Seminary Fen Phase 2 Ecological Study

and

Ecological Assessment of Alternative Corridors

TH 41 Tier 1 DEIS Study

Prepared for
SRF Consulting Group
Minnesota Department of Transportation

Draft

June 2007

BARR

4700 West 77th Street
Minneapolis, MN 55435-4803
Phone: (952) 832-2600
Fax: (952) 832-2601

Seminary Fen Phase 2 Ecological Study
And
Ecological Assessment of Alternative Corridors
TH 41 DEIS Study

Table of Contents

1.0 Introduction 1
1.1 Phase 2 Study Objectives 2
1.2 Calcareous Fen Technical Criteria 3
1.2.1 Hydrology 3
1.2.2 Soil 3
1.2.3 Water Chemistry 3
1.2.4 Vegetation 3
1.3 Boundaries and Heterogeneity of Calcareous Fens 4

2.0 Methods 7
2.1 Fen Field Study Methods 7
2.1.1 Hydrology 7
2.1.2 Water Chemistry 7
2.1.3 Soils 7
2.1.4 Vegetation 8
2.2 Alternative Corridors Study 11
2.3 Bridge Visits 13
2.4 Literature Review and Impact Assessment 14

3.0 Results 15
3.1 Fen Field Study 15
3.1.1 Hydrology 15
3.1.2 Water Chemistry 15
3.1.3 Soils 15
3.1.4 Vegetation 16
3.1.5 Vegetation Mapping and Distribution of Calcareous Fen 19
3.1.6 Conclusions and Discussion 21
3.2 Alternative Corridors Study 25
3.2.1 Native Plant Communities 25
3.2.2 Habitat Fragmentation 28
3.2.3 Protected Species 30
3.2.4 Conclusions 31
3.3 Bridge Visits 32
3.4 Literature Review and Impact Assessment 36
3.4.1 Literature Review 36
3.4.2 Anticipated General Impacts from TH 41 Alternatives 39
3.4.3 Anticipated Impacts Unique to the Seminary Fen Wetland Complex 40
3.4.4 Mitigation 47

4.0 Literature Cited 56

List of Tables

1.1 Calcareous Fen Indicator Species
1.2 Characteristics of Type I and Type II Fens
3.1 Water Chemistry Results
3.2 Cover Type by Alternative Corridor
3.3 Natural Communities by Alternative Corridor
3.4 Natural Community State-Rarity Rankings by Alternative Corridor
3.5 Natural Community Element-Occurrence Rankings by Alternative Corridor
3.6 Biodiversity Area Rankings by Alternative Corridor
3.7 Habitat Fragmentation Impacts by Alternative Corridor
3.8 Summary of Potential Impacts by Alternative Corridor
3.9 Vegetation of the SFWC Within Corridors E1, E1A, and E2
3.10 Fen Status of the SFWC Within Corridors E1, E1A, and E2
3.11 Vegetation of the SFWC Within Groundwater Drawdown Areas
3.12 Fen Status of the SFWC Within Groundwater Drawdown Areas

List of Figures

1.1 Location Map
1.2 Phase 1 and Phase 2 Study Areas
1.3 Phase 2 MLCCS Map
2.1 Phase 2 Sample Locations
2.2 Bridge Environment Study Locations
3.1 Soil Profiles
3.2 Fen Sampling Results
3.3 Vegetation and Fen Areas Western Transect
3.4 Vegetation and Fen Areas Eastern Transect
3.5 Succession of Fen Communities
3.6 TH 41 Alternative Alignments Vegetation Study
3.7 Corridor E1 Drawdown and Native Vegetation
3.8 Corridor E1A Drawdown and Native Vegetation
3.9 Corridor E2 Drawdown and Native Vegetation
3.10 Restoration and Management Needs and Opportunities

List of Appendices

Appendix A. Vascular Plant Vegetation Data

Appendix B. Bryophyte Results

1.0 Introduction

The Minnesota Department of Transportation proposes to construct a new TH 41 river crossing between TH 169 in Scott County and the proposed realignment of TH 212 ("New TH 212") in Carver County in the vicinity of existing TH 41. The project is proposed in order to (1) reduce congestion by increasing river-crossing capacity; (2) improve connectivity, specifically providing a free-flowing, high-volume principal arterial connection between TH 169 and New TH 212 (two high-priority interregional corridors); and (3) provide a facility above the 100-year floodplain to avoid closures due to seasonal flooding.

The proposed project is not currently programmed for construction within the next 20 years. However, there is a need to preserve right-of-way in the corridor that best meets project objectives as soon as possible since the rapid development of the study area will further limit available options for increasing the corridor capacity in the future. Six alternative corridors are under consideration (Figure 1.1). A "tiered" two-step environmental review process [as permitted by the National Environmental Policy Act (NEPA) regulations and by Minnesota Rule 4410.4000] is being utilized for the proposed project in order to identify a preferred corridor.

Among the environmentally sensitive areas potentially affected by the project is the Seminary Fen Wetland Complex (SFWC) (Figure 1.1). The complex is a mosaic of wetland communities, some of which are calcareous fens. Calcareous fens are protected under the Minnesota Wetland Conservation Act (M.S. 103G.223 and M.R. 8420) and as an Outstanding Resource Value Water (M.R. 7050). Calcareous fens are peat-accumulating wetlands dominated by distinct groundwater inflows that have specific chemical characteristics. The water is characterized as circum-neutral to alkaline with a high concentration of calcium and low dissolved oxygen content. The chemistry provides environments for specific, and often rare, hydrophytic plants (M.R. 8420.1020). Detailed discussion of fen characteristics are provided in Carpenter (1995), Amon et al. (2002), Bedford and Godwin (2003), and MnDNR (2005). Calcareous fens are one of the rarest types of wetlands in Minnesota and throughout the world, and many fens have been destroyed or degraded. Most calcareous fens are relatively small but support high plant-species diversity, including many species that are rare or endangered. Seven state-protected, and one formerly state-protected, plant species have been documented in the SWFC.

The Phase 1 study concentrated on areas identified as calcareous fen by the Minnesota Land Cover Classification System (MLCCS; MnDNR 2004; data available electronically from MnDNR Data

Deli: http://deli.dnr.state.mn.us/index.html) of the Minnesota Department of Natural Resources (MnDNR) (Figure 1.2). The Phase 1 study area was divided into 5 areas as shown on Figure 1.2, and calcareous fen was confirmed in Areas 1-3. No calcareous fen was found in Areas 4 and 5. Based on Phase 1 results (PEC 2006), and comments received about those results, a Phase 2 study was initiated. The Phase 2 study concentrated on an area of the SFWC located northwest of the Phase 1 study area (Figure 1.2). During the Phase 1 study, a portion of the Phase 2 study area was also identified as calcareous fen (Figure 1.2). The MLCCS classifications within the Phase 2 study area did not include calcareous fen (Figure 1.3)

1.1 Phase 2 Study Objectives

Among the issues identified through the Phase 1 study were (1) the potential for calcareous fen areas to exist beyond the original Phase 1 study area; (2) the nature of ecological impacts from existing bridges across the Minnesota River Valley; and (3) the potential impacts of the alternative TH 41 river crossing corridor alignments. To address these issues, a combination of field and literature studies were conducted.

Field studies for the ecological component of the Phase 2 study included:

- Walkover studies along sections of the six alternative alignments (Figure 1.1) to verify the MLCCS mapping, assess the quality of plant communities, and determine areas of particular ecological sensitivity.

- Detailed studies of the extended wet meadow/shrub swamp areas located northwest of the Phase 1 study area to determine the presence of calcareous fen plant communities (Figure 1.2). Studies include the analysis of soils, water chemistry, and vegetation. Botanical studies were conducted for vascular plants and bryophytes. The presence of groundwater discharge hydrology was confirmed during the Phase 1 study.

- A review of vegetation impacts underneath existing bridges in the region.

A literature review of potential impacts from the proposed river crossing was conducted. Design considerations were determined from consultation with bridge design engineers. Impacts to groundwater were determined as a separate component of the Phase 2 study. The results of groundwater modeling were used to assess potential ecological impacts to the SFWC.

1.2 Calcareous Fen Technical Criteria

Technical criteria for identifying calcareous fens were first established by the MnDNR in 1995 (Berglund 1995). Revised criteria have been adopted by the DNR following testing and refinement to minimize false positive/false negative results (Leete et al. 2005). Both sets of criteria define parameters related to hydrology, soils, water chemistry, and vegetation. The Phase 2 field studies in the SFWC were conducted to determine if any areas are considered calcareous fen under the original and revised criteria. The specific criteria are described below.

1.2.1 Hydrology

Calcareous fen hydrology in the 1995 and 2005 criteria is defined as "…stable, typically upwelling groundwater inflows sufficient to maintain saturation for the development of a histosol or a histic epipedon soil."

1.2.2 Soil

Calcareous fen soils are defined as histosols or soils with a histic epipedon (i.e., organic soil or an organic layer at top of the soil profile). These soil profiles may include extensive deposits of calcium carbonate in the soil. The 1995 and 2005 soil criteria are identical.

1.2.3 Water Chemistry

Calcareous fen water chemistry is defined as pH $\geq$ 6.7, calcium concentration $\geq$ 30 mg/l, alkalinity $\geq$ 1.65 meq/l, and specific conductance $\geq$ 500 µS/cm. The 1995 and 2005 criteria are identical for these parameters. The 1995 criteria also specified dissolved oxygen levels $\leq$ 2.0 mg/l. The dissolved oxygen parameter was excluded from the 2005 criteria because it does not reliably differentiate between fen and non-fen wetlands.

1.2.4 Vegetation

The vegetation criterion defines certain calcareous fen vascular plant indicator species (calciphiles) and assigns a point value to each species (Table 1.1). Values are 1, 5, or 25 points depending on the fidelity of a species to calcareous fens. The values of all indicator species found in a community or a site are added, and if the sum exceeds 50, the vegetation criterion is met. The 1995 technical criteria defined a state-wide list of indicator species, and the 2005 technical criteria modified the composition of the list and assigned regional indicator values. Regional values are developed for the southeast, southwest, and northwest portions of Minnesota and the Minnesota River Valley. The

criteria also state that areas with scores below 50 may be considered fens or could support fen vegetation under certain circumstances:

> "If the site has calcareous fen soil, hydrology, and water chemistry but the calciphile total ranges from 30 to 50, the area will be considered to meet calcareous fen criteria. If a disturbed site has calcareous fen soil, hydrology, and water chemistry but a calciphile total of less than 30, the disturbed area may have the potential to support a calcareous fen plant community" (Berglund et al. 1995; Leete et al. 2005).

The 2005 criteria initially proposed a set of indicator bryophyte species and a categorical scoring system comparable to vascular plants based on fidelity to calcareous fens (with possible point values of 1, 5 and 25 points). Bryophyte indicator species values have been since revised by Janssens (2005) based on quantitative field data from fens throughout Minnesota. Under this system, point values of individual species are not categorical, but vary according to observed fidelity to calcareous fens. A bryophyte score of 109 is necessary to satisfy the vegetation criterion, rather than the original 50 point proposal.

1.3 Boundaries and Heterogeneity of Calcareous Fens

Determining the boundaries of a calcareous fen can be problematic. Explicit criteria as defined by the MnDNR (Berglund 1995; Leete et al. 2005) provide a means to determine if an area is a calcareous fen, although "area" is undefined. However, within a wetland complex, fen sample points may be interspersed with non-fen sample points as was observed in the Phase 1 study (PEC 2006). Neither set of criteria provide explicit instruction on how to delineate a boundary between fen from non-fen [e.g., "…Plot size and shape are dependent upon the professional judgment of field personnel. Identification plots may be large (400 square meters or larger) whereas delineation plots or other techniques may be smaller to provide more definite boundaries" (Berglund et al. 1995)].

In testing the original and revised indicator species list point systems, Leete et al. (2005) defined a study "area" as an entire wetland complex. Floristic species lists were compiled for each complex, and a cumulative score was calculated. Leete et al. (2005) also recognize the importance of professional judgment on determining plot size and shape.

A review of Midwestern calcareous fens concluded that calcareous fens are typically embedded in complexes of different wetland types, and that boundaries between fen and non-fen cannot be easily drawn: "Most fens have gradational boundaries that are determined subjectively by the observer

based on botanical, geomorphic, hydrologic or soils data…Generally the only sharp boundary we observed in fens is the uphill edge of the peat body on a hillslope, which may grade from mineral soil to organic soil in less than one meter…" (Amon et al. 2002). The text accompanying the 1995 and 2005 technical criteria emphasized the importance of wetland complexes within which calcareous fens are located:

> "Calcareous fen protection and management in Minnesota are best accomplished by addressing the fen ecosystem." (Berglund. 1995).
>
> "The habitat for the calcareous fen plant community is not exclusively the area within a wetland complex that the calcareous fen plant community currently occupies. This difference is often observed when the wetland has suffered anthropogenic impacts or natural disturbance and the calcareous fen plant community retreats from the boundaries of its original habitat. *Thus the delineation of a 'calcareous fen' as a separate entity from any wetland complex within which it exists is not possible; the boundaries of the calcareous fen must be defined as the boundaries of the wetland complex within which a calcareous fen plant community exists.*" (Leete et al. 2005; emphasis added).

Within calcareous fen wetland complexes, a variety of wetland types may occur including wet meadow, sedge meadow, emergent marsh, and shrub carr, in addition to truly calcareous fen communities. These different types of wetlands may be interspersed, and calcareous fens sites dispersed throughout the wetland complex. Calcareous fens are themselves heterogeneous and can vary in terms of species composition and abundance. Various authors acknowledge this heterogeneity through a proliferation of terms for calcareous fen subtypes such as extremely rich fen, calcareous fen, calcareous seep, marl flat, marl pool, marl fen, high organic fen, high carbonate fen, prairie fen, graminoid fen, sedge fen, tall sedge fen, short sedge fen, sedge lawn, and spring run. Recent DNR descriptions of native plant communities summarize this variability within Minnesota fens: "Occurrences of [calcareous fen] are seldom homogeneous. Variation in groundwater flow paths and topography can create noticeable variation in vegetation. Areas of open marly pools and low, tussocky graminoid 'lawns' are most characteristic. These may grade into denser, taller often shrubbier vegetation where the substrate is less saturated or mineral soil is closer to the surface, or into marshes where ponding occurs below the fen." (MnDNR 2005).

Vegetation zones are determined by patterns of water chemistry, hydrology, succession, disturbance, substrate accretion and erosion, nutrient influxes, and topography. Numerous studies have

investigated the relationship between environmental parameters and vegetation patterns. Conflicting results suggest that no single factor controls the plant communities. Carpenter (1995) designated two general calcareous fen communities, Type I and Type II fens, based on empirical studies which have proven to be consistent with other published works on Midwestern fens (Amon et al. 2002; Bowles et al. 2005; Miner and Ketterling 2003). Type I fens are taller-stature communities found on sites with relatively more soil organic matter, less precipitated calcium carbonate, and more variable water tables. Type II fens are shorter-stature communities found on sites with a greater abundance of precipitated calcium carbonate and less variable water table. Type II fens are associated with the most rare species, high fidelity calciphile indicator species, strongest groundwater discharge and hydraulic gradients, and specific conductivity. In a study of 16 Wisconsin calcareous fens, Carpenter (1995) noted that some sites contain only Type I, some sites Type I and II, but no sites consisted only of Type II fens. Type II fens can be confined to microsites that are zones of high calcium carbonate-precipitation (Carpenter, pers, comm.). Zonation of carbonate precipitation may result from heterogeneity in hydrology and geochemistry (Almendinger and Leete 1998a; Boyer and Wheeler 1989; Komor 1994). Table 1.2 summarizes general characteristics of these two types of fens and observations of each documented from the SFWC.

Fen and non-fen wetlands within a wetland complex are interconnected hydrologically and ecologically as components of a dynamic ecosystem. The location and size of different wetland and fen types can change over time through natural processes. Variation in the location and diffusion of groundwater discharge, peat accumulation and erosion, and calcium carbonate precipitation all interact to shape the wetland environment and distribution of wetland plants. Plant communities will shift spatially and temporally through ecological succession. Thus, a portion of a calcareous wetland complex that does not currently support fen vegetation may have done so in the past and may again in the future. Predicting ecological impacts to a wetland complex that includes calcareous fens must consider the dynamics of ecosystem processes and ecological succession.

For this study, the critical factor in determining the location of calcareous fens proved to be vegetation. Consequently, different plant communities were mapped and individual areas were classified as to whether they currently meet the vegetation criterion, may have met the criterion in the past but do not for a variety of reasons, or could meet the criterion if appropriate restoration and management practices are implemented. Details are provided in the methods and results sections below.

2.0 Methods

2.1 Fen Field Study Methods

The location of the sample sites in the Phase 2 study area were initially defined for the botanical survey (Figure 2.1). A subset of these locations was used for water chemistry and soil sampling. An additional location was added for surface water sampling (Figure 2.1).

2.1.1 Hydrology

During the Phase 1 study, numerous sites of strong groundwater discharge were identified near the base of the bluff (see Figure 3.10 in the Phase 1 Report). Two well nests, established in Area 2 of the Phase 1 study area (Figure 1.2), showed higher water levels in piezometers than in water table wells, indicating areas of groundwater discharge (PEC 2006). Saturated soil conditions and areas of groundwater discharge were also noted throughout the Phase 2 study area during the field studies. Based on well studies and observations, it is concluded that the Phase 2 study area satisfies the hydrological technical criterion for calcareous fens.

2.1.2 Water Chemistry

One surface water and four groundwater sites were sampled in the northwestern area of the SFWC on June 22, 2006 (Figure 2.1). No wells or piezometers were located at the water sampling sites. Flowing surface water was collected from Assumption Creek. The groundwater samples were collected using a five-foot length of two-inch Schedule 40 PVC 10-slot well screen with an end cap. The well screen was manually pushed into the organic soil and the water was bailed for sampling. *In situ* measurements of pH, water temperature and electrical conductivity (EC) were collected using a Hach sensION 156 portable pH/temperature/conductivity meter and the appropriate electrode.

Water samples were collected in clean polyurethane sample containers that were transported on ice to a laboratory (Legend Technical Services, Inc., St. Paul, MN) for cation and anion testing. One water sample from each site was collected and the alkalinity value was determined by acid titration within 12 hours of collection as specified in Leete et al. (2005).

2.1.3 Soils

Four soil profiles were described in the northwestern area of the SFWC (Figure 2.1). Two sites were located on the north side and two sites were located on the south side of the study area. Soil samples

were obtained to a minimal depth of 48 inches using a Russian Peat Borer or Flag Sampler (Wildco Company). Soil profiles were described in the field using standard Natural Resources Conservation Service (NRCS) methods and horizon nomenclature (Soil Survey Staff 2003). Digital photographs of each profile were taken and compiled. In addition to the soil descriptions, the presence of organic soil was verified at each transect during the vegetation studies.

2.1.4 Vegetation

The plant species composition of the fen study area was recorded qualitatively and quantitatively to document the presence or absence of fen indicator species. Sampling locations were distributed throughout the study area (Figure 2.1). At each location, quantitative sampling was completed along a transect, and qualitative sampling was conducted through a walkover survey in the vicinity of the transect. Walkover surveys throughout the study area were used to describe the composition and location of different vegetative associations.

Transect locations were assigned by creating points in ArcMap GIS. These points were subsequently located staked in the field using a Trimble GPS unit with sub-meter accuracy. Transect locations were preferentially placed in areas with relatively little shrub cover. It was believed that shading by the shrubs could competitively exclude fen indicator species which tend to be found in open, less shaded locations. Historic aerial photographs demonstrate that the study area was once nearly free of woody vegetation (see PEC 2006). Therefore, to maximize the possibility of observing fen indicator species, sampling was concentrated in relatively open locations. Transects were 16.4 feet (5 m) long and oriented north-south, with the origin at the south end.

2.1.4.1 Vascular Plants

Vascular plants were sampled in five 9.8 in x 9.8 in (25 cm x 25 cm) plots spaced at 3.3 feet (one meter) intervals along each transect. Within each plot, every species was identified and absolute cover was estimated using the Daubenmire cover class scale (Mueller-Dombois and Ellenberg 1974). Walkover surveys were used to generate comprehensive species lists in the vicinity of each transect.

Plot sampling occurred in mid-June and mid-August, 2006. Two sample periods were necessary to identify as many species as possible. For each transect and the general vicinity of each transect, the cumulative value of calciphile species was calculated using both the 1995 and 2005 lists of calciphile indicator species (Berglund 1995; Leete et al. 2005). The quantitative transect sampling provided

data to assist in vegetation mapping, comparing plant communities to those documented in Phase 1, and in assessing if the vegetation is representative of calcareous fen communities.

2.1.4.2 Bryophytes

Bryophyte sampling was conducted in accordance with Janssens (2006) during the June 2006 sampling period. Along each transect, ten sample points were defined prior to sampling using a random number table, ranging from 0 to 500. The random number determined the distance (in cm) along the transect where bryophytes were sampled. A long, straight wire was used to locate the sample point on the ground below a tape measure which stretched along the transect. Bryophytes at each sample point were collected, placed in brown paper bags and dried for several days in front of a fan at room temperature for identification (Janssens 2006). Walkover surveys in the vicinity of each transect were also conducted to locate additional indicator bryophyte species not present on the transect. Calciphile indicator point values for bryophyte species are given in Janssens' report to the MnDNR (2005).

2.1.4.3 Vegetation Mapping

Mapping fen and non-fen vegetation was completed through a combination of quantitative sampling, floristic inventory, walkover surveys, and aerial photograph interpretation. Quantitative sampling was concentrated in areas most likely to meet the vegetation criteria. Sample points were located throughout the study area representing upgradient and downgradient positions on the sloping peatland wetland complex. The thickest areas of shrub carr were generally not quantitatively sampled because 2005 walkover surveys of these communities and Phase 1 results indicated that the herbaceous plant community is less abundant under dense shrub cover. The majority of the calciphile indicator species (Berglund. 1995; Leete et al. 2005) are typically found in open, unshaded locations, and fen species are generally intolerant of shade (Kotowski et al. 2001).

False-color infrared photographs from April 2005 were used to demarcate variation in vegetation structure and composition, and field surveys supplemented the mapping by correlating color signatures on the aerial with observed plant communities. Calciphile index values were calculated for relatively open plant communities around each transect. Because the entire study area was found to meet the technical criteria for soils, hydrology and water chemistry (see results), a score ≥ 30 rather than 50 is required to meet the vegetation criteria, using either the 1995 or 2005 indicator species lists. Not every mapped polygon was sampled quantitatively, but all vegetation types were evaluated through walk-over surveys. When one vegetation type consistently met fen criteria when sampled at

multiple locations, similar vegetation – as determined by walkovers and aerial photo interpretation – were also considered to meet fen vegetation criteria.

After vegetation was mapped, and areas that met the vegetation criteria were designated. Additional areas were identified that may have supported calcareous fen vegetation historically, but do not presently meet the vegetation criteria. Historic aerial photographs, current site conditions (including soils, hydrology and vegetation), and a review of fen successional patterns assisted in this determination. These areas could potentially support fen vegetation in the future through restoration and management. Some of the putative historic fen areas are so ecologically degraded that restoration may be difficult or impossible. However, many areas could be restored such that sustainable populations of fen vegetation could reestablish. Most areas of potentially-restorable fen were likely a tall sedge fen community (Type I), though some areas may have supported a short sedge community (Type II). Hydrological alteration and shrub cover may prevent the current recognition of areas that once included Type II, although management might restore plants common in this fen type. Areas that may have previously contained occurrences of Type II fen were identified through a combination of evidence:

- Obvious strong groundwater discharge as indicated by seepage, spring runs, or quaking peat;
- Proximity to the toe of the bluff, where strongest groundwater discharge and hydraulic gradients would be expected;
- A network of coalescing streams shown in historic aerial photographs, similar to what is seen in an Area 1 Type II fen;
- The presence of high-point calciphile indicator species in the existing plant community; and
- The presence of marl in the upper soil profile.

The mapped vegetation polygons were classified as to whether they currently meet fen technical criteria, may have included Type II fens in the past, and have restoration potential. Specifically, the categories are:

1. Meets fen criteria, short sedge fen possible (i.e., Type I fen present; Type II fen possible);
2. Meets fen criteria (i.e., Type I fen present);
3. Doesn't meet fen criteria, possible historic and restorable fen;
4. Doesn't meet fen criteria, possible historic fen but severely degraded ; and
5. Upland.

The first two categories are used for areas that currently meet fen criteria (there is very little disagreement in conclusion between both the 1995 and the 2005 criteria). The third and fourth categories are used for areas that may have been fen in the past but do not currently satisfy fen criteria. Potentially restorable fen areas include shrub carr and willow swamp areas that retain appropriate soil and hydrology. Brush removal and/or prescribed burning could result in the establishment of fen vegetation. The severely degraded classification refers to areas of major hydrological alteration and invasive and woody species cover in which successful restoration may be difficult.

2.2 Alternative Corridors Study

Identification of native plant communities in the six alternative corridors was accomplished using the MLCCS landcover maps (MnDNR 2004) and Minnesota County Biological Survey (MCBS) native vegetation maps of Carver and Scott Counties that are available from the MnDNR GIS Data Deli, aerial photographs and field verification. Nearly the entire area, including the alternative alignments and surrounding lands, have been mapped and assigned MLCCS codes. A smaller portion of the area has been surveyed by the MCBS. Areas identified as native vegetation by MLCCS and MCBS were visited in the summer of 2006 to verify the classification and to assess the quality of the native plant community. Areas not mapped by MLCCS were visited to document the presence of native vegetation. A query of the MnDNR Natural Heritage Program database also produced records of natural features including native plant communities and protected species documented and characterized by the MCBS.

Although the study corridors are 300 ft. wide, final highway alignments will not occupy the entire width. Changes in land use and destruction of native vegetation independent of the TH 41 project will likely occur between this study and project construction. Acreages of native vegetation that are reported in this study are based on current conditions within the entire width of each corridor. Therefore, actual impacts from the project will likely be less than stated here.

Several methods of classifying the vegetation in the alternative corridors were used. While related, the various approaches provide slightly different, but complementary, ways of describing vegetation and interpreting potential direct, indirect, and cumulative impacts:

- Cover type: A land cover classification based on MLCCS Level 1 categories (MnDNR 2004) that includes native plant communities, non-native plant communities, artificial surfaces and managed lands.

- Native Vegetation or Natural Communities: A classification of individual plant communities that are dominated by native species and appear to be of natural origin. Categories generally correspond to Level 4 and 5 MLCCS floristic groups (MnDNR 2004) and MnDNR Natural Heritage Program community types (MN Natural Heritage Program 1993; MnDNR 2005).

- Natural Community State Rarity Rankings: A classification of natural areas according to the relative rarity or abundance within the state or within regions of the state. Categories are defined in MN Natural Heritage Program (1993).

- Natural Community Element-Occurrence Rankings: A classification of natural areas based on ecological integrity and quality reflecting the presence or absence of human-caused disturbance such as grazing, plowing, logging, or invasive species. Categories are defined by the MnDNR Natural Heritage Program guidelines (MnDNR undated; 2004).

- Biodiversity Area: A classification of aggregated natural areas that may reflect the presence of multiple types of native plant communities, rare species, the size of plant communities, and the landscape context. Unlike the categories described above, the boundaries and classification of biodiversity areas were not verified or modified as part of this study. Biodiversity areas were defined by the MCBS. The extent of each category in the alternative corridors was determined during this study.

- Edge and Interior Habitats: A classification to reflect the effect of fragmentation on the quality of natural areas. Edge areas are generally of lower ecological quality compared to interior areas, but this difference is not captured by the element-occurrence ranking described above. Edge and interior areas were determined for two general categories of plant communities: forest (including woodland) and shrub/herbaceous communities.

For this study, native plant communities within 100 ft. of a boundary with a non-native community or artificial surface are defined as “edge” areas. Native plant communities that are beyond 100 ft. of such a boundary are defined as “interior” areas. By this definition edge areas do not occur at the boundary of different types of natural area (e.g., oak forest and wet meadow or floodplain forest and river). Edge was only quantified if it represented a boundary between native vegetation and an artificial environment (e.g., a highway corridor).

Edges can have detrimental impacts on biodiversity due to alteration of microclimate and increased encroachment of alien or parasitic species. The most detrimental edge impact occurs when a mature

forest is fragmented because of the difference between the microclimate of the intact forest and the open area. Changes in light, air and soil temperature, relative humidity, and wind alter plant succession at the edge of the mature forest. Predatory and parasitic animals can gain access to the forest habitat and may be particularly devastating for nesting success of forest birds. The distance into a forest of altered habitat (also termed depth of edge influence, DEI) varies widely among organisms and site conditions, but for some birds, the DEI can be as great as 656 feet (200 m) due to nest predation. For plants, the DEI can be as great as 164 feet (50 m), and for some invertebrates, 328 feet (100 m) (Fahrig 2003; Forman and Alexandar 1998; Groom et al. 2005; Harper et al. 2005; Ries et al. 2004). For this analysis, the depth of edge influence (DEI) was defined to be 100 ft. in which the most degraded ecological conditions might be expected.

The amount of edge and interior area within each alternative corridor were quantified as a direct measure of potential impact to natural areas differing in relative quality. If a highway corridor bisects a native plant community, the remaining vegetation *outside* the corridor exists in smaller, more isolated patches, and the amount of edge habitat increases. This indirect impact from fragmentation was measured by assessing the amount of *current* interior area that will *become* edge area outside of each alternative corridor.

