Show Me the Progress!

A.k.a./Managing Hardrock AML Cleanup Projects Under the CWAP & GPRA

George M. Stone, Jr.*

Restoring watersheds can pose significant challenges due to the technological complexities of water pollution, the costs of treatment, and the time it takes to identify and clean up the contributing AML sites. The Clean Water Action Plan (CWAP) and its implementing guidance provide a framework for partnership efforts, fund leveraging, and ensuring that wherever possible those persons responsible for the pollution contribute to the cleanup. [1] In addition, today's AML project managers must fulfill the provisions of the Government Performance and Results Act (GPRA),[2] whose sponsors rally around the theme of "what gets measured gets done!" Relatively small annual appropriations add up, and agencies need to demonstrate significant achievements in shot time frames for the monies spent, or risk future funding. This presentation shares some of the successful methods used and "lessons learned" in implementing both the CWAP and GPRA under the BLM's AML program.

Where the BLM has done well, it has been able to enter into partnerships where projects have clearly defined goals, known beneficiaries of the cleanup exist, and where agency roles have been established. Risk-analysis was applied so that the most significant sites were usually addressed first. No polluted sites have been left unreclaimed. Large watersheds have been broken down into manageable segments, which enabled some small to medium size on-the-ground projects to be completed in short time frames while site characterization and other preparation work continued on the more difficult sites or the next watershed segment. Moreover, by developing ways to report progress on the number of sites in the watershed which have been initiated and completed each year, meaningful progress has been reported under the GPRA.

In contrast, there are projects which could be progressing better had certain shortcomings been identified and addressed at the outset, and new project proposals which are unlikely to be funded if corrective adjustments are not made. Examples include projects:

- With questionable objectives and unspecified benefits or beneficiaries.
- Not planned in segments.
- Where prep work or other support activities have been nebulous, not measured and difficult to assess in terms of progress.
- Too difficult technologically for a new program to handle.
- Which did not establish contingency funding to clean up all sites, including those on private lands.
- Where other kinds of pollutants are being overlooked.
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In short, when the inevitable audit compares tomorrow's water sample against today's, will there be a meaningful improvement? Avoid the traps listed above. Report your accomplishments under GPRA. Ensure your AML program is included in your agency's strategic and annual plans. Broadcast your progress, for example, on the Internet. Get key funding and political leaders involved, or at least informed, an keep them up to date on your progress.

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[1] Under the CWAP, State government agencies take the lead to identify polluted watersheds. Next, the States, together with Federal land management agencies like BLM and the Forest Service, determine which polluted watersheds are attributable to AML sites. The government agencies prioritize the watersheds based on risk assessment, and collaborate on a comprehensive plan whereby all of the problem sites are addressed over a certain time period given an anticipated level of funding. If responsible parties can be identified or if willing third parties can contribute to the effort, those factors are taken into account as well.

[2] Briefly, under the Act and related financial management statutes and guidelines, agencies are to operate in more of a business cycle by developing strategic and annual work plans, performance measures tied to budgets, and applying program evaluation (including cost accounting) to hold managers accountable for results and, in turn, to provide input to the next round of plans.

2000 Billings Land Reclamation Symposium

BIOENGINEERED STREAMBANK STABILIZATION ON SILVER BOW CREEK, BUTTE, MONTANA

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ABSTRACT

A newly configured approximately 7,000-foot long (1.3 miles) meandering channel was created at the ARCO Lower Area One, Phase I, Segment II remediation site, Butte, Montana. The project goal was to reclaim and stabilize approximately14,000 lineal feet (2.6 miles) of stream bank and riparian corridor with native seed, herbaceous, shrub (willow) and tree plantings. The finished channel included a 30-45 foot average top width, 30 outside concave banks and 30 inside curve point bars. The channel decreased in elevation 19.7 feet for an average 0.31% gradient. An engineered diversion was located immediately upstream of the project site to divert portions of flows in excess of 35 cfs for a period of five years or until the 30 outside concave banks become stabilized with root structure.

This paper provides a summary of the streambank design, construction techniques and post-construction assessment of those banks. Thirteen of the 30 concave banks were treated and stabilized using eight bioengineered treatment combinations. The remaining 17 banks and point bars were stabilized using an intensive vegetative treatment (IVT) containing three staggered rows of willow cuttings at two-foot centers. Two staggered rows of IVT were installed behind the bioengineered treatments at the 13 locations. Mycorrhiza and osmocote were utilized during willow installation. Observations and quantitative monitoring including measurements of willow stem growth that provided a basis for evaluating bank stabilization with root structure and the restoration of biological function utilizing the nine bioengineered treatments. Measurements after two growing seasons indicated that plant growth and root structure met or exceeded design expectations. Information and understanding gained from the variety of bioengineering designs used on this project will be considered during potential future designs downstream of Butte.

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INTRODUCTION

The uppermost portion of Silver Bow Creek near Butte, Montana was the site of a remediation project titled Lower Area One (LAO) Phase I, Segment II. Remediation included removal of large quantities of tailings and underlying soils with elevated metals concentrations. Clean fill material was imported to construct a 200 to 400 foot wide floodplain and a low flow meandering stream channel. In addition to remediation goals, there was a desire to restore the area to a naturally functioning stream, riparian and wetland ecosystem. Hence, the project presented the need for: 1) creating a fully vegetated riparian floodplain, and 2) restoring the stream channel using a natural geomorphic design and bioengineered bank stabilization treatments.

A plan was developed to avoid subjecting the newly formed floodplain, riparian corridor and channel to the erosive overbank flows of spring snowmelt runoff and isolated storm events by taking advantage of approximately half of the old Silver Bow Creek Channel and constructing a new temporary channel for the remainder. The engineered diversion was located parallel to the project site to divert flow in excess of 35 cfs for a period of up to five years or until the streambanks became stabilized with native plant (i.e., willow) root structure. The diversion channel was sized to convey the runoff from the 10-year-24 hour storm event estimated at 477 cfs.

Project complexity dictated use of an interdisciplinary team approach including experienced professionals with expertise in civil and hydraulic engineering, hydrology, fluvial geomorphology, ecology, botany, bioengineering, habitat restoration, fisheries and other related disciplines. ESA Consultants Inc. under contract to the Atlantic Richfield Company (ARCO) developed the Work Plan; R2 Consultants Inc. produced the geomorphic stream channel design plan; Schafer & Associates Inc. developed the interim revegetation design plans, directed intensive vegetation treatment and conducted steambank oversight and monitoring; and Aquatic and Wetland Company designed and directed the installation of the bioengineered bank stabilization treatments.

The bioengineered stabilization treatments and their variations included using three types of toe material: wattling, brush layering and biologs that are fully described in the methods below. End of the first growing season monitoring during October 1998 included photography and qualitative observations. End of the second growing season monitoring during October 1999 included measurements of willow survival, density, and growth (Ave. and Max. height). The purpose of this paper is to summarize the nine bioengineered streambank designs, key construction techniques used for willow planting and to report the qualitative and quantitative findings from the initial two years monitoring.

METHODS

Species Selection

Careful consideration was given to stabilization of the streambank zone defined by the channel edge or bank toe, bank slope and floodplain terrace associated with the reconstructed channel. Five native willow species were identified for planting in the streambank zone based on their phenology-morphology, environmental tolerances and production characteristics (ARCO 1997). Three of the five species were known to be abundant within the Silver Bow Creek floodplain valley including Sandbar willow (Salix exigua), Booths willow (Salix boothii), and Yellow willow (Salix lutea) and harvest sites were selected accordingly. Other willow species played a minor role and were not considered in the monitoring results discussed below: Geyers willow (Salix geyeriana), Pacific willow (Salix lasiandra), and Bebbs willow (Salix bebbiana).

The construction work steps involved in the bioengineered bank stabilization with willows included harvesting, bundling, handling, soaking and planting willows. The project began by harvesting dormant willows during the early spring of 1998 and planting progressed thereafter during April, May and June.

Willow Preparation

Harvesting Willows. Small lightweight chain saws and heavy-duty brush cutters worked well for harvesting large numbers of willow stems in a short period. Once willows were cut near ground level, they were gathered and piled at a convenient site for processing.

Bundling. Processing willows for ease of handling included forming a bundle by gathering ten stems (plus or minus one inch in diameter). Dead stems were not included in the bundles. The stems were placed on modified "saw horses" positioned five feet apart and each end of a bundle wrapped with plastic wrap. The bundles were placed in piles of ten, loaded onto a covered trailer to keep out of the sun and prevent drying and transported to a site for soaking in water.

Soaking. All willow bundles were placed in a pond and to the extent possible, submerged for a minimum of three days or longer. Soaking willows ensures that the vascular tissue and buds are super saturated thus resulting in dissolution and leaching of an anti-root hormone located in the stems. After soaking, bundles were removed from the pond, transported to the construction site, placed in the creek's flowing water and planted the same day.

Design and Implementation

The newly configured channel extended approximately 7,000 feet (1.3 mile) with 14,000 feet (2.6 miles) of riparian streambanks that were planted with native grass species, herbaceous sedges and rushes, shrubs including willow (Salix spp.) and tree plantings. The planform of the low flow channel was designed with a sinuosity of 1.25 and typical

stream gradients from 0.2% to 0.4%. The constructed channel included a top width ranging between 30 and 45 feet, a bottom depth of 2.5 feet, 1.75:1 side slopes and a capacity to transport 270 cfs before overbanking. Observation and map analysis resulted in identification of 30 outside concave curve banks and 30 point bars or inside convex curve banks for purposes of design. Each curve was numbered beginning at the downstream project boundary (Figure 1).

Bioengineered Treatments. More intensive bioengineered bank treatments were located at 13 of the 30 outside concave bends. Eight bioengineered designs were determined necessary due to higher erosion potential. Specific treatments for the 13 banks were chosen and implemented based on the high and low risk erosion potential and named according to bank slope and toe treatment (Figures 2 to 7). Toe material was considered nonstructural/organic and included wattling (live facines or bundles of willows 6 inches in diameter), brush layering (intensive single line of willow cuttings running parallel with the water edge) and biologs constructed from biodegradable coconut fibers. Wattling was used as the protective toe at five locations for a total 680 feet. A brush layer toe was installed at three locations for a total of 513 feet. A biolog toe was installed at five locations for a total of 650 feet. Therefore, the total concave bank bioengineered treatment length was 1,843 feet (0.35 mile).

A ninth bank treatment, called Intensive Vegetation Treatment (IVT), was applied to the remaining 17 low risk erosion potential banks, point bars and straight reaches extending for 12,157 feet (Figure 8). Treatment included planting willow cuttings, other shrubs and trees above the ordinary high water mark, sedges and rushes from the water edge throughout the capillary zone, and intra-seeding and hydromulching the remaining area. IVT treated bank spacing of willows varied from one to three feet.

Willow cuttings were inserted to the ground water table after punching a three to four foot deep hole with a dibble bar attached to the bucket of a rotating trackhoe. The number of cuttings placed in each dibbled hole varied according to the diameter of the cuttings and ranged between one and three. Two staggered rows on two to three foot centers were planted behind the 13 concave bend banks and three staggered rows on two foot centers were planted along the convex banks, point bars and straight reaches. Planting distance for the first row from the water edge ranged between one-foot for concave banks to three-foot for convex banks.

RESULTS

Successful bank stabilization was judged by two criteria: 1) performance during and after an unpredicted storm flow event, and 2) quantitative measurements of willow plantings. An estimated flow of 450 cfs occurred following a severe thunderstorm on July 31,1998 or approximately three months after treatment implementation. It was estimated that 300 cfs was diverted into the alternate channel and 150 cfs remained in the new Silver Bow Creek channel. Minimal erosion damage was observed after this storm event and no repair work was required. Therefore, it was observed that the bioengineered treatments worked well at the design flow capacity.

Willow Growth (Second Year)

Quantitative measurements based on, stem survival/mortality, density, and above ground growth were taken during the second growing season. Qualitative observations of bank erosion were also made. No erosion was observed in the 17 concave bend areas treated with IVT.

Average plant height and maximum plant height measurements were made at six of the thirteen- banks treated with the different types of bioengineered treatments (Table 1). Stem height was measured within each of three randomly selected one-meter sections for each of six bank treatments for a total of 18 meters (Table 2). The amount of growth was measured from the surface of the ground to the woody-growing tip of the stem. Branches and leaves were not measured.

An overall average height for the six bank treatments ranged between 4.0 and 4.6 feet for an average of 4.2 feet by the end of the second growing season. An average 77 day growing season (range = 74 to 80 frost-free days) was used to estimate the inches of growth per day for the two growing seasons. Average growth per day ranged between 0.33 and 0.38 inches per day or a little over one-third of an inch per day.

Maximum height for the fastest growing stems ranged between 6.8 and 8.6 feet with an average of 7.8 feet for the six banks measured (Table 3). Therefore fast growing stem growth for the two growing seasons ranged between 0.57 inches and 0.72 inches for an average growth rate of nearly two thirds of an inch per day (0.65”). A number of stems achieved a height of 8.6 feet (103.2”) that translates into a growth rate of 0.72 inches per day by the end of the second growing season (77 days + 77 days = 144 days).

In summary, average willow stem growth under the conditions within the Silver Bow Creek was one-third of an inch each day over the two growing seasons and the fast growing stems averaged nearly three-fourths inch per day. Although not evaluated quantitatively, it was observed that the stabilizing underground root development was rapid and comparable to the above ground growth.

Mortality/Survival Planting Density

Interest was expressed regarding the number of willow stems planted per meter for the installed variations of brush layering, which involved dense linear planting of willow stems along a bank. Therefore, three one-meter sections were randomly selected within six of the treatment types (18 meters). The number of live stems and dead stems were counted. The number of willow stems planted per meter did not vary greatly for the six banks sampled and averaged 26 per meter. Average number of stems surviving per meter at the end of the second growing season within the six treatments was 16.3 or 64% of those planted (Table 3). Average number of dead stems counted was 9.3 (36%).

Additional Observations

Although quantitative measurements were not taken by willow species, species differences in willow phenology/morphology and production characteristics contributed greatly to bank stabilization. Sandbar, Booths and Yellow willow cuttings each formed roots within 10 to 15 days of planting. Banks were well stabilized during the first growing season and improved significantly by the end of the second growing season. It was assumed that the amount of above ground growth was reflected in the amount of below ground root growth.

Observations suggested that Booths and Yellow willow cuttings out performed Sandbar willow in terms of short and long-term above ground vegetative production. Booth and Yellow willow species showed greater above ground biomass production by the end of the second growing season than Sandbar willow and appeared to be prime candidates for future projects within the area along with the Sandbar willow.

Finally, casual observations were also made during monitoring of fish already inhabiting the new creek. Game (trout) and non-game (suckers) fish were observed in the newly created habitat consisting of stable banks and overhead cover created by the various willow treatments.

PROJECT COST

A primary interest of this project was to assess the cost/benefit of various bank stabilization designs. Costs for all project elements are summarized as follows.

Design Cost. The engineering design cost for the 13-bioengineered treatments was minimal and is not included in the implementation cost (Table 4). However, design and willow preparation cost is included for that portion of the IVT treatment involving the two staggered rows of cuttings planted behind the eight different bioengineered bank treatments (Table 1, Fig. 2-7).

Implementation Cost. Implementation costs for constructing the bioengineered treatments included toe material, willow bundles, fabric, excavator time and incidentals. Cost for incidental(s) included stakes, rebar, flags, micorrhiza, polymer, and safety related equipment. Costs for travel, lodging, per diem and oversight are not included in the following breakdown.

Labor cost for planting those treatments requiring willows (e.g., 10 of the 13 banks) required wattling and brush layering) was included in the willow harvest cost per bundle ($15). Therefore, the cost for harvesting and planting 1,020 willow bundles was $15,300 (1,020 X $15). Planting required an excavator and operator for five days to construct the four-foot deep trenches into which the willow bundle stems were placed at a cost of

$6,000 plus $500 for mobilization (total $6,500). Five different banks measuring 650 linear feet were treated with 32 biologs measuring 20 feet long and 16 inches in diameter. Log cost and installation was $280 each for a total cost of $8,960 or $14 per foot. A total of eight rolls of erosion control fabric (COIR cf #7) measuring 6.6 feet wide and 165 feet long was applied at nine of the thirteen treated banks. Fabric cost $245 per role (120 sq. yd.) delivered to the construction site and $21.32 per role for installation (0.02 cents/sq. ft) ($245 + $21.32 = $266.32/roll) for a total fabric cost of $2,130.56.

In summary, no willows were used with three of the five banks treated with biologs for a total length of 400 feet. The remaining ten banks measuring 1,143 feet were treated with wattling, brush layering or a combination. Nevertheless, the combined cost for willows ($15,300), excavator ($6,500), biologs ($8,960), and fabric ($2,131) totaled $31,890 or an approximate average cost of $17.30 per foot.

Cost of Willow Portion of IVT (at the 13 Banks)

Implementation of the entire 7,000 foot IVT treatment required an excavator with a dibble bar to poke 3 to 4 foot deep holes for inserting 2-3 stems/hole at a $3,600 cost plus $500 for mobilization for a total cost of $4,100. The 13 treated banks extended 1,843 feet or 26% of the total IVT treatment length (7,000'). The excavator/operator machine time cost was 26% of $4,100 or $1,066. A total of 614 willow bundles at $15/ bundle were required to plant the two staggered rows of cuttings behind the 13 banks receiving treatment at a total cost of $9,214 (incl. harvesting and planting). Therefore, cost of the willow portion of the IVT treatment (2 rows) was $10,280 (excavator time $1,066 + willow/planting $9,214 = $10,280) or approximately $5.58 per foot.

