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Revegetation for riverbank stabilization on the upper Clark Fork River, Montana

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REVEGETATION FOR RIVERBANK STABILIZATION
ON THE UPPER CLARK FORK RIVER, MONTANA

by
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This study, conducted from May 1997 to June 1998, examined the survival and growth of woody vegetation planted for streambank stabilization of laterally unstable and actively eroding streambanks of the upper Clark Fork River. Four planting methods were evaluated: vertical planting of willow cuttings into the upper bank; willow cuttings laid at an angle and perpendicular to the channel on a re-sloped bank; mature transplants; and one-gallon nursery-grown container plants. Growth was measured in terms of above-ground shoot and leaf growth. The three growth measurements taken were a measure of the total length of all shoots, the longest shoot length, and a count of the total number of shoots. Cuttings were considered alive if green coloration was observed when willow cutting bark was scratched with the thumbnail. Simple correlation coefficients indicated no relationship between willow cutting growth and soil pH (all $r < 0.25$). Chi-square analysis indicated significant differences in survival between all planting methods; vertical cuttings vs. angled cuttings; and all rooted plants vs. all willow cuttings (X^2_{calc} = 926.59, 14.36, and 885.36, respectively), but not between mature transplants vs. one-gallon container stock ($X^2_{calc} = 3.95$). A logistic regression (probit model) indicated that soil pH does not have an influence on willow cutting survival at either the 15 cm (6 in) or 45 cm (18 in) depth (R^2 = 0.003 and 0.007, respectively). Management implications and issues are discussed and recommendations for future research are presented.

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INTRODUCTION

The Importance of Riparian Ecosystems

Wetland and riparian areas account for only 1-5% of the landscape in the United States, but they are disproportionately used by humans and wildlife (Knopf 1988a, Hansen and others 1995). Wetland and riparian areas perform many functions including sediment filtering, riverbank building, water storage, aquifer recharge, providing fish and wildlife habitat, serving as centers for vegetative and biotic diversity, and dissipating stream energy (Knopf 1988a, Gregory and others 1991, Hansen and others 1995). These areas also provide recreational and aesthetic benefits. The health of such areas is of great importance and is of special concern in the western United States where water resources are scarce.

A wetland or riparian area that is not maintained in a healthy state loses its abilities to perform its functions (Carothers 1977, Elmore and Beschta 1985, Hansen and others 1995). Impacts from grazing and development can result in bank erosion, increased sedimentation and stream energy, loss of fish and wildlife habitat, lowering of the water table, and other detrimental effects (Carothers 1977, Elmore and Beschta 1985, Hansen and others 1995). Riparian systems effect and are affected by soils types and formation, livestock grazing opportunities, timber growth and harvest activities, wildlife habitat, fisheries resources, recreation, watershed and hydrology, and vegetation.

Hydrology—Wetland and riparian areas are critical elements in hydrologic systems (Brooks and others 1991, Hansen and others 1995). Hydrologically, wetland and riparian areas perform a number of tasks. They filter out nutrients, which can help control agricultural non-point-source pollution (Lowrance and others 1985). As overland runoff flows into riparian and wetland ecosystems, water energy is dissipated and sediment loads settle out, diminishing the waters erosive potential (Karr and Schlosser 1978, Brooks 1991). During floods, a waterway may overflow its banks or shoreline and advance upon its floodplain. Many alluvial aquifers are maintained and recharged by upland runoff in the stream channel or alluvial deposits (Brooks 1991). These aquifers are an important source of water for human use. Water storage in such aquifers is partially responsible for maintaining base flow in western rivers; non-functioning riparian areas can result in dry river beds where water once flowed (Brooks 1991, Hansen and others 1995).

Vegetation—Vegetation condition is a major component of the health of wetland and riparian ecosystems (Hansen and others 1995). Riparian vegetation stabilizes riverbanks, influences bank morphology, and aids in reducing riverbank damage from ice, log debris, and animal trampling (Karr and Schlosser 1978, Platts 1979, Marlow and Pogacnik 1985). Annual turnover of wetland vegetation is an enormous contributor to soil development (Brady 1990).

Riparian vegetation provides shade which controls water temperature fluctuations and aids in cooling water during summer months (Rowe and Taylor 1994). Both these functions are critical to aquatic life, as many species are adversely affected by both fluctuating and high temperatures (Meehan and others 1977). Additionally, cooler temperatures increase waters oxygencarrying capacity, an important consideration when managing for animals requiring cold, well-oxygenated water (e.g. trout) (Meehan and others 1977). Riparian vegetation produces most of the detritus that provides as much as 90% of the organic matter necessary to support stream communities (Campbell and Franklin 1979).

Soil—Soils often have a strong influence on vegetation, but in riparian and wetland areas this influence is often overshadowed by the effect of water availability and moisture gradients (Karr and Schlosser 1978). Variations in soil and water regimes can often be observed as distinct changes in vegetation including species composition and species coverage (Hansen and others 1995).

Wildlife and Fisheries—Riparian areas are of great importance to a wide variety of wildlife species. Across the United States, wetland and riparian areas provide critical habitat for more than 150 bird species and over 200 fish species and riparian areas are utilized as travel corridors for many animal species (Knopf 1988a, Gregory and others 1991). Riparian areas are used by many fish species for year-round habitat and seasonal spawning areas. Banks stabilized by vegetation can become undercut and overhang, providing cover for fish and other aquatic animals (Hansen and others 1995).

Although less than one percent of the western landscape of the United States contains riparian vegetation, this vegetation provides habitat for more species of breeding birds than any other vegetation type on the continent (Knopf 1988b). Riparian habitats, in general, have higher wildlife species diversity than do adjacent habitats or those of other types (Knopf 1988a). The reasons for this include: (1) the juxtaposition of wildlife habitat requirements (i.e. food, cover, and water); (2) the increased number of niches due to more plant species and structural heterogeneity; and (3) the high edge-to-area ratios that result from the linear shape of most riparian zones (Thomas 1979, Knight 1988). Population densities of animals in upland habitat adjacent to riparian or wetland zones are influenced by the presence of riparian and wetland areas (Carothers 1977). When riparian and wetland areas are adversely impacted, wildlife is impacted not only in the riparian or wetland area, but also in surrounding upland areas (Carothers 1977).

Human Use Considerations - Grazing, Timber, Recreation—The effects of grazing on wetland and riparian areas are well-documented (Hansen and others 1995). Cattle tend to congregate in riparian and wetland areas and utilize the vegetation much more intensively than the vegetation of adjacent upland sites (Kauffman and Krueger 1984). Trampling of vegetation and soils, extreme depletion of lush vegetation due to consumption, and change in vegetative cover and composition are common effects of improper grazing strategies (Ames 1977, Rauzi and Hanson 1966), and heavy livestock use can prevent tree and shrub reproduction (Hall 1988).

Timber harvest in riparian areas is often precluded by agency regulation and/or wet soils. However, riparian areas are closely linked with surrounding upland areas (and vice versa) in several ways. Timber harvest on surrounding uplands can result in a raising of the water table (Hansen and others 1995). A reduction in streamside shade can result in increased temperatures (Hall 1988). Improper harvesting techniques or overlyintensive harvesting of timber on uplands can result in increased sedimentation of waterways, thus impacting water quality, wildlife, and fisheries. These resources may also be impacted by the construction of roads used to access harvestable stands (Hall 1988).

Riparian and wetland areas are heavily utilized for recreation during all times of the year. Fishing, hunting, rafting, floating, wildlife-watching and swimming are some of the many activities dependent upon the health of riparian areas. Equally important is the aesthetics of riparian and wetland areas.

The Importance of Riverbank Stability and Factors Contributing to Instability

Rivers naturally migrate across their floodplains, cutting laterally and releasing and redepositing sediments as their channels readjust to flow volumes or sediment loads (Elmore and Beschta 1989, Rosgen 1995). However, this dynamic nature can be exacerbated by human influences, including grazing, timber harvest, recreation, and other uses (Henderson 1986). Stabilization of eroding riverbanks is the goal of many riparian restoration and rehabilitation projects in the western United States (Kondolf 1996).

The Use of Vegetation in Stabilization

The establishment of native riparian vegetation has been recognized as an important tool for successful stabilization programs (Watson and others 1997, Miller 1996, Madej 1992, Carlson and others 1991, Smith 1976). A spectrum of options for bank stabilization treatments range from "hard" to "soft" treatments. Hard treatments typically involve the use of long-term structures that are not typically found within the riparian system, such as large rock rip-rap or concrete retaining walls; soft treatments rely heavily on the performance of vegetation and other natural materials, and generally focus on helping the system in the self-healing process. Established woody vegetation is often more effective and less costly and maintenance intensive than harder treatments such as the use of rock in rip-rap (Elmore and Beschta 1989). The use of vegetation may be more appropriate than harder treatments where aesthetics and site accessibility are of concern.

The use of *Salix* spp. (willow) cuttings to revegetate riparian areas is widely applied across the country, because of local availability and ease of propagation. However, their use for riverbank stabilization is not well-studied, and planting recommendations vary regionally (Chosa and Shetron 1976, Dewar and Berglund 1983, Monsen 1983, Hoag 1991, Hoag 1992, Hoag 1993). There are no planting recommendations or revegetation project evaluations that specifically address problems associated with the Upper Clark Fork River.

Most of the literature presenting post-project evaluations focuses primarily on survival percentages (Chosa and Shetron 1976, Hoag 1991, Svejcar and others 1991), and few provide information on shoot and root growth (Dewar and Berglund 1983, Hoag 1991). Due to temporal and financial constraints, most restoration projects are rarely subjected to systematic and rigorous post-project evaluation (Kondolf 1995). In order to assess the effectiveness of riparian restoration projects and to further the understanding of successful restoration and stabilization techniques, long-term post-project monitoring programs are needed (Klingeman 1984, Platts 1984, Kusler and Kentula 1990, Jensen and Platts 1989, Kondolf 1995, Zonge and Swanson 1996). Understanding the potential for propagation of *Salix* spp. on the Upper Clark Fork River is critical to future revegetation efforts of riverbanks containing mine tailings. The influence of mine tailings in the soil on plant establishment, survival, and growth is not well-explored, though there are some indications that *Salix* spp. may tolerate the presence of mine tailings (Ray 1978, Rice and Ray 1984, Riparian and Wetland Research Program 1996b).

Study Context, Objectives, and Hypotheses

Study Context—This study is a part of the larger Riverbank Stabilization Pilot Study on the Upper Clark Fork River which began in the fall of 1996 under the Riparian and Wetland Research Program (RWRP) at the University of Montana. The Riverbank Stabilization Pilot Study is designed to measure, monitor, and compare changes in channel dimensions (e.g. width:depth ratio), channel movement (e.g. rate of lateral cutting), and vegetation (e.g. species and cover) within and between treatment reaches and between treatment and control reaches (Riparian and Wetland Research Program 1996a).

Much of the Upper Clark Fork River riverbanks are particularly susceptible to erosion, as woody vegetation is largely absent from many reaches due to livestock grazing, removal of vegetation along the floodplain for agricultural use, and the deposition of mine tailings associated with the 1908 and subsequent floods. The objectives of the Riverbank Stabilization Pilot Study are to evaluate the effectiveness of soft riverbank stabilization treatments, and to determine the efficacy of vegetation for reducing the rate and potential for bank erosion by establishing vegetation to stabilize vertical banks undergoing active lateral cutting (Clayton and others 1998). The study presented here contributes to the assessment of the soft riverbank stabilization treatments by evaluating the survival and growth of plant material using several different planting methods.

There are twelve total treatments in the Riverbank Stabilization Pilot Study. This study evaluated five treatments across eight treatment reaches totaling 1,091 m (3,591 ft) of riverbank. Each treatment has received one or more combinations of temporary in-stream stabilization construction treatments and a revegetation treatment.

The in-stream stabilization structures are intended to provide short-term bank protection until the planted riparian vegetation can establish and hold the banks with its deep-binding root mass. Native and natural materials are used for the in-stream structures: 1) log and rock barbs, 2) *Juniperus scopulorum* (Rocky Mountain juniper) and *Pseudotsuga menziesii* (Douglas-fir) revetments, and 3) coir (coconut fiber) erosion control mat. Four planting methods employed are: 1) vertical *Salix* spp. cuttings, 2) angled *Salix* spp. cuttings, 3) mature shrub transplants, and 4) one-gallon, nursery-grown container plants. A full description of planting methods and in-stream structures is presented in the Methods and Materials section. The five treatments combined the stabilization treatments and planting methods in a non-factorial way:

1) Coir fabric and angled *Salix* spp. cuttings
2) Coir fabric, angled *Salix* spp. cuttings, and log barbs
3) Coir fabric, rock barbs, rock toe, and one-gallon container plantings
4) Conifer revetments and vertical *Salix* spp. cuttings
5) Mature shrub transplants and vertical *Salix* spp. cuttings

The Riverbank Stabilization Pilot Study provides an excellent opportunity to examine the potential for revegetation of eroding banks of the Upper Clark Fork River. Before this study was initiated, however, planting methods were implemented to meet the objectives of the larger Riverbank Stabilization Pilot Study, and are distinct from the objectives of this study. Specifically, due to low replication, I was unable to assess the growth and survival of the mature transplant and one-gallon container techniques. The hypotheses formulated for Objective 1, presented below, reflect the limitations of the larger Riverbank Stabilization Pilot Study study design and thus focus on analyses of growth of *Salix* spp. cuttings and survival proportions of all planting methods. These are the hypotheses that could be statistically tested given the design of the study. The analysis presented in this study is aimed, therefore, at determining those relationships between site conditions and plant survival and growth that were possible to detect.

Study Objectives—This study has two main objectives:

1) To assess the effect of planting method and planting site soil conditions on survival and growth of plants used in bank stabilization on the Upper Clark Fork River.

2) To develop recommendations for future revegetation projects and for future research aimed at stabilizing riverbanks of the Upper Clark Fork River.

Hypotheses—To meet the first objective, four testable hypotheses were formulated, and statistical methods for testing each were determined.

H_o1: Soil pH does not have an influence on *Salix* spp. cutting survival.
H_a1: Soil pH does have an influence on *Salix* spp. cutting survival.

A logistic regression will be constructed to determine if there is a critical soil pH threshold, above which *Salix* spp. cutting survival is significantly different than values below. Survival data collected in June of 1998 will be used.

H_o2: Soil pH does not have an influence on *Salix* spp. cutting growth.
H_a2: Soil pH does have an influence on *Salix* spp. cutting growth.

A simple correlation coefficient will be calculated for *Salix* spp. cutting growth versus soil pH. Growth data for *Salix* spp. cuttings alive at the end of the 1997 growing season will be used, and will be calculated for both the 15 cm (6 in) and 45 cm (18 in) sampling depths.

H_o3: Planting method (angled cuttings, vertical cuttings, one gallon container stock, and mature transplants) does not influence survival.

H_a3: Planting method (angled *Salix* spp. cuttings, vertical *Salix* spp. cuttings, one gallon container stock, and mature transplants) does influence survival.

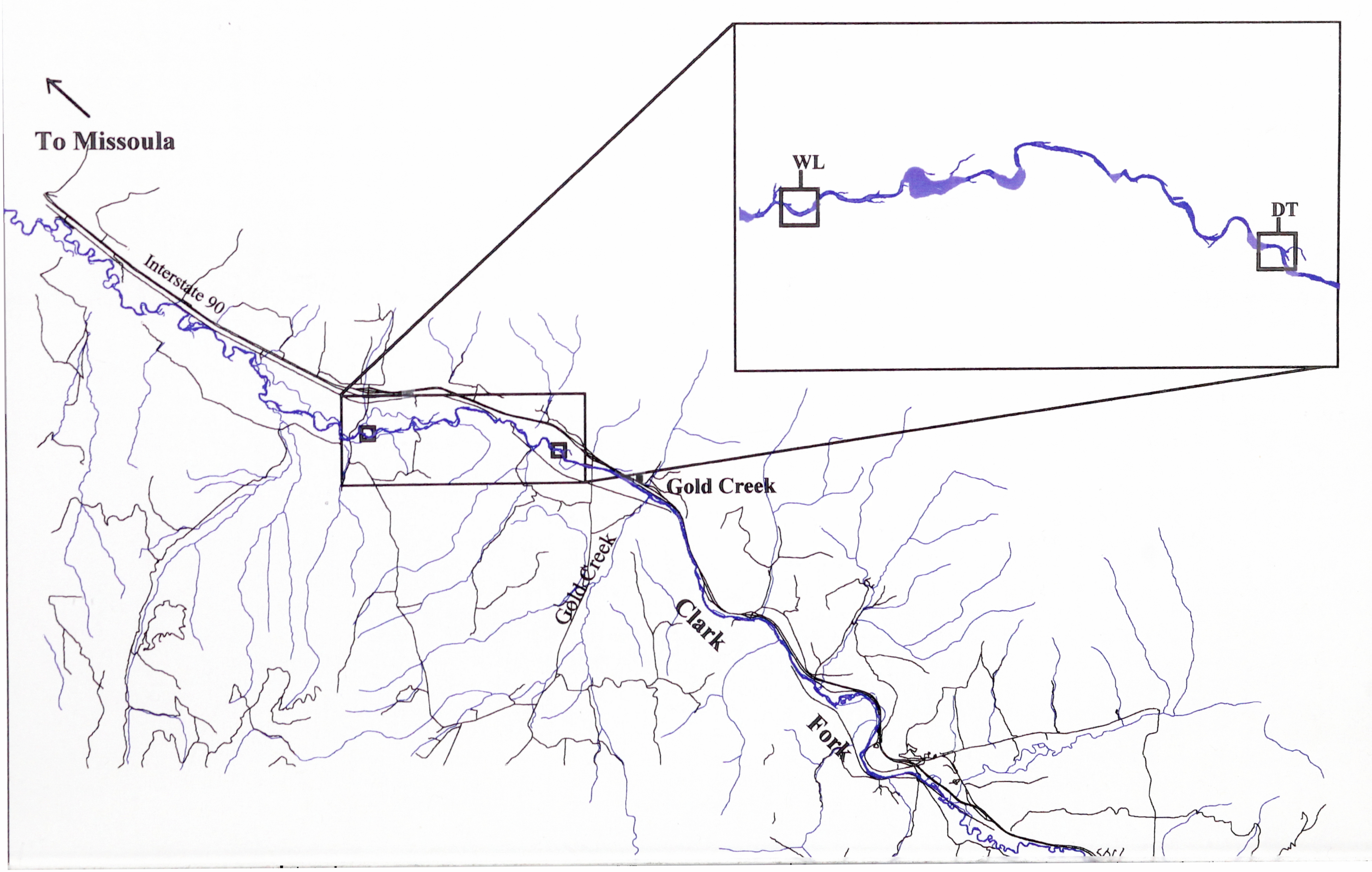
A chi-square test of independence will be conducted to determine if there is a dependency between planting method and survival. Survival data collected in June 1998 will be used and the test will be conducted at the 97.5% confidence level (Bonferroni correction of the chosen 90% confidence level).

