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State of Flood Plain Vegetation Within the Meander Belt of the Clark Fork of the Columbia River, Deer Lodge Valley, Montana

Water-Resources Investigations Report 02-4109

U.S. Department of the Interior
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Boulder, Colorado
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U.S. Department of the Interior

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CONVERSION FACTORS AND ABBREVIATED UNITS

Multiply	By	To obtain
cubic foot per second (ft^3/s)	.02832	cubic meter per second
foot (ft)	.3048	meter
mile (mi)	1.609	kilometer
square foot (ft^2)	.09289	square meter
square mile (mi^2)	2.589	square kilometer

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Abstract

The state of woody riparian vegetation on the flood plain surface within the meander belt of the Clark Fork of the Columbia River through the Deer Lodge Valley has been examined to assess the degree of vulnerability of this system to flood plain surface erosion during overbank flow events. Density and distribution of shrubs along the channel edges and flood plain surfaces between meander bends (flood plain tabs) were determined from large-scale aerial photographs for each of 194 tabs between River Mile 0, near Warm Springs, Montana, and River Mile 31, north of Deer Lodge. The results of this analysis show that 74 percent of the tabs have less than 40 percent of their surface areas covered by shrub canopy, and an average of only 29 percent of the tab surface areas are covered by shrub canopy.

INTRODUCTION

The Clark Fork of the Columbia River through the Deer Lodge Valley, Montana (fig. 1), is a highly sinuous, single-thread meandering stream. A large flood in 1908 left silty deposits of mine tailings on the flood plain surface throughout the Deer Lodge Valley (Nimick and Moore, 1991), primarily within the river meander belt (fig. 2). Upstream from Deer Lodge, many of these deposits are two or more feet thick, and where they crop out at the surface, vegetation is sparse. The barren or nearly barren areas are called slickens. Most of the riparian corridor is privately-owned land, with much of the area heavily grazed by cattle, further contributing to the suppression of woody vegetation.

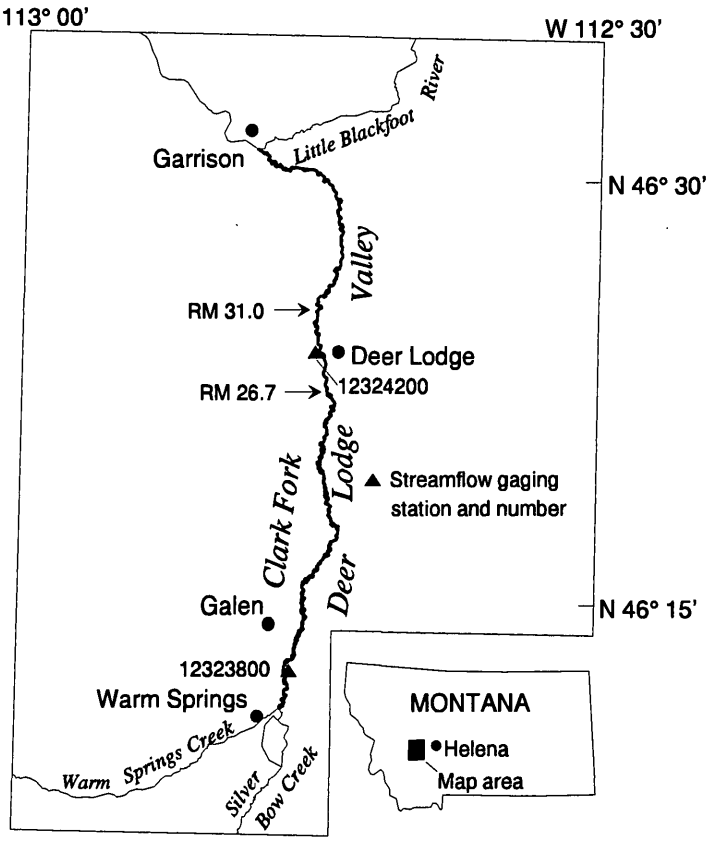


Figure 1. Location of the study area. The reaches of interest in this study are from the confluence of Warm Springs and Silver Bow Creeks at River Mile (RM) 0.0 to RM 31.0, north of Deer Lodge, and from RM 0.0 to RM 26.7, south of (and upstream from) Deer Lodge.

During overbank flows, dense shrubs can add sufficient roughness to the flow to reduce or prevent significant flood plain erosion (Smith, 2001). In contrast, surfaces not protected by shrubs or dense, continuous sod are vulnerable to erosion, which can lead to the creation of channels on the flood plain surface (fig. 3) and transport of contaminants from the flood plain into the river. If the flow is sufficiently deep and sustained, this erosion process can result in removal of the flood plain within a significant

Figure 2. An example of a reach with low shrub density and large deposits of mine tailings on the tabs. This image is from an aerial photograph taken in July 1997 and covers the reach from river mile 5.57 to 6.68, where an average of 22 percent of the tab surfaces are covered by shrub canopies. The exposed mine tailings are the light-colored areas within the river meander belt, which is indicated by the red dashed lines. The arrow indicates flow direction.

fraction of the meander belt. When that occurs, the fluvial system can change its morphology from that associated with a single-thread, meandering stream to that of a much wider braided or partially-braided stream.

Through the Deer Lodge Valley, the woody riparian vegetation within the Clark Fork meander belt consists almost entirely of shrubs, with water birch (*Betula occidentalis*) and a variety of shrub willows (*Salix* spp.) being the dominant large species. Trees (typically cottonwoods) are not present until River Mile (RM) 20.7, downstream from the mouth of Dempsey Creek, and then they are present within the meander belt only in small stands through the rest of the Deer Lodge Valley. The health of the shrubs and their physiological condition are difficult to discern from aerial photographs, but field observations and a video of the river corridor taken during a helicopter flight in May 1997 show that, in many areas, a substantial fraction of the shrubs along the river contain a high proportion of dead stems. Even dead shrubs that remain well-rooted can provide significant resistance to flow during minor overbank events. The dead stems and shrubs have helped to protect the flood plain surface from erosion during the small floods of the last half of the 20th century. Over time, dead roots and stems become brittle and are susceptible to being broken by cattle or during subsequent floods. Physiological deterioration of shrubs and the subsequent removal of dead and physiologically stressed shrubs significantly reduces protection of the flood plain from erosion (Smith, 2001). A model that computes reduction in flow velocity and bed shear stress resulting from flow around and between stems of woody vegetation (Smith, 2001) indicates that systems such as this one with low grass root densities and less than 30 percent stem densities are susceptible to significant flood plain surface erosion during overbank flows.

