type for a fluvial surface depends on the interactions between soil and water. The potential vegetation type for a site can change as the fluvial surface is altered through the processes of erosion and deposition (Kovalchik and Chitwood, 1990). Channel migration leads to the development of extensive riparian zones, which, in turn, increase the stability of the channel (Andrews, 1984).

Major factors influencing the development of riparian vegetation include the magnitude, frequency, and duration of flood events, which can be altered by climate change and land-use practices. Hupp and Osterkamp (1996) found that species distribution was related mainly to the frequency of inundation and the ability of a given species to tolerate flooding. Other factors affecting the distribution of riparian vegetation include water availability, the height of the fluvial surface above the channel bed, the size and distribution of the substrate, as well as the age and successesional patterns of the riparian communities (Hupp and Osterkamp, 1996). Natural flood regimes create abundant substrate heterogeneity, which, in turn, provides for a high level of biodiversity in riparian communities. Freshly deposited fluvial surfaces are colonized by species that are able to tolerate extreme environmental conditions associated with natural flood regimes.

Pioneer species are the first to colonize newly formed fluvial surfaces. In the Rocky Mountain region of North America *Populous* (Cottonwoods) and *Salix* (Willows) are the primary pioneer species that colonize recently deposited fluvial materials (Scott *et al.*, 1996). These species have life cycles timed to produce an abundant amount of seeds late in the spring as flood waters recede. The seeds are only viable for a short period of time in which they are dispersed by wind and water. These plants grow quickly and tolerate unstable slopes and sediment deposition. Many of these fast-growing pioneer species have numerous stems and extensive root systems, which bind stream banks together leading to increased bank stability (Hupp, 1992). While vegetation establishes quickly on freshly deposited fluvial surfaces, its persistence depends on the availability of water, which is correlated to stream flow patterns and the depth of the groundwater (Friedman *et al.*, 1996).

The distribution of riparian communities is determined primarily by flow patterns during the establishment phase, which varies from site to site depending on fluvial processes and landforms. Three fluvial processes primarily affect the development of *Populous* (Cottonwoods) and *Salix* (Willows): channel narrowing, meandering, and flood deposition. As channels narrow, the stream abandons a portion of the former channel bed where vegetation becomes established over a series of low flow years (Scott *et al.*, 1996). The level of the water table determines the extent of perennial riparian vegetation during low flow periods (Madej *et al.*, 1994). Vegetation is established as a series of narrow bands on point bars in meandering channels. The outside of the meander bend is characterized by older vegetation, which is either removed by erosion or replaced by shade-tolerant woody species (Nanson and Beach, 1977). Along constrained channels, flood deposition creates patches of bare, moist substrate at relatively high elevations that are safe from scour. Thus, vegetation becomes established in patches as a result of flood deposition (Scoot *et al.*, 1996). Fluvial processes influence the distribution of riparian vegetation, which, in turn, influences the shape of the channel and the stability of the banks.

Riparian Vegetation Influences Bank Stability and Channel Pattern

Fluvial processes and channel morphology are shaped by riparian vegetation primarily through flow resistance and bank strength (Huang and Nanson, 1997). Riparian vegetation helps to increase the roughness of the bank, which increases the resistance to flow. The location, type, age, and health of the vegetation affects its ability to withstand flood events and strengthen the banks (Hickin, 1984). As riparian communities mature, stem density decreases due to the loss of branches and individual mortality. A decrease in vegetation density reduces the ability of riparian vegetation to resist flows. Thus, stream banks are more prone to scour and erosion as riparian communities mature (McKenny *et al.*, 1995). The strength of the bank is increased by the root systems of riparian vegetation that bind soil particles together (Hickin, 1984). Unstable stream banks devoid of riparian vegetation can lead to changes in channel morphology, increased sedimentation, and the loss of fish habitat (Niaman and Decamps, 1997).