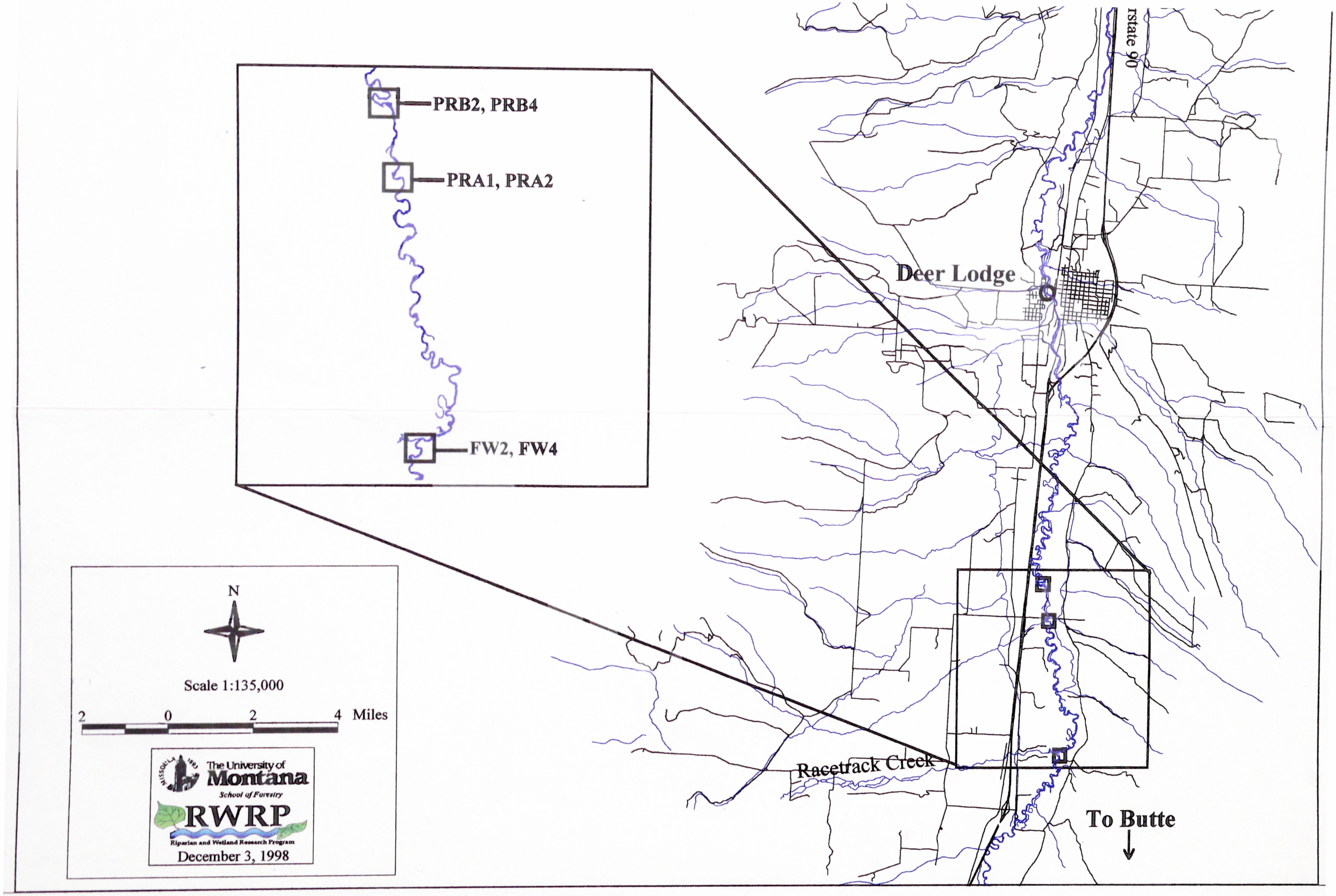
Study Area

History—The Clark Fork River is located in the Northern Rocky Mountains in western Montana. The study areas are located along the Upper Clark Fork River near the towns of Gold Creek and Deer Lodge (Figure 1). Some of the site history presented here is adapted from Clayton (1996). The Upper Clark Fork River, like many western rivers, has been altered by many years of human use. The vegetation, hydrology, and geomorphology of the river have been influenced by years of mining, grazing, timber harvesting, agricultural diversions, and river channelization. The first fur trappers arrived in the Upper Clark Fork River valley in the 1820's. Warren Ferris, a trapper in the American Fur Company brigade, described the region in his 1831 diary:

> "All the streams by which it [the valley] is intersected are decorated with groves and thickets of aspen birch and willow, and occasional clusters of currant and gooseberry bushes. The bottoms are rich and verdant and are resorted to by great numbers of deer and elk" (cited in Hortsman 1984).

Figure 1. Study Site Locations




PRB2, PRB4
PRA1, PRA2
FW2, FW4
rstate 90
Deer Lodge
Racetrack Creek
To Butte
N
Scale 1:135,000
2 0 2 4 Miles
The University of Montana
School of Forestry
RWRP
Riparian and Wetland Research Program
December 3, 1998

Ferris later describes the abundance of wildlife in the area between present-day Deerlodge and Gold Creek:

> "...our hunters killed three grizzly bears, several goats, deer and two buffaloes; the latter, however is seldom found in this country; though it abounds in black and white tailed deer, elk, sheep, antelopes, and sometimes moose, and White mountain goats have been killed here" (cited in Hortsman 1984).

Jean-Pierre DeSmet, a Jesuit missionary, described the conditions of the streams in 1841:

> "...the country is well watered, for it abounds with small lakes and rivulets, and is surrounded by mountains, at whose base are found numberless springs. In no part of the world is the water more limpid or pure, for whatever may be the depth of the rivers, the bottom is seen as if there were nothing to intercept the view" (cited in Hortsman 1984).

Trapping in the Upper Clark Fork River came to an end in the early 1840's, due to the combination of changing fashion and trapped out streams (Hortsman 1984). The first white settlers of the Upper Clark Fork River were retired trappers living with their Indian wives (Hortsman 1984).

Gold was first discovered in Montana in Gold Creek in 1852, and during the 1860's nearly every stream in the drainage was prospected (Hortsman 1984). Early investments in the developing mining industry were made in the construction of ditches and flumes to deliver water for placer mining (Hortsman 1984), which involves turning over and washing out riverbanks in search of gold. Placer mining was soon replaced by hydraulic mining, which used high pressure hoses to wash away whole riverbanks and beds (Hortsman 1984), resulting in huge amounts of tailings into the Upper Clark

Fork River. James A. Garfield, later a U.S. President, traveled down the Clark Fork River in 1872 and wrote in his diary: "The beautiful river has been permanently ruined by the miners; and has been for three years as muddy as the Missouri. Before the discovery of gold, it was as clear and pure as any mountain stream could well be" (cited in Hortsman 1984).

The Mullan Road, a wagon road connecting Walla Walla, Washington, the uppermost navigable point on the Columbia River, with Fort Benton, Montana, its counterpart on the Missouri River, was constructed through Montana in 1860 (Hortsman 1984). The road was reportedly built rapidly in western Montana "partially due to the fact that little grading was necessary along the Upper Clark Fork. But in order to avoid grading around the river's bluffs, the road made many crossing of the river's meanders" (Hamilton 1957, cited in Hortsman 1984). Between Deer Lodge and Missoula, the road crossed the river seven times and crossed two bridges (Hortsman 1984). The construction of the Northern Pacific Railroad was completed in Gold Creek in 1883. The railroad included 10 bridges on the Upper Clark Fork River between its confluence with the Little Blackfoot River and Missoula, and "at two points between Garrison and Missoula, new channels were cut to straighten the river bed, while dikes of piles, brush and rocks were thrown across the old channel" (Smalley 1883, cited by Hortsman 1984). A competing railway, the Chicago, Milwaukee, and St. Paul Railway, followed the same path and further manipulated the river. No sooner was it completed when the great flood of 1908 washed out nearly 120 km (75 miles) of newly-laid track (Hortsman 1984).

Cattle were first brought to the Upper Clark Fork River valley in the 1850's. Many ranches were located in riparian areas, the sheltered, well-watered drainages, near wild hay meadows for horse pasture (Hortsman 1984). The grasses that supported such abundant game were put to the use of raising cattle, and provided great benefits to area ranchers. Many prosperous cattle ranches existed in the 1860's, but mountain ranges were also overcrowded and overgrazed by the early 1870's (Hortsman 1984), and overgrazing associated with droughts was reported again in the 1930's (Hortsman 1984).

Agriculture came to support the mining and ranching industries, and grain and hay crops were well-established in the Deer Lodge Valley by 1870 (Hortsman 1984). Later, as logging operations cleared forests, more farms were developed (Hortsman 1984). The railroads fostered development of the lumber industry, and in the 1880's mills were built in the Upper Clark Fork River valley to supply materials for building more railroads in western Montana (Hortsman 1984). During the development of the Upper Clark Fork River watershed, riparian trees may have been used by miners and ranchers for fuel, fenceposts, and building materials -- similar to the situation in other parts of Montana (Hansen and others 1995).

In the 1870's, copper was discovered in the silver mines at Butte, and in 1882 the copper market flourished as the demand for copper for recent inventions (electric light and telephone) increased (Hortsman 1984). Copper mining continued through the 1980's. Since the discovery of gold in 1852, well over a century of mining has left its mark on the Upper Clark Fork River. The 100-year floodplain of the Clark Fork River from the river's origin near Anaconda to the Milltown Dam near Missoula, about 193 km (120 mi) downstream, is now on the National Priorities List (Superfund) because of concerns associated with heavy metals tailings deposited after the breach of an impoundment during the 1908 flood. Tailings in many of the riverbanks have been deposited as a discrete lens; in other areas the tailings is mixed with other depositional material. U.S. Interstate Highway 90 now also follows a path through the valley close to that of the railways. Together the road and the railways restrict or preclude lateral migration of the river, causing it to be functionally channelized for multiple stretches.

Despite this long period of heavy use, the Upper Clark Fork River watershed today continues to support ranching, hay production, timber harvesting, and limited mining (Clayton 1995). The river and its major tributaries (Little Blackfoot River, Flint Creek, and Rock Creek) are also popular with fishermen. Based upon a mail survey, Montana Department of Fish, Wildlife and Parks estimated over 30,000 angler days on the Upper Clark Fork River in the 1989 license year (McFarland 1992).

Description of Study Area—The seven reaches observed in this study are located in the Upper Clark Fork River watershed in western Montana. Study reaches are located on private property and are named after the landowner: one reach each at DT and Wallace WL, two reaches at FW (FW02 and FW04), and four reaches at PR (PRA1, PRA2, PRB2, and PRB4). The FW, PR, and WL reaches are located in Powell County; DT is located in Granite County. The DT and WL sites are located near Gold Creek, approximately 100 km (62 mi) upstream of Missoula, and the FW and PR sites are located near Deer Lodge, approximately 210 km (130 miles) southeast (upstream) of Missoula (Figure 1).

Vegetation. The vegetation in these reaches is typical of alluvial floodplains west of the Continental Divide (Hansen and others 1995). The dominant tree species are *Populus trichocarpa* (black cottonwood), *Populus tremuloides* (quaking aspen), *Juniperus scopulorum* (Rocky Mountain juniper), with occasional *Pinus ponderosa* (ponderosa pine) and *Pseudotsuga menziesii* (Douglas-fir). Shrubs include *Alnus incana* (mountain alder), *Betula occidentalis* (water birch), *Cornus stolonifera* (red-osier dogwood), *Salix drummondiana* (Drummond willow), *Salix exigua* (sandbar willow), *Crataegus douglasii* (black hawthorne), *Ribes* spp. (currant), *Rosa woodsii* (woods rose), and *Symphoricarpus occidentalis* (western snowberry). Grass and forb species include *Bromus inermis* (smooth brome), *Elerocharis* spp. (spikesedge), *Phalaris arudinacea* (reed canarygrass), *Equisetum arvense* (field horsetail), *Iris missouriensis* (Rocky Mountain iris), *Typha latifolia* (common cattail), *Rumex crispus* (curled dock), *Taraxacum officinale* (common dandelion), *Agrostis stolonifera* (redtop), *Phleum pratense* (common timothy), *Poa pratensis* (Kentucky bluegrass), *Centaurea maculosa* (spotted knapweed), *Cirsium arvense* (Canada thistle), *Euphorbia esula* (leafy spurge), and *Tanacetum vulgare* (common tansy).

Geology. The geology of the area is mostly Tertiary basin fill with some Cretaceous sediments in the uplands (Alt and Hyndman 1986). Soils are primarily coarse, well-sorted alluvial deposits (loamy sand, Brady 1990) consisting of Entisols and Inceptisols (Clayton 1990). Through the Deer Lodge area and Gold Creek Area study reaches, the channel is composed primarily of gravel substrates and is meandering with a low gradient, point bars, pools, and riffles (C4 Rosgen Type [Rosgen 1996]); some braided, wide sections with eroding banks (D4 Rosgen Type [Rosgen 1996]) also exist (Riparian and Wetland Research Program 1995). Native soils on the Upper Clark Fork River floodplain are composed of fluvial silts, fine-to-coarse sands, and gravels (Riparian and Wetland Research Program 1995). In wetland portions of the study area, where vegetation and soils are relatively undisturbed by either fluvial or human impacts, dark, organic soil horizons have developed (Riparian and Wetland Research Program 1995).

Climate. Climate data is from the NOAA Drummond Aviation Station (No. 242500) located about 5 km (3 mi) south of Drummond in Granite County at an elevation of 1,198 m (3,929 ft). The area receives an average of 328 mm (12.93 in) of precipitation per year, with the majority occurring in the spring and summer. The 1997 and 1998 temperatures were very close to the long-term normal (5.97°C [42.75°F] and 6.00°C [42.8°F], respectively), and precipitation was slightly less in 1997 and greater in 1998 than the long term averages (Table 1).

Streamflow data used for the study reaches is from the USGS Clark Fork River near Galen station (No. 1232800) located approximately 8 km (5 mi) upstream of the Deer Lodge area study sites in Powell County. Continuous data is available from the site for a nine year period of record (water years 1988 through present; water year 1998 is provisional), and all data is reported as mean daily discharge (MDD). The station is located at an elevation of 1,444 m

Table 1. Mean temperatures in °C and precipitation in mm for Drummond, Montana. The °F and in equivalents are presented in parentheses.

	Apr	May	June	July	Aug	Sept	Oct
Mean monthly temperature, 1963-1998	6.1 (42.9)	10.6 (51.0)	14.8 (58.7)	17.9 (64.3)	17.4 (63.3)	12.3 (54.2)	6.4 (43.6)
Mean monthly temperature, 1997	3.5 (38.3)	11.0 (51.8)	13.8 (56.8)	15.9 (60.6)	16.7 (62.0)	13.1 (55.5)	5.4 (41.7)
Mean monthly temperature, 1998	6.1 (42.9)	10.8 (51.5)	11.9 (53.4)	18.9 (66.0)	17.1 (62.7)	- -	- -
Mean monthly precipitation, 1963-1998	25.4 (1.0)	45.7 (1.8)	50.8 (2.0)	30.5 (1.2)	33.0 (1.3)	30.5 (1.2)	20.3 (0.8)
Mean monthly precipitation, 1997	10.2 (0.4)	55.9 (2.2)	63.5 (2.5)	43.2 (1.7)	5.1 (0.2)	20.3 (0.8)	17.8 (0.7)
Mean monthly precipitation, 1998	7.6 (0.3)	58.4 (2.3)	71.1 (2.8)	48.3 (1.9)	7.6 (0.3)	- -	- -

(4,736 ft) and the river drains a 1,481 square km (572 square mi) catchment above this point. For the period of record, the river has a mean flow of 4.07 cms (144 cfs) and a total annual discharge of nearly 130,000,000 cubic meters (104,700 acre-feet), most of which comes as spring snowmelt. Water year 1997 discharge was the wettest in the ten-year record, with the MDD and total discharge at 200% of the nine-year average; water year 1998 was not as wet, but was still well above the period of record average (Table 2).

Table 2. Mean daily discharge and total annual discharge for the Clark Fork River near Galen, Montana (USGS Station 1232800).

	Mean Daily Discharge, cms (cfs)		Total Annual Discharge, m^3 (acre-feet)	
1988-1998	4.07	(144)	129,157,920	(104,700)
1997	8.15	(288)	257,203,800	(208,600)
1998	5.12	(181)	161,724,960	(131,100)

Grazing and Wildlife Utilization. Study sites have been grazed (as described below) by cattle, horses, and sheep. *Alces alces* (moose), *Odocoileus virginianus* (white-tailed deer), *Cervus elaphus* (elk), and *Castor canadensis* (beaver) are also present on the study sites.

Description of Study Reaches. Prior to treatment, each reach consisted of near vertical banks that were approximately 1 m (3 ft) in height above the baseflow water level (i.e. the average annual lowest water level) and actively eroding. Banks were not randomly selected. Potential treatment areas were identified based on willingness of landowners to participate in the Riverbank Stabilization Pilot Study and allow access to the riverbanks; accessibility by construction equipment; and approval by federal agencies, state agencies, and Atlantic Richfield Company. As such, the treatment reaches in this study may not be representative of all the Upper Clark Fork River riverbanks and more likely represent a group of banks experiencing greater than average rates of erosion. Furthermore, the placement of treatments required some subjectivity, as RWRP attempted to both design a pilot study and place the treatments where it was believed that they would work based on expected erosion rates, channel dimensions, and existing site conditions (Clayton and others 1998).

Channel and riparian area features referred to in this study are bankfull, floodplain, terrace, and toe of slope. A floodplain is the portion of the bank which is inundated with overbank flow on average once every 1.5-2.0 years (Leopold and others 1964, Dunne and Leopold 1978, Rosgen 1996). Bankfull is the stage (elevation) in the channel which corresponds with the 1.5-2.0 year flow (Leopold and others 1964, Dunne and Leopold 1978, Rosgen 1996). Terraces are high banks which experience overbank flow less frequently than once every two years (Leopold and others 1964, Dunne and Leopold 1978, Rosgen 1996). The majority of banks in this study are terraces. The toe of the slope of a riverbank is the base of the slope, or the point at which the channel bottom turns upward to form the bank. A description of each study reach, from upstream to downstream, follows.

FW02: This reach is located on the left bank upstream of the confluence of Racetrack Creek and the Clark Fork River (left and right bank specifications are based on the perspective of an observer facing downstream). The landowner had tried to reduce bank erosion by placing gravel along the bank and transplanting mature *Betula occidentalis* (water birch). The rock appeared to slow erosion temporarily, but the *Betula occidentalis* (water birch) did not survive transplanting. Crews placed log barbs and angled *Salix* spp. cuttings covered with erosion control fabric in October 1996. The mean width and depth of the river through the treatment area is 35.5 m (116 ft) and 0.67 m (2.20 ft), respectively.

FW04: This reach is located on the left bank downstream of the confluence of Racetrack Creek and the Clark Fork River. Ice floes during the 1996 winter caused significant bank erosion. Ten years ago, the landowners had installed a riparian exclosure at this site. When the fence was installed, they also planted *Salix* spp. stakes approximately 1 m (3 ft) long. These cuttings did not survive, possibly because they were not long enough to reach the baseflow water level. Limited sheep and horse grazing has occurred since then in an attempt to control *Euphorbia esula* (leafy spurge) at the site. Some *Euphorbia esula* (leafy spurge) is still present. The crews placed *Pseudotsuga menziesii* (Douglas-fir) revetments in October 1996 and augered in *Salix* spp. poles in March 1997. The mean width and depth of the river through the treatment area is 18.5 m (61 ft) and 1.09 m (3.58 ft), respectively.

<u>PRA1:</u> This reach is located on the right bank just upstream of the Sager Lane bridge. In 1990 mature *Salix* spp. and *Betula occidentalis* (water birch) were cleared from this bank when small berms were created to reduce surface erosion on the terrace caused by summer thunderstorms. The cleared brush was piled in a windrow (3 m [1 ft] tall and 5 m [15 ft] wide) along the bank. The windrow was placed on the bank to reduce erosion but had no effect because it was piled on the terrace and not the toe of the slope. This piled brush appeared to have been inhibiting the growth of riparian vegetation on the bank. The area has not been grazed recently except for occasional trespass cattle. The crew removed the windrow and placed sloped *Salix* spp. poles covered with erosion control fabric in March 1997. The mean width and depth of the river through the treatment area is 21.3 m (69.9 ft) and 0.85 m (2.79 ft), respectively.