PURPOSE AND SCOPE

The purpose of this work was to assess the state of woody vegetation on the flood plain surface within the meander belt of the Clark Fork through the Deer Lodge Valley. The Clark Fork begins at the confluence of Warm Springs and Silver Bow Creeks at RM 0 (fig. 1). In this study, a segment between RM 0 and the downstream end of Grant-Kohrs Ranch at RM 31, north of Deer Lodge, was examined. The same analysis was done for a shorter reach upstream from Deer Lodge, from RM 0 to 26.7,

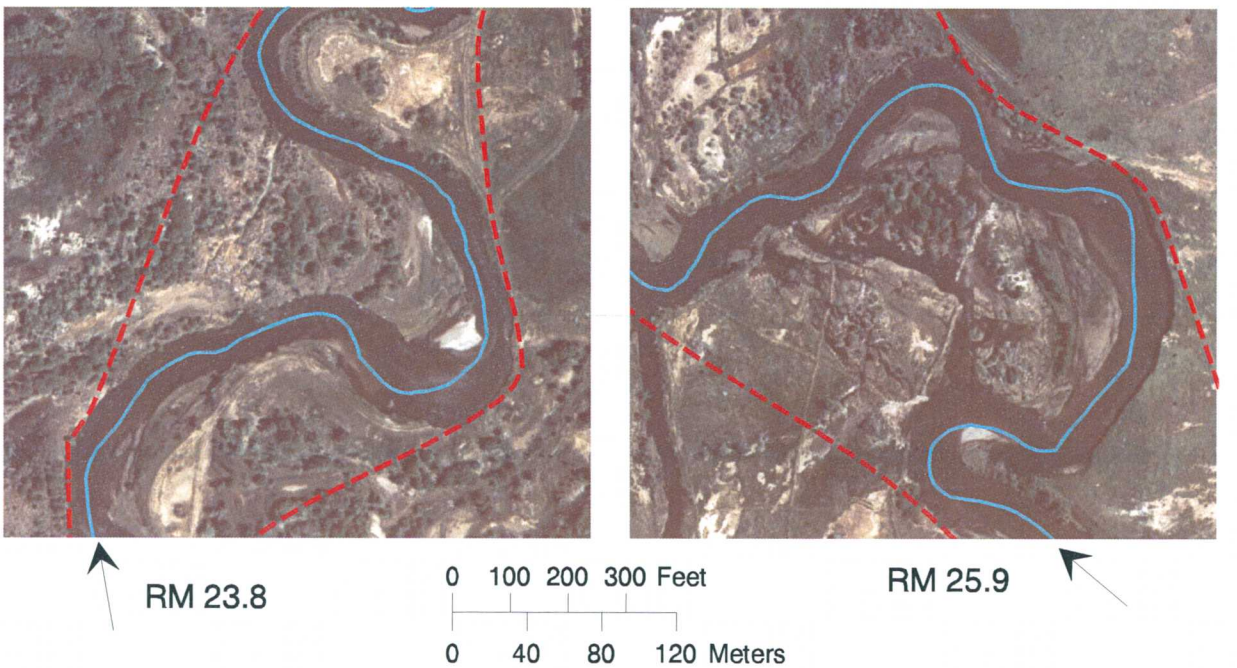


Figure 3. Two examples of tabs dissected by channels cut during overbank flows. Arrows indicate flow direction. The left image shows the tab at RM 23.95, with a visible gully cutting into the surface of the tab neck on the downstream side. In the right image, a channel has cut all the way across the tab at RM 26.15 to sufficient depth that water was in this channel following the June 1997 bankfull event. The blue lines are the river centerline identified for a study of bank erosion rates (R2 Resource Consultants, Inc., unpub. data, 1998).

excluding the developed area through the town of Deer Lodge and the reach through Grant-Kohrs Ranch. The Clark Fork segment from RM 31 to Garrison (RM 45) was not studied because it has been substantially altered by road and railroad construction.

The first step in this analysis was to define the extent of the meander belt. After the flood plain area within the meander belt was identified, a visual examination of scanned and rectified large-scale aerial photographs taken in July 1997 was made to determine the state of woody vegetation. Density and distribution of woody vegetation within the meander belt were quantified for all 194 flood plain surfaces (tabs) between meander bends from RM 0 to 31 and for the 178 flood plain tabs from RM 0 to 26.7.

In addition to the state of flood plain vegetation, various other inputs were derived for a model designed to assess vulnerability of flood plain surfaces to erosion during overbank flows (Smith, 2001). Average bankfull channel width, reach-averaged river and valley slope, sinuosity, and dimensions of the flood plain tab (width and down-valley length) were measured for this purpose. Tab area was estimated from the measured width and down-valley length. The Smith model computes reduction in flow velocity and bed shear stress caused by flow around and between the stems of woody vegetation. The model can be used to examine the effects of various flood scenarios on individual tabs, and to assess the overall stability of the flood plain along the Clark Fork through Deer Lodge Valley.

Amounts and distribution of woody vegetation are highly variable on the flood plain tabs of the Clark Fork, and vegetation on the interior tab surface is not a good indicator of vegetation along the tab edges. Many tabs were found to have dense shrub canopy along the edges of the river (only one or a few shrubs deep), but few shrubs on the central tab surface. This was the case particularly in areas where work had been performed to amend tailings deposits or to construct berms to inhibit surface runoff from carrying tailings into the river. While the shrubs along the river banks help protect against bank erosion during in-channel flows, they are much less effective in reducing surface erosion during overbank flows. In order to provide sufficient detail on shrub distributions for the overbank flow model, density and distribution of woody vegetation were quantified for the central tab surface and along both the upstream and downstream tab edges. The density and distribution of woody vegetation were then used to classify each tab's resistance to erosion.

AVAILABLE DATA

Data examined in this effort included a geographic information system (GIS) coverage of the Clark Fork centerline, created for a bank erosion rate study (R2 Resource Consultants, Inc., unpub. data, 1998) and scanned and georeferenced aerial photographs taken in July 1997 at a scale of about 1:11,800 (processed by R2 Resource Consultants, Inc., Redmond, Washington, and provided by ARCO Environmental Remediation L.L.C, Anaconda, Montana, 2000). The high-resolution digital photographs were analyzed in detail to determine the state of woody vegetation within the river meander belt. The reach from RM 17.5 to 19.8 was not covered by the set of 1997 images, so aerial photographs taken in September 1988 at a scale of about 1:7,000 were examined to assess the extent of woody vegetation in this reach. In other areas along the river, significant changes in the extent of woody vegetation on tab surfaces occurred between 1988 and 1997 (fig. 4). Efforts to amend tailings deposits and to construct berms included the removal of many shrubs on central