Stream banks bound by the extensive root system of dense riparian vegetation resist erosion and encourage sediment deposition much better than sparsely vegetated banks (Hickin and Nanson, 1984). Floodplain forests along the Beatton River in northeastern British Columbia densely vegetated with *Populous* (Cottonwood) and *Picea*

(Spruce) are stabilized by long roots that reach below the channel bed and provide a strong network that reinforces the banks (Hickin and Nanson, 1984). *Alnus* (Alder) and *Salix* (Willow) initially colonized point bars along the Beatton River, followed by various grass species, *Populous* (Cottonwood), and finally *Picea* (Spruce) (Nanson, 1980). This pattern of succession is similar to that of the Tobacco River. Sedimentation on point bars initially exceeds 10 centimeters per year along the Beatton River. Over bank deposition of sediments declines abruptly on surfaces greater than 50 years old, while surfaces over 200 hundred years old have insignificant sedimentation rates. The initial development of the point bar along the inside of a meander bend is primarily related to the nature of the bend, while point bar expansion is sustained by sedimentation resulting from dense riparian vegetation (Nanson, 1980).

Lateral migration rates of meandering channels are influenced by the presence of riparian vegetation. Channel bends along several rivers in southern British Columbia that lacked riparian vegetation were five times more likely than vegetated bends to erode during major flood events. Semi-vegetated bends eroded at rates in-between non-vegetated and vegetated bends (Beeson and Doyle, 1995). The lateral migration of channels on tributaries to the Missouri River with unforested banks was 4.8 feet per year, while channel bends with forested banks migrated only 1.6 feet per year (Burkhardt and Todd, 1998). Thus, riparian forests significantly reduce the rate of lateral migration, which, in turn, reduces the input of sediment into the river. Smith (1976) found that bank sediments with 16-18% root volume and a 5-centimeter thick mat of vegetation have 20,000 times the resistance to erosion as non-vegetated banks. Hickin and Nanson (1984) found that a river flowing through a cleared floodplain erodes at twice the rate of a river flowing through a naturally forested floodplain.

Bank stability in channelized reaches is dependent upon the establishment of vegetation on freshly deposited fluvial surfaces (Hupp and Simon, 1991). Stream banks are usually cleared of riparian vegetation during the channelization process. Land-use activities that result in channelization often lead to channel degradation. Lowering of the streambed results in the further loss of riparian vegetation as the banks fail and the stream becomes wider. During this period vegetation cannot become established, though *Salix* (Willow) and *Betula occidentalis* (Water Birch) will colonize the site. Aggradation occurs at the downstream end on the channelized reach as the slope decreases and excess sediment is deposited against the banks. Riparian vegetation helps to stabilize the stream bank as the bed begins to rise. At this point, primarily *Salix* (Willow) and *Populous* (Cottonwood) become established. These species can produce roots from buried branches and trunks. Thus, they can tolerate the high rate of accretion associated with bank building (Hupp, 1992). However, the influence of riparian vegetation varies based on the height of the bank, which is correlated with the size of the river.

Riparian vegetation performs different functions at different scales. In small drainage basins stream banks are stabilized by the roots of woody vegetation that reach below the bankfull depth, while the root systems of riparian vegetation in larger drainage basins typically do not reach the bankfull depth. In large drainage basins forested floodplains are maintained primarily by the slow rate of lateral migration. Woody vegetation can cause either erosion or deposition depending on the diameter and density of the stems and the direction of the flow. In low energy reaches, vegetation can increase flow resistance and sediment deposition on gravel bars along the inside of meander bends, though cutbanks on the outside of bends are not stabilized by vegetation because the banks are usually taller than the rooting depth. Along high-energy stream reaches vegetation primarily functions to increase the erosional resistance of the stream banks (McKenny *et al.*, 1995). The astounding variety of natural channel forms across a wide range of scales obscures the role of riparian vegetation in channel morphology.

It is difficult to quantify the effect of vegetation on bank stability and, thus, the effect of bank stability on channel pattern (Hickin 1984). Millar's (2000) model for a meandering-braiding threshold indicates that bank vegetation exerts a significant control on alluvial channel patterns. The density of vegetation is the largest factor influencing bank stability in this model. Thus, land-use practices involving the removal of bank vegetation can lead to increased channel erosion, widening, and steepening, which is accompanied by deposition and braiding (Miller and Quick, 1993). Sparsely vegetated banks or banks covered by species with ineffective roots lead to wide, shallow braided streams, while meandering channels develop when the banks are covered with dense or deep-rooted vegetation (Millar, 2000). Thus, the type of vegetation can alter the pattern of the channel, while the clearing of banks, which reduces their erosional resistance, can convert a meandering channel into a braided channel (Millar, 2000). The complete removal of trees and shrubs destroys the root system, thus destabilizing the banks, which leads to bank erosion and channel widening (Hey and Thorne, 1986).