2.3 Bridge Visits

Qualitative assessments of possible ecological impacts of existing large-bridge crossings of the Minnesota River were conducted during visits in June through August, 2006. Anecdotal observations were made of the general environmental setting of each bridge and used to infer possible impacts from the proposed TH41 river crossing. Potential impacts fell into two general categories: (1) impacts to pre-existing native vegetation and natural areas, and (2) the success or failure of revegetation with native species through deliberate restoration or unmanaged dispersal and establishment.

Bridges were selected that are similar to the proposed project, in that they cross a large portion of Minnesota River floodplain and are relatively high bridges. Because nearly the entire length of the Minnesota River Valley crossing will be made on bridges, rather than on filled embankments or at grade, the assessment focused on impacts under and surrounding existing elevated bridges. The bridges visited were Highway 169, Interstate 35W, Highway 77, Interstate 494, Highway 5 (Mendota Bridge), and Interstate 35E (Figure 2.2). Other bridges on the Minnesota or Mississippi Rivers were excluded because they are not elevated bridges, cross relatively steep, narrow valleys (not expansive

floodplains), or the surrounding land use is highly developed and not informative for bridge impacts on floodplain biota.

2.4 Literature Review and Impact Assessment

A literature review was conducted to assess potential ecological impacts of highway construction in a uniquely-sensitive environment such as the SFWC, with a focus on natural communities and native vegetation. General impacts from road construction on native communities and wetland were evaluated, as well as specific impacts anticipated to the SFWC and vegetation in the six alternative corridors. A literature review was included in the Phase 1 study, and was expanded upon in the Phase 2 literature review to better assess potential impacts from the TH 41 project.

Primary scientific literature was compiled using existing literature on calcareous fens, internet searches, and electronic databases. The databases and relevant literature were accessed through the University of Minnesota library system. Databases that yielded the most pertinent citations included Agricola, BIOSIS, Biological Abstracts, and Web of Science (Science Citation Index). Use of scientific literature, including both observational and experimental studies, for predicting impacts allows for general predictions. However, because of the idiosyncrasies of alternative scenarios, the large number of influencing and interacting factors, and the limits of experimentation in evaluating all possible factors and interactions, a literature-based prediction of impacts is qualitative rather than quantitative. The most likely types of ecological alterations can be identified from literature and from field studies. Unfortunately, the rate at which those impacts may develop, especially indirect impacts, is difficult to predict, largely because of confounding factors, unknown factors, and interactions among factors.

3.0 Results

3.1 Fen Field Study

3.1.1 Hydrology

Numerous areas of groundwater discharge were observed throughout the study area. Those observations, combined with the Phase 1 well nest monitoring, demonstrate that the entire Phase 2 study area satisfies the hydrology criterion for calcareous fens. The results of well measurements and field observations demonstrated that the Phase 2 study area is an active area of groundwater discharge, which is necessary for the existence of calcareous fens.

3.1.2 Water Chemistry

The pH, EC, calcium, and alkalinity parameters for all ground and surface water samples met the calcareous fen criteria. A sample site meets the fen criteria when pH > 6.7, calcium > 30 mg/l, EC > 500 uS/cm and alkalinity > 1.7 meq/l. Analytical values for the water samples are shown in Table 3.1.

The pH of the ground water samples ranges from 7.1 to 7.5, calcium ranges from 88 to 100 mg/l, EC ranges from 695 to 840 uS/cm, and alkalinity ranges from 4.6 to 7.8 meq/l. The pH of the surface water sample was 7.7, calcium was 100 mg/l, EC was 742 uS/cm, the alkalinity was 3.0 meq/l. All ground and surface water samples exceeded the minimum values of a calcareous fen.

The pH values were all within the range of values observed throughout the SFWC during Phase 1. Conductivity values were higher than most observations made in Phase 1, except for the northeast portion of Area 1. Calcium concentrations and alkalinity were also typically higher than most Phase 1 samples except for the northeast portion of Area 1. Within this area of high groundwater discharge, marl soils, and abundant calciphiles, the EC values ranged from 908 to 946 uS/cm. Outside of this area, the Phase I EC values were between 500 and 700 uS/cm. Low EC values measured in Area 2 during Phase 1 were believed to be in error (PEC 2006). Phase 2 results confirm that EC values in this portion of the SFWC meet the technical criterion.

3.1.3 Soils

All soil sample profiles were composed of peat to a depth of at least 48 to 51 inches below the soil surface (Figure 3.1). These organic soils were identified as variants of Houghton soil (euic, mesic

Typic Haplosaprists). The northern sample sites, 53 and 61, have snail shells and fragments of snail shells throughout the profile. The soil profiles were slightly effervescent at the surface and violently effervescent throughout the remainder of the profile. This weak effervescence indicates there is groundwater recharge at the soil surface. Sample site 61 has a buried Oa-horizon at 49 inches which was only slightly effervescent. Sample site 61 was the only profile that contained mineral soil, coarse sand mixed with the peat, from 35 to 44 inches. These profiles were primarily well-decomposed organic material (sapric) with some more poorly decomposed (hemic) organic material also found within the profiles. Marl was observed at the soil surface near these sample sites, although it did not occur within the sampled soil profiles.

The southern sample sites, 62 and 49, did not have any snail shells or fragments in the profiles. Sample site 62 was slightly effervescent from 0 to 5 inches and 11 to 34 inches. This weak effervescence indicates there is recharge at the soil surface. The remainder of the profile was violently effervescent. Sample site 49 was slightly effervescent at the surface (0 to 2 inches) and from 11 to 48 inches. The profile was violently effervescent from 2 to 11 inches. These profiles contained primarily well decomposed organic material (sapric) with some more poorly decomposed (hemic and fibric) organic material also found within the profiles.

The soil technical criterion requires the presence of a histic epipedon or a histosol, and the observed soil profiles are histosols. Therefore, they meet the soil technical criterion for calcareous fens.

3.1.4 Vegetation

3.1.4.1 Vascular Plants

The sample sites that meet calcareous fen vegetation criteria are distributed throughout the Phase 2 study area (Figure 3.2). Indicator scores were tallied using both the 1995 criteria and 2005 criteria. Using the 50-point threshold, the two sets of criteria yield identical results with respect to which areas satisfy calcareous fen criteria. The 1995 criteria indicator species scores are lower than the 2005 criteria scores, but if the 2005 score was >50, the 1995 score was also >50. Using the broader vegetation criterion (requiring a vegetation score between 30 and 50 if all other criteria are met), the 2005 criteria indicate more sample sites are calcareous fen than the 1995 criteria. Four additional sample sites satisfy the broader calcareous fen vegetation criterion as compared to using the strict 50-point threshold.

The communities observed in the Phase 2 study area largely represent a subset of the communities documented in the Phase 1 study. No areas were found in the Phase 2 study area with a concentration of high-point calciphiles or protected plant species. Such areas are present in the northeast portion of Area 1 (PEC 2006; Figure 1.2), where numerous sites of groundwater discharge and extensive calcium carbonate deposition is present. These areas in Area 1 also have much higher hydraulic gradients than observed in Area 2.

Despite the absence of communities with the greatest concentration of fen species as are found in Area 1, many fen species and many locations of calcareous fen vegetation are present in the Phase 2 study area. Much of the area was mapped by the MLCCS as shrub carr (Figure 1.3), due to the extensive coverage of willows (e.g., Bebb willow – *Salix bebbiana*, pussy willow – *S. discolor*, meadow willow – *S. petiolaris,* and autumn willow – *S. serissima*) and red osier dogwood (*Cornus sericea*), which has developed over the past four decades (see PEC 2006 for historic aerial photographs). However, the MLCCS classification reflects current dominant landcover and does not assess past ecological conditions or the presence of remnant fen indicator species which were likely more common historically. Within regions of dense willow swamp or shrub carr, fen indicator species were infrequently observed, presumably due to shading from the shrubs. In the western portion of the Phase 2 study area, lowland hardwood forest has established on some of the most hydrologically altered sites. Dominant species include early successional trees such as box elder (*Acer negundo*), green ash (*Fraxinus pennsylvanica*), American elm (*Ulmus americana*), and common buckthorn (*Rhamnus cathartica*).

The most common community documented in the Phase 2 study area is a tall sedge fen (Type I fen), that is itself heterogeneous. Dominant species include prairie sedge (*Carex prairea*), sterile sedge (*Carex sterilis* – a state-protected species), Sartwell's sedge (*Carex sartwellii*), tussock sedge (*Carex stricta*), and mat muhly (*Muhlenbergia richardsonis*). Common wet and sedge meadow forb species are also present. Several calciphile species are also found in this community. The most common species are relatively low-point calciphiles such as sage willow (*Salix candida*), bulbous bittercress (*Cardamine bulbosa*), bottlebrush sedge (*Carex hystericina*), northern bog aster (*Aster borealis*), fringed brome (*Bromus ciliatus*), long-bracted tussock sedge (*Carex aquatilis*), and lesser fringed gentian (*Gentianopsis procera*). High-point calciphiles are uncommon, with the exception of the abundant prairie sedge and sterile sedge. However, two high-point species are present at a few locations: grass of Parnassus (*Parnassia glauca*) and brook lobelia (*Lobelia kalmii*).

Most transects located within the tall sedge fen satisfy the vegetation component of both the 1995 criteria and 2005 criteria. Those transects are fairly widely distributed across the study area (43, 44, 45, 46, 55, 56, 57, and 60). The highest indicator scores were found at transect 43 (130 points; 2005 criteria) and transect 60 (125 points; 2005 criteria). Transect 60 is heavily overgrown with shrubs, making it difficult to survey the vicinity for fen indicators. However, several indicator species were found including prairie sedge, sterile sedge, grass of Parnassus, and brook lobelia. Additionally, the scent of arrowgrass (*Triglochin* spp.) was detected, suggesting the presence of another high point, high-fidelity calciphile (either marsh arrowgrass or seaside arrowgrass (*T. palustris* or *T. maritima*)). The presence of arrowgrass would raise the indicator score of transect 60 to 150 points, which is among the highest scores recorded in Area 1 during the Phase 1 study.

A sedge meadow dominated by prairie sedge was documented at transects 59 and 61. No other high-point calciphiles were observed, but low-point indicators were found including bulbous bittercress and bottlebrush sedge. The area around transect 61 is dominated by lake sedge (*Carex lacustris*), and prairie sedge; the tall sedge fen community is confined to a microsite. Neither transect satisfied the 50-point criterion for calcareous fen vegetation, although both transects were between 30 and 50 points; therefore these transect areas are considered examples of the tall sedge fen community.

A community dominated by tussock sedge was also observed at four transect locations: 49, 50, 51, and 53. Transects 51 and 53 met the 1995 and 2005 fen vegetation criteria. The plant communities at these locations supported other species that are common in calcareous fen communities, such as Sartwell's sedge, prairie sedge, bottlebrush sedge, and bulbous bittercress, as well as wet meadow forbs. Transects 49 and 50 failed to meet the 50 point threshold under either the 1995 or 2005 criteria, but each location scored 30 points using the 2005 criteria. These transects had a notable presence of lake sedge and only a small amount of prairie sedge. Sterile sedge was absent from these four transects.

Lake sedge meadows were dominated by lake sedge and common wet meadow forbs. Calciphile indicator scores were often very low in these communities. Transects 52, 54, and 62 sampled this community. These sites appear to be wetter than tall sedge fen and are seasonally inundated.

A community not documented in Phase 1 was observed at transect 58. The community was dominated by water horsetail (*Equisetum fluviatile*), with approximately 90% cover. Other species present as minor components of the community include fen and sedge meadow species such as tussock sedge, Sartwell's sedge, joe pye weed, (*Eupatorim maculatum*), boneset (*Eupatorium*

perfoliatum), rough bugleweed (*Lycopus asper*), greater water dock (*Rumex orbiculatus*), and narrowleaf cattail (*Typha angustifolia*). A soil core revealed granular peat structure of morsch soil, indicative of a drained or partially-drained peat soil. The unusual plant community composition likely originated as a result of hydrological alteration of an original wet meadow or fen community. Surrounding this location is a larger area dominated by lake sedge. Transect 58 is located just east of an extensive growth of reed canarygrass (*Phalaris arundinacea*), indicating a disturbed ecosystem. Historic aerial photographs and field observations suggest that ditching, sediment deposition from uplands, and ongoing surface water discharge may have affected local patterns of groundwater discharge and vegetation.

3.1.4.2. Bryophytes

The sample sites that satisfy fen criteria based on bryophyte indicator species are nearly identical to the sites that satisfy the most inclusive vascular plant criteria for the 2005 criteria (see Appendix B). Many of the bryophyte indicator scores are relatively high and exceed the threshold of 109. One sample location, transect 46, had a bryophyte indicator score of 346, which equals the previous highest score documented from any fen in Minnesota (Ottawa Fen). Transect 46 is located outside of the original MLCCS calcareous fen map unit, but scored moderately high (90) for vascular plant indicator species (2005 criteria). As with most of the Phase 2 study area, transect 46 is overgrown with shrub cover, which may limit the abundance or detectability of vascular plant fen indicator species. It is also located at the base of the bluff, which is where high hydraulic gradients would be expected.

The compositions of bryophyte communities among the various sample locations throughout the SFWC were compared (see Appendix B). The resulting similarity and interspersed species distributions suggest that all sample locations are part of a calcareous fen ecosystem, even in the Phase 2 sample sites where high-fidelity vascular plant calciphiles are less abundant than Phase 1 sample sites. Major divisions in bryophyte flora were not found between short sedge fen and tall sedge fen areas.

3.1.5 Vegetation Mapping and Distribution of Calcareous Fen

The original MLCCS mapping of the Phase 2 study area identified most of the area as shrub carr – not calcareous fen reflecting the dominance of shrub species. Wet meadow was also mapped in sections of the Phase 2 study area where less shrub cover was present (Figure 1.3). However, since the original MLCCS mapping, technical criteria for identifying fens have been issued and refined. A

vegetation map was prepared taking into consideration cover type, dominant species, and calcareous fen criteria (Figures 3.3 and 3.4). Despite the level of detail in the map, vegetation within map units is not homogeneous, and variation can occur on small spatial scales.

In many instances, wetland and fen communities as described above and in the Phase 1 report were combined with other dominant cover types for mapping. For example, tall sedge fen is shown on the map as a distinct map unit as well as in combination with scattered dogwood, thick dogwood, and cattails. Within each of these map units characteristic and indicator species were found allowing designation as tall sedge fen component of calcareous fen. However, substantial cover from shrubs and dogwoods warranted recognition of variations of tall sedge fen.

The status of each map unit as calcareous fen was also designated. Areas of tall sedge fen within which evidence of short sedge fen microsites occurs were indicated. These areas might support new populations of rare or protected species with appropriate management and restoration (sterile sedge, a state-threatened species, is currently found throughout areas mapped as tall sedge fen). All areas of tall sedge fen meet all fen criteria, even if dogwood cover is extensive. Areas that did not meet vegetation criteria, but met the physical criteria, were mapped as possible historic fen. Anthropogenic disturbance, fire suppression, and encroachment of invasive species could all degrade fen plant communities and exclude fen indicator species. Areas of willow swamp and some lowland hardwood forest were mapped as potentially-restorable fen with proper management. Areas with substantial hydrological alteration or dominance by invasive species were mapped as possible historic fen that is severely degraded. Restoration of fen vegetation in these sites may not be possible. Vegetation map units that meet fen vegetation criteria are interspersed with map units that do not, with the exception of the western portion of the study area which uniformly fails to meet the vegetation criterion.

Figures 3.3 and 3.4 also show profile views of transects running across the Phase 2 study area and corridors E1A and E2. The distribution of vegetation types and status as calcareous fen are also shown. The strongest hydraulic gradients and most focused groundwater discharge would be closest to the bluff, at higher elevations on the peat blanket. This topographic position is where most indications of short sedge key (e.g., carbonate precipitates, indicator species, turgid or quaking peat) were observed. The profiles show that sites that meet the fen vegetation criteria are found at elevations above and below areas that do not meet the fen vegetation criteria. Lateral groundwater flow through the porous organic soil links these zones chemically and hydrologically.

The vegetation map demonstrates that the Phase 2 study area is degraded ecologically in several ways and is threatened with continued degradation. Despite the presence of several fen indicator species and the abundance of some of them, including one protected species, the amount of calcareous fen and native wetland plant communities has been substantially reduced over time. Shrub coverage and invasive species encroachment are serious and immediate threats to remaining fen vegetation regardless of the TH 41 project.

3.1.6 Conclusions and Discussion

The entire Phase 2 study area satisfies all of the physical parameters using both the 1995 and 2005 criteria. Groundwater discharge has been observed or measured throughout the study area. Water chemistry parameters were met everywhere they were measured across the study areas. A thick layer of organic soil extends over the entire wetland complex. The vegetation criterion is met at most sample sites throughout the study area, using either the 1995 criteria or 2005 criteria for both vascular plants and bryophytes, although not every transect sampled met the vegetation criterion. The number of fen indicator species is not as high as in Area 1, nor are as many high-fidelity fen species present or as abundant as in Area 1.

Different plant communities, wetland types, and variants of calcareous fen are interconnected and spatially and temporally dynamic in calcareous fen wetland complexes. Natural succession processes involving both biotic and abiotic factors can cause one type of ecological community to morph into another. This can be observed spatially as species distribution changes along environmental gradients. However, it occurs also temporally as environmental conditions change and species individually respond. Changes also occur as humans change land use, alter ecosystem processes, and introduce new species. Figure 3.5 presents a conceptual model of fen succession and disturbance within the SFWC. This model includes predominant plant community types and important physical and biological factors that influence successional changes. These relationships are based on Phase 1 and 2 studies of the SFWC, anecdotal observations of other fen and wetland complexes, and scientific studies of calcareous fens and related wetlands (Almendinger and Leete 1998a,b; Amon et al. 2002; Bowles et al. 2005; Boyer and Wheeler 1989; Carpenter 1995; Godwin et al. 2002; Green and Galatowitsch 2001; Hershock 2002; Kercher et al 2004; Kotowski et al. 2001; Mauer et al. 2003; Miller and Zedler 2003; Miner and Ketterling 2003; Muir-Hotaling, undated; Panno et al. 1999; PEC 2006; Picking and Veneman 2004; Reed 2002; Richburg et al 2001; Wassen et al. 1990; Weltzin et al. 2000; Werner and Zedler 2002; Wetzel et al. 1998; Wilcox 1986; Zedler and Kercher 2004).

This model incorporates major plant communities, ecological factors, and successional pathways but omits many transitional stages, minor variations of plant communities and complex interactions. The pathways among the rectangles on Figure 3.5 indicate successional patterns that could be expected to occur naturally, free from anthropogenic disturbance or management. Pathways to or from ovals are transitions that become more prevalent as a result of anthropogenic impacts. However these are not exclusively human-caused transitions. For example, movement between fen, dogwood, and willow communities is naturally dynamic through periodic fire. Fire suppression, however, shifts the direction of succession towards shrubs. Double-headed arrows indicate pathways may be reversible under some circumstances through natural processes (without confounding anthropogenic influences) or through relatively straightforward management practices such as prescribed fire and shrub removal. Single-headed arrows indicate pathways that result from interactions of factors or transitions that are not easily reversible, if at all. Reversing them may require intensive and multiple forms of management such as restoring hydrology, prescribed burning, and invasive species removal. Even with intensive management, it may not be possible to restore fen vegetation on sites that are severely degraded.

The distributions of calciphilic plant species are represented by stars on Figure 3.5.

- One Star: Communities in which fen species are sometimes present, and which sometimes meet the fen vegetation criterion, are indicated with one star. The occasional presence of indicator species may reflect a transitional stage along successional pathways.

- Two Stars: Tall sedge fen communities that consistently include multiple fen indicator species and meet the fen vegetation criterion are marked with two stars.

- Three Stars: Short sedge fen communities, in which the greatest number of high-point indicator species and protected species are found, are marked with three stars.

The two types of calcareous fen discussed earlier, Type II, short sedge fen and Type I, tall sedge fen (Table 1.2), share many species and occupy similar environments. However, several environmental differences have been correlated with the difference in vegetation including: magnitude of hydraulic head; diffusion of groundwater discharge; proportion of growing season the water table is near the soil surface; available phosphorous, and amount of calcium carbonate precipitates in the upper soil profile (Almendinger and Leete 1998a,b; Amon et al. 2002; Bowles et al. 2005; Boyer and Wheeler 1989; Carpenter 1995; Godwin et al. 2002; Komor 1994; PEC 2006; Picking and Veneman 2004; Reed 2002; Wassen et al. 1990). Soil profiles from fens often indicate that levels of calcium

carbonate fluctuate temporally, and marl and peat zones have been observed to expand, contract, and replace each other in response to groundwater discharge, peat accumulation, and erosion (Almendinger and Leete 1998a; Miner and Ketterling 2003; PEC 2006). Although some species occur in both types of fen, differences in species composition, abundance, and dominance change as relative competitive abilities vary between Type I and II fens (Carpenter 1995; Hershock 2002).

Water tables are near the soil surface in both Type I and II fens, although the duration may vary. Fen plants are generally not adapted to prolonged inundation, flooding or water table drawdown. Hydrogeological or disturbance factors that result in higher water tables will cause the plant community to change. Within the SFWC, tall sedge fen communities would shift (Figure 3.5) towards communities of lake sedge or emergent marshes (described as communities of lake sedge, sweet flag (*Acorus americanus*) and bur-reed (*Sparganium eurycarpum*) in the Phase 1 report; PEC 2006). This pattern can be observed in Area 2 where the railroad embankment has apparently impounded water. Temporally, this would be recognized as succession from calcareous fen to wet meadow and emergent marsh.

When tall sedge fen communities are drained either through artificial drainage or natural alterations in groundwater discharge, vegetation will include species better adapted to the drier conditions and fewer fen species. Within the SFWC, such communities are designated sedge/meadow-rue and sedge/goldenrod (i.e., *Carex-Thalictrum* and *Carex-Solidago* in PEC 2006). Transitions between these communities can be seen in the SFWC on the sides of peat domes, in areas of tiling or ditching, and in the western half of Area 1. That region is down slope – and on the opposite side of the railroad embankment – from the lake sedge and emergent marsh site mentioned above. It is presumed that these two regions once were part of a large, contiguous area of tall sedge fen, but railroad construction separated them hydrologically and sent them on divergent successional trajectories. At the extreme end of a drainage gradient, the vegetation would become dominated by upland grasses (Figure 3.5) as has happened at the far western end of the SFWC near Audubon Drive. These successional steps are analogous to a transition from calcareous fen to wet prairie to mesic prairie (although many prairie species are absent from the SFWC).

Human impacts can dramatically change the direction and rate of successional changes through drainage and impoundment as previously mentioned (e.g. fire suppression, loss and fragmentation of natural areas, soil disturbance, peat degradation, runoff of salt, nutrients and surface water, and introduction of invasive species). Fire suppression increases the abundance of shrubs and trees in fens, wet meadows and prairies. Land use changes around the SFWC have prevented the spread of

wildfires, and historic photographs show a substantial increase in woody vegetation. Areas mapped as dogwood, willow swamp or lowland hardwood forest in the SFWC were once open communities dominated by herbaceous vegeatation. Given the hydrological, chemical and edaphic conditions of the SFWC and distribution of certain fen indicator species, it is reasonable to conclude that much – if not most – of the SFWC was once the tall sedge fen (Type I) form of calcareous fen. Consequently, some map units of trees and shrubs were mapped "possible historic and restorable fen". Shrub removal and/or prescribed burning could push succession away from woody vegetation back to the more species-rich and diverse fen communities. Drainage can interact with fire suppression to create pathways from herbaceous wetland communities to marginal or non-wetland woody communities such as buckthorn (*Rhamnus cathartica*) thickets or lowland hardwood forest. Succession can also be towards low diversity herbaceous communities dominated by reed canarygrass, narrow-leaf cattail or common reed (*Phragmites australis*). In drained locations, reed canary grass communities can also shift towards woody vegetation.

Given the strength of disturbance factors, and interactions among them, such as drainage and fire suppression, it is not expected that succession will occur from non-fen vegetation back to fen vegetation without ecological restoration and land management. The area currently mapped as calcareous fen vegetation is believed to be smaller than what was historically present, and woody vegetation continues to increase. Without active and sustained management of the SFWC, by the time TH41 is constructed, there will be much less fen vegetation than at present. Wetlands will still be present, but a much greater area of wetland will be dominated by shrubs, invasive species, lowland hardwood forest, and emergent marsh. Those communities will include few or no fen indicator species or protected species.

The results of the field studies, in conjunction with a review of fen ecology, lead to several conclusions:

- The SFWC is a large, interconnected wetland ecosystem that is spatially and temporally dynamic and heterogeneous.

- All areas sampled within the Phase 1 and 2 study areas satisfy calcareous fen hydrology, soil and water chemistry criteria (low EC values in well nest 2B are believed to be in error; PEC 2006)

- Areas of fen vegetation are dispersed throughout the area and are interspersed with non-fen wetland vegetation. This interspersion sometimes occurs on relatively small spatial scales, possibly in response to environmental variables.

- Sites that satisfy fen vegetation criteria are found upslope and downslope from sites that do not. Groundwater is upwelling and flowing laterally throughout these sites, thus chemically and hydrologically linking fen and non-fen areas.

- Through ecological succession, areas of fen vegetation can and do change over time. Certain areas that do not currently support fen vegetation probably did in the past and could potentially be restored and revegetated with fen species.

- Without active management, the distribution and abundance of calcareous fen vegetation will continue to decrease.

3.2 Alternative Corridors Study

Six proposed corridors were evaluated that occur in a landscape of development, agriculture and fragmented natural communities (Figure 3.6; Table 3.2). The average acreage of the alternative corridors is 255.5 acres. The majority of land in each corridor (average 64.8%) is a combination of artificial surfaces (lawns, buildings, roads) and agriculture (planted or cultivated areas).

3.2.1 Native Plant Communities

The amount of native vegetation varies among the corridors with 29.6 acres present in E1 and 81.6 acres present in C2A. The remaining corridors have between 48.9 acres and 59.3 acres. The distribution of different types of natural communities in the alternative corridors is presented in Table 3.3. The most common vegetation types include floodplain forest, maple-basswood forest, and mixed emergent marsh.

State rarity rankings for plant communities (Table 3.3) are most pronounced in Corridors E1A and E2 (Table 3.4), due to the presence of calcareous fen which is rated “1 – critically imperiled” in the state. No other plant communities in any of the alternative corridors is rated as rare as calcareous fen. Other plant communities with notable rarity rankings are distributed among the six alternatives and include maple-basswood forest, oak forest, floodplain forest, and mixed emergent marsh (all rated as 2 – imperiled). The greatest acreage of natural areas with state rarity rankings 1 through 3 is found in C2A, and the least is in E1 (Table 3.4).

The distribution of high quality native plant communities in the various corridors generally reflects the distribution of native vegetation (Table 3.5). No "A" ranked native communities were identified in any of the corridors when the Minnesota DNR Element Occurrence evaluation was applied. However, the area and relative cover of "B" and "BC" ranked native plant communities were highest in corridors with less disturbance and higher coverage of native plants. In Corridor E1, for example, over half of the area of remaining native plant communities is ranked "D", or "poor condition." In contrast, Corridors C2 and W2 have over 64% of their remaining native plant communities rated "B", or "good quality". Corridor C2A has over 55% of its native plant communities ranked "B". The majority of native plant communities in Corridors E1A and E2 are ranked "BC", or somewhere between "good quality" and "moderate condition."

Within Corridor C2A, one of the better-quality native plant communities is a maple-basswood forest ranked "B." It is found on relatively steep hillsides above Chaska Creek. The steepness of the slopes undoubtedly prevented conversion to agriculture. The stream valley has been altered by construction of County Road 110 (Creek Road) and a few houses. The maple-basswood forest in the Corridor C2A is found on the west side of Creek Road. This road cuts a relatively narrow opening in the forested valley which also supports lowland hardwood forest, oak forest, and additional maple-basswood forest outside Corridor C2A. The value of the maple-basswood forest in the corridor is enhanced by its adjacency to other forests and the relatively low density of development in the immediate area. The total area of this forest is 45.8 acres, of which 22.4 acres are found within Corridor C2A. The total area of contiguous forest that is bisected by Creek Road is 113.3 acres. Although approximately 30 acres of the forest is mapped as altered/non-native woodland, the relatively large area of contiguous forest is unusual in this part of the growing metropolitan region.

The forest was observed to have an uneven-aged distribution of trees, including many that are between 20 and 36 inches diameter at breast height (dbh). Snags are present as well as coarse woody debris on the ground. No evidence of logging or grazing was noted, although the possibility that such anthropogenic disturbance has occurred cannot be discounted. Seedlings and saplings of shade tolerant species such as sugar maple (*Acer saccharum*), basswood (*Tilia americana*), and hop hornbeam (*Ostrya virginiana*) are abundant in the forest. Invasive species such as buckthorn or garlic mustard (*Alliaria petoliata*) are either absent or present only at the margins of the forest. The herbaceous ground cover is species rich and includes longstalk sedge (*Carex pedunculata*), wild leek (*Allium tricoccum*), Virginia waterleaf (*Hydrophyllum virginianum*), bloodroot (*Sanguinaria canadensis*), wild ginger (*Asarum canadense*), nodding trillium (*Trillium cernuum*), maidenhair fern

(*Adiantum pedatum*), dutchman's breeches (*Dicentra cucullaria*), wood anemone (*Anemone quinquefolia*), and large-flower bellwort (*Uvularia grandiflora*).

