



Wetland Mitigation in Abandoned Gravel Pits

Minnesota
Department of
Transportation

**RESEARCH
SERVICES**

Office of
Policy Analysis,
Research &
Innovation

Kurt W. Johnson, Principal Investigator
Natural Resources Research Institute
University of Minnesota Duluth

March 2010

Research Project
Final Report #2010-11

Your Destination... Our Priority



Technical Report Documentation Page

1. Report No. MN/RC 2010-11	2.	3. Recipients Accession No.	
4. Title and Subtitle Wetland Mitigation in Abandoned Gravel Pits		5. Report Date March 2010	
		6.	
7. Author(s) Kurt W. Johnson		8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Minnesota Duluth Natural Resources Research Institute 5013 Miller Trunk Highway Duluth, MN 55811-1442		10. Project/Task/Work Unit No.	
		11. Contract (C) or Grant (G) No. (c) 89261 (wo) 14	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services Section 395 John Ireland Boulevard, MS 330 St. Paul, MN 55155-1899		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://www.lrrb.org/pdf/201011.pdf			
16. Abstract (Limit: 200 words) <p>It is becoming increasingly difficult to provide on-site mitigation for wetland impacts due to road construction in northeastern Minnesota counties that retain greater than 80 percent of their pre-settlement wetlands. Abandoned gravel pits are one of the few remaining areas that can serve as wetland mitigation sites. The overall goal of the project is to develop cost-effective methods for creating functional mitigation wetlands on abandoned gravel pit sites to compensate for wetland impacts due to road construction. Two approximately 1-hectare wetland creation demonstration sites were established in adjacent abandoned gravel pits within the U.S. Trunk Highway 53 reconstruction corridor to evaluate techniques for wetland establishment. Wet meadow and shrub swamp wetlands were attempted on one site, and wooded swamp and bog wetlands on the other. Wetland seed mixes provided both positive and negative effects on the developing plant communities on both sites initially but their effect was limited to the first year. Alder thicket and bog donor soil applications had positive effects but not until the third year of the study. Hardwood willow cuttings were effective for establishing a shrub component. Conifer seedlings did not survive unless planted on soil mounds. Fertilizer proved ineffective for promoting wetland plant growth during the study period. The use of straw mulch is questionable on saturated wetland sites such as those in this study.</p>			
17. Document Analysis/Descriptors Road construction, Donor soil, Organic soils, <i>Salix</i> , Hardwood, Wetlands, Wetland seed mixes, Seeds, Wet meadow, Shrub swamp, Wooded swamp, Swamps, Bogs, Conifer seedlings, Trees, Plants, Wetland plants, Wetland creation		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Springfield, Virginia 22161	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 59	22. Price

Wetland Mitigation in Abandoned Gravel Pits

Final Report

Prepared by:

Kurt W. Johnson

Center for Applied Research and Technology Development
Natural Resources Research Institute
University of Minnesota Duluth

March 2010

Published by:

Minnesota Department of Transportation
Research Services Section
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

This report represents the results of research conducted by the authors and does not necessarily represent the views or policies of the Minnesota Department of Transportation or the University of Minnesota Duluth. This report does not contain a standard or specified technique.

The authors, the Minnesota Department of Transportation, and the University of Minnesota Duluth do not endorse products or manufacturers. Any trade or manufacturers' names that may appear herein do so solely because they are considered essential to this report.

Acknowledgements

I would like to thank the Minnesota Department of Transportation (Mn/DOT) and the Minnesota Board of Water and Soil Resources (Mn/BWSR) for co-funding this study, especially the efforts of Robert Jacobson (Mn/DOT and Mn/BWSR) and Greg Larson (Mn/BWSR) in championing this research. I would also like to acknowledge the University of Minnesota Duluth, Natural Resources Research Institute (NRRI) for providing additional funding to help extend the project another year. I greatly appreciate the support given by Sarma Straumanis (Mn/DOT), the project Technical Liaison, and Debra Fick (Mn/DOT), the project Administrative Liaison. Thanks to the Technical Advisory Panel, including Howard Maki (Mn/DOT), Dan Squires, (Mn/DOT), Greg Larson (Mn/BWSR), and Tom Malterer (NRRI), for all their advice and encouragement. A special thanks to the staff at the Mn/DOT District 1 Office in Virginia, including Dan Squires, Andrew Johnson, Kevin Adolfs, and Lori Ross, for their efforts on the basin design, site layout, remedial work, construction cost monitoring, and contractor communications. Thanks to KGM Contractors Inc. for cooperating in this project, and to its engineer, Heath Line, for his assistance. Rick Viita of Viita's Black Dirt completed the remedial bog donor applications in March 2009. I would like to recognize my colleagues at NRRI who assisted in plot establishment, planting, monitoring and other, often difficult, field work, including Noah Kroening, Robert Hell, Elliot Nitzkowski, and Tom Malterer. Other NRRI staff who contributed to the project included Marsha Patelke, who helped set up and organize data spreadsheets, Steve Hauck, who edited and reviewed the final report, and Anda Bellamy, who prepared the final report for submission. Thanks also to Joannes Janssen and Gerald Wheeler for conducting donor material species identification. Finally, thanks to Gary Walton, the project botanist, whose exceptional plant species identification skills and extraordinary knowledge of plants in general helped make this project possible.

Table of Contents

Chapter 1. Introduction.....	1
Overview.....	1
Report Organization.....	2
Chapter 2. Wet Meadow and Shrub Swamp Mitigation Wetlands.....	3
Background.....	3
Materials and Methods.....	3
Site Selection.....	3
Construction.....	4
Experimental Treatments.....	6
Monitoring.....	10
Data Analyses.....	10
Results and Discussion.....	11
General Observations.....	11
Treatment Effects.....	14
Construction Costs.....	18
Chapter 3. Wooded Swamp and Bog Mitigation Wetlands.....	21
Background.....	21
Materials and Methods.....	21
Experimental Treatments.....	22
Monitoring and Data Analysis.....	24
Results and Discussion.....	25
Flooding and Remedial Activities.....	25
General Observations.....	26
Treatment Effects.....	31
Construction Costs.....	32
Chapter 4. Conclusions.....	34
Wet Meadow and Shrub Swamp Mitigation Wetlands.....	34
Wooded Swamp and Bog Mitigation Wetlands.....	36
References.....	39
Appendix A Mitigation Wetland Substrate Data	
Appendix B Donor Site Plant Surveys	

List of Tables

Table 2-1. Native sedge/wet meadow seed mix.....	9
Table 2-2. Mitigation Site 5 – Wet meadow and shrub swamp species dominance (determined by percent cover).....	15
Table 2-3. Mitigation 5 site construction costs.....	18
Table 3-1. Mitigation Site 4 – Wooded swamp and bog species dominance (determined by percent cover).....	30
Table 3-2. Mitigation 4 site construction costs.....	33

List of Figures

Figure 2-1. Mitigation Sites 4 and 5 water flow and relation to new county road construction. (Source: Mn/DOT District 1 Virginia Office.)	4
Figure 2-2. Substrate and donor soil placement plan for Mitigation Sites 4 and 5.....	5
Figure 2-3. Bog and alder donor soil sites in relation to the research site. (Source: Mn/DOT District 1 Virginia Office.).....	8
Figure 2-4. 2007 Mitigation Site 5 water levels.	11
Figure 2-5. 2008 Mitigation Site 5 water levels.	12
Figure 2-6. 2009 Mitigation Site 5 water levels.	12
Figure 2-7. Mitigation Site 5 – Wet meadow and shrub swamp total and native species richness. Percentages shown are native species richness as a percent of total species richness.....	13
Figure 2-8. September 2009 Mitigation Site 5 data showing the beneficial effect of donor soil on total species richness, Simpson’s index of diversity, native species richness, and native species percent cover. Mean + standard error, n=50.	17
Figure 2-9. 2009 <i>Salix</i> species mean percent survival + standard error (n=25). Species with the same letter are not significantly different at the p=0.05 level.	19
Figure 2-10. 2009 <i>Salix</i> species mean height + standard error (n=25). Species with the same letter are not significantly different at the p=0.05 level.....	19
Figure 3-1. 2007 Mitigation Site 4 water levels.	27
Figure 3-2. 2008 Mitigation Site 4 water levels.	27
Figure 3-3. 2009 Mitigation Site 4 water levels.	28
Figure 3-4. Mitigation Site 4 – Wooded swamp and bog total and native species richness. Percentages shown are native species richness as a percent of total species richness.....	29
Figure 3-5. September 2009 Mitigation Site 3 conifer tree seedling survival and height growth with and without soil mounds. Means + standard error, n=80.	32

Executive Summary

Wetland impacts are often an inevitable consequence of road construction. Federal and State “no-net-loss” wetland policies require compensatory mitigation for any unavoidable wetland impacts. A recent report by the Minnesota Board of Water and Soil Resources (Mn/BWSR) predicts potential wetland impacts due to public road projects in northeastern Minnesota of approximately 60 hectares annually through the year 2012. This 18-county area still retains more than 80 percent of its pre-European settlement wetland acreage, presenting very few opportunities for traditional mitigation such as wetland restoration. Abandoned gravel pits are one of the few remaining areas that can serve as wetland mitigation sites within the affected watersheds. These mitigation wetlands can potentially be created as an integral part of the road construction process.

New U.S. Army Corps of Engineers (USACOE) mitigation guidelines state a preference for “in-place” and “in-kind” wetland mitigation, generally meaning compensation within the same watershed with the same wetland type as those being affected. Mitigation provided in other watersheds and/or with different wetland types are subject to higher compensation ratios that could result in substantially higher costs. To date, most compensatory mitigation wetlands associated with highway construction in Minnesota have been deep marshes or open water ponds, even though most of the affected wetlands were originally a different type. Wooded swamp, wet meadow, shrub swamp, and bog wetlands have rarely been replaced in-kind.

The U.S. Trunk Highway 53 reconstruction in northeast Minnesota resulted in approximately 34 hectares of unavoidable wetland impacts. These impacts included wet meadow (0.6 ha), shrub swamp (11.5 ha), wooded swamp (11.5 ha), bog (10.0 ha), and other wetlands (0.4 ha). This reconstruction resulted in an abundance of high-quality displaced soil that could potentially be used for mitigation wetland creation.

Two approximately 1-hectare wetland creation demonstration sites were established in adjacent abandoned gravel/borrow pits within the U.S. Trunk Highway 53 reconstruction corridor in July 2007 by the University of Minnesota Duluth, Natural Resources Research Institute (NRRI), in cooperation with the Minnesota Department of Transportation (Mn/DOT), to evaluate techniques for wetland establishment. Wet meadow and shrub swamp wetlands were attempted on one site, and wooded swamp and bog wetlands on the other site. An abundance of displaced organic soil from the highway construction allowed for its use in the wetland creation sites. Within each site, treatment plots were established to determine the effect of alder and bog donor soil amendments, direct seeding, tree and shrub plantings, and fertilizer on wetland establishment. Plant species and percent cover, and tree/shrub survival and height were recorded for each plot in June and September of each year following establishment. Water level monitoring was conducted on both sites throughout the growing season. The study ran from July 2007 through September 2009.

This study to date has shown that there is good potential for creating wet meadow and shrub swamp mitigation wetlands in abandoned gravel pits, especially when the wetland mitigation can be directly integrated with the road construction project. The wet meadow and shrub swamp site hydrology and vegetation were consistent with the goal wetlands. Water levels met the USACOE

technical standard for wetland hydrology over the study period, and although there were seasonal fluctuations, for the most part the soils remained saturated with intermittent periods of shallow inundation.

Vegetation in general progressed well on the wet meadow and shrub swamp site with native species richness and percent cover increasing over time. Effects of the Mn/BWSR Wetland Temporary (WT1) and Mn/BWSR native sedge/wet meadow (W2) direct seeding treatments were more evident early on in the study. The September 2007 plant survey data showed significant effects of seed mixes with increased total percent cover, higher number of WT1 species, and greater percent WT1 species cover. Significant negative effects of the direct seeding treatments early in the study included lower species richness, lower Simpson's index of diversity, lower native species richness, reduced percent native species cover, and increased percent foreign species cover. These negative effects were a result of the foreign species annual rye-grass (*Lolium italicum*) from the WT1 seed mix dominating the plots in the first year. However, by September 2009 there were no significant positive or negative effects due to direct seeding, bringing into question their value for wetland creation sites that have a good organic substrate with a potentially considerable native seed bank.

In contrast to the direct seeding treatments, significant effects of the donor soil treatment were not evident until 2009, the third year of the study. Significant effects included increased total percent cover, species richness, Simpson's index of diversity, native species richness, native species percent cover, and the number of W2 seed mix plants. It is important to emphasize that none of these beneficial effects were evident until the end of the third growing season. These effects underscore the importance of longer-term monitoring on wetland creation sites.

Invasive species such as reed canary grass, narrow leaved cattail, and purple loosestrife were present on the mitigation sites but were effectively controlled by hand pulling and spot spraying with glyphosate herbicide for the duration of the study.

Native hardwood willow cuttings planted on the wet meadow and shrub swamp site showed good potential for adding a shrub component to mitigation wetlands. The cuttings were relatively easy to collect and prepare, and could be planted by hand in considerable numbers. Overall, hardwood willow cuttings (*Salix petiolaris*) in treatment plots surveyed in September 2009 had a mean survival rate of 60 percent and a mean height of 66 cm. Mean survival for five willows tested in additional species trials ranged from 40 percent to 92 percent, and mean height ranged from 41 cm to 74 cm, with *S. petiolaris* and *S. planifolia* performing the best. However, a mix of several native species is recommended to increase diversity and to insure that at least some species establish.

Based on this study, the potential for wooded swamp and bog mitigation wetlands in abandoned gravel pits is not as promising as for wet meadow and shrub swamp wetlands. Due to unanticipated flooding in fall 2007 and spring 2008, and the need to re-establishment plots in spring 2009, the study did not reveal enough information within the funding period to reach many solid conclusions. Just by their very nature, wooded swamps and bogs take longer to

establish and mature than wet meadows and shrub swamps, so extended study is required to determine success.

Conifer seedlings (tamarack and black spruce) planted on the wooded swamp and bog site did not survive the flooding, and they were not included as a treatment when the bog donor was re-applied in March 2009. However, conifer seedlings were planted on a nearby mitigation site on soil mounds in May 2009. The soil mounding study showed a significant positive effect of soil mounds on tree seedling survival and height after one growing season. This method may be an effective way to establish trees on wetland sites.

The WT1 seed mix treatment applied to the wooded swamp and bog site had results similar to those for the wet meadow and shrub swamp site. According to the September 2007 plant survey prior to the flooding, WT1 seed mix applications had higher percent total cover, number of WT1 species, foreign species percent cover, and WT1 percent cover than plots without seed mix. Plots with WT1 seed mix applications also had lower species richness, Simpson's index of diversity, number of native species, and percent native cover than plots without seed mix. As with the wet meadow and shrub swamp site, the effects of the WT1 seed mix diminished over time.

Analysis of the September 2009 plant survey data showed no significant effects of the bog donor treatments or fertilizer re-applied in March 2009 on the vegetation parameters measured or on *Sphagnum* moss percent cover. Previous research on bog restoration in Minnesota has shown that *Sphagnum* moss often takes until the second year after establishment before any substantial cover is evident. Some *Sphagnum* moss was present on the plots so the potential exists for it to establish. Plant surveys in subsequent years may provide a better indication of bog donor performance.

Although the construction costs were quite high—\$84,283/hectare (\$34,109/acre) for the wet meadow and shrub swamp site, and \$151,288/hectare (\$61,225/acre) for the wooded swamp and bog site—it is important to note that mitigation and road construction costs are hard to separate in this instance because the mitigation was integrated into the entire road construction project. Much of the mitigation site work would have been done for the road construction regardless. This project was ideal for this kind of integration because the borrow material was on-site and there was an abundance of high-quality displaced organic soil available. Other road construction projects may not have these resources available, and resulting wetland mitigation costs could be much higher.

Chapter 1. Introduction

Overview

Wetland impacts are often an inevitable consequence of road construction. Federal and State “no-net-loss” wetland policies require compensatory mitigation for any unavoidable wetland impacts. A recent report by the Minnesota Board of Water and Soil Resources (Mn/BWSR) predicts potential wetland impacts due to public road projects in northeastern Minnesota of approximately 60 hectares annually through the year 2012 (Mn/BWSR, 2006). This 18-county area still retains more than 80 percent of its pre-European settlement wetland acreage, presenting very few opportunities for traditional mitigation such as wetland restoration. Abandoned gravel pits are one of the few remaining areas that can serve as wetland mitigation sites within the affected watersheds. These mitigation wetlands can potentially be created as an integral part of the road construction process.

For the purposes of this project and to comply with regulations concerning mitigation wetlands, abandoned gravel pits are defined as those depleted of usable material that have no more value for borrow. This definition includes: 1) recently depleted pits to be used as project-specific mitigation with either an exposed water table or no standing water; or 2) pits that have been depleted for some time, but have no standing water or other wetland characteristics. Application for mitigation credit must be made within 10 years after the last day that extraction activities have taken place (Minnesota Rules, 2009).