<u>PRA2</u>: Located on the left bank just upstream of Sager Lane bridge, the meander has been manipulated at least once since the bridge was installed sometime between 1947 and 1960. Large berms were built, probably in an effort to force the river under the bridge. The river cut through the berms at it began to revert to the original meander pattern. An irrigation diversion is located between the lower end of the treatment reach and the bridge. This

bank has more mature shrubs on it than any other bank treated with structural protection. This area has not been grazed recently except for occasional trespass cattle. The crew placed *Juniperus scopulorum* (Rocky Mountain juniper) revetments against the bank and planted *Salix* spp. cuttings in March 1997. The mean width and depth of the river through the treatment area is 23.1 m (75.8 ft) and 0.79 m (2.59 ft), respectively.

PRB2: Located on the left bank downstream of the Sager Lane Bridge, this reach is a terrace bank in a wet meadow that is seasonally grazed by cattle. Crew transplanted mature shrubs and dibbled *Salix* spp. poles in March 1997. The mean width and depth of the river through the treatment area is 30.7 m (100.7 ft) and 0.67 m (2.20 ft), respectively.

PRB4: This reach is located on the right bank downstream of the Sager Lane Bridge and PRB2. In 1990 mature *Salix* spp. and water birch (*Betula occidentalis*) were cleared from this bank when small berms were created to reduce surface erosion on the terrace caused by summer thunderstorms. The cleared brush was piled in a windrow (2 m tall [6 ft] and 4 m [12 ft] wide) along the bank. The windrow was placed on the bank to stop erosion but had no effect because it was piled on the terrace and not the toe of the slope. This piled brush appears to have been inhibiting the growth of riparian vegetation on the bank. The area has been grazed by cattle. The crew removed the windrow and placed sloped *Salix* spp. poles covered with erosion control fabric in March 1997. The mean width and depth of the river through the treatment area is 28.9 m (94.8 ft) and 0.85 m (2.79 ft), respectively.

DT: This reach is located on the right bank approximately 3 km (2 mi) downstream of the confluence of Gold Creek and the Upper Clark Fork River. As a result of ice and high flows in 1996, the landowner had lost sections of riverbank as wide as 3 m (9 ft) in one year. This site is affected by over 13 km (8 mi) of upstream channelization of the river by Interstate 90 and the railroad. The channel substrate is more coarse and the gradient is steeper than the other treatment areas. The treatment reach is the riverbank of a hay field and winter cattle pasture. The crews installed rock barbs and transplanted mature shrubs in October 1996 and placed *Salix* spp. poles covered by coir fabric in April 1997 where the barbs are keyed into the bank. The mean width and depth of the river through the treatment area is 31.9 m (104.6 ft) and 0.91 m (2.98 ft), respectively.

WL: This reach is located on the right bank approximately 10 km (6 mi) downstream of the confluence of Gold Creek and the Upper Clark Fork River. The banks at this reach have been grazed by cattle. Some seasonal grazing still occurs. After observing high rates of lateral channel migration approximately 15 years ago, the landowners buried large rock into the upper terrace about 35 m (115 ft) from the then-cutting bank in anticipation of continued erosion. The rock was placed this distance from the channel so as to avoid complicated permitting for channel alteration projects. The river cut into that rock several years ago, and continued to erode the banks. The substrate is coarse gravels. Approximately 122 m (400 ft) of vertical, 1 - 4 m (3 - 12 ft) high banks were re-sloped and covered with erosion control fabric. Over 1,200 one-gallon container shrubs were then planted into the bank. The mean width and depth of the river through the treatment area is 41 m (134.5 ft) and 0.80 m (2.62 ft), respectively.

METHODS AND MATERIALS

In the fall of 1996 and the spring of 1997, three sites were planted with vertical *Salix* spp. cuttings (FW04, PRA2, PRB2), three sites with angled *Salix* spp. cuttings (FW02, PRA1, PRB4), two sites with mature transplants (PRB2 and DT), and one site with container plants (WL). These sites and planting methods are described in detail below. Livestock exclosure fences were installed at all sites after planting to prevent trampling and grazing damage to plants.

Description of Terms

Four types of planting methods were employed in this study: 1) angled and 2) vertical *Salix* spp. cuttings, 3) one-gallon container plants, and 4) mature shrub transplants. An angled *Salix* spp. cutting is a 2 to 3 m (6 to 10 ft), single-stem cutting of a mature *Salix* spp. plant, laid against a re-sloped bank and then covered with soil and coir fabric. A vertical *Salix* spp. cutting is an 2 to 3 m (6 to 10 ft), single-stem cutting of a mature *Salix* spp. plant, planted into a hole in the upper bank and backfilled with soil. A one-gallon container plant is a nursery grown, rooted shrub. Mature transplant shrubs were gathered from source areas nearby each planting site. Shrubs were generally 1 - 1.5 m (3 to 4.5 ft) in diameter at the base and 2 to 3 m (6 to 10 ft) tall.

Each planting treatment had a corresponding temporary structural treatment designed for temporary bank protection. Those treatments include log and rock barbs, and conifer revetments. A log barb is a log approximately 12 m (40 ft) long and 0.5 m (18 in) in diameter. The bottom 3 m (10 ft) of the log is buried into the bank with the upper end angled upstream approximately 30°. The tip of the log is buried in the channel bottom (with an angle of approximately 15°), and it is designed to deflect waterflow away from the outside bank and create slow water areas near the edge of the outside bank (Figure 2).

A rock barb is similar to the log barb, but constructed with large (B-axis diameter of approximately 0.5 m [20 in]) rock (Figure 3). A conifer revetment is the arrangement of 2 to 3 m (6 to 10 ft) conical *Juniperus scopulorum* (Rocky Mountain juniper) and *Pseudotsuga menziesii* (Douglas-fir) trees along the face of a bank. The trees are placed upside-down and angled downstream, with adjacent trees overlapping each other by one-half their width. The revetments are anchored with smooth wire to sunken steel fenceposts in the upper bank (Figure 4). Objectives of the revetments are to reduce the erosive force of the river water and to cushion the banks from the impact of winter ice floes.

Collection of Vegetation Data

Seven species of *Salix* are native to the Upper Clark Fork River system: *Salix bebbiana* (Bebbs willow); *Salix boothii* (Booth willow); *Salix drummondi* (Drummond willow); *Salix exigua* (sandbar willow); *Salix geyeriana* (Geyer willow); *Salix lasiandra* (Pacific willow); and *Salix lutea* (yellow willow)

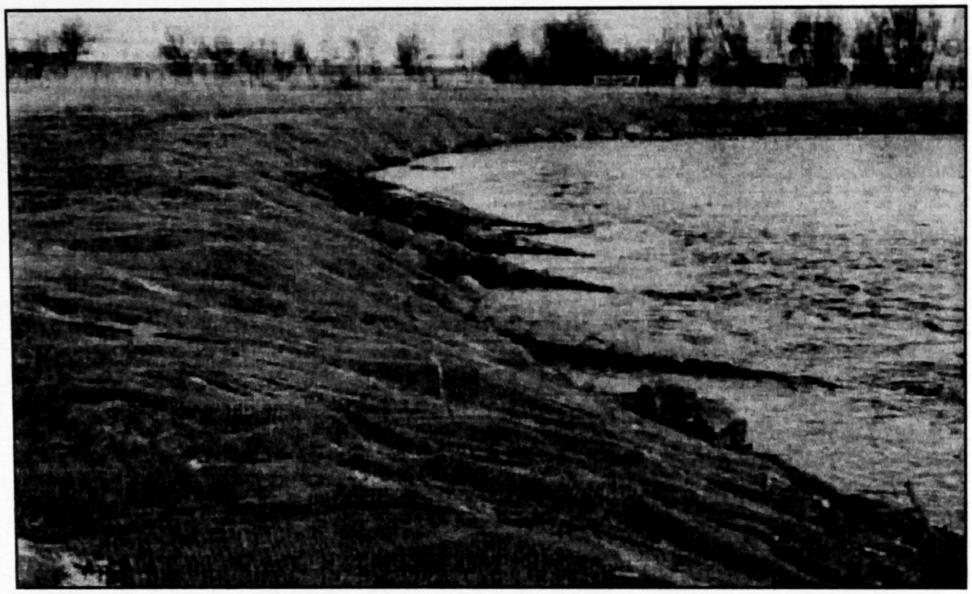


Figure 2. Placement of log barbs to deflect the erosive force of the current away from the bank and toward the center of the channel.

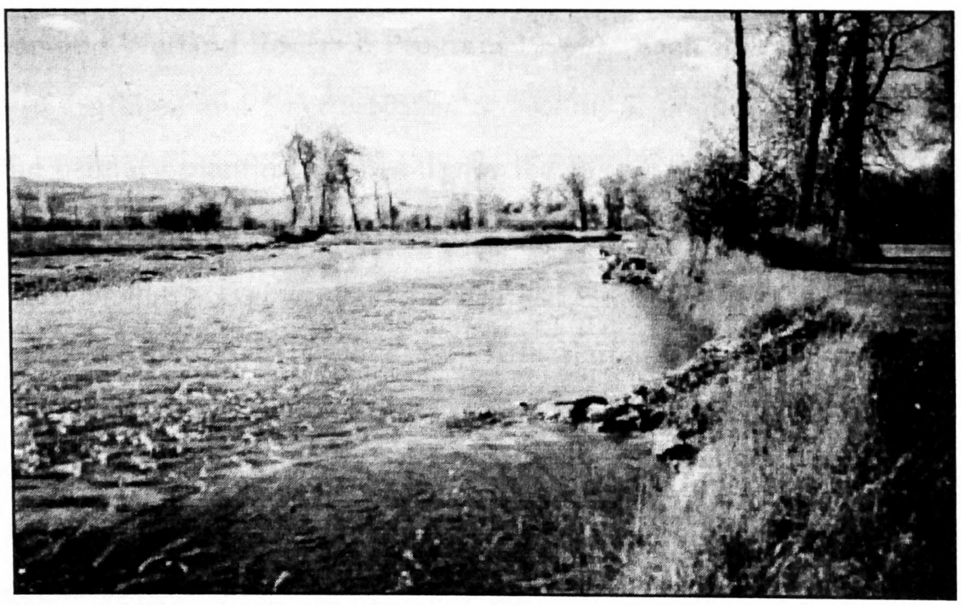


Figure 3. Placement of rock barb in stream channel to deflect force of current away from the bank and toward the center of the channel.

Figure 4. Placement of *Juniperus scopulorum* (Rocky Mountain juniper) revetments along the outer edge of a vertical bank. The revetments are designed to reduce the erosive force of the current and to minimize the impact of winter ice floes.

(Riparian and Wetland Research Program 1996b). Each species was a potential source of cuttings, and *Salix bebbiana, S. boothii, S. exigua,* and *S. geyeriana* were the primary planting species under the Riverbank Stabilization Pilot Study, though small numbers of *S. lutea* and *S. lasiandra* were also planted. *Salix bebbiana and S. boothii* are the two most common *Salix* species along the Upper Clark Fork River floodplain (Riparian and Wetland Research Program 1996b). In addition to *Salix* spp. cuttings, the revegetation component of the pilot study employed mature *Salix* spp. transplants and container plantings, including all of the above *Salix* spp. plus *Alnus incana* (thin-leaved alder), *Rosa woodsii* (Woods rose), *Cornus stolonifera* (red-osier dogwood), and *Betula occidentalis* (water birch).

The planting methods described below are grouped into three categories: 1) *Salix* cuttings, 2) mature transplants, and 3) one-gallon container plants.

***Salix* cuttings**—Methods for gathering cuttings for the vertical and angled methods are identical, but plant placement and measurement vary. All cuttings were gathered from areas as close to the planting site as possible, and most were gathered within 0.4 km (0.25 mi). To preserve the health of the source plant, no more than one-third of the stems of any individual source plant was cut for transplanting (Hoag 1993). Cuttings species were selected based on availability, and preference was given for cuttings with a butt-end diameter of 2.5 - 4 cm (1 - 1.5 in), based on previous studies (Hoag 1991, Hoag 1993, Watson and others 1997). All side branches and leaves were removed from the cuttings, leaving a single stem approximately 3 m (10 ft) long. Tips were dipped in sealant (1:1 black latex paint:water in the fall and TreeKote™ brand in the spring) to prevent excessive water loss, insect invasion, and to mark the top end for planting (Hoag 1991, Hoag 1993, Watson and others 1997). Cuttings were stored with the butt in the river until planting, which took place within several hours of the time of cutting (Hoag 1991, Hoag 1993, Watson and others 1997). Many cuttings were planted within minutes of being cut.

Vertical cuttings. Three sites were planted with vertical cuttings: FW04, PRA2, and PRB2. Cuttings planted vertically into the upper bank were inserted into both power-augered (approximately 10 cm [4 in] diameter) and dibbled (approximately 8 cm diameter [3 in]) holes. The dibble is a straight 2 m (6 ft) long metal rod attached to the front-end of a small front-end loader

(Bobcat®). The dibble is driven into the ground to create a planting hole. Holes were located in three rows arranged in a 1 m (3 ft) spacing off the center row. Holes were then backfilled either with site soil or clean off-site sand. The distance the row closest to the stream channel was set back from the edge of the bank depended upon channel conditions at that point and predicted erosion rate, but was usually 1 m (3 ft) and was never more than 2 m (6 ft).

At sites with vertical cuttings, random individual cuttings totaling 20 percent of the total number of planted cuttings at that site were sampled. Every cutting at each site was assigned a number corresponding to its location on the bank. A random number generator was used to determine the individual sample cuttings. A representative photograph of this planting method is presented in Figure 5.

Figure 5. The vertical Salix spp. cutting planting method. Cuttings extend approximately 30 cm (1 ft) above the bank surface.

Angled cuttings. Three sites were planted with angled cuttings: FW02, PRA1, and PRB4. Treatment areas with angled cuttings consisted of vertical banks that were sloped back to a 2:1 or 3:1 slope with the bucket of a track-mounted excavator. Cuttings, approximately 2 to 3 m (6 to 10 ft) in length and 2 to 4 cm (1 to 1.5 in) in diameter, were placed against the bank every 0.3 m (1 ft) with the butt end in the channel to the depth of the expected base-flow water level. Base-flow water level was determined by researching U.S. Geological Survey historic flow data. Cuttings were covered with approximately 2.5 to 5 cm (1 to 2 in) of site soil along their entire length. The bank was then covered with coconut fiber erosion control fabric, which was secured to the slope with rebar staples. The fabric is designed to help maintain bank integrity for 5-8 years so plantings have time to establish. This planting method is depicted in Figures 6 and 7.

Because the exact number and location of cuttings planted under soil and coir fabric was not recorded during installation and could not be determined without significant disturbance, construction specifications (instructing crews to place cuttings at 0.3 m [1 ft] spacing) were assumed to have been followed exactly; construction monitoring and supervision verified specification implementation. However, because cuttings were probably not spaced at exact 0.3 m (1 ft) intervals, the total length of each bank with this treatment has been divided into sampling sections. Randomly located sections were sampled, within which all found cuttings were measured. It was assumed that there are 25 cuttings within each sampling section; all cuttings located were counted and those that produced new shoots or were green when scratched with the thumbnail were flagged, numbered, and counted as alive.

Figure 6. Placement of angled *Salix* spp. cuttings along a re-sloped bank. Cuttings are approximately 3 m (10 ft) long and spaced at 30 cm (1 ft).

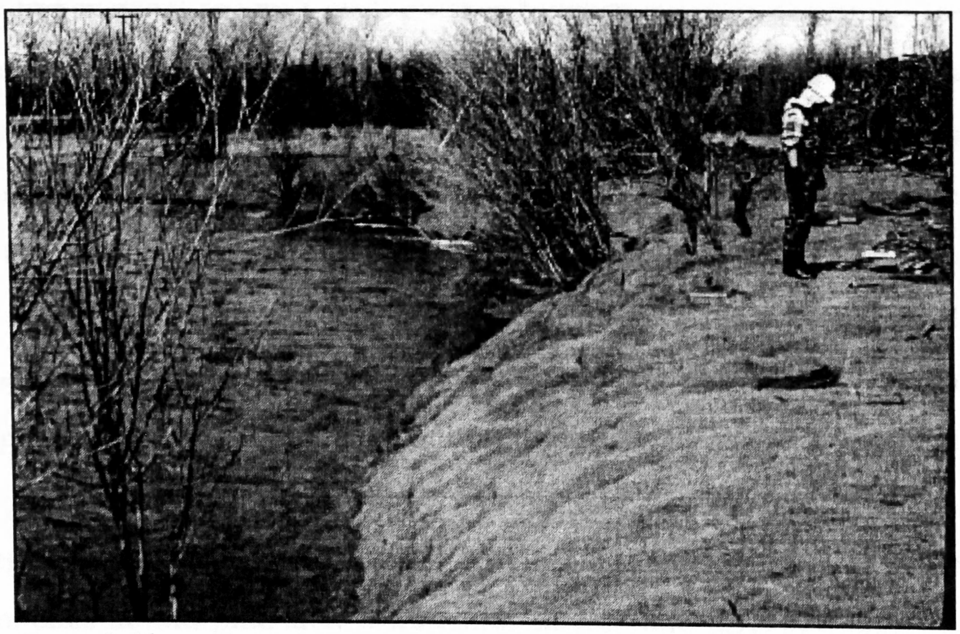


Figure 7. The angled *Salix* spp. cutting treatment covered with soil and erosion control fabric.

All located dead cuttings were flagged numbered, and counted as dead, and cuttings not located were counted as such. At the end of the two field seasons, unlocated cuttings still not found or without shoots were counted as dead. Twenty percent of the number of sample sections at each site were measured.

Measurement methods for both vertical and angled plantings. Four measurements were recorded on each measurement date for each located cutting: 1) survival, 2) total number of shoots (TNS), 3) total shoot length (TSL), and 4) longest shoot length (LSL). Also recorded were species, condition (from a five-category condition scale), and whether the cutting had been damaged by beaver, livestock or deer, and/or insects.

A living cutting is one that either produced new growth or was green when scratched with the thumbnail. The number of cuttings lost to erosion was noted, and survival analysis distinguishes between cuttings physically lost to erosion and cuttings that died on-site. TNS is the count of all shoots on a cutting. TSL is the sum of lengths of all live shoots coming off main stem of a cutting, from cutting to shoot tip. Or, if a shoot emerged from a portion of the cutting below ground, TSL is the length from ground level to shoot tip. LSL is the length of longest live shoot coming off main stem of cutting, from cutting to shoot tip. Or, if the longest shoot emerged from a portion of the cutting below ground, LSL is length from ground level to shoot tip.

All vegetation samples were measured three times during the 1997 growing season: once in mid-June after leafing out, once in mid-July, and once in late

August to early September before leaves dropped. A survival count was conducted in June 1998 to determine overwintering and post-runoff survival.

Mature transplants—Mature transplants were planted into the upper bank at two sites (PRB2 and DT). All shrubs were obtained from areas as close to the planting site as possible, and none were obtained further than 0.4 km (0.25 mi) away. Preference was given for shrubs that appeared to be healthy (i.e. vigorous leaf and shoot growth and no apparent diseases). Shrubs were collected when dormant during the late fall and early spring and were planted the same day. A track-mounted excavator (Komatsu PC200LC) with a thumb attachment was used at one site (DT) to collect and transplant shrubs in the fall of 1996, and a four-blade tree spade (Vermeer 50M) mounted on an articulated front-end loader (Cat 950) was used on a second site (PRB2) in the spring of 1997. Shrubs were watered after transplant. A survival count was conducted in early June 1998 to determine overwintering and post-runoff survival. A representative photograph of this planting method is presented in Figure 8.