The characteristics of this maple-basswood forest might normally lead to an "A (high quality)" ranking. However, there is little or no duff present on the forest floor, and castings and exposed roots of trees and saplings indicate that earthworms are present. This condition lowers the EO ranking to "B." Nevertheless, the relative rarity of maple-basswood forests which are largely free of disturbance and support high species richness and diversity in the metro area warrants recognition of this forest as a valuable natural community.

As described in the methods section, MnDNR Element Occurrence Ranking Guidelines do not provide "A-D" rankings for calcareous fens. Based on the field surveys conducted, and consultation with field notes of previous DNR botanical surveys, the calcareous fen areas in Corridors E1A and E2 were ranked "BC". This is primarily because the fen area has been degraded by drainage alterations, shrub cover, and invasive species. Nevertheless, higher quality ("A" and "AB") calcareous fen areas are nearby, and the presence of fen vegetation, including protected species, justifies recognition as a valuable natural area. The MnDNR Natural Heritage Program database ranked the various communities in the fen complex as "A-C".

The lowland hardwood forest in Corridor C2 was given a "B" ranking because of large size classes of canopy trees, relative lack of anthropogenic disturbance, and the understory species diversity. Canopy species include basswood, red oak (*Quercus rubra*), white oak (*Q. alba*), burr oak (*Q. macrocarpa*), American elm (*Ulmus americana*), and green ash (*Fraxinus pennsylvanica*). Most of the individual trees that dominate the canopy, in particular oaks and basswood, reach diameters of 30 to 36 inches. A rich assemblage of herbaceous species are present including Virginia waterleaf, bloodroot, wild ginger, nodding trillium, dutchman's breeches, wood anemone, jack in the pulpit (*Arisaema triphyllum*), marsh fern (*Thelypteris palustris*), wood nettle (*Laportea canadensis*), and red baneberry (*Actaea rubra*).

The lowland hardwood forest community extends over 6.1 acres, of which 2.7 acres are found in Corridor C2, and 2.9 acres are found in Corridor W2 (Table 3.3). The Highway 212 corridor will eliminate approximately 2 acres of this forest, regardless of development of Corridors C2 or W2. The lowland forest is contiguous with a larger tract of upland oak forest (17.7 acres) that is outside of the C2, W2 or Highway 212 corridors. These two forest communities are surrounded by roads and agricultural land, isolating them from other native plant communities.

Table 3.5 shows the cumulative amounts of highest quality native vegetation (Ranks “B”, and “BC” combined). The relative cover of “B-BC” ranked communities is similar in Corridors C2, C2A, E2 and W2. These all range between 14.2% and 15.5% area in “B-BC” ranked native plant communities. The largest area of “B-BC” ranked communities is in Corridor C2A (44.9 acres; 14.7 percent of corridor) and the smallest is in E1 (2.8 acres; 1.1 percent of corridor). Corridor W2 has the highest percentage area (15.5 percent) of “B-BC” ranked communities, although the acreage (33.3 acres) is lower than in Corridors C2, C2A and E2. The distribution of the lowest ranked communities (“D” ranking) ranges from zero in Corridor C2 to 15.8 acres in Corridor E1 (15.8 acres).

Areas rated “outstanding” for biodiversity by the MCBS are found in Corridors E1, E1A, and E2, due to presence of the SFWC and contiguous lowland and upland forests (Table 3.6). Areas rated as “moderate” or “below the minimum threshold” are fairly evenly distributed among the six alternatives.

3.2.2 Habitat Fragmentation

The previous section discussed the potential direct loss of native plant communities among the alternative corridors. Additional ecological impacts can indirectly result from loss of habitat through the process of fragmentation. Fragmentation describes the process of breaking apart patches of natural communities or wildlife habitat. This process results in smaller patches, greater isolation among patches, altered biotic and abiotic conditions along new patch edges and possible barriers to movement for organisms. Fragmentation was assessed in this study by a qualitative overview of the corridors within the landscape and by quantitative measurement of new edges created in natural communities.

Figure 3.6 shows the distribution of native vegetation in and around each corridor. The native vegetation within each corridor was documented above. In general, native vegetation in the region is already highly fragmented from decades of agriculture and development. Individual patches are often small or isolated. The largest areas remaining are found on the Minnesota River floodplain, where development is limited by flooding, and sizable areas are preserved under public ownership. The largest contiguous expanse of native vegetation above the limits of flooding is found within the SFWC.

It is evident from Figure 3.6 that the three western corridors, C2, C2A, and W2, pass through large sections of contiguous natural communities, particularly on the floodplain. These areas are primarily mixtures of floodplain forest, wetlands, and lowland forests. The corridors also intercept smaller

areas of upland vegetation, particularly upland forests such as oak and maple-basswood forests. Corridors W2 and C2A bisect the largest areas of native vegetation which would be fragmented by corridor construction. Corridor C2A has the greatest impact to both interior and edge forest (Table 3.7). The proportion of impacted forest that is interior, compared to edge, is greatest in Corridor W2, although the acreage of both is less than in C2A. Corridor C2 impacts a greater total area of forest compared to W2, but the proportion and acreage of interior forest is less than that of W2. The amount of impacts to shrub and herbaceous communities is similar for Corridors C2, C2A and W2, although C2A affects the greatest proportion of interior area. (Table 3.7)

In contrast to the western alignments, the eastern alignments pass through relatively smaller patches of native vegetation. A greater amount of the floodplain in these corridors has been converted to agricultural fields. Corridors E1 and E1A intercept less floodplain vegetation than Corridor E2. Above the floodplain, Corridor E1 intercepts relatively little native vegetation and the smallest proportion of interior area. Impacts occur in some upland oak forest patches that are already isolated and infiltrated by suburban development. Corridors E1A and E2 impact similar areas of interior forest to each other and to C2, but the proportion of interior forest is greater than C2 (Table 3.7). In shrub and herbaceous communities, E2 impacts more interior areas and a greater proportion of interior areas than E1 and E1A. A considerable portion of impacts from E1A and E2 are found in the SFWC.

Indirect impacts, through degradation of natural areas resulting from fragmentation, can be estimated as the amount of native plant communities that are currently interior regions that will be converted to edge regions. The greatest indirect impact will be from C2A, and most of that impact will be in forests, particularly floodplain forests. Corridor W2 will create more new edge environments than C2, in forest and shrub/herbaceous communities. The alignment of C2 along the existing Highway 41 corridor reduces its fragmentation impact compared to C2A and W2. Total fragmentation impacts from Corridors E1A and E2 are comparable to or lower than C2. The greatest impact occurs where Corridors E1A and E2 pass through the SFWC and adjacent upland forests. Corridor E1 has the least fragmentation impact through creation of edge areas of all the six alternative corridors (Table 3.7).

3.2.3 Protected Species

This study was not designed to look exhaustively for threatened, endangered or special concern species. However, information is available from the MnDNR Natural Heritage Program database and the Phase 1 and Phase 2 studies. Documented protected species in SFWC include the following:

Species	Common Name	State Status
Carex sterilis	Sterile sedge	Threatened
Cladium mariscoides	Twig-rush	Special Concern
Cypripedium candidum	Small white lady's-slipper	Special Concern
Eleocharis rostellata	Beaked spikerush	Threatened
Rhychospora capillacea	Hairlike beakrush	Threatened
Scleria verticillata	Whorled nutrush	Threatened
Triglochin palustris	Marsh arrowgrass	Formerly Special Concern
Valeriana edulis var. *cilata*	Edible valerian	Threatened

Many of the protected species tend to be found in fen soils with extensive deposits of calcium carbonate in the form of marl or tufa. Such soils are largely absent from the alternative corridors except in microsites; in contrast, soils within the alternative corridors in the SFWC are deep peat without marl or tufa. In the SFWC, marl and tufa soils are largely restricted to the northeast portion of Area 1. Correspondingly, most current locations protected species are not within the limits of Corridors E1A or E2. Two exceptions are sterile sedge as well as small white lady's-slipper.

Within Corridors E1A and E2, sterile sedge is abundant. This species has a high fidelity to calcareous fens, and it is found in numerous locations within the Phase 2 study area. In many of these locations, it is extremely abundant and often a dominant species. Development of Corridors E1A or E2 would represent the loss of a vigorous population of sterile sedge and current and potential habitat.

Small white lady's slipper (*Cypripedium candidum*), another protected species, has been observed in Area 2 during Phase 1 studies. It is not among the species that are primarily found on marl soils. Its distribution includes wet and mesic prairies and sedge meadows, as well as calcareous fens. The species was not observed in the corridors or at any of the Phase 2 sample sites; however, most of the SWFC is appropriate habitat. The distribution of the small white lady's slipper within the SFWC may be restricted because of the shade created by the thick shrub growth. Alternatively, the species may be more abundant than noted but was simply not observed because of the shrub cover or insufficient search efforts. Any efforts at restoration or management of the SFWC that reduces shrub growth,

decreases litter, or stimulates forb germination, such as prescribed burning, would be expected to expand the distribution and population size of the small white lady's slipper. Management may also restore appropriate conditions for some of the currently absent protected species on high marl microsites.

Bald eagles (*Haliaeetus leucocephalus*), a federally-threatened and state-special-concern species, are known to be present along the Minnesota River. Mature trees along the river should be considered potential roosting or nesting sites. No nest locations have been documented within any of the alternative corridors. All six corridors cross the Minnesota River and will impact riparian forests. Therefore, each alternative corridor will reduce potential roosting and nesting locations.

The MnDNR Natural Heritage Program database also noted the presence of a bat colony in a floodplain forest near the area where Corridor C2A crosses the Minnesota River, close to Gifford Lake. The exact location of the colony is not known, and no observed bats are considered to be protected species. Many little brown bats (*Myotis lucifugus*) were observed in the area, suggesting the presence of a maternal colony. Additional bats observed in the area included big brown bat (*Eptesicus fuscus*), red bat (*Lasiurus borealis*), and hoary bat (*Lasiurus cinerns*). While all the alternative corridors intercept floodplain forests, which may provide bat habitat, the proximity of Corridor C2A to a known nesting location suggests a possibility of disrupting this colony.

The southern end of Corridor W2 is found near documented locations of three state-protected species: regal fritillary butterfly (*Speyeria idalia*; special concern), and the plants kitten tails (*Besseya bullii*; threatened) and Hill's thistle (*Cirsium hillii*; special concern). The prairie habitat for these species has been eliminated, at least within the boundaries of the corridor, and therefore the populations are believed to have been extirpated.

The Minnesota River supports populations of many species of mussel, some of which are protected species. All alternative corridors are expected to have similar impacts, or lack of impacts, on mussel species. Specific impacts are not predicted here and should be evaluated during the environmental review process once a preferred alignment has been chosen and is under design.

3.2.4 Conclusions

Table 3.8 summarizes the potential impacts to native vegetation, protected species and vegetative communities. From the standpoint of loss of native vegetation in the proposed alignments, Corridor E1 would represent the least impact. Corridor C2A would represent the greatest impact. The

remaining four corridors would have moderate levels of impact. These results are similar for the highest quality native communities, with the least impact in Corridor E1, the greatest impact in Corridor C2A, and moderate impacts in the remaining corridors. The greatest impacts associated with Corridor C2A result from the length of the corridor and its location in the less-developed western half of the Phase 2 study area.

The western corridors (C2, C2A, and W2) intercept and fragment larger tracts of native vegetation than the eastern corridors (E1, E1A, and E2). Among the western corridors, the fragmentation impacts of Corridor C2 are largely restricted to edges of existing native vegetation patches, rather than occurring in the interior of patches as found in Corridors C2A and W2. Among the eastern corridors, E1A and E2 fragment native wetland, fen and forest communities that are largely avoided by Corridor E1. Corridors E1A and E2 will both intersect calcareous fen communities, which are considered to be critically imperiled in Minnesota. The SFWC is considered an area of outstanding biodiversity value, because of the fen, associated wetland and upland communities, and several state-protected plant species.

Regarding the creation of new habitat edges, Corridor E1 would represent the least impact. Corridor C2A would represent the greatest impact. The remaining four corridors would have moderate levels of impact. Among those four corridors, W2 would bisect and fragment the largest area of floodplain forest, which is reflected in the estimates of impacts to interior forest and creation of new edge areas.

As noted, this study was not designed to provide an exhaustive survey for protected species. However, using available information, it is clear that Corridors E1A and E2 would impact known populations and potential habitat of protected species. The remaining corridors may impact currently unknown populations of protected species. Given what is known about the corridors and the type and distribution of native plant communities, it is extremely unlikely that any corridor would have the magnitude of impact to protected species as Corridors E1A and E2. Furthermore, if restoration and management of the SFWC is undertaken before construction of TH 41, there may be more protected fen plant species present in Corridors E1A and E2.

3.3 Bridge Visits

The bridges visited in June-August, 2006 included Highway 169, Interstate 35W, Highway 77, Interstate 494, Highway 5 (Mendota Bridge), and Interstate 35E (Figure 2.2). Several conclusions can be drawn from anecdotal observations of large highway bridges across the Minnesota River Valley. These are not quantitative conclusions made from empirical comparative, longitudinal, or

experimental studies, but they are based on the observations and opinions of two professional plant ecologists with expertise in assessing anthropogenic impacts on natural communities.

None of the bridges visited are in environmental settings identical to the SFWC. The bridges cross marshes, shallow lakes, floodplain forests, and communities dominated by invasive or exotic species. In many cases, the surrounding land use hinders the ability to infer ecological impacts from the bridge itself. The level of prior and ongoing disturbance also varies across the bridges visited. For example, the Highway 77 and Mendota bridges have parking lots and boat ramps beneath them, which encourage heavy use of those areas. The areas underneath the Interstate 494 and Interstate 35E bridges are more remote, with less ongoing use or disturbance. The Interstate 35W bridge appears to have had recent construction or maintenance work conducted under its southern end.

No existing bridge locations were found that are similar to the proposed construction of elevated bridges across a sloping peatland with areas of groundwater discharge, lateral groundwater flow, and calcareous fen vegetation. The existing bridges that cross river valleys on Interstate 494, Highway 77, and Interstate 35W are near calcareous fens (Fort Snelling Fen, Nichols Meadow Fen, and Black Dog Fen, respectively); however, numerous differences exist. Interstate 494, Highway 77, and Interstate 35W are built on filled embankments rather than on elevated bridges. The remaining fens in these areas are either slightly removed from the highway corridors or are ecologically degraded. The degradation is extensive and may be due to many factors other than the highways. Where the existing bridges cross wetlands that have organic soils, the wetlands are in depressional positions that are covered by surface water.

Despite the differences between the existing bridges and proposed TH 41 corridors, the following observations were noted:

- Higher bridges have more vegetation, more native vegetation and less bare area beneath them. Lower bridges have more bare soil and more invasive species, especially reed canary grass, beneath them.

- Wider bridge decks have lower vegetation cover, lower-quality vegetation and more bare soil. These effects may be attenuated by spacing of bridge decks. For example, the total width of the two bridge decks of the TH 77 bridge is 120 feet, which is similar to the approximately 110 feet deck widths of I-35W and I-35E. However, the decks of TH 77 are set 45 feet apart, allowing for greater penetration of sunlight beneath the decks, and higher vegetation coverage and quality beneath.

- Forest communities are absent underneath bridges, with the exception of an early successional community of box elder trees under the Mendota Bridge, which is a relatively high bridge. There is no direct evidence of floodplain forests recovering or reestablishing under bridges.

- Herbaceous wetlands beneath the higher bridges, and in more open sites (i.e., not forested), tend to have more native vegetation, in terms of abundance and species richness, than beneath lower bridges and in less open sites.

- Permanently or semi-permanently flooded wetlands beneath the bridges tend to have more native vegetation, in terms of abundance and species richness, than seasonally or temporarily flooded wetlands.

- White crystalline deposits were observed beneath lower bridges and in upland and seasonally-flooded wetlands. These deposits may be accumulated road salts, but no laboratory analyses were conducted to confirm.

- Floodplain forests can grow very close to the edges of the bridges. Where mature forest vegetation is close to the bridges, the forest edge is not thickly populated by shrubs, saplings, or invasive species.

The height of the bridges and surrounding vegetation are important because of shading impacts. Taller bridges in more open settings allow greater amounts of light to penetrate beneath the bridge. Greater spacing between parallel bridges also allows for greater light penetration. Therefore, the height of a bridge affects both the amount and duration of light penetration beneath a bridge. This in turn appears to influence the species richness and distribution of plant communities under and immediately adjacent to the bridge. Lower bridges, with a wider area of prolonged or constant shade directly beneath the bridge, were observed to develop a noticeable zonation of plant communities that appeared to correlate with the amount of available sunlight. The area directly beneath a lower bridge tends to have more bare ground and is dominated by one or two invasive non-native species. Moving away from the bridge, the species richness and native cover tend to increase, and bare ground coverage decreases. The increased light penetration and the elimination of a constantly shaded zone under higher bridges appear to improve species richness beneath these bridges.

Vegetation under a bridge may also experience drought stress because precipitation is intercepted by the bridge and directed to stormwater detention basins. As with solar radiation, higher bridges in

open areas should allow for the greatest lateral entrance of precipitation. Precipitation barriers created by the bridge may pose challenges to wetland revegetation where water tables are seasonally variable. Limited precipitation may also prevent dilution and flushing of salts.

The accumulation of road salts underneath bridges may also influence the species composition of vegetation communities underneath bridges. It is assumed that road salts accumulate beneath bridges by the settling of salt-laden mists generated by traffic, conveyance by drainage structures, or a combination of the two. In any case, visits to the bridges indicate the elevated salt levels underneath the bridges favor salt-tolerant species, including the exotic species burning bush (*Kochia scoparia*) and native prairie cordgrass (*Spartina pectinata*). The distribution and cover of burning bush in particular suggest that most of the salt contribution comes from the drainage outfalls underneath the bridges. For example, at the Highway 77 Bridge, much of the area directly beneath the bridge is dominated by burning bush, which is adjacent to patches of bare ground. These bare areas are nearest the outfall structures for the bridge, and would be most frequently inundated by stormwater runoff. Burning bush cover is reduced when moving out from under the bridge, away from areas where runoff accumulates. If the salt deposition were primarily from road mists, then burning bush would be expected to be more broadly distributed adjacent to the bridge.

A primary factor in the impacts to forest edges is altered microclimate. An intact forest microclimate differs from an open area or forest edge microclimate due to less extreme and variable air temperatures, soil temperatures, relative humidity, soil moisture, and wind speeds. Solar radiation is also reduced at the ground level in an intact forest. One sign of an altered forest microclimate effect on vegetation is the observation of thickets of shrubs and saplings along a forest edge. The thicket species include invasive shrubs such as buckthorn which can colonize along edges and proliferate in the edge microclimate. Forests near the existing elevated bridges did not appear to have elevated populations of shrubs and saplings near the edges adjacent to the bridges. Buckthorn was rarely present. It appears that the shade of the bridges ameliorates the microclimate impacts of forest fragmentation to some extent. It is expected that quantitative observations of vegetation and wildlife may reveal altered edge environments along bridges, but this qualitative assessment suggests that edge effects near elevated bridges are not as great as when forest edges border open environments such as pavement, lawn, or natural herbaceous communities. If the highways were constructed at grade, rather than on elevated structures that create shade, then greater edge impacts would be expected.

For purposes of revegetation with native herbaceous species following bridge construction, it appears that a low bridge through a thick forest will have the greatest shading impacts, and would be expected to result in the greatest challenges to revegetation. A higher bridge, through an open area, such as an herbaceous community, will have less shading impacts, and would be expected to have fewer challenges to revegetation, although restoration of the pre-existing native plant communities may not be possible. Road salt deposition may also hinder revegetation. An interaction of factors may create the most challenging circumstances for establishing vegetation underneath bridges including low bridges creating dense shade, forested vegetation close to the edges preventing lateral entrance of sunlight, and salt deposition that is not diluted by bodies of permanent or flowing water.

3.4 Literature Review and Impact Assessment

3.4.1 Literature Review

An extensive list of scientific and government publications were reviewed for both Phase 1 and 2 Seminary Fen Projects, some of which were summarized in the Phase 1 report (PEC 2006) and in the vegetation section above. The following description of impacts focuses on ecological issues and impacts most relevant to the TH 41 crossing of the Minnesota River Valley and the SFWC. Road.

3.4.1.1 Road Salt

Roadway salt contributes ions to the soils adjacent to roadways. These ions include sodium, chloride, calcium, potassium and magnesium, depending upon the deicing agent used (Trombulak and Frissell 2000). The most prevalent ions contributed to soils adjacent to roadways are sodium and chloride, and most studies and reviews of the literature on deicing salts focus on these two elements. Individually, both sodium and chloride ions can have negative biotic impacts. Replacing sodium chloride with calcium chloride or potassium chloride as deicers will eliminate impacts from sodium but not chloride. Most literature on the environmental effects of deicing agents focuses on sodium and chloride and does not address agents such as potassium acetate. Salts can alter osmotic pressure in plant tissue as well as replaceable ions and ionic ratios in soil. These changes may cause tissue or plant mortality as well as alter soil structure and permeability. Ions in deicing salts also increase the mobility of heavy metals in soil, leading to increased heavy metal contamination in groundwater and streams. Deleterious effects of road salt on vegetation are not limited to visible leaf injury. Mortality or stress on individual organisms can result in changes in the distribution of species and composition of ecological communities (Environment Canada 2001, Forman and Alexander 1998, Hanes et al.

1970, Kaushal et al. 2005, Miklovic and Galatowisch 2005, Oster and Shainberg 2001, Panno et al. 1999, Richburg et al. 2001, Ruiz-Vera and Wu 2006, Wilcox 1986).

Chloride ions that enter the soil and groundwater move with water and can ultimately be expected to reach surface water (Environment Canada 2001). Moreover, chloride concentrations may not return to baseline levels in the summer months when deicing activities are suspended. Rather, the buildup of chloride ions in the soil over time leads to salinization of the groundwater. Labadia and Buttle (1996) traced sodium chloride contaminated snowmelt as it penetrated unsaturated soils adjacent to a roadway, and found movement of particles in the meltwater at approximately 0.02 meters (0.8 in.) per day. Soil samples taken in late summer at depths > 2 meters (> 6.5 ft.) found sodium and chloride concentrations at 500 mg/l and 1000 mg/L, respectively. Salinization of the groundwater in turn leads to salinization of streams and other groundwater-fed surface waters during summer months (Kaushal et al 2005).

Although most salt spray is expected to fall in the immediate vicinity of the highway, salt-capture and dispersion modeling studies suggest that aerosol transport of road salts may extend beyond the zone of observable injury to vegetation (e.g., Williams et al. 2000, Williams and Stensland 2006, A. Williams, Illinois State Water Survey, pers. comm.). Additional examination of literature regarding road salt is on-going and will be reported in the final Phase 2 fen study prior to determination of a preferred TH41 alternative.

Studies of ecological affects of deicing salts include examinations of their impact on amphibians (Sanzo and Hecnar 2006), macroinvertebrates (Benbow and Merritt 2004), groundwater contamination (Labadia and Buttle 1996, Panno et al 1999, Richburg et al 2001) vegetation community structure, including salt damage and invasion by salt tolerant species (Forman & Alexander 1998, Schaufler et al 1996, Miklovic and Galatowitsch 2005, Richburg et al 2001).

Sodium and chloride impacts on amphibians include decreased activity and weight and increased abnormalities in tadpoles exposed to short-term elevated sodium chloride levels. Exposure of wood frog tadpoles to sodium chloride concentrations that increased from 0 to 1030 mg/L over a 90-day period resulted in decreases in survivorship, weight, activity and time to metamorphosis (Sanzo & Hecnar 2006). This study found that “road salts had toxic effects on larvae at environmentally realistic concentrations.” Benbow and Merritt (2004) studied the effect of deicing salts on macroinvertebrates in a Michigan wetland. Chloride concentrations in the wetland ranged from 18 mg/L to 2700 mg/L, with 75% of the samples at or below 334 mg/L. They found that lethal

concentrations (LC50) for chloride for the four species studied ranged from 2558 mg/L to over 10,000 mg/L.

Damage from airborne sodium chloride includes leaf injury to trees up to 400 feet from the road, especially downwind and downslope, with most severe injury nearest the road. Tree species tend to be more sensitive to salt than shrub, herb and grass species (Environment Canada 2001, Bryson and Barker 2002, Forman and Alexander 1998). Schauffler et al. (1996) found that the capture of atmospheric influxes of chloride were up to four times higher in wooded areas than in treeless sites the same distance from the road. The greater canopy surface area of a stand of trees increases capture of airborne sodium and chloride.

Another effect of sodium and chloride on vegetation communities is the alteration of species composition through the invasion and/or increased cover of salt-tolerant species. A wide range of salt concentrations has been observed to be detrimental to vegetation. Kaushal et al. (2005) note that chloride concentrations as low as 30 mg/L may negatively impact vegetation. However, in a study of deicing salt contamination of a fen-wetland complex in northeastern Illinois (Panno et al 1999), the median concentration of sodium was 6.27 mg/L in uncontaminated areas, and 16.6 mg/L in areas contaminated with deicing salts, with a peak value of 153 mg/L. Studies of common reed intrusion into a Massachusetts fen and swamp found weak correlation between elevated salt levels and occurrences of common reed. However, the increased coverage of common reed resulted in decreased species richness in areas where it had invaded. In addition, the high sodium (> 112 mg/L) and chloride (> 54 mg/L) levels in the fen correlated with decreases in species richness, evenness and overall cover (Richburg et al 2001). Individual wetland species were observed to be sensitive to salt concentrations of 112 mg/L sodium and 168 mg/L chloride, and endemic wetland species were completely absent at concentrations above 486 mg/L sodium and 1,215 mg/L chloride. (Wilcox 1986). In an greenhouse study, species diversity and richness decreased at elevated concentrations of sodium chloride (500-1,000 mg/L) through direct effects of sodium chloride and indirect effects of increased competition from cattails (Miklovic and Galatowisch 2005).

3.4.1.2 Ecological Impacts

Ecological impacts from road and bridge construction can be numerous and varied. Biotic impacts can include loss of native vegetation and wildlife habitat, spread of invasive or predatory species, barriers to migration and dispersal, mortality, or modification of animal behavior. Abiotic impacts may include altered ground and surface water hydrology, shading, sedimentation, erosion, and the spread of chemicals and salts (Forman and Alexandar 1998; Trombulak and Frissell 2000; Venner

Consulting and Parsons Brinckerhoff 2004). Indirect impacts may occur as a result of fragmentation of natural areas and habitat fragmentation and increased development pressure on the surrounding landscape (Fahrig 2003; Hansen et al. 2005). The resulting changes in landscape ecology can include reduced patch size of natural areas, modified patch shape, increased edge effects, isolation of patches, and altered landscape matrix, all of which may have negative impacts on biota. Conversely, these changes can benefit populations of some species, but often those species are plants and animals considered to be weedy, undesirable, or nuisance species.

The unique physical environment – water chemistry, soils, and hydrology – of a calcareous fen is essential for the existence of the characteristic plant communities (Amon et al. 2002; Bedford and Godwin 2003; Bridham et al. 1996; Bowles et al 2005; Picking and Veneman 2004; Reed 2002) and alteration of any these features can lead to permanent loss of fen vegetation (Amon et al. 2002; Bedford and Godwin 2003; Fisher et al 1996; Panno et al. 1999; Schot and Van der Wal, 1992).

Wetlands can be particularly sensitive to disturbance, which leads to ecological degradation. Among wetlands, calcareous fens can be especially sensitive. Changes in surrounding land use have been observed to correspond to degradation of wetlands (Galatowitsch et al. 2000; Houlahan et al. 2006; Owen 1999). Alterations in hydrology and sedimentation can cause changes in wetland flora and fauna (Kercher et al. 2004; Richburg et al., 2001; Werner and Zedler 2002). Introduction of salt from road deicing operations modifies the chemical environment of a wetland (Miklovic and Galatowitsch 2005; Richburg et al., 2001; Schauffler et al. 1996). Multiple disturbances, such as salt deposition, hydrological alteration, and introduction of invasive species, can exacerbate the impact of any single factor and create conditions that lead to loss of native species (Zedler and Kercher 2004; Richburg et al., 2001; Panno et al. 1999)

3.4.2 Anticipated General Impacts from TH 41 Alternatives

Construction of a bridge across the Minnesota River Valley is expected to eliminate native vegetation and natural areas within the footprint of the corridor. Indirect impacts are likely outside the corridor, as a result of altered hydrology, microclimate, introduction of invasive species, isolation of habitat patches, and dispersal barriers. Section 3.2 describes the types and quality of native vegetation in each alternative corridor. It should be noted that this description is based on current conditions and that TH41 construction will not occur for decades. Inevitable land use changes will alter the amount and quality of native vegetation in each alternative. Furthermore, the descriptions of vegetation are based on the entire 300 feet corridor. The areas impacted for construction will be a subset of that width. Therefore, impacts will be less than reported in this study, and opportunities exist for planning

final alignments within the chosen corridor to reduce or avoid some impacts to environmentally sensitive areas. Tables 3.2-3.11 summarize and compare the amounts and types of native vegetation and potential impacts in the alternative corridors.

3.4.3 Anticipated Impacts Unique to the Seminary Fen Wetland Complex

Impacts of highway construction in the vicinity of the SFWC can result from many factors. The successional model (Figure 3.5) provides a framework for conceptualizing and evaluating potential impacts to the SFWC. By understanding historic impacts and resulting changes, future impacts can be better predicted. Among the most important factors are alterations to wetland hydrology and direct loss of native vegetation. The impacts of altered hydrology can be qualitatively predicted from scientific literature and observations of the SFWC itself. Ecological impacts can be reasonably inferred, but the magnitude and rate of impacts are difficult to predict. Many factors are known that are associated with highway construction and development that negatively impact native wetland vegetation in general, and calcareous fens in particular. Empirical studies demonstrate the significance of these factors, but do not provide a means to easily quantify predictions. Interactions among factors may create novel and untested conditions, which will likely hasten the rate and severity of detrimental impacts.