New U.S. Army Corps of Engineers (USACOE) mitigation guidelines (USACOE, 2009) state a preference for “in-place” and “in-kind” wetland mitigation, generally meaning compensation within the same watershed with the same wetland type as those being affected. Mitigation provided in other watersheds and/or with different wetland types are subject to higher compensation ratios that could result in substantially higher costs. To date, most compensatory mitigation wetlands associated with highway construction in Minnesota have been deep marshes or open water ponds, even though most of the affected wetlands were originally a different type. Wooded swamp, wet meadow, shrub swamp, and bog wetlands have rarely been replaced in-kind.

The U.S. Trunk Highway 53 reconstruction in northeast Minnesota resulted in approximately 34 hectares of unavoidable wetland impacts. These impacts included wet meadow (0.6 ha), shrub swamp (11.5 ha), wooded swamp (11.5 ha), bog (10.0 ha), and other wetlands (0.4 ha). These impacts resulted in an abundance of high-quality displaced soil that could potentially be used for mitigation wetland creation.

Two approximately 1-hectare wetland creation demonstration sites were established in adjacent abandoned gravel/borrow pits within the U.S. Trunk Highway 53 reconstruction corridor in July 2007 by the University of Minnesota Duluth, Natural Resources Research Institute (NRRI), in cooperation with the Minnesota Department of Transportation (Mn/DOT), to evaluate techniques for wetland establishment. Wet meadow and shrub swamp wetlands were attempted on one site (Mitigation Site 5), and wooded swamp and bog wetlands on the other site (Mitigation Site 4). An abundance of displaced organic soil from the highway construction allowed for its use in the

wetland creation sites. Within each site, treatment plots were established to determine the effect of donor soil amendments, direct seeding, tree and shrub plantings, and fertilizer on wetland establishment. Plant species and percent cover, and tree/shrub survival and height were recorded for each plot in June and September of each year following establishment. Water level monitoring was conducted on both sites throughout the growing season.

The overall goal of the project is to develop cost-effective methods for creating functional mitigation wetlands on abandoned gravel pit sites to compensate for wetland impacts due to road construction. In keeping with the new USACOE mitigation guidelines, the aim is to achieve “in-kind” compensation by creating wetlands of the same type and function as those being disturbed, such as wet meadow, shrub swamp, wooded swamp, and bog.

Report Organization

The second chapter of this report focuses on the creation of wet meadow and shrub swamp wetlands on Mitigation Site 5, and the third chapter addresses the creation of wooded swamp and bog wetlands on Mitigation Site 4. The background and construction aspects of both mitigation sites are described primarily in the second chapter. The experimental design, plant establishment, monitoring, and results and discussion sections for each mitigation site are presented separately in their designated chapters. The conclusions are presented in Chapter 4, and additional data is included in the Appendices.

Chapter 2. Wet Meadow and Shrub Swamp Mitigation Wetlands

Background

The U.S. Trunk Highway 53 reconstruction in northeast Minnesota resulted in approximately 34 hectares of unavoidable wetland impacts. These impacts included wet meadow (0.6 ha), shrub swamp (11.5 ha), wooded swamp (11.5 ha), bog (10.0 ha), and other wetlands (0.4 ha). Mn/DOT classified these wetlands according to Fish and Wildlife Service (FWS) Circular 39 (Shaw and Fredine, 1971). For consistency, this wetland classification system was also used to describe the mitigation wetlands created for this research project. This classification system is less precise than the Cowardin, et al. (1979) system; however, the research team felt it better suited to describe created wetlands that may have a broader, more uncertain range of outcomes.

Wet meadows (Type 2) are classified in FWS Circular 39 as wetlands with water levels usually within a few inches (5-8 cm) of the surface causing saturated conditions, but without standing water for most of the growing season. Typical plant species present include grasses, sedges, rushes, and some scattered forbs.

Shrub swamps (Type 6) usually have saturated soils during the growing season and may have as much as 6 inches (15 cm) of standing water (Shaw and Fredine, 1971). Typical plant species present include alders, willows, and dogwoods with an understory of grasses, sedges, ferns, and forbs. Minnesota shrub swamp wetlands are further categorized as shrub-carrs or alder thickets depending on the dominant shrub species (Eggers and Reed, 1997).

The road construction and wetland impacts resulted in an abundance of high-quality displaced soil that could potentially be used for mitigation wetland creation. The gravel and borrow material needed for the road construction was also available on site, making it possible to use the depleted pits as mitigation sites. The relatively close proximity of the depleted pits and displaced organic wetland soil allowed a cost-effective scenario for creating mitigation wetlands on site, as the materials were being transported regardless as part of the construction project.

Materials and Methods

Site Selection

The study was conducted at a site located within the U.S. Trunk Highway 53 reconstruction corridor in central St. Louis County in northeastern Minnesota (47°38' N, 92°34' W). The site was selected due to its location adjacent to existing shrub swamp, wooded swamp, and bog wetlands and its proximity to donor soil and plant materials. The project location was previously an upland home site that was mined for borrow material for the road construction and was also the site for a road connecting the new Highway 53 with the old highway. Two gravel pit basins were excavated, one on each side of this road (see Figure 2-1). In one basin, Mitigation Site 4, the goal was to create wooded swamp and bog wetlands. The total size was 0.83 hectares. In the other basin, Mitigation Site 5, wet meadow and shrub swamp wetlands were the objective. Mitigation Site 5 was 1.3 hectares in size.

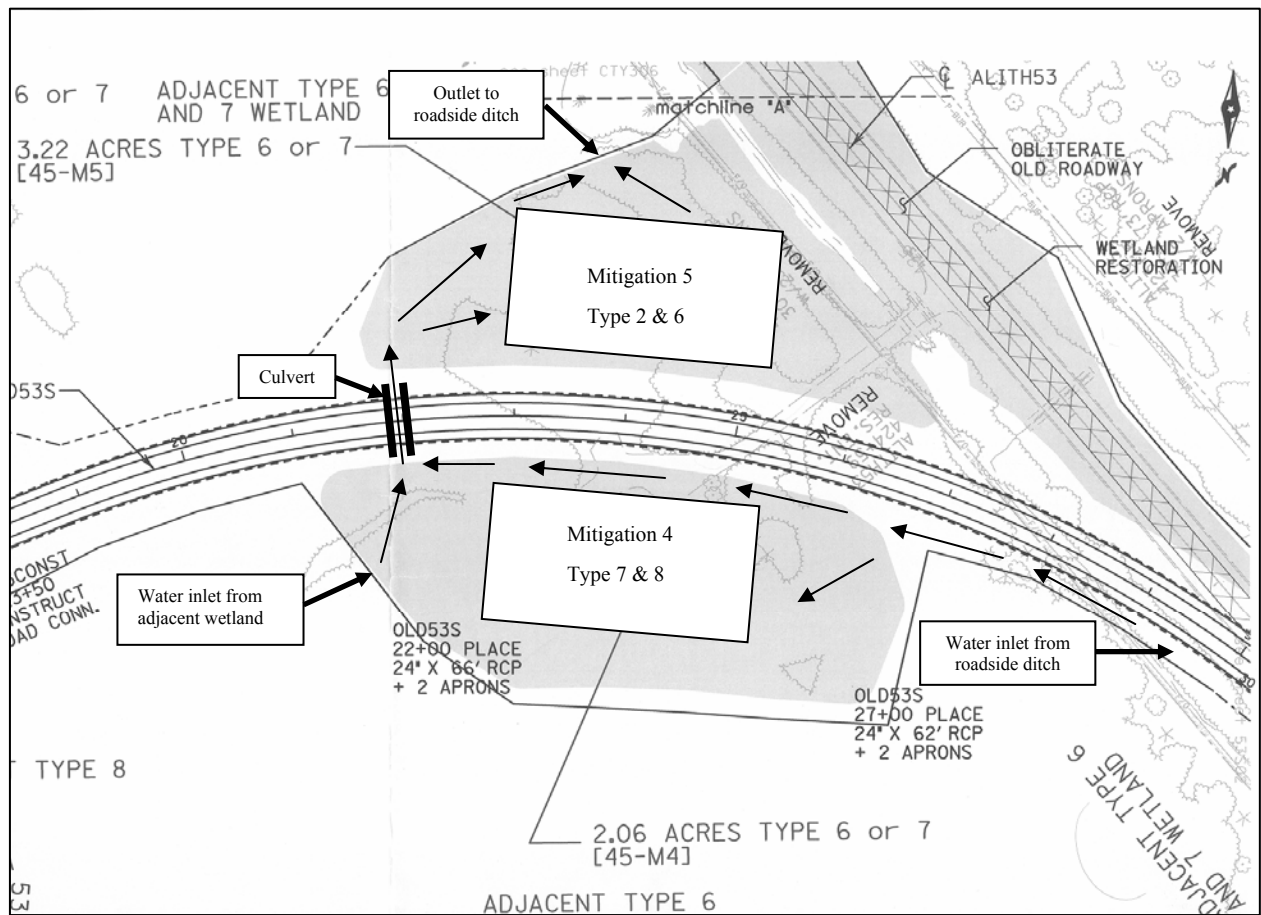


Figure 2-1. Mitigation Sites 4 and 5 water flow and relation to new county road construction. (Source: Mn/DOT District 1 Virginia Office.)

Construction

The two different soil components of wetland systems are the “substrate” and “subgrade” (Gilbert, 2000). The substrate is the upper layer that serves as the plant growth and biological medium, while the subgrade is the underlying material that provides structural support and retains water to sustain wetland hydrology. For this research project, the depleted pit bottom served as the subgrade, and the salvaged organic soil became the substrate.

Wetland hydrology in both basins was achieved by excavating borrow material to a level below the water table. Approximately 52,000 m³ total of borrow material was removed from the two basins and used in the road construction leaving a mineral subgrade of predominantly loamy sand. The basin perimeters were then contoured to a 3:1 or 4:1 slope (Buttleman, 1992; Norman and Lingley, 1992; Wenzel, 1992).

Both mitigation sites were constructed according to the plan (see Figure 2-2), with organic soil coming from nearby sites affected by the road construction. The entire Mitigation Site 5 was covered with a 60 cm layer of organic soil or "muck" salvaged from the road construction. The pH of the muck substrate was around 5.3. For Mitigation Site 4 the entire site was covered first with a 75 cm layer of the same muck used on Mitigation Site 5. Then a 15 cm layer of sedge peat collected from a depth of 15 – 60 cm at a bog donor site located nearby was spread over the entire Mitigation Site 4. This upper sedge peat substrate layer had a pH of 4.5. Additional soils data are presented in Appendix A. The 3 cm layer of donor soil shown in Figure 2-2 is explained in more detail in the following sections for each mitigation site. All construction was completed by the road construction contractor (KGM Contractors, Inc.) using heavy equipment including dump trucks and backhoes. Due to a wet spring, major site construction was not completed until the end of June 2007, with considerable difficulty in applying the different layers of organic material.

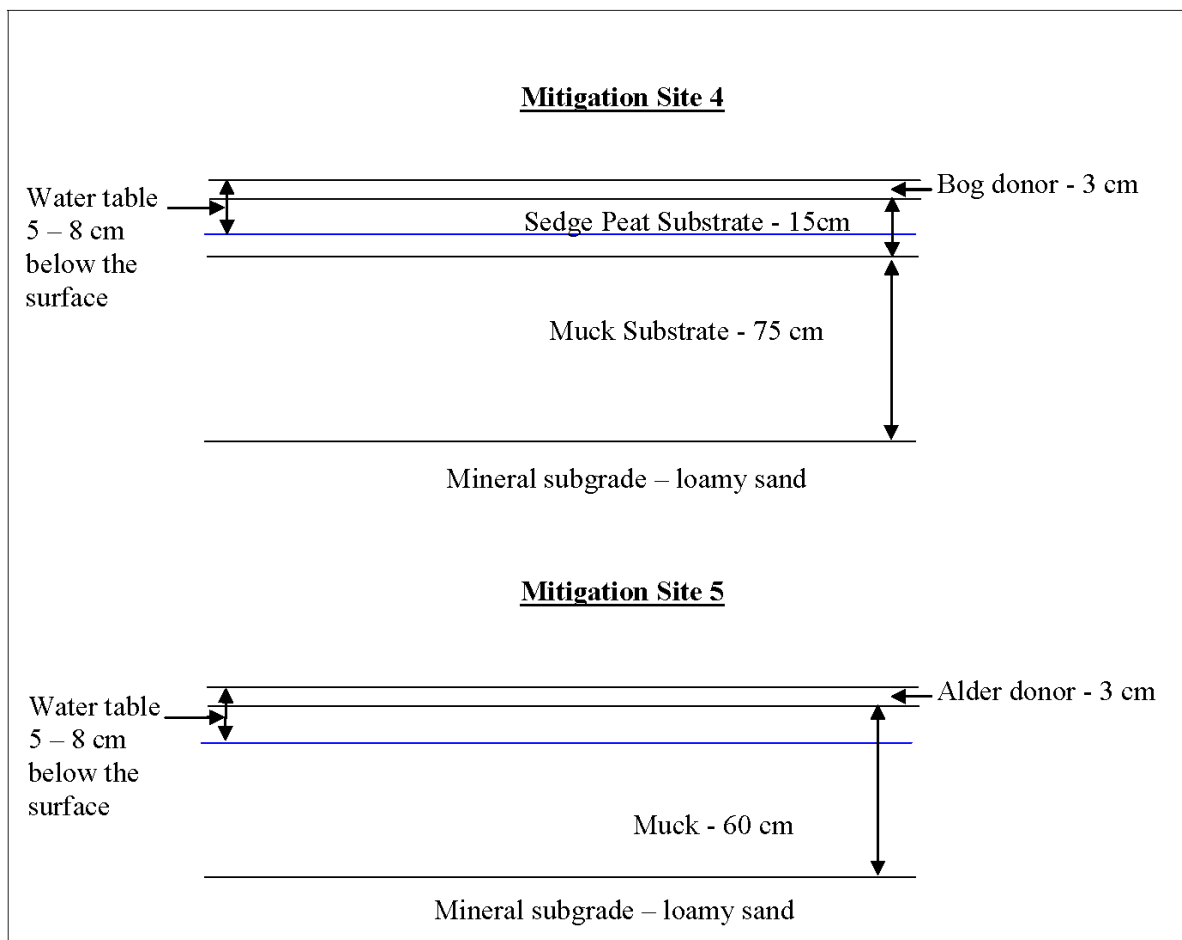


Figure 2-2. Substrate and donor soil placement plan for Mitigation Sites 4 and 5.

In addition to the groundwater, supplementary water can enter the site through an inlet to Mitigation Site 4 from the existing roadside ditch along old Highway 53. Additional water enters Mitigation Site 4 from an adjacent wetland located on the eastern edge of the site. A culvert

under the new road connects Mitigation Site 4 to Mitigation 5. There is an outlet from Mitigation 5 that leads back to the roadside ditch (see Figure 2-1).

The goal was to have a saturated soil with minimal standing water for most of the growing season on both sites. Three water table wells were installed at each site to monitor water levels.

Experimental Treatments

The goal for Mitigation Site 5 was to establish vegetation characteristic of wet meadow and shrub swamp wetlands. Several approaches used to establish wetland vegetation included donor soil applications, direct seeding, and planting of hardwood willow cuttings. To test the various vegetation establishment strategies, a total 10 experimental treatment combinations were applied. These treatments included the following:

- 1) Donor soil;
- 2) No donor soil;
- 3) Wetland temporary seed mix;
- 4) Wetland temporary seed mix + donor soil;
- 5) Willow cuttings;
- 6) Willow cuttings + donor soil;
- 7) Native sedge/wet meadow seed mix;
- 8) Native sedge/wet meadow seed mix + donor soil;
- 9) Willow cuttings + wetland temporary seed mix; and
- 10) Willow cuttings + wetland temporary seed mix + donor soil.

The study was established in a randomized block design with five replications (blocks) of each treatment combination resulting in a total of 50 – 5 m x 5 m (25 m²) plots each separated by a 2 m buffer. Blocks were arranged parallel to and at varying distances from the road. The treatments are described in the following sections.

Donor Soil

Donor wetland soil applications have been shown to increase plant species richness, percent wetland plant cover, and soil organic matter (Brown and Bedford, 1997; Stauffer and Brooks, 1997; Cooper and Foote, 2003; Johnson and Valppu, 2003; McKinstry and Anderson, 2005). Where available, donor soil applications generally result in wetland vegetation better adapted to the site.