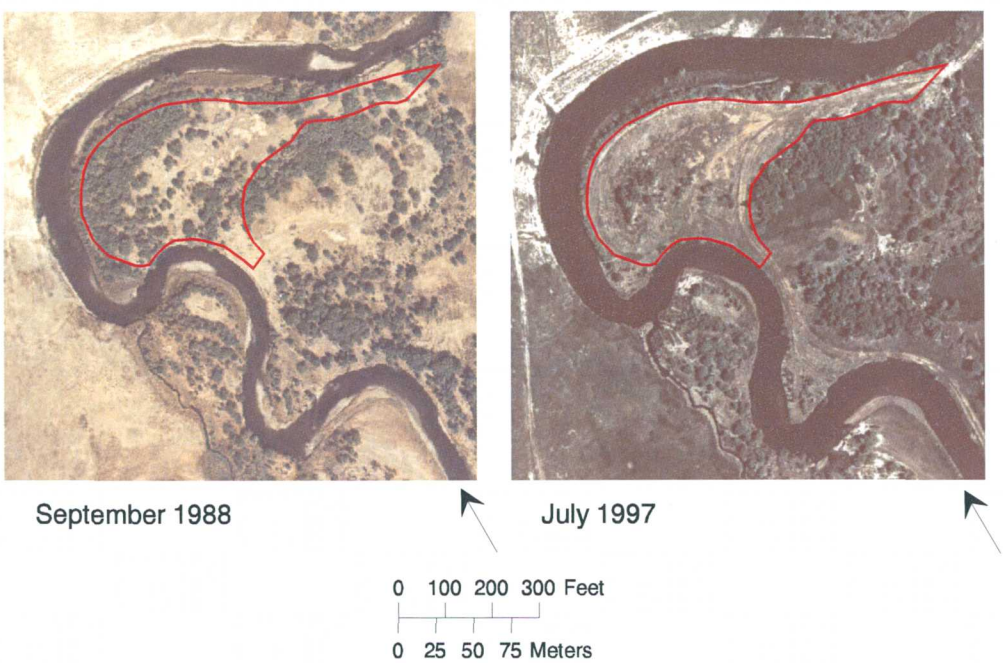


Figure 4. Many shrubs were removed between 1988 (left) and 1997 (right) from the area outlined in red on the tab at RM 22.52 during the process of constructing berms to inhibit surface runoff. Arrows indicate flow direction.

tab surfaces. In these areas, the extent of woody vegetation present within the meander belt in 1988 was greater than the extent of woody vegetation remaining there in July 1997.

A video taken during a helicopter flight over the Clark Fork in May 1997 by the Montana Department of Justice, Natural Resources Damage Assessment (NRDA) group, provided an additional, close-up view of the river corridor through the Deer Lodge Valley. The physical state of the shrubs in 1997 was much clearer in the video than in the aerial photographs. Furthermore, the May 1997 video showed the extent of cross-tab flow in many of the channels on the flood plain surface within the meander belt and its correlation with the impoverished state of vegetation on many of the tabs.

SITE CHARACTERIZATION

Physical characteristics, including planform geometry of the river channel and its associated flood plain, were first identified from the georeferenced aerial photographs and available map data. For future use in reach-averaged flow, sediment transport, and flood plain erosion models, average channel width, slope, and sinuosity as functions of distance downstream (river mile) were determined, as well as the average angle between the river centerline and the centerline of the meander belt at each location where the two lines cross.

Identification of the River Meander Belt

The meander belt of the river was first defined by creating a GIS line coverage from points identified in the scanned aerial photographs on the outside bank at the apex of each meander bend. A spline function was then applied to smooth the curve representing the edge of the meander belt (fig. 5). Total area of the meander belt from RM 0 to 31 was determined to be 1.58 mi^2, including the channel.

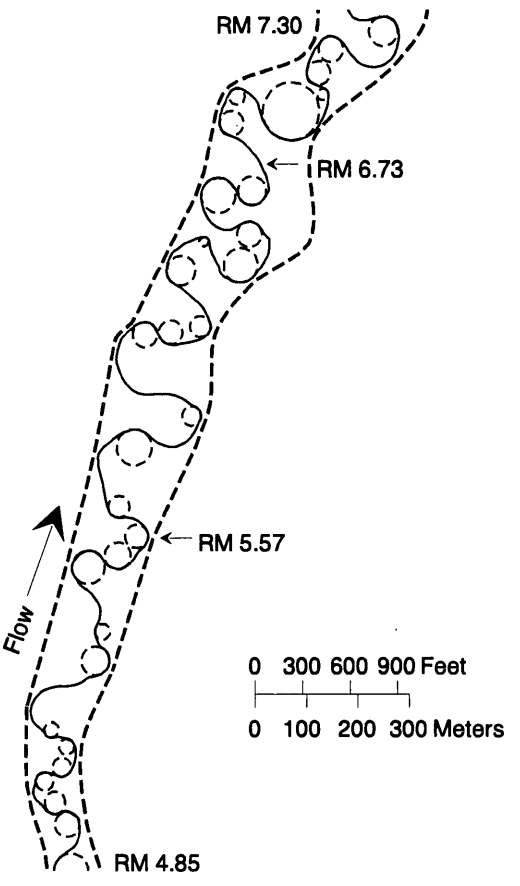


Figure 5. The Clark Fork follows a highly-sinuous path within the meander belt (heavy dashed lines). Sinuosity of the river centerline (solid line) is about 2.0 through this 2.5-mile reach. The dashed circles are bends identified for a previous study of cut-bank erosion rates (Griffin and Smith, 2001).

The average width of the meander belt was computed by dividing the total area between the edges of the meander belt by the meander belt centerline length. The result is an average width of 512 ft. Average width of the meander belt for RM 0 to 26.7 was calculated to be 509 ft, nearly the same as that for the longer reach.

Tab area was defined as the area of the flood plain surface on one side of the river within the meander belt and between two adjacent points where the outside bank meets the edge of the meander belt (fig. 6). Lengths measured for each tab include: distance from A to B along the river centerline; distance from A to B across the tab (in the down-valley direction); and distance from C to D (tab width).

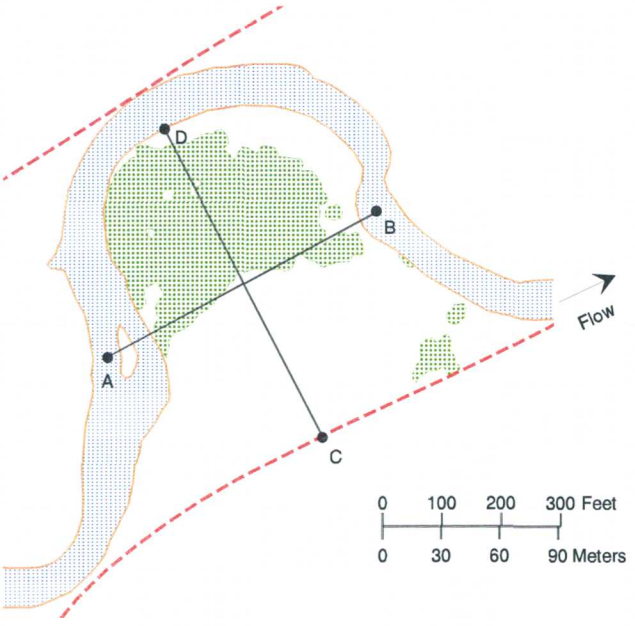


Figure 6. Line drawing of the tab at RM 11.59, showing the lengths measured for each tab. The green shaded areas were covered by shrub canopy in 1997.