As with native vegetation described for the alternative corridors, the description of the SFWC provided in Phase 1 and 2 is a statement of current conditions. Substantial ecological degradation has occurred in the SFWC as a result of hydrological alteration, soil disturbance, fire suppression, and invasive species colonization. These factors have altered the flora of the SFWC (Figure 3.5) such that the amount of fen vegetation and high quality fen has decreased and is continuing to decrease (Tables 3.9 and 3.10). Without active and sustained ecological restoration and management, by the time TH41 is constructed, it is possible that there will be few areas that satisfy the fen vegetation criteria within the corridor footprints or within the entire Phase 2 Study Area. Fen vegetation will be lost to increased shrub, forest, and invasive species cover (Figure 3.5). With appropriate land management, however, Corridors E1A and E2 could intercept a greater acreage of fen vegetation than the current assessment.

3.4.3.1 Wetland Hydrology Impacts

Groundwater modeling predicted that dewatering associated with bridge pier construction would result in lowered water tables in or near portions of the SFWC. The MnDOT has indicated that construction in these conditions requires cofferdams and bottom seals as standard practice to

minimize the area of wetlands that experience drawdown. However, even temporary dewatering could have profound impacts on the fen over a large area.

The groundwater models took into account the use of sheet pile coffer dams and grout seals to minimize the work and dewatering areas. Calcareous fen communities have been documented in Areas 1, 2, and 3 of the Phase 1 study area (Figure 1.2). Drawdown in Areas 1 and 3 would be less than 0.1 ft during construction for all alternative corridors (with the exception of a small, degraded area at the western tip of Area 1; Figure 3.9). Therefore, it is not expected that this drawdown would have a negative impact on plant communities in Areas 1 and 3, especially if drawdown occurs during the dormant season. Area 2, on the other hand, may be impacted by groundwater drawdown.

Groundwater modeling of Corridors C2, C2A, and W2 indicated no effect on the hydrology of the SFWC because of the distance between the corridors and the SFWC. The eastern corridors, however, would result in localized lowering of water tables. Corridor E1, located west of the SFWC, would create a minor water table drawdown of 0.1 to 0.6 feet in the SFWC wetlands (Figure 3.7). The extent of current fen vegetation that would be affected by a drawdown less than 0.6 feet is 0.45 acres. The area of historic but degraded fen in the < 0.6 feet drawdown area is 9.72, and area in the ≥ 0.6 feet drawdown is 5.86 acres (Tables 3.11 and 3.12). Corridor E1A is located at the base of the bluff in the north portion of the SFWC. The alignment crosses portions of the wetlands that meet all criteria for calcareous fen or are considered historic and restorable fen. The base of the bluff is also an area of many sites of groundwater discharge that are critical to the hydrology of the Area 2 wetlands, Assumption Creek, and Area 3 wetlands including calcareous fen. The drawdown in SWFC wetlands from the construction of Corridor E1A would be between 0.1 and 4 feet (Figure 3.8). Corridor E2 crosses portions of the wetlands that meet all criteria for calcareous fen or are considered historic and restorable fen. The drawdown in SWFC wetlands from construction of Corridor E2 would be between 0.1 and 4 feet (Figure 3.9). The extent of current fen in the <0.6 feet drawdown zone is 4.25 acres from E1A and 9.39 acres from E2. The extent of current fen in the >0.6 feet drawdown zone is 7.13 acres from E1A and 19.98 acres from E2. The extent of historic fen in the <0.6 feet drawdown zone is 19.26 acres from E1A and 21.05 acres from E2. The extent of historic fen in the >0.6 feet drawdown zone is 21.05 acres from E1A and 20.11 acres from E2 (Tables 3.11 and 3.12).

3.4.3.2 Soil Impacts

Soil compaction from construction traffic would probably be worse in dewatered conditions than in saturated conditions because the normal buoyancy of saturated organic soil would be lost. Generally,

saturated organic soils resist compaction. Organic soils are displaced – rather than compacted – when pressure is applied. The use of swamp mats under equipment spreads the weight and prevents displacement and creation of ruts. However, even the use of mats on dewatered organic soil could cause irreversible compaction. This compaction would lower the soil surface and alter the flow of groundwater through the peat. After the completion of dewatering, restoration of water tables would probably yield water levels that are substantially higher than the soil surface, due to compaction, depression and subsidence. Modeling suggests that groundwater flows will be altered from soil compaction after construction on a peat-substrate wetland.

The net result of hydrological alterations means that some areas of the wetland complex may experience more groundwater discharge, and some areas may experience less. Soil compaction or subsidence may occur in some areas; groundwater flow paths may be altered. These impacts may result in new areas of ponding or inundation, areas of seasonally variable water tables, areas with soils not saturated to the surface for long portions of the growing season, and areas in which precipitation and surface water assume greater importance. Furthermore, disruption of organic soil and salt deposition can lead to altered soil structure, permeability, and erodibility. Any of these changes can alter plant community composition and succession (Figure 3.5) away from calcareous fen plant communities.

3.4.3.3 Invasive Species

In the SFWC, areas that become drier or exhibit a more seasonally-variable water table would be expected to become dominated by reed canarygrass or common buckthorn. Areas that become wetter, or even inundated or ponded, would be expected to become dominated by cattails and common reed.

Development of Corridors E1A and E2 will increase the amount of altered edge within the Area 2 wetland complex. Even if loss of fen and wetland vegetation is initially limited to within the corridor footprint, the altered habitat in the corridor will likely provide opportunities for encroachment of invasive species. Roads and edges provide opportunities for invasive encroachment (Christen and Matlack 2006; Forman and Alexandar 1998; Rentch et al. 2005; Trombulak and Frissell 2000). This process can be seen in the SFWC itself, where reed canarygrass is encroaching along a ditch within a transmission line corridor through the Phase 2 study area. Construction of either Corridor E1A or E2 will exacerbate the encroachment of reed canarygrass into the wetlands. It is also common underneath many of the large highway bridges in the Minnesota River Valley and along highways that cross wetlands. The presence of reed canarygrass throughout the length of the corridor in the

SFWC would provide an abundant seed source as well as propagules for clonal expansion out of the corridor and into remnant wetlands, including fen communities.

3.4.3.4 Road Salt Impacts

Salt spray may create an additional stress. Salt deposition is known to favor invasive species to the detriment of native vegetation in various types of wetlands, including calcareous fens. The amount of salt runoff from the proposed highway corridors and salt deposition patterns were not modeled or estimated. However, runoff concentrations can be several orders of magnitude greater than background concentrations or those necessary to alter vegetation.

Salt addition to the SFWC could have a negative impact, although the extent and severity of impact has not been quantitatively estimated. The amount of salt necessary to cause a detrimental impact on fen vegetation may be relatively low (e.g., as low as 16.6 mg/L in contaminated fen areas studied by Panno et al. 1999, although higher values are more commonly cited; see above, Section 3.4.1.1). The highest quality fen and most protected species of the SFWC found in Area 1 are not immediately adjacent to any of the alternatives. Alternative E2 comes within 3,000 ft of the highest quality Type II fen in Area 1. Protected species are scattered throughout the SFWC (particularly *Carex sterilis*), but sizable populations of other species are found within 2,300 ft of E2. Alternative E1A comes within 3,300 ft of Area 1 Type II fen, and 2,700 ft of aggregated populations of protected species. Alternative E1 is within 5,500-6,500 ft of these sensitive areas. Most salt spray is expected to fall in the immediate vicinity of the highway, although the possibility of longer distance dispersal cannot be excluded.

An additional hazard of salt spray in the wetland complex is the possibility of the salt migrating away from the initial deposition site through ground and surface water. Surface water is present in the Phase 2 study area as result of groundwater discharge. The surface water in the SFWC coalesces to create the origin of Assumption Creek, which passes through a region of apparent strong groundwater recharge. The SFWC water may reappear as groundwater discharge south of the current Highway 212 alignment, where extensive wetlands are located, including calcareous fen in Area 3. Highway salts could flow into groundwater near the highway and be discharged in fen and wetland areas down gradient, including the western portions of Area 1, as well as Areas 3-5. These groundwater patterns suggest that road salt could migrate away from the highway corridor in ground and surface water and be discharged in additional wetlands. Furthermore, infiltration of road salts into groundwater in the fen recharges areas north of the SFWC could conceivably reach Area 1 (see Figures 4-8 and 4-9 of the Phase 2 Hydrology Report). The net result could be detrimental for native wetland vegetation

including fen species, even if they are not adjacent to the proposed highway corridors. As with hydrological alterations, wetland succession would likely be towards communities with lower richness and diversity of native species and increased abundance of exotic and invasive species (Figure 3.5).

The concentration of sodium and chloride ions in the northeast portion of Area 1 are the highest values recorded from the SFWC (PEC 2006). Observed values of sodium of 0.38 – 0.8 meq/L translate to 8.74 – 18.4 mg/L, and observed values of chloride of 0.005 – 1.83 meq/L translate to 1.78 – 64.87 mg/L. Some of these values are above the minimum impact thresholds documented in other studies (see above) and above observations at Savage Fen (Komor 1994). It is unknown if a portion of these salts come from road salt infiltration in the fen aquifer recharge area. Although the northeast portion of Area 1 is referred to as the highest quality fen area, it is not pristine, and sizable areas of invasive species such as buckthorn and cattail are present. Regardless of the source of ions in the groundwater, the existing concentration of dissolved salts in Area 1 may already be affecting plant communities, and additional salts from new sources may negatively impact the soil and vegetation of the calcareous fen. Numerous uncertainties make it difficult to confidently assess the level of risk to Area 1 from road salt that may be associated with TH41.

3.4.3.5 Construction Impacts

Construction through the uplands adjacent to the SWFC has the potential for erosion, which leads to the deposition of sediment in wetlands. Such sedimentation would bury vegetation and increase nutrient availability. Surface water runoff would alter the chemical environment of the fen. Both would shift wetland succession towards invasive or ruderal species.

3.4.3.6 Native Fen Vegetation Impacts

Lowered water tables from the construction of Corridor E1 would affect very little native vegetation. A portion of a wet meadow wetland is located in an area of predicted drawdown between 0.1 and 0.6 feet. A larger area of lowland hardwood forest and reed canarygrass wetland will experience greater drawdown. The forest is not a original community since the entire SFWC area was once nearly devoid of woody vegetation. Trees have become established through secondary succession only after partial site drainage from ditches and tiles or from sedimentation. Relatively small areas of native plant communities will be found in the zone where drawdown will be between 0.1 and 0.6 feet. These communities are wet meadow and sedge meadow communities. A few calcareous fen indicator species are found in the northern most area (around Transect 61).

Corridors E1A and E2 both directly impact vegetation identified by this study as calcareous fen, albeit ecologically degraded calcareous fen (Tables 3.3, 3.8 – 3.10). Much of the calcareous fen area is also habitat for state protected plants, particularly sterile sedge. This fen area could be lost within and around the highway alignments due to temporary dewatering, construction traffic, soil compaction, and shading by the bridges. Corridor E1A intersects calcareous fen at the toe of the bluff, which is the site of what is probably some of the highest-quality original fen in the Phase 2 study area. Corridor E2 has a more perpendicular orientation to the bluff and, therefore, directly impacts less of the toe-of-the-bluff calcareous fen. Construction of both corridors would result in water table drawdowns between one and several feet over a large portion of the area newly-identified as calcareous fen by the Phase 2 study.

Construction of Corridors E1A and E2 in and near areas of calcareous fen would have complex ecological impacts. Stress to native wetland vegetation can alter patterns of succession and species composition (Figure 3.5). Generally these alterations result in the loss of native species to the benefit of exotic and invasive species. Several examples of anthropogenic disturbance and altered vegetation can be seen within the SFWC itself. There has been degradation due to drainage tiles, ditching, peat mining, construction of the railroad embankment, increased cover of woody vegetation, and invasive species colonization. While natural ecosystems have some resiliency to withstand (or benefit from) certain disturbances, multiple, extreme, and long-lasting disturbances can overwhelm this capacity and lose native species (Gunderson 2000).

Areas with drainage impacts correspond to the presence of invasive species. Locations with impounded water support emergent marsh vegetation rather than fen or wet meadow species. The western portion of Area 1 appears to have reduced groundwater flow due to the presence of the railroad embankment. This area has large populations of reed canarygrass and other species associated with disturbance and seasonally-fluctuating water tables.

Hydrological impacts from corridors E1A and E2 could have negative effects on wetlands and associated vegetation. Bridge pier construction during the dormant season will likely minimize dewatering impacts to surrounding wetlands. Although many wetland plants are adapted to fluctuating water tables and soils that are not saturated for extended portions of the growing season, fen species are found in environments that are, essentially, permanently saturated to the surface. Lowered water tables could stress or kill fen vegetation, depending on the timing and duration of the drawdown. Competitive interactions would be altered, favoring species that aggressively exploit

hydrologically altered environments. Conducting dewatering activities when the plants are dormant should reduce stress, mortality, and altered succession, thus reducing ecological impacts.

It should be recognized, however, that a dormant-season water table drawdown may have detrimental impacts on wetland vegetation, including fen species. Most wetland plant species in the SFWC are perennials with long-lived underground organs such as rhizomes, tubers and bulbs. Normally, when these tissues are dormant, the soil matrix is saturated. During the winter, the soil matrix is filled with ice rather than air. A water table drawdown during the dormant season could produce a frozen soil matrix that is filled with air rather than ice. Low humidity levels during the winter could result in perennating tissue to be, essentially, freeze dried. This atypical stress may reduce the viability of wetland plants. Apical meristems may be killed, reducing resprouting potential, or entire plants may be killed. Although the extent of stress or mortality cannot be quantitatively predicted, it is expected that some native wetland vegetation will be impacted.

The effect of stress would likely manifest as altered competitive hierarchies and successional trajectories. In other words, conditions may become more conducive for invasive colonization and competitive displacement of native species (Figure 3.5). Even a temporary dormant-season drawdown could change successional patterns and initiate a multi-year process of succession towards invasive species.

3.4.3.6 Conclusions

No direct or indirect impacts to calcareous fen are anticipated from Corridors C2, C2A, or W2. Among the three eastern alternative corridors, E1 has the least impact to native vegetation and calcareous fen communities in terms of habitat loss, temporary dewatering, permanent hydrological alteration, and habitat fragmentation. No calcareous fen areas are within the E1 corridor. Very few fen areas are near the corridor, down gradient from it, or within the area of water table drawdown.

Corridors E1A and E2, in contrast, cross substantial areas of calcareous fen, are upgradient from additional fen, and pass through areas of strong groundwater discharge critical for the hydrology of the large peatland that is in the Phase 2 study area. As described above, there are many factors that could degrade the SFWC and its calcareous fen communities. The extent of potential impact from any one factor is difficult to accurately predict. Predictability is even less reliable when multiple factors are simultaneously present and possibly interacting.

The net result, however, is that large areas of calcareous fen will be directly lost from construction and operation of Corridors E1A and E2, and non-fen wetland areas will likely be degraded. That degradation may be so severe as to eliminate calcareous fen from large areas outside of the actual corridors. Both Corridors E1A and E2 have the potential to completely eliminate calcareous fen from the combined Phase 1-Area 2/Phase 2 study area. Such a large impact may not occur, but the western portion of this combined area is at risk from Corridor E1A, and the eastern portion of the combined area from Corridor E2. However, there may be little or no fen vegetation present in Area 2 and Phase 2 study area by the time the highway is constructed. Without management, fen vegetation will likely be absent from the site by the time construction commences. However, with management, fen vegetation could occupy a greater portion of the site than at present. The highway project could eliminate whatever fen vegetation is present at the time if is not accompanied by diligent management efforts. In particular, revegetation after construction, sustained and intensive efforts to control invasive species, and techniques to minimize and contain road salts are needed if any fen vegetation is to persist in the Phase 1-Area 2/Phase 2 study area portion of the SFWC.

Impacts to Area 1, where the highest-quality calcareous fen in the SFWC currently exists, will be less severe, or even minimal, compared to Area 2. The most severe impacts would likely occur in the western portion of Area 1. That area has already been highly degraded, likely from the railroad embankment altering the hydrology. The highest-value calcareous fen within the entire SFWC is in the northeast portion of Area 1. Groundwater modeling does not indicate substantial alteration of hydrology to that area by the alternative corridors. Other ecological factors that are important in Area 2, such as habitat fragmentation and direct loss of fen vegetation should not affect the northeast portion of Area 1. However, indirect impacts may extend beyond limits of construction, but the likelihood of negative indirect impacts in the northeast portion of Area 1 is difficult to predict with confidence.

3.4.4 Mitigation

3.4.4.1 Impact Avoidance and Minimization

Several techniques are available for minimizing adverse impacts to the SFWC. Complete avoidance of impacts to the wetland complex is only possible by excluding corridors E1A and E2. Without active management and restoration, there may be very little ecologically-intact calcareous fen by the time construction of TH41 occurs. However, the site will still be a large, ground-water supported wetland complex. Consequently, it is possible there will be little or no fen in the corridor alignments to impact or avoid. The techniques described below pertain to impact minimization to the wetland

complex, regardless of the presence of fen vegetation. These techniques may not prevent all detrimental impacts to the wetlands.

Coffer Dams

The use of coffer dams and a bottom grout seal is considered essential for any bridge pier construction in or near wetlands and is standard MnDOT practice. Coffer dams and bottom grout seals will limit the portion of the SFWC that is affected by groundwater drawdown.

Swamp Mats

Using swamp maps under construction traffic to the extent possible will help reduce compaction of organic soils by distributing, rather than concentrating, weight. However, it should be recognized that under dewatered conditions, organic soil may be compacted even with the use of swamp mats. This compaction may be severe enough to alter groundwater flow, surface elevation, plant growth, and competition. All of these changes can alter the composition of plant communities. Altering groundwater flow may affect vegetation down gradient of the compaction, thus creating impacts well beyond the construction footprint.

Dormant Season Construction

Dewatering and construction of bridge piers during the dormant season will likely reduce, but not eliminate, detrimental impacts on native vegetation. However, compared to dewatering during the growing season, dormant season dewatering is preferred.

Surface Water

Discharges of surface water from the highway and from surrounding uplands should be minimized. Inputs of surface water and transported nutrients and sediments will be detrimental to fen vegetation.

Erosion Control - Sedimentation

Sedimentation from uplands should be controlled, both during and after construction. Removal of existing vegetation and earthwork in the uplands above the SFWC increases the potential for sediment deposition in the wetlands. Any deposition is detrimental to fen vegetation.

Relocation of Fen Vegetation

It is possible under certain circumstances to collect soil and/or plants from wetlands to be impacted and relocate them to new sites. This should be considered within and around the construction

footprints if corridor E1A or E2 are selected. The relocated plants and soil could be used to revegetate restoration sites. Relocation has the advantage of preserving the existing species and local genotypes that are present in the SFWC, providing potentially species rich vegetation in restoration sites, and possibly saving populations of protected plant species. Possible restoration sites are available in Area 1 of the SWFC (see below).

Several factors are important for maximizing the chances of success transplantation. A dormant season collection and transport will minimize stress on the vegetation. Collecting the entire rooting zone of the soil (approximately the upper foot) and maintaining intact sections of sod will allow transfer of intact seeds, roots and rhizomes. Transplantation of the collected soil and plants should occur immediately after collection, and collected soil should remain wet. Stockpiling will reduce the chances of successful transplantation.

Soil and hydrology of the receiving sites should be appropriate for fen species. Degraded organic soil should be removed. Hydrological restoration may be necessary through reversal of drainage or removal of the upper soil profile. Discharging groundwater should have the appropriate chemistry. Water table levels in the restoration site and in intact fen areas should be monitored to ensure the restoration site has appropriate elevations and groundwater discharge. Even at sites within fens, water tables can vary seasonally, and the duration of rooting zone saturation with groundwater is important for fen vegetation. Consequently, long term-well studies may be necessary for planning restoration sites.

If possible, several years of preparation of the impact and restoration sites should be conducted. The impact area could be managed with shrub and invasive species removal and prescribed burning for several years before transfer to increase populations of desirable fen species. Invasive species in the restoration site should be eliminated, and the upper soil profile soil removed if it contains a seedbank of invasive species. Invasive species will attempt to colonize restoration sites from adjacent land, so control of undesirable species is necessary in and around restoration sites for several years after transplantation.

Currently, in the proposed impact areas, two protected species are known, sterile sedge and small white lady's slipper. Many sedge species can be successfully transplanted, especially if rhizomes are transferred intact in the wetland sod. As long as the restoration site has discharging groundwater with the appropriate chemical parameters, sterile sedge could be successfully relocated. Native orchids, such as small white lady's slipper, can be extremely difficult to transplant successfully. Orchids are

dependent on mycorrhizal associations, and disruption of these associations may be a factor preventing transplantation. However, if construction impacts are inevitable, it would be better to attempt transplantation than allow the loss of a small white lady's slipper population. Transplantation of any protected species would be coordinated with MnDNR and other interested parties.

Transplantation may preserve some fen vegetation from direct impact areas, but the proposed highway corridors still have risks of soil degradation, altered hydrology, and introduction on invasive species into fen areas outside of the highway right of way. If transplantation will be necessary, small-scale trials are recommended prior to highway construction to perfect techniques.

Vegetation Management

Disturbed areas are routinely revegetated following construction. However, disturbance and habitat edges create opportunities for the spread of invasive and undesirable species. Not only should appropriate native species be planted and invasive species controlled in disturbed areas, areas surrounding construction should be actively managed to control invasive species. Such control may be necessary for at least 10 years following the cessation of all construction activity. Propagules of invasive species such as reed canarygrass, common reed, and common buckthorn are abundant in and around the SFWC. Soil disturbance and habitat fragmentation associated with highway construction will provide fresh sites for colonization and spread of invasive species. While the highway project is not responsible for the presence of the invasive species in the SFWC, without intensive and ongoing vegetation management, the project could substantially increase invasive species distribution.

Salts

Technologies should be evaluated for minimizing or preventing salt spray and runoff from the highway. Any addition of salts, particularly those containing chloride anions or sodium cations, could exacerbate an already stressed fen wetland complex. Certain compounds, such as potassium acetate, show promise as effective deicing agents with fewer negative environmental side effects than traditional deicers such as sodium chloride or magnesium chloride. However, the full environmental implications of alternative deicing compounds have not been investigated. Acetate is a component of many metabolic pathways, and introduction into a wetland complex may create unforeseen biological chain reactions. The movement of water through this wetland ecosystem means that any deicing compound used should be expected to migrate well beyond the limits of the highway right-of-way. By the time bridge design and construction occurs, new technologies may be available, and environmental effects of relatively new deicing agents will be better understood. Options for

preventing salt release should be thoroughly evaluated. A monitoring plan should be developed and implemented to document baseline conditions and the spread of deicing agents in the SFWC after the highway opens.

3.4.4.2 Restoration and Management for Compensatory Mitigation

Several opportunities exist for the management and restoration within the SFWC in order to provide compensatory mitigation for the TH 41 project or for fen restoration activities in general (Figure 3.10). Some of these opportunities require straightforward vegetation management, and others pose more complex and challenging hydrological and ecological challenges with a lower probability of success. Given the difficulties of fen restoration and management, it should not be assumed that an impacted fen can simply be recreated at another site. However, the SFWC is ecologically degraded in many locations in different ways, and this deterioration will continue without active management. Therefore, restoration and management throughout the SFWC could potentially offset impacts from the TH 41 project.

Fen restoration has been attempted less often than other types of wetland restoration. The characteristic environmental conditions of a fen make such restoration challenging (Moorhouse 2004). Therefore, some restoration efforts may have a low probability of success, at least without detailed background studies, careful design and rigorous management. For some restoration activities, a trial-and-error approach is recommended, whereby small-scale restoration projects can be attempted, replicated, and monitored before attempting larger scale projects. Compensatory mitigation for the TH41 project could begin years, or even decades, before the impacts occur. Whereas advance mitigation is generally preferable to after-the-fact mitigation, the challenges of fen restoration and mitigation make advance mitigation even more important.

The highest priorities for restoration and management of the SFWC should be to preserve the remaining high-quality fen areas and prevent further degradation through erosion-control measures. The next priority should be to maintain and enhance the overall viability of fen vegetation through shrub removal, invasive species removal, and prescribed burning. Finally, numerous opportunities are present to reverse historic impacts from excavation, ditching, tiling, impoundment, railroad and transmission line construction, and fire suppression. These opportunities may require hydrological restoration, soil manipulation, and revegetation. Methods for hydrological restoration include blocking or filling drainage ditches, breaking drain tiles within the fen, and regrading or removing soil to intercept the water table. Soil removal from upper soil profiles of potential restoration areas may be necessary to eliminate highly-degraded organic soil that may not be optimal for fen plants.

Revegetation may involve seeding, growing plants in greenhouses or collecting in the field for transplantation, or collection and spread of topsoil to relocate seedbanks and living rhizomes. Plugs of soil and plants could be collected throughout the SFWC for use in restoration. Additionally, soil in future impact areas could be collected and used for restoration. Impact areas could be managed through shrub removal and prescribed burning for years before construction to increase the viability of plant populations and seedbanks before relocation.

In any wetland restoration project, assuring appropriate hydrology and control of invasive and undesirable species are critical. For fen restoration to be successful, a continuous supply of groundwater must be present that will saturate the soil to the surface for most of the year (Amon et al. 2005; Jansen et al. 2001). Once the hydrology has been restored, the likelihood of fen vegetation restoration is greatly increased. Long-term well studies should be conducted before, during and after hydrological restoration to ensure that appropriate hydrology is present and to assist in troubleshooting and developing corrective actions. Effective hydrologic restoration would saturate soil to the surface without causing inundation. The well studies would provide information on the optimal ground surface elevation within the hydrologically degraded portions of the fen. It may be necessary to regrade or remove soil so that the saturation will occur. An excavated portion of Area 1 with windrows of peat provides an unintended experiment in restoration (Figure 3.10). Between the windrows, the organic soil is saturated to the surface and high quality fen plants are found here on turgid, quakey peat. At the top of the windrows, the peat has become dried and granular because of decreased saturation periods. Poorer quality, invasive species such as cattails and reed canarygrass are typically found growing on the windrows. Although the site experienced extensive soil disturbance which typically favors low-diversity communities dominated by non-native species, the continuously saturated microsites have allowed native fen vegetation to persist. This case study and published reports of fen restoration (Amon et al. 2005; Jansen et al. 1996, 2001, 2004; Jansen and Roelofs 1996) demonstrate the potential for restoration within the SFWC.

Much of the SFWC could be restored to tall sedge fen communities (Figure 3.5) with appropriate management. One sizeable area of short sedge fen exists which should be a priority (Area 1; discussed below). With hydrological restoration and vegetation management (e.g., prescribed burning), microsites of short sedge fen may reestablish (e.g., certain locations near the toe of the bluff in the Phase 2 study area). Within the Phase 1 and Phase 2 study areas, there are unique vegetative communities as well as specific hydrologic alterations and other impacts. Therefore, restoration and management methods are discussed for specific areas of the SWFC.

Phase 1 Study - Area 1

The northeast portion of Area 1 is characterized by a short sedge fen community (Figure 3.10). Initial restoration activities should include reduction of buckthorn and shrub advancement using typical eradication methods. A prescribed burn would help to reduce invasive species and allow higher-quality fen species to compete. Within Area 1, gully erosion is occurring in the northeast within the dense patches of buckthorn and shrubs where there is minimal ground cover. Erosion control methods and buckthorn removal are needed. Since this is the only large area of short sedge fen in the SWFC, intensive restoration and management should be a high priority.

The east side of the peat dome in Area 1 (Figure 3.10) is dominated by a reed canarygrass community with the potential for restoration to a tall sedge fen community. Since the reed canarygrass is generally found in areas of hydrologic alteration (e.g., lowering of the water table by ditches or tile), it is necessary to restore the hydrology by breaking existing drain tile. Vegetative restoration would require removal of reed canarygrass and woody vegetation using typical eradication methods. Once the hydrology is stabilized, fen vegetation would be introduced into the area using seeds, plugs or other methods.

The west side of the peat dome in Area 1 (Figure 3.10) is characterized by a mosaic of tall sedge fen, sedge/meadow-rue, and sedge/goldenrod communities and non-native communities with the potential for restoration to a tall sedge fen community. The hydrology of this area has been altered with a lowered water table so that invasive species, such as reed canarygrass, common reed, and buckthorn, are common along with red osier dogwood and willow shrubs. Ditching, along with excavation of soils, have channeled surface water away from this area so that the hydraulic gradient in the peat dome has been reduced. Retaining water within the peat dome, rather than allowing the water to flow away from the dome in ditches, could potentially increase the water table levels throughout the west side of the peat dome. This may require soil and hydrological manipulations. Vegetative restoration would require shrub and invasive species control and possibly planting.

The western portion of Area 1 (Figure 3.10) is characterized by a mosaic of tall sedge fen, sedge/meadow-rue, sedge/goldenrod and non-native communities with the potential for restoration to a tall sedge fen community. An old roadbed along the north side (not the current bike trail) could be regraded or removed to allow saturation of the soil surface upon hydrologic restoration. The western part of Area 1 likely has degraded organic soils that have not been continuously saturated and have undergone oxidation and subsidence. These soils may need to be removed if they cannot be adequately re-saturated and to insure sufficient groundwater discharge for fen vegetation (Jansen et

al. 1996, 2001, 2004; Jansen and Roelofs 1996). In addition, vegetative restoration would require removal of invasive herbaceous and woody species. The western portion of Area 1 could be an ideal location for trial fen restoration projects because of the large disturbed area somewhat distant from portions of the fen with the highest ecological value and integrity.