Several sites were surveyed and evaluated for use as potential wetland soil donor sites. Plant surveys were conducted by the project botanist on several shrub swamp sites that were scheduled to be disturbed by the highway construction. Alder thickets are common in this area, and therefore, one was chosen to serve as a soil donor site. It was located approximately 1.5 km north of the mitigation sites (see Figure 2-3). The plant survey indicated alder shrubs and associated plants at the site (see Appendix B). Soil from the top 10 cm layer of the “alder donor” site was collected using a backhoe and transported by dump truck to a stockpile location adjacent to Mitigation Site 5 on July 3, 2007. Only the top 10-15 cm layer was used as donor to insure an

adequate supply of viable seeds, rhizomes and other plant materials to regenerate an alder thicket wetland at the research site. The stockpile was approximately 1.5 m high with a 3 m circumference. The donor material was spread as soon as possible to avoid potential heating and composting in the stockpile. Because of the wet conditions at the time of construction, the donor soil was transported from stockpiles adjacent to the wetlands to the individual plots using a large plastic snowmobile sled pulled behind a tracked all-terrain vehicle. The donor material was spread on each plot designated to receive it in the experimental design by NRRI personnel with hand shovels in a thin layer (~ 2-3 cm) at a rate of approximately 1 m³ per 5 m x 5 m plot. Donor soil applications on Mitigation Site 5 were completed on July 9, 2007.

Direct Seeding

Direct seeding of appropriate wetland plant seed mixes can aid native vegetation establishment on restored or created wetlands (Shaw, 2000; Jacobson, 2006). Two wetland seed mixes, wetland temporary and native sedge/wet meadow, developed by the Minnesota Department of Transportation and Minnesota Board of Water and Soil Resources (Jacobson, 2006), were applied to selected plots in the study.

The wetland temporary seed mix, also known as WT1, consists of 30 percent American slough grass (*Beckmannia syzigachne*), 40 percent annual rye-grass (*Lolium italicum*), and 30 percent fowl bluegrass (*Poa palustris*). The intended purpose of this temporary seed mix is to provide short-term stabilization of a site and serve as a cover crop while the permanent vegetation establishes from the donor soil seed bank (Jacobson, 2006). The wetland temporary seed mix was applied at the recommended rate of 22.4 kg pure live seed per hectare.

The native sedge/wet meadow seed mix (also known as W2) shown in Table 2-1 contains species from both native sedge and wet meadow community types that grow in saturated or moist soil (Jacobson, 2006). The mix can be used statewide. The native sedge/wet meadow seed mix was applied at the recommended rate of 9.0 kg pure live seed per hectare. Both WT1 and W2 seed mixes were applied to the appropriate plots on Mitigation Site 5 on July 13, 2007.

Willows

In addition to the trees and shrubs that will likely establish from the seeds, roots, and rhizomes in the donor soil, hardwood willow cuttings were also planted at the site. Willows will root readily from dormant hardwood cuttings collected in the winter or early spring and kept in cold storage until planting in mid-to-late May (Chmelar, 1974; Hoag, 2007). Hardwood willow cuttings were collected on March 22, 2007 west of the town of Cook at a St. Louis County brushland site managed for sharptail grouse habitat. The site had been sheared in the last several years, resulting in an abundance of approximately 2- to 3-year-old willow shoots. The willow shoots were cut into 20 cm cuttings using a band saw, sealed in plastic bags, and stored at approximately minus 3° C to maintain dormancy. Cuttings were planted while still dormant, with the buds oriented upward with only 3-5 cm of the cutting remaining above ground level. A total of 500 willow (*Salix petiolaris*) cuttings, each 20 cm in length (Rossi, 1999), were planted at 1 m spacing on the designated plots (25 cuttings per plot) on July 11, 2007. An additional five plots were established with five cuttings each of *S. petiolaris*, *S. bebbiana*, *S. planifolia*, *S. pyrifolia*,

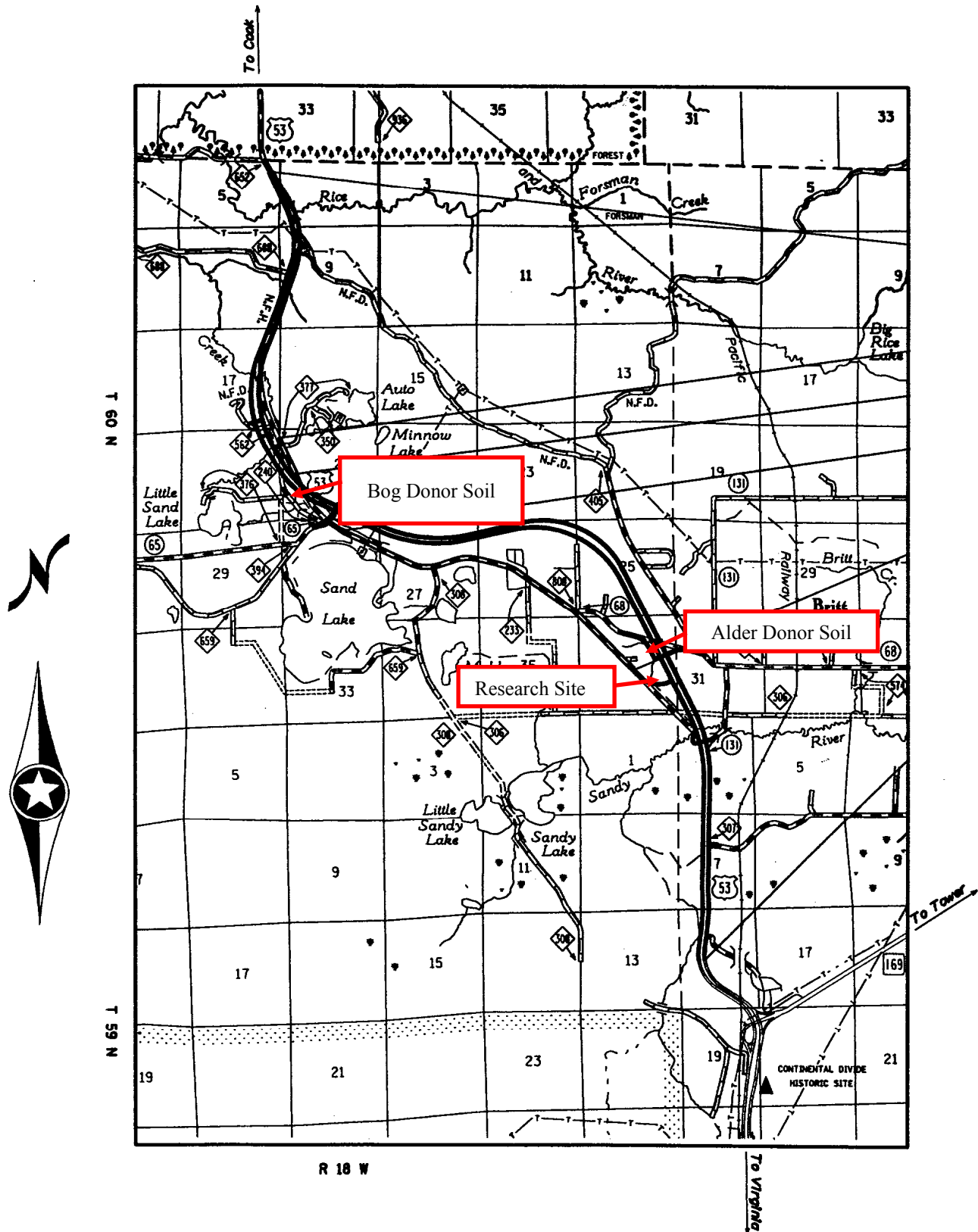


Figure 2-3. Bog and alder donor soil sites in relation to the research site. (Source: Mn/DOT District 1 Virginia Office.)

Table 2-1. Native sedge/wet meadow seed mix.

Common Name	Scientific Name
American slough grass	<i>Beckmannia syzigachne</i>
Fringed brome	<i>Bromus ciliatus</i>
Blue joint grass	<i>Calamagrostis canadensis</i>
Virginia wild rye	<i>Elymus virginicus</i>
Reed manna grass	<i>Glyceria grandis</i>
Fowl manna grass	<i>Glyceria striata</i>
Fowl bluegrass	<i>Poa palustris</i>
Bottlebrush sedge	<i>Carex comosa</i>
Porcupine sedge	<i>Carex hystericina</i>
Fox sedge	<i>Carex vulpinoidea</i>
Slender rush	<i>Juncus tenuis</i>
Green bulrush	<i>Scirpus atrovirens</i>
Wool grass	<i>Scirpus cyperinus</i>
River bulrush	<i>Scirpus fluviatilis</i>
Soft-stem bulrush	<i>Scirpus validus</i>
Canada anemone	<i>Anemone canadensis</i>
Marsh milkweed	<i>Asclepias incarnata</i>
Swamp aster	<i>Aster puniceus</i>
Flat topped aster	<i>Aster umbellatus</i>
Joe pye weed	<i>Eupatorium maculatum</i>
Boneset	<i>Eupatorium perfoliatum</i>
Grass leaved goldenrod	<i>Euthamia graminifolia</i>
Sneezeweed	<i>Helenium autumnale</i>
Serrated sunflower	<i>Helianthus grosseserratus</i>
Blue flag iris	<i>Iris versicolor</i>
Meadow blazingstar	<i>Liatris ligulistylis</i>
Great-blue lobelia	<i>Lobelia siphilitica</i>
Monkey flower	<i>Mimulus ringens</i>
Mountain mint	<i>Pycnanthemum virginianum</i>
Giant goldenrod	<i>Solidago gigantea</i>
Blue vervain	<i>Verbena hastata</i>
Ironweed	<i>Veronia fasciculata</i>
Culver's root	<i>Veronicastrum virginicum</i>

and *S. serissima* to determine survival and growth differences between different willow species. Not only are the willow cuttings expected to establish a shrub swamp wetland, but a dense stand of willows have also been shown to reduce reed canary grass invasion (Kim et al., 2006).

Mulch

Mn/DOT certified Type 3 weed-free straw mulch was spread over the entire wetland site at a rate of approximately 2,250 kg/ha. According to Mn/DOT project engineers, any wetland mitigation occurring in a national forest, such as this project, is required to use Mn/DOT certified weed-free Type 3 mulch. Spreading was done with a tractor-pulled round bale spreader and by hand to ensure adequate coverage. Mulch was spread equally over all research plots, and it was not tested as an experimental treatment.

Monitoring

Water table wells were established on the Mitigation 4 and 5 sites in August 2007. Water table levels were recorded throughout the frost-free period beginning in August 2007 through November 2009 at three wells on each site.

Along with wetland hydrology, the criteria for successful wetland creation are wetland plant cover, tree and shrub survival, and absence of invasive species. An initial plant survey of the research plots on Mitigation 4 and 5 sites was conducted on September 18, 2007. Subsequent plant surveys were conducted in June and September 2008 and 2009. Plant surveys were conducted using the relevé method (Minnesota Department of Natural Resources, 2007) to estimate percent cover by each plant species. Because of overlapping species coverage, most plots ended up with greater than 100 percent cover, especially in the later surveys as plant growth increased substantially. All data collected were sorted in order to categorize plant species as native, foreign (introduced), invasive, or originating from the WT1 seed mix, W2 seed mix, or donor soil. The total number of plant species and percent cover for each category was then calculated for each plot, in addition to total percent plant cover, total species richness, and Simpson's index of diversity (Krebs, 1989). All of the revised data were entered into database spreadsheets for each mitigation site. For plots containing willows, survival and individual plant height was determined in September 2007, 2008, and 2009.

Construction costs for the wet meadow and shrub swamp mitigation site were monitored and recorded by the Mn/DOT engineers in cooperation with the contractor, KGM Contractors, Inc.

Data Analyses

Statistical analyses were conducted on study data to determine the treatment effects on plant species diversity, and percent plant cover and species richness, for total, native, introduced, seeded, and invasive species. SigmaPlot® 11 software was used to conduct the analyses and graph the results. The General Linear Model procedure was used to determine treatment effects. Normal distribution and equal variance assumptions for data were tested using a p value of 0.05. SigmaPlot tests for normality using the Kolmogorov-Smirnov test and for equal variance using the Levene Median test (Systat Software, Inc., 2008). When data failed to meet these tests, they were transformed to meet the normal distribution and equal variance assumptions. Treatment effects were considered significant at the $p = 0.05$ level.

Results and Discussion

General Observations

Water Levels

Ongoing water level monitoring on Mitigation Site 5 indicated remedial action was required to lower water levels in fall 2007. Remedial bypass ditching was conducted by the contractor in January 2008. Since then water levels appear to have stabilized to a point where they will not disturb plant growth. Water levels at Mitigation Site 5 continue to be highest in the spring and fall, with the lowest levels observed during July and August (see Figures 2-4, 2-5, 2-6).

According to the U.S. Army Corps of Engineers technical standard (USACOE, 2005), wetland hydrology is present when:

“The site is inundated (flooded or ponded) or the water table is ≤ 12 inches below the soil surface for ≥ 14 consecutive days during the growing season at a minimum frequency of 5 years in 10 ($\geq 50\%$ probability). Any combination of inundation or shallow water table is acceptable in meeting the 14-day minimum requirement. Short-term monitoring data may be used to address the frequency requirement if the normality of rainfall occurring prior to and during the monitoring period each year is considered.”

As seen in Figures 2-4, 2-5, and 2-6 the water table was within 12 inches (30 cm) of the soil surface for at least a 14-day period in both the spring and fall of each year of the study, so the wetland hydrology standard was met during the study period.

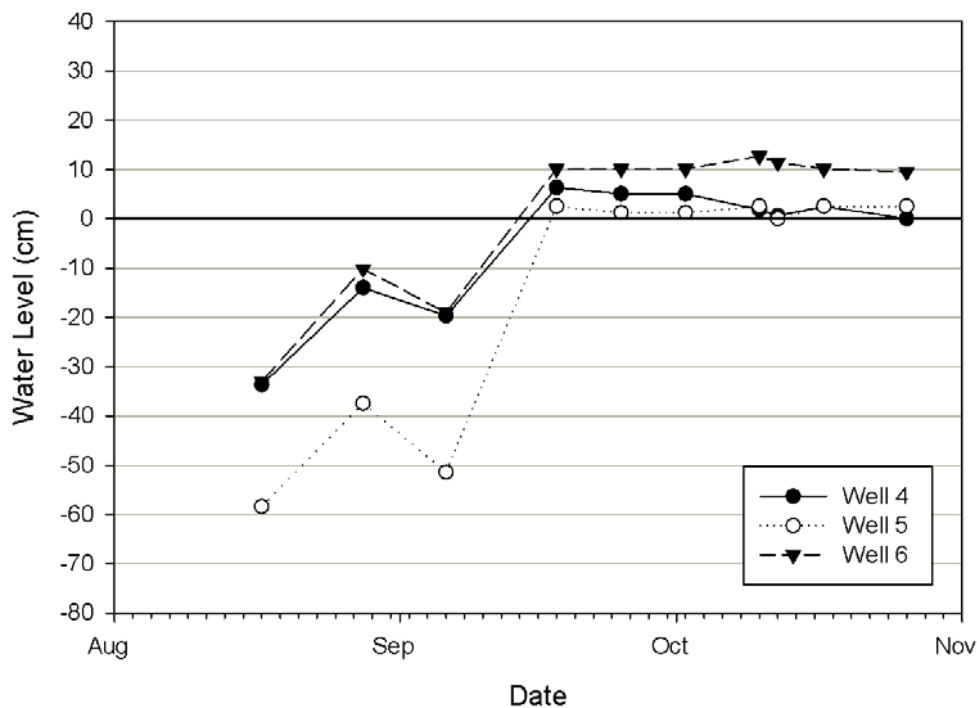


Figure 2-4. 2007 Mitigation Site 5 water levels.

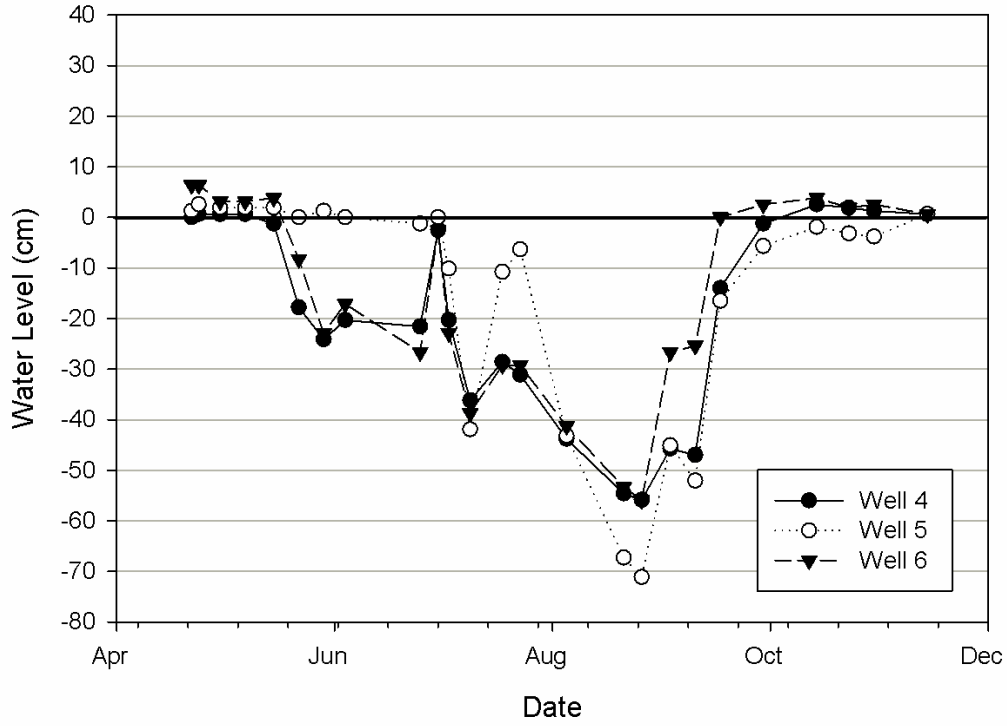


Figure 2-5. 2008 Mitigation Site 5 water levels.