The Influence of Riparian Vegetation on Channel Width

Erosion of the banks causes the channel to become wider without getting deeper (Huang and Nanson, 1997). Channel equilibrium is partially controlled by bank stability. As rivers widen, they are pushed out of their original equilibrium configuration and into a new equilibrium that is related to the amount of sediment input (Madej *et al.*, 1994). Along the Merced River in California Madej *et al.* (1994) found that the destruction of riparian vegetation by trampling and the effects of the bridges during high flows were the primary causes of bank instability, while poorly installed channel revetments were secondary causes. Channel widening was positively correlated with the amount of bare ground and low stream bank stability ratings due to the lack of riparian vegetation as a result of land-use acitivites. Thirty-nine percent of the banks were eroding along the impacted reach of the Merced River, while only 17% of the banks were eroding along the non-impacted control reach, which migrated 45 meters in 75 years while the width remained constant (Madej *et al.*, 1994).

Channel width is influenced by the type and density of vegetation found on the channel banks. Rivers lacking trees and shrubs are wider for a given discharge than rivers with trees and shrubs (Hey and Thorn, 1986). Huang and Nanson (1997) found that channels with unvegetated banks tend to be 2-3 times wider than channels with densely vegetated banks. Andrews (1984) found rivers in Colorado with densely vegetated banks were about the same depth, but had higher velocities, were narrower, and were twice as steep as rivers with sparsely vegetated banks. Hey and Thorne (1986) found that channels with herbaceous banks tend to be 1.8 times the width of channels lined by trees and shrubs. However, Trimble (1997) found that forested channels along Wisconsin streams were wider and had greater maximum depths than grass-lined channels, which were narrower and had smaller width-to-depth ratios. Grass protects banks and leads to the deposition on fine sediments (Clary and Webster, 1990). Thus, the grassy reaches were able to store more sediment and decrease downstream sediment yields (Trimble, 1997). The relationship between channel width and riparian vegetation varies regionally and depends on the type and density of the vegetation as well as the channel substrate.

Gravel-bed rivers, such as the Tobacco River, that meander through large alluvial valleys are characterized by a mobile bed during bankfull flows. As flows exceed bankfull, the channel width increases rapidly while the depth and shear stress increase slowly. Particles at the toe of the bank are acted on by fluid shear stress and gravity. Erosion begins when forces exceed the threshold value for motion. Eroded bank material supplies bed load material to the channel, which is too coarse to be suspended within the flow. Thus, there is no way for the stream to replace the eroded bank particle. As a result, the channel widens until the shear stress at the toe of the bank is reduced back to the threshold value (Andrews, 1984). Ikeda and Izumi (1990) theorize that increased vegetation density leads to deeper, narrower channels by reducing the shear stress along the banks and creating a situation where the channel bed is mobile while the channel banks remain immobile. Thus, vegetation reduces the velocity of the flow and the effective shear stress near the banks, leading to less erosion.

The Use of Vegetation in Stream Restoration Projects

The re-establishment of riparian vegetation is important in stream restoration projects (Jackson and Van Haveren, 1984). Where land-use activities have lead to the removal of riparian vegetation, stream bank stabilization depends on the banks being aggressively replanted (Madej *et al.*, 1994). Stream bank stabilization incorporating vegetation depends on the height of the bank and the ability of the plant roots to reach a depth that provides for bank reinforcement (Miler, 1999). Biodegradable erosion control fabrics are often incorporated into stream restoration projects as short-term protection against erosion during the establishment of newly planted riparian vegetation (Hoitsma and Payson, 1998). Stream bank stabilization techniques that utilize rocks and large root wads artificially constrain natural bank migration. Successful stream restoration depends on the ability of channel banks to change over time. The creation of well-vegetated banks, which allow for erosion and lateral channel migration to occur at natural rates, is a fundamental aspect of successful stream restoration projects (Miller, 1999).

Miller (1999) promotes the design of a deformable stream bank which, "allows for maintenance of channel stability through gradual planform change via lateral bank migration." Deformable banks are designed to stabilize the stream bank for a short period of time while vegetation becomes established. There are two components in the design of deformable banks: the upper bank, which supports herbaceous and woody vegetation, and the lower bank, or bank toe, which is submerged, and does not support vegetation. Bank toes are composed of sand, gravel, and cobble materials designed to be mobilized during bed scour caused by high flow events, though the bank toe must initially be immobile, which can be achieved by wrapping the gravels in a coir fabric. During the establishment of riparian vegetation, the stability of the upper bank depends on the stability of the bank toe. The developing root structure of the newly established riparian vegetation provides long-term stability for the upper bank (Miller, 1999).