This western portion of Area 1 is also unique in the SWFC because the railroad bed appears to cause surface water to inundate on the north side and create a marshy wetland. Inundation within a tall sedge fen will create areas of emergent marsh or lake sedge (Figure 3.5). Directly south of the marshy wetland, beyond the railroad bed, the vegetation is dominated by communities adapted to drier conditions including sedge/meadow-rue, and sedge/goldenrod communities. Hydrologic restoration could involve a combination of lowering the water table on the north side of the railroad bed and raising the water table on the south side of the railroad bed by excavating the original culverts and allowing surface water to flow north to south and/or removal of the upper, degraded soil profile. Wet areas located north and south of the railroad bed have the potential to be restored to a tall sedge fen community.

Phase 1 Study - Area 2/Phase 2 Study Area

This area is characterized by emergent marsh, lake sedge, tall sedge fen, cattail/common reed, reed canarygrass, dogwood/willow, buckthorn, and lowland hardwood forest communities. The area has the potential for restoration primarily due to a tall sedge fen community. However, small areas of short sedge fen may be present and become evident after shrub reduction and/or prescribed burning. There are numerous ditches in the western part of the area, and drain tiles are present in the eastern part (Figure 3.10). Vegetation management requires eradication and control of invasive herbaceous and woody vegetation. A transmission line crosses the area and acts as a conduit for the expansion of reed canarygrass into native fen and wetland communities. In 2006, beaver dams were constructed, impounding water along the south edge of the area. Affected areas are primarily disturbed reed canarygrass wetlands, but control of beavers should be considered if they threaten higher-value fen areas.

There are extensive sediment plumes that may need to be removed in order to allow hydrologic restoration as well. An alternative to sediment removal would involve planting native upland species in these sediment areas that are on the edge of the SWFC. Some of these alluvial fans now support lowland hardwood forest, but many have been colonized by reed canarygrass. These sites are sources of propagules for further encroachment of the invasive grass. Vegetation restoration would require the removal and control of invasive herbaceous and woody vegetation. The sediment plumes indicate

historic surface water discharges into the fen complex, but the importance of current surface water discharge should be investigated. Numerous gullies lead down the bluff to the SFWC, and at least one large culvert discharges into a small stream the leads to the SFWC. These surface water discharges may be transporting fertilizers and road salts and negatively affects fen vegetation. Coincidentally, most reed canarygrass, lowland hardwood forest, and degraded lake sedge communities in the western part of this portion of the SFWC are downstream from this culvert discharge. These areas are all highly disturbed and do not meet calcareous fen vegetation criteria despite the presence of organic soil and some groundwater discharge. Historic photos suggest the SFWC once extended west of Audubon Drive. However, development and stream channelization may have irreparably altered groundwater hydrology. The western portion of the Phase 2 area is highly degraded and may be difficult to restore and low on the restoration priority list. However, invasive vegetation could be controlled through burning and eradication methods and the area reseeded with native upland vegetation.

Phase 1 Study – Area 3

Area 3 is characterized by tall sedge fen, dogwood, and cattail/common reed communities with the potential for restoration to a tall sedge fen community (3.10). There are large portions of Area 3 that have robust colonies of common reed that will be difficult to eradicate. Restoration would require controlled burns to control invasive species and shrubs along with additional management around the radio towers and buildings located in this area. No evidence of short sedge fen has been seen in Area 3, although the protected species, sterile sedge, is present.

4.0 Literature Cited

Almendinger, J.E., and J.H. Leete. 1998a. Peat characteristics and ground-water geochemistry of calcareous fens in the Minnesota River Basin, U.S.A. Biogeochemistry. 43(1):17-41.

Almendinger, J.E., and J.H. Leete. 1998b. Regional and local hydrology of calcareous fens in the Minnesota River Basin, U.S.A. Wetlands. 18(2):184-202.

Amon, J.P., C.A. Thompson, Q.J. Carpenter, and J. Miner. 2002. Temperate zone fens of the glaciated Midwestern USA. Wetlands. 22(2): 301-317.

Amon, J.P, C.S. Jacobson, and M.L. Shelly. 2005. Construction of fens with and without hydric soils. Ecological Engineering. 24:341-357.

Bedford, B.L., and K.S. Godwin. 2003. Fens of the United States: distribution, characteristics, and scientific connection versus legal isolation. Wetlands. 23(3): 608-629.

Benbow, M.E., and R.W. Merritt. 2004. Road-salt toxicity of select Michigan wetland macroinvertebrates under different testing conditions. Wetlands. 24(1):68-76.

Berglund, E. (Chairman). January 1995. Technical criteria for identifying and delineating calcareous fens in Minnesota. Minnesota Department of Natural Resources, St. Paul, Minnesota.

Bowles, M.L., P.D. Kelsey, and J.L. McBride. 2005. Relationships among environmental factors, vegetation zones, and species richness in a North American calcareous prairie fen. Wetlands. 25(3): 685-696.

Boyer, M.L.H., and B.D. Wheeler. 1989. Vegetation patterns in spring-fed calcareous fens: Calcite precipitation and constraints on fertility. The Journal of Ecology. 77(2):597-609.

Bridgham, S.D., J. Pastor, J.A. Janssens, C. Chapin, and T.J. Malterer. 1996. Multiple limiting gradients in peatlands: A call for a new paradigm. Wetlands. 16(1):45-65.

Bryson, G.M. and A.V. Barker 2002. Sodium accumulation in soils and plants along Massachusetts roadsides. Communications in Soil Science and Plant Analysis. 33:67-78.

Carpenter, Q.J. 1995. Toward a new definition of calcareous fen. Ph.D. Thesis. University of Wisconsin-Madison, Madison, Wisconsin.

Christen, D., and G. Matlack. 2006. The role of roadsides in plant invasions: a demographic approach. Conservation Biology. 20(2):385-391.

Environment Canada. 2001. Priority substances list assessment report – road salts. Environment Canada, Health Canada, Minister of Public Works and Government Services 2001, Ottawa, ON, Canada.

Fahrig, L. 2003. Effects of habitat fragmentation on biodiversity. Annual Review of Ecology, Evolution and Systematics. 34:487-515.

Forman, T.T. and L.E. Alexandar. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics. 29:207-231+C2.

Galatowitsch, S.M., D.C. Whited, R. Lehtinen, J. Husveth, and K. Schik. 2000. The vegetation of wet meadows in relation to their land-use. Environmental Monitoring and Assessment. 60:121-144.

Godwin, K.S., J.P. Shallenberger, D.J. Leopold, and B.L. Bedford. 2002. Linking landscape properties to local hydrogeologic gradients and plant species occurrence in minerotrophic fens of New York State, USA: A hydrogeologic setting (HGS) framework. Wetlands. 22(4):722-737.

Green, E.K., and S.M. Galatowitsch. 2001. Differences in wetland plant community establishment with additions of nitrate-N and invasive species (*Phalaris arundinacea* and *Typha x glauca*). Can. J. Bot. 79:170-178.

Groom, M. G.K. Meffe and C.R. Carroll. 2005. Principles of Conservation Biology. Sinauer Associates, Sunderland, MA, 3rd edition.

Gunderson, L.H. 2000. Ecological resilience – in theory and practice. Annual Reviews of Ecology and Systematics. 31:425-439.

Hanes, R.E., L.W. Zelaney, and R.E. Blaser. 1970. Effects of deicing salts on water quality and biota: Literature review and recommended research. National Cooperative Highway Research Program, Report 91. National Academy of Sciences. Washington, D.C.

Hansen, A.J, R.L. Knight, J.M. Marzluff, S. Powell, K. Brown, P.H. Gude, and K. Jones. 2005. Effects of exurban development on biodiversity: patterns, mechanisms and research needs. Ecological Applications, 15:893–1905.

Harper, K.A., S.E. MacDonald, P.J. Burton, J. Chen, K.D. Brosofske, S.C. Saunders, E.S. Euskirchen, D. Roberts, M.S. Jaiteh, and P. Esseen. 2005. Edge influences on forest structure and composition in fragmented landscapes. Conservation Biology. 19:768-782.

Hershock, C. 2002. Plant community structure in calcareous fens: effects of competition, soil environment and clonal growth architecture. Ph.D. Thesis. University of Michigan, Ann Arbor, Michigan.

Houlahan, J.E, P.A. Keddy, K. Makkay, and C.S. Findlay. 2006. The effects of adjacent land use on wetland species richness and community composition. Wetlands. 26(1): 79-96.

Muir-Hotaling, N.E. undated. New York State Fens. The Roosevelt Wildlife Station. Syracuse, New York. http://www.esf.edu/ResOrg/RooseveltWildlife/Research/Fen/Fen.htm

Jackson, R.B., and E.G. Jobbagy. 2005. From icy roads to salty streams. PNAS. 102(41):14487-14488.

Janssens, J.A. 2005. Classification of the Bryophyte Assemblages of Minnesota's Extreme Rich Fens and the Bryophyte Criterion for the Evaluation of Potential Calcareous-Fen Ecotopes, update October 2005. Report to the Minnesota Department of Natural Resources, Division of Waters. Lambda-Max Ecological Research, Minneapolis, MN. Available from the author janss008@tc.umn.edu.

Janssens, J.A. 2006. Methods for the study of bryophyte ecology. Update 2006. Lambda-Max Ecological Research, Minneapolis, MN. Available from the author janss008@tc.umn.edu.

Jansen, A.J.M., M.C.C. de Graaf, and J.G.M Roelofs. 1996. The restoration of species-rich heathland communities in the Netherlands. Vegetatio. 126:73–88.

Jansen, A.J.M., F.T.W. Eysink, and C. Maa. 2001. Hydrological processes in a *Cirsio-Molinietum* fen meadow: Implications for restoration. Ecological Engineering.17:3–20

Jansen, A.J.M, L.F.M. Fresco, A.P. Grootjans, and M.H. Jalink. 2004. Effects of restoration measures on plant communities of wet heathland ecosystems. Applied Vegetation Science. 7:243-252.

Jansen, A.J.M. and J.G.M Roelofs. 1996. Restoration of *Cirsio molinietum* wet meadows by sod cutting. Ecological Engineering. 7:279–298.

Kaushal, S.S., P.M. Groffman, G.E. Likens, K.T. Belt, W.P. Stack, V.R. Kelly, L.E. Band, and G.T. Fisher. 2005. Increased salinization of fresh water in the northeastern United States. Proceedings of the National Academy of Sciences. 102(38): 13517-13520.

Kercher, S.M., Q.E. Carpenter, and J.B. Zedler. 2004. Interrelationships of hydrologic disturbance, reed canary grass (*Phalaris arundinaca* L.), and native plants in Wisconsin Wet Meadows. Natural Areas Journal 24: 316-325.

Komor, S.C. 1994. Geochemistry and hydrology of a calcareous fen within the Savage Fen wetlands complex, Minnesota, USA. Geochimica et Cosmochimica Acta. 58(16):3353-3367.

Kotowski, W., J. van Andel, R. van Diggelen, and J. Hogendorf. 2001. Responses of fen plant species to groundwater level and light intensity. Plant Ecology. 155:147-156.

Labadia, C.F., and J.M. Buttle. 1996. Road salt accumulation in highway snow banks and transport through the unsaturated zone of the Oak Ridges Moraine, Southern Ontario. Hydrological Processes. 10(12):1575-1589.

Leete, J.H., W.R. Smith, J.A. Janssens, and N. Aaseng. 2005. Final report to the USEPA: Test of the technical criteria for identifying and delineating calcareous fens in Minnesota and draft revised technical criteria for identifying calcareous fens in Minnesota. Clean Water Act Section 104(b)(3) Grant Number CD-97504601-3, Minnesota Department of Natural Resources, St. Paul, Minnesota.

Maurer, D.A., R. Lindig-Cisneros, K.J. Werner, S. Kercher, R. Miller, and J.B. Zedler. 2003. The replacement of wetland vegetation by reed canarygrass (*Phalaris arundinacea*). Ecological Restoration. 21(2):116-119.

Miklovic, S., and S.M. Galatowitsch. 2005. Effect of NaCl and *Typha angustifolia L.* on marsh community establishment: A greenhouse study. 25(2):420-429.

Miller, R.C., and J.B. Zedler. 2003. Responses of native and invasive wetland plants to hydroperiod and water depth. Plant Ecology. 167:57-69.

Miner, J.J., and D.B. Ketterling. 2003. Dynamics of peat accumulation and marl formation in a calcareous fen, Midwestern United States. Wetlands. 23(4):950-960.

Minnesota Department of Natural Resources. 2004. Minnesota land cover classification system user manual version 5.4. Minnesota Department of Natural Resources. St. Paul, Minnesota.

Minnesota Department of Natural Resources. 2005. Field guide to the native plant communities of Minnesota: the Eastern Broadleaf Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and the Natural Heritage and Nongame Research Program. Minnesota Department of Natural Resources. St. Paul, Minnesota.

Minnesota Department of Natural Resources. Undated. Natural community element occurrence ranking guidelines. Draft Document. Minnesota Natural Heritage Program, Minnesota Department of Natural Resources, St. Paul, Minnesota.

Minnesota Natural Heritage Program. 1993. Minnesota's native vegetation: A key to natural communities. Version 1.5. Minnesota Department of Natural Resources, St. Paul, Minnesota.

Moorehouse, T.P. 2004. The restoration of fen habitats on former arable land: a literature review. The National Trust. P.O. Box 39, Warrington England WA5 7WD. (http://www.wicken.org.uk/newpage15.htm)

Muir-Hotaling, N.E. undated. New York State Fens. The Roosevelt Wildlife Station. Syracuse, New York. http://www.esf.edu/ResOrg/RooseveltWildlife/Research/Fen/Fen.htm

Oster, J.D. and I. Shainberg. 2001. Soil responses to sodicity and salinity: challenges and opportunities. Australian Journal of Soil Research. 39:1219-1224.

Owen, C.R. 1999. Hydrology and history: land use changes and ecological responses in an urban wetland. Wetlands Ecology and Management. 6:209-219.

Panno, S.V., V.A. Nuzzoo, K Cartwright, B.R. Hensel, and I.G. Krapac. 1999. Impact of urban development on the chemical composition of ground water in a fen-wetland complex. Wetlands 19(1): 236-246.

Peters, N.E., and J.T. Turk. 1981. Increases in sodium and chloride in the Mohawk River, New York, from the 1950s to the 1970s attributed to road salt. Water Resources Bulletin 17: 586-598.

Peterson Environmental Consulting, Inc. 2005. Phase 1 Characterization: Seminary Fen Wetland Complex; TH 41 over the Minnesota River Highway Project; Carver County, Minnesota. Peterson Environmental Consulting, Inc., Mendota Heights, Minnesota.

Picking, D.J., and P.L.M. Veneman. 2004. Vegetation patterns in a calcareous sloping fen of southwestern Massachusetts, USA. Wetlands. 24(3):514-528.

Pugh IV, A.L., S.A. Norton, M. Schauffler, G.L. Jacobson Jr., J.S. Kahl, W.F. Brutsaert, C.F. Mason. 1996. Interactions between peat and salt-contaminated runoff in Alton Bog, Maine, USA. Journal of Hydrology. 182:83-104.

Reed, D.M. 2002. Environmental correlates of vegetation types in southeastern Wisconsin fens. Ph.D. Thesis, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin.

Rentch, J.S., R.H. Fortney, S.L. Stephenson, H.S. Adams, W.N. Grafton, and J.T. Anderson. 2005. Vegetation-site relationships of roadside plant communities in West Virginia, USA. Journal of Applied Ecology 42:129–138.

Richburg, J.A., W.A. Patterson III, and F. Lowenstein. 2001. Effects of road salt and Phragmites australis invasion on the vegetation of a western Massachusetts calcareous lake-basin fen. Wetland. 21(2):247-255.

Ries, L., R.J. Fletcher, Jr., J. Battin, and T.D. Sisk. 2004. Ecological responses to habitat edges: mechanisms, models and variability explained. Annual Review of Ecology, Evolution, and Systematics. 35:491-522.

Ruiz-Vera, V.M. and L. Wu. 2006. Influence of sodicity, clay mineralogy, prewetting reate, and their interaction on aggregate stability. Soil Science of Society of America Journal. 70:1825-1833.

Sanzo, D., and S.J. Hecnar. 2006. Effects of road de-icing salt (NaCl) on larval wood frogs (*Rana sylvatica*). Environmental Pollution. 140:247-256.

Schauffler, M., G.L. Jacobson Jr., A.L. Pugh IV, S.A. Norton. 1996. Influence of vegetational structure on capture of salt and nutrient aerosols in a Maine peatland. Ecological Applications. 6(1):263-268.

Schot, P.P., S.C. Dekker, and A. Poot. 2004. The dynamic form of rainwater lenses in drained fens. Journal of Hydrology. 293:74-84.

Soil Survey Staff. 2003. Keys to soil taxonomy, 9th Ed. U.S. Department of Agriculture, Natural Resources Conservation Service. US Government Printing Office, Washington DC.

Trombulak, S.C., and C.A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology. 14(1): 18-30.

Venner Consulting and Parsons Brinckerhoff. 2004. Environmental stewardship practices, procedures, and policies for highway construction and maintenance. American Association of State Highway and Transportation Officials (AASHTO) Standing Committee on the Environment. http://www.trb.org/NotesDocs/25-25(4)_FR.pdf.

Wassen, M.J., A. Barendregt, P.P. Schot, and B. Beltman. 1990. Dependency of local mesotrophic fens on a regional groundwater flow system in a poldered river plain in the Netherlands. Landscape Ecology. 5(1):21-38.

Wassen, M.J., and A. Barendregt. 1992. The relative importance to river plain fen ecosystems of their topographic position and the chemistry of supply water. J. Veg. Sci. 3:447-456.

Wassen, M.J., A. Barendregt, A. Palczynski, J.T de Smidt, and H. de Mars. 1990. The relationship between fen vegetation gradients, groundwater flow and flooding in an undrained valley mire at Biebrza, Poland. The Journal of Ecology. 78(4):1106-1122.

Wegner, W., and M. Yaggi. 2006. Environmental impacts of road salt and alternatives in the New York City watershed. The Journal for Surface Water Quality Professionals. www.newyorkwater.org/downloadedArticles/ENVIRONMENTANIMPACT.cfm

Weltzin, J.F., J. Pastor, C. Harth, S.D. Bridgham, K. Updegraff, and C.T. Chapin. 2000. Response of bog and fen plant communities to warming and water-table manipulations. Ecology. 81(12):3464-3478.

Werner, K.J., and J.B. Zedler. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands. 22(3):451-466.

Wetzel, P.R., and A.G. van der Valk. 1998. Effects of nutrient and soil moisture on competition between *Carex stricta, Phalaris arundinacea*, and *Typha latifolia*. Plant Ecology. 138:179-190.

Wilcox, D.A. 1986. The effects of deicing salts on vegetation in Pinhook Bog, Indiana. Canadian Journal of Botany 64:865-874.

Williams, A.L., G.J Stensland, C.R. Peters, and J. Osborne. 2000. Atmospheric dispersion of deicing salt applied to roads: First progress report. Contract Report 2000-5. Illinois State Water Survey, Atmospheric Environment Section, Illinois Department of Natural Resources, Champaign, Illinois.

Williams, A.L. and G.J Stensland. 2006. Atmospheric dispersion study of deicing salt applied to roads: Part II final report for period July, 2002 to June, 2004. Report No. FHWA/IL/HRC.2006_1. Illinois State Water Survey, Atmospheric Environment Section, Illinois Department of Natural Resources, Champaign, Illinois

Zedler, J.B., and S. Kercher. 2004. Causes and consequences of invasive plants in wetlands: Opportunities, opportunists, and outcomes. Critical Reviews in Plant Sciences. 23(5):431-452.

Tables

Table 1.1. Vascular Plant Calcareous Fen Indicator Species.
Point values are from Berglund (1995) and Leete et al. (2005).

1995 Point Value	2005 Minnesota Valley Point Value	Latin Name	Common Name
0	5	*Aster borealis*	northern bog aster
0	5	*Berula erecta*	cutleaf waterparsnip
0	5	*Betula pumila*	bog birch
0	5	*Bidens coronata*	crowned beggarticks
0	5	*Bromus ciliatus*	fringed brome
1	5	*Cardamine bulbosa*	bulbous bittercress
0	5	*Carex aquatilis*	long-bracted tussock sedge
1	0	*Carex granularis*	limestone meadow sedge
1	5	*Carex hystericina*	bottlebrush sedge
0	5	*Carex interior*	inland sedge
25	25	*Carex prairea*	prairie sedge
25	25	*Carex sterilis*	sterile sedge
5	0	*Carex viridula*	little green sedge
5	25	*Cladium mariscoides*	smooth sawgrass
25	25	*Eleocharis rostellata*	beaked spikerush
0	1	*Eriophorum angustifolium*	tall cottongrass
0	5	*Gentianopsis procera*	lesser fringed gentian
5	0	*Juncus alpino-articulatus*	northern green rush
5	0	*Juncus brevicaudatus*	narrow panicled-rush
1	5	*Liparis loeselii*	yellow widelip orchid
1	25	*Lobelia kalmii*	brook lobelia
1	5	*Oxypolis rigidior*	stiff cowbane
5	25	*Parnassia glauca*	American grass-of-Parnassus
1	0	*Parnassia palustris*	Arctic grass-of-Parnassus
1	25	*Potentilla fruticosa*	shrubby cinquefoil
5	25	*Primula mistassinica*	Mistassini primula
25	25	*Rhynchospora capillacea*	needle beaksedge
5	5	*Salix candida*	sageleaf willow
5	0	*Saxifraga pensylvanica*	swamp-saxifrage
5	25	*Scirpus cespitosus*	tufted bulrush
25	25	*Scleria verticillata*	low nutrush
5	25	*Tofieldia glutinosa*	sticky false asphodel
1	25	*Triglochin maritima*	seaside arrowgrass
25	25	*Triglochin palustris*	marsh arrowgrass
5	5	*Valeriana edulis*	edible valerian

Table 1.2. General Characteristics of Type I and II Fens with Application to the Seminary Fen Wetland Complex

Characteristic	Type I fens	Type II fens
Groundwater input	Steady and diffuse Rarely "quakey"	Strong and concentrated "Quakey" areas common
Water chemistry	Dominated by Ca and Mg	Dominated by Ca and Mg
Soils	Highly organic (70-85% OM) Calcareous (<5% $CaCO_3$)	Less highly organic (10-50% OM) Highly calcareous (> 10% $CaCO_3$)
Vegetation	Tall, vigorous Many transitional species Fewer rare species	Often dwarfed Fewer transitional species More rare species
Synonyms	Fen meadow Tall fen High organic	Marl meadow Short fen High carbonate
Designations used in SFWC Phase 1 Study	Tall sedge fen; Some occurrences of *Carex stricta* seep/spring run; *Carex-Thalictrum* meadow; *Carex-Solidago* meadow	Short sedge fen lawn Marl meadow
Dominant Species in SFWC Occurrences	*Carex aquatilis* *Carex prairea* *Carex sartwellii* *Carex sterilis* *Carex stricta* *Muhlenbergia richardsonis*	*Eleocharis rostellata* *Parnassia glauca* *Scleria verticillata* *Triglochin maritimum*
Indicator Species in SFWC Occurrences	*Aster borealis* *Bromus ciliatus* *Cardamine bulbosa* *Carex aquatilis* *Carex hystericina* *Carex interior* *Carex prairea* *Carex sterilis* *Eriophorum angustifolium* *Gentianopsis procera* *Lobelia kalmii* *Salix candida* *Valeriana edulis*	*Cardamine bulbosa* *Carex sterilis* *Cladium mariscoides* *Eleocharis rostellata* *Liparis loeselii* *Lobelia kalmii* *Parnassia glauca* *Rhynchospora capillacea* *Scleria verticillata* *Triglochin maritima* *Triglochin palustris*
Distribution in SFWC	Widespread in Areas 1, 2 and 3 and the Phase 2 study area	Restricted; one large area in the northeast portion of Area 1. Scattered microsites observed or possible in Areas 1 and 2 and the Phase 2 study area. No evidence of occurrence in Area 3

General characteristics are taken from Carpenter (1995); Seminary Fen information based on the Phase 1 study (PEC 2006).

Table 3.1. Water chemistry data collected from the Seminary Fen, June 2006. Calcareous fen chemical criteria (Leete et al., 2005) are shown in bold underlined font. Shading indicates water samples that meet the applicable chemical criterion.

Sample ID[1]	Date	pH[2]	EC[3] uS/cm	Cations[4]					Anions[6]				Ca/Mg ratio[9] %	Alkalinity ratio[10] %	Alkalinity ratio[11] %
				Ca[5] mg/l	Ca meq/l	Mg meq/l	Na meq/l	K meq/l	Alkalinity[7] meq/l	Alkalinity[8] meq/l	Cl meq/l	SO_4 meq/l			
49	6/22/2006	7.28	695	88	8.78	5.27	0.43	0.17	7.72	7.40	0.17	0.96	96	87	93
53	6/22/2006	7.48	840	93	9.28	6.58	0.36	0.07	4.64	9.40	1.02	1.12	97	68	88
61	6/22/2006	7.13	719	100	9.98	5.27	0.41	0.17	7.80	7.40	0.42	1.58	96	80	87
62	6/22/2006	7.13	780	98	9.78	4.94	0.48	0.13	7.80	7.80	0.37	2.12	96	76	86
SW	6/22/2006	7.65	742	100	9.98	5.76	0.48	0.09	3.04	7.40	0.45	1.37	96	62	88

[1]The ground water samples at transects 49, 53, 61 and 62 correspond to vegetative transects. There was one surface water (SW) sample. See map for locations.

[2]The pH value was determined in the field. The calcareous fen chemical criteria requires pH > 6.7.

[3]The electrical conductivity (EC) value was determined in the field. The calcareous fen chemical criteria requires EC > 500 uS/cm.

[4]Major cations include calcium (Ca), magnesium (Mg), sodium (Na) and potassium (K).The values were determined by Legend Technical Services, Inc.

[5]The calcareous fen chemical criteria requires Ca > 30 mg/l.

[6]Major anions include alkalinity, chloride (Cl) and sulfate (SO_4).The values were determined by Legend Technical Services, Inc. except as noted in footnote #7.

[7]The alkalinity value was determined by acid tritration on samples within 24 hours of collection as specified in Leete et al. (2005). The calcareous fen chemical criteria requires alkalinity > 1.65 meq/l.

[8]The alkalinity value was determined by Legend Technical Services, Inc.

[9]The calcium/magnesium (Ca/Mg) ratio = ((Ca + Mg)/(Ca + Mg + Na + K)) as specified in Leete et al. (2005).

[10]Using the acid titration results for alkalinity, the alkalinity ratio = ((alkalinity)/(alkalinity + Cl + SO_4)) as specified in Leete et al. (2005).

[11]Using the Legend results for alkalinity, the alkalinity ratio = ((alkalinity)/(alkalinity + Cl + SO_4)).

Table 3.2. Cover Type by Corridor

Cover Type[1] (acres)	Alternative Corridor					
	C2	**C2A**	**E1**	**E1A**	**E2**	**W2**
Total Alignment Area	250.6	305.9	260.4	259.8	241.4	214.8
Artificial Surfaces Area	103.2	99.2	103.4	76.5	82.1	101.0
Planted/Cultivated Areas	66.7	84.3	83.6	89.6	65.3	37.0
Forested Areas	38.6	61.3	22.3	33.0	26.3	33.9
Woodland Areas	2.5	15.4	8.9	7.6	7.6	6.0
Shrubland Areas	10.3	1.8	3.7	3.9	0.6	2.1
Grassland Areas	26.1	38.6	35.3	46.3	53.1	30.5
Water Surfaces Area	3.1	5.2	3.2	2.9	6.4	4.3

[1] Based on MLCCS categories (MnDNR 2004) after field verification and includes native and non-native dominated vegetation.

Table 3.3. Natural Community by Corridor and State Rarity Ranking

Vegetation [rarity ranking][1] (acres)	Alternative Corridor					
	C2	C2A	E1	E1A	E2	W2
Aspen Woodland [5]	0.9	0.0	0.0	0.0	0.0	0.0
Wetland Complex containing Calcareous Seepage Fen [1]	0.0	0.0	0.0	10.0	12.1	0.0
Floodplain Forest [3]	15.9	20.9	7.1	7.2	9.3	25.0
Lowland Hardwood Forest [4]	5.6	11.6	0.7	8.2	2.3	2.9
Maple-Basswood Forest [2]	11.2	22.4	10.4	10.7	13.4	0.0
Mixed Emergent Marsh [2]	3.6	16.2	1.0	1.0	8.7	19.3
Mixed Hardwood Swamp [3]	0.0	0.0	0.7	0.7	0.0	0.0
Native Dominated Temporarily Flooded Shrubland [4]	7.8	0.0	0.0	0.0	0.0	0.0
Oak Forest [2]	3.9	1.9	3.5	6.2	1.1	4.6
Oak Woodland-Brushland [4]	0.0	8.6	0.0	4.9	7.6	0.0
Wet Meadow [3]	3.5	0.0	6.4	0.04	4.3	0.0
Willow Swamp [4]	2.6	0.0	0.0	0.0	0.6	0.0
Total Natural Area	54.8	81.6	29.6	48.9	59.3	51.7

[1] Ranks of natural communities are defined in Minnesota Natural Heritage Program (1993). The numerical ranks range from 1 to 5 and "*…are intended to reflect the extent and condition of the natural communities in Minnesota…those ranked '1' are considered critically endangered in Minnesota, while communities ranked '5' are considered secure under present conditions.*" Where subtypes were possible, the ranking for the "Big Woods Section" subtype was used.