One gallon container stock—One site (WL) was planted with container stock. Container stock was obtained from Bitterroot Native Growers of Corvallis, Montana. Stock of all species used was germinated in a greenhouse from seed collected in the upper Clark Fork River Valley. Shrubs were planted by hand with shovels where the bank had been sloped back to a 2:1 slope and covered with coconut fiber erosion control fabric. The fabric was cut by hand to expose each planting site. Location of species on the sloped bank was determined based on existing knowledge of environmental tolerances and optimums for

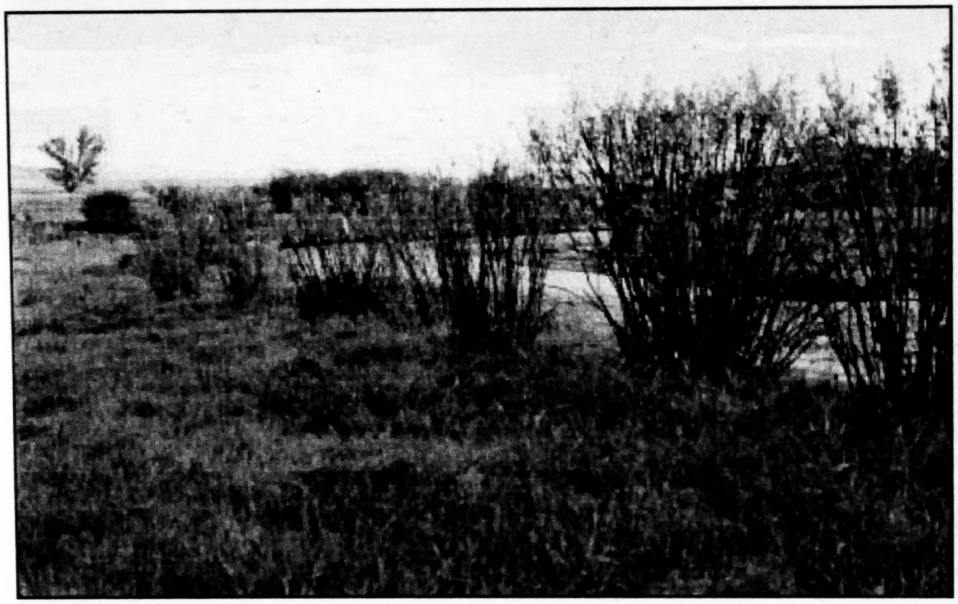


Figure 8. Placement of mature *Salix* spp. transplants. Transplants are approximately 2 to 2.5 m (6 to 8 ft) tall.

each, particularly in relation to proximity to the water table. For example,*Salix exigua* (sandbar willow) was planted low on the bank and nearest to the baseflow water level, while *Alnus incana* (thin-leaf alder) and *Rosa woodsii* (Woods rose) were planted higher up the bank. A survival count was conducted in June 1998 to determine overwintering and post-runoff survival. A representative photograph of this planting method is presented in Figure 9.

Collection of Hydrology Data

Records of the height of the water table throughout the growing season are important, as water availability strongly influences the survival and establishment of plants (Watson and others 1997). Personal observations in the field in 1996 indicated that *Salix* spp. cuttings that did grow roots only did so above the lowest water table elevation of the growing season, i.e. the

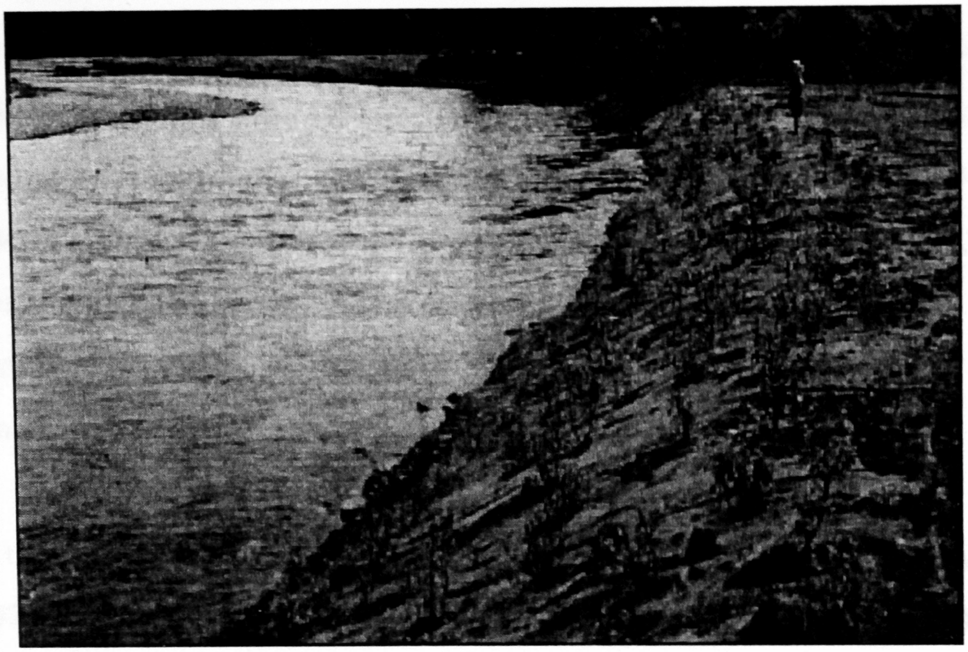


Figure 9. Arrangement of one-gallon container shrubs planted through erosion control fabric on a re-sloped bank.

cuttings did not grow roots below the water table. These observations are similar to the results of Shields and others (1998). As such, water level measurements were taken on a weekly basis during the 1997 growing season (May through September) to determine the depth from the upper bank to the lowest water table. This information was used to develop the soil sampling protocol described below.

Due to the close proximity of treatments to the channel (at all sites, distance from channel of outside edge of treatment <4.5 m [15 ft]), the in-channel water height was used to extrapolate water table height at planting sites. For this study, it was assumed that the in-channel water level is a reasonable and reliable estimate of near-channel in-bank water level (Hansen pers. comm. 1997). Measurements of in-channel water height and water table taken in spring 1997 (as measured in augered holes, excavated holes and natural depressions) were within 2 mm (0.08 in) of each other. The weekly in-channel water level measurements were taken to a 0.25 mm (0.01 in) resolution by using a infrared laser level (David White Autolaser 350) and telescoping rod with infrared receiver. Each site has several permanent cross-section monuments in place, the height of which was also taken weekly. Weekly water level measurements were standardized by relating measurements to the static height of the permanent cross-section monuments.

For those reaches where soil cores were taken (FW02, FW04, PRA1, PRA2, PRB2, PRB4), the height of the in-channel water level throughout the 1997 growing season was recorded and is included in Appendix A.

Collection of Soils Data

Soil pH was used to characterize planting site soils because of the influence of pH levels on plant survival and growth, and the high correlation of pH with total soluble copper and available metals levels (Larcher 1983). Previous work along the Upper Clark Fork River has shown pH to be directly related to soil copper concentrations (Nimick and Moore 1991). At pH values below 6.0, pH is highly correlated with concentration of Cu^{++}, Cd, Zn, and As, with available metals declining sharply at higher pH values (Larcher 1983). Soil pH is easily measured in the field with relatively low-cost, making it a useful tool for landowners and land managers on the Upper Clark Fork River.

Sampling was at 15 cm (6 in) and 45 cm (18 in). Fifteen cm (6 in) was chosen becuase most nutrient uptake in plants and most "feeder" roots occur within the top 15 cm (6 in) of the soil profile (DeLuca 1998 pers. comm.). Forty-five cm (18 in) was sampled to determine if there is an influence of soil conditions and mine tailings present at depths below 15 cm (6 in) and above the lowest elevation of the water table (*Salix* spp. cuttings were observed on the Clark Fork River and in another study [Shields and others 1998] to not grow roots below the lowest elevation of the water table, i.e. saturated conditions). The 45 cm (18 in) sampling depth was chosen after determination of maximum depth to the lowest elevation of the water table at all treatment reaches during the 1997 growing season.

To compare plant growth and soil pH for all cuttings, soil cores were taken within 20 cm (8 in) of every *Salix* spp. cutting for which growth measurements were recorded. Samples were taken only at cuttings that are on-site and that have a known location, i.e., soils were not sampled at known former locations of cuttings that had washed away, nor were cores taken at assumed intervals of unlocated angled cuttings.

Soil cores (4 cm [1.5 in] long and 2.5 cm [1 in] diameter) were taken with a steel soil probe with the midpoint of the sample at the 15 (6 in) and 45 cm (18 in) depth. Some samples could not be collected where extremely coarse substrate precluded penetration of the soil probe. Samples were placed in Ziploc™ freezer bags and tested for pH the same day. An equal weight of distilled, de-ionized water was added to the soil sample in a 50 ml Pyrex™ beaker, and stirred manually with a stainless steel rod for approximately one minute. Soil pH was recorded using an electronic pH meter (Cole-Parmer Model 59002-00) that was calibrated every 10-15 measurements with stock solutions.

Variables Measured

Independent variables measured include: plant species; planting methods (i.e. vertical planting into the upper terrace, angled planting against a re-sloped bank, one-gallon container plants, and mature transplants); soil pH; and height of in-channel water surface elevation. Dependent variables measured include: survival of *Salix* spp. cuttings, container plants, and mature transplants; and total number of shoots (TNS), total shoot length (TSL); and longest shoot length (LSL) for all *Salix* spp. cuttings.

Statistical Analysis and Rejection Rules

Critical values for rejection rules of Hypotheses 1 and 2 are based on categorization by Fowler and Cohen (1990) (Table 3). For these two hypotheses, the chosen critical values are based on an attempt to determine whether or not a "strong correlation" exists between independent and dependent variables. The chi-square test for Hypothesis 3 was conducted at the 0.025 alpha level, for reasons identified below.

Hypothesis 1: Soil pH does not have an influence on *Salix* spp. cutting survival—Survival data was plotted against soil pH and analyzed by a logistic regression. A critical R^2 value of 0.70 was used to indicate a strong relationship between variables (Fowler and Cohen 1990). I rejected H_o1 if the logistic regression between soil pH and *Salix* spp. cutting survival yields an R^2 value greater than 0.70.

Hypothesis 2: Soil pH does not have an influence on *Salix* spp. cutting growth—Natural log-transformed growth measurements of all alive cuttings (both angled and vertical plantings) from August 1997 were plotted against soil pH at both the 15 cm (6 in) and 45 cm (18 in) sampling depth. Growth data was log-transformed; pH data was normally distributed as collected. A simple correlation coefficient (r) was calculated for each combination of three growth measurements (TLS, LSL, TNS) and two soil sampling depths. A critical value of 0.70 was used to test for a strong correlation (Fowler and Cohen 1990). I rejected H_o2 if the absolute value of the calculated simple correlation coefficient for soil pH vs. *Salix* spp. cutting growth exceeded 0.70.

Hypothesis 3: Planting method (angled cutting or vertical cutting) does not influence survival—Counts of alive and dead cuttings, mature transplants, and one-gallon containers were analyzed against planting method using chi-square tests. Four chi-square tests were used on various combinations of the same survival data set, so a Bonferroni adjustment was applied by dividing the selected alpha level (0.10) by the number of tests conducted (4). The result is an alpha level of 0.025. I rejected H_o3 if the chi-square tests yield a chi-square value less than what would be expected due to chance at a exceedence probability of 0.025.

RESULTS

Soil pH

Soil pH values at both 15 cm (6 in) and 45 cm (18 in) were normally distributed (Figure 10). Fewer samples were collected at 45 cm (18 in) than at 15 cm (6 in) (52 and 104, respectively) because coarse soils at depth sometimes precluded penetration of the soil core. The 15 cm (6 in) data had a maximum value of 8.28, a minimum of 3.85, and a mean of 6.69. The 45 cm (18 in) data had a maximum value of 7.79, a minimum of 3.55, and a mean of 6.68. It is important to note that at both the 15 cm (6 in) and 45 cm (18 in) sampling depths, the great majority of pH values (86 of 104 samples [83%] and 47 of 52 samples [90%], respectively) were above 6.0.

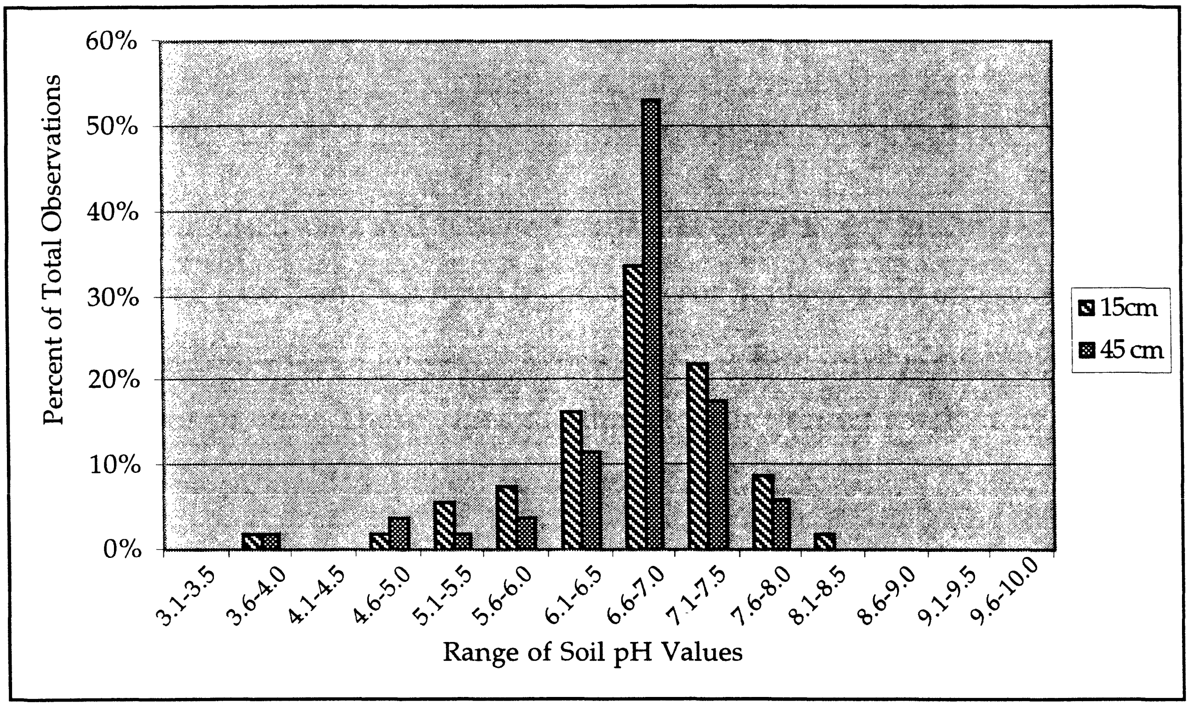


Figure 10. Soil pH histogram for the 15 cm (6 in) and 45 cm (18 in) sampling depths. Upper Clark Fork River, Montana.

Plant Survival

Survival was calculated as the number of plants surviving divided by total number of plants alive, dead or unlocated; that is, plants lost to bank erosion were not included. Survival percentages varied: angled cuttings = 9.35%, vertical cuttings = 36.52%, one-gallon containers = 96.49%, and mature transplants = 92.39% (Figure 11).

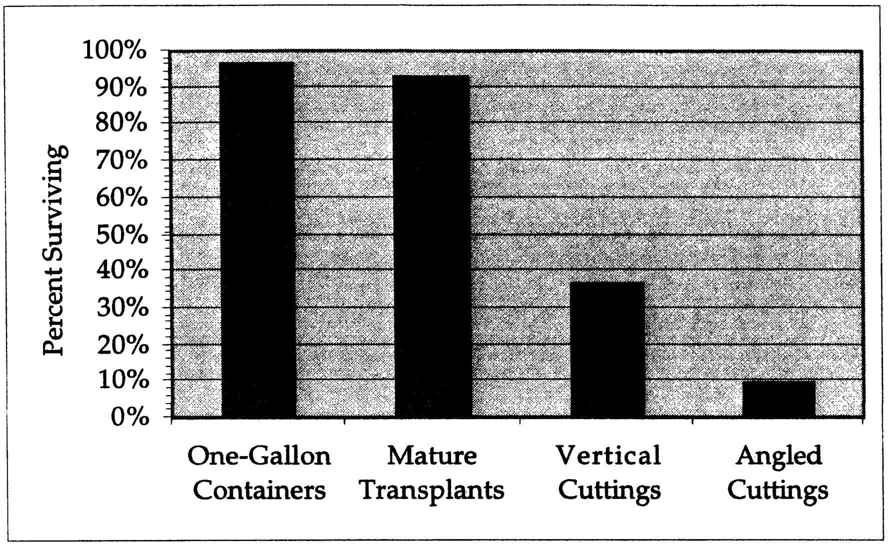


Figure 11. Second-year survival percentages for all planting methods.

Cattle entered two sites and browsed shoots from cuttings. Entry was made possible by a gate being left open by an adjacent landowner in one case, and by the fencing contractor's failure to install a gate before cattle were moved into the adjacent pasture. These types of administrative errors resulted in some cuttings being trampled and many shoots being eaten.

Hypothesis 1: Relationship of Soil pH to *Salix* spp. Cutting Survival

The logistic regression of soil pH at 15 cm (6 in) and 45 cm (18 in) versus *Salix* spp. cutting survival yielded R^2 values of 0.003 and 0.007, respectively (Figures 12 and 13). Because the logistic regression yielded R^2 values below the critical rejection value of 0.70, I fail to reject H_01 and conclude that there is no evidence of a correlation between soil pH and *Salix* spp. cutting survival within the range of pH values measured at these sites.

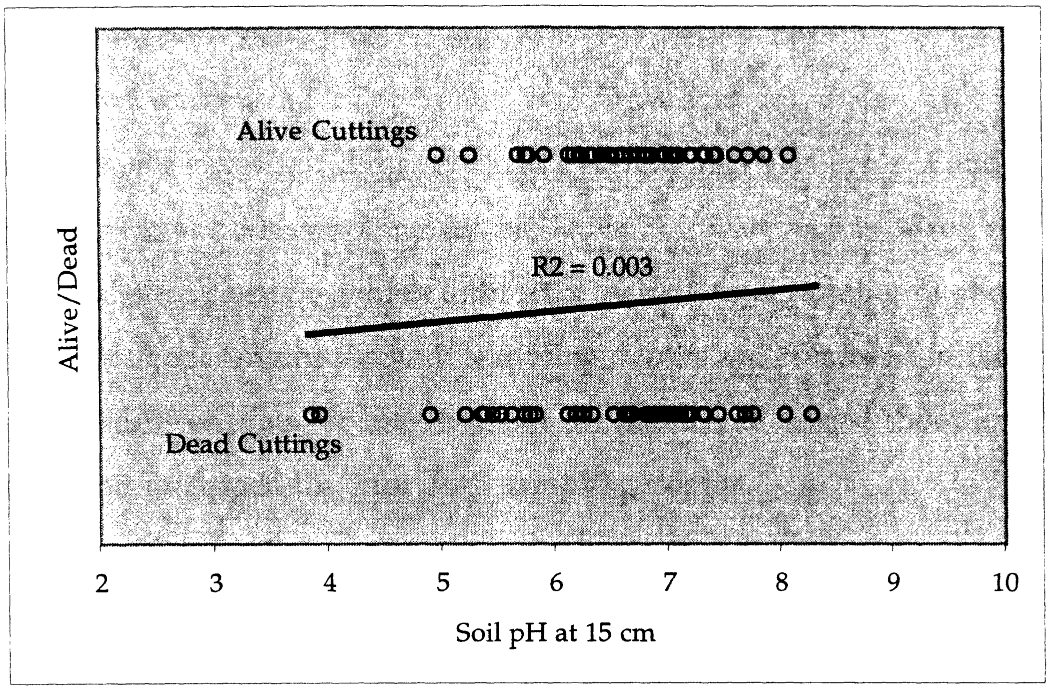


Figure 12. Logistic regression plot of *Salix* cutting survival versus soil pH at the 15 cm sampling depth.