The use of willow poles to stabilize stream banks is the one of the primary tools involved in stream bank stabilization projects incorporating natural materials. *Salix* (Willow) poles planted along the base of the bank provide a source for new root systems, which strengthen the banks. *Salix* (Willow) poles decrease the velocity against the bank, increase the roughness of the bank, provide a microclimate for colonization by other species, and trap debris from upslope soil failures (Watson *et al.*, 1997). McKenny *et al.*, (1995) found sedimentation rates were highest in dense bands of willows. Thus, the addition of willows to a stream bank should help to trap sediments and build the bank. Rowntree *et al.* (1999) found that *Salix* (Willow) planted at the base of the bank have stabilized the bank and induced accretion. However, critical areas of bank erosion may require biotechnical bank protection devices (Madej *et al.*, 1994). Willow pole planting can be enhanced in areas of severe erosion by performing mechanical bank sloping and the placement of erosion protection devices at the toe of the bank (Watson *et al.*, 1997). Stabilizing stream banks and increasing the amount of riparian habitat at the local scale benefits the entire watershed through stream corridor connectivity.

The Importance of Riparian Vegetation to Water Quality

The stream network and the riparian corridor connect the watershed from the headwaters to the mouth of the river. The riparian corridor encompasses both sides of the stream channel and acts as an interface between terrestrial and aquatic ecosystems within the watershed. Interfaces on the landscape regulate the flow of energy and material between adjacent environmental patches (Naiman and Descamps, 1997). Environmental conditions, ecological processes and plant communities change rapidly along a gradient from the uplands to the river channel (Gregory *et al.*, 1991). The linear shape of the riparian corridor results in a high proportion of edge, which enables extensive interactions with adjacent ecosystems (Lowrance *et al.*, 1985). Interactions between adjacent ecosystems result in a mosaic of patches that form a unique ecotone in the riparian zone (Niaman *et al.*, 1988). Frequent disturbances to the riparian corridor by floods create a shifting mosaic of landforms and vegetative patches over broad spatial and temporal scales (Niaman *et al.*, 1993). Large patches of riparian vegetation maintain the connectivity of the stream network while protecting water quality through the filtering of nutrients and sediments delivered from the uplands (Forman, 1995). Localized land-use practices within the stream corridor influence the aquatic ecosystem throughout the stream network.

The unique location of riparian vegetation upon the landscape imparts a natural ability to buffer the stream ecosystem from the terrestrial ecosystem and land-use practices. The ability of the riparian corridor to reduce the input of nutrient and sediments from the terrestrial ecosystem has lead to the practice of maintaining and restoring vegetative buffer strips along stream channels. Riparian corridors reduce the nutrient loading to streams through several processes: 1) the trapping of nutrient-bound sediments in surface runoff, 2) the uptake of soluble nutrients in groundwater by roots systems and microbes, and 3) the absorption of soluble nutrients in groundwater by organic and inorganic soil particles (Osborne and Kovacic, 1993). Water moving from the uplands to the riparian ecosystem as subsurface flow in groundwater can have a large effect on stream dynamics since the levels of nitrogen and phosphorus tend to be higher in groundwater than in river surface water ((Lowrance *et al.*, 1984; Ward, 1989). It is thought that up to 35 % of total nitrogen and 29% of total phosphorus enter the river through subsurface flows (Osborne and Kovacic, 1993). The filter function of riparian vegetation leads to improved water quality by reducing nutrient loading through plant uptake and the physical trapping of sediments (Lowrance *et al.*, 1984). A well-vegetated riparian corridor reduces the impact of land-use practices within the surrounding watershed.

A number of studies have indicated that a 20-30m vegetative buffer strip is necessary for the protection of stream ecosystems, though larger buffer strips are capable of removing a greater amount of nutrients over a longer period of time (Osborne and Kovacic, 1993). Peterjohn and Correll (1984) found that the first 19m of riparian vegetation provided the greatest reduction in the amount of dissolved nitrogen compounds in surface runoff. This study found that 89% of nitrogen was retained by the riparian vegetation, while crop lands only retained 8% of nitrogen runoff. Riparian vegetation retained 80% of phosphorus runoff, while crop land removed only 41%. Peterjohn and Correll (1984) also found that forested buffer strips 30-50m wide reduced nitrate in surface runoff by 79-98%, while forested buffer strips 6-50m wide reduced total phosphorus runoff by 61-83%. Various other studies have indicated that forested vegetative buffer strips can remove 40-100% of the nitrogen from the subsurface waters (Osborne and Kovacic, 1993). Thus, forested riparian buffer strips can reduce the impact of land-use practices upon the stream ecosystem.