In summary, the overall cost for the IVT treatment ($10,280 or $5.58/ft.) and the 13 bioengineered bank treatments ($31,890 or $17.30/ft.) totaled $42,170 or an approximate average per foot cost of $22.88.

Cost per Foot

Table 4 is a cost per foot comparison of the bioengineered treatments with a riprap treatment designed for the Cashe La Poudre River, Colorado: a Corps of Engineers project. The specifications required type M riprap ten feet wide and two feet thick at $12/ton (4 tons/lf = $48/ft). The riprap was transported to the site (2 hr. @ $65/hr. = $130) with a 22 cubic yard end dump that translates into $11.81 per ton. An excavator was used to place the riprap at $4.33 per foot and eight inches of soil was placed on top (0.9 cents/sq./ft). The area was then seeded for 0.6 cents per square foot. Therefore, the cost of a typical riprap bank treatment was $65.64 per lineal foot.

Costs for both the hard and soft bank treatments assume eight to ten feet of bank coverage per lineal foot extending from the channel invert upward and the ability to withstand water velocities of 10 feet per second or greater. Costs per foot for the bioengineered treatments ranged between $14.50 (IVT only, 3 rows) and $43.00 depending on treatment complexity. Treatments requiring brush layering used one bundle

of 10 stems per foot ($15). The IVT only treatment (assuming 3 rows with 3 stems/hole) averaged one half of bundle per foot ($7.50). IVT treatment planted behind and in combination with the bioengineered treatment used one-third willow bundle per foot at a cost of $5.00. Wattling used one-third of a bundle per foot of overlapping stems at a cost of $5.00 per foot. The total individual cost per treatment can be calculated by using the total length treated (Table 1) by the total cost per foot (Table 4).

LESSONS LEARNED

Major lessons learned from this project included:

- IVT (only) as designed and constructed in this project, was very successful in stabilizing newly constructed streambanks (rapid willow growth and lower mortality that in other comparable projects in the basin).
- Use of intensive treatments (biologs, brush layering, wattles) may not be needed in conditions with controlled flood flows during the initial 2 to 5 growing seasons.
- Fabric on banks is not necessary if flood flows are controlled in the initial 2-5 post construction years.
- Willow preparation steps, as used in this project, are critical for success of rapid willow establishment.
- Given general cost/benefit assessment (cost per foot, Table 4, and bank stability using qualitative observation and quantitative measurement), no one bioengineered bank treatment is a preferentially better performer using strictly the costs per foot of each treatment, treatment 3 (wattle toe, IVT) and 9 (IVT only) appear preferred.
- Willow cuttings with diameters in excess of one inch showed higher survival rates and better growth than cuttings with diameters less than one inch.
- Brush layering appeared equally successful with or without a protective toe constructed with either wattling or biolog.

Other lessons learned.

- Wattling must be located where soil moisture is high but not flooded or submerged. When soil moisture conditions are excessively wet, willow cutting survival and growth was decreased.
- Growth rate was similar for willow cuttings used for brush layering, wattling or as willow cuttings planted in holes created with a dibble bar (IVT).

Conclusion

Second year monitoring indicated a highly successful stabilization project based on absence of erosion, vegetation survival, density, growth, and streambank stability. The design objectives have been met. The concave, convex and straight reaches of the streambanks are stable, riffle/run/pool habitat is present, several species of fish have been observed, waterfowl have become residents, and site aesthetics are developing as expected. The Lower Area One, Phase I, Segment II should be an example project of how traditional nonfunctional hard riprap stabilization approaches can be replaced by biologically functional bioengineered approaches to erosion and bank stabilization challenges. Much information on specific designs and construction techniques are

transferable to other projects, given proper caution that flood flows were controlled for up to 5-years post construction.

Acknowledgments

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Table 1. Bank number, treatment type and length.
IVT = Intensive Vegetation Treatment

Bank Number	TREATMENT TYPE	Treatment Length ft.	Treatment Type Subtotal ft.	Toe Treatment Subtotal ft.
10	1. Wattle Toe, Brush Layer, Fabric, IVT	105	-	
12	1. Wattle Toe, Brush Layer, Fabric, IVT	205	310	
24	2. Wattle Toe, Fabric, IVT	205	-	
25	2. Wattle Toe, Fabric, IVT	65	270	
26	3. Wattle Toe, IVT	100	100	
	TOTAL	680		680
7	4. Biolog Toe, Fabric, IVT	80	380	
28	5. Biolog Toe, IVT	160	-	
30	5. Biolog Toe, IVT	160	320	
3	6. Biolog Toe, Brush Layer, Fabric, IVT	100	-	
5	6. Biolog Toe, Brush Layer, Fabric, IVT	150	250	
	TOTAL	**650**		650
22	7. Brush Layer Toe, IVT, no fabric	72	72	
23	8. Brush Layer Toe, Fabric, IVT	165	-	
29	8. Brush Layer Toe, Fabric, IVT	276	441	
		513	= 1,843 (0.35 mile)	513
Control banks	9. Intensive Vegetative Treatment only (IVT)	12,257		

Table 2 **Number of willow cuttings planted per meter and number and number and percent survival.**

Bank Number	Treatment Type	Average Live/M #/m	Average Live/M %	Average Dead/M #/m	Average Dead/M %
3	Biolog Toe, Brush Layer	17	68	8	32
5	Biolog Toe, Brush Layer	14	61	9	39
10	Wattle Toe, Brush Layer	20	65	11	35
12	Wattle Toe, Brush Layer	17	57	13	43
23	Brush Layer, Fabric	16	70	7	30
29	Brush Layer, Fabric	14	64	8	36
	AVERAGE	**16.3**	**64**	**9.3**	**36**

Table 3 **Willow cutting growth at end of second growing season.**

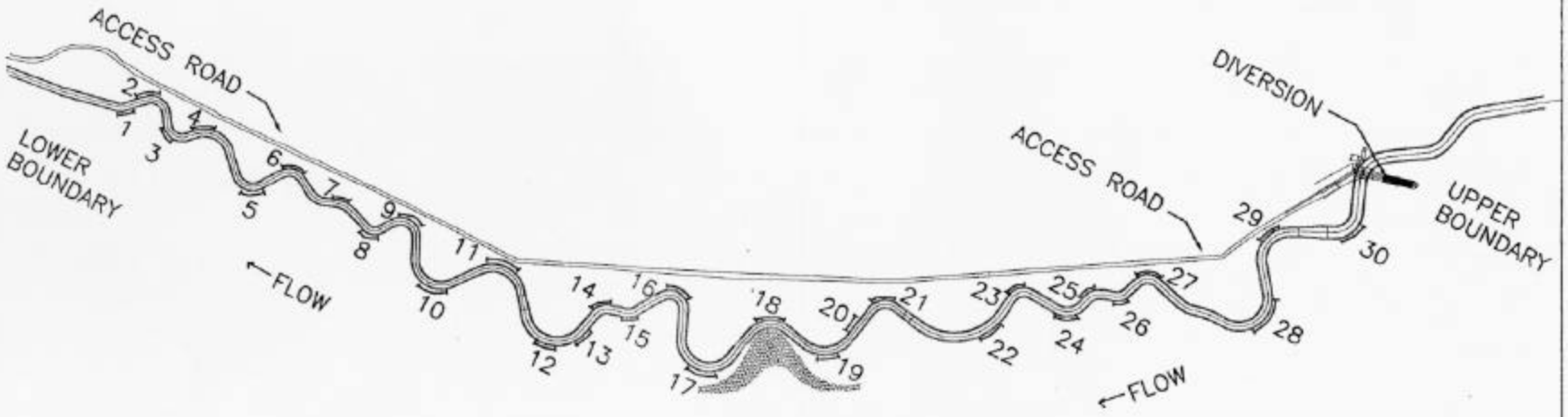
Bank Number	Treatment Type	Average Height ft.	Maximum Height ft.
2	Intensive	4.2	8.2
3	Biolog Toe, Brush Layer	4.6	7.4
5	Biolog Toe, Brush Layer	4.1	7.7
10	Wattle Toe, Brush Layer	4.4	7.8
23	No Toe, Brush Layer	4.0	8.6
29	No Toe, Brush Layer	4.1	6.8
	AVERAGE	**4.2**	**7.8**

Table 4: Cost per lineal foot comparison of bioengineered and riprap treatments. Costs assume completion of bank shaping/grading; all treatments extend 8-10 lf up the bank. Water velocities are assumed to be 10ft./sec. IVT=2 rows unless indicated otherwise and one-third bundle per foot at $5.00.

Treatment Type	Toe Material $	Willow Bundle $	Fabric[2] $	Excavator[5] Time $	Incidentals[6] $	Total $
1. Wattle Toe[1], Brush Layer, Fabric[2], IVT	5.00	20.00	2.00	4.00	3.00	34.00
2. Wattle Toe, Fabric, IVT	5.00	5.00	2.00	4.00	3.00	19.00
3. Wattle Toe, IVT	5.00	5.00	0.00	4.00	3.00	17.00
4. Biolog Toe[3], Fabric[2], IVT	14.00	5.00	2.00	4.00	3.00	28.00
5. Biolog Toe, IVT	14.00	5.00	0.00	4.00	3.00	26.00
6. Biolog Toe, Brush Layer, Fabric, IVT	14.00	20.00	2.00	4.00	3.00	43.00
7. Brush Layer Toe, IVT	15.00	5.00	0.00	4.00	3.00	27.00
8. Brush Layer Toe, Fabric, IVT	15.00	5.00	2.00	4.00	3.00	29.00
9. IVT only[7] (3 rows)	0.00	7.50	0.00	4.00	3.00	14.50
Riprap[8]	-	-	-	-	-	$65.64 lf

Footnotes
1. Wattling = overlapping cuttings tied and wired together: eight inches in diameter
2. Fabric = 6.5 feet wide and 165 feet long, material and installation
3. Biologs were 16" in dia. and 20' long
4. Brush layering equal one cutting per inch i.e., or one bundle per foot
5. Excavator time = $4.00 per lineal foot
6. Incidentals = micorrhiza, polymer, osmocote, stakes, wire, rebar, etc.
7. IVT @ 2' centers requires 1/2 bundle per lineal foot.
8. See text.

SILVER BOW CREEK



NUMBERS INDICATE LOCATIONS OF
BIOENGINEERED STABILIZATION TREATMENTS

FIGURE 1

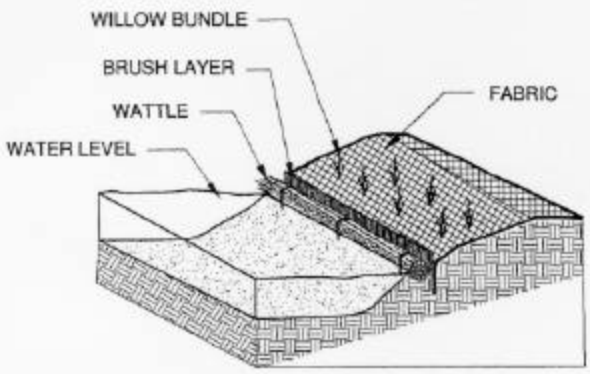


FIGURE 2. WATTLE TOE, BRUSH LAYER, FABRIC, IVT (TREATMENT 1)

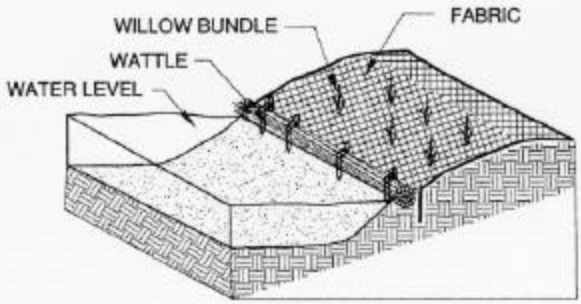


FIGURE 3. WATTLE TOE, IVT, FABRIC (TREATMENT 2)

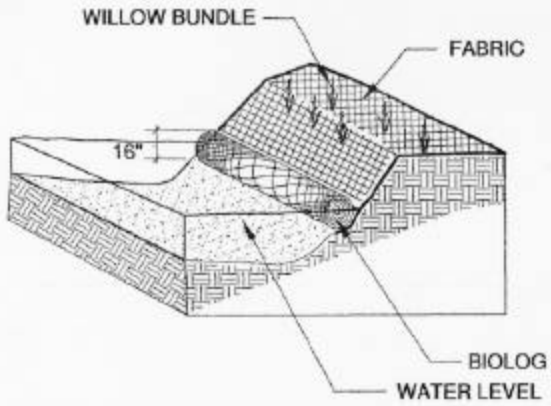


FIGURE 4. BIOLOG TOE, IVT, FABRIC (TREATMENT 4)

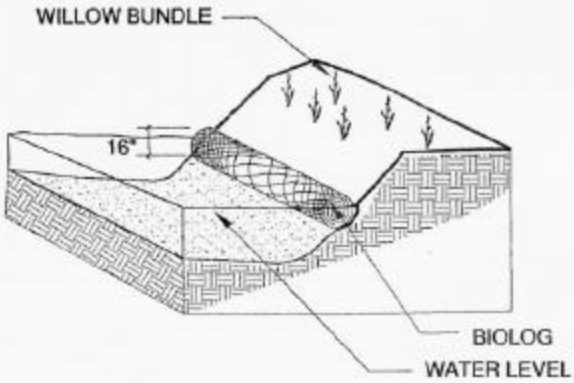


FIGURE 5. BIOLOG TOE, IVT (TREATMENT 5)

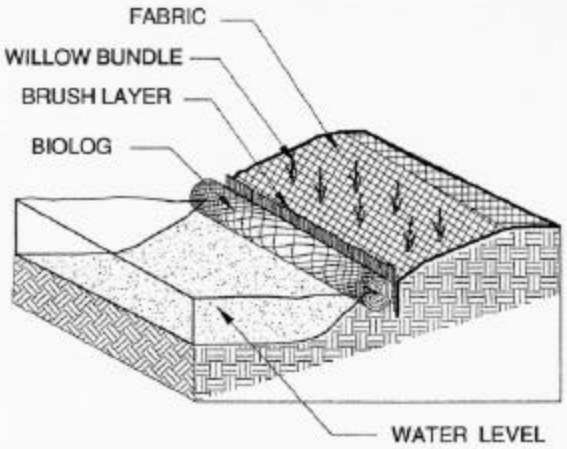


FIGURE 6. BIOLOG TOE, BRUSH LAYER, FABRIC, IVT (TREATMENT 6)

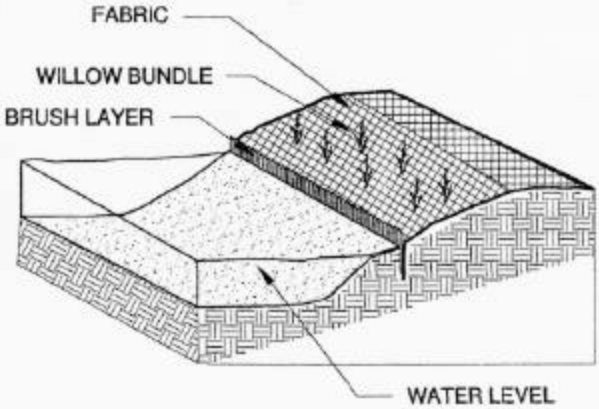


FIGURE 7. BRUSH LAYER TOE, IVT, FABRIC (TREATMENT 8)

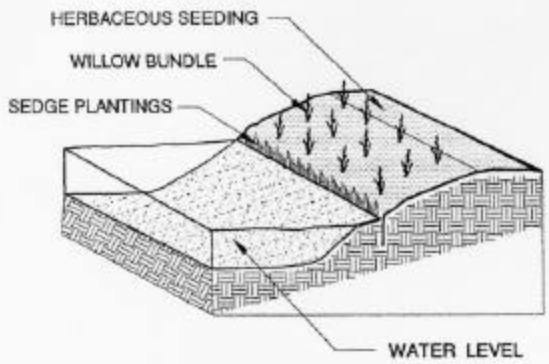


FIGURE 8. IVT (TREATMENT 9)

2000 Billings Land Reclamation Symposium

An Evaluation of Revegetation Success Within a Floodplain System Impaired by Sulfide Mine Waste

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Abstract

The long-term reclamation success of the stream portion of the LAO Operable Unit (LAO OU), a riparian system impaired by mining and development activity downstream of Butte, Montana, depends on vegetation to minimize floodplain erosion and stabilize streambanks. Another key objective of the LAO project is restoring the area to a naturally functioning riparian habitat. Reclamation activities at LAO entailed mine tailings removal, backfilling with unimpacted material, construction of a meandering stream channel and 100-year floodplain, and revegetation of the reconstructed floodplain. As part of the revegetation design process, LAO was divided into four hydrologic zones, streambank, wetland, subirrigated, and upland. Species selection and placement was based primarily on these zones.

Revegetation efforts initiated in October 1997 and completed in October 1998 consisted of seeding herbaceous species; planting dormant cuttings and containerized woody and wetland species; and transplanting trees and large willow shrubs. Silver Bow Creek streambanks were stabilized with cuttings planted at high densities and bioengineered streambank stabilization treatments.