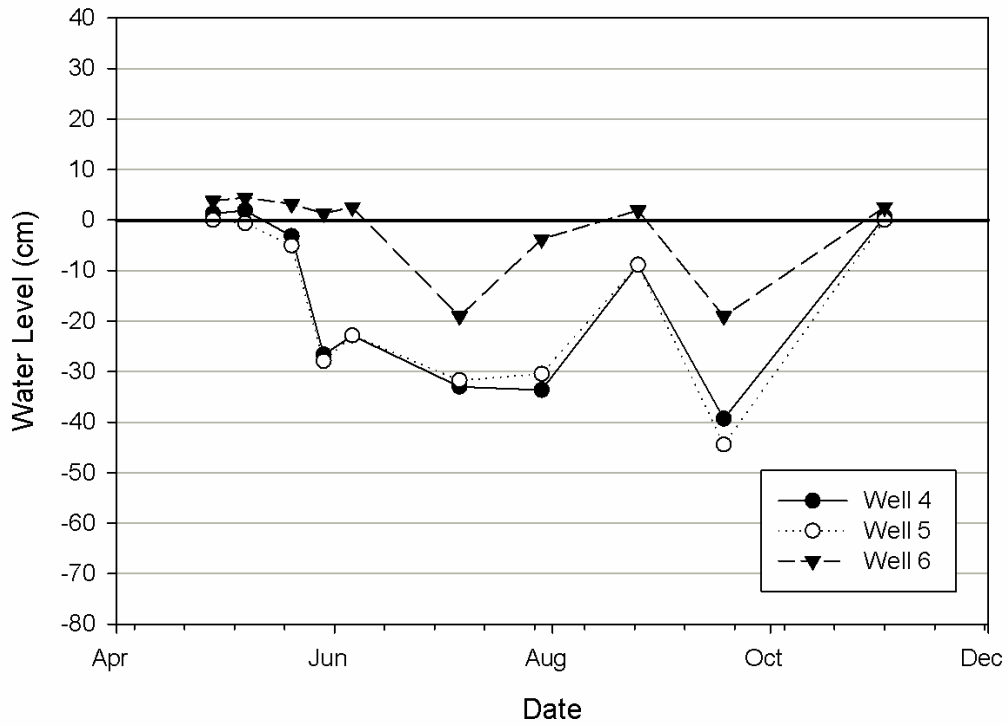


Figure 2-6. 2009 Mitigation Site 5 water levels.

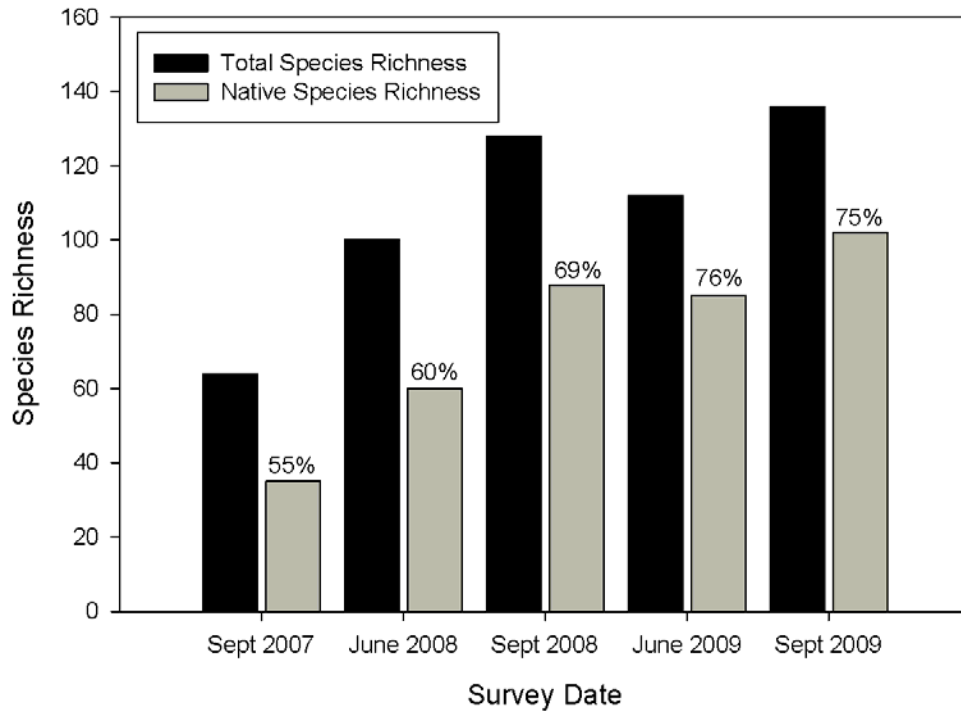


Figure 2-7. Mitigation Site 5 – Wet meadow and shrub swamp total and native species richness. Percentages shown are native species richness as a percent of total species richness.

Vegetation

Overall, vegetative cover is progressing quite well on the wet meadow and shrub swamp created wetland. There is almost complete vegetative cover, and species richness has steadily increased from 64 species in September 2007 to 136 species in September 2009 (see Figure 2-7). The percentage of total species that are native has also increased from 55 percent in September 2007 to 75 percent in September 2009, suggesting succession to a more stable natural state. Invasive species such as reed canary grass (*Phalaris arundinacea*) and narrow leaved cattail (*Typha angustifolia*) were present at the site but were effectively controlled by hand pulling and spot spraying with glyphosate herbicide (Foster and Wetzel, 2005; Adams and Galatowitsch, 2006).

Based on percent cover, plant species dominating the site overall changed over time (see Table 2-2). The species in the WT1 seed mix dominated early on but were gradually replaced by native species, including those that were part of the W2 seed mix.

Mulch

Mulch can be very beneficial for plant establishment on uplands and certain created or restored wetland types such as bogs (Quinty and Rochefort, 2003). In areas with sufficient soil moisture such as the mitigation sites in this study, the beneficial effect of mulch is questionable. High water levels experienced in fall 2007 and spring 2008 caused the mulch to drift and accumulate to a significant depth in some areas, resulting in little or no vegetation due to excess mulch.

Because mulch was spread over both sites in their entirety, and it was not included as an experimental treatment, this observation is only anecdotal. Future research should address the need for mulch on wetland creations or possibly ways to anchor it and prevent it from drifting.

Treatment Effects

Data from each of the vegetation surveys conducted in September 2007, June and September 2008, and June and September 2009 were individually analyzed to determine treatment effects. Only significant effects will be discussed in the following sections.

Donor Soil

Donor soil applications on Mitigation Site 5 significantly increased soil organic matter and potassium on the research plots. An increase in organic matter on a wetland creation site is beneficial for plant growth.

There were no significant effects of donor soil on vegetation until September 2008, when the data showed a significantly higher number of donor species (species present at the site where the donor soil was collected) ($p=0.002$) on plots that received the donor soil treatment. This effect on the number of donor species was also significant in June 2009 ($p=0.036$), but only for plots that had not received any direct seeding treatments. In September 2009, there again was a significant positive effect of donor soil on the number of donor species ($p=0.008$). Although this was a positive result, it was only the difference of one or two additional species due to the donor soil applications.

Table 2-2. Mitigation Site 5 – Wet meadow and shrub swamp species dominance (determined by percent cover).

Date	Species	Designation	Mean Percent Cover (n=50)
Sept 2007	<i>Lolium italicum</i>	Foreign, WT1 seed mix	29.3
	Unknown grass seedlings	Unknown	5.2
	Cyperaceae	Unknown	4.2
	<i>Glyceria</i> sp.	Unknown	1.2
	<i>Polygonum lapathifolium</i>	Native	1.1
June 2008	<i>Beckmannia syzigachne</i>	Native, WT1 & W2 seed mix	4.0
	<i>Carex stipata</i>	Native	3.2
	<i>Juncus effusus</i>	Native, W2 seed mix	2.8
	<i>Carex tenera</i>	Native	2.3
	<i>Glyceria striata</i>	Native, W2 seed mix	2.3
Sept 2008	<i>Glyceria striata</i>	Native, W2 seed mix	11.8
	<i>Scirpus cyperinus</i>	Native, W2 seed mix	11.0
	<i>Glyceria grandis</i>	Native, W2 seed mix	10.8
	<i>Beckmannia syzigachne</i>	Native, WT1 & W2 seed mix	4.7
	<i>Juncus effusus</i>	Native, W2 seed mix	3.9
June 2009	<i>Scirpus cyperinus</i>	Native, W2 seed mix	24.2
	<i>Glyceria grandis</i>	Native, W2 seed mix	23.4
	<i>Carex stipata</i>	Native	20.0
	<i>Juncus effusus</i>	Native, W2 seed mix	7.1
	<i>Carex canescens</i>	Native	5.8
Sept 2009	<i>Scirpus cyperinus</i>	Native, W2 seed mix	36.0
	<i>Glyceria grandis</i>	Native, W2 seed mix	31.4
	<i>Juncus effusus</i>	Native, W2 seed mix	13.9
	<i>Carex stipata</i>	Native	12.4
	<i>Calamagrostis canadensis</i>	Native, W2 seed mix, donor	12.2

In June 2009, the data showed a significantly higher number of invasive species ($p=0.042$) on plots that did not receive donor soil. This same effect was also significant in September 2009 ($p=0.049$). Again, a beneficial effect of donor soil, but only a difference of one species, since only two invasive species (narrow-leaved cattail and reed canary grass) was present at the site. Donor soil had a significant negative effect on percent cover by plants from the W2 seed mix in June 2009 ($p=0.001$). Plots with donor soil also had significantly less cover by W2 seed mix plants in September 2009 ($p=0.012$).

The September 2009 plant survey data revealed a number of beneficial effects due to donor soil applications (see Figure 2-8). Donor soil significantly increased total percent cover ($p=0.033$), species richness ($p=0.003$), Simpson's index of diversity ($p=0.001$), the number of native species ($p=0.001$), native species percent cover ($p=0.044$), and the number of W2 seed mix plants ($p=0.001$). Some of the more important benefits due to donor soil included a 35 percent increase in mean species richness, an 11 percent increase in mean Simpson's index of diversity, a 40 percent increase in mean native species richness, and a 12 percent increase in mean percent native cover. It is important to note that none of these beneficial effects were evident until the end of the third growing season. This is possibly due to native seeds requiring more time to germinate. Continued monitoring of the site should be conducted to determine if this trend continues.

Direct Seeding

Effects of the WT1 and W2 direct seeding treatments were more evident early on in the study. The September 2007 plant survey data showed a significant positive effect of seed mixes with increased total percent cover ($p<0.001$), higher number of WT1 species ($p<0.001$), and greater percent WT1 species cover ($p<0.001$). These positive effects can be attributed primarily to annual ryegrass (*Lolium italicum*) that was part of the WT1 seed mix and dominated plots in the first year. In subsequent years, the only effects that remained significant were an increased number of WT1 species and increased percent WT1 species cover. These effects were likely due to American slough grass (*Beckmannia syzigachne*) becoming a dominant component on the seeded plots. American slough grass was included in both the WT1 and W2 seed mixes. In contrast to the effects of donor soil applications, by September 2009 there were no significant effects due to direct seeding.

The September 2007 plant survey data also showed several significant negative effects of direct seeding with lower species richness ($p<0.001$), lower Simpson's index of diversity ($p<0.001$), lower number of native species ($p<0.001$), reduced percent native species cover ($p<0.001$), and increased percent foreign species cover ($p<0.001$). By September 2008, the only significant negative effect that remained was decreased percent native species cover ($p=0.003$), especially on the plots receiving the WT1 seed mix. By June 2009 significant negative effects of seed mix were no longer evident.

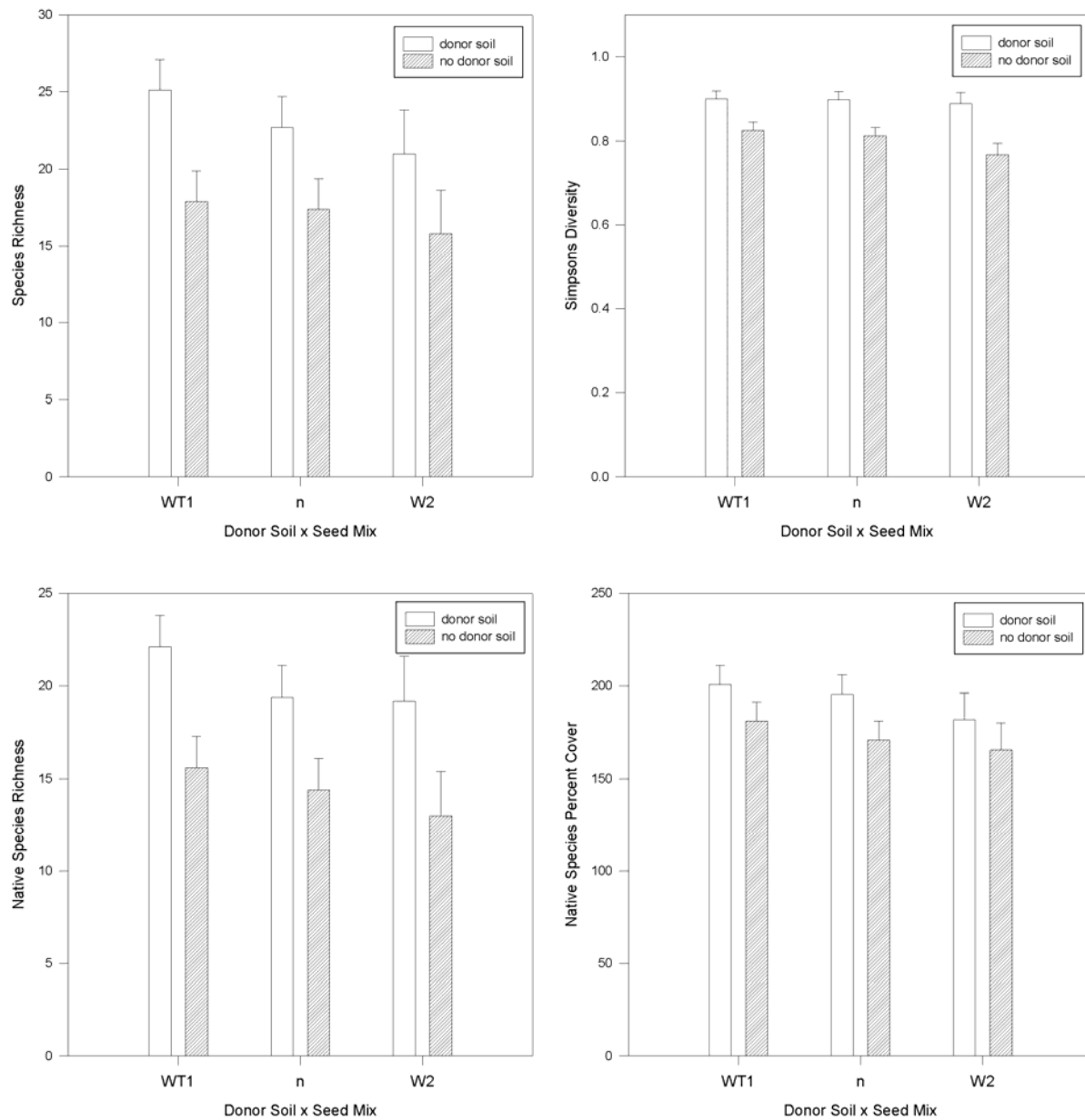


Figure 2-8. September 2009 Mitigation Site 5 data showing the beneficial effect of donor soil on total species richness, Simpson's index of diversity, native species richness, and native species percent cover. Mean + standard error, n=50.

Willows

Overall, mean hardwood willow cutting (*Salix petiolaris*) survival in treatment plots surveyed in September 2009 was approximately 60 percent. This percentage was down from 66 percent in 2008 and 91 percent in 2007. Mean height in September 2009 was about 66 cm, up from 35 cm in 2008 and 19 cm in 2007. There was no significant effect of donor soil or seed mix on willow survival or height. Willows had no significant effect on the number or percent cover of invasive species, such as reed canary grass. This condition is to be expected at this time, as the willows are still too small to shade out the invasive species.