Water quality degradation often results from nonpoint source nutrient pollution due to land-use practices (Tim and Jolly, 1994). Land-use practices can negatively impact the aquatic system by increasing the input of nitrogen and phosphorus. Nitrogen and phosphorus dynamics depend on soil content, geology, topography, precipitation, as well as the size and shape of the watershed. The interstitial flow of groundwater through the hyporheic zone delivers nutrients to the active channel, which can lead to increased autotrophic production in the river (Stanford and Ward, 1993). The availability of nitrogen and phosphorus is the limiting factor in primary production within aquatic ecosystems. The removal of riparian vegetation leads to increased summer water temperatures, which, in turn, decreases the stream's oxygen carrying capacity and increases nutrient availability (Karr and Schlosser, 1978). Increasing the amount of nutrients in the water column can lead to the growth of aquatic plants and algae, which leads to a reduction in the amount of dissolved oxygen in the water at night, while the decay of plant biomass further reduces the amount of dissolved oxygen. Reduced levels of oxygen stresses biological communities and forces fish to pump more water over their gills (Cooper, 1993).

Agricultural practices are the largest contributors of nonpoint source pollution to water systems (Tim and Jolly, 1994, Delong and Brusven, 1991). Agricultural fields contribute water, nutrients, pesticides, herbicides, and sediments to the aquatic ecosystem at accelerated rates of erosion (Lowrance *et al.*, 1985). Tufford *et al.* (1998) found that land-use practices within 150m of the channel alter nutrient concentrations, while land-use practices greater than 150m from the stream did not. Under aerobic conditions nitrifying bacteria are dominant, while denitrification increases under anaerobic conditions. The removal of riparian vegetation for crop land often results in the loss of native plant communities and an increase in exotic plant species, which are capable of colonizing frequently disturbed sites. Exotic plant species, such as spotted knapweed, are often poor controls of erosion. Increased erosion leads to greater nutrient inputs, since a large proportion of nutrients leaving agricultural lands are associated with sediments (Omerlick *et al.*, 1981). Stream habitats shaped within the watershed context can be altered by land-use practices.

Appendix B. GPS points for each transect and water sample site.

Transect locations.

Transect	GPS Location	
1	48:52:49.52 N	115:03:32.74 W
2	48:52:50.60 N	115:03:33.64 W
3	48:52:52.22 N	115:03:35.08 W
4	48:52:54.02 N	115:03:36.28 W
5	48:52:54.98 N	115:03:38.44 W
6	48:52:54.74 N	115:03:41.62 W
7	48:52:55.46 N	115:03:44.32 W
8	48:52:57.44 N	115:03:45.34 W
9	48:52:58.76 N	115:03:47.44 W
10	48:53:00.38 N	115:03:49.06 W
11	48:53:01.94 N	115:03:50.20 W
12	48:53:02.84 N	115:03:53.02 W
13	48:53:03.98 N	115:03:56.32 W
14	48:53:05.72 N	115:03:58.06 W
15	48:53:07.58 N	115:03:58.30 W
16	48:53:08.96 N	115:03:59.02 W
17	48:53:10.16 N	115:03:59.44 W
18	48:53:12.26 N	115:04:01.18 W
19	48:53:13.64 N	115:04:02.20 W
20	48:53:16.22 N	115:04:04.66 W
21	48:53:17.78 N	115:04:06.28 W
22	48:53:18.44 N	115:04:09.40 W
23	48:53:19.64 N	115:04:11.32 W
24	48:53:20.54 N	115:04:13.54 W
25	48:53:21.50 N	115:04:16.06 W
26	48:53:22.28 N	115:04:18.82 W
27	48:53:23.06 N	115:04:21.94 W
28	48:53:23.00 N	115:04:24.88 W
29	48:53:22.46 N	115:04:27.22 W
30	48:53:22.22 N	115:04:30.52 W
31	48:53:23.06 N	115:04:33.34 W
32	48:53:24.92 N	115:04:33.76 W
33	48:53:26.48 N	115:04:35.14 W
34	48:53:27.86 N	115:04:37.18 W

Water quality sample site locations (*located at a transect).