The average tab width (distance from C to D) for the 194 tabs was found to be 394 ft, with a standard deviation of 182 ft (fig. 7). For the 178 tabs between RM 0 and 26.7, the average tab width was 387 ft, with a standard deviation of 183 ft. Average width of the flood plain surface within the meander belt (i.e., excluding the channel area) was also computed by subtracting the estimated area of the channel from the total area of the meander belt, then dividing by the meander belt length. Channel area for the study reach was estimated by multiplying an average channel width by the reach length. Average tab width calculated in this manner was 398 ft for RM 0 to 31, and 389 ft for RM 0 to 26.7, both of which are consistent with (less than 1 percent different from) the values calculated directly from the measured distance from C to D for each tab in the respective reach.

Average Channel Width, Slope, and Sinuosity

Average bankfull channel width as a function of river mile was calculated by dividing the area of the bankfull channel by the centerline length for 31 long reaches (average of 0.30 mile) between RM 0 and 31 (fig. 8). The 1997 aerial photographs were taken when flow was about one-half bankfull at Deer Lodge (841 ft^3/s). At this stage along the Clark Fork through the Deer Lodge Valley, water surface width typically changes little from the crossing through the bend. A non-linear curve fit to the points of width as a function of river mile has the equation

$$b = 49.63 \cdot d^{0.110}, \qquad (1)$$

where b is average bankfull width, in feet, and d is the distance downstream from the confluence of Warm Springs and Silver Bow Creeks, in river miles. An average channel width for RM 0 to 31 was computed to estimate width of the flood plain surface within the meander belt. Channel width calculated from the above equation for RM 15.5, which is the middle of the study reach, is 67.3 ft. The mean bankfull channel width calculated directly from the average widths of the 31 long reaches between RM 0 and 31 is 65.6 ft, with a standard deviation of 9.2 ft.

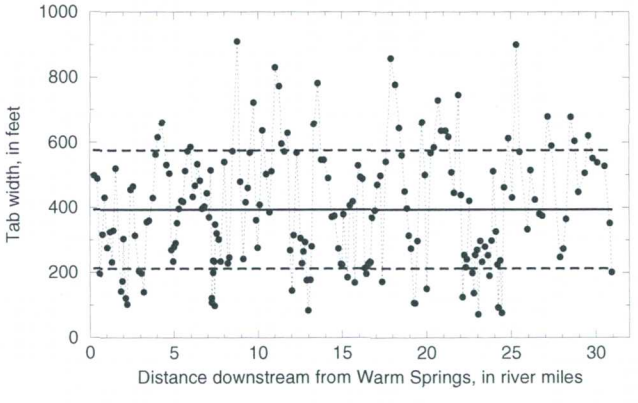


Figure 7. Tab width as a function of river mile for all 194 tabs (points). Although tab width increases or decreases systematically over several short reaches, the measured widths vary over a wide range, with a mean of 394 ft (solid line) and a standard deviation of 182 ft (dashed lines).

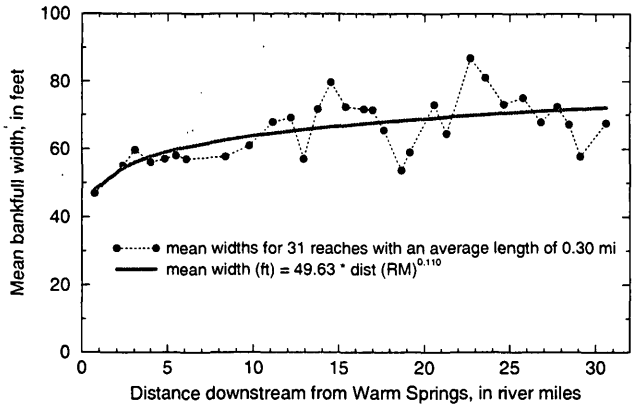


Figure 8. Mean bankfull channel width as a function of river mile for 31 long reaches. The points are the locations of the centers of each reach for which average width was calculated. The equation for the best-fit, non-linear relation between bankfull width and distance downstream is shown. The widest reach is in a marshy area upstream from Deer Lodge, where a secondary channel rejoins the main channel (RM 23.6).

Average river and valley slopes were also determined for the reach from RM 0 to 31. Average river slope was calculated from the locations of the 20-ft contour crossings on the scanned 7.5-minute maps and distance along the river centerline (fig. 9). The average river slope from RM 0 to 31 is 0.00192, with the only important differences being between RM 8 and 14. Reach-averaged river slope is less than average from RM 8.3 to 11.8 (0.00107), and greater than average from RM 11.8 to 13.2 (0.00274), where the river has been straightened along a large pond near the town of Dempsey. Average river slope is also greater than 0.00192 from RM 13.2 to 14.2 (0.00388), upstream from the mouth of Racetrack Creek. The average valley slope over the reach from RM 0 to 31 is 0.00338. Average river and valley slopes are similar from RM 0 to 26.7, where they are 0.00194 and 0.00353, respectively.

Average sinuosity was computed from the sinuosity of 1-river-mile segments along the Clark Fork from RM 0 to 31, and determined to be 1.76 (fig. 10). The sinuosity ranges from a low of 1.12, through the town of Deer Lodge, to a high of 2.61 from RM 6 to 7, between the towns of Galen and Racetrack. Sinuosity decreases on average downstream from RM 22. As a result, the average sinuosity for the reach from RM 0 to 26.7 (1.82) is slightly greater than that for the reach from RM 0 to 31. Upstream from and into the town of Deer Lodge, from RM 22 to 27, there are many large areas with thick, exposed deposits of mine tailings (Schafer and Associates, 1997). In addition, patterns of tailings deposition clearly indicate numerous channels cut off before the 1908 flood.

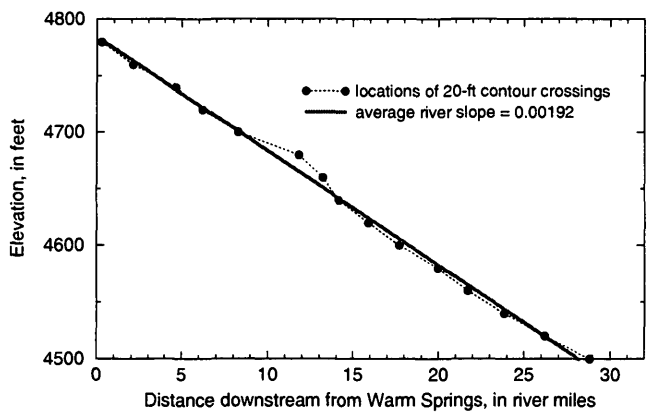


Figure 9. Elevation as a function of river mile, with the locations of the 20-ft contour crossings marked and reach-averaged river slope indicated. The river slope deviates from the average value of 0.00192 between RM 8 and 14.