Mean survival for the five willows in the species trials ranged from 40 percent (*S. pyrifolia*) to 92 percent (*S. planifolia*) as of the September 2009 plant survey (see Figure 2-9). The only significant difference was between *S. planifolia* at the highest survival rate, and *S. pyrifolia* and *S. bebbiana* at the lowest. Mean height for the five willow species surveyed in September 2009 ranged from 41 cm (*S. pyrifolia*) to 74 cm (*S. planifolia*) (see Figure 2-10). *Salix petiolaris* and *S. planifolia* were significantly taller than *S. pyrifolia* and *S. serissima*. *Salix bebbiana* mean height was not significantly different from any species except *S. planifolia*. Based on survival and height growth in this study, the best willow species to use on similar sites in the same geographic area appear to be *S. petiolaris* and *S. planifolia*. However, a mix of several native species is recommended to increase diversity and to insure that at least some species establish.

Construction Costs

Construction costs for the 1.3 hectare Mitigation Site 5 included: land purchase, clearing and grubbing, borrow excavation, muck excavation, muck placement, and seeding and mulching (Table 2-3). Excavation and placement costs included hauling. Cost estimates did not include research plot establishment, maintenance, or monitoring costs.

Table 2-3. Mitigation 5 site construction costs.

Land purchase	\$15,625/ha	\$20,361
Clearing and grubbing	\$6,029/ha	\$7,857
Borrow excavation	23,702 m ³ @ \$2.07/ m ³	\$48,978
Muck excavation	7,583 m ³ @ \$2.07/ m ³	\$15,670
Muck placement	7,583 m ³ @ \$1.96/ m ³	\$14,877
Seeding and mulching	\$1,602/ha	\$2,088
Total project cost		\$109,831
Total per hectare cost		\$84,283

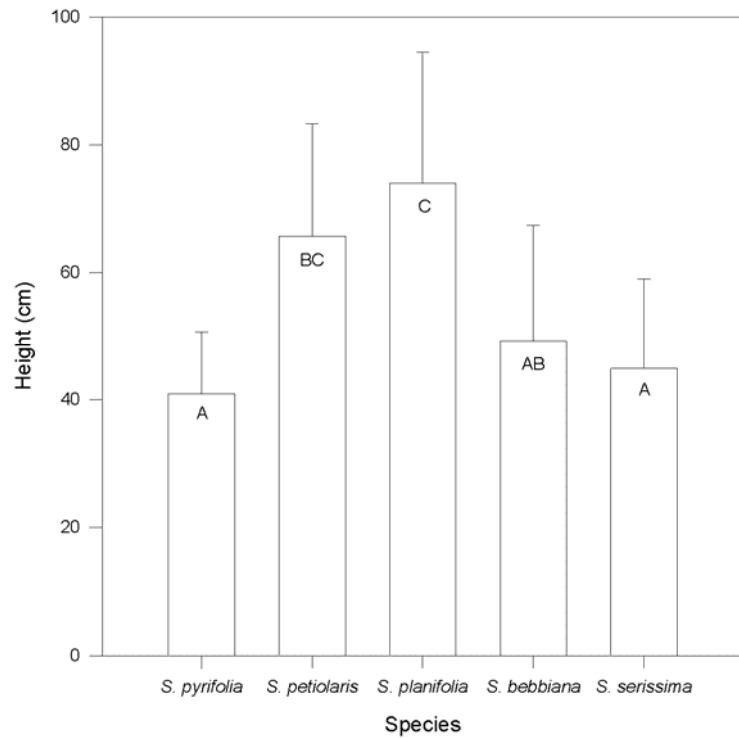


Figure 2-9. 2009 *Salix* species mean percent survival + standard error (n=25). Species with the same letter are not significantly different at the p=0.05 level.

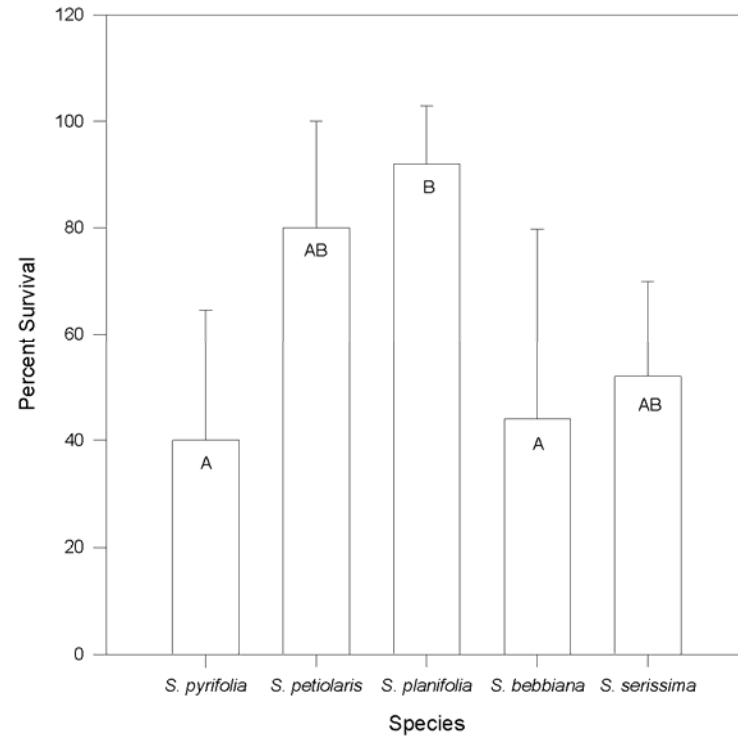


Figure 2-10. 2009 *Salix* species mean height + standard error (n=25). Species with the same letter are not significantly different at the p=0.05 level.

Although the construction costs were quite high (\$84,283/hectare, \$34,109/acre), it is important to note that mitigation and road construction costs are hard to separate in this instance because the mitigation was integrated into the entire road construction project. Much of the mitigation site work would have been done for the road construction regardless. Therefore, it is difficult to get a reliable cost estimate for the mitigation alone. Cost savings were realized overall on this construction project because it was a “balanced job,” meaning all construction materials were available on site. The cost for the borrow materials excavated from the mitigation site would have been considerably higher if they had to come from an off-site source. Land costs were also substantially higher at the mitigation site than they would have been elsewhere because it was previously a residential site.

Chapter 3. Wooded Swamp and Bog Mitigation Wetlands

Background

As mentioned previously in the background information for Chapter 2, the U.S. Trunk Highway 53 reconstruction also resulted in unavoidable wetland impacts to wooded swamp (11.5 ha) and bog (10.0 ha) wetlands. Both of these wetland types are common in northeast Minnesota. Large peatland areas containing both bogs and coniferous swamps occur throughout the northern part of the state (Minnesota Department of Natural Resources, 1981).

Wooded swamps (Type 7) have saturated soils with the water table usually within a few inches (5-8 cm) of the surface, but may at times have up to a foot (30 cm) of standing water. Trees present on wooded swamps in northern areas such as Minnesota include tamarack, arborvitae, black spruce, balsam, red maple, and black ash (Shaw and Fredine, 1971). Northern evergreen swamps common in northeast Minnesota may also have a ground cover of mosses in addition to tamarack and black spruce trees. These wetlands are also classified as coniferous bogs (Eggers and Reed, 1997).

Bogs (Type 8) have saturated peat soils that support a thick covering of *Sphagnum* moss. Other plant species present may include leather-leaf, Labrador tea, cranberries, *Carex*, cottongrass, black spruce and tamarack. (Shaw and Fredine, 1971). Minnesota bogs are further categorized as open bogs with scattered, often stunted black spruce and tamarack present, or coniferous bogs with mature black spruce and tamarack dominating the site (Eggers and Reed, 1997).

Bog creations are very limited in the literature and restricted to a sphagnum bog in a quarry in Ohio (Andreas and Host, 1983) that took approximately 70 years to develop without human intervention. Considerable success has been achieved in restoring mined sphagnum bogs in Canada and Minnesota (Johnson et al., 2000; Rochefort et al., 2003; Quinty and Rochefort, 2003), but these sites are restorations rather than creations and, therefore, usually have the appropriate substrate and hydrology in place.

Wooded swamps, whether hardwood or coniferous, can take an extended period of time to create because of the slow nature of tree growth. Both wooded swamps and bogs can take decades to fully mature. Therefore, the intention of this study was to create the proper substrate and hydrology at the site followed by the introduction of plants and tree seedlings to start the wetland on the path to wooded swamp and bog development. True success can only be determined in the long-term.

Materials and Methods

Site selection and overall construction for both Mitigation Sites 4 and 5 were described in Chapter 2.

Experimental Treatments

The goal for Mitigation Site 4 was to establish vegetation characteristic of wooded swamp and bog wetlands. Approaches used to establish wetland vegetation included donor soil applications, direct seeding, planting of conifer seedlings, and fertilizer applications. To test the various vegetation establishment strategies, a total 10 experimental treatment combinations were applied. These treatments included the following:

- 1) Donor soil;
- 2) No donor soil;
- 3) Wetland temporary seed mix;
- 4) Wetland temporary seed mix + donor soil;
- 5) Conifer seedlings;
- 6) Conifer seedlings + donor soil;
- 7) Fertilizer;
- 8) Fertilizer + donor soil;
- 9) Conifer seedlings + fertilizer; and
- 10) Conifer seedlings + fertilizer + donor soil.

The study was established in a randomized block design with five replications (blocks) of each treatment combination resulting in a total of 50 – 5 m x 5 m (25 m²) plots each separated by a 2 m buffer. Blocks were arranged parallel to and at varying distances from the road. The treatments are described in the following sections.

Donor Soil

As previously mentioned, donor wetland soil applications have been shown to increase plant species richness, percent wetland plant cover, and soil organic matter (Brown and Bedford, 1997; Stauffer and Brooks, 1997; Johnson and Valppu, 2003; McKinstry and Anderson, 2005). Where available, donor soil applications generally result in wetland vegetation better adapted to the site.

Research conducted to date on the restoration of *Sphagnum* dominated peatlands has demonstrated the potential for re-establishing native vegetation on harvested or disturbed sites by spreading moss and other plant fragments, collected from natural, undisturbed, donor sites, on bare peatland surfaces (Elling and Knighton, 1984; Poschlod and Pfadenhauer, 1989; Rochefort et al., 1995). This encourages the primarily vegetative reproduction of *Sphagnum* (Darlington, 1964; Cronberg, 1993) and allows associated peatland plant establishment from seeds, rhizomes, and other plant structures included with the donor vegetation. In the case of sphagnum bogs mined for horticultural peat, research has shown that application of *Sphagnum* moss fragments and associated peatland plants collected from the top 10-15 cm of a donor site have the potential to restore bog vegetation on disturbed sites (Campeau and Rochefort, 1996; Quilty and Rochefort, 2003).

A suitable bog donor site was identified approximately 8 km north of the research site (see Figure 2-3). This small bog was directly affected by the road construction so presented a good opportunity to salvage soil and plants. To provide a more suitable substrate to regenerate bog

plants at Mitigation Site 4, the underlying peat at the bog donor site with a pH of 4.5 and relatively low nutrient content was collected using a backhoe and transported to the study site. Since the bog donor site was some distance from Mitigation Site 4, only enough peat to provide a 15 cm surface layer was transported to overlay the underlying organic soil at the study site. This layer was spread over the entire site using a backhoe according to the plan shown in Figure 2-2.

The plant survey of the bog donor site identified a surface layer of *Sphagnum* moss, ericaceous shrubs, and other plants characteristic of a bog and suitable as donor material (Appendix B). The bog donor material was collected using a backhoe from the surface 10-15 cm of the bog. The donor material was then hauled by truck to the mitigation site and stockpiled in windrows on July 5, 2007. The windrows were approximately 1 m high by 2m wide. The donor material was spread as soon as possible to avoid potential heating and composting in the windrows. Because of the fibrous nature of the bog donor, the material was chopped into smaller pieces using a garden tiller before being spread on the research plots. Because of the wet conditions at the time of construction, the donor soil was transported from stockpiles adjacent to the wetlands to the individual plots using a large plastic snowmobile sled pulled behind a tracked all-terrain vehicle. The donor material was spread on each plot designated to receive it in the experimental design by University personnel with hand shovels in a thin layer (~ 1-3 cm) (Campeau and Rochefort, 1996; Quilty and Rochefort, 2003) at a rate of approximately 1 m³ per 5 m x 5 m plot. The goal was to have a thin layer of donor material in contact with the moist soil to allow the *Sphagnum* moss fragments to regenerate. Bog donor application to 25 of the 50 plots on Mitigation Site 4 was completed on July 19, 2007.

Direct Seeding

Since the vegetation goals for Mitigation Site 4 did not include native sedge/wet meadow species, only the wetland temporary seed mix was applied at this site. The wetland temporary seed mix, also known as WT1, consists of 30 percent American slough grass (*Beckmannia syzigachne*), 40 percent annual rye-grass (*Lolium italicum*), and 30 percent fowl bluegrass (*Poa palustris*). The intended purpose of this temporary seed mix is to provide short-term stabilization of a site and serve as a cover crop while the permanent vegetation establishes from the donor soil seed bank (Jacobson, 2006). The wetland temporary seed mix was applied at the recommended rate of 22.4 kg pure live seed per hectare to selected plots in the study. A small hand-held seeder was used to evenly distribute the seed. Seeding was completed on 10 of the 50 plots on Mitigation Site 4 on July 20, 2007.

Conifer Seedlings

A common type of wooded swamp in northern Minnesota and the study area is the coniferous bog (Eggers and Reed, 1997) characterized by mature black spruce (*Picea mariana*) and tamarack (*Larix laricina*) trees with a groundcover of *Sphagnum* moss and ericaceous shrubs. In addition to the trees and shrubs that will likely establish from the seeds, roots, and rhizomes in the donor soil, black spruce and tamarack bare-root seedlings were planted on Mitigation Site 4 to attempt to establish a forest component. A total of 100 black spruce and 100 tamarack bare root seedlings were planted at 2-meter spacing on designated plots on Mitigation Site 4 on August 8 and 9, 2007. These seedlings had been in cold storage since mid-May 2007,

anticipating site construction completion in late May to early June. Due to construction delays, the seedlings were in fair-to-poor condition when planted, and it became evident by late August 2007 that few, if any, of the seedlings would survive. On August 28, 2007, new containerized seedlings were planted to replace the bare root seedlings planted earlier. Tree seedlings were planted on 20 of the 50 plots on Mitigation Site 4, and an additional 25 seedlings each of black spruce and tamarack were also planted on the surrounding wetland.

Fertilizer

Fertilization can help to establish and maintain wetland plant species in some situations. In other instances, fertilization can increase the occurrence of introduced, invasive, or other unwanted species. Studies in Canada have shown a beneficial effect of phosphorus fertilization on sphagnum bog restoration (Quinty and Rochefort, 2003). The phosphorus doesn't directly increase *Sphagnum* growth, but does stimulate the growth of *Polytrichum* moss, which helps the *Sphagnum* to establish. *Polytrichum* not only serves as a companion species, but also reduces frost heaving, which is a common problem on peatland restoration sites. As in Canada, the phosphorus fertilizer for this study was applied as granulated phosphate rock, a slow release form, at a rate of 150 kg/hectare. Fertilizer was only applied as a treatment on Mitigation Site 4 to designated plots using a hand-held spreader. Fertilization was completed on 20 of the 50 plots on July 27, 2007.

Mulch

As on Mitigation Site 5, Mn/DOT certified Type 3 weed free straw mulch was spread over the entire Mitigation Site 4 at a rate of approximately 2,250 kg/ha. Spreading was done with a tractor-pulled round bale spreader, a stationary "cannon" type spreader, and by hand to ensure adequate coverage. Mulch was spread equally over all research plots, and it was not tested as an experimental treatment.

Monitoring and Data Analysis

Water table and vegetation monitoring were conducted in the same manner for Mitigation Site 4 as described in Chapter 2 for Mitigation Site 5. The same statistical analyses were also conducted on the data collected for both Mitigation Sites 4 and 5.

Construction costs for the wooded swamp and bog mitigation site were monitored and recorded by the Mn/DOT engineers in cooperation with the contractor, KGM Contractors, Inc.

Results and Discussion

Flooding and Remedial Activities

Severe flooding occurred on Mitigation Site 4 in fall 2007 and spring 2008 due to unusually wet weather and some site design limitations. Despite some remedial ditching conducted in January 2008, severe flooding still occurred on Mitigation Site 4 in spring 2008, compromising the study by displacing mulch, disturbing plot treatments, and killing the planted conifer seedlings. The contractor lowered the discharge culvert and installed a bypass ditch on Mitigation Site 4 in June 2008 to further reduce water levels and prevent future flooding. Although higher water levels continue to occur in the spring and fall of each year, they are not catastrophic and appear to have stabilized to a point where they will not disturb plant growth.

As a result of the flooding, it was agreed by the Principal Investigator, Technical Liaison, and Administrative Liaison that a no-cost extension for the project should be pursued to re-establish the Mitigation Site 4 donor soil and fertilizer treatments in spring 2009 and monitor plots on both mitigation sites for another growing season.