Site	GPS Points	
1	48:47:55.45 N	114:57:06.78 W
2	48:52:38.72 N	115:03:09.22 W
3	48:52:54.74 N	115:03:41.62 W
4*	48:53:24.92 N	115:04:33.76 W
5*	48:53:36.98 N	115:05:13.30 W
6	48:53:45.08 N	115:07:39.33 W

Appendix C. Lotic wetland health assessment field score sheet (Bitterroot Restoration, 2001).

LOTIC WETLAND HEALTH ASSESSMENT
FIELD SCORE SHEET

1. Vegetative Cover of Floodplain and Streambanks. **Score:________**
6 = More than 95% of the reach soil surface is covered by plant growth.
4 = 85% to 95% of the reach soil surface is covered by plant growth.
2 = 75% to 85% of the reach soil surface is covered by plant growth.
0 = Less than 75% of the reach soil surface is covered by plant growth.

2. Invasive Plant Species. **Score:________**
6 = No invasive species (noxious weeds) on the site.
4 = Weed density/distribution in a class from 1 to 3, *AND* weed canopy cover is less than 1%.
2 = Weed density/distribution in a class from 4 to 7, *AND* weed canopy cover is less than 1%.
0 = Weed density/distribution in class 8 or higher, *OR* weed canopy cover is 15% or more.

3. Disturbance-Caused Undesirable Herbaceous Species. **Score:________**
3 = Less than 5% of the site covered by disturbance-caused undesirable herbaceous species.
2 = 5% to 25% of the site covered by disturbance-caused undesirable herbaceous species.
1 = 25% to 45% of the site covered by disturbance-caused undesirable herbaceous species.
0 = More than 45% of the site covered by disturbance-caused undesirable herbaceous species.

4. Preferred Tree and Shrub Establishment and Regeneration. **Score:________**
6 = More than 15% of the total canopy cover of preferred trees/shrubs is seedlings and saplings.
4 = 5% to 15% of the total canopy cover of preferred trees/shrubs is seedlings and saplings.
2 = Less than 5% of the total canopy cover of preferred tree/shrubs is seedlings and saplings.
0 = Preferred tree/shrub seedlings or saplings absent.

5. Utilization of Preferred Trees and Shrubs. **Score:________**
= None (0% to 5% of available second year and older leaders of preferred species are browsed).
2 = Light (5% to 25% of available second year and older leaders of preferred species are browsed).
1 = Moderate (25% to 50% of available second year and older leaders of preferred species are browsed).
0 = Heavy (More than 50% of available second year and older leaders of preferred species are browsed).

6. Standing Decadent and Dead Woody Material. **Score:________**
3 = Less than 5% of the total canopy cover of woody species is decadent or dead.
2 = 5% to 25% of the total canopy cover of woody species is decadent or dead.
1 = 25% to 45% of the total canopy cover of woody species is decadent or dead.
0 = More than 45% of the total canopy cover of woody species is decadent or dead.

7. Streambank Root Mass Protection. **Score:________**
6 = More than 85% of the streambank has a deep, binding root mass.
4 = 65% to 85% of the streambank has a deep, binding root mass.
2 = 35% to 65% of the streambank has a deep, binding root mass.
0 = Less than 35% of the streambank has a deep, binding root mass.

8. Human-Caused Bare Ground. **Score:________**
6 = Less than 1% of the site is human-caused bare ground.
4 = 1% to 5% of the site is human-caused bare ground.
2 = 5% to 15% of the site is human-caused bare ground.
0 = More than 15% of the site is human-caused bare ground.

9. Streambank Structurally Altered by Human Activity. **Score:________**
6 = Less than 5% of the bank is structurally altered by human activity.
4 = 5% to 15% of the bank is structurally altered by human activity.
2 = 15% to 35% of the bank is structurally altered by human activity.
0 = More than 35% of the bank is structurally altered by human activity.

Manual current as of 6/28/01 23 Check www.bitterrootrestoration.com for latest dataset and form

10. Pugging and/or hummocking. Score:________

3 = Less than 5% of the polygon is affected by pugging and/or hummocking.
2 = 5% to 15% of the polygon is affected by pugging and/or hummocking.
1 = 15% to 25% of the polygon is affected by pugging and/or hummocking.
0 = More than 25% of the polygon is affected by pugging and/or hummocking.