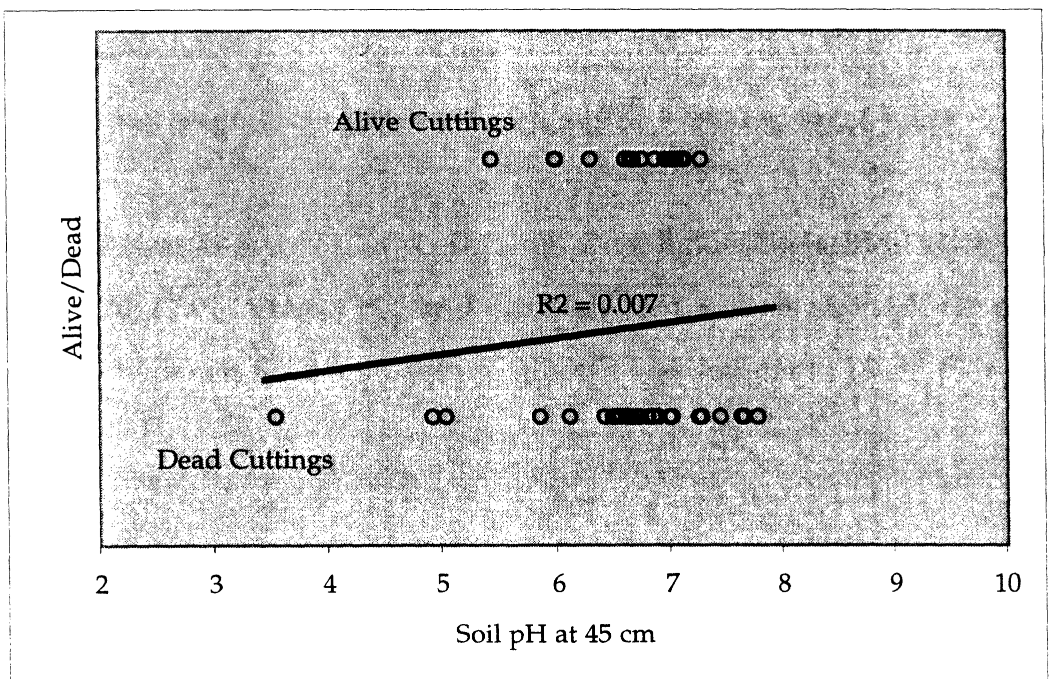


Figure 13. Logistic regression plot of *Salix* cutting survival versus soil pH at the 45 cm sampling depth.

Hypothesis 2: Relationship of Soil pH to *Salix* spp. Cutting Growth

Simple correlation coefficients (r values) were used to characterize the relationship between the independent and dependent variables. All r values were extremely low, indicating very weak correlations between pH and cutting growth at both sampling depths (Table 3). Scatter plots of soil pH versus total shoot length (which indirectly include total number of shoots and longest shoot length) for both sampling depths are presented in Figures 14 and 15. Scatter plots for total number of shoots and longest shoot length are included in Appendix B for both sampling depths.

Table 3. Simple correlation coefficients between soil pH at two sampling depths and August 1997 growth measurements of *Salix* cuttings planted on the Upper Clark Fork River, Montana.

Soil Sampling Depth	Growth Measurements		
	TSL*	LSL*	TNS*
15 cm (6 in) (n=104)	0.006	0.064	0.100
45 cm (18 in) (n=52)	0.020	0.242	0.002

*TSL = total shoot length, LSL = longest shoot length, TNS = total number of shoots

Because all simple correlation coefficients were below the critical rejection value of 0.70, I fail to reject H_o2 and conclude that there is no evidence of a correlation between *Salix* spp. cutting growth and soil pH at 15 cm (6 in) or 45 cm (18 in).

Hypothesis 3: Relationship of Planting Method to Vegetation Survival

Chi-square analysis was used to test the hypothesis that second-year plant survival proportions would differ by planting method. In order to thoroughly test this hypothesis, four analyses were conducted to test survival

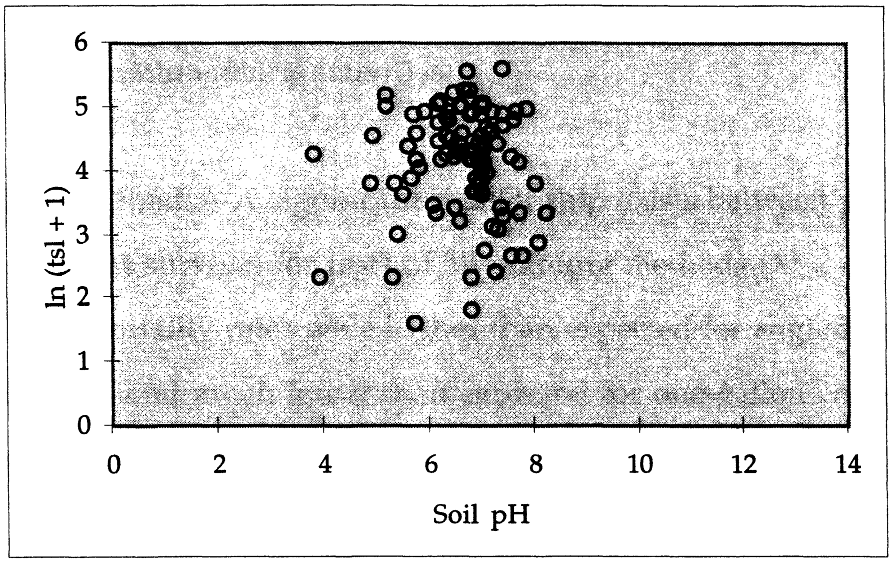


Figure 14. Scatter plot of soil pH at 15 cm (6 in) versus *Salix* cutting growth as measured by total shoot length (n=104).

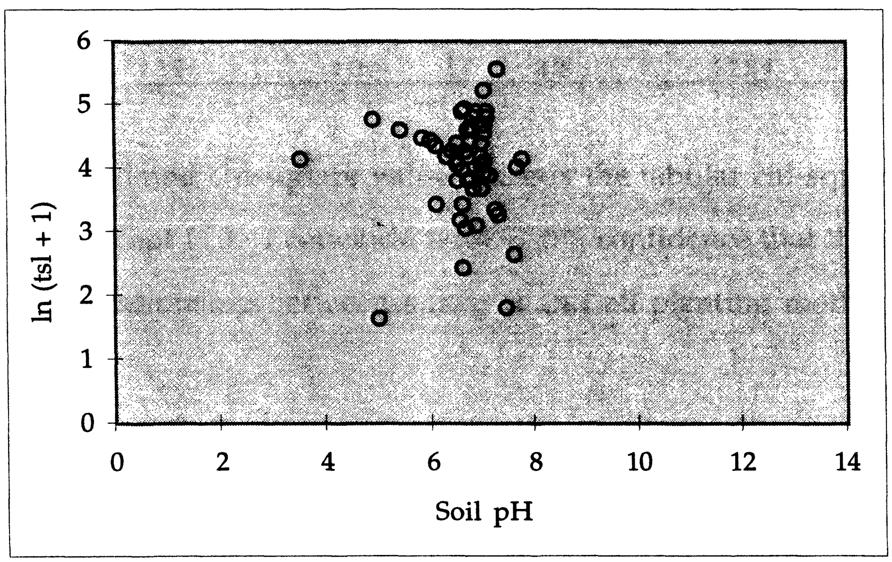


Figure 15. Scatter plot of soil pH at 45 cm (6 in) versus *Salix* cutting growth as measured by total shoot length (n=52).

of: (1) all planting methods; (2) angled cuttings versus vertical cuttings; (3) mature transplants versus one-gallon container stock; and (4) all cuttings versus all rooted plants. All analyses were conducted at the 0.025 alpha level.

Data analyzed excluded plants that were washed away or lost due to construction or maintenance activities.

All Planting Methods—A significant relationship exists between planting method and plant survival for tests of all planting methods ($X^2_{calc} = 926.59$; $X^2_{3,0.025} = 9.35$). Mortality rates were higher than expected for angled and vertical cuttings, and much lower than expected for one-gallon container plants (Table 4, see also Figure 11).

Table 4. Observed survival numbers for all planting methods. Chi-square values are in parentheses.

	Vertical Cuttings	Angled Cuttings	Mature Transplants	One-Gallon Containers	Total
Alive	13 (93.16)	42 (27.42)	85 (0.64)	1210 (20.61)	1350
Dead	126 (515.42)	67 (151.73)	7 (3.56)	44 (114.04)	244
Total	139	109	92	1254	1594

Because the calculated chi-square value exceeds the tabular chi-square value, I reject H_o3 and accept H_a3. I conclude with 97.5% confidence that there is evidence of a relationship between survival and all planting methods.

Angled vs. Vertical *Salix* Cuttings—A significant relationship exists between survival and planting method for the two planting methods of *Salix* spp. cuttings, angled and vertical ($X^2_{calc} = 14.36$; $X^2_{1,0.025} = 5.02$) (Table 5). Vertical cuttings experienced higher survival rates than angled cuttings (36.52% and 9.35%, respectively).

Because the calculated chi-square value exceeds the tabular chi-square value, I reject H_o3 and accept H_a3. I conclude with 97.5% confidence that there is evidence of a relationship between survival and planting method for angled and vertical *Salix* spp. cuttings.

Table 5. Observed survival numbers for vertical and angled cuttings. Chi-square values are in parentheses.

	Vertical Cuttings	Angled Cuttings	Total
Alive	86 (2.43)	64 (5.13)	150
Dead	129 (2.19)	38 (4.61)	167
Total	215	102	317

Mature Transplants vs. One-gallon Containers—Mature transplants and one-gallon containers experiences similar survival rates (92.39% and 96.49%, respectively). I found a no evidence of a relationship between survival and planting method for mature transplants and one-gallon containers. The calculated chi-square value was less than would be expected by chance (X^2_{calc} = 3.95; $X^2_{1,0.025}$ = 5.02). Transplant mortality was slightly higher than expected (Table 6). Because the calculated chi-square value does not exceed the tabular chi-square value, I fail to reject H_o3 and conclude with 97.5% confidence that there is no evidence of a relationship between survival and planting method for mature transplants and one-gallon containers.

Table 6. Observed survival numbers for mature transplants and one-gallon container plants. Chi-square values are in parentheses.

	Mature Transplants	One-Gallon Containers	Total
Alive	85 (0.14)	1210 (0.01)	1295
Dead	7 (3.54)	44 (0.26)	51
Total	92	1254	1346

All Cuttings vs. All Rooted Stock—Survival percentages of all cuttings and all rooted plants were 21.65% and 96.21%, respectively (Figure 16). A

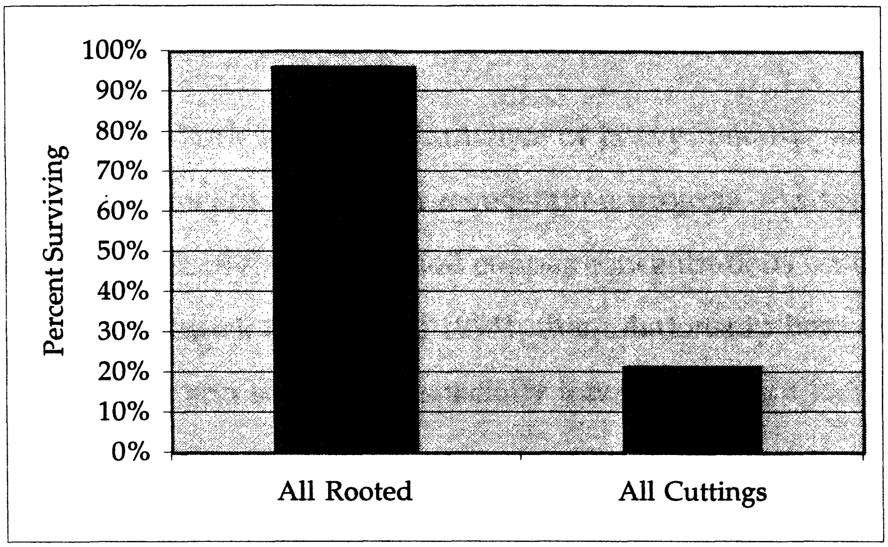


Figure 16. Survival percentages for all rooted plants (mature transplants and one-gallon container plants) and all cuttings (vertical and angled).

significant relationship exists between survival and planting method for the test comparing all cuttings against all rooted plants ($X^2_{calc} = 885.36$; $X^2_{1,0.025} = 5.02$). Cuttings experienced much higher mortality than expected based on overall survival proportions (Table 7).

Table 7. Observed survival numbers for all cuttings and all rooted stock. Chi-square values are in parentheses.

	Cuttings	Rooted Stock	Total
Alive	55 (114.44)	1295 (21.09)	1350
Dead	193 (633.17)	51 (116.66)	244
Total	248	1346	1594

Because the calculated chi-square value exceeds the tabular chi-square value, I reject H_o3 and accept H_a3. I conclude with 97.5% confidence that there is evidence of a relationship between survival and planting method for all *Salix* spp. cuttings and all rooted stock.

DISCUSSION AND IMPLICATIONS FOR MANAGEMENT

On the Upper Clark Fork River, the influence of heavy metals, particularly copper, is a major concern of riparian revegetation projects. As soil pH has been shown to be directly related to soil copper concentrations on the Upper Clark Fork River (Nimick and Moore 1991), this relationship between plant survival and growth and soil pH is especially interesting.

Soil pH and Soluble Copper (Cu^{++}) Concentrations

On-going work on the relationship between plant available copper (in the form of the cupric ion Cu^{++}, the most prevalent form of soluble copper in Upper Clark Fork River soils) and soil pH has yielded a regression equation demonstrating that plant available copper is highly correlated with low soil pH, but the correlation becomes weaker at pH values above 6.0 (Massey 1998, unpublished data). However, the scatter about the regression line at these relatively higher pH values is at concentrations so low as to be not considered a factor influencing plant survival or growth (DeLuca, pers. comm. 1998). Recall that the great majority of pH values (86 of 104 samples [83%] and 47 of 52 samples [90%], respectively) were above 6.0. Thus, on the one hand, the problem of an unreliable regression relationship at pH values above 6.0 renders it unusable in this study, and copper concentrations cannot be estimated. On the other, the fact that the great majority of samples had relatively high pH values implies that copper is present at concentrations so low as to not likely affect plant survival or growth (DeLuca pers. comm. 1998).

Soil pH and Salix spp. Cutting Survival and Growth

As demonstrated by very low correlation coefficients (Table 4), and by the results of the logistic regression, there is no evidence of a relationship between soil pH and *Salix* spp. cutting growth or survival, *at least at the pH values observed in this study*. The range of pH values encountered in this study, though quite narrow, is not unlike those found in riverbanks throughout the Upper Clark Fork River. Soil samples collected from the riverbanks of the Clark Fork River in 1997 by Schaffer and Associates of Bozeman, Montana, yielded a mean pH of 6.75, a minimum of 3.80, and a maximum of 9.90 (See Appendix C).

Chi-square analyses indicate that planting method has a significant influence on plant survival. Of the two planting methods for *Salix* spp. cuttings, those planted vertically into the upper bank fared better than cuttings angled against a re-sloped bank. Rooted stock had much higher survival rates than cuttings, and there was no significant difference in survival between mature transplants and one-gallon container stock. These results suggest, at least at the range of pH values observed in this study, that planting method is a more important factor than is soil pH.

Available literature on *Salix* spp. cutting survival reports extremely high first year survival (Chosa and Shetron 1976, Stewart and Berglund 1983, Hoag 1991, Svejcar and others 1991). Most do not report survival after the first year. Differences in survival between the first year and second year for vertical and angled cuttings observed in this study (Figure 17) underscore the importance of multiple-year follow-up monitoring in developing an accurate assessment of revegetation success.

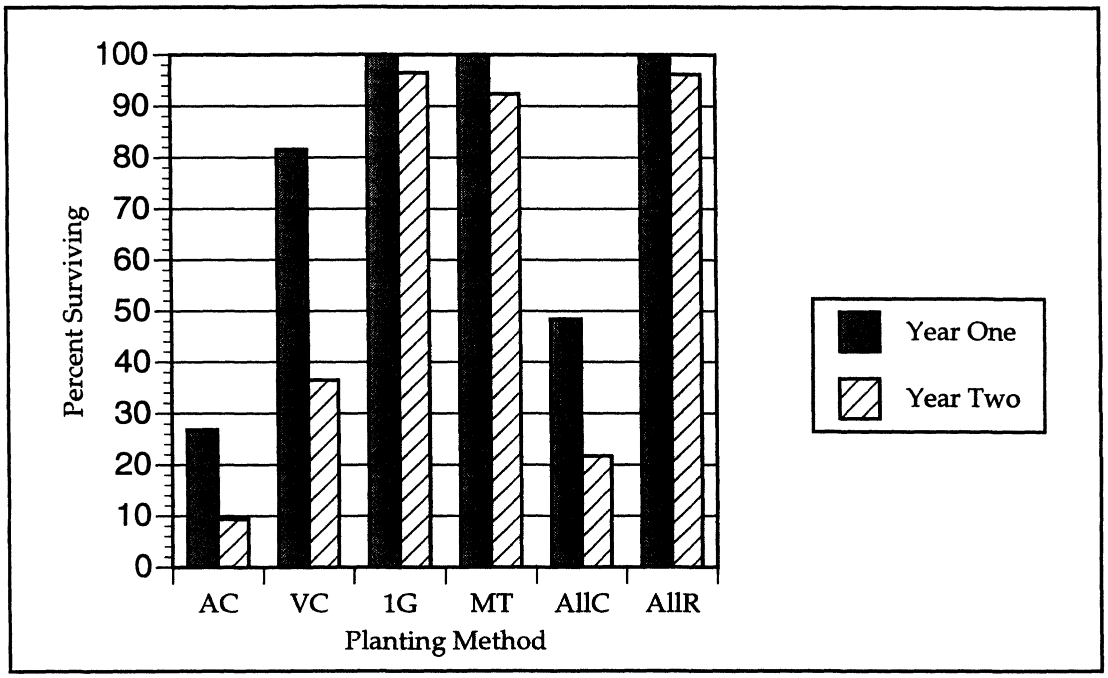


Figure 17. Survival percentages of all planting methods. Planting method codes: AC = angled cuttings, VC = vertical cuttings; 1G = one-gallon containers; MT = mature transplants; AllC = all cuttings (sum of all angled and vertical cuttings); AllR = all rooted stock (sum of all one-gallon containers and mature transplants).

The low survival rates observed for angled cuttings is likely a direct result of the susceptibility of that treatment (re-sloped bank covered with erosion control fabric) to erosion. Observation of all treatments before, during, and after spring runoff indicated that while the erosion control fabric protected the banks from debris impact, water circulated underneath the fabric, eroding bank material and thus the rooting matrix for those cuttings. Angled cuttings that were physically washed away were not included in survival analyses, but it is likely that many of the cuttings remaining on site were adversely affected by the erosive force of the water as contact of the cutting with the bank was reduced. Erosion was observed at the toe of re-sloped banks, leaving the bottom ends of many angled cuttings exposed in the channel. Though water is presumed to have not been a limiting factor for plant survival of any treatment (1997 and 1998 runoffs were well above the annual means for a ten-year period of record), a lack of rooting medium for angled cuttings may have been. For these reasons, the susceptibility to erosion may have influenced survival of this planting method more than other treatments, as bank erosion at other plantings (vertical cuttings, containers, and transplants) was more likely to result in the physical loss of the plant itself.