Because of higher than anticipated water levels at this site even after remedial ditching and the outlet culvert was lowered, it was determined that site conditions were not suitable for coniferous tree seedling establishment, and this treatment was discontinued. Existing vegetation was cut and removed in October 2008 from plots that had received donor soil in the original study to prepare for re-seeding with bog donor material the next spring. Vegetation was also cut and removed from a 0.2 hectare area around the research plots in preparation for large-scale bog donor spreading. To dispose of this cut vegetation, it was applied to the slopes surrounding the site as a mulch. In March 2009, bog donor material was collected and transported to Mitigation Site 4 from two donor sites that were being used for concurrent peatland restoration projects. One donor site was located at Premier Horticulture's Black Lake Bog horticultural peat operation west of Cromwell, Minnesota (46°43' N, 92°56' W), and the other was located at the University of Minnesota Duluth's Fens Research Facility south fields near Sax, Minnesota (47°14' N, 92°35' W). Plant survey data for each of the sites is included in Appendix B. Bog donor collection and spreading was completed in March when the ground was still frozen at the donor sites and Mitigation Site 4, allowing the use of a farm tractor, manure spreader, and small tracked front-end loader (Quinty and Rochefort, 2003). Approximately 1 m³ of bog donor from the Black Lake Bog was spread on each of 10 separate plots using the tracked front-end loader. The same was done with the Fens Research Facility donor for a total of 20 plots. Five of the 10 plots with each bog donor source received the phosphorus fertilizer treatment for a total of 10 fertilized plots. No mulch was applied to these plots. The live vegetation on these plots was anticipated to serve as companion plants to aid in *Sphagnum* establishment (Ferland and Rochefort, 1997; Boudreau and Rochefort, 1998), without the drawbacks of drifting mulch previously mentioned.

An additional 30 m³ of bog donor from the Fens Research Facility was spread on the 0.2 hectare area surrounding the research plots using an agricultural tractor and manure spreader according to methods developed for restoring bogs harvested for horticultural peat in Canada by Quinty and Rochefort (2003). All bog donor spreading was completed by March 30, 2009.

To test the effect of mulch on bog establishment, ten additional 5 m x 5 m plots were set up in the area surrounding the original research area on Mitigation Site 4 in April 2009. Five of the plots received straw mulch and five did not. The mulched plots were covered with a plastic mesh material to hold the straw in place and prevent drifting during any potential high water periods. Despite the problems with planned treatments, plant surveys for all plots within Mitigation Site 4 continued for the project duration to get an indication for the overall condition and evolution of the site as a whole. Because of the Mitigation Site 4 flooding and compromised treatments, statistical analysis was only conducted on the data collected in September 2007 prior to the flooding, and the data collected in June and September 2009 after the donor soil plots were reestablished.

Tree Mounding Study

Since Mitigation Site 4 was found to be too wet for tree seedlings to survive, another site, Mitigation Site 3, located directly east of Mitigation Sites 4 and 5, was used to test strategies for establishing conifer seedlings. To alleviate poor tree seedling survival on wet soils, sometimes seedlings are planted in elevated soil mounds to keep them above the water table and prevent the roots from becoming waterlogged. To test this method, containerized black spruce and tamarack seedlings were planted on Mitigation Site 3 in May 2009. As with Mitigation Sites 4 and 5, this site was used for borrow material for the road construction and also had an overlying layer of organic muck soil to serve as a substrate. Soil mounds approximately 15-20 cm in height and 30-40 cm in diameter were formed using hand shovels. Eight tree seedlings each of black spruce and tamarack were planted with and without soil mounds in each of five blocks, for a total of 40 tree seedlings of each species. The treatments were arranged in a randomized block design. The seedlings were planted on May 29, 2009. Trees were surveyed on October 8, 2009 to determine survival and height.

General Observations

Water Levels

Overall water levels continued to be slightly higher at Mitigation Site 4 than at Mitigation Site 5, even after the remedial ditching was completed and the culvert was lowered. As seen in Figures 3-1, 3-2, and 3-3, the water table on Mitigation Site 4 was within 12 inches (30 cm) of the soil surface for at least a 14-day period in each year of the study, so the wetland hydrology standard was met during the study period.

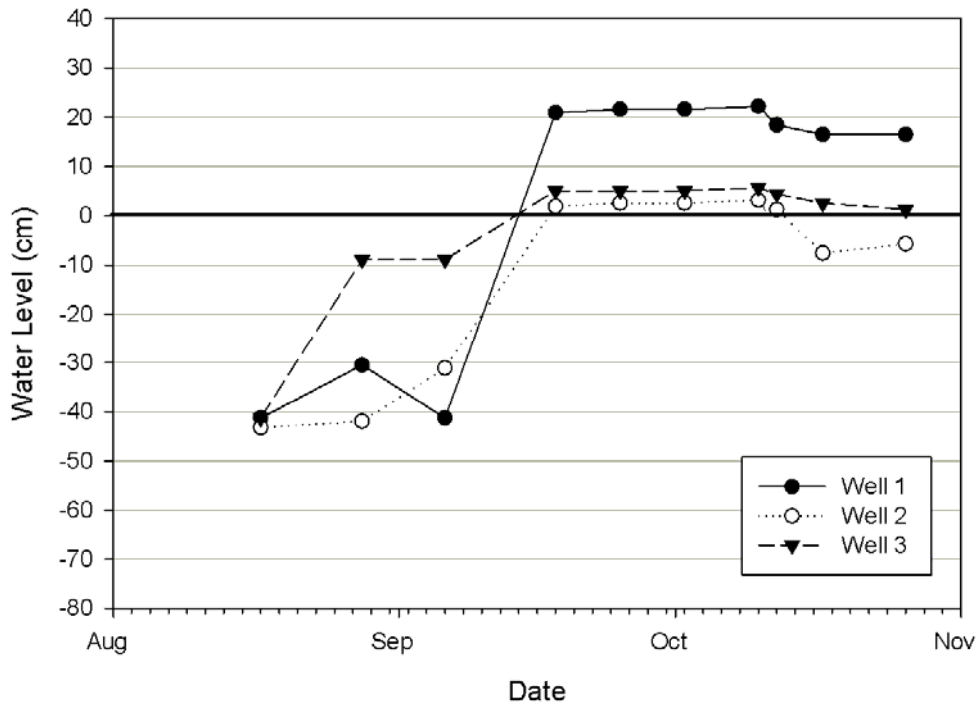


Figure 3-1. 2007 Mitigation Site 4 water levels.

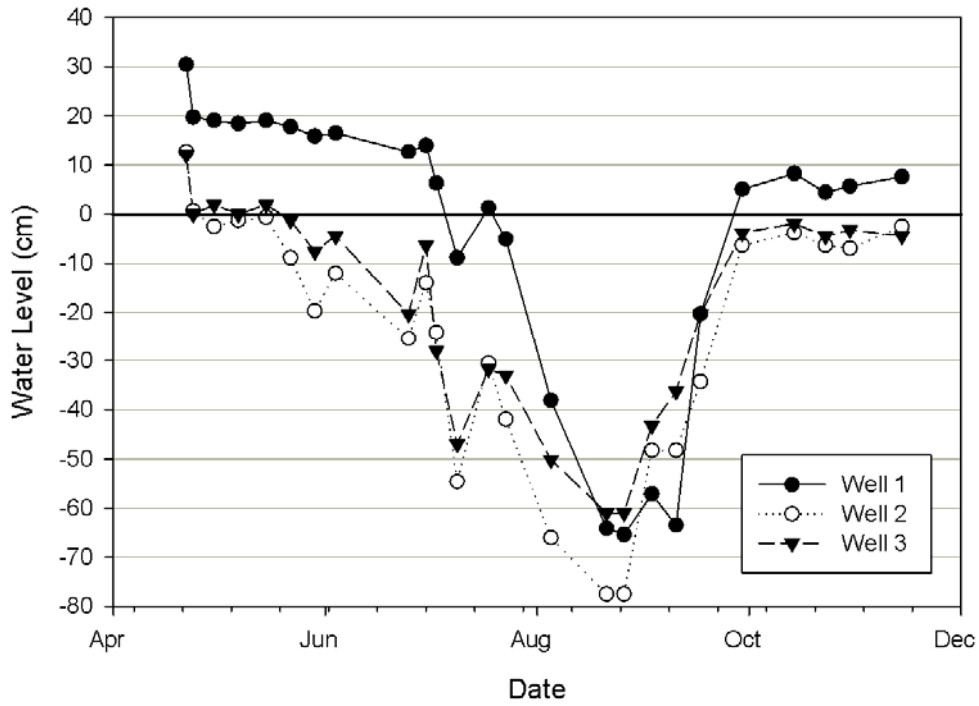


Figure 3-2. 2008 Mitigation Site 4 water levels.

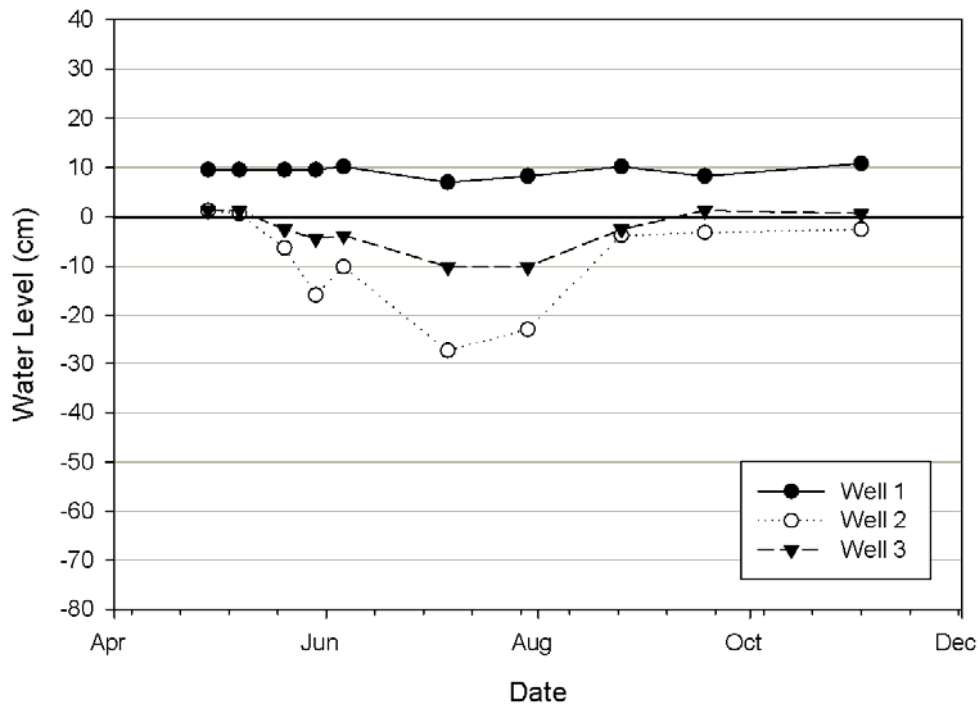


Figure 3-3. 2009 Mitigation Site 4 water levels.

Vegetation

Despite severe flooding in fall 2007 and spring 2008, vegetative cover overall for Mitigation Site 4 is progressing reasonably well. There is almost complete vegetative cover, and species richness has increased from 68 species in September 2007 to 97 species in September 2009 (see Figure 3-4). The percentage of total species that are native also increased from 49 percent in September 2007 to 81 percent in September 2009, suggesting succession to a more stable natural state. Mitigation Site 4 had considerably lower species richness than Mitigation Site 5, which is consistent with the relatively low species richness observed in natural bogs.

Plant species dominating the site based on percent cover changed over time (see Table 3-1). Species from the WT1 seed mix dominated the site early on, followed by native species and those that were part of the W2 seed mix. It is important to note that the W2 seed mix was not applied to Mitigation Site 4, yet species from this mix, *Scirpus cyperinus*, *Glyceria grandis*, and *Juncus effusus*, did come to dominate the site. This indicates for both Mitigation Sites 4 and 5 that these dominant plant species were most likely present in the organic soil seed bank and were not necessarily the result of W2 seed mix applications.

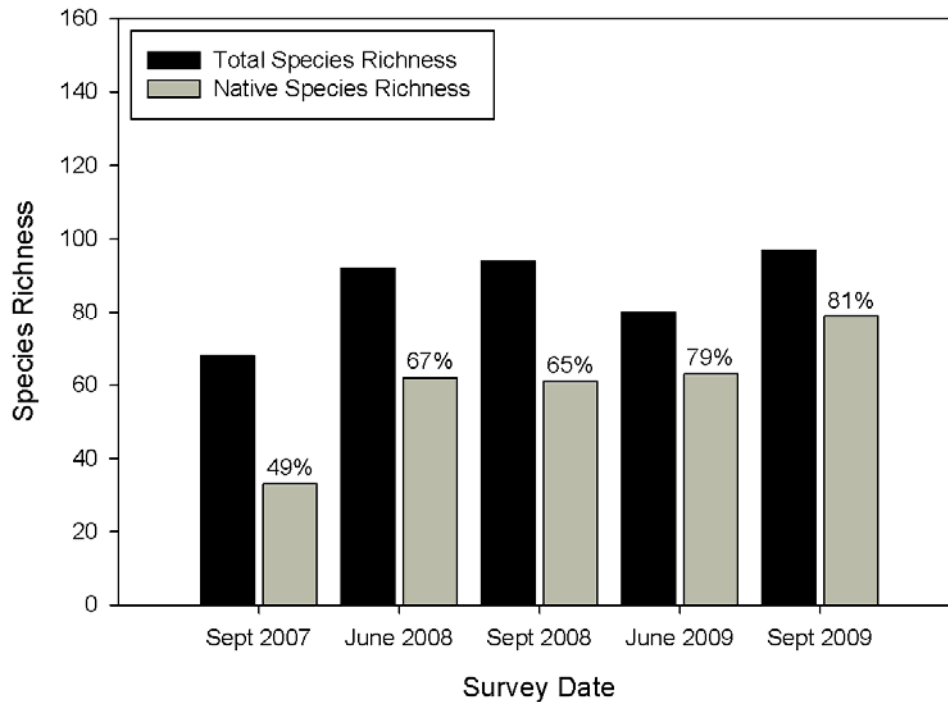


Figure 3-4. Mitigation Site 4 – Wooded swamp and bog total and native species richness. Percentages shown are native species richness as a percent of total species richness.

Invasive species occurring on Mitigation Site 4 included reed canary grass (*Phalaris arundinacea*), narrow leaved cattail (*Typha angustifolia*), and purple loosestrife (*Lythrum salicaria*). Although purple loosestrife was not found at the bog donor site, it is possible it was brought in with the lower level muck substrate or attached to construction equipment that may have been used on infested sites. Purple loosestrife was first found on Mitigation Site 4 in September 2007, and approximately 275 individual plants were hand pulled in October 2007. All invasive species have been effectively controlled by hand pulling and spot spraying with glyphosate herbicide (Foster and Wetzel, 2005; Adams and Galatowitsch, 2006) for the duration of the project.

Mulch

As on Mitigation Site 5, the benefits of mulch applications on Mitigation Site 4 are questionable. In addition to drifting mulch accumulating in certain areas due to flooding and smothering plant growth, the mulch also aggravated the flooding problem by blocking the Mitigation Site 4 outlet culvert. Further study should be conducted to determine the necessity of mulch applications in such wet conditions, or if it can be cost effectively anchored to prevent drifting.

Table 3-1. Mitigation Site 4 – Wooded swamp and bog species dominance (determined by percent cover).

Survey Date	Dominant Species	Designation	Mean Percent Cover (n=50)
Sept 2007	<i>Lolium italicum</i>	Foreign, WT1 seed mix	11.9
	<i>Carex</i> sp.	Unknown	7.6
	<i>Glyceria</i> sp.	Unknown	3.2
	Unknown grass seedlings	Unknown	2.8
	<i>Juncus</i> sp.	Unknown	2.5
June 2008	<i>Scirpus cyperinus</i>	Native, W2 seed mix	7.2
	<i>Glyceria grandis</i>	Native, W2 seed mix	3.5
	<i>Juncus effusus</i>	Native, W2 seed mix	2.8
	<i>Carex</i> (Ovales)	Native	2.2
	<i>Eleocharis obtusa</i>	Native	0.8
Sept 2008	<i>Scirpus cyperinus</i>	Native, W2 seed mix	41.5
	<i>Glyceria grandis</i>	Native, W2 seed mix	16.9
	<i>Juncus effusus</i>	Native, W2 seed mix	8.9
	<i>Gnaphalium uliginosum</i>	Foreign	8.4
	<i>Bidens cernua</i>	Native	6.0
June 2009	<i>Scirpus cyperinus</i>	Native, W2 seed mix	43.3
	<i>Glyceria grandis</i>	Native, W2 seed mix	22.6
	<i>Juncus effusus</i>	Native, W2 seed mix	9.5
	Unknown dicot seedlings	Unknown	8.7
	Unknown grass seedlings	Unknown	6.9
Sept 2009	<i>Scirpus cyperinus</i>	Native, W2 seed mix	64.0
	<i>Glyceria grandis</i>	Native, W2 seed mix	23.0
	<i>Juncus effusus</i>	Native, W2 seed mix	18.3
	<i>Glyceria canadense</i>	Native	9.5
	Unknown grass seedlings	Unknown	9.2

Treatment Effects

Donor Soil

Analysis of the September 2007 plant survey data showed donor soil applications resulted in a significantly lower number of native species ($p=0.033$) and lower native species percent cover ($p=0.007$) than plots without donor soil. This decrease in native species average suggests that the acidic, nutrient-poor donor soil may have had a negative effect on some native species. There were no other significant effects of donor soil applications in September 2007.