Table 3.4. Natural Community State Rarity Rankings by Corridor

State Rarity Ranking[1] (acres)	Alternative Corridor					
	C2	C2A	E1	E1A	E2	W2
1	0.0	0.0	0.0	10.0	12.1	0.0
2	18.7	40.5	14.8	17.9	23.2	23.8
3	19.4	20.9	14.1	8.0	13.6	25.0
4	15.9	20.2	0.7	13.1	10.4	2.9
5	0.9	0.0	0.0	0.0	0.0	0.0
Total	54.8	81.6	29.6	48.9	59.3	51.7

[1] Rarity ranks reflect the scarcity of different types of native plant communities within the state and within regions of the state. Ranks of natural communities are defined in Minnesota Natural Heritage Program (1993). The numerical ranks range from 1 to 5 and "*…are intended to reflect the extent and condition of the natural communities in Minnesota…those ranked '1' are considered critically endangered in Minnesota, while communities ranked '5' are considered secure under present conditions*." The ranks of individual plant communities in the study area is given in Table 3.3.

Table 3.5. Natural Community Element-Occurrence Rankings by Corridor

E-O Rank[1] (acres)	Alternative Corridor					
	C2	**C2A**	**E1**	**E1A**	**E2**	**W2**
A	0.0	0.0	0.0	0.0	0.0	0.0
B	36.3	44.9	2.8	8.1	8.7	33.3
BC	0.0	0.0	0.0	20.0	25.5	0.0
C	18.5	36.0	11.0	18.9	23.7	16.0
D	0.0	0.7	15.8	2.0	1.5	2.4

[1] The MnDNR Natural Heritage Program guidelines (MnDNR undated; 2004) were used for assessing and ranking the integrity of natural communities:

A – "*Highest quality natural community, no disturbances, and natural processes intact.*"

B – "*Good quality natural community. Has its natural processes intact, but shows signs of past human impacts. Low levels of exotics.*"

C – "*Moderate condition natural community with obvious past disturbance but is still clearly recognizable as a native community. Not dominated by weedy species in any layer.*"

D – "*Poor condition natural community. Includes some natives, but is dominated by non-natives and/or is widely disturbed and altered.*"

Table 3.6. Biodiversity Area Rankings by Corridor

Biodiversity Ranking[1] (acres)	Alternative Corridor					
	C2	C2A	E1	E1A	E2	W2
Outstanding	0.0	0.0	0.5	30.6	26.0	0.0
High	0.0	0.0	0.0	0.0	0.0	0.0
Moderate	0.0	0.0	13.6	14.0	10.8	0.0
Below Minimum Threshold	36.4	47.7	39.8	40.8	41.8	61.2
Total	36.4	47.7	53.9	85.4	78.5	62.1

[1] Biodiversity areas are defined and classified by the Minnesota County Biological Survey of the MnDNR. Categories are defined as follows:

Outstanding – "*Sites containing the best occurrences of the rarest species, the most outstanding examples of the rarest native plant communities, and/or the largest, most intact functional landscapes present;*"

High – "*Sites containing the 'best of the rest,' such as sites with very good quality occurrences of the rarest species, high quality examples of the rarest native plant communities, and/or important functional landscapes;*"

Moderate – "*Sites containing significant occurrences of rare species, and/or moderately disturbed native plant communities and landscapes that have a strong potential for recovery;*"

Below minimum threshold – "*sites lacking occurrences of rare species and/or natural features that meet MCBS standards for an Outstanding, High, or Moderate rank. These include areas of conservation value at the local level, such as habitat for native plants and animals, corridors for animal movements, buffers surrounding higher quality natural areas, and open spaces.*"

Table 3.7. Estimates of Habitat Fragmentation Impacts by Corridor

Type of Impact (acres or percent)	Alternative Corridor					
	C2	**C2A**	**E1**	**E1A**	**E2**	**W2**
Impact to Forest Edge	18.76	31.88	16.18	14.25	11.63	9.08
Impact to Forest Interior	20.75	33.55	12.17	20.05	21.77	24.86
Percent of Forest Impact that is Interior Habitat	52.5%	51.3%	42.9%	58.4%	65.2%	73.2%
Impact to Shrub/herbaceous Edge	5.14	0.00	0.94	5.95	7.99	6.54
Impact to Shrub/herbaceous Interior	12.19	16.20	0.01	3.52	16.62	14.71
Percent of Shrub/herbaceous Impact that is Interior Habitat	70.3%	100.0%	1.5%	37.1%	67.5%	69.2%
Creation of Forest Edge (outside corridor)	13.57	23.26	6.95	11.59	10.19	15.90
Creation of Shrub/herbaceous edge (outside corridor)	6.82	6.74	0.00	3.16	9.51	9.96

Table 3.8. Summary of Potential Impacts. Darker shades indicate greater potential impacts to natural areas and native species. Lighter shades indicate less potential impact.

Parameter (reported as acres or text)	Alternative Corridor					
	C2	C2A	E1	E1A	E2	W2
Native Vegetation	54.8	81.6	29.9	48.9	59.3	51.7
High Quality Native Vegetation (BC rank or better)	36.3	44.9	2.8	28.1	34.2	33.3
State Rarity Ranking of Native Vegetation (Rank 1-3)	38.1	61.4	28.9	35.9	48.9	48.8
Outstanding Biodiversity Area	0.0	0.0	0.5	30.6	26.0	
Forested Areas	38.6	61.3	22.3	33.0	26.3	33.9
Impact to Forest Interior	20.75	33.55	12.17	20.05	21.77	24.86
Creation of New Forest Edge	13.57	23.26	6.95	11.59	10.19	15.90
Current Fen[1]	0.0	0.0	0.0	3.96	5.84	0.0
Possible Historic and Restorable Fen[1]	0.0	0.0	0.0	3.62	3.93	0.0
Possible Historic and Severely Degraded Fen[1]	0.0	0.0	0.95	11.93	1.99	0.0
Protected Species Habitat or Occurrence	Potential bald eagle nest and roost sites	Potential bald eagle nest and roost sites	Potential bald eagle nest and roost sites	Potential bald eagle nest and roost sites; protected fen plants	Potential bald eagle nest and roost sites; protected fen plants	Potential bald eagle nest and roost sites

[1] Fen impacts are based on the acreage within the 300 ft. width corridor, not on the area of water table drawdown from dewatering.

Table 3.9. Vegetation types of the Seminary Fen Wetland Complex within Corridors E1, E1A, and E2.

Vegetation Type (acres)	Alternative Corridor		
	E1	E1A	E2
Agriculture	0.00	0.00	0.67
Common reed	0.00	0.00	0.00
Emergent marsh	0.00	0.00	0.00
Lake sedge meadow	0.00	0.93	0.00
Lake sedge/cattail	0.00	0.00	0.00
Lake sedge/common reed	0.00	0.00	0.00
Lowland hardwood forest	0.00	4.65	1.65
Open water	0.00	0.00	0.00
Reed canarygrass	0.95	8.58	1.99
Scattered dogwood/ tall sedge fen	0.00	0.00	2.80
Tall sedge fen	0.00	0.40	2.57
Tall sedge fen/cattail	0.00	0.00	0.47
Thick dogwood/tall sedge fen	0.00	3.14	0.53
Upland grasses	2.92	2.08	0.21
Upland oak forest	0.07	2.36	0.43
Willow swamp	0.00	3.50	3.39
Total	3.94	25.65	14.72

Table 3.10. Fen status of the Seminary Fen Wetland Complex within Corridors E1, E1A, and E2.

Fen Status (acres)	Corridor		
	E1	E1A	E2
Meets fen criteria	0.00	0.38	4.89
Meets fen criteria; short sedge fen possible	0.00	3.58	0.95
Possible historic and restorable fen	0.00	3.62	3.93
Possible historic fen but severely degraded	0.95	11.39	1.99
Upland	3.00	6.68	2.97
Total	3.95	25.65	14.72

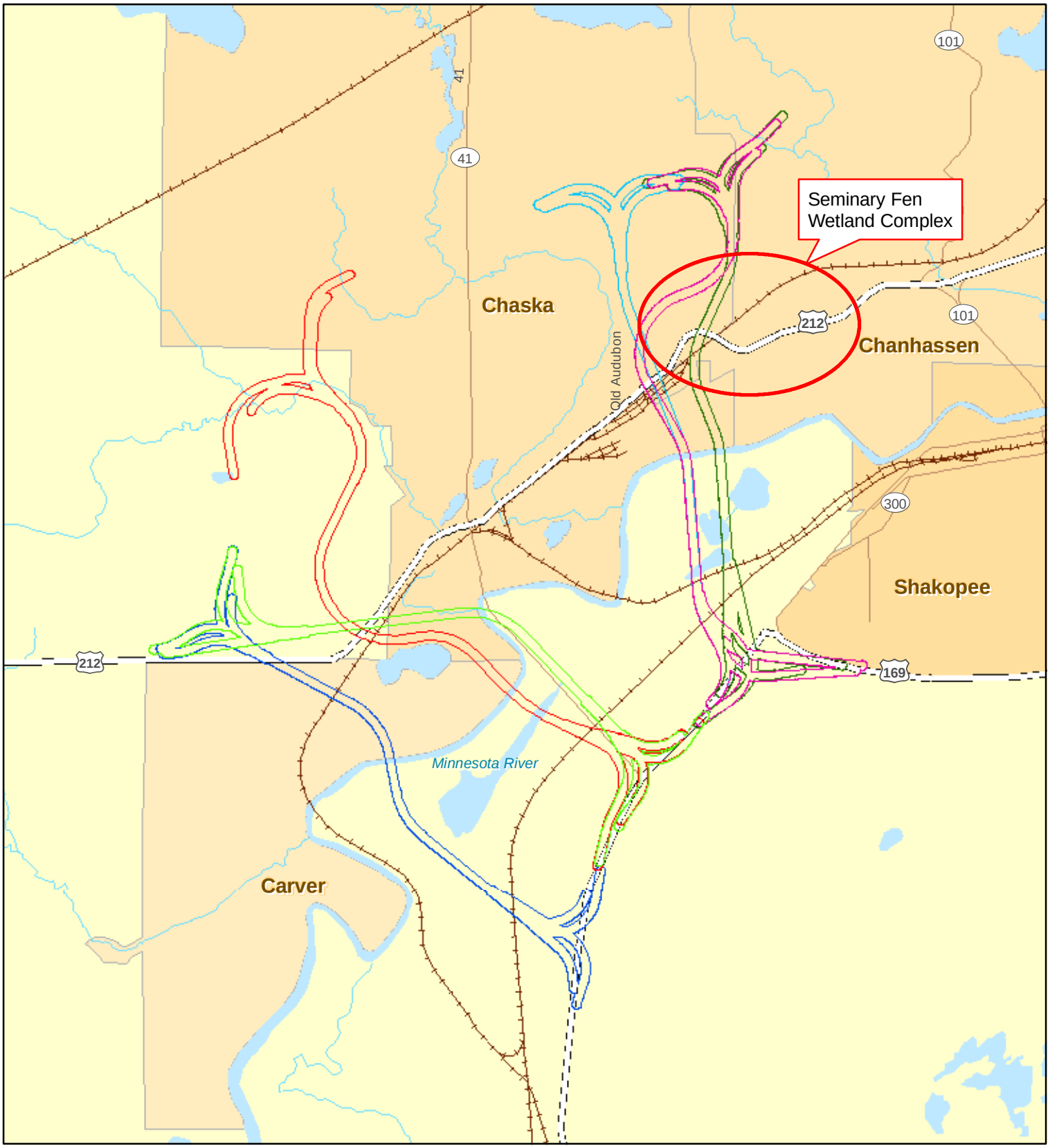
Table 3.11. Vegetation types in the 0.1 to 0.6 ft and ≥0.6 ft groundwater drawdown areas of Corridor E1, E1A, and E2.

Vegetation Type (acres)	Alternative Corridor and Groundwater Drawdown					
	E1		E1A		E2	
	0.1-0.6 ft	≥0.6 ft	0.1-0.6 ft	≥0.6 ft	0.1-0.6 ft	≥0.6 ft
Agriculture	2.35	0.00	3.03	0.00	2.75	2.44
Common reed	0.00	0.00	0.00	0.00	2.96	0.00
Emergent marsh	0.00	0.00	0.00	0.00	0.25	0.00
Lake sedge meadow	0.45	0.00	2.00	3.86	1.43	0.65
Lake sedge/cattail	0.00	0.00	0.48	0.00	0.00	0.00
Lake sedge/common reed	0.00	0.00	0.00	0.00	0.00	0.00
Lowland hardwood forest	4.62	0.91	4.02	14.75	4.44	10.83
Open water	0.00	0.00	0.07	0.00	0.01	0.15
Reed canarygrass	5.10	4.95	9.95	16.55	10.76	7.45
Scattered dogwood/ tall sedge fen	0.00	0.00	0.56	0.00	0.86	9.24
Tall sedge fen	0.00	0.00	3.62	0.95	6.70	8.89
Tall sedge fen/cattail	0.00	0.00	0.00	0.00	0.00	1.25
Thick dogwood/tall sedge fen	0.00	0.00	0.81	4.18	1.58	1.17
Upland grasses	1.71	3.66	2.88	3.86	0.34	2.22
Upland oak forest	1.52	0.36	0.70	9.63	2.95	2.18
Willow swamp	0.00	0.00	4.66	9.55	4.29	10.44
Total	15.76	9.88	32.80	63.33	40.53	56.89

Table 3.12. Fen status in the 0.1 to 0.6 ft and ≥0.6 ft groundwater drawdown areas of Corridor E1, E1A, and E2.

Fen Status (acres)	Corridor and Groundwater Drawdown					
	E1		E1A		E2	
	0.1-0.6 ft	≥0.6 ft	0.1-0.6 ft	≥0.6 ft	0.1-0.6 ft	≥0.6 ft
Meets fen criteria	0.00	0.00	4.17	1.32	9.39	12.93
Meets fen criteria; short sedge fen possible	0.45	0.00	0.08	5.81	0.00	6.05
Possible historic and restorable fen	0.00	0.00	6.49	12.25	8.84	12.04
Possible historic fen but severely degraded	9.72	5.86	12.77	26.99	12.21	8.07
Upland	5.59	4.02	9.29	16.95	10.10	17.81
Total	15.76	9.88	32.80	63.33	40.53	56.89

Figures



Barr Footer: Date: 1/11/2007 9:46:23 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_1.1_rev.mxd User: cdf

Corridors

- C2
- C2A
- E1A
- E1
- E2
- W2

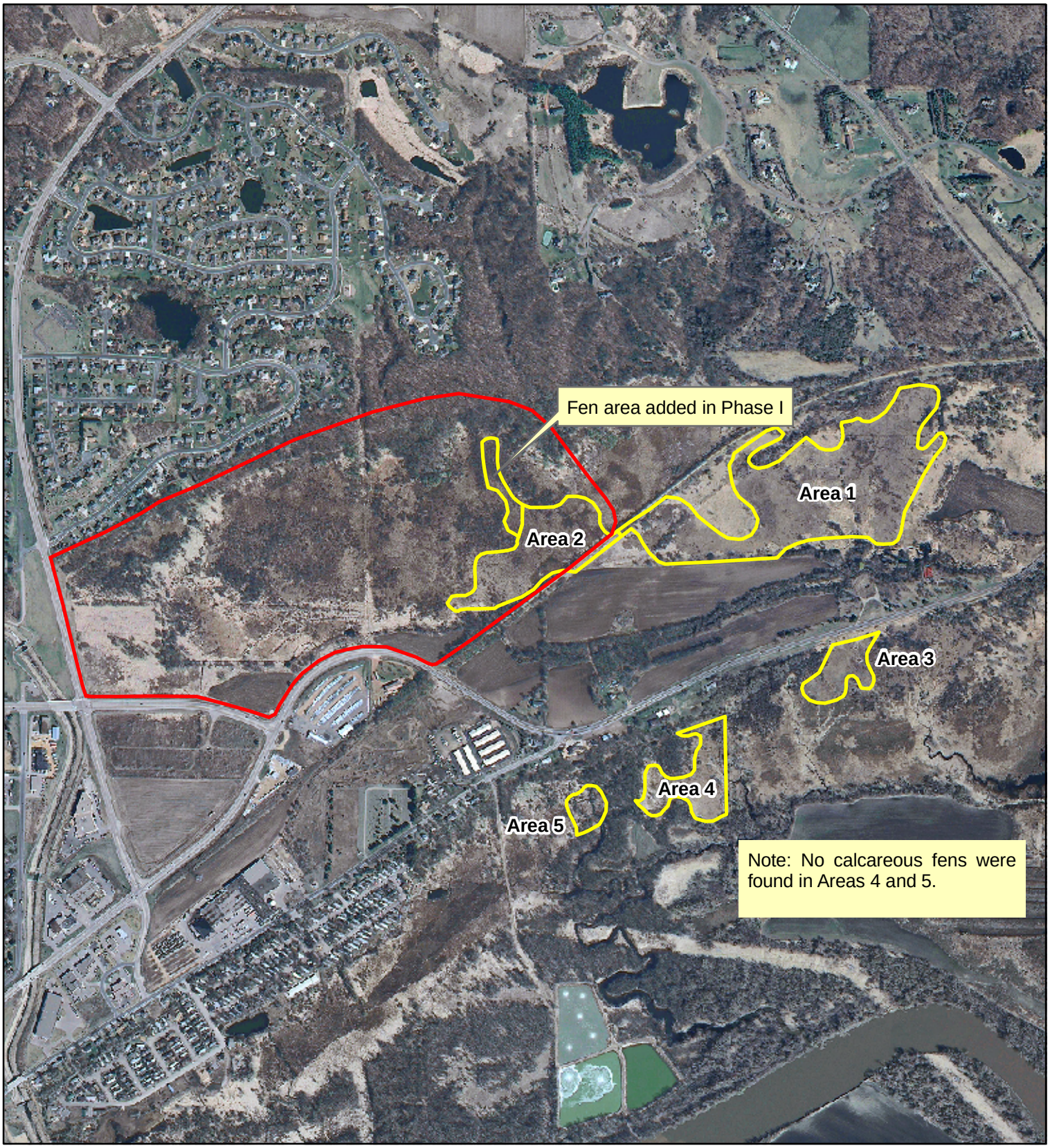
N

0 0.5 1 2 Km

0 0.25 0.5 1 1.5 2 Miles

BARR

Figure 1.1
LOCATION MAP
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



2005 FSA Aerial Photo

Barr Footer: Date: 1/11/2007 9:55:02 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_1.2_rev.mxd User: cdf

Study Areas

Phase I Study Area

Phase II Study Area

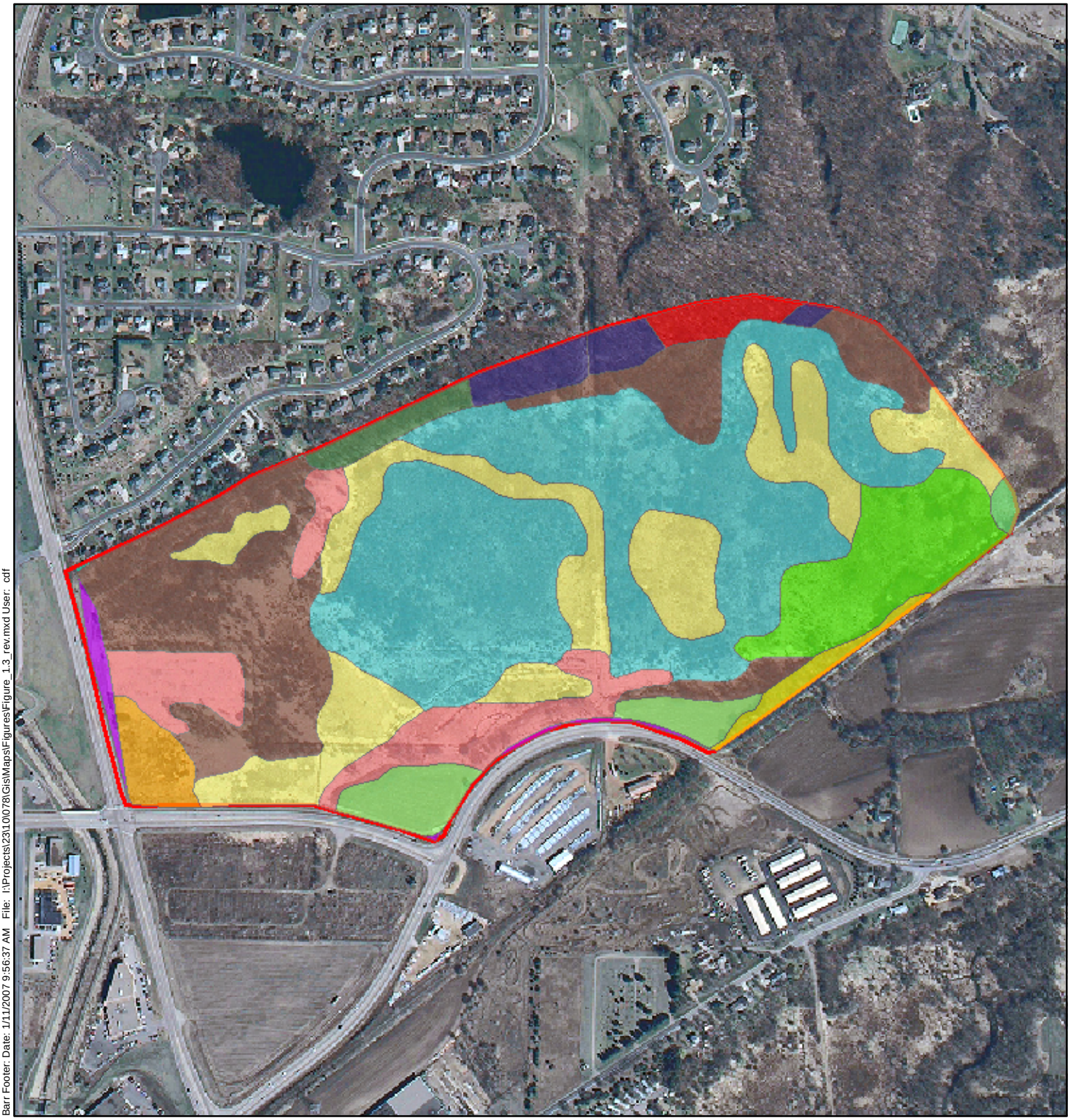
N

0 125 250 500 Meters

0 500 1,000 2,000 Feet

BARR

Figure 1.2
PHASE 1 AND PHASE 2 STUDY AREAS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



2005 FSA Aerial Photo

MLCCS

- 26% to 50% impervious cover with deciduous trees
- 51% to 75% impervious cover with perennial grasses
- 76% to 90% impervious cover
- Calcareous seepage fen prairie subtype
- Lowland hardwood forest
- Maple-basswood forest
- Medium-tall grass altered/non-native dominated grassland
- Mixed emergent marsh - seasonally flooded
- Oak forest mesic subtype
- Oak woodland-brushland
- Saturated altered/non-native dominated graminoid vegetation
- Shrub swamp seepage subtype
- Upland soils - cropland
- Wet meadow

N

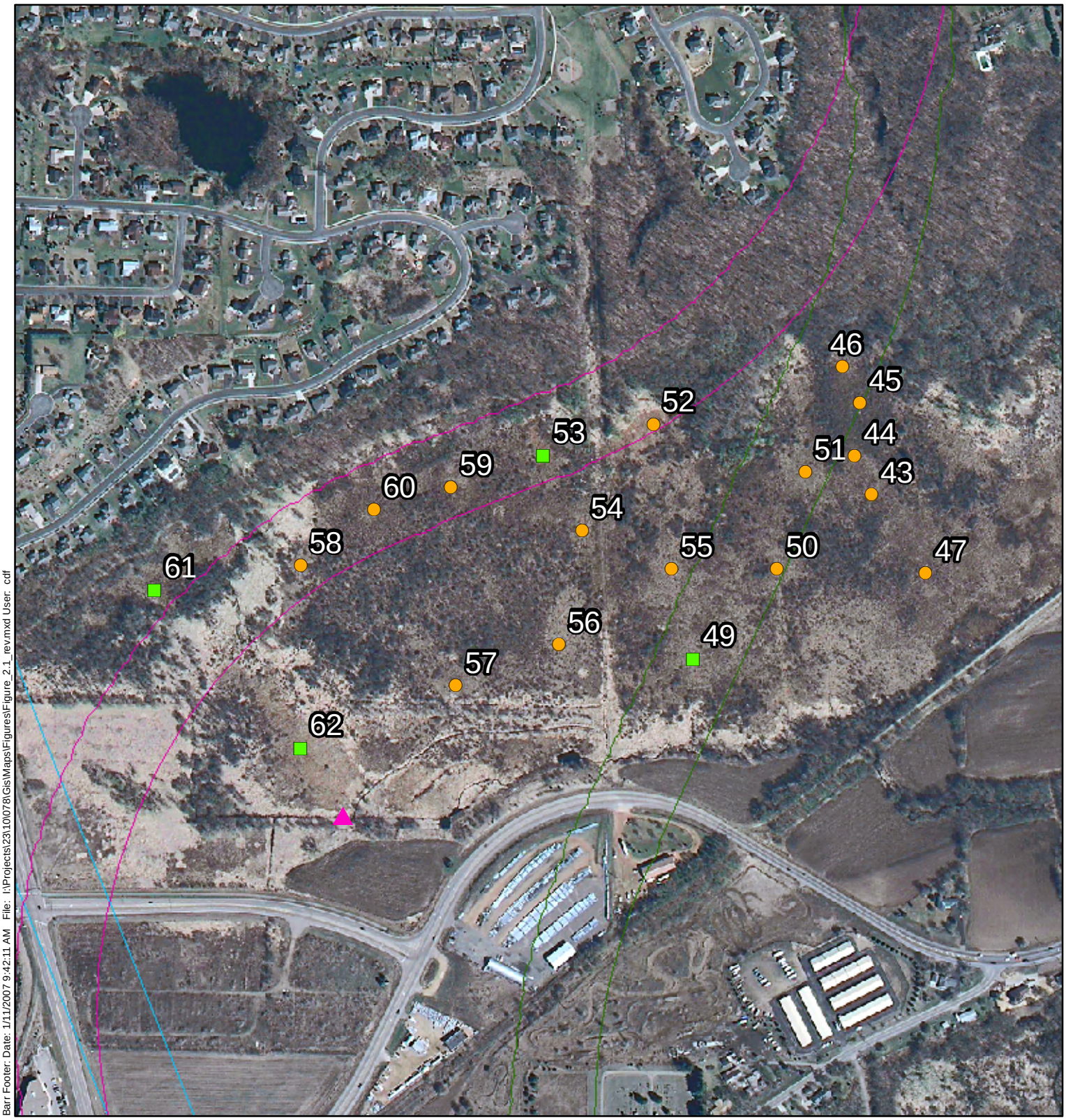
0 100 200 300 Meters

0 500 1,000 Feet

BARR

Figure 1.3
MNDNR MLCCS MAP
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT

Barr Footer: Date: 1/11/2007 9:56:37 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_1.3_rev.mxd User: cdf



2005 FSA Aerial Photo

Sample Sites

- Surface Water Sample Site
- Botanical, Soil and Groundwater Sample Sites
- Botanical Sample Sties