The site was monitored qualitatively in 1998 and 1999 to provide data to support post-construction management decisions and to determine the success of the planting effort. With few exceptions, estimated cover values in 1999 ranged from 55% to 75% on upland zones and 75% to 95% on subirrigated, streambank and wetland zones. The diversity and seedhead production of seeded species increased notably from 1998 to 1999. Few areas of erosion or weed infestations were observed. The major concern in the initial post-construction phase is weed invasion. Weed control measures consisting of manual pulling and spot spraying were effective in minimizing the spread of invasive species. The majority of containerized plants exhibited good vigor and low mortality. Greater than 90% of several thousand cutting planted along streambanks have survived to date, exhibiting excellent growth and vigor and extensive root systems.

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INTRODUCTION

Between 1881 and 1910, eight ore-processing plants flourished in Butte, Montana, including the Butte Reduction Works and the Colorado Smelter. Tailings, a byproduct of the historic smelting processes, were deposited along a stretch of Silver Bow Creek (SBC) between the Reduction Works and Colorado Smelter. The tailings wastes led to the loss of vegetation and wildlife, leaving roughly 43 acres barren and sterile for over 80 years. This barren area, Lower Area One (LAO) is shown below.

Lower Area One (before tailings removal) looking east

After eight years of study, a cleanup plan was developed for LAO that divided the project into two phases. The first phase, completed between 1993 and 1998, entailed removal of approximately 1.2 million cubic yards of tailings, reconstruction of the SBC channel and floodplain, and restoration of the reconstructed riparian system. Once the tailings were removed, the excavated areas were backfilled with soil from borrow sources located near Butte. A meandering stream channel and 100-year floodplain were subsequently constructed and revegetated, essentially completing reclamation of the southern portion of LAO. The second phase of the project addressing reclamation of the northern portion of LAO is expected to be completed at a future date (2002-2004). It is not part of this paper.

Revegetation of the SBC streambanks and floodplain was integral to the long-term objectives of the project; specifically, floodplain erosion control, streambank stabilization, and restoration of the site to a naturally functioning riparian habitat. This paper describes the revegetation design and implementation process used at LAO, beginning in 1996 and ending in October 1998. The paper summarizes post-construction qualitative monitoring results collected in 1998 and 1999, concluding with an assessment of the selected revegetation methods and the applicability of the methods to other sites. Design and implementation details are presented in the Interim Revegetation Design for LAO, Phase I, Segment II (ARCO 1997); Draft Post-Construction Summary Report for LAO Revegetation (ARCO 1998a); and Draft LAO 1998 and 1999 Qualitative Vegetation Monitoring Reports (ARCO 1998b and 1999).

REVEGETATION DESIGN APPROACH

The revegetation design approach was based on a combination of principles from reclamation science, direct experience gained from various demonstration projects in the Butte/Anaconda region (ARCO 1989, 1994, 1996), and indirect experience of revegetation experts. The first step in the revegetation design process was characterization of the site's post-construction soil, topography, and hydrology. Design elements addressed site-specific physiographic and hydrologic conditions and soil substrate characteristics of the borrow material, forming the basis for selection of plant species and materials best suited to LAO.

The physiographic location of a particular plant species depends, in part, on its tolerance to inundation, saturation, and desiccation, which is related to the duration of low and high flows of surface water and groundwater. The reconstructed stream channel, streambanks, floodplain, and dike areas of the SBC corridor differed in hydrologic and topographic setting. For design purposes, the floodplain corridor was divided into four revegetation zones according to hydrologic regime. Wetland, subirrigated, and upland zones were delineated according to groundwater depth thresholds. The streambank zone was defined on the basis of proximity to the stream channel where vegetation was subject to extended periods of inundation.

The revegetation zone descriptions incorporated definitions of duration and frequency for inundation and saturation from various literature sources (National Research Council 1995; Hansen et al 1995). Establishing minimum thresholds for groundwater depth based on existing data provided a means to delineate planting zones onsite within a relatively short time period. Groundwater thresholds specified in Table 1 were assumed to occur for one to two weeks or more in May through June (high water flow conditions) at a frequency of one out of every two years.

Table 1-LAO Revegetation Zone Descriptions

Zone	Description
Streambank	Areas with nominal bank heights associated with a bankfull level of an instantaneous 2-year peak flow of 270 cfs in SBC. Incorporates bank toe, slope and top. The streambank zone encompassed approximately 1 acre.
Wetland	Areas saturated to a depth of 1 foot or less below the ground surface (bgs). The wetland zone encompassed approximately 9 acres.
Subirrigated	Areas saturated to a depth greater than 1 foot to 3.5 feet bgs. The subirrigated zone encompassed approximately 17 acres.
Upland	Areas saturated at depths greater than 3.5 feet bgs. The upland zone encompassed approximately 11 acres.

The revegetation zone boundaries were drawn on design maps according to the best available groundwater monitoring data. The zone boundaries incorporated construction specifications for backfill elevations. A minimum of 18 inches of finer-grained topsoil was placed in the streambank and upland zones. A minimum of 6 inches of topsoil material was placed where groundwater elevations were expected to be within 0 to 18 inches of the ground surface. A minimum of 12 inches of topsoil material was placed where groundwater was expected to be 12 to 36 inches bgs.

Plant Species Selection

The inherent heterogeneity of the SBC floodplain corridor was addressed by using different seed mixes, plant materials, and planting strategies for each vegetation zone. The goal of revegetating LAO according to four zones was to maximize the success of vegetation establishment given the anticipated post-construction soil and water conditions and to incorporate a diversity of vegetation typically found in a natural riparian area.

Species lists were formulated from several sources of information: existing or neighboring plant communities (survey of SBC by Bitterroot Native Growers); species performance on other reclamation projects; and consultation with Dr. Paul Hansen (University of Montana), Dr. Warren Keammerer (Keammerer Ecological Consultants), Dr. Chris Hoag (NRCS), Dr. Frank Munshower (Montana State University), Schafer and Associates, Aquatic and Wetland Consultants, Western Reclamation, and Circle S Seed.

Critical factors considered for development of herbaceous and woody species lists were adaptability to the defined hydrologic regime; ability to establish easily and quickly to facilitate soil stabilization and deter the initial invasion of undesirable volunteer species; and ability to minimize

weed competition. Cover soil characteristics, species diversity, and aesthetics were also considered. Selected plants were comprised primarily of native species. Naturalized species such as White Dutch clover and strawberry clover were used when availability of native species was limited.

Plant selection for the **streambank zone** focused on quick-establishing herbaceous species with a dense root mass that would aid in soil stabilization such as slender wheatgrass, Canby bluegrass, and strawberry clover. Woody species such as Bebb willow, Booth willow, sandbar willow, yellow willow, and red-osier dogwood were selected for ease of propagation and extensive root systems. Rhizomatous wetland species such as beaked sedge, Nebraska sedge, and hardstem bulrush were planted to facilitate erosion control at the base of the bank of the water's edge.

The **wetland zone** seed mix was a combination of species suited to temporarily and semi-permanently flooded soil conditions. The herbaceous species included fowl bluegrass, fowl mannagrass, ticklegrass, tufted hairgrass, and Baltic rush.

The **subirrigated zone** herbaceous species mix was designed to provide a broad range of adaptation for variable groundwater conditions. The list contained a range of grasses able to tolerate higher groundwater depths such as tufted hairgrass and alkali grass. Canby bluegrass, Great Basin wildrye, and Western wheatgrass were selected for adaptation to drier conditions. Woody species included plants suited to moist environments such as Booth and Bebb willow and plants adapted to drier environments such as Woods rose, Western serviceberry, golden currant, and common chokecherry. Quaking aspen and black cottonwood were designated for transitional areas between subirrigated and upland zones.

The **upland zone** herbaceous mix was designed with species that tolerate drought and reduce weed competition by establishing quickly and by developing rhizomatous root systems. The species included sheep fescue, bluebunch wheatgrass, Indian ricegrass, and white yarrow.

Plant Material Selection

A variety of plant materials were utilized to better ensure vegetation success within each zone. Species, plant location, availability, and cost dictated the material used. An important component of the planning process was the identification of sources, availability, and costs of the various seed mixes and plant materials in order to procure the required materials prior to construction.

Direct seeding was implemented sitewide using seed mixes customized to each zone. Some of the wetland species for the floodplain wetlands were direct seeded with a specialized mix tested in similar climates. **Cuttings** were used extensively to establish woody species on streambanks and to provide long-term bank stabilization. Additional

stability on outside curves was provided by planting multiple cuttings per hole with the holes placed at high densities. Cuttings provide several advantages as a plant source including a high concentration of root primordia, a large size that out-competes other species, minimal disturbance to soil during installation, a means of reaching the water table on steep and high bank slopes, and use of native genetic plant material. The success of the cuttings was optimized by using specific harvesting and planting procedures such as collecting select species and sizes, utilizing healthy stock material, storing harvested cuttings in oxygenated water, and properly timing harvesting and planting. **Containerized species** were used to add immediate visual impact, an established root system, aboveground growth, and carbohydrate reserves that enhance survival. The revegetation design specified the use of tubelings and 1- and 5-gallon containerized plants. **Transplants** were to be used on a limited basis in the original design. One of the changes made prior to planting was to increase the number of large containerized plants (10- and 15-gallon) and transplants to provide seral variability, quick maturity, and aesthetic enhancement.

REVEGETATION IMPLEMENTATION

Planning

Final design maps delineated the revegetation zones, plant clusters, and associated seed mixes, seeding methods, and plant materials. Live plant material clusters were numbered on the maps and identified according to plant community type. Streambank curves were also numbered and designated as straight reaches, inside curves, or outside curves depending on planform position. Once the design maps were completed, the revegetation zones and cluster locations were staked in the field prior to seeding and planting.

The SBC channel was reconstructed in Fall 1997 followed by seeding of the majority of the site in November 1997 and March and May 1998. The cuttings were harvested in early April 1998. Cuttings and the majority of containerized plants were planted from late April to early May. Wetland and woody tubelings and 1-gallon willows were planted in mid-May.

Installation

Seeding

Drill seeded areas were fertilized and chisel plowed before seeding. Seed for the upland, subirrigated, and wetland zones was applied with a custom drill seeder. The seeded areas were mulched and crimped with weed-free wheat straw mulch at a rate of approximately 3,000 pounds per acre. To minimize erosion, most of the streambanks were hydroseeded with a mixture of seed, mulch, and tackifier. Steep upland slopes and wet areas were hand-broadcasted.

Cuttings Harvest and Installation

The design for streambank revegetation, willow wattles (willow bundles laid at bank toe), and brush layering (intensive planting of cuttings at the bank toe) required a total of 20,000 willow cuttings. The criteria for selection of the cuttings specified collection of the stems from healthy stands in the spring before bud break. Willow stems were 1 to 2 inches in diameter and 5 to 7 feet long. Once harvested, the cuttings were stored in oxygenated water for 7 to 10 days to remove anti-rooting hormones. Cuttings were planted to base flow groundwater depths with the aid of a dibble bar mounted on a trackhoe. After insertion, fertilizer pellets and sand were added to the holes. The sand was compacted to ensure adequate soil/stem contact. Each hole was watered thoroughly after planting.

Containerized Plants and Transplants

The holes for the containerized plants were dug manually as a result of restricted equipment access. Fertilizer pellets were added to containerized plant materials. Approximately 1,213 woody tubelings, 5,700 wetland tubelings, and 1,270 1-gallon, 270 5-gallon, and 36 15-gallon containerized plants were installed. Access restrictions limited the number of transplants installed. A tree-spade was used to harvest and plant approximately 40 black cottonwood, quaking aspen, and Booth, Bebb, Geyer, and sandbar willow transplants.

ONGOING SITE MANAGEMENT

Ongoing monitoring and maintenance of vegetation after planting is critical to the success of the planting effort. Temporary irrigation was used at LAO to aid the establishment of containerized and tranplanted woody plants located on the floodplain and upper streambanks. Portable pumps and hoses were used to irrigate portions of the site during the first two growing seasons. The condition of the containerized plants and transplants will be assessed in the third season to determine if additional irrigation is needed. Onsite noxious weeds have been controlled using a combination of manual removal and chemical spraying. Areas adjacent to LAO were blanket sprayed to limit the migration of weed seeds to the site. The site was fertilized in late August 1998 and again in November 1999.

QUALITATIVE MONITORING RESULTS

Qualitative monitoring was conducted at LAO in 1998 and 1999 to evaluate general site conditions, uniformity of vegetation cover, presence of bare or chlorotic zones, evidence of reproduction, weed infestations, and erosive areas. Permanent cover transects, belt transects, and monitoring sites (plant clusters) were established within representative zones, streambank curves , and plant cluster types across the site. Each transect and monitoring site has been photodocumented. Cover for seeded species was estimated visually along each monitoring transect. Survival rates for

cuttings and containerized species were estimated based on individual plant counts within plant clusters and belt transects. Counts were completed immediately following construction and in the two subsequent growing seasons. Quantitative monitoring will be completed in year 3 using appropriate statistical methods to ensure data usability. Site-specific performance standards will be developed for LAO that will be closely tied to management objectives and proposed land uses.

1998 Qualitative Monitoring Results

First year qualitative monitoring was conducted in late August 1998. With few exceptions, estimated cover values on monitored wetland sites ranged from 75 percent to 90 percent. Cover on subirrigated sites was estimated at 60 percent to 90 percent and on upland sites, at 35 percent to 60 percent. In general, areas that were drill seeded in fall 1997 exhibited higher cover values and greater diversity than areas drill seeded in spring 1998. Cover in the wetland and subirrigated zones was typically higher, likely the result of greater groundwater availability. The upland areas at LAO are primarily located on steep slopes that do not retain moisture as well as flat terrain. Streambanks that were hydroseeded in March 1998 exhibited excellent growth by August with estimated cover values ranging from 80 to 90 percent. Diversity was reduced on hand-seeded banks, likely the result of inadequate mixing of the seed mix. Few areas of erosion or weed infestations were noted. Small infestations of spotted knapweed were observed particularly on the streambanks in the east portion of the site. Isolated areas of erosion were observed in areas where seeding was delayed. No erosion rills or gullies were observed on upland slopes.

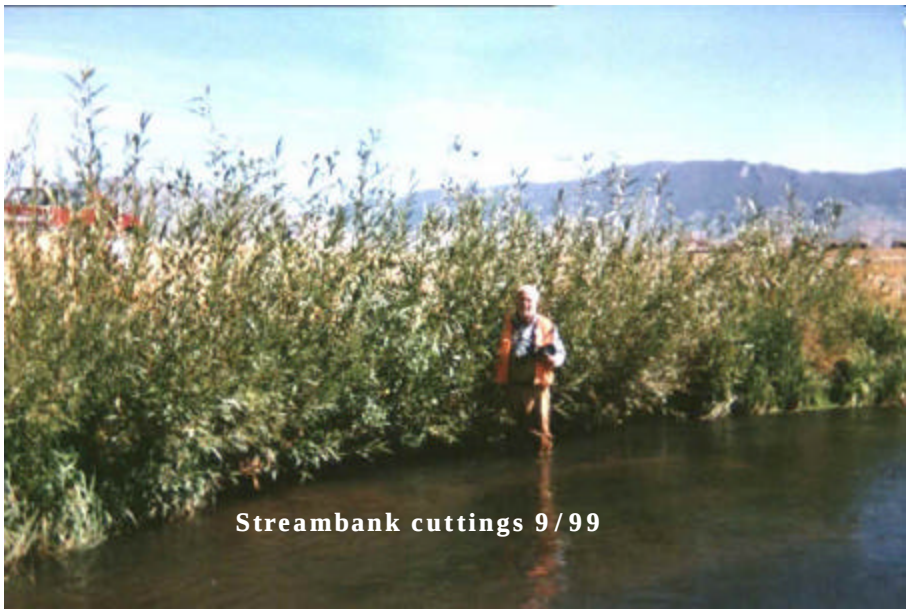
Throughout the site, the cuttings exhibited excellent growth and survival reaching heights of up to three feet by August 1998. Yellow willow species appeared to be the most successful of the species propagated. The majority of containerized plants exhibited good vigor and low mortality within the belt transects monitored. Some mortality was noted in the large containerized and transplanted black cottonwood and quaking aspen trees. Wetland tubelings planted on the streambanks showed excellent growth and vigor throughout the site.

1999 Qualitative Monitoring Results

Qualitative monitoring was conducted for the second year in mid-August, 1999. Second year monitoring results indicated higher species richness sitewide, particularly in areas seeded by fall 1997 and spring 1998. Species such as Indian ricegrass, Western wheatgrass, fringed sagebrush, white yarrow, sheep fescue, cicer milkvetch, sloughgrass, bluebunch wheatgrass, yellow sweet clover, mannagrass and rush species were either observed for the first time or occurred at a higher frequency. Sitewide cover improved notably from the first to second year of monitoring. Seeded plants displayed excellent vigor and seedhead production. Wheatgrass species were 3 to 4 feet high. Estimated cover contributed by volunteer wheat

introduced with the straw mulch decreased in 1999. Cover range estimates reported for 1999 included results for areas seeded in late fall 1998 that were not monitored in August 1998.