Analysis of the June and September 2009 plant survey data showed no significant effects of the bog donor treatments re-applied in March 2009 on the vegetation parameters measured. The primary goal of the bog donor application is to establish *Sphagnum* moss, the predominant species occurring on northern bog wetlands, so the effect of donor soil treatments on *Sphagnum* percent cover was also tested. The data showed no significant effect of bog donor applications on *Sphagnum* moss percent cover. Previous research on bog restoration in Minnesota (Johnson et al., 2000) has shown that *Sphagnum* moss often takes until the second year after establishment before any substantial cover is evident. Plant surveys in subsequent years may provide a better indication of bog donor performance.

Direct Seeding

A number of significant effects of the WT1 seed mix were evident from the September 2007 plant survey. Similar to the 2007 data from Mitigation Site 5, plots with WT1 seed mix applications had higher percent total cover ($p<0.001$), higher number of WT1 species ($p<0.001$), higher foreign species percent cover ($p<0.001$), and higher WT1 percent cover ($p<0.001$) than plots without seed mix. Plots with WT1 seed mix applications also had lower species richness ($p<0.001$), lower Simpson's index of diversity ($p<0.001$), lower number of native species ($p<0.001$), and lower percent native cover ($p<0.001$) than plots without seed mix. As with Mitigation Site 5, the effect of the WT1 seed mix would have likely diminished over time. The WT1 seed mix was not included as a treatment when the bog donor was re-applied in March 2009.

Conifer Seedlings

No conifer seedlings survived on Mitigation Site 4 in 2007, and they were not included as a treatment when the bog donor was re-applied in March 2009. There was, however, a study initiated on Mitigation Site 3 in May 2009 to test the effect of soil mounds on conifer seedling survival and height growth. Statistical analysis of data collected on site 3 in October 2009 showed a significant positive effect of soil mounds on tree seedling survival ($p=0.035$), with mean seedling survival on mounds at 90 percent versus 70 percent for seedlings without mounds (see Figure 3-5). There was also a significant effect of species on tree seedling survival ($p=0.017$). Tamarack seedlings had a mean survival of 92 percent, compared to 67 percent for black spruce seedlings. There was a significant positive effect of mounds on tree seedling height ($p=0.003$), with mean seedling height on mounds at 32 cm versus 26 cm for seedlings without mounds.

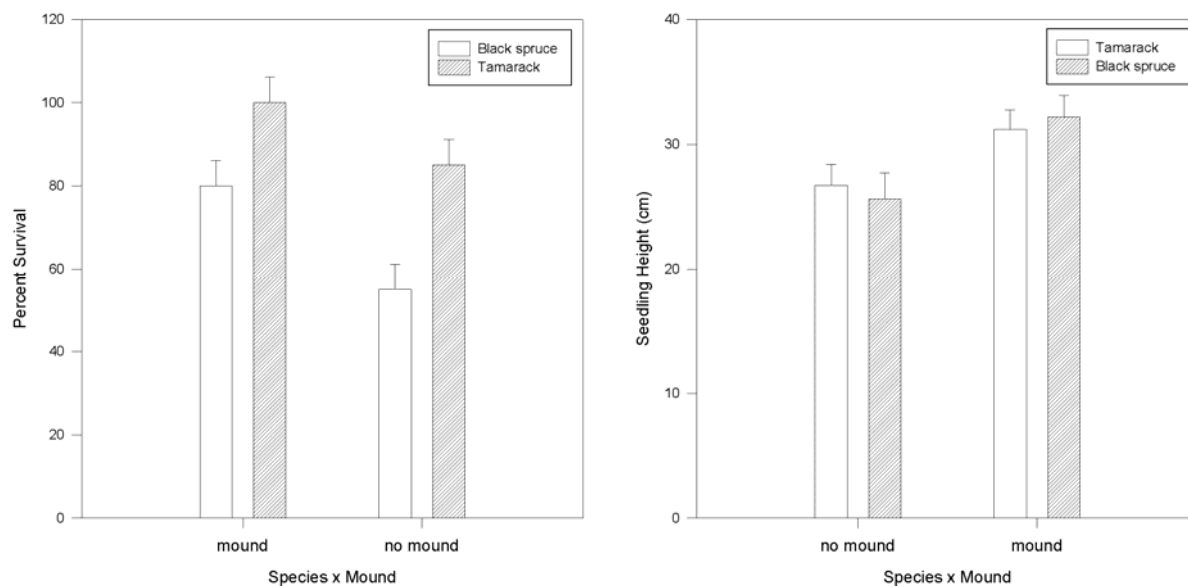


Figure 3-5. September 2009 Mitigation Site 3 conifer tree seedling survival and height growth with and without soil mounds. Means + standard error, n=80.

Fertilizer

Analysis of the September 2007 plant survey data showed no significant effect of fertilizer. Analysis of the June and September 2009 plant survey data showed no significant effect of the fertilizer treatments applied in March 2009 on the vegetation parameters measured. There was also no significant effect of fertilizer treatments on *Sphagnum* moss percent cover.

Mulch

Analysis of the June and September 2009 plant survey data showed no significant effect of mulch applications on the vegetation parameters measured or *Sphagnum* moss cover.

Construction Costs

Construction costs for the 0.83 hectare Mitigation Site 4 included: land purchase, clearing and grubbing, borrow excavation, muck excavation, muck placement, and seeding and mulching (Table 3-2). Additional costs included extra peat placement, extra ditching and rip rap, and lowering the outlet culvert. Excavation and placement costs included hauling. Cost estimates did not include research plot establishment, maintenance, or monitoring costs.

Table 3-2. Mitigation 4 site construction costs.

Land purchase	\$15,625/ha	\$13,026
Clearing and grubbing	\$6,029/ha	\$5,026
Borrow excavation	27,938 m ³ @ \$2.07/ m ³	\$57,732
Muck excavation	7,444 m ³ @ \$2.07/ m ³	\$15,383
Muck placement	7,444 m ³ @ \$1.96/ m ³	\$14,604
Seeding and mulching	\$2,687/ha	\$2,240
Extra peat placement	\$11,507/ha	\$9,593
Extra ditching and rip rap	\$4,198/ha	\$3,500
Lower culvert	\$6,022/ha	\$5,020
Total project cost		\$126,124
Total per hectare cost		\$151,288

The construction costs were quite high, totaling \$151,288/hectare or \$61, 225/acre. However, as mentioned in the Mitigation Site 5 cost estimate, it is important to note that mitigation and road construction costs are hard to separate in this instance because the mitigation was integrated into the entire road construction project. Much of the mitigation site work would have been done for the road construction regardless. Therefore, it is difficult to get a reliable cost estimate for the mitigation alone. Cost savings were realized overall on this construction project because it was a “balanced job,” meaning all construction materials were available on site. The cost for the borrow materials excavated from the mitigation site would have been considerably higher if they had to come from an off-site source. Land costs were also substantially higher at the mitigation site than they would have been elsewhere because it was previously a residential site. Better site design at the beginning of the project may have reduced the cost of remedial activities such as ditching and culvert level adjustment.

Costs incurred for re-establishing Mitigation Site 4 bog donor plots and large scale bog donor spreading in March 2009 included equipment and operator costs to collect, transport, and spread the bog donor material. Total costs for this additional work were approximately \$2,500 for the 0.2 hectare site, or about \$12,500 per hectare. These costs, although substantial, are not necessarily prohibitive.

Chapter 4. Conclusions

Wet Meadow and Shrub Swamp Mitigation Wetlands

This study to date has shown that there is good potential for creating wet meadow and shrub swamp mitigation wetlands in abandoned gravel pits, especially when the wetland mitigation can be directly integrated with the road construction project. The synchronized hauling of borrow material for the road construction and disposal/placement of displaced organic soil on-site makes the mitigation much more feasible than if materials had to be hauled any appreciable distance. The fact that these hauling operations would be taking place for the road construction regardless of the wetland mitigation is also a benefit and should be considered a significant cost savings.

The wet meadow and shrub swamp site hydrology and vegetation were consistent with the goal wetlands. Water levels met the USACOE technical standard for wetland hydrology over the study period and, although there were seasonal fluctuations, for the most part the soils remained saturated with intermittent periods of shallow inundation. It is important to note that although water is essential for creating wetlands, there can be too much water, especially when a saturated rather than flooded condition is required for the target wetlands.

Vegetation in general progressed well with native species richness and percent cover increasing over time. Effects of the WT1 and W2 direct seeding treatments were more evident early on in the study. The September 2007 plant survey data showed significant positive effects of seed mixes with increased total percent cover, higher number of WT1 species, and greater percent WT1 species cover. This increase can be attributed primarily to annual ryegrass (*Lolium italicum*) that was part of the WT1 seed mix and dominated plots in the first year. Significant negative effects of the direct seeding treatments early in the study included lower species richness, lower Simpson's index of diversity, lower native species richness, reduced percent native species cover, and increased percent foreign species cover. However, by September 2009 there were no significant positive or negative effects due to direct seeding, bringing into question their value for wetland creation sites that have a good organic substrate with a potentially considerable native seed bank.

In contrast to the direct seeding treatments, significant effects of the donor soil treatment were not really evident until 2009, the third year of the study. Significant effects included increased total percent cover, species richness, Simpson's index of diversity, native species richness, native species percent cover, and the number of W2 seed mix plants. Some of the more important benefits due to donor soil included a 35 percent increase in mean species richness, an 11 percent increase in mean Simpson's index of diversity, a 40 percent increase in mean native species richness, and a 12 percent increase in mean percent native cover. It is important to emphasize that none of these beneficial effects were evident until the end of the third growing season. This delay in native species growth is possibly due to native seeds requiring more time to germinate. This delay also underscores the importance of longer-term monitoring on wetland creation sites. Future monitoring of Mitigation Site 5 should be conducted to determine if these beneficial trends continue, but based on results to date, the use of donor soil where available can be very beneficial. Large scale application of donor soil may present some problems, but could possibly

be done with a manure spreader in the winter months when the site is frozen, or during other times of year with a wide tracked backhoe.

Invasive species such as reed canary grass and narrow leaved cattail were present Mitigation Site 5 but were effectively controlled by hand pulling and spot spraying with glyphosate herbicide (Foster and Wetzel, 2005; Adams and Galatowitsch, 2006).

Although mulch can be very beneficial for plant establishment in most situations, on areas with sufficient soil moisture, such as the mitigation sites in this study, the advantages of mulch are questionable. High water levels experienced in fall 2007 and spring 2008 caused the mulch to drift and accumulate to a significant depth in some areas, resulting in little or no vegetation due to excess mulch. Because mulch was spread over both sites in their entirety and it was not included as an experimental treatment, this observation is only anecdotal. Based on these observations, mulch should be used on the wetland side slopes and surrounding upland areas, but not in the wetland basin itself. Future research should address the need for mulch on wetland creations or possibly ways to anchor it and prevent it from drifting.

Based on this study, native hardwood willow cuttings show good potential for adding a shrub component to mitigation wetlands. The cuttings were relatively easy to collect and prepare, and could be planted by hand in considerable numbers. Overall, hardwood willow cuttings (*Salix petiolaris*) in treatment plots surveyed in September 2009 had a mean survival rate of 60 percent and a mean height of 66 cm. There was no significant effect of donor soil or seed mix on willow survival or height. Willows had no significant effect on the number or percent cover of invasive species, such as reed canary grass. This condition is to be expected at this time, as the willows are still too small to shade out the invasive species. Mean survival for the five willows in the species trials ranged from 40 percent (*S. pyrifolia*) to 92 percent (*S. planifolia*) as of the September 2009 plant survey. Mean height for the five willow species surveyed in September 2009 ranged from 41 cm (*S. pyrifolia*) to 74 cm (*S. planifolia*). Based on survival and height growth in this study, the best willow species to use on similar sites in the same geographic area appear to be *S. petiolaris* and *S. planifolia*. However, a mix of several native species is recommended to increase diversity and to insure that at least some species establish.

Although the construction costs were quite high (\$84,283/hectare, \$34,109/acre), it is important to note that mitigation and road construction costs are hard to separate in this instance because the mitigation was integrated into the entire road construction project. Much of the mitigation site work would have been done for the road construction regardless. Therefore, it is difficult to get a reliable cost estimate for the mitigation alone. Cost savings were realized overall on this construction project because it was a “balanced job,” meaning all construction materials were available on site. The cost for the borrow materials excavated from the mitigation site would have been considerably higher if they had to come from an off-site source. Land costs were also substantially higher at the mitigation site than they would have been elsewhere because it was previously a residential site. The best way to reduce wetland mitigation costs is to integrate the wetland creation into the entire road construction project. This project was ideal for this kind of integration because the borrow material was on-site, and there was an abundance of high-quality displaced organic soil available. Other road construction projects may not have these resources available, and resulting wetland mitigation costs could be much higher.

Wooded Swamp and Bog Mitigation Wetlands

Based on this study, the potential for wooded swamp and bog mitigation wetlands in abandoned gravel pits is not as promising as for wet meadow and shrub swamp. Due to unanticipated flooding on Mitigation Site 4 and the need to re-establishment plots in spring 2009, the study did not reveal enough information within the funding period to reach many solid conclusions. Just by their very nature, wooded swamps and bogs take longer to establish and mature than wet meadows and shrub swamps, so extended study is required to determine success. Even so, there are a number of lessons that can be learned from the study.

Overall water levels continued to be slightly higher at Mitigation Site 4 than at Mitigation Site 5, even after the remedial ditching was completed and the culvert was lowered. Therefore, the USACOE wetland hydrology standard was met during the study period. Too much water can be a very real problem in wetland creations other than ponds. Even wetland adapted tree species, such as black spruce and tamarack, will not survive prolonged high water level conditions.

Vegetative cover overall for Mitigation Site 4 is progressing reasonably well. There is almost complete vegetative cover, and species richness has increased from 68 species in September 2007 to 97 species in September 2009. The percentage of total species that are native also increased from 49 percent in September 2007 to 81 percent in September 2009. Mitigation Site 4 had considerably lower species richness than Mitigation Site 5, which is consistent with the relatively low species richness observed in natural bogs. Plant species dominating the site based on percent cover changed over time. Species from the WT1 seed mix dominated the site early on, followed by native species, and those that were part of the W2 seed mix. It is important to note that the W2 seed mix was not applied to Mitigation Site 4, yet species from this mix, *Scirpus cyperinus*, *Glyceria grandis*, and *Juncus effusus*, did come to dominate the site. This indicates for both Mitigation Sites 4 and 5 that these dominant plant species were most likely present in the organic soil seed bank and were not necessarily the result of W2 seed mix applications.

As with any wetland mitigation project, a major ongoing concern is the control of invasive species. Invasive species occurring on Mitigation Site 4 included reed canary grass, narrow leaved cattail, and purple loosestrife. Even though there was no purple loosestrife observed growing on the donor site, it may have been dormant in the seed bank, unintentionally brought in from another site, or attached to construction equipment. Having a person on site that is solely in charge of the mitigation overseeing the construction may be beneficial to reduce invasive species contamination issues. When invasives are present early control is essential to allow native species the chance to establish and prevent invasives from dominating a site. Annual spot spraying or wick applications of glyphosate herbicide by a trained observer can help keep invasive species in check. How long these annual applications are required depends on a number of factors including native species success, site conditions, and invasive species reserve in the seed bank. Although adequate control of invasives for this project was achieved during the study period, longer-term monitoring is required to determine success.

As on Mitigation Site 5, the benefits of mulch applications on Mitigation Site 4 are questionable. In addition to drifting mulch accumulating in certain areas due to flooding and smothering plant growth, the mulch also aggravated the flooding problem by blocking the Mitigation Site 4 outlet

culvert. The mulch applied to plots in spring 2009 was anchored in place using plastic netting and wire stakes to prevent drifting. Results of the Mitigation Site 4 mulch study after one growing season showed no significant effect of mulch applications on the vegetation parameters measured or *Sphagnum* moss cover.

Analysis of the September 2007 plant survey data showed donor soil applications resulted in a significantly lower number of native species and lower native species percent cover than plots without donor soil. This difference suggests that the acidic, nutrient-poor donor soil may have had a negative effect on some native species.

Analysis of the June and September 2009 plant survey data showed no significant effects of the bog donor treatments re-applied in March 2009 on the vegetation parameters measured or on *Sphagnum* moss percent cover. Previous research on bog restoration in Minnesota (Johnson et al., 2000) has shown that *Sphagnum* moss often takes until the second year after establishment before any substantial cover is evident. Some *Sphagnum* moss was present on the plots so the potential exists for it to establish. Plant surveys in subsequent years may provide a better indication of bog donor performance.