Soil texture may influence *Salix* spp. cutting survival, but was not quantified in this study due to a lack of replicates in each soil type for each planting method. The planting holes of all vertical cuttings were backfilled with coarse sand. One site (PRA2) had vertical cuttings planted into a sandy floodplain, and another (PRB2) had vertical cuttings planted into a dense, black clay, then backfilled with sand. Though survival differences between these two planting sites cannot be statistically analyzed, raw survival percentages varied greatly between these two soil types (Figure 18).

For these same two sites, two-sample t-tests were conducted for all three growth measurements (total shoot length, longest shoot length, and total number of shoots). Each test indicated that mean growth was significantly different between the sand site and the clay site (for all three tests, $\alpha=0.10$ and $P<0.0001$). Given the observed differences in survival rates between a sandy site and a clayey site, soil texture may have a pronounced influence on cutting survival and growth. However, PRB2, the clay soil site, experienced severe insect utilization, more than any of the other study sites. Nearly all cuttings were defoliated at the end of the first growing season, and very few survived

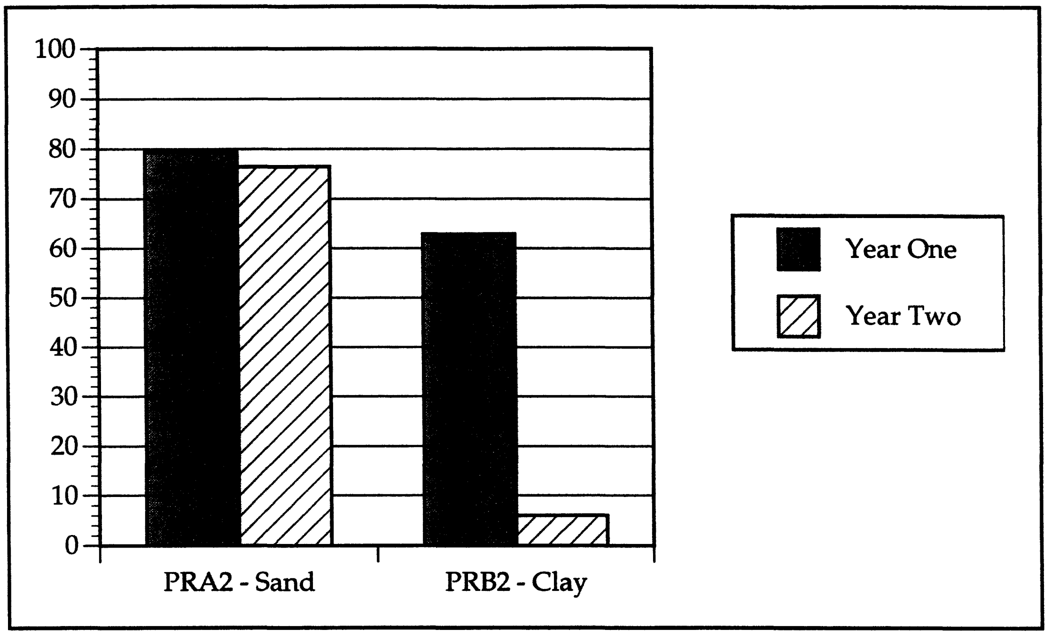


Figure 18. Survival percentages of vertical *Salix* spp. cuttings planted in a sandy floodplain (PRA2, n=34) and in a clay bank backfilled with sand (PRB2, n=35).

the winter. It is unclear whether low survival on this site was due to soil conditions, insect utilization, a combination of both, or some other factor. If, in fact, low survival was due to soil texture, then it is clear that even backfilling augered holes in a clayey soil may not provide a sufficient growth medium for cuttings.

Possible Confounding Factors of Plant Survival and Growth

I could find no literature that discussed the benefits of one species of *Salix* over another for cutting propagation and riverbank stabilization, but it is possible that some species are more suited than others to these types of projects. Because selection of species for collection and planting of cuttings was driven by availability, most (71% [68 of 91]) identified vertical cuttings were *Salix boothii* (Booth willow). The same percentage likely holds for angled plantings, though it cannot be quantified since 56% of all angled cuttings could not be identified (either because they were never located under the coir fabric or they were located but never grew shoots and leaves).

The literature is inconclusive as to whether timing of cutting and mature transplant harvest influences survival (Hoag 1991, Hoag 1992, Hoag 1993). There is no indication that cuttings harvested in the late fall experience higher survival rates than those harvested in the early spring. Though timing of cutting harvest for planting on this project varies from site to site and could potentially affect cutting survival, it was ignored as an independent variable.

Condition of source plants could have an effect on cutting or transplant survival and/or growth. Healthy source plants growing in areas with low soil pH or elevated heavy metals concentrations could be better conditioned for transplant to stressful conditions. Conversely, source plants taken from relatively normal growing conditions and planted in sites with harsher growing conditions may be more likely to fail. Though unclear, it appears that these source plant considerations may not be important at these sites, given the relatively high pH values and corresponding low copper concentrations.

As discussed above, soil texture and insect utilization may have a pronounced effect on cutting survival. Some sites received greater degrees of ungulate browsing on shoots than others. Cuttings that were browsed often had pieces of bark stripped from the cutting (Figure 19). All these factors vary between sites and may affect survival and growth.

Figure 19. Example of cutting damage as a result of utilization by white-tailed deer.

The presence of tailings lenses in the soil profile could affect survival and growth. In order to standardize the sampling protocol, soil samples taken were obtained at fixed sampling depths. Thus, tailings lenses were only included in soils analysis coincidentally, if a lens was encountered at one of the two pre-determined sampling depths.

All these factors vary between sites and may affect survival and growth. Based on my observations, I believe that *Salix* spp. cutting survival, outside of the likely influence of erosion on angled cuttings, is most directly influenced by the combined effects of depth to the water table and soil texture. The portion of the PRA2 treatment reach that received the vertical cutting treatment experienced the highest survival rates of the three vertical cutting sites. It is also the only bank in the study that is not a terrace. As such, cuttings at PRA2 were much closer to the water table. Soil at PRA2 was coarse sand. Perhaps the high survival rates of mature transplants and container plants were aided by the fact that they were planted in excavated holes in the bank, putting established roots in direct or close contact with the baseflow water level.

If the proximity of cuttings to the baseflow water level indeed has a pronounced influence, the fact that both the 1997 and 1998 runoff, summer flow, and spring and summer precipitation were much higher than average for the period of record indicates that it may be more difficult to revegetate high terrace banks in average to dry water years. In areas where plant establishment in dry years or on terrace banks is critical, it is interesting to note that irrigation of cuttings has resulted in extremely high survival and growth of vertical *Salix* spp. cuttings in a project on the Red River in Idaho (Clayton, pers. comm. 1998)

Management Implications and Issues

Results presented here indicate that rooted plant material (mature transplants and one-gallon container stock) offers the greatest likelihood for successful revegetation of actively eroding riverbanks of the Upper Clark Fork River. However, further evaluation of plant performance in terms of site conditions, plant species, and planting methods, as well as their interactions, are needed before broad-scale revegetation recommendations can be made for the riverbanks of the Upper Clark Fork River. This section will evaluate the reported results in relation to management considerations.

Given that rooted stock had much higher survival than cuttings, it may be advisable to focus revegetation studies on rooted plants. The parent project of this study (the Riverbank Stabilization Pilot Study) has found that costs of implementation vary greatly between planting methods. Of the four methods discussed in this study, the ranking from least to most expensive are: mature transplants, vertical cuttings, angled cuttings, and one-gallon container plants. Given the discrepancy between cost of mature transplants (approximately $20 per lineal meter [$6 per lineal foot]) and one-gallon containers (approximately $260 per lineal meter [$80 per lineal foot]) and the finding of no evidence of difference in survival rates for both methods, it clearly makes financial sense to research the option of using mature transplants for revegetation projects. Much of the cost of container plants is associated with the price of the plants, the heavy machinery work of re-sloping vertical or near-vertical banks and creating suitable planting sites for small plants, the extensive costs of hand-planting many individual plants, and the expense of purchasing and installing coir fabric and/or rock toes to temporarily protect the disturbed slope.

Approximate costs for vertical cuttings are approximately $32 per lineal meter ($10 per lineal foot). This estimate does not include any type of in-channel revetment structure, which would increase the cost to approximately $130 per lineal meter ($40 per lineal foot). Though the conifer revetments can likely be obtained for no charge, the large increase in cost is due to the amount of labor required for revetment installation. The angled cutting method, which is not recommended for future use, costs approximately $82 per lineal meter ($25 per lineal foot).

The vertical cutting method costs approximately 60% more than mature transplants. Unless future research finds evidence that vertical cuttings provide greater structural benefit than mature transplants, it would not be feasible to plant greater numbers of cuttings to allow for mortality and still achieve a desired number of surviving plants. This is underscored by the fact that if source plants are available for cuttings, then they are likely available for transplants.

When transplanting mature shrubs, a critical factor is having a nearby transplant source. On the Upper Clark Fork River, many potential revegetation sites have a source either on the landowner's property or on an adjacent property. Establishing and maintaining landowner-rehabilitator relationships along the entire Upper Clark Fork River would serve managers well, not only in terms of managing a continuous, linear system like the Upper Clark Fork River riparian zone, but also in terms of creating and maintaining possibilities for transplant material sources.

Damage done to cuttings by cattle entering two planting sites could have been avoided. In the case where a gate was left open by an adjacent landowner, communication with owners of adjoining parcels (not just of treatment sites) regarding the goals of the project and the susceptibility of treatments to damage by livestock may have prevented the incident. The second case, in which the fencing contractor failed to install a gate before cattle were moved into the adjacent pasture, could have been prevented simply by coordination between the planting crew, the contractor, and the landowner.

Surface disturbance associated with planting and construction of temporary in-stream structures may make banks more susceptible to invasion by noxious weeds. On at least on site, *Euphorbia esula* (leafy spurge) was introduced to a previously uninfested stream bank with the transplanting of mature shrubs. Efforts should be taken to select plant source areas that are free of noxious weeds.

In sum, management and revegetation of riverbanks is a task complicated by biological and logistical considerations and constraints. The findings of this study should help structure further research efforts, rather than be applied directly to revegetation projects.

RECOMMENDATIONS FOR FUTURE RESEARCH

Because this study was an off-shoot of a larger project that had different objectives, and because I did not begin research until riverbank treatment and plantings were completed, a rigorous experimental design was not in place to properly measure and analyze treatment effects. What can be taken from this project, however, is a better understanding of important research components that can be incorporated into future project designs. Specific recommendations are presented in this section.

Where possible, future projects should design replicates for planting methods within treatment reaches. The number and strength of tests would be increased with replicates, allowing for a better assessment of between-treatment differences. For example, a 300-foot treatment reach could be divided into three 50-foot replicates each of two planting methods, or three 100-foot replicates with two planting methods nested within each to evaluate differences in growth at a site. Replicating treatment reaches, however is more difficult, if possible at all. Downstream reaches are affected by upstream counterparts in many ways. The continuous nature of riparian areas results in inherent risks of autocorrelation. Similarly, the force of riverflow against treatment banks may not be comparable between sites. Bank failure at planting treatment areas could be misattributed to treatment performance, when failure is more likely due to between-site differences.

More information is needed on plant performance at low pH values under-represented in this study. Though pH values of less than 6.0 are not common in this study or in the data collected by Schaffer and Associates in 1997, areas with soil pH values in this range may pose a greater challenge to successful revegetation and riverbank stabilization, and thus may warrant further consideration.

A count of all *Salix* spp. cuttings should be made before planting; this count should include the number of each species planted, so that species identification is in place even for cuttings that never leaf out. This information is essential to making between-species comparisons of survival and growth.

Future studies might investigate the influence of soil texture and the presence/absence of tailings lenses on plant survival and/or growth in general and by species. Such information would be useful in determining if particular methods or species are more suitable for different planting sites. Also, the influence of the position of plantings relative to the baseflow water level must be better understood in order to successfully approach revegetation of terrace banks. A related and equally important research topic is the effectiveness of terrace irrigation on plant survival on the Upper Clark Fork River, though this is likely a costly option and one that may be complicated by water rights issues.

The effect of insect herbivory on plant performance is unclear, and is worthy of consideration in future revegetation projects. Though purely observational, it appears that intense insect herbivory of new shoots and leaves on *Salix* spp. cuttings may have influenced plant survival on at least one study reach.

It is uncertain at this point what the long-term (5-, 10-, and 20-year) survival rates of different planting methods would be. It is also unclear whether or not there is an added structural benefit of one planting method over another. Does the existing root mass of container plants and transplants proliferate and contribute to bank stability more quickly than surviving *Salix* spp. cuttings? Beyond survival rates, is there a benefit of having large, multiple-stemmed shrubs on a bank rather than many single stems (cuttings), in terms of increased resistance to overbank flow, thus decreasing overbank flow rates, increasing sediment deposition, and contributing to bank formation? Many questions remain regarding the best options for revegetation of the Upper Clark Fork River for bank stabilization.

Future research and planning would do well to consider re-establishing well-vegetated riparian zones in locations where they no longer exist. Vegetative stabilization goals should use species native to the system, and keep survival rates in mind when planning for adequate establishment. Where this study tested planting methods in single, 2 m (6 ft) wide rows of transplants and triple, 3 to 4 m (10 to 13 ft) rows of *Salix* spp. cuttings and container plants, planting in 10 to 15 m (35 to 50 ft) strips parallel to the river channel would greatly improve long-term bank stability, the likelihood of natural regeneration, and benefits to fish and wildlife. Though beyond the scope of this study, future revegetation efforts should consider design criteria that could be easily included in revegetation plans to maximize benefits to wildlife. Research into this topic might focus on optimum riparian zone width, vertical and horizontal structure, food sources for birds and mammals, and overhanging structure for fish habitat.

Stabilization of the unstable riverbanks of the Upper Clark Fork River is a challenging task, yet critical to the reestablishment and maintenance of the historical and natural dynamic equilibrium inherent to riparian systems. Landowners, decision-makers, and planners must realize that a stable riverbank and a static riverbank are two completely different states. The only way to have a static riverbank on the Upper Clark Fork River is to channelize and/or riprap long stretches of bank, effectively converting the river into a conduit. Those involved in planning on the Upper Clark Fork River should try to understand and work with the dynamic nature of riparian systems. This is often easier said than done, as many landowners on the Upper Clark Fork River are fairly small ranches. Yearly riverbank losses on the edge of a hay field quickly translate into real and sometimes significant losses in productivity.

Future riverbank work should try to estimate the "natural" rate of lateral channel migration, and then work to determine an acceptable rate. The fact that vegetation is used should not lead landowners, planners, and decision-makers to expect that the river will cease to migrate as plants grow to stabilize banks. Rather, planning should include both goals of slowing exacerbated, human-caused erosion rates as well as expectations of continued lateral migration.