Streambank cuttings just after planting 5/98



Streambank cuttings 9/99

Planted and seeded wetland species in inundated or saturated wetland perimeters were robust, especially hardstem bulrush, Baltic rush, Nebraska and beaked sedge, common rush, and creeping spikerush. Containerized willows and volunteer cattails exhibited good growth and vigor. Vegetation was slow to establish in drier areas of the wetland seeded in October 1998. Estimated cover ranged from 90 percent on wetland areas

seeded in November 1997 and March 1998 to 35 percent on the area seeded in October 1998. Cover on subirrigated sites was estimated at 60 percent to 90 percent. Cover on upland sites ranged from 55 percent to 70 percent, slightly higher than in 1998. Species in the subirrigated zone were dominated by slender and thickspike wheatgrass, Canby bluegrass, tufted hairgrass, meadow foxtail, Western wheatgrass, and alkali sacaton. Dominant upland species included streambank wheatgrass, Canada bluegrass, sheep fescue, Great Basin wildrye, bluebunch and Western wheatgrass, white yarrow, Indian ricegrass, blue flax and fringed sagebrush. No signs of erosion were observed in 1999. Several isolated areas of spotted knapweed were noted. The cuttings continued to exhibit excellent growth, vigor, and extensive root systems as evidenced by hundreds of new willow shoots at the root stem. Survival rates for cuttings planted using a dibble bar on monitored streambank sites were greater than 90 percent. The majority of cuttings were 4 to 7 feet high. Yellow willow, Booth willow, and sandbar willow appeared to be the most successful species based on height, vigor, and aboveground biomass.

The majority of containerized plants exhibited good vigor although some mortality was observed in 1999, particularly in the east end of the site where soil clay content was higher and ponded groundwater was observed. Seventeen 5-gallon and 15-gallon quaking aspen, red-osier dogwood, common chokecherry and black cottonwood plants died within the sites monitored. Approximate mortality rates for containerized plants were 10 to 15 percent. Approximately 3 to 5 transplants out of the 40 planted did not survive.

CONCLUSIONS

The revegetation design strategy for LAO was unique, driven by LAO's high-profile location and the goal of establishing a restored floodplain and recreational end land use. Although there was no regulatory incentive, several components of the LAO design exceeded standard reclamation practices and tended toward habitat restoration. Long-term bank stabilization and vegetation growth were facilitated by diversion of peak flows from the SBC channel for 5 years, which was unique to this site. The backfill material met strict soil criteria standards for growth media. The revegetation design accounted for varying hydrologic and topographic conditions by delineating four revegetation zones and by tailoring species and and plant material selection to these four zones. Containerized plant materials and transplants were used extensively to provide more immediate visual impact and diversity.

Facets of the LAO revegetation design may have limited applicability to other reclamation sites, primarily when considering the cost versus benefit. Labor costs for implementation alone (excluding design costs) were approximately $5580 per acre. Plant materials and seed mixes were approximately $1160 per acre. Although the containerized plants were visually effective, material and labor costs may be prohibitive on a larger

scale. Temporary irrigation is often necessary for optimum survival of containerized plants in southwest Montana, which can be extremely expensive and impractical in areas with limited water and access. Cuttings were planted at high densities at LAO to stabilize the banks and to ensure the establishment of streambank vegetation. Without flood diversion, the success of the cuttings observed to date may not have been feasible without erosion control fabric or bank toe treatments. The option of diverting flows is not available at most sites.

The implementation of the revegetation strategies at LAO provided important information that can be applied to other sites. The project demonstrated that the logistics of seeding and planting for four different revegetation zones was manageable and effective on a relatively large scale. Two years of qualitative monitoring indicate that selected herbaceous and woody species appear to be well-adapted to the respective hydrologic regimes. Based on floodplain and streambank vegetation maturity after two years of growth, the SBC channel may be able to withstand flood flows by the third year. Containerized material sizes should be streamlined to the extent possible. Planting would have been facilitated by limiting the number of sizes of containerized plants to either 1- or 5-gallon and 10- or 15-gallon sizes. Although woody tubelings are relatively inexpensive, their use complicated the planting effort. They were difficult to identify before and after planting and highly susceptible to damage. Wetland tubelings provided the only material source for several wetland species, and consequently, were a necessary part of the design.

The most notable success to date in terms of plant growth has been the cuttings planted on the streambanks. The design called for approximately 20,000 cuttings, which necessitated implementation of a well-defined plan for harvesting, transporting, storing, and planting the willow stems. The technical specifications were followed carefully with the exception that some of the cuttings planted at a later date were soaked in water for up to three weeks or stored under cold, wet conditions. This did not appear to compromise success. Cuttings were planted at especially high densities on the streambanks to allow for anticipated mortality rates of up to 50-70% estimated for cuttings subject to normal flood flow conditions. Actual mortality rates were closer to 10-15%. Planting cuttings at lesser densities would likely have been equally successful, given the fact that flood flows were being diverted.

Estimated cover percentages contributed by wheat during the first year of monitoring indicated that the mulch contained more cereal seed than recommended. Annual species tend to compete with seeded species for limited water and nutrient sources. Mulch should be certified weed-free with less than 5 percent cereal seed. Mulch stems should be 8 to 10 inches long to allow for a single crimping pass.

Weed control measures consisting of annual hand-pulling and spraying have been effective to date although manual removal would

become impractical on a large scale. It is important to note that regardless of the initial success of a diverse vegetation community, non-weedy volunteer species such as red top may eventually invade the site.

The long-term success of revegetation at LAO in achieving reclamation goals will be determined through continued qualitative and quantitative monitoring evaluated in the context of site-specific performance standards. The LAO SBC Revegetation Design implemented several innovative alternatives to standard reclamation practices in order to achieve project objectives. As discussed above, most were successful, some were not, while some were excessive when the cost was weighed against the benefit. The information gained on this project was valuable and can be used to facilitate the success of other stream reconstruction projects.

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2000 Billings Land Reclamation Symposium

CHARACTERIZATION OF MYCORRHIZAE AND SEED BANK COMPOSITION IN AN EASTERN MONTANA WETLAND

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ABSTRACT

The majority of soil survey work in the context of mine reclamation has focused on the physico-chemical quality of soil, with little attention to biological properties. This study characterizes the mycorrhizal colonization levels in wetland plants, mycorrhizal infectivity potential of wetland soils, and seed bank composition. The work took place in a portion of a drainage bottom that is classified as jurisdictional wetland at the Absaloka Mine (Westmoreland Resources, Inc.), Big Horn County, Montana. The hydric soil was moderately alkaline, non-saline, and rich in total nitrogen and phosphorus. Soil samples were collected along bank-to-bank transects across the wetland and analyzed for mycorrhizal inoculation potential and seed bank composition. Hydrophytic plants, including *Spartina pectinata*, *Carex nebraskensis*, and *Carex lanuginosa*, were analyzed for mycorrhizal colonization level. Mycorrhizal colonization levels were high in *S. pectinata* and *C. nebraskensis*. Mycorrhizal inoculation potential was also high, but decreased at the center of the wetland. The density of seeds in the seed bank did not differ between sites within the wetland. There was a high proportion of weed species found throughout the wetland. Understanding the role of AM fungi in wetland plant establishment will contribute to wetland soil handling and revegetation efforts. An assessment of the seed bank is also important prior to management decisions about using wetland soils as a source of seeds for restored wetland sites.

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INTRODUCTION

Despite the ecological significance of wetland ecosystems, our understanding of the ecological restoration of wetlands is at a rudimentary stage. Soil survey work in wetland reclamation on mine sites has focused primarily on the physico-chemical quality of soil, with little attention to biological properties. This study focuses on two biotic components of the soils: mycorrhizal fungi and the soil seed bank.

Vesicular arbuscular mycorrhizae (AM), otherwise known as endomycorrhizae, are a plant-fungal symbiosis, where the fungus (Endogonaceae) colonizes plant roots. The effect of AM on the host plant varies depending on environmental conditions, and ranges from mutualistic to parasitic (Johnson et al. 1997). The plant provides the fungus with a carbon source, while the fungus benefits the plant by increasing the uptake of nutrients (especially phosphorus) and water (Stahl 1998), and protecting the plant from pathogens (Newsham 1995).

Mycorrhizae may be especially important for plant success in disturbed areas (Allen 1989), and restoration ecologists have focused on methods to reintroduce mycorrhizal fungi to restoration projects, in an effort to speed succession on disturbed sites. The ecological role of mycorrhizae in wetlands and in wetland restoration has not been well investigated (Turner and Friese 1998). This study was undertaken to look for the presence or absence of mycorrhizal fungi along a wetland cross-section.

The seed source for revegetation of many wetlands comes from either the natural seed bank (Galatowitsch and van der Valk 1996), or propagule inflow (Mitsch et al. 1998). Because recommendations for wetland restoration include the use of intact wetland soils to serve as a source of native seeds (Galatowitsch and van der Valk 1994; Brown and Bedford 1997), it is important to assess the composition of wetland seed banks. This is especially true of wetlands that border on weed-infested land, since the establishment of unwanted, invasive species is a major problem for wetland restoration (Galatowitsch and van der Valk 1994).

Our research objectives were: 1) to measure the presence of mycorrhizal fungi in the wetland soils; 2) to assess whether there were significant differences in the occurrence of mycorrhizal fungi that correlated with a gradient across the wetland; and 3) to determine the density and composition of the wetland soil seed bank.

METHODS

Soil and plant samples were collected in May of 1998 from a wetland located on the Absaloka Mine, of Westmoreland Resources, Inc., east of Hardin in Big Horn County, Montana. The study site was located in Drainage 25 (T1N, R38E, sw quarter of Section 29). This segment (304 m) was located between an active stripping limit and a county road, and was scheduled to be disturbed in 1998.

The wetland occurred on a ½ percent slope, with an east aspect. It was a subirrigated upland drainage bottom with a trapezoidal shape. Mean annual precipitation at the mine is 343 mm, mean annual air temperature is 10°C, and the elevation is 1061 m. Soils were and hydric, with the following redoximorphic characteristics: H_2S present near the surface, matrix chroma # 2, oxidized and precipitated Fe or Mn, prominent

mottling below 6 inches of sediment, and prolonged ponding at localized depressions. Soil chemistry data are summarized in Table 1. The study area contained a mixture of native wetland plant species and exotic species including Kentucky bluegrass (*Poa pratensis*), Canada thistle (*Cirsium arvense*), and marsh sow-thistle (*Sonchus uligonosa*).

Plant and soil samples were collected from five sites along each of three transects that crossed the wetland, from N to S, for a total of 15 collection points. The transects were approximately 41 m apart. The five sites represented 2 bank midslopes (Sites 1 and 5), two edges of drainage bottom (Sites 2 and 4), and the center of drainage bottom (Site 3). The bank-to-bank distance ranged 41 to 51 m. The presence of mycorrhizae in the wetland soils was determined through two methods: direct assessment of colonization levels of plants found in the wetland, and inoculation potential of wetland soils.

Table 1. Drainage 25 soil chemistry data*.

Depth (m)	pH	Electrical Conductivity (dS/m)	Total Kjeldahl N (*u*g/g)	Total Olsen P (*u*g/g)	Organic Matter (%)	Texture
0-0.15	7.8	2.1	4983	8.6	11.6	L
0.15-0.3	8.1	1.0	2053	1.6	3.6	SiL
0.3-0.6	8.2	0.8	1163	1.2	1.8	L
0.6-1.2	8.2	0.8	477	<1	0.6	SL
1.2-1.5+	8.2	0.9	497	1	0.8	L

* Values represent the average of three profiles located at the center of the transects.

Mycorrhizal Colonization Levels

Nineteen plants were collected for determination of mycorrhizal colonization levels in the field. Plants were collected from the center of the wetland. Thirteen of the plants collected were from the genus *Carex*, and 6 plants were *Spartina pectinata. Carex* spp. A and B were not positively identified, because of the lack of reproductive structures available for species identification. They could be the young of the two identified species, or possibly *C. praegracilis*, which was identified in the mine vegetation baseline data.

Fine roots were randomly selected from each individual plant and prepared according to a modified Phillips and Hayman (1970) method. Root samples were soaked in 2.5% KOH for 48 hours, rinsed with distilled water, soaked in 3% HCl for 12 hours, and soaked in Trypan Blue stain for 24 hours. Mycorrhizal structures were quantified according to the magnified intersections method detailed by McGonigle, et al. (1990). Up to 151 intersections of root tissue were assessed per individual for presence of fungal hyphae, vesicles or arbuscules. Data were arc-sine transformed, and analyzed with two-way ANOVA, to test for effects of species or site effects on colonization levels. Post hoc LSD tests, alpha=0.05, were used to test for significant differences between samples.

Mycorrhizal Inoculation Potential

Mycorrhizal inoculation potential is a relative measure of the number of AM fungal propagules in the soil. Soil samples were placed in 750 ml pots, 12 cm dia x 12

cm high, and planted with Sudan grass (*Sorghastrum sudanese*) as a bait plant. After eight weeks plants were harvested, cleared and stained, and mycorrhizal colonization levels were quantified, as described above. A total of 96 intersections was assayed for each individual. Data was arc-sine transformed, and analyzed with a two-way ANOVA to test whether there were transect or site effects on colonization levels. Post hoc LSD tests, alpha=0.05, were used to test for differences between samples.

Seed Bank Analysis

Seed bank density and composition was determined by seedling emergence—soil samples are brought into the greenhouse and the quantity and identity of germinating seedlings is monitored. Seedling emergence is one of the most accurate measures for assessing community-level studies of seed banks (Gross 1990), including wetland seed bank studies (Poiani and Johnson 1988).

Two soil cores, 5.6 cm in diameter and 5 cm deep, were extracted from each of the 15 sample sites in May, 1998. Each core was split length-wise, and root segments were removed. Samples of soil were spread in small trays (17cm x 25cm x 8cm deep) on top of greenhouse potting soil and subjected to one of two treatments: moist soil or inundated soil with the water level 1 cm above the surface of the soil. Previous research has shown an increase in the number of germinants when both a moist and an inundated treatment are used (Bliss and Zedler 1998). Inundated pots were maintained for 6 months, during which time seedling emergence was negligible (2 graminoids total), so pots were allowed to dry, and kept moist to monitor subsequent germination. Pots were monitored weekly for number and identity of seedlings. Seedlings were grown until identification was possible, or until the end of this study, which lasted 15 months. Two way ANOVA was used to test that there were transect or site differences in the total number of seeds/m^2 and total weed seeds.

RESULTS

Plants collected from the field were mycorrhizal, with an average colonization level of 58%. Many of the fungal hyphae present in the roots were in small fragments, and not necessarily functional. This may be due to the timing of sampling, since AM activity is known to fluctuate seasonally (Koide and Schreiner 1992). Two-way ANOVA on the mycorrhizal data showed that there was a significant species effect on mycorrhizal colonization levels ($F_{4,19}$=6.27, P=0.007), but site was not significant ($F_{1,19}$=0.46, P=0.51). Colonization levels were significantly higher in *C. nebraskensis* and *S. pectinata* than in the other species of Carex (Figure 1).

Mycorrhizal infectivity potential was also high across soil samples. Between 53% and 86% of all root intersections had a fungal hypha, vesicle or arbuscule present. There was not a significant transect effect on inoculation potential of the soils ($F_{2,29}$=1.55, P=0.246), but there was a significant site effect ($F_{4,29}$=8.21, P=0.001). Site 3, which represented the wettest portion of the wetland, had the lowest level colonization, significantly lower than levels at Sites 1, 4 and 5 (Figure 2).

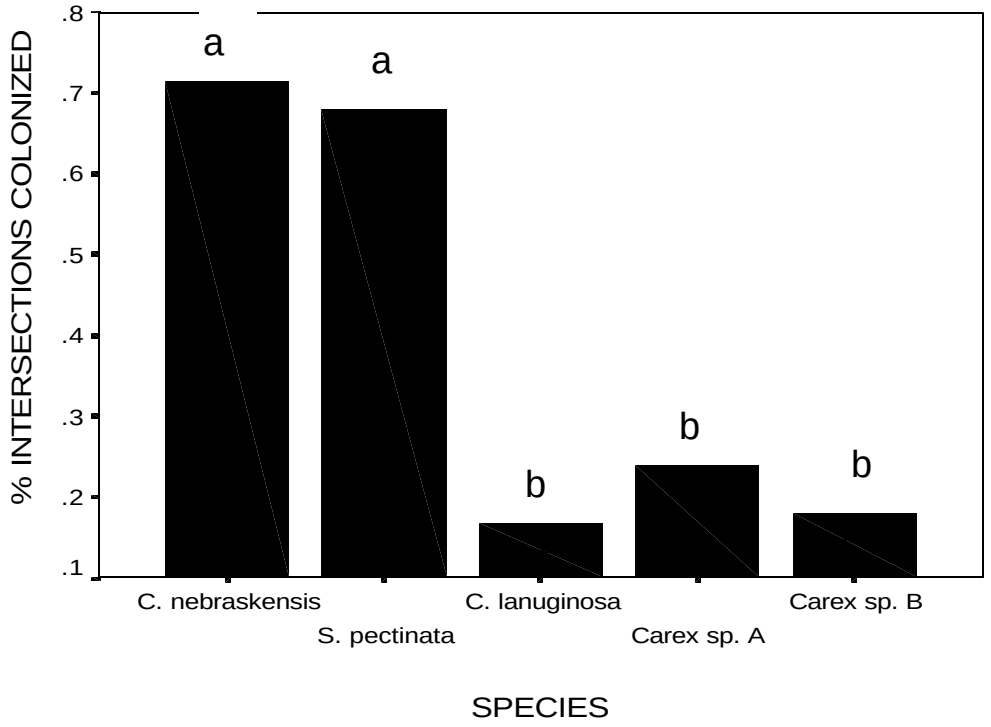

Figure 1. AM Colonization Level of Wetland Plants. Similar letters above bars indicate values that do not differ significantly.