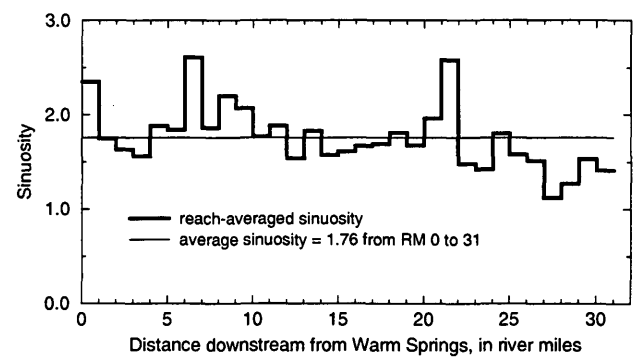


Figure 10. Reach-averaged sinuosity as a function of river mile, for 1-mile river segments. Sinuosity is below average along most of the river from RM 22 downstream through Deer Lodge.

Average Crossing Angle

The meanders on the Clark Fork in the Deer Lodge Valley are well-approximated by sine-generated curves (Langbein and Leopold, 1966; Smith and McLean, 1984). The shape of this type of "ribbon candy"-like curve is specified by the angle with which it crosses the down-valley (meander belt) axis. The crossing angle is the angle between the river centerline and the centerline of the meander belt, on the downstream side of their intersection and in the down-valley direction. The average river crossing angle for each tab was determined from the averages of the upstream and downstream crossing angles (a total of 194 pairs). The result is an average crossing angle of 77°, with a standard deviation of 22° (fig. 11). The crossing angle is consistently large where sinuosity is high (e.g., from RM 4 to 7.5, where the crossing angle averages about 90°, and average sinuosity is about 2.1) and small where sinuosity is low (e.g, from RM 25 to 29, where the crossing angle averages about 50°, and average sinuosity is about 1.4). The statistics for the crossing angles are similar upstream from RM 26.7, with an average value of 78° and standard deviation of 21°.

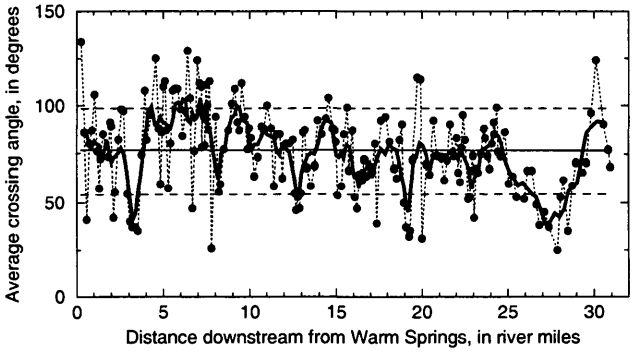


Figure 11. Average of the crossing angles upstream and downstream from each tab as a function of river mile (points). A 5-point running average (heavy solid line) shows that the crossing angles are typically large where sinuosity is high (for example, from RM 4 to 7) and small where sinuosity is low (from RM 25 to 27, for example). The average crossing angle is 77° (solid line), with a standard deviation of 22° (dashed lines).

METHOD

A classification scheme was first developed to provide a means of grouping tabs by amount and distribution of woody vegetation, then applied to the 194 tabs between RM 0 and 31. Classification of the tabs included an estimate of the percent of the tab surface area covered by shrub canopy and a description of shrub distribution along the tab edges and on the interior tab surface. Criteria for ranking the classes were then identified based on the relative vulnerability of each class to flood plain erosion.

Tab Classification Scheme

The classification scheme used to assess vulnerability of the flood plain to surface erosion during overbank flows was created after visually examining a large number of tabs to determine the characteristics that needed to be described in sufficient detail for application of the overbank flow model. This scheme includes a total of 49 possible classes (Appendix A), not all of which are represented by tabs along the Clark Fork. The flood plain tabs were examined in the aerial photographs, and the following parameters were determined for each of the 194 tabs between RM 0 and 31:

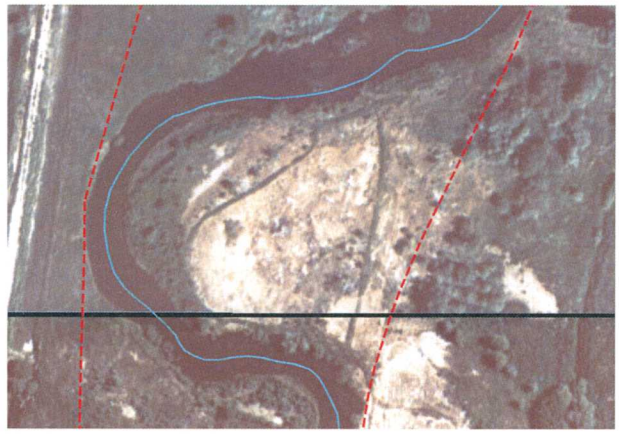
- percent of the tab surface area covered by woody vegetation canopy or shrubs with dominantly dead stems (estimated by eye from aerial photographs);
- distribution of shrubs on the tab (clumped, with large open flow paths, or evenly distributed);
- spatial density of shrub canopy along the upstream tab edge;
- width of the band of shrubs along the upstream tab edge (perpendicular to the tab edge);
- spatial density of shrub canopy along the downstream tab edge;
- width of the band of shrubs along the

downstream tab edge (perpendicular to the tab edge);
- total width of unobstructed flow paths across the tab surface in the down-valley direction. In the example (fig. 6), almost half of the tab width (distance C-D) is completely free of shrubs and would form a preferred path for overbank flow and erosion; and
- spatial density of shrubs blocking the down-valley flow path where it is blocked.

The shrub densities listed above were classified as either dense (canopies in contact), moderate (fairly dense canopy, but open spaces between shrub canopies), sparse, or none. Classes were ranked by their vulnerability to erosion (Appendix A) using the following criteria in order of decreasing importance:

1) the percent of tab area covered by shrub canopy;
2) for tabs with more than 40 percent of the area covered by shrub canopy, whether or not the shrubs are clumped together or more evenly distributed across the tab surface;
3) whether or not there are shrubs along the upstream and/or downstream tab edges;
4) density of shrubs along each tab edge.

According to the Smith (2001) model, the boundary shear stress on the flood plain surface decreases by a factor of five between 40 percent and 90 percent shrub coverage. Shrub distribution on tabs with less than 40 percent shrub canopy cover (item 2 above) was not found to be an important issue because, on those tabs, there are not enough shrubs to significantly reduce flow velocities in any case. Examples of several of the classes (fig. 12A-J) demonstrate different aspects of the classification scheme. These examples give some indication of the high variability in shrub canopy cover and distribution along the Clark Fork through the Deer Lodge Valley.



A. Tab 34 at RM 5.18; an example of vulnerability class 10.0 (the most vulnerable class), with less than 20 percent shrub canopy cover. Berms (dark lines across the tab) surround much of the tailings deposit. Flow is from bottom to top.

B. Tab 145 at RM 22.38; an example of vulnerability class 20.0, with 20 percent - 40 percent shrub canopy cover, but few shrubs along the tab edges. Flow is from right to left. The smaller channel ending at the downstream edge of the tab neck is connected to a marshy area a short distance up-valley.