Corridors

- E1A
- E1
- E2

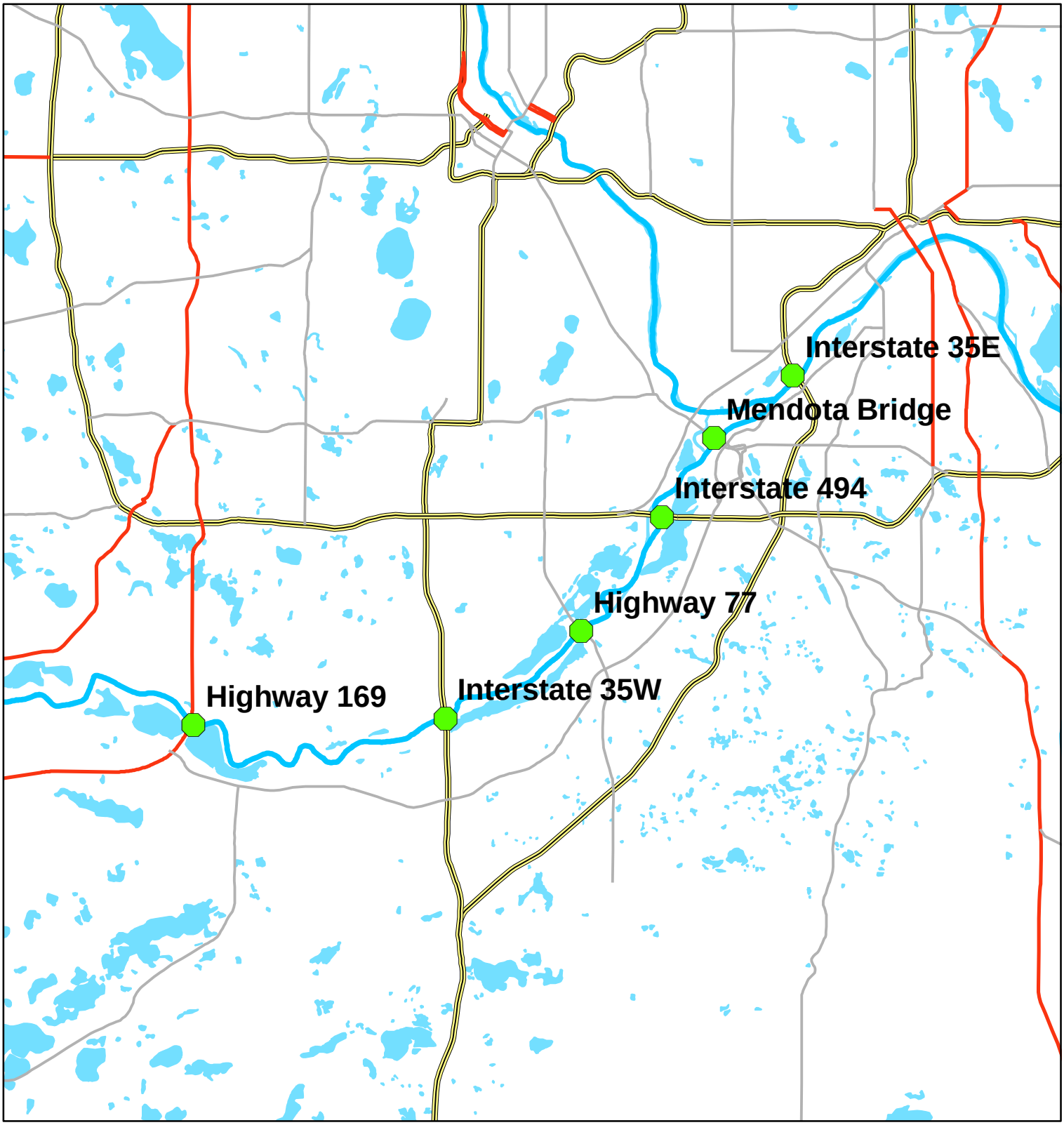
N

0 50 100 200
300
Meters
0 250 500
1,000
Feet

BARR

Figure 2.1
PHASE 2 SAMPLE LOCATIONS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT

Barr Footer: Date: 1/11/2007 9:42:11 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_2.1_rev.mxd User: cdf



Barr Footer: Date: 1/11/2007 9:40:49 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_2.2_rev.mxd User: cdf

N

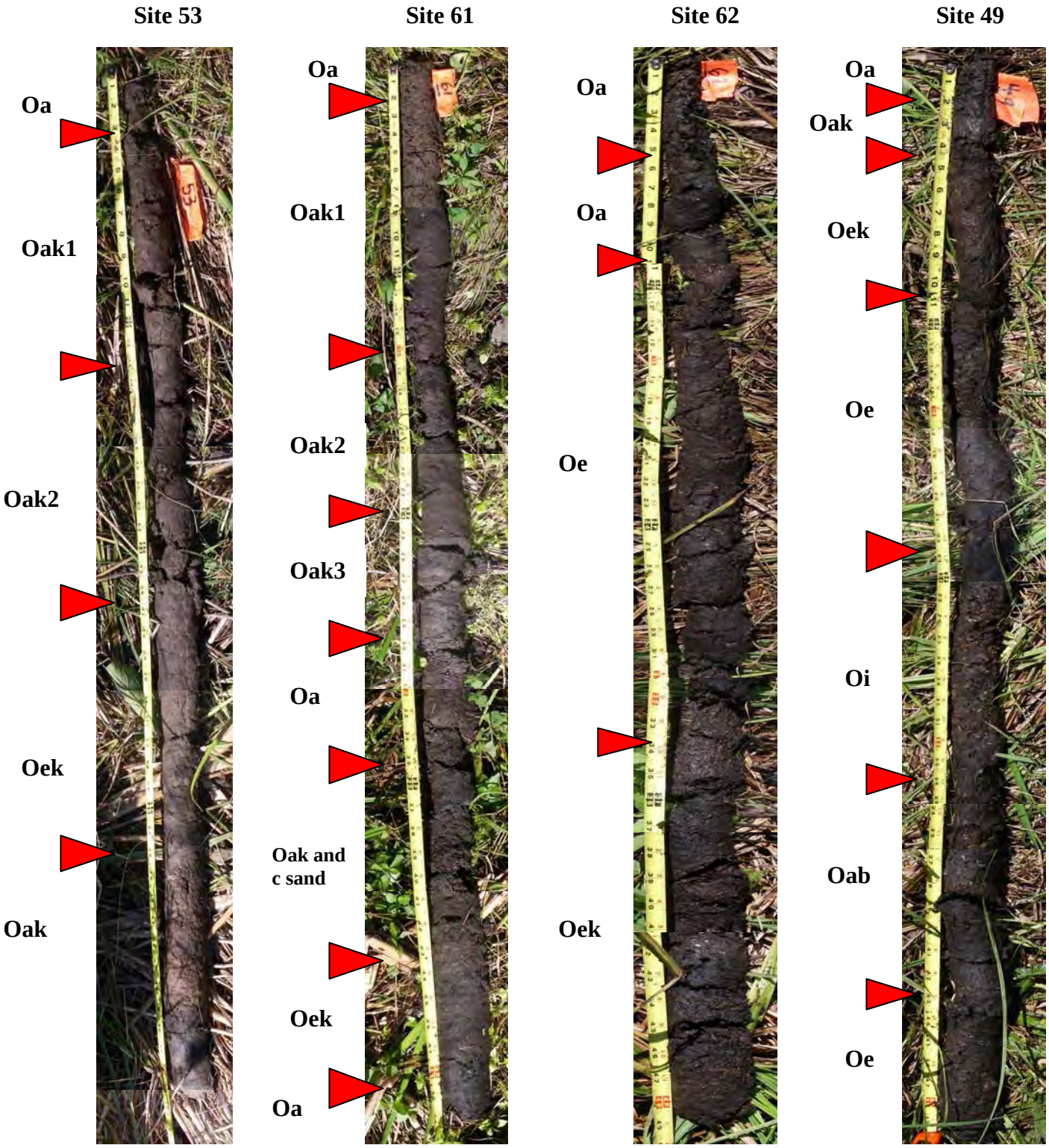
BARR

Bridge Locations

2 0 2 4 6 Km

1 0 1 2 3 4 Miles

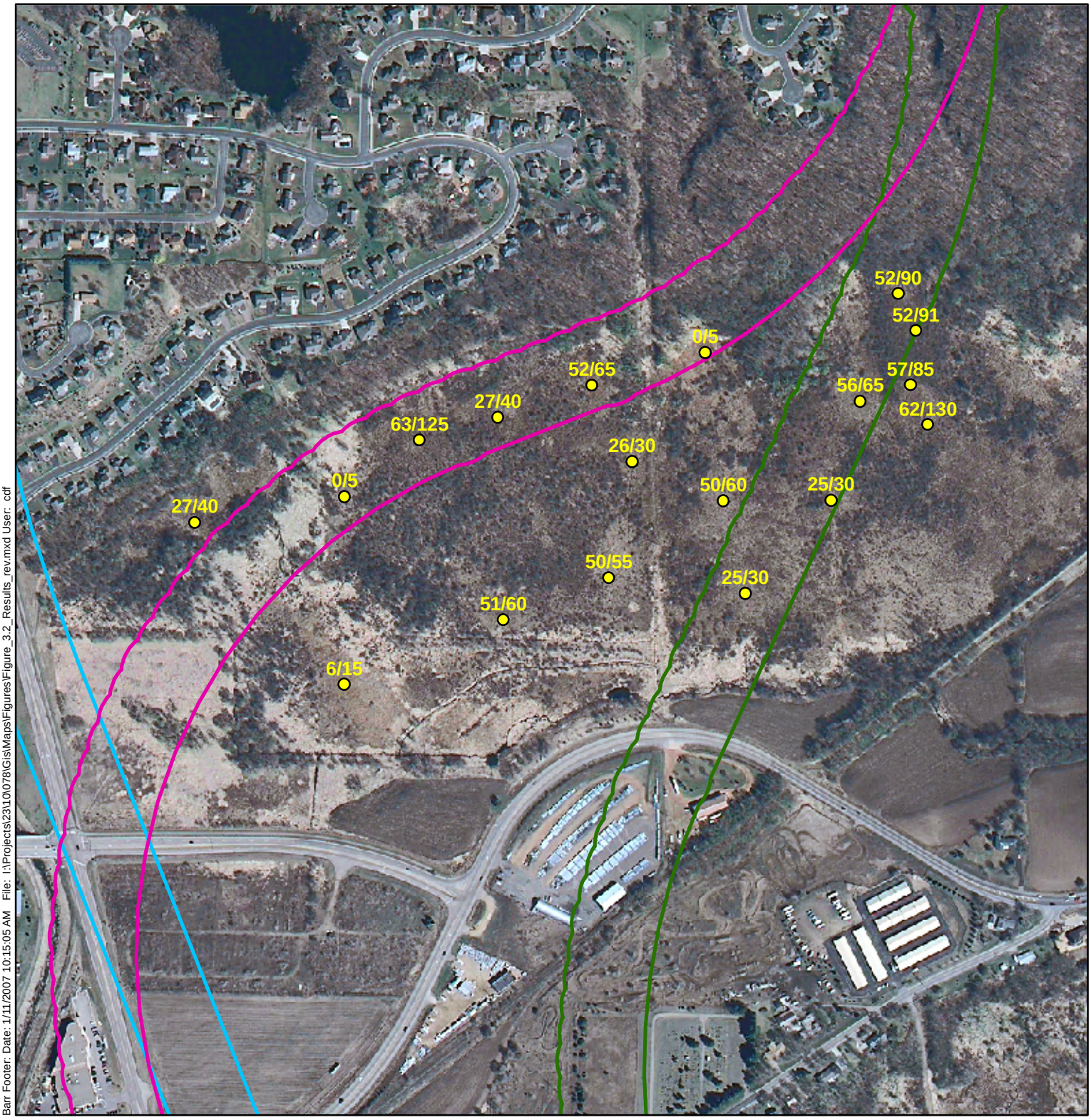
Figure 2.2
BRIDGE ENVIRONMENT
STUDY LOCATIONS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



Note: Soil profiles for the Seminary Fen were described and colored in the field on September 5, 2006. No soil pedons were collected. The soil colors of the compiled jpegs do not reflect the actual field colors due to differences in the flash (use/no use), shadows and moisture content of the pedon. See soil profile descriptions for more details. Soil horizon distinctions were based on effervescence, fiber content, structure and color.

Soil Horizon Designations: Well decomposed or sapric organic layer (Oa); decomposed or hemic organic layer (Oe); Poorly decomposed or fibric organic layer (Oi); Accumulation of carbonates (k); Buried soil surface (b) and Coarse sand (c sand). A number at the end of the soil horizon nomenclature indicates a sequence of similar horizons in the profile (e.g. Oak2).

Figure 3.1
SOIL PROFILES
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



Barr Footer: Date: 1/11/2007 10:15:05 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_3.2_Results_rev.mxd User: cdf

2005 FSA Aerial Photo

Sample Sites

Corridor E1A

Corridor E1

Corridor E2

Sample sites are labelled with calcareous fen vascular plant indicator species scores using 1995 guidelines (left) and 2005 guidelines (right).

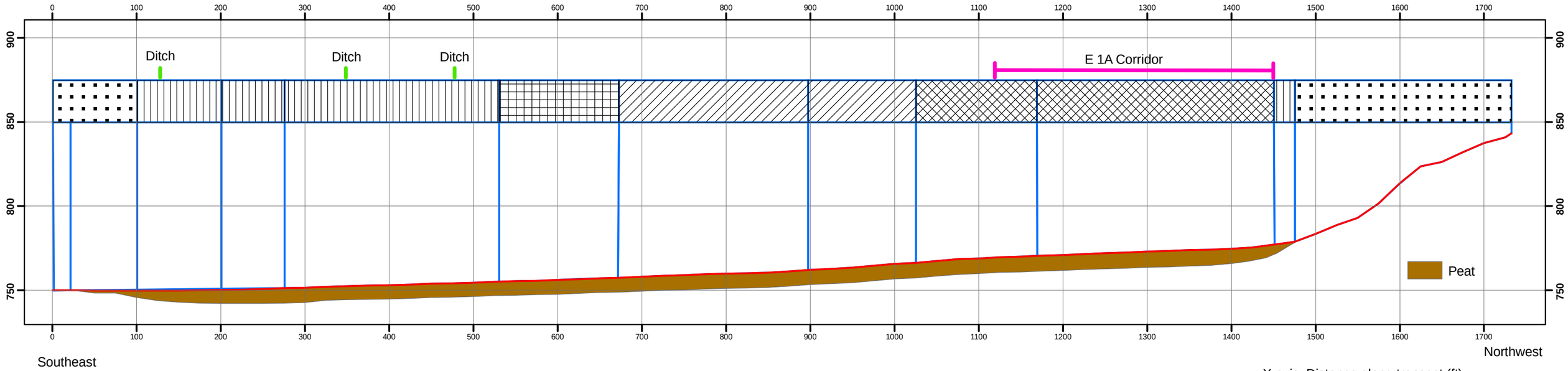
N

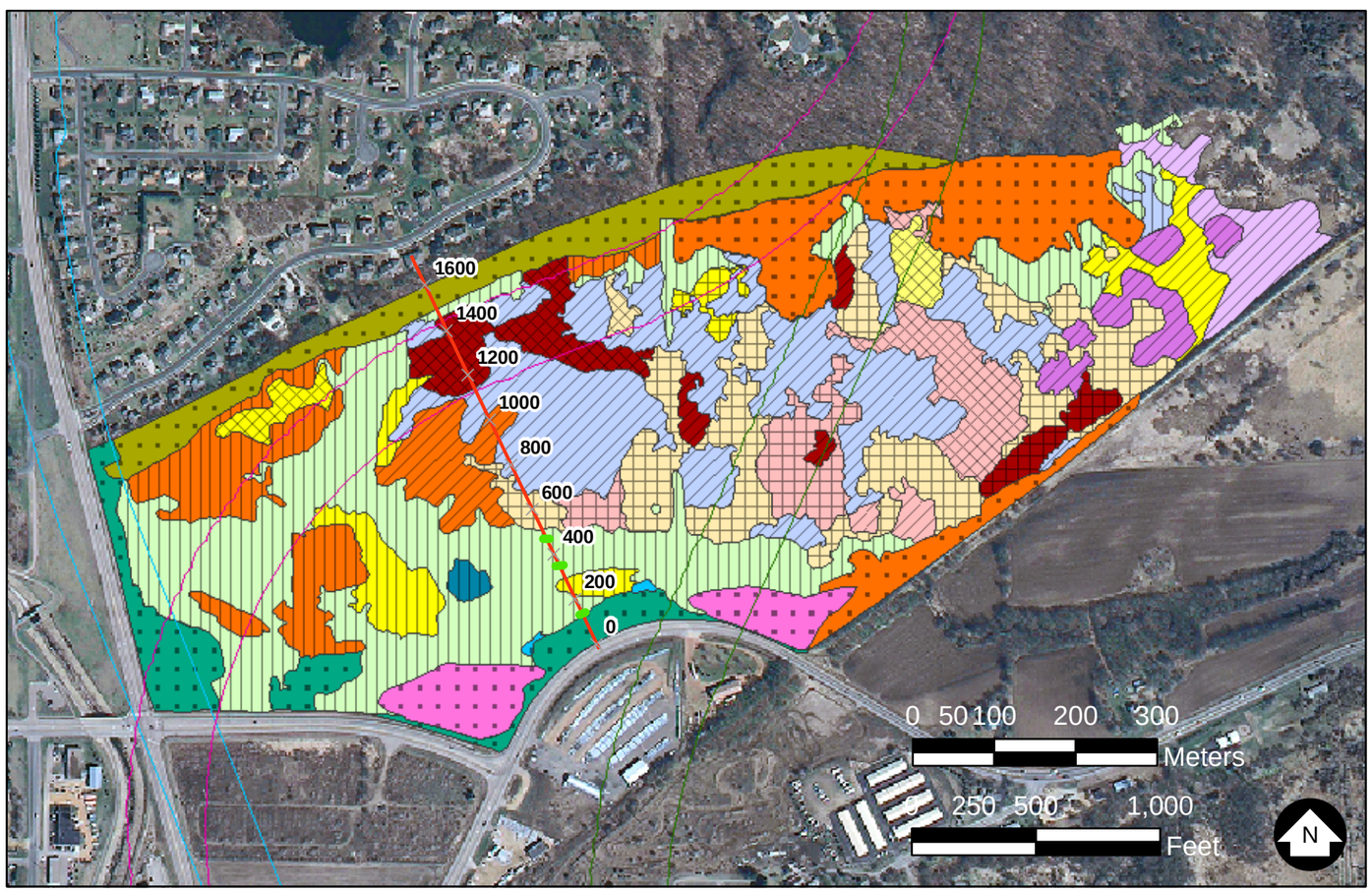
0 50 100 200 300 Meters

0 250 500 1,000 Feet

BARR

Figure 3.2
VASCULAR PLANT FEN INDICATOR SPECIES SAMPLING RESULTS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT





Fen Status

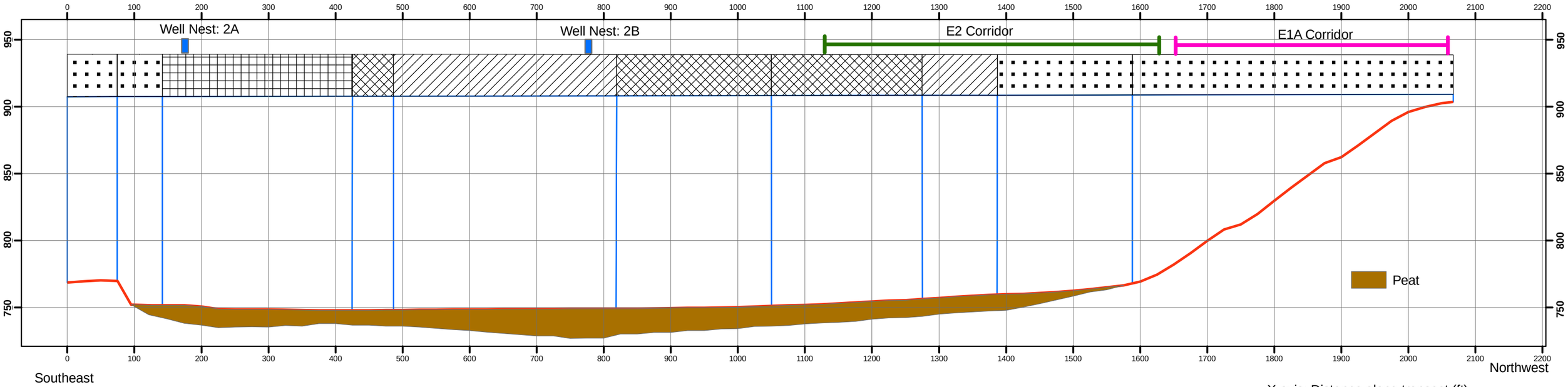
- Meets fen criteria
- Meets fen criteria; short sedge fen possible
- Possible historic and restorable fen
- Possible historic fen but severely degraded
- Upland
- Transect
- Ditch Crossing

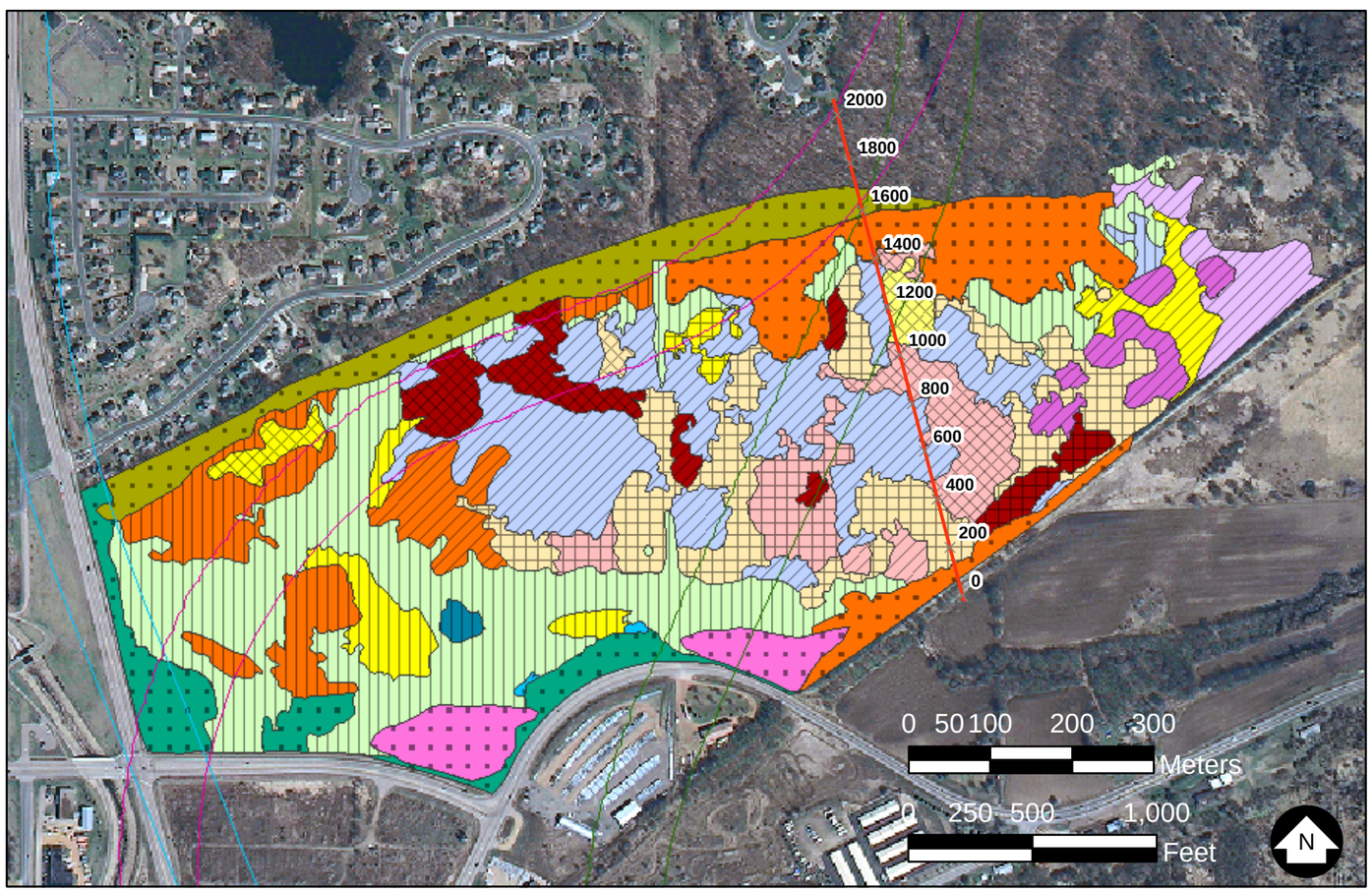
Vegetation

- Agriculture
- Common reed
- Emergent marsh
- Lake sedge meadow
- Lake sedge/cattail
- Lowland hardwood forest
- Open water
- Reed canarygrass
- Scattered dogwood/tall sedge fen
- Tall sedge fen/cattail
- Tall sedge fen
- Thick dogwood/tall sedge fen
- Upland grasses
- Upland oak forest
- Willow swamp

BARR

Figure 3.3
VEGETATION AND FEN AREAS
WESTERN TRANSECT
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT





Fen Status

- Meets fen criteria
- Meets fen criteria; short sedge fen possible
- Possible historic and restorable fen
- Possible historic fen but severely degraded
- Upland
- Transect

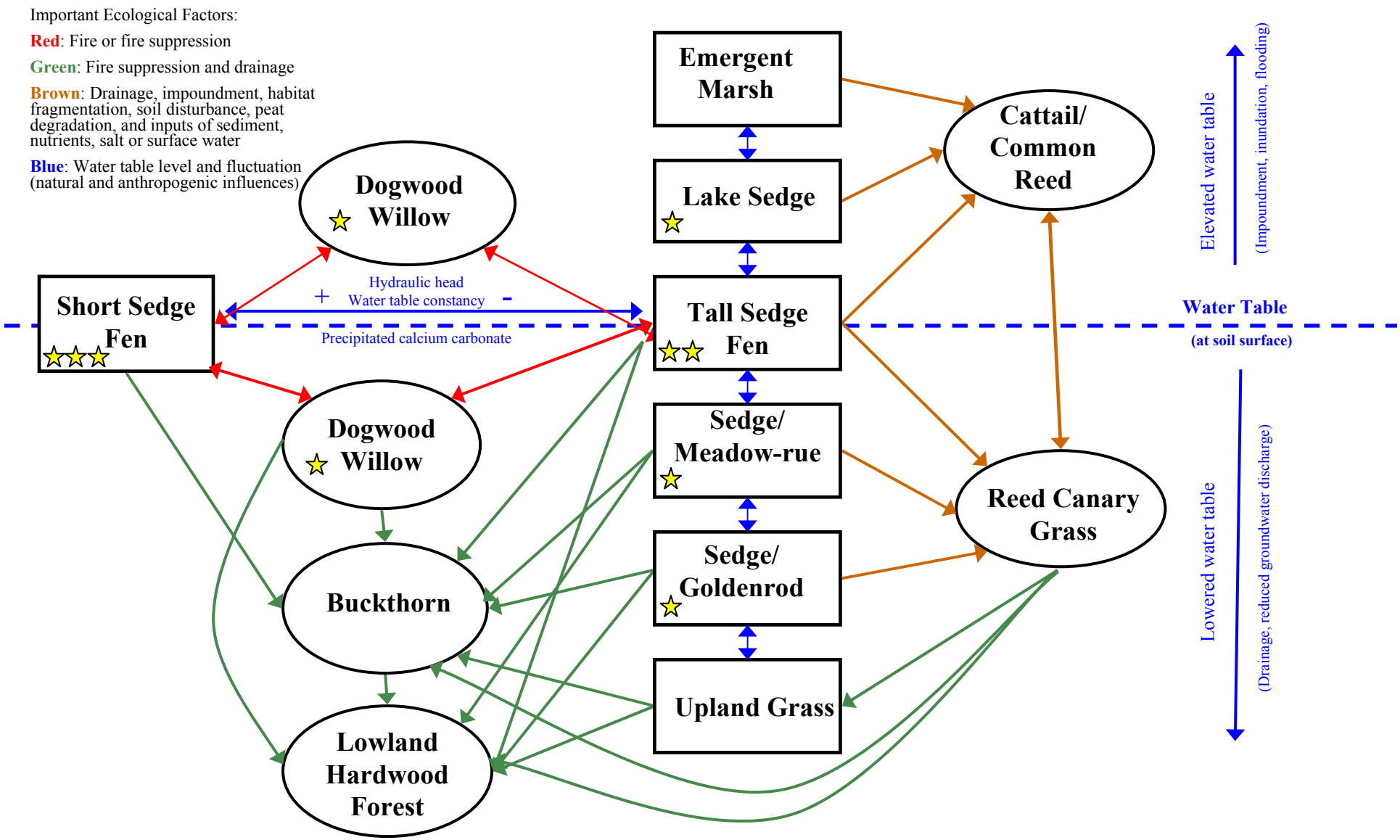
Vegetation

- Agriculture
- Common reed
- Emergent marsh
- Lake sedge meadow
- Lake sedge/cattail
- Lowland hardwood forest
- Open water
- Reed canarygrass
- Scattered dogwood/tall sedge fen
- Tall sedge fen/cattail
- Tall sedge fen
- Thick dogwood/tall sedge fen
- Upland grasses
- Upland oak forest
- Willow swamp

BARR

Figure 3.4
VEGETATION AND FEN AREAS
EASTERN TRANSECT
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT

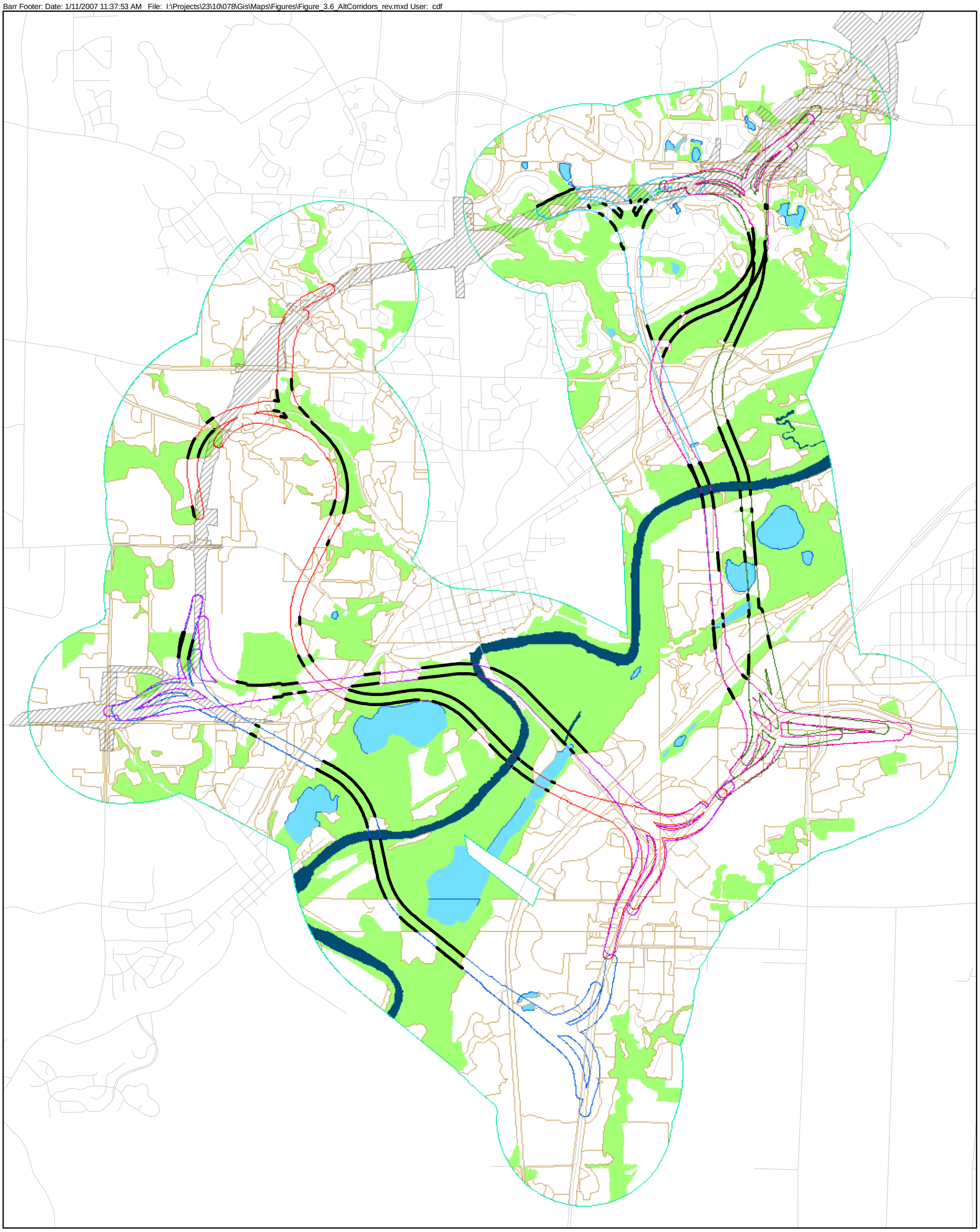
Barr Footer: Date: 1/11/2007 11:07:59 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_3.4_Profile_east_final_rev.mxd User: cdf



Note: Double-headed arrows indicate pathways resulting from natural and anthropogenic factors. The pathways may have been reversible historically through natural succession or could potentially be reversed through restoration and management. Single-headed arrows indicate pathways resulting from complex interactions of factors, most of which are anthropogenic impacts. These pathways may not be reversible, or if they are, only through intensive restoration and management. See text for more explanation.