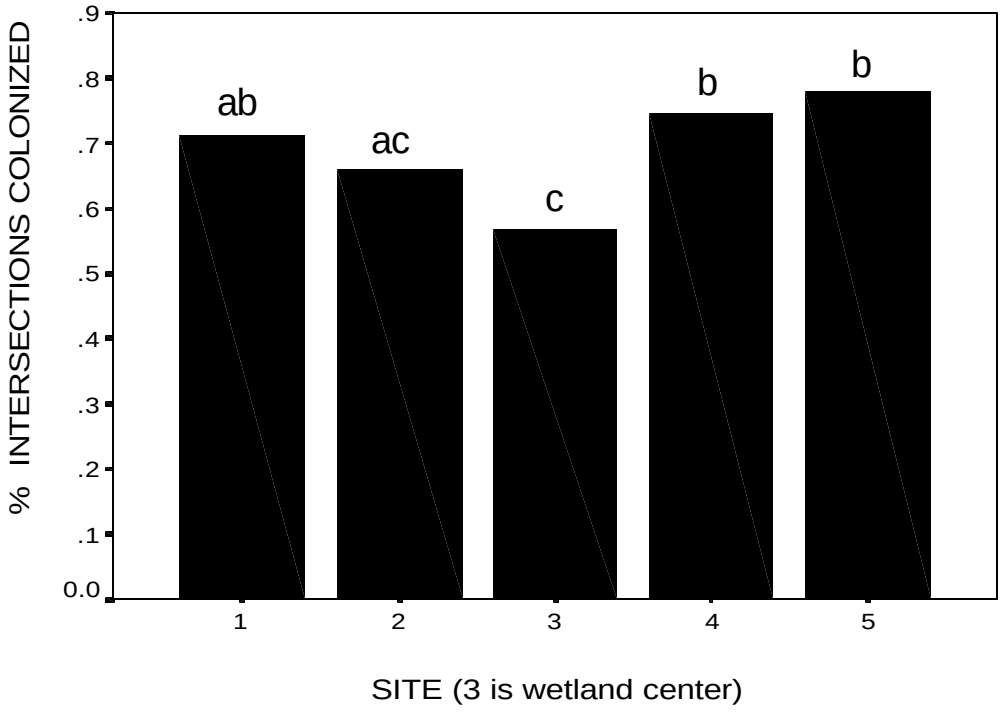

Figure 2. Mycorrhizal infectivity potential as measured by AM colonization level in bait plants. Similar letters above bars indicate values that do not differ significantly.

Seed bank density was 45,000 seeds/m^2. This estimate is high, but fits within the range found in other studies (Leck 1989). It should also be noted that this density estimate is based on a smaller than recommended number of cores used for the analysis (Brock et al. 1994). Density did not differ either across transects ($F_{2,14}$=0.05, P=0.95) or sites throughout the wetland ($F_{4,14}$=1.12, P=0.37; Figure 3).

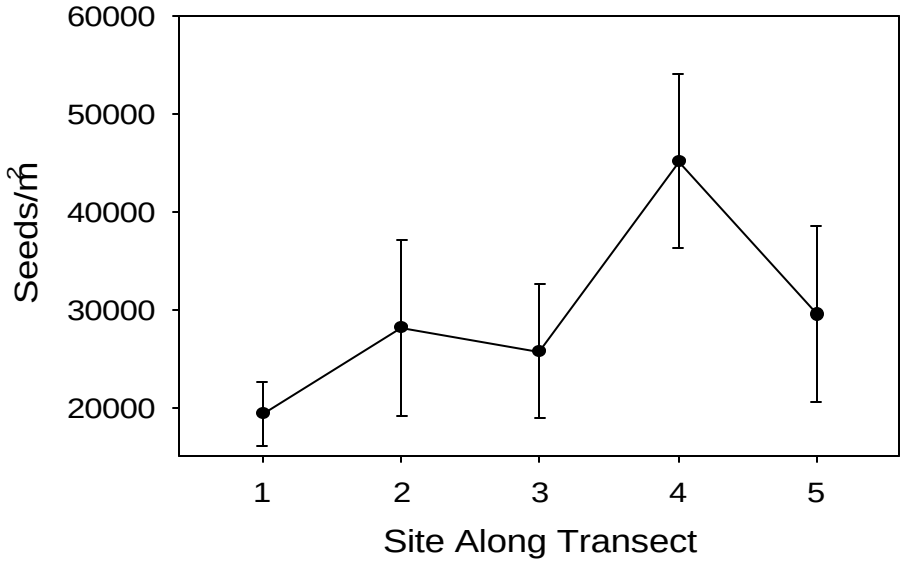

Figure 3. Seed bank density across wetland transects. Error bars represent the standard error of the mean. Site 3 is the center of the wetland.

There were a total of 18 taxa which emerged in this study (Table 2). Of the 10 taxa identified to species, 9 were non-native. The single native species was *Rumex salicifolius*, which occurred in 3 samples. The genus of *Carex*, not identified to species, also occurred in 3 samples. Unknowns E, J and N were relatively uncommon. Unknown K, tentatively identified as *Antennaria* sp., was a small rosette, with dark green, hirsute leaves. Graminoids were a large category that included a mixture of species, many of which germinated, produced one or two leaves, and then died. *Bromus tectorum* flowered, and *Poa pratensis* was identified by leaf traits. The category "seedlings" consists of individuals that germinated but did not attain a size that could allow for them to be categorized or identified.

Table 2. Number of seedlings emerged from 6 cores extracted from each site type (combined across transects). Total area sampled for each site type was 0.0015 m^2.

Species	Site 1	Site 2	Site 3	Site 4	Site 5
			Non-native forbs		
Chenopodium album	0	1	0	0	0
Cirsium arvense	1	0	4	8	0
Medicago sativa	0	0	0	0	1
Melilotus officinalis	0	11	1	4	3
Sonchus uligonosa	8	11	16	28	20
Taraxacum officinale	0	0	0	3	1
Thlaspi arvense	0	15	0	7	11
			Non-native graminoids		
Bromus tectorum	2	0	0	0	2
Poa pratensis	0	10	16	0	0
			Native forbs		
Rumex salicifolius	0	1	4	0	1
			Native graminoids		
Carex species	0	0	3	1	0
			Unknowns		
Unknown E	0	0	0	2	1
Unknown J	0	1	0	0	0
Unknown K	2	0	4	7	4
Unknown N	1	0	0	0	7
Graminoids	50	55	56	128	61
Seedlings	10	20	12	12	7

DISCUSSION

This study has shown two things that are relevant to mycorrhizae in wetland restoration. The first is that there is a fairly high concentration of mycorrhizal propagules present in the soil. The water table at this site was 48 inches below the surface, and while the soils are classified as hydric, the standing water may occur in relatively discrete patches, leaving much of the soil available to AM fungal colonization. And the second finding is that two of the dominant species in this wetland have a high level of mycorrhizal colonization.

While these results are of interest, especially in light of the increasing role of mycorrhizal fungi in restoration programs, it should be noted that we still have a very poor understanding of the functional role of mycorrhizal fungi in wetland ecosystems (Turner and Friese 1998). Future work should address the role of AM fungi in the establishment of wetland sites on recently restored sites. Sampling across time and with changing reproductive status of the host plant would help us to understand seasonal and phenological effects on mycorrhizal colonization (Koide and Schreiner 1992, Lu and Koide 1994). For example, AM may be more important during flowering and seed

production than during seedling establishment. This kind of information would be very important for restoration ecologists.

The potential for the seed bank to contribute to wetland revegetation has been shown in a number of studies (van der Valk and Pederson 1989), as has the effect of seeding on species diversity and richness of native wetland species (Reinartz and Warne 1993). A caveat added to recommendations for the use of "donor seed banks" is that they should be checked for problematic species (Galatowitsch and van der Valk 1994).

While the results of the seed bank study should be interpreted cautiously, because of the small sample size and the low success rate for growing species until they reproduced for positive identification, there are several points that can be gleaned from the data. The first is that there is a high percentage of weed species present in the seed bank. This suggests that the seed bank in this wetland is not a good source of native wetland species, but instead a source for non-native propagules. The high proportion of weedy species may be due to past grazing and the adjacent grazing-impacted land, which has a high proportion of non-native species. However, there may also be a potential for greater native species representation in the soils with the inclusion of root fragments. Native perennial vegetation may be most likely to propagate from root fragments as opposed to seeds.

While this study was small in scale, and covered only one site, the results underscore the importance of studying wetlands in their landscape context. Mycorrhizal fungi and seeds stored in the soil will be influenced by vegetation adjacent to the wetland. Studies that include gradients across the landscape will give us better information on how adjacent land use practices affect the soil biota of wetland fragments.

Finally, at this site, wetland soil was dewatered and salvaged in July 1998 and stockpiled to be used for wetland reconstruction at the end of mine life. While the practice of direct hauling of soil is preferred by Montana coal mines, the results of this study show there are pros and cons to the stockpiling approach. Long-term storage might diminish the reserve of weed seed over the next 10-20 years; it would certainly also destroy the integrity of the soil biota. Setting aside the wetland soil now, however, means that the mine will have the appropriate volume, texture and biological remnants at the end of mining to initiate wetland reclamation. If the wetland soil had been direct-hauled to reclaim a drainage bottom, it is likely that mycorrhizal propagules would survive the mechanical disturbance, but the weeds could outcompete the seeded native perennial species. Therefore, in the case of wetland replacement, the pros and cons of different soil handling options must be weighed by site-specific factors.

Because we did not identify the species of the mycorrhizae present in the wetland, we do not know if there were mycorrhizae that were unique to plants and soils that occupied the wet parts of the wetland. If such special adaptation exists, then a strong argument for using only the original soil for wetland reconstruction could be made, in hope of recovering the plant species which existed prior to disturbance. This concept then suggests the need for future studies to measure the survival and distribution of mycorrhizae in native soil, in soil stockpiles, and in reclamation.

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2000 Billings Land Reclamation Symposium

A HYDROLOGIC APPROACH TO WETLAND DELINEATION

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ABSTRACT

Wetland accounting is required to prevent their loss, and the hydrologic regimes of altered riparian areas must be predicted for revegetation planning. Both conditions applied to our study area along Silver Bow Creek, Montana. Reclamation of this riparian zone involves removing metal-contaminated sediment and replacing it with clean borrow, generally lowering the floodplain, and relocating the stream channel. A temporary diversion ditch will temporarily carry high stream flows away from the reconstructed stream channel.

Standard jurisdictional wetland delineation procedures are inappropriate for drastically disturbed areas such as Silver Bow Creek. With adequate data, hydrologic parameters can be used to delineate wetlands better than procedures requiring edaphic and vegetational indicators. In a fluvial setting where the hydrologic regime is determined predominantly by groundwater, we delineated wetlands based solely on application of jurisdictional hydrologic criteria (Env. Lab., 1987, as further elaborated by NRC, 1995). Based on the water table, wetlands were defined as:

> Those areas inundated with less than two meters of water or saturated within one-third meter of the surface for two or more consecutive weeks during the plant growing season approximately every other year.

Using a set of shallow wells, drive points, and seasonal observations, a groundwater contour map was constructed by hand and digitized into a geographic information system (GIS). By combining this with a very accurate topographic map, a computer-generated depth-to-groundwater map portrayed wetlands and other hydrologic zones. This map was field verified and as a result slightly modified. For the designed postremediation topography, another depth-to-groundwater map was constructed and used to predict the location and extent of wetlands and for revegetation planning.

Key Words: wetland hydrology, jurisdictional wetland delineations, groundwater contours, depth-to-water maps, revegetation planning.

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"The long-term success of any wetland restoration or creation project is, to a very large extent, dependent upon restoring, establishing, or developing and managing the appropriate hydrology."

D. Hammer (1997)

INTRODUCTION

Wetlands that fall under the provisions of the Clean Water Act (CWA) and Executive Order 11990 ("no net loss") are called "jurisdictional wetlands." They are identified using procedures described in a federal delineation manual (Env. Lab. 1987, herein called the 1987 Manual). Wetland delineation is the process by which the investigator identifies and locates wetlands, typically through consideration of hydrological field indicators, soil profiles, and vegetation sampling and inventory (Tammi 1994).

Positive indicators of wetland hydrology, hydric soils, and hydrophytic vegetation are required for an area to be a jurisdictional wetland. But although soils and vegetation may be given weight equal to hydrology in a delineation procedure, they are mere indicators. Hydrology is the force that creates wetlands. Unfortunately, in the delineation procedure it often is impossible to place current hydrologic conditions into a temporal context. Since many delineations are based on brief visits to the site, hydrology often is inferred from other evidence as a practical necessity. This is not strictly allowed. Although "hydrology is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field" (Env. Lab. 1987, p. 34), proof of wetland hydrology is required. "It is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season" (Env. Lab. 1987, p. 34).

In some contaminated environments, soils and plants don't reliably reflect the hydrologic regime, and hydrology assumes preeminence when identifying wetlands. In restoring wetlands, understanding hydrology is likely to be the most important consideration (Hammer 1997, p. 152).

At a fluvial riparian Superfund site near Butte, Montana, an alternative approach to wetland delineation was more reliable for two reasons relating to the reliability of vegetation and soils as wetland indicators:

1. Plants were absent from some areas that consisted of phytotoxic, metal-contaminated tailings. Elsewhere, some vascular plant species rated as obligate (e.g., Baltic rush, sandbar willow) or facultative (e.g., tufted hairgrass) wetland species in Region 9 (Reed 1988) can occur locally as dominants over a range of soil moisture regimes, including habitats much drier than wetlands. The dominant streamside grasses (two introduced *Agrostis* species), while the sole dominants in some saturated or vernally inundated streambank wetlands, are rated as neutral wetland indicators or not listed (Reed 1988). In the case of the

streambank grasses, metal tolerance and fertile stream water probably account for their occurrence in otherwise atypical hydrologic zones.

2. Hydric soils were more difficult than usual to identify because:

a) Tailings in the soil profile may appear as mottles (i.e., colors that result from alternating oxidation and reduction of that part of the soil profile). This could lead to identification of a hydric soil where none existed.

b) Gley colors, indicating the prevalence of a low redox potential, are often less distinct in coarse sediments, such as those found in upper Silver Bow Creek, than in loamy or heavier textured soils. Soil color is a poor indicator of hydric conditions in sandy soils, where long-term saturation and anaerobic conditions may not result in colors corresponding to gley soils (Tammi 1994, p. 45). This could lead to identification of nonhydric soil where the soil was hydric.

In this environment, a rather rigorous body of hydrologic information can provide a more appropriate basis for wetland delineation than edaphic and vegetational inference.

STUDY AREA AND ENVIRONMENT

Silver Bow Creek originates at a copper mine in Butte, Montana, at latitude 45.95, longitude 111.05. Elevation ranges from about 1,676 meters (5,500') at Butte to 1,493 m (4,900') 43 km (27 stream miles) downstream where Silver Bow Creek enters a series of settling ponds before joining Warm Springs Creek to form the Clark Fork River. The entire length of Silver Bow Creek and its floodplain is a Superfund site, but only the uppermost 2 km (1.2 mi.) comprises the study area for this investigation. The floodplain is relatively narrow there, ranging from 120 to 200 meters wide. Climate is cool and dry. Average annual precipitation in Butte between 1964-1998 was 32.5 cm (12.8 inches). During that period, precipitation exceeded 46 cm (18 inches) in four years, but in six years it was less than 23 cm (9 inches).

Silver Bow Creek is predominantly a gaining stream. In the past century, it has aggraded with mine tailings combined with granitic alluvium. The uncontaminated alluvium largely consists of pea gravel, sand and silt typically with little clay. Tailing deposits in the upper reaches of the site average between 0.2 to 0.5 m (0.5 to 1.5 feet) in depth with a maximum of 1.2 m (4 feet). During low flows, surface water discharge in the creek at the upper end of the operable unit averages about 21 cfs, but more than 250 cfs has been recorded. Surface water has elevated concentrations of copper, lead, cadmium, mercury and zinc, especially following intense runoff events.

The Superfund remedy calls for removing tailings and contaminated soil and backfilling with clean borrow. In the process, the stream will be relocated and the surface elevation lowered. For purposes of preliminary wetland accounting and revegetation planning, the location and extent of

preremediation wetlands first had to be quantified, and then postremediation wetlands had to be predicted.

Groundwater levels in the study area respond to precipitation/snowmelt and changes in stream stage. Groundwater levels close to the creek respond more quickly to changes in stream stage and precipitation/snowmelt events than on the fringes of the floodplain (Abdo 1994). Groundwater ranges in depth from above-surface to 0.9 meters (3 feet) belowground within Reach A, the focus of this report. Seasonal groundwater fluctuations in Reach A range from about 0.2 to 0.6 meters (0.7 to 2.0 feet).

WETLANDS DEFINED

The National Research Council (1995) provided the following reference definition of wetlands, which clearly distinguishes between the functional role of hydrology and indicator values of soils and vegetation:

saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. **These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development.** (Emphasis added.)

The Environmental Protection Agency (EPA) and U.S. Army Corps of Engineers (USACE) define wetlands this way (Env. Lab. 1987):

> Wetlands are areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that **under normal circumstances** do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (Emphasis added.)

The phrase “under normal circumstances” was included in the definition because there are circumstances in which the vegetation in a wetland has been altered as a result of human activity, and vegetational or edaphic indicators may be misleading. “In such cases, an alternative method must be employed in making wetland delineations” (Env. Lab. 1987, p. 8). Our alternative method of identifying wetlands is based solely on hydrology.

Our working definition of wetland hydrology comes from National Research Council (NRC 1995), which lists on p. 93 four criteria for wetlands. These are: 1) depth of inundation or saturation in relation to the water table, 2) timing of inundation/saturation, 3) frequency of saturation or flooding, and 4) duration of saturation or inundation. Thresholds are needed for each criterion because thresholds define boundaries, and wetland delineation is largely a matter of identifying boundaries.