Figure 12. Examples of tabs with characteristics representative of the various classes. The images shown are all taken from the 1997 aerial photographs. The blue line is the river centerline identified for the bank erosion rate study (R2 Resource Consultants, Inc, unpub. data, 1998), and the red dashed lines are the edges of the meander belt.

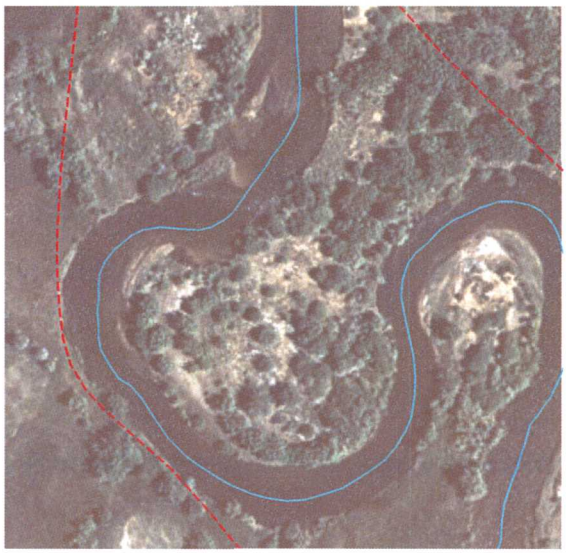
C. Tab 134 at RM 20.67; an example of vulnerability class 31.1, with 20 percent - 40 percent shrub canopy cover and sparse shrubs along the downstream tab edge. Flow is from bottom to top. The few shrubs along the downstream edge of this tab are about the minimum considered as sparse density. This tab includes the first stand of cottonwoods encountered when traveling downstream from Warm Springs.

D. Tab 31 at RM 4.95; an example of vulnerability class 32.3, with 20 percent - 40 percent shrub canopy cover and dense shrubs along the upstream tab edge. Flow is from bottom to top.

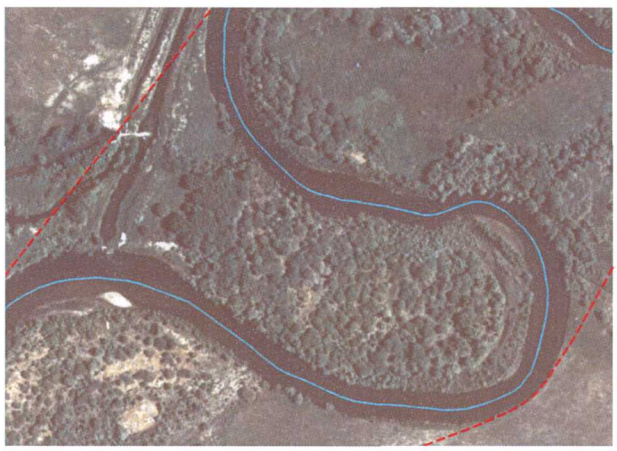
E. Tab 75 at RM 11.59; an example of vulnerability class 33.1, with 20 percent - 40 percent shrub canopy cover and sparse shrubs along both tab edges. Flow is from left to right. The centerline of the meander belt is shown (orange line), and overbank flow across the tab would be generally parallel to this line. In this case, the few shrubs along the edges are clumped together, away from the tab neck, leaving a wide open flow path across the tab neck.

F. Tab 59 at RM 8.95; an example of vulnerability class 43.3, with 40 percent - 60 percent shrub canopy cover, generally clumped in the tab interior, and dense shrubs along both tab edges. Flow is from bottom to top.

Figure 12. Examples of tabs with characteristics representative of the various classes. The images shown are all taken from the 1997 aerial photographs. The blue line is the river centerline identified for the bank erosion rate study (R2 Resource Consultants, Inc, unpub. data, 1998), and the red dashed lines are the edges of the meander belt--Continued.

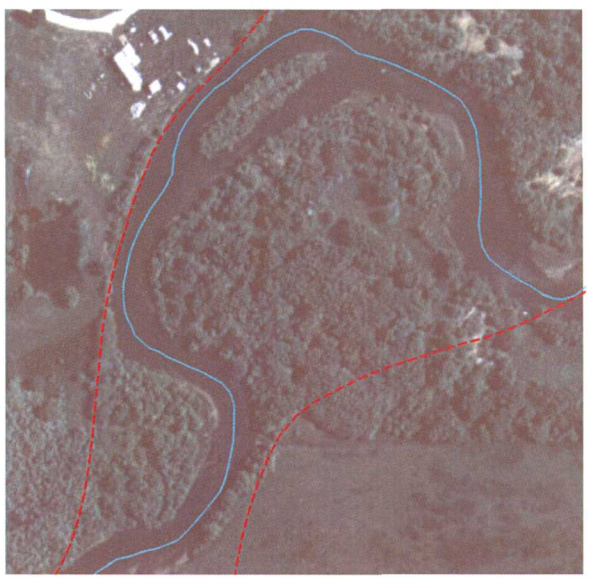


G. Tab 106 at RM 16.22; an example of vulnerability class 53.2, with 40 percent - 60 percent shrub canopy cover, fairly evenly distributed across the tab interior, and moderately-spaced shrubs along the tab edges. Flow is from bottom to top.



H. Tab 72 at RM 11.02; an example of vulnerability class 63.2, with 60 percent - 85 percent shrub canopy cover, shrubs clumped in the tab interior, leaving an open flow path across the tab neck, and moderate density of shrubs along both tab edges. Flow is from left to top, and an irrigation ditch runs along the tab neck.

I. Tab 109 at RM 16.54; an example of vulnerability class 73.2, with 60 percent - 85 percent shrub canopy cover, shrubs fairly evenly distributed on tab interior, and moderate density of shrubs along both tab edges. Flow is from bottom to top. Although the shrubs along the upstream edge are dense, the classification was based on an average density of shrubs along the two edges.



J. Tabs 78 (the smaller tab at lower left) and 79 (the large tab in the center) at RMs 12.01 and 12.13, respectively; both are examples of vulnerability class 80.0, with greater than 85 percent shrub canopy cover. These tabs are examples of the class least vulnerable to surface erosion during overbank flows. Flow is from left to right.

Figure 12. Examples of tabs with characteristics representative of the various classes. The images shown are all taken from the 1997 aerial photographs. The blue line is the river centerline identified for the bank erosion rate study (R2 Resource Consultants, Inc, unpub. data, 1998), and the red dashed lines are the edges of the meander belt--Continued.

Percent of tab surface area covered by shrub canopy was measured for 10 tabs in order to verify that the estimates made by eye of the shrub canopy coverage are sufficiently accurate to place them into the correct class. Shrub canopy areas on these tabs were measured by identifying polygons from the aerial photographs using the GIS. Examples of tabs representing each of 9 original classes were selected for this procedure. The original classes were based only on percent of the tab surface covered by shrub canopy, using the same ranges as listed in Appendix A, and general distribution of the shrubs on the tabs (i.e., whether clumped or more evenly distributed). The measured percents of area covered by shrub canopy were found to agree well with the estimated values, and the tabs were determined to be classified correctly.