11. Stream Channel Incisement (vertical stability). Score:________

9= Channel vertically stable and not incised; 1-2 year high flows access a floodplain appropriate to the stream type. Active downcutting is not evident. Any old incisement is characterized by a broad floodplain inside which perennial riparian plant communities are well established. This condition is illustrated in Figure 3 by the following three stages.

Stage A-1. A stable, unincised meandering meadow channel (Rosgen E-type). Flows greater than bankfull (1-2 year event) spread over a floodplain more than twice the bankfull channel width.

Stage A-2. A fairly stable, unincised wide valley bottom stream with broad curves and point bars (Rosgen C-type). Although these streams typically cut laterally on the outside of curves and deposit sediment on inside point bars, bankfull flows (1-2 year events) have access to a floodplain more than twice bankfull channel width.

Stage A-3. A stable, unincised mountain (Rosgen A-type) or foothill (Rosgen B-type) channel with limited sinuosity and slopes greater than 2%. Although bankfull flow stage is reached every 1-2 years, the adjacent floodplain is often narrower than twice the bankfull channel width. Consequently, overflow conditions are not so obvious as in Stages A-1 and A-2 systems.

6 = Either of two incisement phases: (a) an improving phase with a sinuous curve/point bar system (Rosgen C-type) or a narrow, meandering stream (E-type) establishing in an old incisement which now represents the new floodplain, although this may be much narrower than it will become;(b) an early degrading phase in which a narrow, meandering meadow stream (E-type) is degrading into a curve/point bar type (C-type) or a wide, shallow channel (Rosgen F-type). In either case, the 1-2 year high flow event can access only a narrow floodplain less than or only slightly wider than twice the bankfull channel width. Perennial riparian vegetation is well established along much of the reach. These conditions are represented in Stage B of Figure 3.

3 = Two phases of incisement fit this rating. (a) A deep incisement that is starting to heal. In this phase new floodplain development, though very limited, is key. This phase is characterized by a wide, shallow channel unable to access a floodplain (Rosgen F-type) evolving into a curve/point bar system (C-type) through sediment deposition and lateral cutting. Pioneer perennial plants are beginning to establish on the new depositional surfaces. (b) An intermediate phase with downcutting and headcuts probable. Flows less than a 5-10 year event can access a narrow floodplain less than twice bankfull channel width. These conditions are represented in Stage C of Figure 3.

0 = The channel is deeply incised to resemble a ditch or a gully. Downcutting is likely ongoing. Only extreme floods overtop the banks, and no floodplain development has begun. Both Stages D-1 and D-2 of Figure 3 fall into this rating.

Stage D-1. An incised stream with a wide, shallow (F-type) channel. Commonly found in fine substrates (sands, silts, and clays), channel banks are very erodable. Only limited vegetation, primarily pioneer species, is present along the side of the stream.

Stage D-2. A narrow, deep "gully" system (Rosgen G-type) downcut to the point that only extreme floods can overtop the banks. Distinguished from narrow mountain streams (A-type) by the presence of a flat floodplain through which the stream has downcut and by banks consisting of fine materials rather than larger rocks, cobbles, or boulders.

Additional Management Concerns (OPTIONAL)

12a. Streambank Rock Volume. Rate the streambank rock volume as the highest appropriate one of the following four categories: Score:________

3 = More than 40% of streambank volume is rocks at least 2.5 inches.
2 = 20% to 40% of streambank volume is rocks at least 2.5 inches.
1 = 10% to 20% of streambank volume is rocks at least 2.5 inches.
0 = Less than 10% of streambank volume is rocks at least 2.5 inches.

12b. Streambank Rock Size. Rate the streambank rock size for the polygon as the highest appropriate one of the following four categories: Score:________

3 = At least 50% of rocks present are boulders and large cobbles (>5 inch).
2 = 50% of rocks present are small cobbles and larger (>2.5 inches).
1 = At least 50% of rocks present are coarse gravels and larger (>0.6 inches).
0 = Less than 50% of rocks present are coarse gravels and larger (>0.6 inches).

13. Vegetative Use by Animals. Use the categories below to score the amount of utilization. **Score:________**

3 = 0 to 25% available forage taken.
2 = 26 to 50% available forage taken.
1 = 51 to 75% available forage taken.
0 = 76 to 100% available forage taken.