1. DEPTH. With occasional exception, wetlands are inundated with less than two meters of water, above which an aquatic habitat is indicated. At the lower threshold, wetlands should be inundated or saturated to the soil surface (Env. Lab. 1987). However, in making jurisdictional wetland delineations, soil profiles must be examined at least 0.4 meters (16 inches) deep, and observation are made just below the A horizon or at 0.25 meters (10 inches).
NRC (1995, p. 104) concurred that seasonal saturation should be near the ground surface, interpreting it as the upper 30 cm (one foot) of soil, which corresponds to the control zone for very poorly drained soils in Natural Resource Conservation Service terminology. In defining hydric soils, the Soil Conservation Service (1991) includes all Aquic suborders and subgroups that are somewhat poorly drained and have a "frequently occurring water table less than one-half foot from the surface for a significant period (usually more than two weeks) during the growing season" for very sandy soils, or at a depth of one foot (0.3 m) for less permeable soils.
Most soils in the study area are coarse to very coarse, and coversoils (transported fill) will be predominantly sandy loams with <10% clay. Capillary rise is not expected to be significant in this environment. The saturation zone was assumed to be the elevation of the groundwater surface.

Considering these factors, we set the threshold for seasonal saturation at 15 cm (six inches).

2. TIMING. Hydrology during the growing season is the critical factor for vegetation. In saturated/inundated soils, vascular plants and soil microbes quickly deplete free oxygen during the growing season, while at the same time sulfur compounds and other plant toxins accumulate. We assume that late May to mid-September inclusive is the effective growing season, and that high groundwater is most likely to occur during spring runoff (May-June).

3. FREQUENCY. Since it is rarely measured, either in reference wetlands or jurisdictional candidates, frequency is imprecisely addressed, e.g., wetlands must be inundated/ saturated "periodically" (Env. Lab. 1987) or "recurrently" (NRC 1995). A minimum frequency of one out of two years seems to be the consensus (NRC 1995, pp. 5,107), so yearly frequency of inundation/saturation should be >50%.

4. DURATION. Environmental Laboratory (1987, Table 5, p. 36) lists 12.5% of the growing season as the minimal duration for wetlands. Based on a 120-day growing season, this equals 15 days of inundation or saturation. (See also U.S. Army Corps of Engineers 1992, 15 consecutive days of saturation or 7 consecutive days of flooding.) The definition of hydric soils also specifies a criterion of "usually more than 2 weeks" of saturation (SCS 1991). The Comprehensive Wetlands Conservation and Management Act of 1995, passed by the House but not the Senate, specifies that wetlands must have water present at the land surface for 21 consecutive days during the growing season.

For saturation to exert a major influence on soils and plants, the minimum duration must be consecutive. While we are aware that anaerobic conditions will develop more quickly in saturated soils at the end of June than at the beginning of May, we assume that two or more weeks of consecutive saturation in May-June is an acceptable threshold in our area.

Summing up: wetlands were defined hydrologically as those areas inundated with less than two meters of water or saturated within 15 cm (0.5 feet) of the surface for two or more consecutive weeks in the plant growing season at least every other year (NRC 1995, p. 5). Wetlands were identified through the relation of water table and ground surface elevations. We further distinguished inundated wetlands (those usually covered by water for more than two weeks during the growing season) from those usually saturated but less commonly and more briefly inundated. This distinction allows tailoring revegetation strategies to two classes of wetlands that differ significantly in redox potential and plant suitability.

METHODS

Due to the time constraints associated remedy design, groundwater levels during a single growing season were used in delineating wetlands for Reach A. We could have extrapolated from historic stream gauge data. That approach would involve numerous assumptions without necessarily providing more accurate wetland delineations. As remediation design efforts progress downstream, hydrology from multiple growing seasons will be factored into delineations.

This wetland delineation procedure was predicated on accurate topographic maps derived from recent aerial photography and ground-truthing. In application, the scale was 1":100' with two-foot contour intervals. Maps of equal accuracy depicted the postremediation topography.

Delineating Existing Wetlands

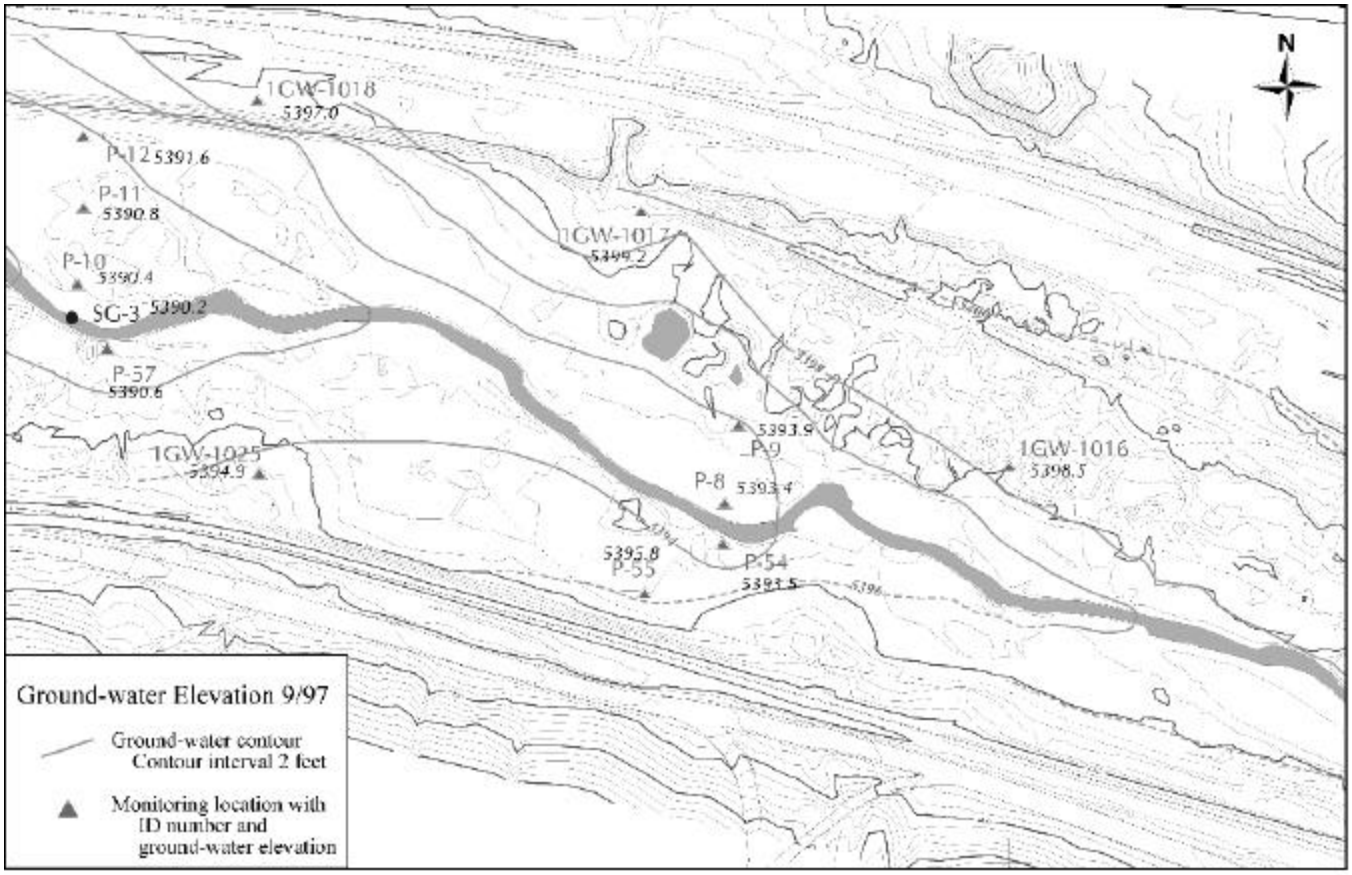
Existing wetland areas were delineated through the following series of steps:

1. Preparing groundwater contour maps based on a set of 38 well/drive points and three surface water staff gages within a 2 km (1.2 mile) stretch of Silver Bow Creek (Figure 1) using September 1997 data. Wetlands were identified where groundwater was less than 46 cm (1.5 feet) below the ground surface (rather than 15 cm, see wetland definition) because groundwater levels in September are usually about one foot lower than during the height of the growing season (May – June). Our data suggest that a one-foot seasonal variation in groundwater depth was representative for Reach A, given variations among wells and drive points.

2. Generating depth-to-water maps based on the groundwater contour maps,

3. Verifying wetland delineations based on previous experience (e.g., observations of seasonal inundation) and several dozen shallow holes power augered to the water table or a depth of two feet,

4. Editing the groundwater contour maps, then producing revised jurisdictional wetland maps, and



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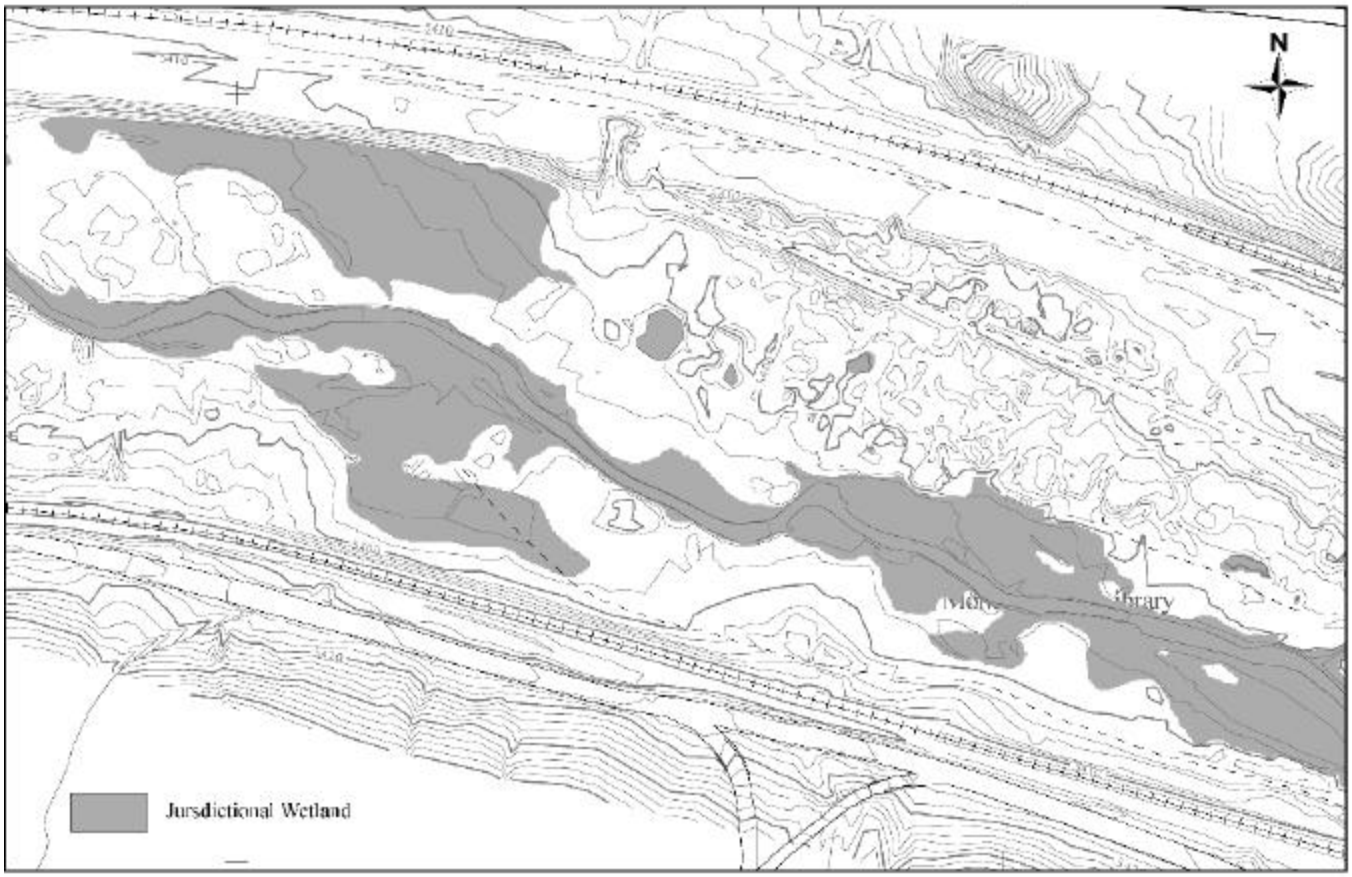


Figure 1. Ground-water contour map (above) and jurisdicitonal wetlands (pre-remediation).

5. Correcting the depth-to-water maps by hand where ground-truthing conflicted with the wetland map, but further changes to the groundwater contour map seemed unjustified.

Topographic information came from the Arc/Info TOPOGRID module. The Montana Natural Resource Information System compiled the depth-to-groundwater maps by subtracting surface elevations from groundwater elevation contours. Projections of postremediation wetlands were similarly compiled from design plans (topographic model) and predicted groundwater contour maps, which incorporated the effects of a temporary diversion channel.

Depth-to-water was mapped in three increments based on two-week seasonal highs:

1. Groundwater above the land surface (inundated wetlands, always less than two meters deep),

2. 0-0.5 feet below land surface (saturated wetlands),

3. >0.5 feet below land surface (nonwetlands, further divided into three subcategories).

Predicting Wetlands for Reclamation Planning

Because this segment of Silver Bow Creek has aggraded, it was possible to lower the stream and floodplain elevations during construction subject to some vertical controls. This obviously would create more wetlands. However, constructing a temporary diversion ditch to handle high stream flows was found to be cheaper than armoring streambanks to withstand very high flows that are unlikely in the short-term, but which pose considerable risk if they did occur. In places, this ditch is expected to sometimes intercept groundwater, acting as a drain. A final complication was that the stream channel was relocated away from horizontal controls.

The first step in predicting the location of jurisdictional wetlands in the postremediation landscape was to create a groundwater contour map. Control points used to construct this map included existing groundwater levels in several wells/drive farthest from Silver Bow Creek and those up-gradient from the diversion ditch. In addition, surface water elevations were incorporated from a projected flow of 30 cfs in the reconstructed stream channel and about 10 cfs in diversion ditch.

Once the groundwater surface was approximated, a GIS procedure combined groundwater and surface elevation information to provide a depth-to-groundwater map. The same hydrologic definition of wetlands was used.

RESULTS

Existing Wetlands

Existing jurisdictional wetlands are shown on Figure 1. The initial wetland maps constructed from the preliminary groundwater contour maps indicated 9.6 ha (23.7 acres) of wetlands, including the riverine component. With final revisions, the final map indicated 9.9 ha (24.6 acres) of wetlands, a relative difference of just 4 %.

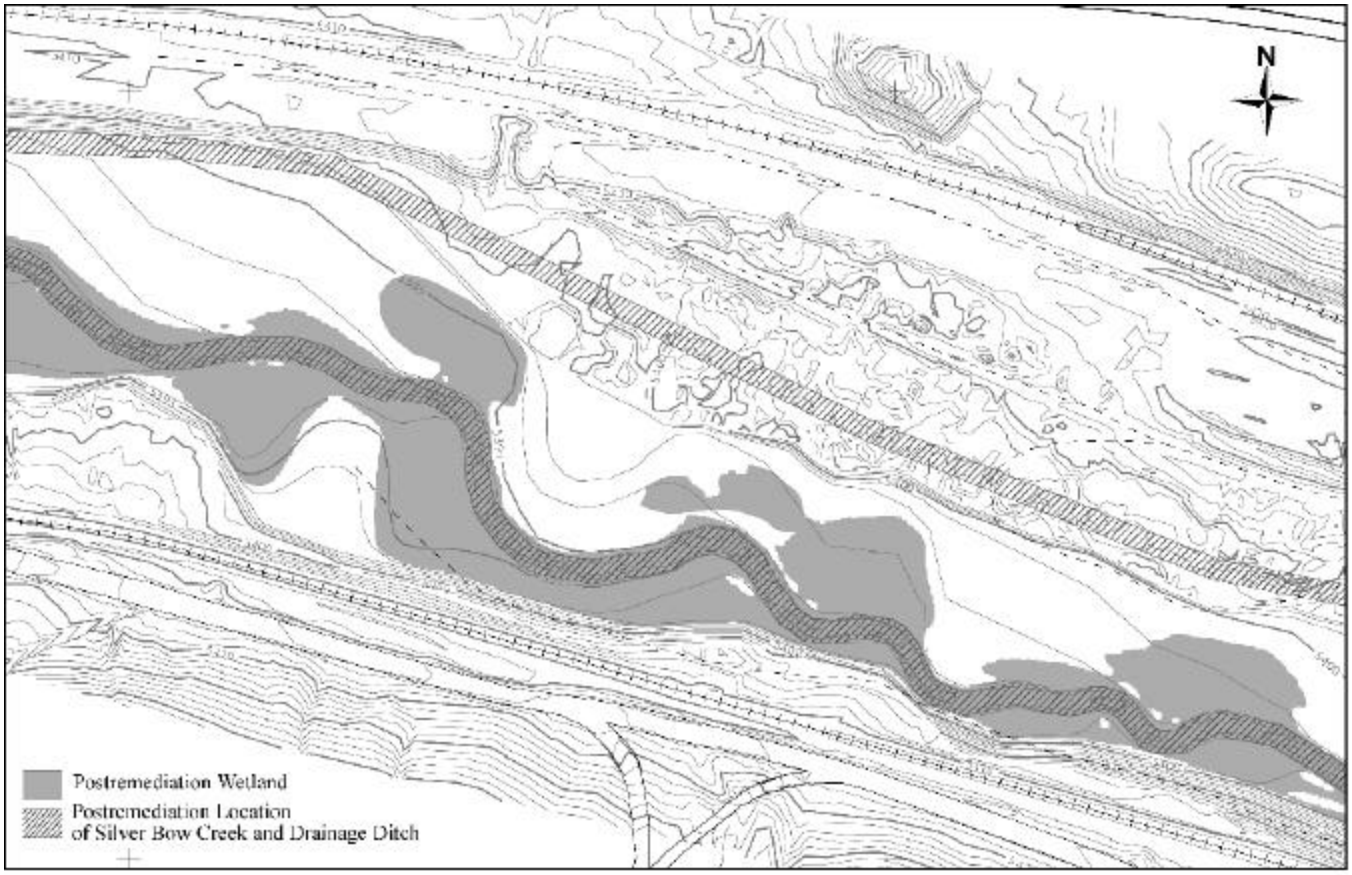
Predicted Wetlands

Since the floodplain elevation will be lowered when tailings are removed, one would expect more wetland acreage following remediation. However, the stream elevation as well as the floodplain elevation are being lowered, so the postremediation wetland acreage is similar to the current one (Figure 2). In the short term, however, the diversion ditch will intercept the water table, resulting in drier hydrologic conditions (Figure 2). The map of hydrologic regimes will be field-verified following construction.