Calculation of Average Percent Shrub Canopy Cover Weighted by Tab Area

Individual tab areas (fig. 13) were estimated by subtracting the estimated bankfull channel width (equation 1) from the distance downstream across the tab between points A and B in figure 6 and multiplying by the width of the tab (distance C-D, fig. 6). Estimating tab area in this manner results in a total area of flood plain within the meander belt of 1.36 mi^2, which is less than 1 percent different from the area measured directly from meander belt polygons with channel area subtracted (also 1.36 mi^2). The percent of the tab covered by shrub canopy was then converted to an area, and both total tab areas and total canopy areas were calculated. The average percent of the tabs covered by shrub canopy, weighted by the tab areas, was then computed.

RESULTS

In the 31-mile reach, the 194 tabs fall into 30 of the 49 classes in our scheme (table 1). Of those 30 classes, 13 include only one tab, while another 13 classes include 4 or more tabs. Tabs

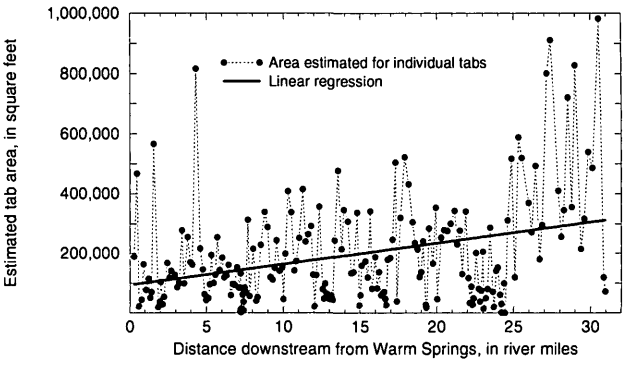


Figure 13. Estimated tab area as a function of river mile for the 194 tabs. Tab area is highly variable, with a mean of 194,800 ft^2 and standard deviation of 176,900 ft^2. The regression line shows that tab area increases on average in the downstream direction.

in the 13 classes with 4 or more tabs make up 88 percent (171) of the 194 tabs. Shrub canopy covers less than 40 percent of 144 (74 percent) of the 194 tabs (fig. 14). Included in this group are 93 tabs (48 percent of the total) that also have few, if any, shrubs along both tab edges. For the 178 tabs in the reach from RM 0 to 26.7, the proportional distribution of tabs in the classification scheme is similar to that in the reach from RM 0 to 31 (table 1).

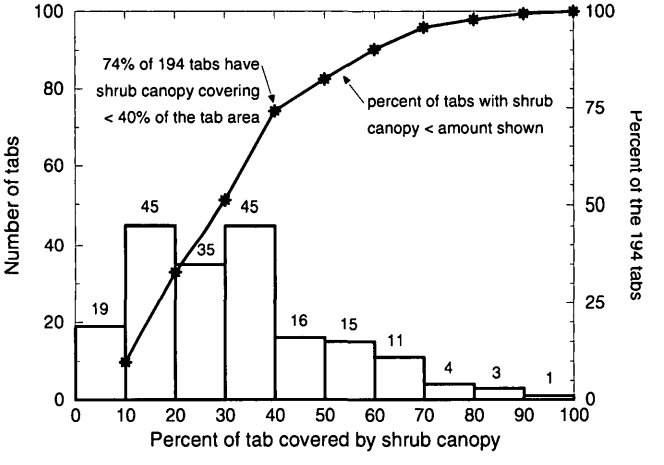


Figure 14. Distribution (boxes) and cumulative distribution (line) of tabs by percent shrub canopy cover. The cumulative distribution curve shows that 74 percent of the 194 tabs have shrub canopy covering less than 40 percent of the tab area.

Table 1. Number and percent of tabs in the 30 classes represented between RM 0 and 31 and between RM 0 and 26.7

% of tab area covered by shrub canopy	class	number of tabs in class, RM 0-31	% of total (194 tabs)	number of tabs in class, RM 0-26.7	% of total (178 tabs)
less than 20%	10.0	64	33.0	59	33.0
20% - 40%	20.0	16	8.2	15	8.4
	31.1	7	3.6	4	2.2
	31.2	3	1.5	3	1.7
	32.1	8	4.1	8	4.5
	32.2	13	6.7	13	7.3
	32.3	2	1.0	2	1.1
	33.1	14	7.2	13	7.3
	33.2	16	8.2	14	7.9
	33.3	1	0.5	1	0.6
Totals, 20% - 40%:		80	41.2	73	41.0
40% - 60% and shrubs clumped in tab interior	41.3	1	0.5	1	0.6
	42.1	1	0.5	1	0.6
	42.2	1	0.5	1	0.6
	42.3	1	0.5	1	0.6
	43.1	3	1.5	3	1.7
	43.2	6	3.1	6	3.4
	43.3	6	3.1	6	3.4
40% - 60% and shrubs distributed throughout tab surface	52.1	1	0.5	1	0.6
	52.2	1	0.5	1	0.6
	53.1	2	1.0	2	1.1
	53.2	7	3.6	4	2.2
	53.3	1	0.5	1	0.6
Totals, 40% - 60%:		12	6.2	9	5.1
60% - 85% no shrubs along banks	60.0	1	0.5	1	0.6
60% - 85% and shrubs clumped in tab interior	63.1	1	0.5	1	0.6
	63.2	5	2.6	5	2.8
	63.3	1	0.5	1	0.6
60% - 85% and shrubs distributed throughout tab surface	72.2	1	0.5	1	0.6
	73.2	5	2.6	4	2.2
	73.3	1	0.5	1	0.6
Totals, 60% - 85%:		15	7.7	14	7.9
greater than 85%	80.0	4	2.1	4	2.2

The cumulative totals of tab area and area covered by shrub canopy indicate that an average of 29 percent of the tab surface area between RM 0 and 31 is covered by the canopy of living or dead shrubs. Where there are shrubs along the upstream tab edge, the average width of shrub canopy (length perpendicular to the tab edge) is 30 ft. Along downstream tab edges where shrubs are present, the average width of the shrub canopy is 27 ft. The minimum shrub band width is about 11 ft, which is close to the canopy diameter typical of "mature" willow or water birch shrubs.

Variability in percent of tab area covered by shrub canopy is high in most reaches (fig. 15). However, there are three long river segments where the shrub canopy cover does not exceed 40 percent on any tab. They are: 1) RM 1.32 to 6.82; 2) RM 16.78 to 18.84; and 3) RM 24.43 to 27.38. These reaches cover a total of 10.51 river miles, or 34 percent of the 31 river miles. For the 64 tabs in these reaches, the average percent of tab area covered by shrub canopy is only 19.2 percent, with a standard deviation of 9.8 percent.