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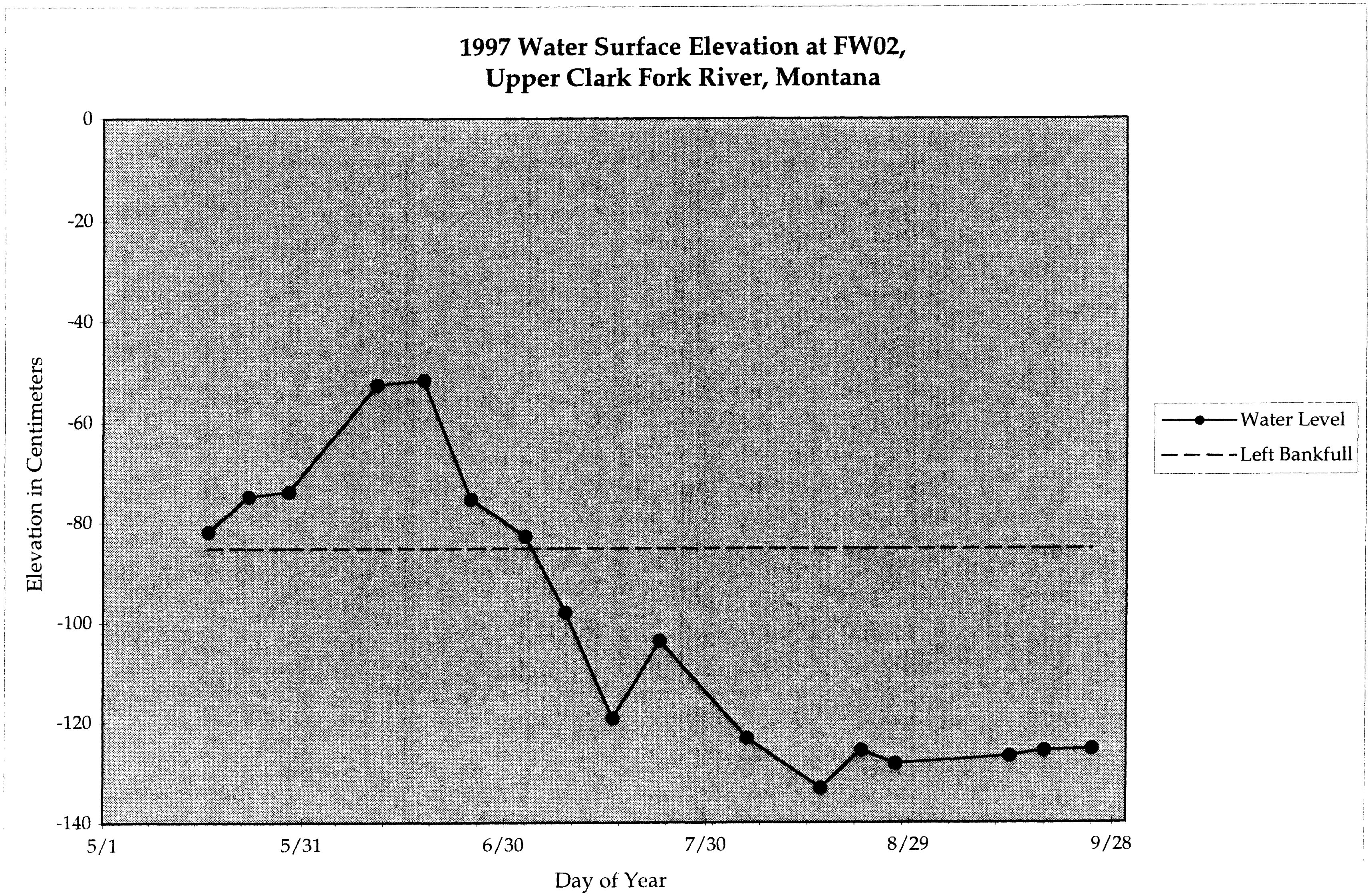
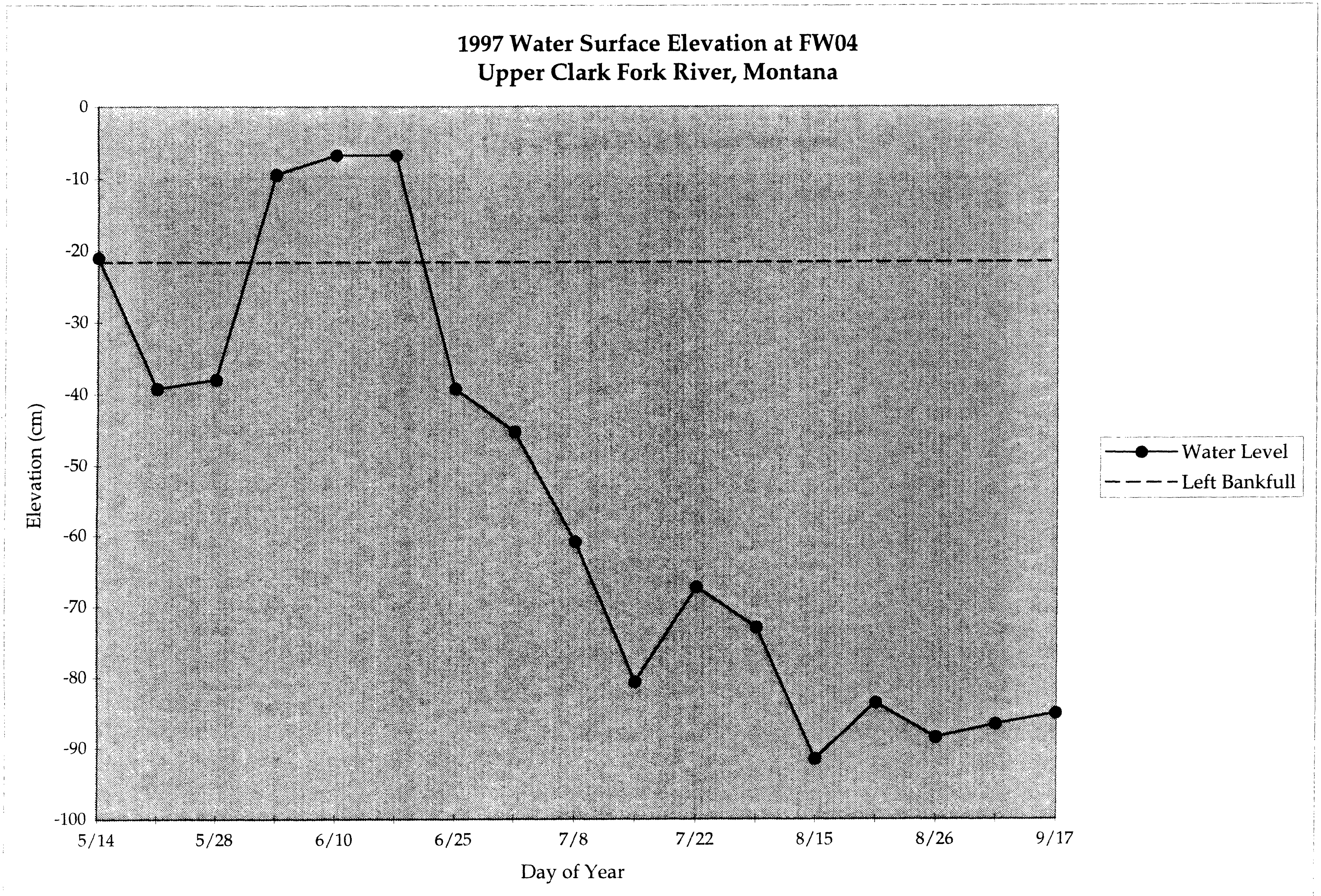
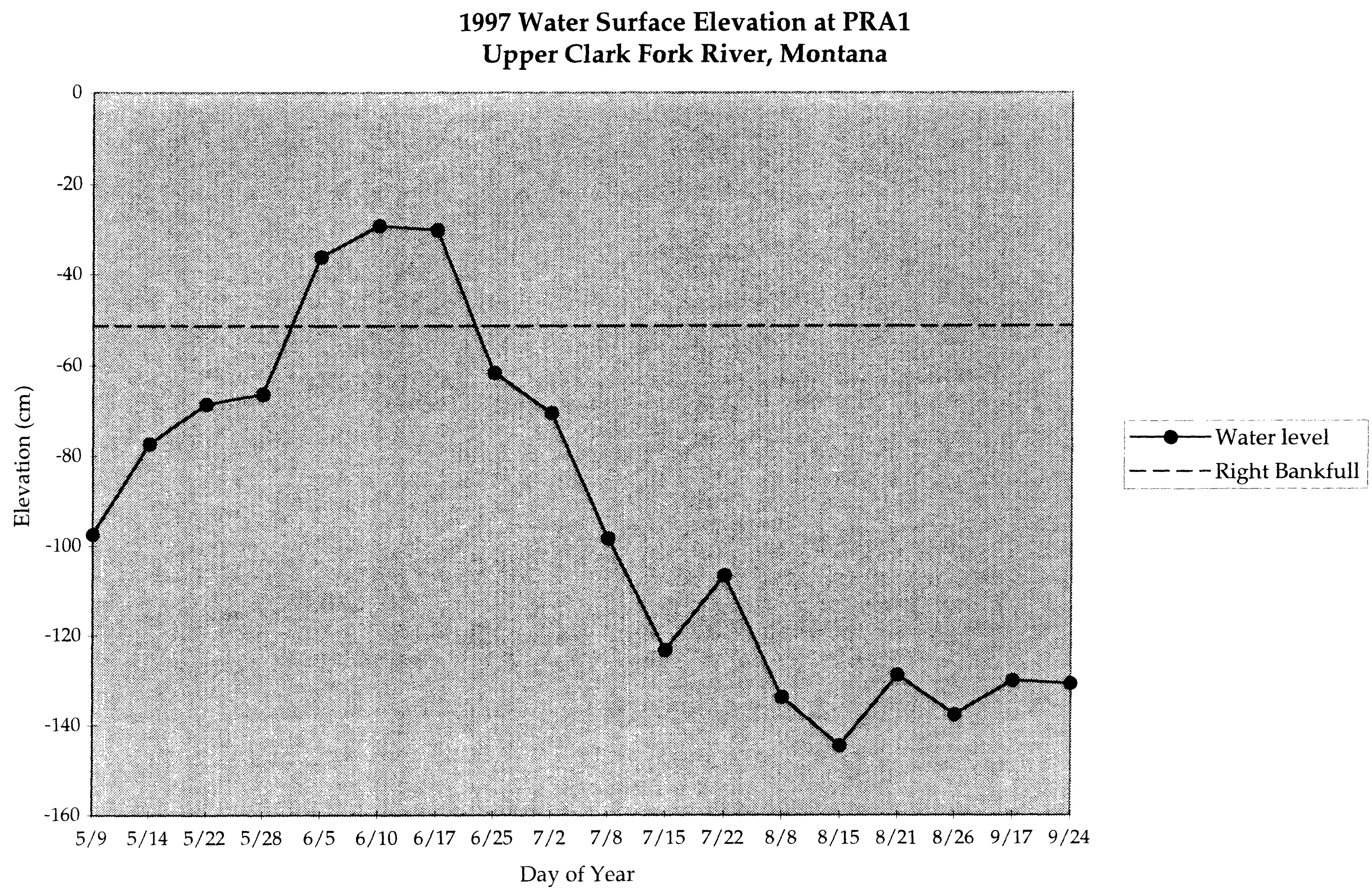
APPENDIX A

Water Level Graphs
1997 Growing Season

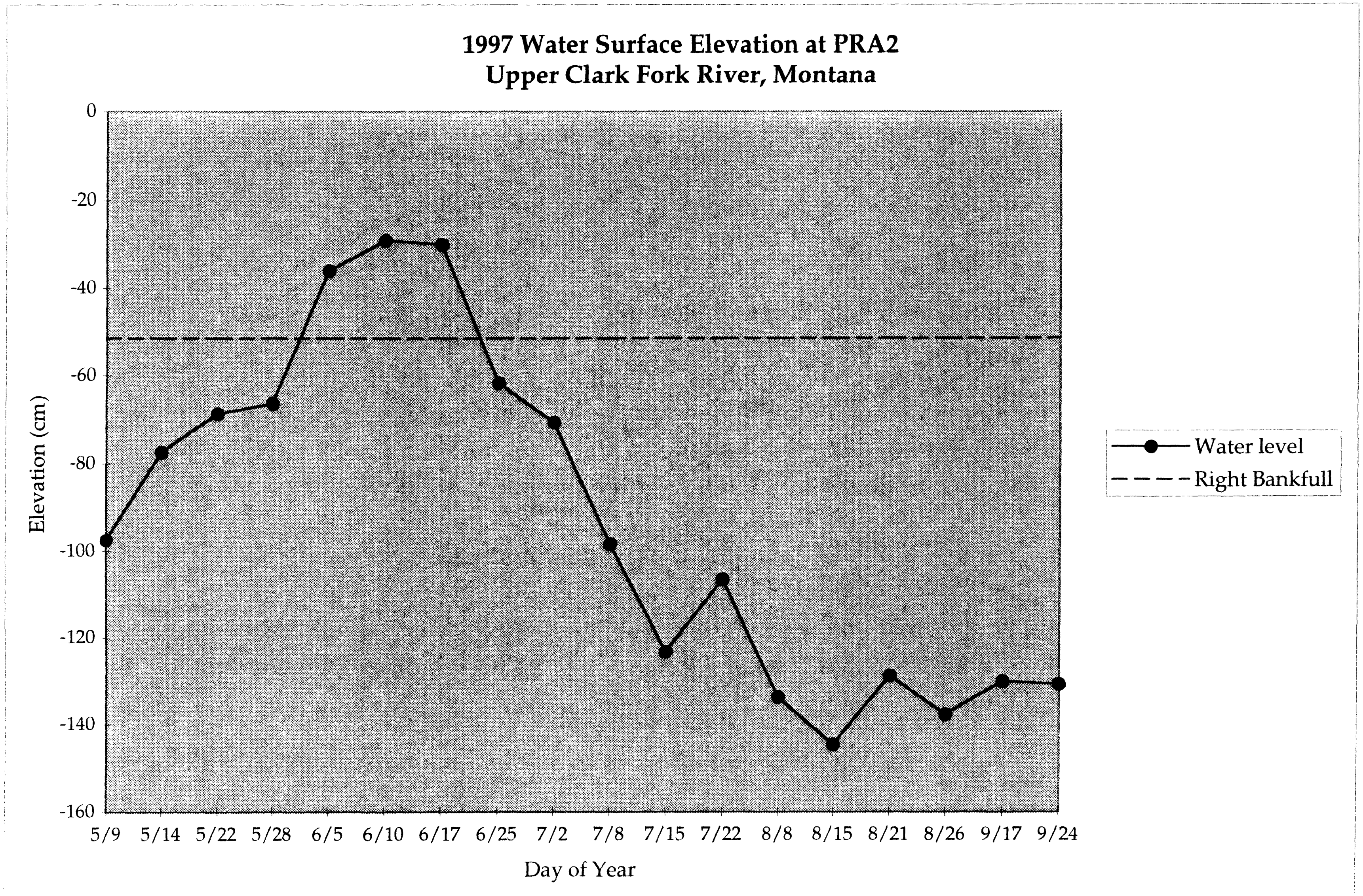

1997 Water Surface Elevation at FW02,
Upper Clark Fork River, Montana
0
-20
-40
-60
-80
-100
-120
-140
Elevation in Centimeters
5/1
5/31
6/30
7/30
8/29
9/28
Day of Year
Water Level
Left Bankfull

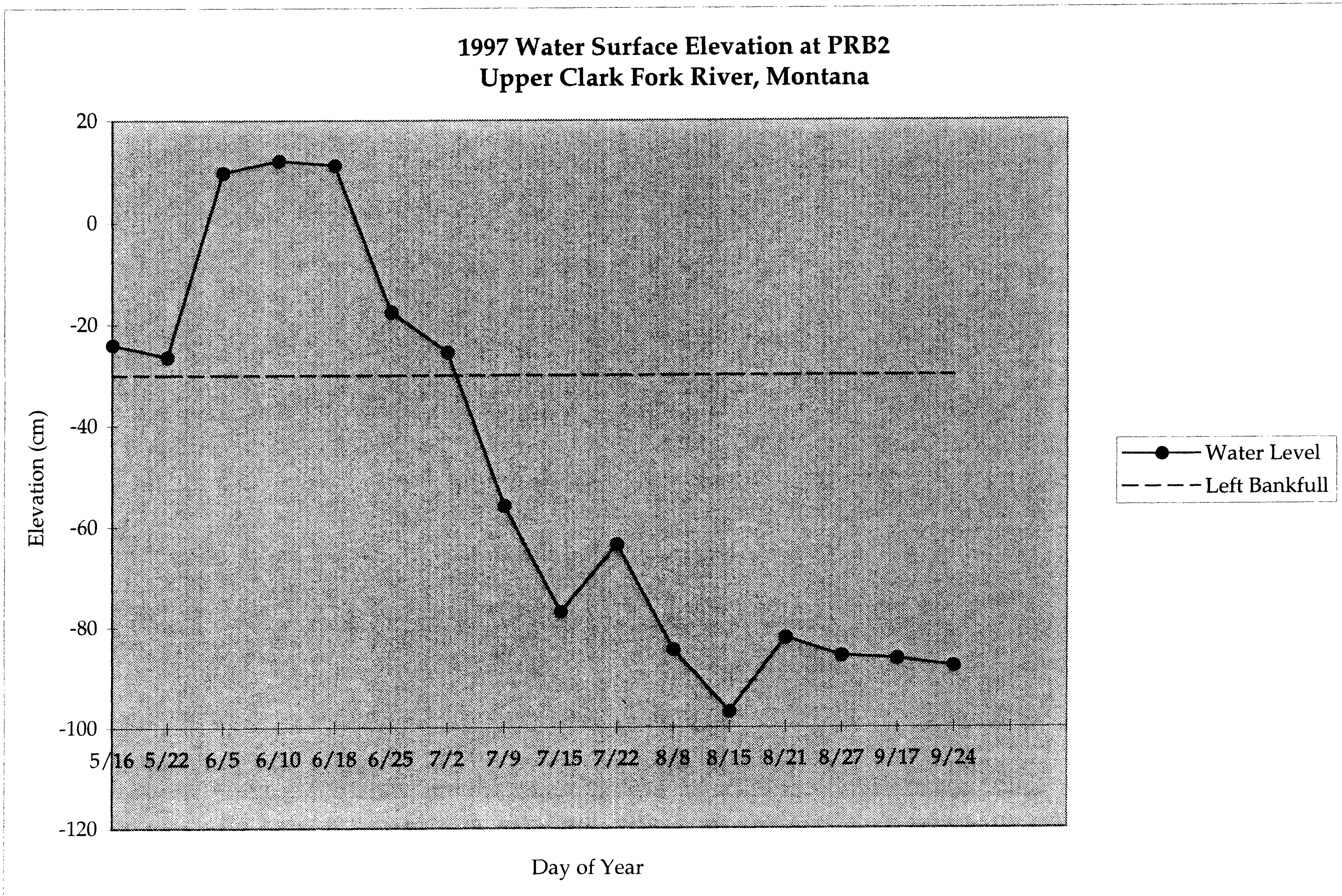


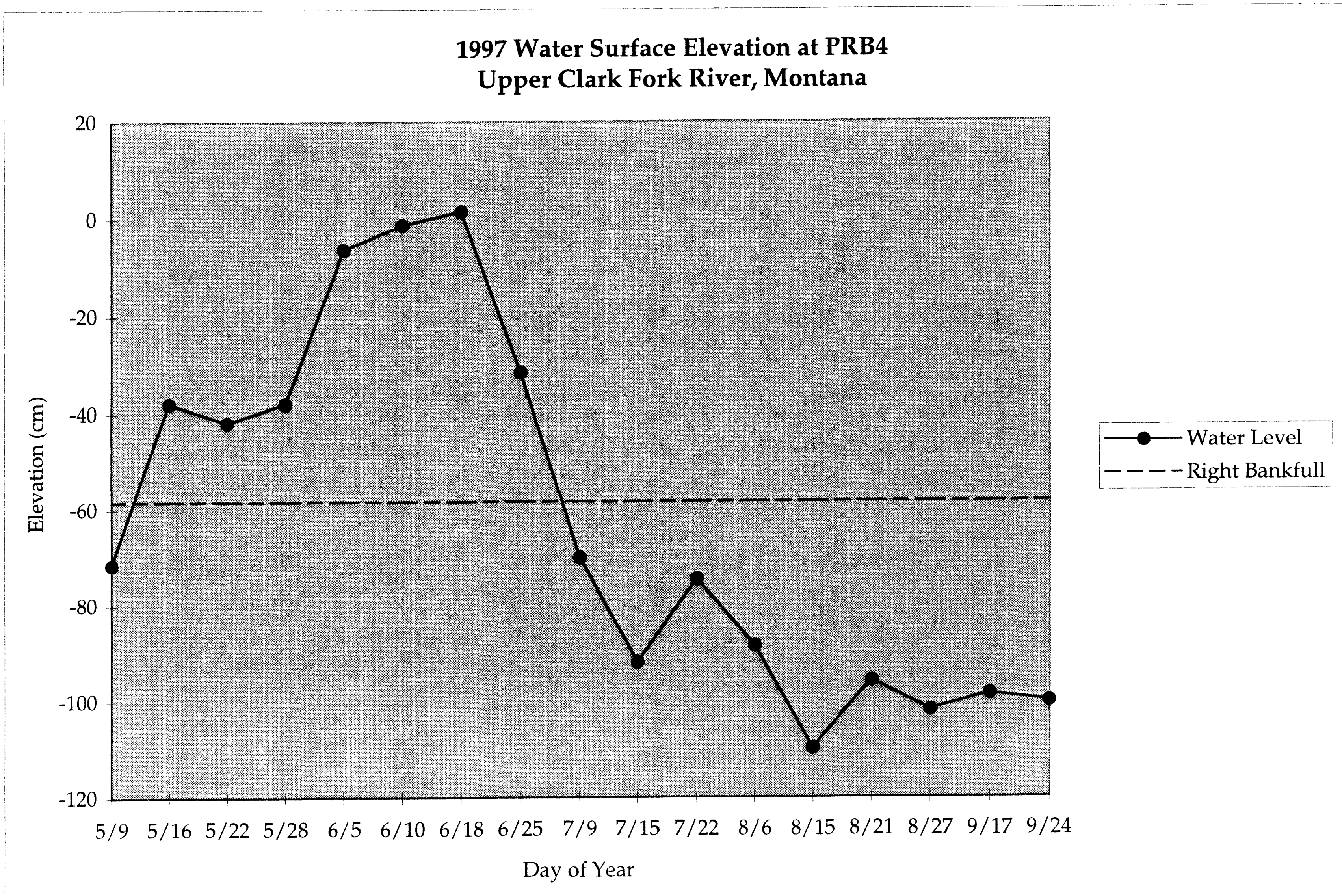
1997 Water Surface Elevation at FW04
Upper Clark Fork River, Montana
Elevation (cm)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
5/14
5/28
6/10
6/25
7/8
7/22
8/15
8/26
9/17
Day of Year
Water Level
Left Bankfull



1997 Water Surface Elevation at PRA1
Upper Clark Fork River, Montana
0
-20
-40
-60
-80
-100
-120
-140
-160
Elevation (cm)
5/9 5/14 5/22 5/28 6/5 6/10 6/17 6/25 7/2 7/8 7/15 7/22 8/8 8/15 8/21 8/26 9/17 9/24
Day of Year
Water level
Right Bankfull