With the diversion channel, postremediated wetlands are projected to cover approximately 4.9 ha (12.2 acres). Once the ditch is removed, wetland acreage is anticipated to be nine hectares (22.3 acres, Figure 2), indicating a net loss of 0.9 wetland hectares (2.3 acres) from the baseline condition (Figure 1). In wetland accounting, wetland functions and values, while more often guessed than measured, are considered along with wetland acreage. Since restored wetlands are expected to function better than the existing ones, a net gain in wetlands is anticipated.

DISCUSSION

While based on the 1987 Manual and NRC (1995), our hydrologic definition of wetlands was tailored to the study area. With a few modifications, it may be appropriate for other groundwater discharge wetlands with a sound groundwater database. Duration of inundation/saturation may be modified for longer or shorter growing seasons. Where capillary rise is significant, an increment would have to be added to the water table elevation. There are a great variety of wetland types (Cowardin and others 1979). Our approach would be inappropriate for wetlands resulting from perched water tables, tides, and some other conditions.



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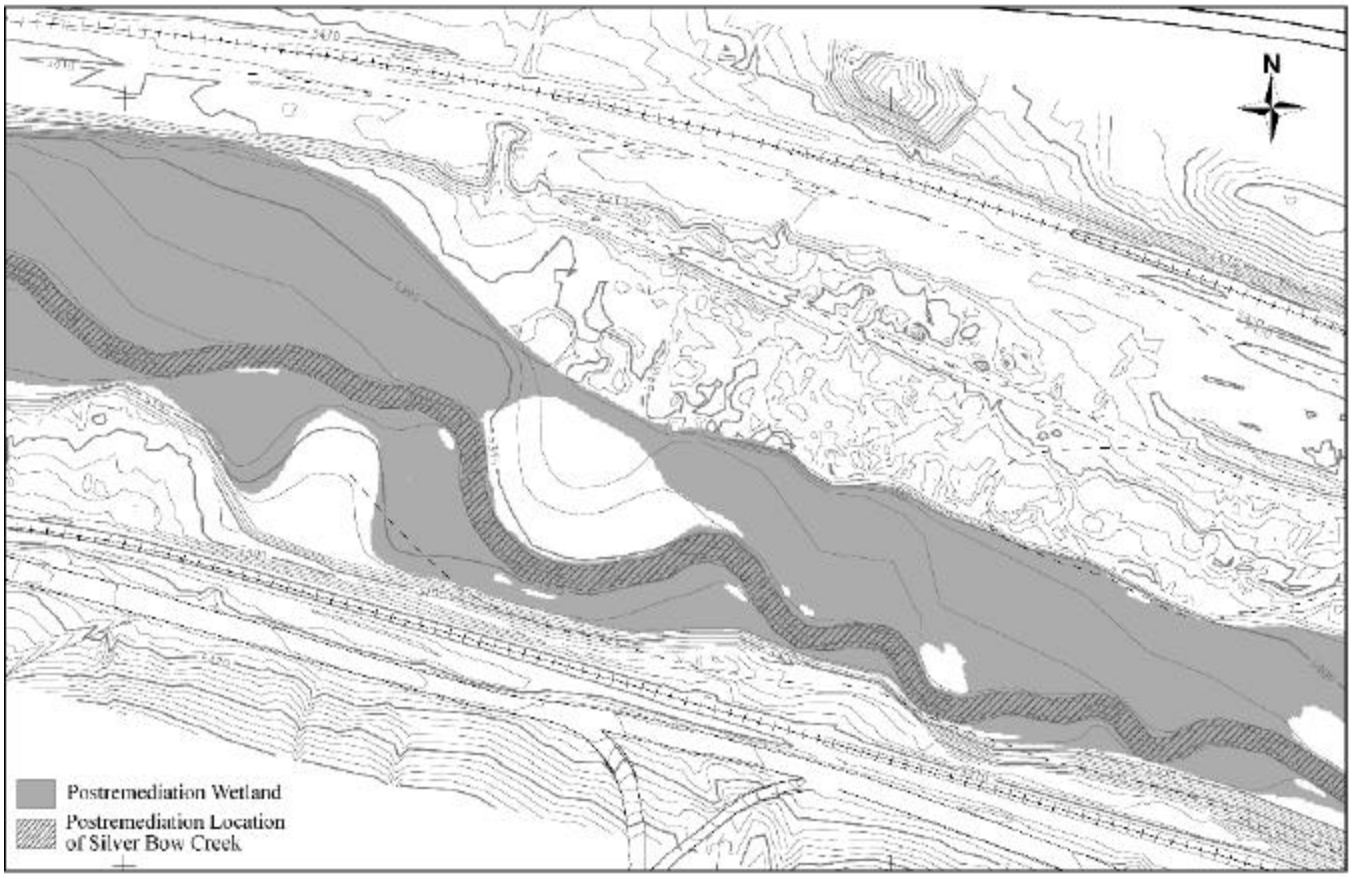

Figure 2. Area of postremediation wetlands with and without drainage ditch.

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Effects of Riparian Resource Gradients on the Establishment of Native and Invasive Plants

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ABSTRACT

Successful revegetation of disturbed stream-side lands is central to rehabilitating watersheds and creating healthy ecosystems. Of particular concern is the role disturbed riparian areas can play in the spread of noxious weeds. This greenhouse study investigated the influences of depth to water table and plant available nitrogen on the seedling establishment of four native species and two invasive weeds. The objective was to investigate the influence of soil resources on establishment of early successional, late successional and invasive weedy species. Three upland species (annual sunflower-*Helianthus annuus*, bluebunch wheatgrass-*Agropyron spicatum*, and spotted knapweed-*Centaurea maculosa*) and three wetland species (American sloughgrass- *Beckmannia syzigachne*, tufted hairgrass-*Deschamspia cespitosa* and Canada thistle-*Cirsium arvense*) were broadcast seeded in separate pots filled with a uniform soil. Treatments consisted of factorial combinations of seven depth to water table and three nitrogen treatments (6 species x 7 water levels x 3 nitrogen treatments x 2 replications=252 pots). The seven water levels ranged from "dry" with no sub-irrigation to saturated with water at or above the soil surface. Nitrogen treatments included: a control, high nitrogen addition (100 Kg N/Ha) and a nitrogen depletion through the addition of sucrose (1000 Kg C/Ha). Emergence was counted 70 days after seeding. At this point, plants were thinned to one individual per pot. Plants were harvested 60 days later and final, above ground biomass was measured. Depth to water table significantly influenced seedling emergence of *A. spicatum*, *C. maculosa*, *D. cespitosa* and *B. syzigachne* ($P<0.10$) with highest emergence occurring with a water table from 10 cm to 30 cm below the soil surface. In addition, nitrogen treatments significantly effected emergence of *B.syzigachne* with highest emergence occurring with the high nitrogen addition. Depth to water table was also found to significantly influence biomass of *A. spicatum*, *C. maculosa* and *D. cespitosa* with highest biomass with water tables 10 cm to 30 cm below the soil surface. Nitrogen treatments influenced biomass for *A. spicatum* and *C. maculosa*. In addition, *C. maculosa* growth was greatly inhibited by sucrose additions. Biomass of both these species increased in the high Nitrogen treatments, but this effect was much more pronounced in *C. maculosa*. These results suggest that disturbed riparian areas may be restored to a healthy, weed-free condition through the appropriate selection of species for a given hydrologic setting, and the management of plant available soil nitrogen at relatively low levels. Additionally, results suggest that sub-irrigated sites are most favorable for revegetation, but are also most vulnerable to weed invasion.

INTRODUCTION

Riparian areas provide many ecological and hydrologic benefits. Healthy riparian vegetation can stabilize banks, improve fisheries habitat and provide depositional buffer zones for pollutants carried in surface runoff (Satterlund and Adams 1992, Osborne and Koviac 1993). Streams passing through riparian areas can also serve as dispersal agents for native and exotic plant species (Pysek and Prach 1993). This seed transport mechanism, coupled with disturbances associated with seasonal flooding or land use, provides opportunities for the establishment of non-indigenous species. As a result riparian areas may be vulnerable to weed invasions and may also serve as beachheads for invasions of the surrounding landscape (Pysek and Prach 1993).

Weed invasions are of particular concern in restoration efforts involving disturbed riparian sites and adjacent uplands. Weeds can prevent the successful establishment of desirable vegetation. Successful establishment of stands of desirable vegetation from seed is a pre-requisite to the development of viable, weed-free plant communities (Sheley and Petroff 1999). Because plant species respond differently to environmental conditions, information on the interactive influences of soils and hydrology on seedling establishment is necessary for the restoration of riparian areas.

The effects of hydroperiod and nutrient concentration on plant competition have been investigated by Grace, Newman and Koebel (1996) who found these factors interact to create species specific advantages for *Typha domigenesis, Cladium jamaicense* and *Eleocharis interstincta* in the Everglades ecosystem. They suggested that the responses of these species are associated with species growth rate, tissue concentrations of P, and response to contrasting environmental conditions. In upland ecosystems, species with early successional characteristics or traits (rapid growth rates, high tissue nutrient concentrations, annual life cycles and rapid nutrient uptake rates) have been found to be significantly favored by high levels of soil nitrogen (Tilman & Wedin 1991, McLendon & Redente 1991, Redente et al. 1992). Conversely low levels of available nitrogen favor late successional species.

Plant community research directed at understanding general effects of resources has largely focused on survival and competition of established plants with less attention to emergence and early establishment of seedlings. This seedling establishment phase is a bottleneck that restoration ecologists struggle with in the development of healthy, native plant communities (R. Sheley, *personal communication* 1998). While much research has been conducted on the influences of nitrogen on successional dynamics, particularly in uplands, little information is available on the effects of hydrology on succession in non-forested riparian systems.

The overall objectives of this study, and a companion field study, were to determine the influences of hydrologic setting and nutrient availability on seedling establishment and early successional trajectories in a rangeland, riparian ecosystem. This paper explores initial results of the greenhouse study. There were two specific objectives:

I. <u>To determine the influence of a hydrologic gradient on the seedling establishment of early successional, late successional and invasive weedy species</u>. We hypothesized that highest seedling establishment and growth for all species would occur in aerobic conditions with high soil water

availability. Such environments are present in intermediate locations along gradients from streams to upland range where a shallow water table maintains ample soil water by sub-irrigation but is not high enough to induce prolonged, waterlogged, anaerobic conditions.

II. To investigate the influences of plant available nitrogen on the seedling establishment of early successional, late successional and invasive weedy species along a hydrologic gradient. Following Tilman and Redente we hypothesized that early successional and weedy species would respond strongly to nitrogen availability with greatly enhanced seedling establishment and growth in a high nitrogen environment and inhibited establishment and growth in low nitrogen environments. By comparison, late successional species would have smaller positive responses to high Nitrogen and smaller negative responses to low N. Consequently they would have relatively high seedling establishment and growth in low nitrogen environments compared to early successional species and weeds.

METHODS

Species

Six species common to the Northern Rocky Mountains were selected for their contrasting, life history characteristics (Tables 1 & 2). Two upland, native species were selected to represent early and late successional species (Stubbendieck, Hatch and Butterfield 1991, R. Sheley and J. Jacobs *personal communication* 1998). In addition an upland, perennial noxious weed was selected (Sheley and Petroff, 1999).

Table One: Characteristics of selected upland species

	Life Cycle	Growth Form	Characteristic Successional Stage
Agropyron spicatum	Perennial	Grass	Late
Centaurea maculosa	Perennial	Invasive Forb	Early (Invasive Weed)
Helianthus annuus	Annual	Forb	Early

Two wetland native species were selected to represent species with high short term revegetation potential and high long term revegetation potential (Hansen et al. 1997) and annual and perennial life cycles (Cooper & Meirings 1989). These criteria were used rather than successional status as the utility of classical concepts of succession for wetland plant communities has been questioned (P. Lesica, *personal communication* 1998). Life cycle and short term versus long term revegetation potential may correlate with successional status or with the ability to exploit resource rich

Table Two: Characteristics of selected wetland species

	Life Cycle	Growth Form	Characteristic Successional Stage	Short Term Revegetation Potential	Long Term Revegetation Potential
Deschampsia cespitosa	Perennial	Grass	Late	Low	High
Cirsium arvense	Perennial	Invasive Forb	Early (Invasive Weed)		
Beckmannia syzigachne	Annual	Grass	Early	Moderate	Low

sites versus the ability to survive and compete in resource poor, highly competitive environments. A perennial, invasive weed common in riparian areas was also selected (Sheley and Petroff 1999, J. Klausman, *personal communication* 1998).

Water Treatment

A depth-to-water-table gradient was created using 42 plastic tubs (40 cm deep by 40 cm wide by 50 cm long) maintained at one of seven, randomly assigned, water levels. Water levels were maintained at a depth of 0 and 2 cm above the soil surface and 5, 10, 20 and 30 cm below the soil surface with an automatic, drip irrigation system. In addition, a "dry" treatment was maintained with no sub-irrigation. Six, 10 cm by 10 cm by 36 cm tapered tree pots packed with a sandy, clay loam soil were placed in each tub. Pots were left open at the bottom to allow water flow into and out of the soil column. To account for fluctuations in water levels due to soil swelling and shrinkage actual water levels in each pot were measured weekly for the first four weeks of the experiment. All pots were watered from above weekly with 155 ml of deionized water to simulate rain. Each pot was planted with one of six selected species at a rate of 3000 seeds/square meter.

Nitrogen Treatments

One of three nutrient treatments was randomly assigned to each tub: a control hereafter referred to as OO, a high nitrogen addition hereafter referred to as N2 (100 Kg N/ha) and a nutrient depletion through the addition of sucrose hereafter referred to as CO (1000 Kg C/ha). Sucrose provides a carbon source for microbes leading to increased immobilization of nitrogen. These treatments were applied through weekly additions of 155 ml of deionized water, ammonium chloride solution or sucrose solution. This volume of solution was selected to simulate average spring precipitation for Norris, MT, the location of the accompanying field study. Each combination of species, nitrogen treatment, and water level was replicated twice yielding 252 pots in 42 tubs.

Data collection

Emergent seedlings were counted 70 days after planting. At this time plants were thinned to a single individual per pot. Above ground biomass was harvested 130 days after planting then dried to a constant weight and weighed.

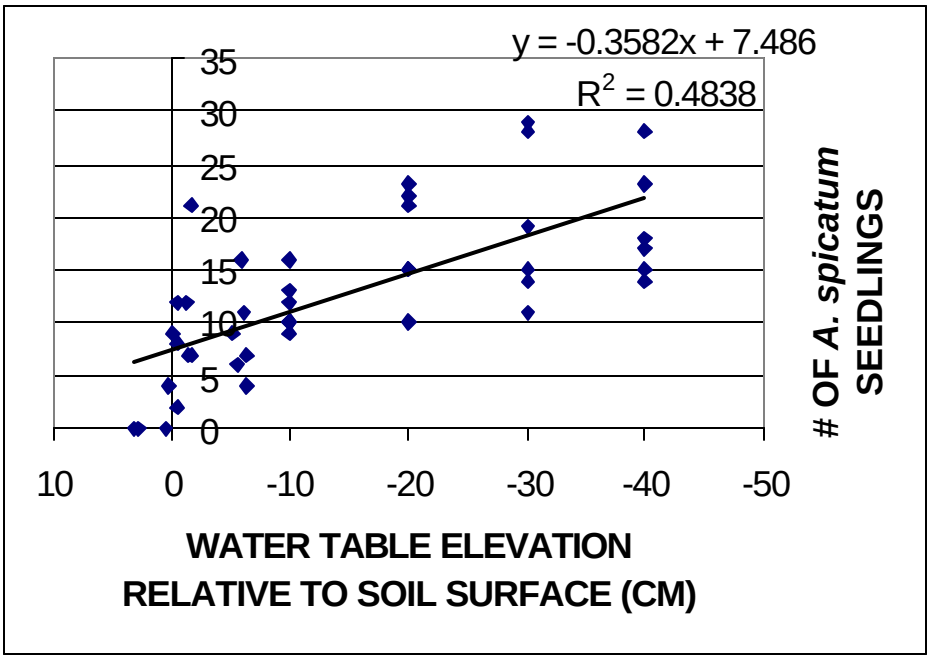
Multiple, linear regression analysis was used to assess the effects of treatments on seedling establishment and final biomass. The initial models tested included depth to water table, nitrogen treatments, and location in the greenhouse as independent variables and either seedling emergence or final biomass as the dependent variables. Independent variables were tested at the 0.10 level of significance. The final models presented were constructed by a step wise elimination of insignificant, independent variables; they do not include nonlinear models that may better describe results.