Downstream variation in the percent of tab area covered by shrub canopy (fig. 15) clearly indicates which tabs are more vulnerable to flood plain surface erosion during overbank flows. The total difference between flood plain surface area and area covered by shrub canopy over the 31-mile reach is about 0.97 mi^2, or about 71 percent of the total area of the flood plain surface within the meander belt. The reach with the greatest difference is from about RM 24.5 to RM 30, which includes about 2.1 river miles through the town of Deer Lodge. Many areas through Deer Lodge lacking shrub canopy are actually paved roads or other man-made structures. However, the same calculation for the reach upstream from Deer Lodge (RM 0 to 26.7) indicates that 70 percent of the floodplain surface area lacks shrub canopy cover, nearly the same as that for RM 0 to 31.

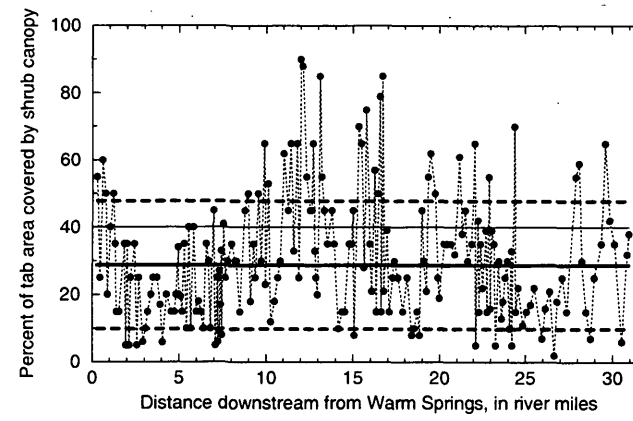


Figure 15. Percent of tab area covered by shrub canopy as a function of river mile for the 194 tabs. The average percent of tab area covered by shrub canopy (weighted by tab area) is 28.8 percent (heavy solid line), with a standard deviation of 18.9 percent (dashed lines). Through three long reaches, the percent of tab area covered by shrub canopy does not exceed 40 percent (thin solid line).

Another characteristic indicating vulnerability to flood plain surface erosion is the percent of tab width open to flow down-valley across the tab (fig. 16). The average unblocked path width for the 194 tabs is 230 ft, with a standard deviation of 161 ft. Compared with an average tab width of 394 ft, this indicates that flow across more than half of the tab width typically would be met with little resistance. In addition, there are several reaches (e.g., from RM 17 to 19)

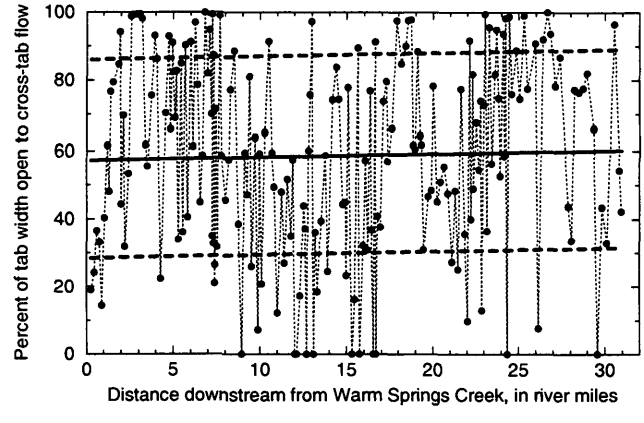


Figure 16. Percent of tab width open to flow down-valley across the tab as a function of river mile. The mean value (solid line) is 58.6 percent, and the standard deviation (heavy dashed line) is 28.8 percent. Where the percent of tab width open to flow approaches 100, there are few, if any, shrubs to block flow down-valley across the tab.

where successive tabs have much of the tab width open to flow down-valley across the tab (fig. 16), leaving those reaches more susceptible to floodplain surface erosion during overbank flows. Tabs without open flow paths down-valley across the tab (values near 0 percent) are those with more dense shrub canopy (greater than 60 percent) and shrubs distributed throughout the tab surface. Tabs with all or almost all of the width open to down-valley flow have less than 40 percent shrub canopy cover (less than 10 percent in most cases) and only narrow bands of shrubs along the tab edges, if any.

Differences in slope for flow across the tabs as opposed to flow in the channel around the tab were also determined. For the individual tabs, the slope down-valley across the tabs is an average of 1.9 times the slope along the river channel.

CONCLUSIONS

The results of this assessment of the state of woody vegetation along the Clark Fork of the Columbia River through the Deer Lodge Valley show the extent of areas vulnerable to surface erosion during overbank flows. Flow down-valley over the tabs would be unobstructed through the 71 percent of the flood plain surface area from RM 0 to 31 where there is little to no woody vegetation. Canopy cover does not exceed 40 percent on any of the 64 tabs in three long reaches covering a total of 10.51 river miles. Thirty-three percent of the tabs have shrub canopy covering less than 20 percent of their area, and a total of 93 (48 percent) of the 194 tabs have less than 40 percent shrub canopy cover and few, if any, shrubs along the tab edges.

The lack of dense woody vegetation identified in this report may lead to a significant vulnerability to erosion of contaminated sediment on the flood plain and to possible geomorphic alteration of this system during overbank flows. In the event of a deep overbank flow, the stream may be vulnerable to change from a single-thread, meandering stream with an average width of 67.3 ft, to a braided channel occupying an area with an average width of up to 512 ft.

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Appendix A: Classification scheme for woody vegetation coverage of flood plain tabs

Class	Description
10.0	less than 20% of the tab surface covered by shrub canopies
20.0	20% - 40% shrub canopy cover, and few shrubs along tab edges
31.1	20% - 40% shrub canopy cover, and sparse shrubs along downstream edge of tab
31.2	20% - 40% shrub canopy cover, and moderately-spaced shrubs along downstream edge of tab
31.3	20% - 40% shrub canopy cover, and dense shrubs along downstream edge of tab
32.1	20% - 40% shrub canopy cover, and sparse shrubs along upstream edge of tab
32.2	20% - 40% shrub canopy cover, and moderately-spaced shrubs along upstream edge of tab
32.3	20% - 40% shrub canopy cover, and dense shrubs along upstream edge of tab
33.1	20% - 40% shrub canopy cover, and sparse shrubs along both edges of tab
33.2	20% - 40% shrub canopy cover, and moderately-spaced shrubs along both edges of tab
33.3	20% - 40% shrub canopy cover, and dense shrubs along both edges of tab
41(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along downstream edge of tab
42(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along upstream edge of tab
43(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along both edges of tab
51(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along downstream edge of tab
52(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along upstream edge of tab

Appendix A: Classification scheme for woody vegetation coverage of flood plain tabs

Class	Description
53(.1, .2, or .3)	40% - 60% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along both edge of tab
60.0	60% - 85% shrub canopy cover, and few, if any, shrubs along tab edges
61(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along downstream edge of tab
62(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along upstream edge of tab
63(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs clumped in tab interior, and (sparse, moderately-spaced, or dense) shrubs along both edges of tab
71(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along downstream edge of tab
72(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along upstream edge of tab
73(.1, .2, or .3)	60% - 85% shrub canopy cover, shrubs fairly evenly distributed on tab, and (sparse, moderately-spaced, or dense) shrubs along both edges of tab
80.0	shrub canopy covers more than 85% of tab surface