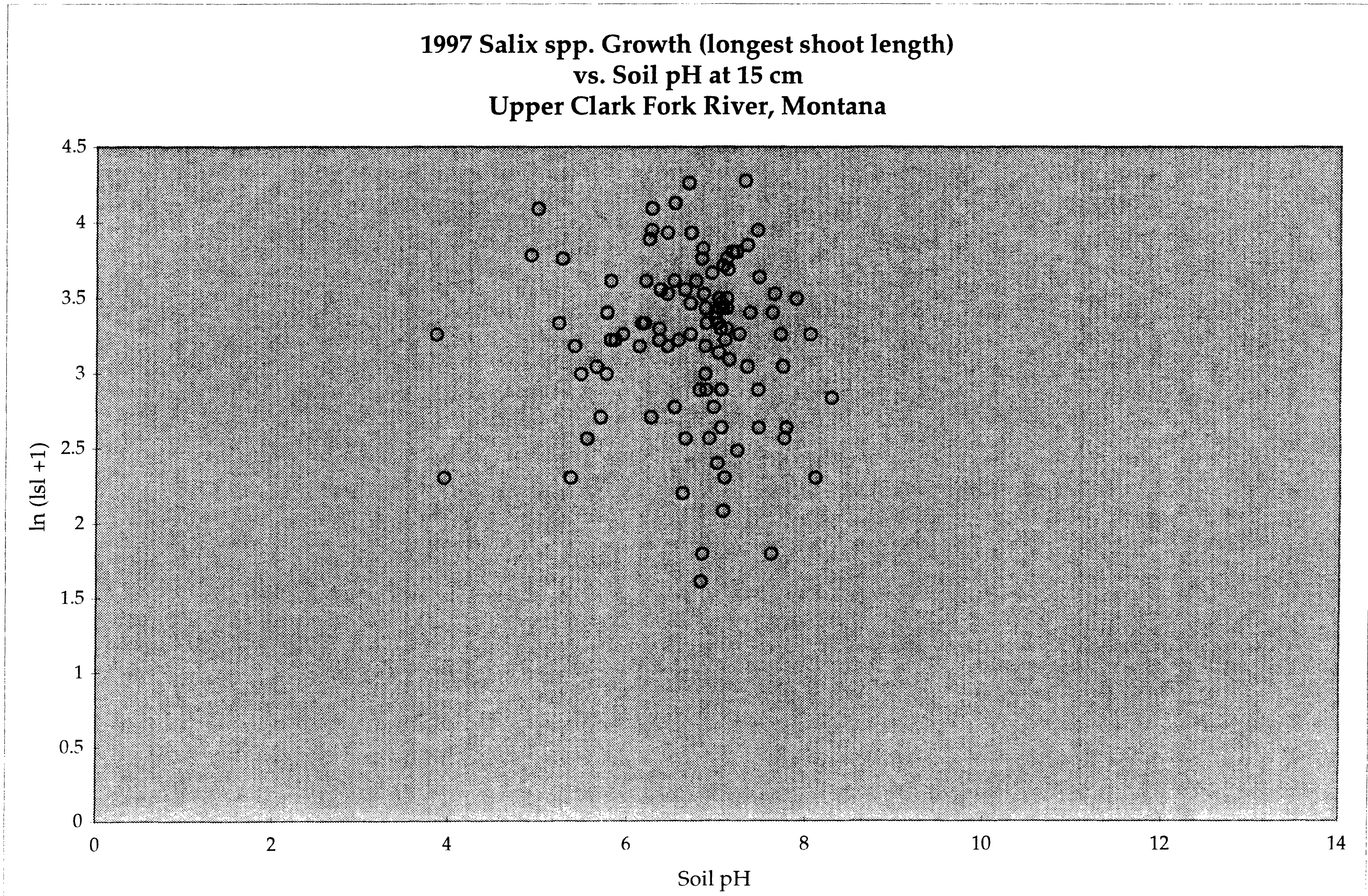

1997 Water Surface Elevation at PRA2
Upper Clark Fork River, Montana
0
-20
-40
-60
-80
-100
-120
-140
-160
Elevation (cm)
5/9
5/14
5/22
5/28
6/5
6/10
6/17
6/25
7/2
7/8
7/15
7/22
8/8
8/15
8/21
8/26
9/17
9/24
Day of Year
Water level
Right Bankfull

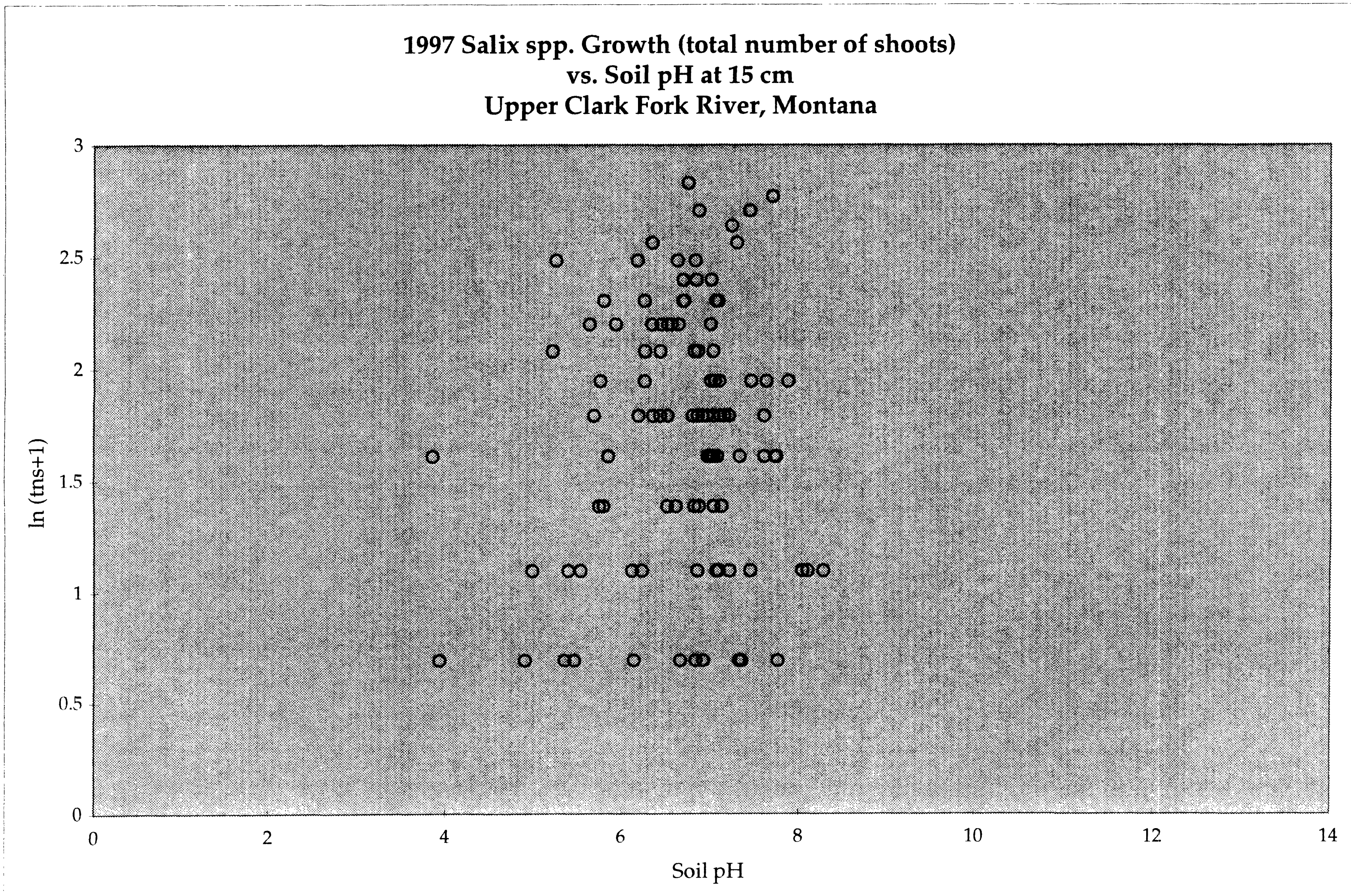

1997 Water Surface Elevation at PRB2
Upper Clark Fork River, Montana
20
0
-20
-40
-60
-80
-100
-120
Elevation (cm)
5/16 5/22 6/5 6/10 6/18 6/25 7/2 7/9 7/15 7/22 8/8 8/15 8/21 8/27 9/17 9/24
Day of Year
Water Level
Left Bankfull

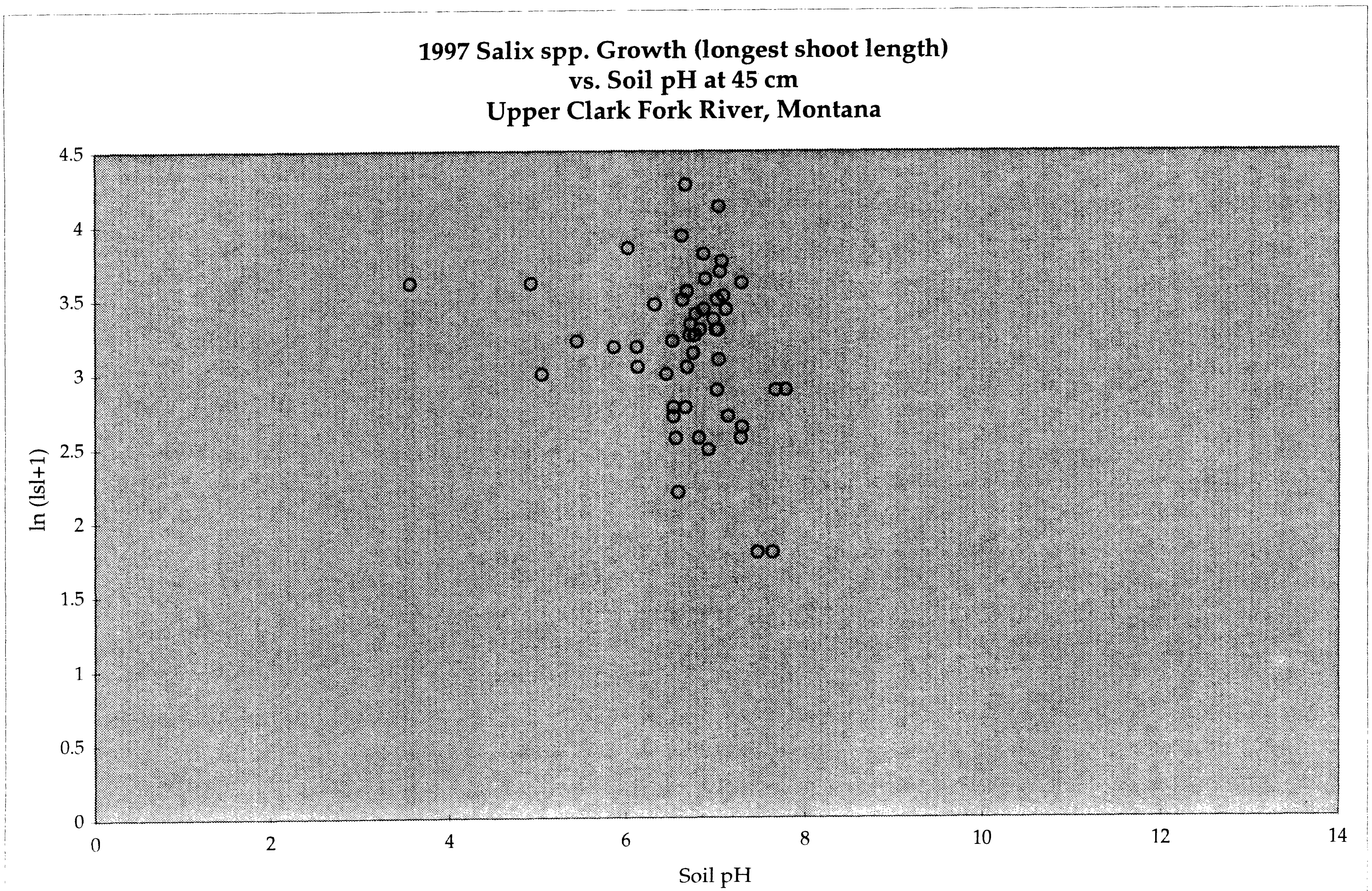

1997 Water Surface Elevation at PRB4
Upper Clark Fork River, Montana
20
0
-20
-40
-60
-80
-100
-120
Elevation (cm)
5/9
5/16
5/22
5/28
6/5
6/10
6/18
6/25
7/9
7/15
7/22
8/6
8/15
8/21
8/27
9/17
9/24
Day of Year
Water Level
Right Bankfull

APPENDIX B

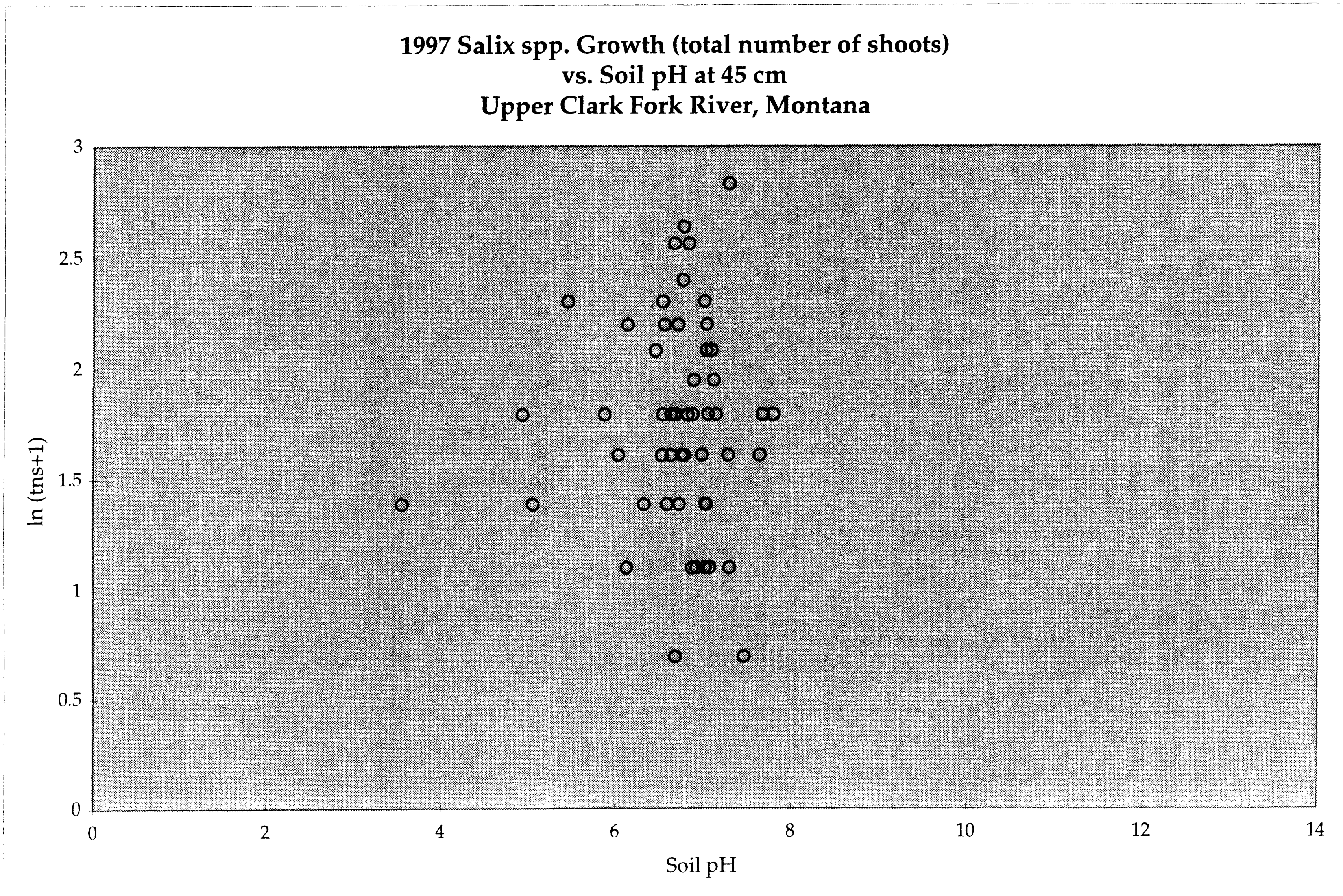
Plots of Willow Cutting Growth
vs. Soil pH


1997 Salix spp. Growth (longest shoot length)
vs. Soil pH at 15 cm
Upper Clark Fork River, Montana
ln (lsl +1)
Soil pH
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
2
4
6
8
10
12
14


1997 Salix spp. Growth (total number of shoots)
vs. Soil pH at 15 cm
Upper Clark Fork River, Montana
ln (tns+1)
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
Soil pH



1997 Salix spp. Growth (longest shoot length)
vs. Soil pH at 45 cm
Upper Clark Fork River, Montana
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
ln (lsl+1)
0
2
4
6
8
10
12
14
Soil pH


1997 Salix spp. Growth (total number of shoots)
vs. Soil pH at 45 cm
Upper Clark Fork River, Montana
ln (tns+1)
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
10
12
14
Soil pH

APPENDIX C

Soil pH Histogram

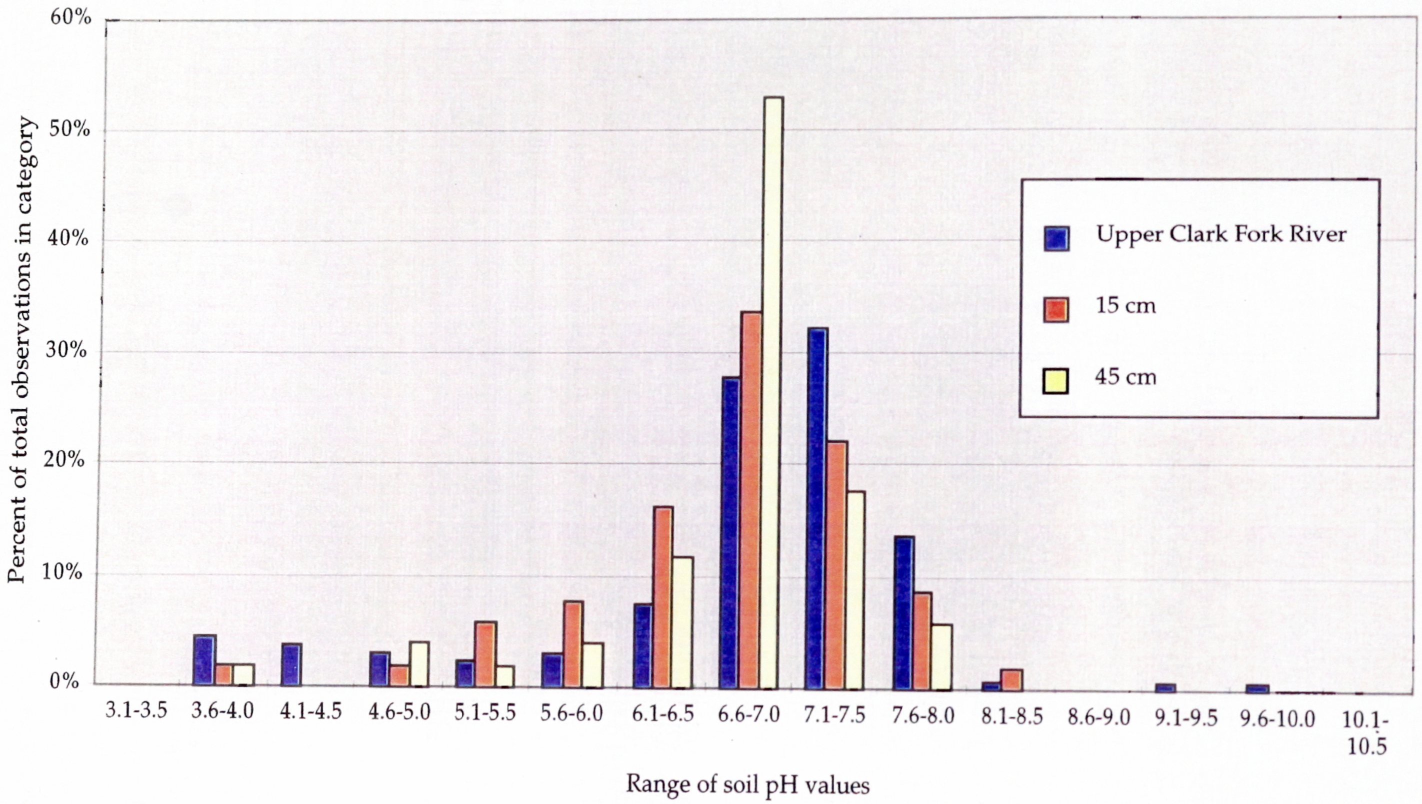


Figure 11. Histogram of Soil pH Values—Upper Clark Fork River vs. All Study Sites. Upper Clark Fork River Data provided by Schaffer and Associates, Bozeman, MT