14. Susceptibility of Parent Material to Erosion. **Score:________**

3 = Not susceptible to erosion (well armored).
2 = Slightly susceptible to erosion (moderately armored).
1 = Moderately susceptible to erosion.
0 = Extremely susceptible to erosion.

15. Percent of Streambank Accessible to Livestock. **Percent:________**

16. Trend. Select one: Improving, Degrading, Static, or Status Unknown **Trend:________________________**

17. Comments and Observations:

Appendix D. Summary of physical measurements made at each transect (distance in meters, RR = river right, RL = river left, facing downstream).

Transect	Wetted Width	Bankfull Width	Mean Depth	Width-to-Depth Ratio	Bank Angle		Canopy Cover						Riparian Zone Width		Slope	Bearing
					RR	RL	RR	center RR	center upstream	center RL	center downstream	RL	RR	RL		
1	21.1	22.3	0.85	26	10	90	17	3	0	1	0	13	63	0	0.5	295
2	23	27.7	0.71	39	10	25	12	2	0	9	0	17	41	26	0.8	316
3	13.3	27.1	0.68	40	4	31	3	2	4	9	0	17	6	62	0.5	328
4	13.6	18	1.1	16	90	7	17	12	1	0	1	0	8	80	0.8	295
5	13.5	19.3	1.5	13	90	9	15	6	1	0	7	0	40	58	1	250
6	13.5	28.7	0.71	40	4	6	0	0	0	0	0	0	75	15	1	259
7	12.1	21.3	1	21	4	35	0	0	0	1	0	10	81	0	0.5	308
8	20.8	21.5	0.76	28	80	24	13	0	0	5	0	17	81	2	1.8	312
9	15.4	38.5	0.71	54	15	5	0	0	0	0	0	0	63	0	0.3	314
10	21.4	26.2	0.91	29	19	52	0	0	0	0	0	12	41	64	1	317
11	22.8	26	0.66	39	8	32	3	0	0	0	0	2	14	76	0.5	303
12	16.6	21.1	0.82	26	38	10	16	10	1	1	0	4	58	64	1.3	265
13	13.6	21.4	0.85	25	2	9	1	0	5	11	2	17	79	43	0.8	303
14	17.7	29.1	1.2	24	4	36	0	0	0	2	0	16	53	0	0.5	341
15	25	28	0.65	43	7	90	16	0	0	0	0	16	38	7	1	341
16	24.9	26	0.64	40	90	19	17	3	0	0	1	17	6	20	0.5	342
17	17.2	17.2	0.77	22	90	90	17	12	2	0	1	15	1	22	1	315
18	16.6	23.4	0.74	32	90	4	17	2	0	0	0	0	45	9	0.5	307
19	19	20.3	0.78	26	5	15	13	0	0	0	0	16	16	2	0	313
20	14	26	1.3	20	5	29	0	0	0	0	0	3	12	0	0.3	319
21	14.7	16.7	0.99	17	16	25	10	2	0	0	0	9	1	1	1.5	290
22	23.7	24.9	0.61	40	90	14	6	0	0	0	0	0	2	0	0.5	278
23	19.3	29.1	1.4	21	24	90	2	0	0	0	0	2	3	1	0.8	286
24	25	25.4	0.59	43	10	20	13	0	0	0	0	9	4	4	1	278
25	9	30.8	0.62	50	11	5	0	0	0	0	0	0	7	0	0.8	282
26	18.1	24	0.65	37	20	28	1	0	0	12	2	17	11	7	1.5	275
27	19	20	0.66	30	90	15	17	2	0	0	0	2	25	20	0.8	263
28	16.8	21.8	1.3	17	18	6	6	7	0	0	0	0	40	28	0.5	233
29	17.5	36.1	0.67	53	10	13	0	0	0	0	0	1	132	18	0.8	235
30	22	47.3	0.63	75	6	90	0	0	0	0	0	17	112	37	1.5	277
31	20.9	45.4	0.51	89	9	46	0	0	0	0	0	17	127	43	1.8	308
32	18.1	31.4	0.51	61	24	23	5	0	0	0	0	0	101	47	1	343
33	17.1	17.8	0.74	24	90	90	14	0	0	0	0	17	3	151	1.5	317
34	12.6	20.6	0.8	25	90	7	14	0	0	0	0	0	3	160	NA	NA

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