RESULTS AND DISCUSSION

Seedling Emergence

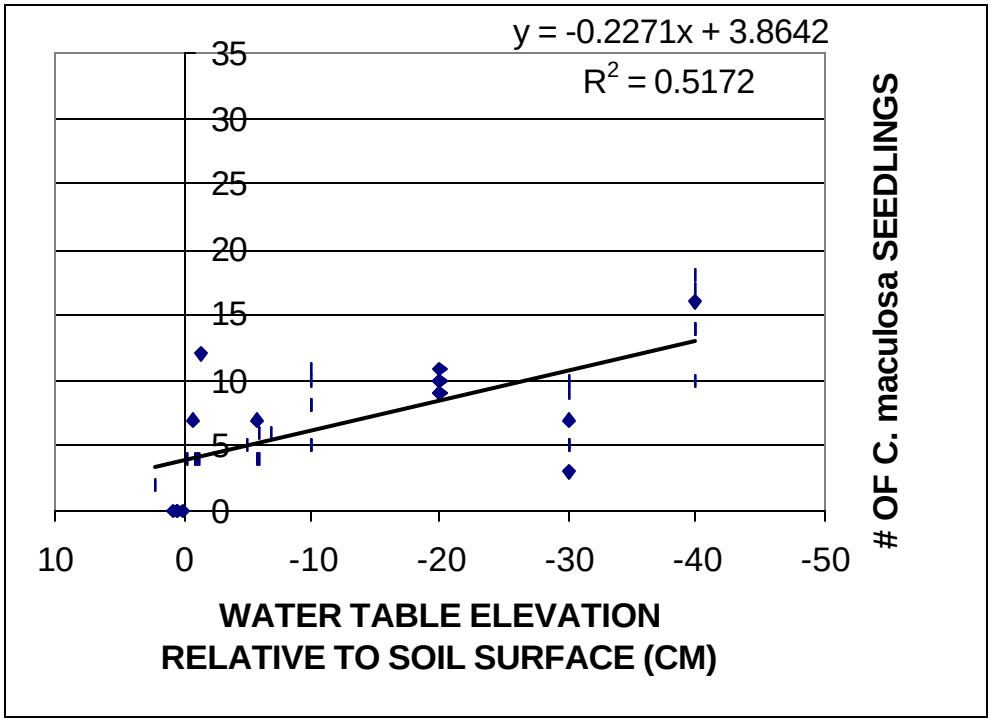
Analysis of seedling emergence of upland species found no significant relationship between seedling emergence, depth to water table and nitrogen treatments for *H. Annuus* ($P<0.10$). Analysis of seedling emergence of *A. spicatum* and *C. maculosa* yielded a single linear regression models with depth to water table predicting seedling emergence (Figures 1 & 2).

The model explained 48% and 52% of seedling emergence for *A. spicatum* and *C. maculosa,* respectively, with water table elevation (Table 3). No significant relation was found between nitrogen treatments and seedling emergence for these species. Both *A. spicatum* and *C. maculosa* had highest emergence in relatively dry pots and responded negatively to increased wetness. *Agropyron spicatum* emergence was high in dry pots and with deeper sub-irrigation (-20 cm and -30 cm). *Centuarea maculosa* emergence tended to be higher in dry pots than all other treatments (Figures 1 & 2). The only water input to "dry" pots came from weekly applications of 155 ml of water, nitrogen solution or sucrose solution, which was designed to simulate spring rainfall. These results contradict the hypothesis that emergence is optimized by sub-irrigation because emergence of *A. spicatum* and *C. maculosa* was as high or higher in pots with no sub-irrigation. Neither species tolerated even moderate flooding stress well, but *C. maculosa* was less able to tolerate sub-irrigation than *A. spicatum*. *Centuarea maculosa* emergence appeared to be inhibited even by relatively deep sub-irrigation (-30 cm) while *A. spicatum* appeared to be inhibited by water levels of 10 cm or less from the surface. It is notable, however, that C. maculosa may be able to occupy all locations along an upland-wetland gradient short of actual flooding. There is little prior research on upland weeds to support this concept, although research on obligate wetland plants indicates species specific responses to hydrology (Grace, Newman and Koebel 1996) with some invasive species enjoying a competitive advantage on wetter sites (David 1999).



Note: -40= "dry" treatment with no sub-irrigation

Figure One: *A. spicatum* seedling emergence in response to water table elevation.



Note: -40= "dry" treatment with no sub-irrigation

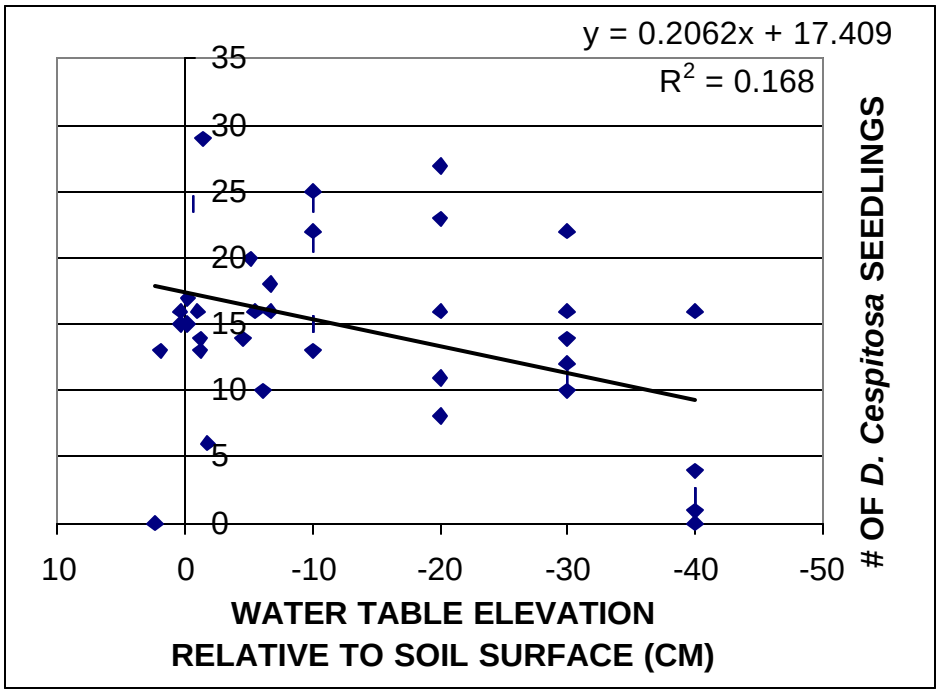
Figure Two: *C. maculosa* seedling emergence in response to water table elevation

Table Three: Regression coefficients, P values and R squares for seedling emergence.

species	Beta 0	Beta 1 depth	Beta 2 N treatment	P value depth	P value N treatment	R square
A. spicatum	7.49	-0.36	*NS	0.00	*NS	0.48
C. maculosa	3.86	-0.23	*NS	0.00	*NS	0.52
H. annuus	*NS	*NS	*NS	*NS	*NS	*NS
D. cespitosa	17.41	0.21	*NS	0.01	*NS	0.17
B. Syzigachne	17.74	0.1536	-2.83	0.00	0.00	0.33

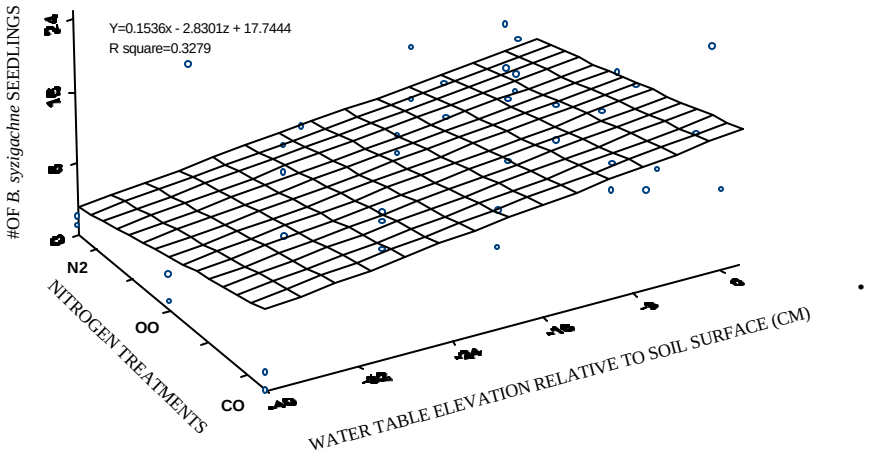
*NS=Not Significant

Among the wetland plants, species specific responses to hydrology were demonstrated by *D. cespitosa* and *B. syzigachne* which, in contrast to upland species, had highest emergence with water at or near the soil surface (Figures 3 & 4). Both these species, though, had successful seedling establishment in all but the driest tubs. Indeed, with *D. cespitosa* only 17% of the variability in emergence was explained by water table elevation. The multiple, linear regression model for *B. syzigachne* yielded a better fit with 33% of variability explained by depth to water and nitrogen treatments (Table 3).



Note: -40= "dry" treatment with no sub-irrigation

Figure Three: *D. cespitosa* seedling emergence in response to water table elevation



Note: -40= "dry" treatment with no sub-irrigation

Figure Four: *B. syzigachne* seedling emergence in response to nitrogen treatments and depth of water table below the soil surface in centimeters.

Results for *B. syzigachne* support the hypothesis that emergence of this rapidly establishing species is favored by high nitrogen, but other species showed no significant effect of Nitrogen on emergence. Controls on emergence of *C. arvense* were not analyzed because germination was very poor. This was surprising considering the prevalence of this weed in riparian areas. Further investigation of establishment requirements for *C. arvense* would aid interpretation of these results.

Biomass

Analysis of biomass for upland species indicated that both depth to water table and nitrogen treatments significantly affected biomass of *A. spicatum* and *C. maculosa* ($P<0.10$) (Table Four). Neither variable affected biomass of *H. Annuus*. The multiple linear regression models for *A. spicatum* and *C. maculosa* indicated highest biomass with a water table 40 cm below the soil surface in tubs with nitrogen added (Figure 5 and 6). Both *A. spicatum* (a late successional, perennial grass) and *C. maculosa* (an invasive weed) were favored by added Nitrogen, but response to Nitrogen was much more pronounced in *C. maculosa*. The coefficient for nitrogen's effect in the multiple, linear regression model for *C. maculosa* is over twice that of *A spicatum's* (1.90 and .72 respectively) demonstrating that, in this experiment, nitrogen had a much greater influence on *C. maculosa* growth. The strong,

positive response of *C. maculosa* to high nitrogen environments is supported by earlier research by Herron (1999). Similar responses to high nitrogen environments have been seen with early seral species (Tilman and Wedin 1991, McLendon and Redente 1991, Redente et al. 1992). It should be noted, though, that both the *A. spicatum* and the *C. maculosa* models accounted for only slightly more than 20% of the variability in biomass. In other words, approximately 80% of the variability in biomass is due to factors not investigated in this experiment or is associated with nonlinear responses to Nitrogen and water level treatments.

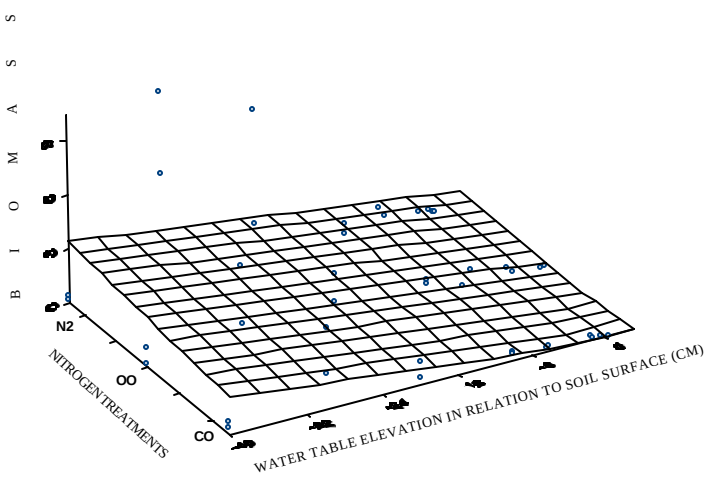
The only other species to show a significant growth response to Nitrogen treatments was *D. cespitosa*. The regression model for this species (Figure 7) showed biomass to increase with increasing nitrogen, but the Nitrogen treatments only explained 12% of the variability in biomass.

Seedling emergence and growth results for *C. maculosa* may have important management implications. In our experiment this aggressive, noxious weed established in many upland and intermediate locations along the hydrologic gradient. This suggests that disturbance of riparian areas, with a wide range of hydrologic conditions, may place them at high risk for weed invasion. This risk may be moderated by low ambient nitrogen availability or by the addition of a carbon source (McLendon and Redente 1991, Redente et al. 1992). Alternatively, the planting of an ephemeral cover crop with high Nitrogen uptake rates may favor desirable natives over invasive species (Herron 1999). Reductions in plant available Nitrogen may also significantly reduce biomass accumulation in desirable, perennial grasses, but this modest tradeoff should be preferable compared to the impacts of noxious weeds.

Table Four: Regression coefficients, P values and R squares for biomass of final harvest.

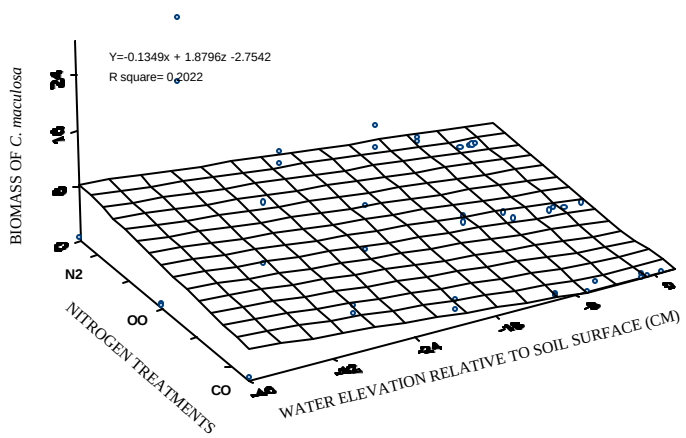
species	Beta 0	Beta 1 depth	Beta 2 N treatment	P value depth	P value N treatment	R square
A. spicatum	-1.00	-0.06	0.72	0.01	0.07	0.21
C. maculosa	-2.75	-0.13	1.88	0.02	0.06	0.20
H. annuus	*NS	*NS	*NS	*NS	*NS	*NS
D. cespitosa	0.99	*NS	1.81	*NS	0.02	0.12
B. Syzigachne	*NS	*NS	*NS	*NS	*NS	*NS

*NS=Not Significant



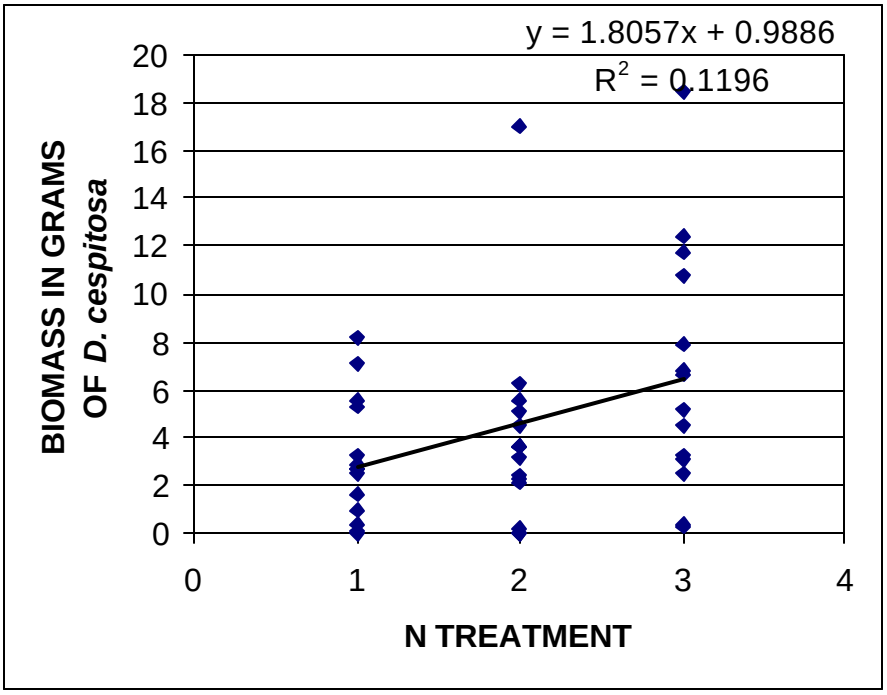
Note: -40= “dry” treatment with no sub-irrigation

Figure Five: *A spicatum* biomass seedling emergence in response to nitrogen treatments and depth of water table below the soil surface in centimeters.



Note: -40= “dry” treatment with no sub-irrigation

Figure Six: *C. maculosa* biomass in response to nitrogen treatments and depth of water table below the soil surface in cm.



Note:1=CO, 2=OO, 3=N2

Figure Seven: *D. cespitosa* biomass in response to nitrogen treatments

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