A number of significant effects of the WT1 seed mix were evident from the September 2007 plant survey. Similar to the 2007 data from Mitigation Site 5, plots with WT1 seed mix applications had higher percent total cover, higher number of WT1 species, higher foreign species percent cover, and higher WT1 percent cover than plots without seed mix. Plots with WT1 seed mix applications also had lower species richness, lower Simpson's index of diversity, lower number of native species, and lower percent native cover than plots without seed mix. As with Mitigation Site 5, the effects of the WT1 seed mix would have likely diminished over time.

Analysis of the September 2007 plant survey data showed no significant effect of fertilizer. Analysis of the June and September 2009 plant survey data also showed no significant effect of the fertilizer treatments applied in March 2009 on the vegetation parameters measured or on *Sphagnum* moss percent cover. Again, longer-term monitoring may reveal some effect of fertilizer applications.

No conifer seedlings survived on Mitigation Site 4 in 2007, and they were not included as a treatment when the bog donor was re-applied in March 2009 due to continued wet conditions unsuitable for tree survival. However, the Mitigation Site 3 soil mounding study established in May 2009 showed a significant positive effect of soil mounds on tree seedling survival and height after one growing season. The mounding may be an effective way to establish trees on wetland sites. Mounds for this study were created manually with hand shovels, but could be done with a backhoe or other equipment if available and site conditions allowed.

The construction costs for Mitigation Site 4 were substantially higher than for Mitigation Site 5, totaling \$151,288/hectare or \$61,225/acre. Costs for the 0.83 hectare Mitigation Site 4 included: land purchase, clearing and grubbing, borrow excavation, muck excavation, muck placement, seeding and mulching, plus additional costs including extra peat placement, extra ditching and rip rap, and lowering the outlet culvert. Better site design at the beginning of the project may have reduced the cost of remedial activities such as ditching and culvert level adjustment.

Costs incurred for re-establishing Mitigation Site 4 bog donor plots and large scale bog donor spreading in March 2009 included equipment and operator costs to collect, transport, and spread the bog donor material. Total costs for this additional work were approximately \$2,500 for the 0.2 hectare site, or about \$12,500 per hectare. These additional costs, although substantial, are not necessarily prohibitive. As with Mitigation Site 5, much of the mitigation site work would have been done for the road construction regardless. Therefore, it is difficult to get a reliable cost estimate for the mitigation alone, although it would likely be considerably less.

By September 2009 the wooded swamp and bog site was a respectable wet meadow that is too wet for tree growth but has the potential to become a sphagnum bog over time. Additional monitoring in the future is recommended to examine the evolution of the site.

References

- Adams, C.R., and S.M. Galatowitsch (2006). "Increasing the effectiveness of reed canary grass (*Phalaris arundinacea* L.) control in wet meadow restorations." *Restoration Ecology*, vol. 14, no. 1: 441-451.
- Andreas, B.I., and G.E. Host (1983). "Development of a sphagnum bog on the floor of a sandstone quarry in northeastern Ohio." *Ohio Journal of Science*, vol. 83, no. 5: 246-253.
- Boudreau, S., and L. Rochefort (1998). "Restoration of post-mined peatlands: Effect of vascular pioneer species on *Sphagnum* establishment." *Proceedings of the International Peat Conference Peatland Restoration and Reclamation*, Duluth, MN, July 14-18.
- Brown, S.C., and B.L. Bedford (1997). "Restoration of wetland vegetation with transplanted wetland soil: an experimental study." *Wetlands*, vol. 17: 424-437.
- Buttleman, C.G. (1992). *A handbook for reclaiming sand and gravel pits in Minnesota*. St. Paul, MN: Minnesota Department of Natural Resources, Division of Minerals.
- Campeau, S., and L. Rochefort (1996). "*Sphagnum* regeneration on bare peat surfaces: field and greenhouse results." *Journal of Applied Ecology*, vol. 33, no. 3: 599-608.
- Chmelar, J. (1974). "Propagation of willows by cuttings." *New Zealand Journal of Forestry Science*, vol. 4, no. 2: 185-190.
- Cooper, N., and A.L. Foote (2003). "Revegetating composite/consolidated tailings wetlands using donor wetland soils, in the oil sands mining region of Fort McMurray Alberta." *Proceedings of the 2003 Mining and the Environment Conference*, Sudbury, Ontario, May 25-28.
- Cowardin, M., V. Carter, F. Golet, and E. LaRoe (1979). *Classification of wetlands and deep water habitats of the United States*. Washington, D.C.: U.S. Department of the Interior, U.S. Fish and Wildlife Service.
- Cronberg, N. (1993). "Reproductive biology of *Sphagnum*." *Lindbergia*, vol. 17: 69-82.
- Darlington, H.T. (1964). *The Mosses of Michigan*. Bloomfield, MI: Cranbrook Institute of Science, Bulletin Number 47.
- Eggers, S.D., and D.M. Reed (1997). *Wetland Plants and Plant Communities of Minnesota and Wisconsin, Second Edition*. St. Paul, MN: U.S. Army Corps of Engineers.
- Elling, A.E., and M.D. Knighton (1984). "*Sphagnum* moss recovery after harvest in a Minnesota bog." *Journal of Soil and Water Conservation*, vol. 39: 209-211.
- Ferland, C., and L. Rochefort (1997). "Restoration techniques for *Sphagnum*-dominated peatlands." *Canadian Journal of Botany*, vol. 75: 1110-1118.

Foster, R.D., and P.R. Wetzel (2005). "Invading monotypic stands of *Phalaris arundinacea*: a test of fire, herbicide, and woody and herbaceous native plant groups." *Restoration Ecology*, vol. 13, no. 2: 318-324.

Gilbert, M.N. (2000). "Substrate Characteristics and Development." *Wetlands Engineering Handbook*, compiled by D.F. Hayes, T.J. Olin, J.C. Fischenich, and M.R. Palermo. Vicksburg, MS: U.S. Army Corps of Engineers, Environmental Laboratory, U.S. Army Engineer Research and Development Center.

Hoag, J. (2007). *How to plant willows and cottonwoods for riparian restoration*. Technical Note, TN Plant Materials No. 23. Boise, ID: USDA-Natural Resources Conservation Service.

Jacobson, R.L. (2006). *Restoring and managing native wetland and upland vegetation*. St. Paul, MN: Minnesota Department of Transportation and the Minnesota Board of Water and Soil Resources.

Johnson, K., C. Maly, and T. Malterer (2000). "Effects of mulch, companion species, and planting time on restoration of post-harvested Minnesota peatlands, U.S.A." *Sustaining Our Peatlands: Proceedings of the 11th International Peat Congress*, Quebec City, Canada, August 6-12.

Johnson, K., and S. Valppu (2003). *Fen restoration – final project report*. Duluth, MN: Natural Resources Research Institute Technical Report NRRI/TR-2003/32.

Kim, K.D., K. Ewing, and D.E. Giblin (2006). "Controlling *Phalaris arundinacea* (reed canarygrass) with live willow stakes: a density dependent response." *Ecological Engineering*, vol. 27: 219-227.

Krebs, C.J. (1989). *Ecological Methodology*. New York, NY: Harper & Row.

McKinstry, M.C., and S.H. Anderson (2005). "Salvaged-wetland soil as a technique to improve aquatic vegetation at created wetlands in Wyoming, U.S.A." *Wetlands Ecology and Management*, vol. 13: 499-508.

Minnesota Board of Water and Soil Resources (2006). *Northeastern Minnesota Wetland Management Strategy*. St. Paul, MN: Minnesota Board of Water and Soil Resources, December 2006.

Minnesota Department of Natural Resources (2007). *A Handbook for Collecting Vegetation Plot Data in Minnesota: The Relevé Method*. St. Paul, MN: Minnesota County Biological Survey Biological Report No. 92.

Minnesota Department of Natural Resources (1981). *Minnesota Peat Program Final Report*. St. Paul, MN: Minnesota Department of Natural Resources, Division of Minerals.

Minnesota Rule 8420.0526, Sub part 7, Minnesota Office of the Revisor of Statutes, August 26, 2009, St. Paul, MN.

Norman, D.K., and W.S. Lingley, Jr. (1992). "Reclamation of sand and gravel mines." *Washington Geology*, vol. 20, no. 3: 20-31.

Poschlod, P., and J. Pfadenhauer (1989). "Regeneration of vegetative parts of peat mosses - A comparative study of nine *Sphagnum* species." *Telma*, vol. 19: 77-88.

Quinty, F., and L. Rochefort (2003). *Peatland Restoration Guide*, second edition. Quebec: Canadian Sphagnum Peat Moss Association and New Brunswick Department of Natural Resources and Energy.

Rochefort, L., R. Gauthier, and D. Lequere (1995). "*Sphagnum* regeneration - Toward an optimisation of bog restoration." *The Restoration of Temperate Wetlands: Proceedings of the British Ecological Society Mire Symposium*. Sheffield, England: John Wiley & Sons Ltd.

Rochefort, L., F. Quinty, S. Campeau, K. Johnson, and T. Malterer (2003). "North American approach to the restoration of *Sphagnum* dominated peatlands." *Wetlands Ecology and Management*, vol. 11: 3-20.

Rossi, P. (1999). "Length of cuttings in establishment and production of short-rotation plantations of *Salix 'Aquatica'*." *New Forests*, vol. 18, no. 2: 161-177.

Shaw, D.B. (2000). *Native vegetation in restored and created wetlands – its establishment and management in Minnesota and the upper Midwest*. St. Paul, MN: Minnesota Board of Water and Soil Resources.

Shaw, S.P., and C.G. Fredine (1971). *Wetlands of the United States*. Circular 39. Washington, D.C.: U.S. Department of the Interior, U.S. Fish and Wildlife Service.

Stauffer, A.L., and R.P. Brooks (1997). "Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania." *Wetlands*, vol. 17: 90-105.

Systat Software, Inc. (2008). *SigmaPlot® 11.0 User's Guide, Part 2 – Statistics*. San Jose, CA: Systat Software, Inc.

U.S. Army Corps of Engineers (2009). *St. Paul District Policy for Wetland Compensatory Mitigation in Minnesota*. St. Paul, MN: U.S. Army Corps of Engineers.

U.S. Army Corps of Engineers (2005). Technical Standard for Water-Table Monitoring of Potential Wetland Sites, *WRAP Technical Notes Collection* (ERDC TN-WRAP-05-2). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Wenzel, P.E. (1992). *Minnesota wetland restoration guide*. St. Paul, MN: Minnesota Board of Water and Soil Resources.

Appendix A
Mitigation Wetland Substrate Data

WETLAND MITIGATION IN ABANDONED GRAVEL PITS

Substrate Analyses

Muck substrate	pH	SS	NO₃	NH₄	P	K	Ca		
	5.3	39	5	2	<1	4	69		
	Mg	Na	Fe	Mn	Zn	Cu	Mo	B	
	34	6	0.07	0.67	0.04	<0.01	<0.01	<0.03	
Sedge peat substrate	pH	SS	NO₃	NH₄	P	K	Ca		
	4.5	7	<5	3	<1	2	14		
	Mg	Na	Fe	Mn	Zn	Cu	Mo	B	
	3	3	0.07	0.08	0.02	<0.01	<0.01	<0.03	

Analyzed using the Spurway Method by the University of Minnesota, Florist Testing Service, Departments of Horticulture and Soil, Water and Climate. All concentration units for nutrients are in parts per million (ppm) in the media extract. Soluble Salts (SS) are a measure of electrical conductivity. The SS units are "mhos/cm X 10⁻⁵" for the Spurway method and as "mhos/cm X 10⁻³ (mmhos/cm)" for the Saturated Media Extract (SME) method. The symbol "<" means less than our detection limits.

Appendix B
Donor Site Plant Surveys

ALDER DONOR SITE

Gary B. Walton

June 25, 2007

This area was just outside the construction zone for the HWY 53 expansion and was visited on May 24, 2007. The site was saturated to the surface with some small areas of standing water (2 to 4 inches deep) between moss covered (including *Sphagnum*) root hummocks and sedge hummocks. The soil was mucky.

The overstory of black ash and balsam fir was patchy allowing more light to reach down below to the shrub layer of tag alder. Herbaceous species grew abundantly on the hummocks.

Outside of this area where construction was proceeding, a similar looking saturated mucky soil was observed. Much of the woody and herbaceous vegetation had been removed, but some small plants of marsh marigold, white violet, bluebead lily, and the sedge *Carex brunnescens* were noted.

Overstory

Black ash (*Fraxinus nigra*), balsam fir (*Abies balsamea*).

Shrub Layer

Tag alder (*Alnus rugosa*), mountain maple (*Acer spicatum*), alder-leaf buckthorn (*Rhamnus alnifolia*), lake currant (*Ribes lacustre*), red currant (*Ribes triste*), red osier (*Cornus stolonifera*), Canada yew (*Taxus canadensis*).

Herbaceous Layer

Marsh marigold (*Caltha palustris*), aralia (*Aralia nudicaulis*), dewberry (*Rubus pubescens*), white violet (*Viola pallens*), sedges (*Carex brunnescens*, *C. disperma*), jewelweed (*Impatiens capensis*), bedstraw (*Galium asprellum*), Canada mayflower (*Maianthemum canadensis*), goldthread (*Coptis groenlandica*), starflower (*Trientalis borealis*), strawberry (*Fragaria virginiana*), wild iris (*Iris versicolor*), miterwort (*Mitella nuda*), turtlehead (*Chelone glabra*), swamp goldenrod (*Solidago uliginosa*), flat-top white aster (*Aster umbellatus*), swamp aster (*Aster puniceus*), Canada bluejoint grass (*Calamagrostis canadensis*), bluebead lily (*Clintonia borealis*), short-husk grass (*Brachyelytrum erectum*), wood-fern (*Dryopteris carthusiana*), crested wood-fern (*Dryopteris cristata*), oak-leaf fern (*Gymnocarpium dryopteris*).

BOG DONOR SITE

Gary B. Walton

April 12, 2007

Small bog between Peel Road and HWY 53

This small bog is in a small isolated depression between the Peel Road and HWY 53 south of Cook, MN. No inlet or outlet was visible. The terrain is hummocky with several species of *Sphagnum* moss. Two other mosses (*Aulacomnium* and *Polytrichum*) were also seen. Small patches of lichens (*Cladonia* and *Cladina*) were seen on a few of the moss hummocks. There was no indication of standing or pooled water except near the edge of HWY 53.

The vegetation in the bog is composed of only few species with black spruce (*Picea mariana*) that varied in size from one foot to about 25 feet tall, small cranberry (*Vaccinium oxycoccus*), leatherleaf (*Chamaedaphne calyculata*), cotton-grass (*Eriophorum spissum*), and a sedge (*Carex oligosperma*). Other species noted, but not very common, were bog birch (*Betula pumila*), Labrador tea (*Ledum groenlandicum*), pitcher plant (*Sarracenia purpurea*), beaked sedge (*Carex rostrata*), and stunted individuals of white pine (*Pinus strobus*) and red pine.

The surrounding uplands are mixed conifer/hardwood forests on sandy soil. Dominant tree species in the uplands are red pine (*Pinus resinosa*), jack pine (*P. banksiana*), big tooth aspen (*Populus grandidentata*) and quaking aspen (*P. tremuloides*).

PREMIER HORTICULTURE BLACK LAKE BOG DONOR SITE

Content of donor sample from Premier Horticulture, Inc. - Black Lake Bog identified by Joannes A. Janssens (bryophytes) and Gerald A. Wheeler (vascular plants):

Bryophytes:

Pohlia nutans

Polytrichum strictum

Sphagnum fuscum

Sphagnum magellanicum

Sphagnum rubellum

Vascular plants:

Andromeda glaucophylla

Carex cf. oligosperma

Chamaedaphne calyculata

Vaccinium oxycoccus

All plants commonly found in oligotrophic (nutrient-poor) bogs. These species also occur in poor fens, but there are no other species in the material that can be considered obligate indicators of minerotrophic (nutrients from groundwater) influence.

FENS RESEARCH FACILITY SAX BOG DONOR SITE

Content of donor samples from Fens Research Facility Sax Bog identified by Joannes A. Janssens (bryophytes) and Gerald A. Wheeler (vascular plants):

SAMPLE 1:

Bryophytes:

Aulacomnium palustre
Polytrichastrum longisetum
Polytrichum commune
Polytrichum strictum
Sphagnum angustifolium
Sphagnum centrale
Sphagnum fimbriatum
Sphagnum magellanicum
Sphagnum warnstorffii

Vascular plants:

Alnus incana subsp. rugosa
Betula pumila
Calamagrostis stricta
Chamaedaphne calyculata

SAMPLE 2:

Bryophytes:

Aulacomnium palustre
Polytrichum commune
Polytrichum strictum
Sphagnum angustifolium
Sphagnum russowii, hemiisophyllous modification
Sphagnum fimbriatum
Sphagnum teres, approaching S. squarrosum
Sphagnum warnstorffii

Vascular plants:

Betula pumila
Calamagrostis stricta
Chamaedaphne calyculata