☆ = fen species occasionally present
☆☆ = some fen species common
☆☆☆ = greatest occurrence of fen species

Figure 3.5
CONCEPTUAL MODEL OF FEN SUCCESSION AND DISTURBANCE
Seminary Fen Phase 2 Project
SRF/MNDOT



New vegetation edge
Half-mile buffer
C2
C2A
E1A
E1
E2
W2
Developed area or non-native vegetation
Native vegetation
Open water
River or moving water
Highway 212 Corridor

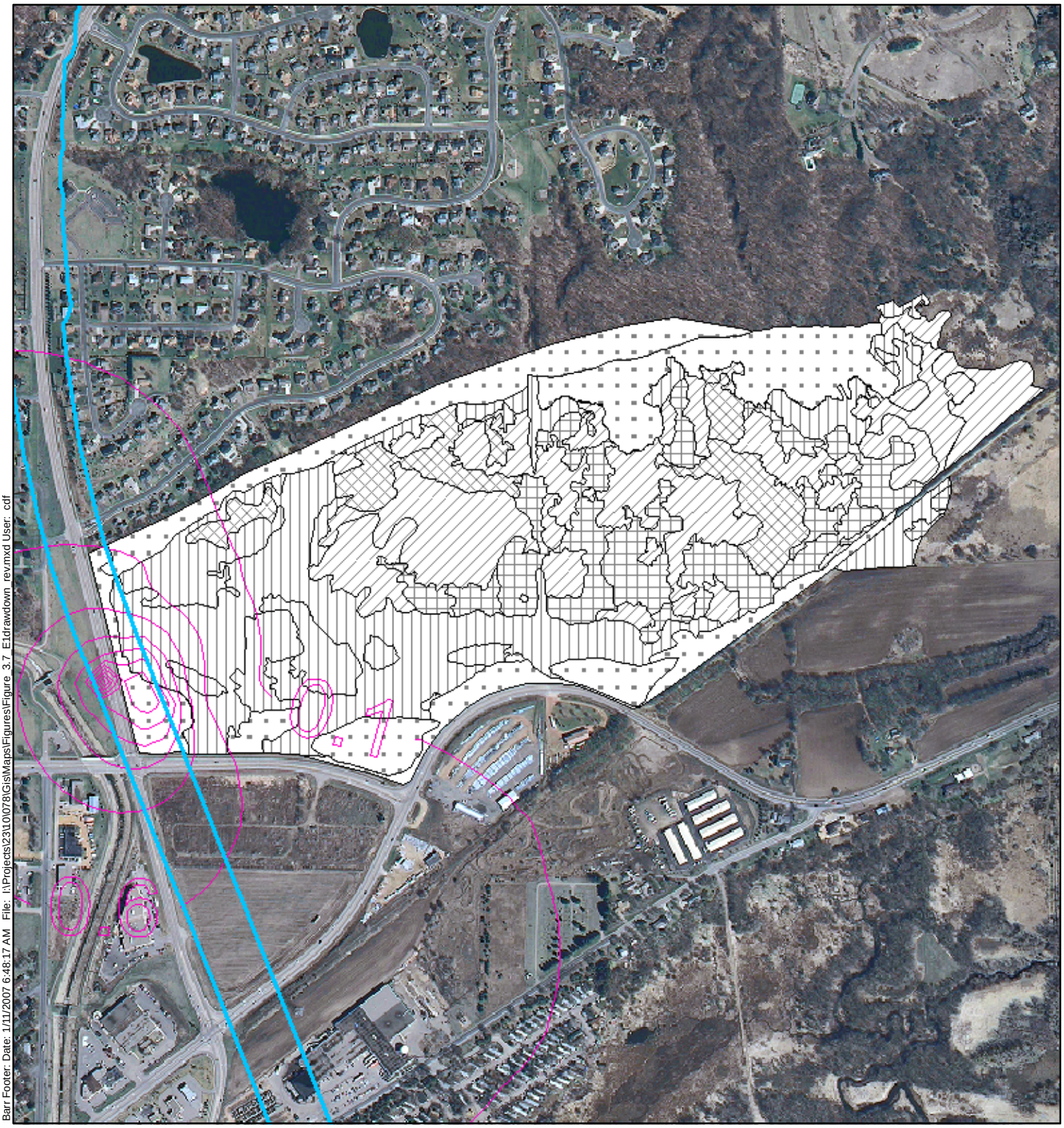
N

1,000 0 1,000 2,000 Meters

0.5 0 0.5 1 Miles

BARR

Figure 3.6
TH 41 ALTERNATIVE ALIGNMENTS
VEGETATION STUDY
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



Barr Footer: Date: 1/11/2007 6:48:17 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_3.7_E1drawdown_rev.mxd User: cdf

2005 FSA Aerial Photo

E1 Drawdown

Corridor E1

Fen Status

- Meets fen criteria
- Meets fen criteria; short sedge fen possible
- Possible historic and restorable fen
- Possible historic fen but severely degraded
- Upland

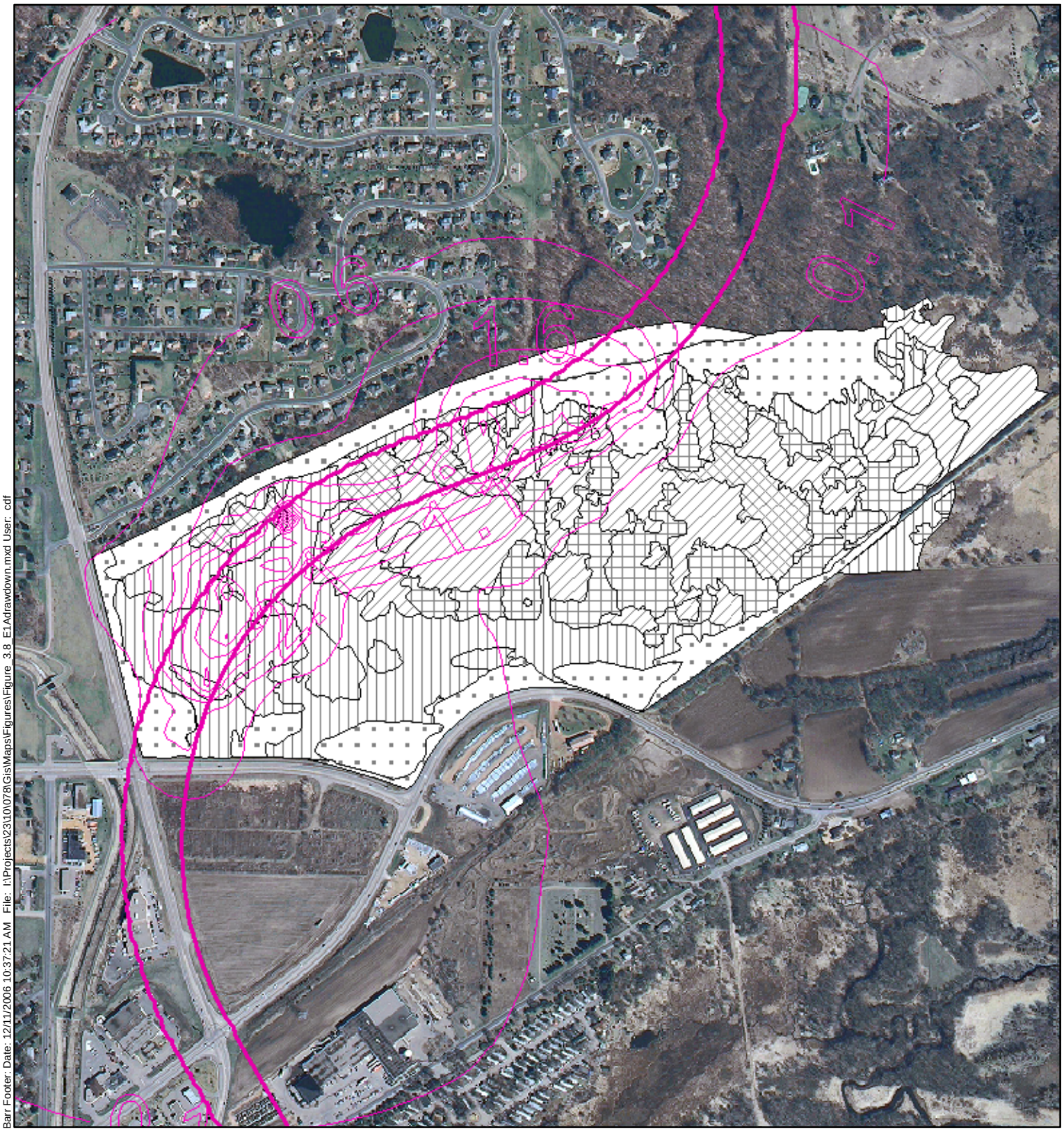
N

0 50 100 200 300 Meters

0 250 500 1,000 Feet

BARR

Figure 3.7
E1 DRAWDOWN AND
CALCAREOUS FEN AREAS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



Barr Footer: Date: 12/11/2006 10:37:21 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_3.8_E1Adrawdown.mxd User: cdf

2005 FSA Aerial Photo

E1A Drawdown

Corridor E1A

Fen Status

- Meets fen criteria
- Meets fen criteria; short sedge fen possible
- Possible historic and restorable fen
- Possible historic fen but severely degraded
- Upland

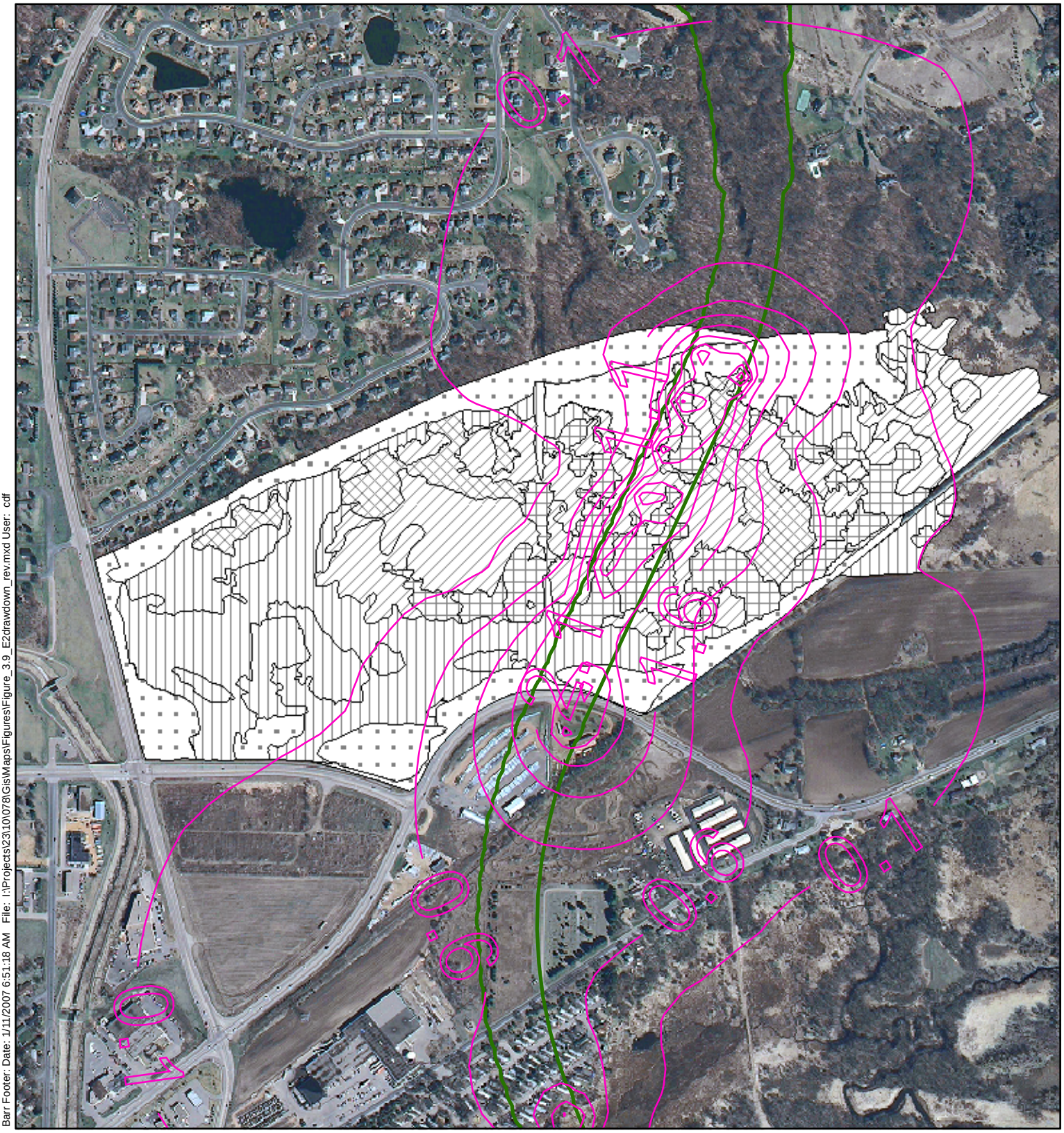
N

0 50 100 200 300 Meters

0 250 500 1,000 Feet

BARR

Figure 3.8
E1A DRAWDOWN AND
CALCAREOUS FEN AREAS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT



2005 FSA Aerial Photo

E2 Drawdown

Corridor E2

Fen Status

- Meets fen criteria
- Meets fen criteria; short sedge fen possible
- Possible historic and restorable fen
- Possible historic fen but severely degraded
- Upland

N

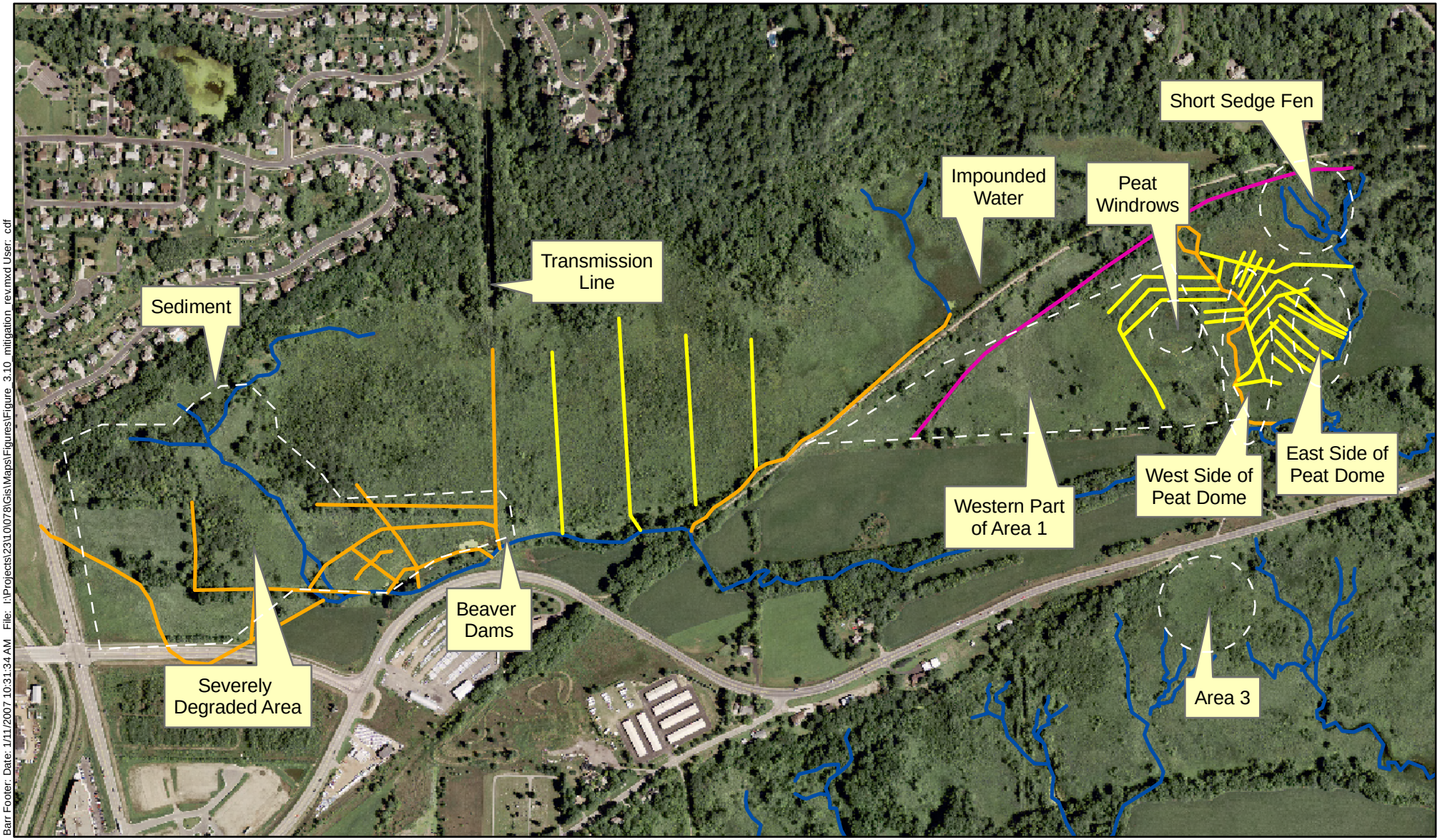
0 50 100 200 300 Meters

0 250 500 1,000 Feet

BARR

Figure 3.9
E2 DRAWDOWN AND CALCAREOUS FEN AREAS
Seminary Fen Phase 2 Study
SRF/MNDOT
DRAFT

Barr Footer: Date: 1/11/2007 6:51:18 AM File: I:\Projects\23\10\078\Gis\Maps\Figures\Figure_3.9_E2drawdown_rev.mxd User: cdf



2006 FSA Aerial Photo

Natural Drainageways
Probable Draintiles
Surface Ditches
Abandoned Road Bed

N

100 0 100 200 300 400 500 Meters

500 0 500 1,000 1,500 Feet

BARR

Figure 3.10
RESTORATION AND MANAGEMENT NEEDS AND OPPORTUNITIES
Seminary Fen Phase 2 Project
SRF/MNDOT
DRAFT

Barr Footer: Date: 1/11/2007 10:31:34 AM File: I:\Projects\2310\078\Gis\Maps\Figures\Figure_3.10_mitigation_rev.mxd User: cdf

Appendices

Appendix A. Vascular Plant Data

Appendix A. Vascular Plant Sampling Results. Data presented represents cover class of species within plots.

Species	Transect 43					44					46					49					50				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Acer negundo																									
Aster borealis																									
Aster firmus																	1		2	3					
Aster puniceus																						2			
Aster spp.					1	2		2	2		2				2		2	3	2	2					
Aster umbellatus											2					3		1			1		1		1
Bromus ciliatus								2	2	2															
Calamagrostis canadensis											1														
Caltha palustris																					3	3	3	1	4
Campanula aparinoides							1	1		1	2		2	1	1			2							
Cardamine bulbosa																									
Carex hystericina																									
Carex lacustris																2	3	2	3	3					
Carex lasiocarpa								2																	
Carex prairea						2	2	3	2	2		2	5	4	3						2				
Carex sartwellii	2	1	3	2	4	3		2	3	3	2	4			3						2	2	5	5	5
Carex sterilis				2		2								2											
Carex stricta					1	3					2					4	3	5	3	3	5	2		1	1
Cicuta bulbifera																				1					
Cicuta maculata																								1	
Cirsium muticum																									
Cuscuta pentagona																									
Eleocharis spp.						1						1													
Equisetum																						2			
Equisetum pratense																		3							
Eupatorium maculatum			3			1			2		2			2	2				1						
Eupatorium perfoliatum																		2							1
Galium labradoricum			1			1						1													
Glyceria striata															2										
Helianthus grosseserratus																				1					
Helianthus spp												3		1						2					
Hieracium sp.																									
Impatiens capensis																2	1		2	1			1	1	1
Leersia oryzoides																									
Lycopus americanus																									
Lycopus asper																									
Lycopus uniflorus					1										1	1	1	1		1		1			
Lysimachia thyrsifolia																									
Mentha arvensis																									
Mentha canadensis																			1						
Muhlenbergia mexicana						3																			
Muhlenbergia racemosa																									
Muhlenbergia spp.																									

Species	Transect 51					52					53					54					55				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Acer negundo																									
Aster borealis																									
Aster firmus																									
Aster puniceus	4	2		2																					
Aster spp.											2	2	2									2	1	3	3
Aster umbellatus																									
Bromus ciliatus																									
Calamagrostis canadensis																									
Caltha palustris																									
Campanula aparinoides											1	2	2	2	2										1
Cardamine bulbosa																									
Carex hystericina																									
Carex lacustris						3	4	5	4	3	2			4	3	4	2	4	4	3					
Carex lasiocarpa				1																					
Carex prairea		2			1						2										2		2	2	
Carex sartwellii																2	3	2	3	2	4	4	4	3	2
Carex sterilis																									
Carex stricta	5	6	5	3	3					3	3	3	4	3	2		2					2			4
Cicuta bulbifera																	1								
Cicuta maculata																									
Cirsium muticum																									
Cuscuta pentagona																									
Eleocharis spp.																									
Equisetum																					2				
Equisetum pratense																									
Eupatorium maculatum		2		2	1					2		2			3							2			
Eupatorium perfoliatum													2												
Galium labradoricum																								2	
Glyceria striata																									
Helianthus grosseserratus																									
Helianthus spp																									2
Hieracium sp.																									
Impatiens capensis					1			2		2	2		1	2		1	2						1		
Leersia oryzoides																									
Lycopus americanus																								2	1
Lycopus asper																									
Lycopus uniflorus	1		1																		1				
Lysimachia thyrsifolia							2	2																	
Mentha arvensis																									
Mentha canadensis																									
Muhlenbergia mexicana																									
Muhlenbergia racemosa																									
Muhlenbergia spp.																									

Species	Transect 56					57					60					61					62				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Acer negundo																	1								
Aster borealis																		1							
Aster firmus																			2						
Aster puniceus																									
Aster spp.	3	2		3	2					1									2						
Aster umbellatus																									
Bromus ciliatus		1		2	2		2	2																	3
Calamagrostis canadensis																									
Caltha palustris							3		2																
Campanula aparinoides						2	2	2	2	1						2	2	1	4	1		1			2
Cardamine bulbosa									2															2	
Carex hystericina															2										
Carex lacustris																					2	4	4	3	4
Carex lasiocarpa				2																					
Carex prairea												2		2		4	3	2							
Carex sartwellii	3	3	4	3	3		4	3	3		2	4	5	2	2										
Carex sterilis		4		3		1					2														
Carex stricta	2	3	2		3	3			2	2					4		2	3	3	4				3	
Cicuta bulbifera							1																		
Cicuta maculata																									
Cirsium muticum																1									
Cuscuta pentagona																	1	2	1	2					
Eleocharis spp.																									
Equisetum																									
Equisetum pratense																									
Eupatorium maculatum						2	4	2			5					6	5	3	5		5	4	3	4	5
Eupatorium perfoliatum																				3					
Galium labradoricum		2				1																			
Glyceria striata		2			1								1												
Helianthus grosseserratus																									
Helianthus spp						2	2	3																	
Hieracium sp.																		2	2	2					
Impatiens capensis						2	2	1	2	2						4	3	3	3	6		1		2	1
Leersia oryzoides														3											
Lycopus americanus	2	2		1																					
Lycopus asper				2																	3	2		2	2
Lycopus uniflorus							2			1	1	2	1							2					
Lysimachia thyrsifolia																									
Mentha arvensis						2																			
Mentha canadensis																									
Muhlenbergia mexicana																									
Muhlenbergia racemosa										1							2								
Muhlenbergia spp.					2																				

Species	43					44					46					49					50				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Pedicularis lanceolata											2				1										
Pilea fontana																									
Poa spp.																									
Rubus pubescens	3	3	2	2						2															
Rumex orbiculatus																								2	
Sagittaria latifolia																					3	2	2	2	
Salix candida																									
Salix spp.	1																								
Scirpus acutus								1		2	2														1
Solidago spp.						1										2									
Sparganium eurycarpum			2																						
Thalictrum dasycarpum										2						3									
Thylepteris palustris	3			4	3	2					2	1	2	1											
Typha angustifolia																				1					
Ulmus americana																									
Viola nephrophylla			1	2							2	1		2	1			1							

Species	51					52					53					54					55				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Pedicularis lanceolata											3			2	2										
Pilea fontana																									
Poa spp.																									
Rubus pubescens																									
Rumex orbiculatus																									
Sagittaria latifolia																									
Salix candida																									
Salix spp.																									
Scirpus acutus												2	2												
Solidago spp.																									
Sparganium eurycarpum																									
Thalictrum dasycarpum																									
Thylepteris palustris					4				3	2															
Typha angustifolia						2						2				3		2		3					
Ulmus americana																									
Viola nephrophylla																						1			2

Species	56					57					60					61					62				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Pedicularis lanceolata																	2	2	3						
Pilea fontana																2	2	3	1	5					
Poa spp.	1	2						1	2		4														
Rubus pubescens																									
Rumex orbiculatus																									
Sagittaria latifolia																									
Salix candida															2								2		
Salix spp.																									
Scirpus acutus												2		3											
Solidago spp.	2			2				3																	
Sparganium eurycarpum																	2	3	2	2					
Thalictrum dasycarpum																									
Thylepteris palustris																									
Typha angustifolia			2	2				1															2		
Ulmus americana																	1								
Viola nephrophylla	1										1	1													

Appendix B. Bryophyte Results

BRYOPHYTES OF CARVER COUNTY MINNESOTA

Update August 2006

Joannes A. Janssens

Lambda-Max Ecological Research
1061 25th Ave SE
Minneapolis, MN 55414-2637
janss008@tc.umn.edu

Cite as: J.A. Janssens. 2006. Bryophytes of Carver County, Minnesota, update August 2006. Report to the Minnesota Department of Natural Resources, County Biological Survey.

INTRODUCTION and METHODS

This report lists all bryophyte records I identified or annotated from sites 2349, 2491-2530, 6179-6185, 6462, 6644-6646, and 6664-6673 within Carver County: see maps on the following pages and the appendix. Bryophyte records from either comprehensive sites (where an attempt is made to record most species in an ecological context) and from occasional collection sites are listed in the County Checklist appendix to this report. Moss species recorded for the county are also listed in the County Atlas of Minnesota Mosses (Janssens 2000), but this atlas is out-of-date for the sites surveyed after 1999. There is no liverwort checklist published later than Schuster's Boreal Hepaticae (1977), except for a catalog based on this work (Janssens & Orf 1999).

The appendix to this report might also include some species not assigned to the sites listed above. These additional species are based on specimens deposited in the University of Minnesota, St. Paul (MIN) herbarium, but they are still in need of annotation and their detailed locality information is not yet databased.

The comprehensively studied sites within this county are all part of the Seminary Fen locality and are discussed together. Sites with occasional bryophyte records are listed only in the appendix. Within each comprehensive site I differentiated at least one, sometimes several ecotopes (mesohabitats, Janssens 2006). The bryophyte floristics — and often the composition of the bryophyte vegetation cover — are presented in the form of tables.

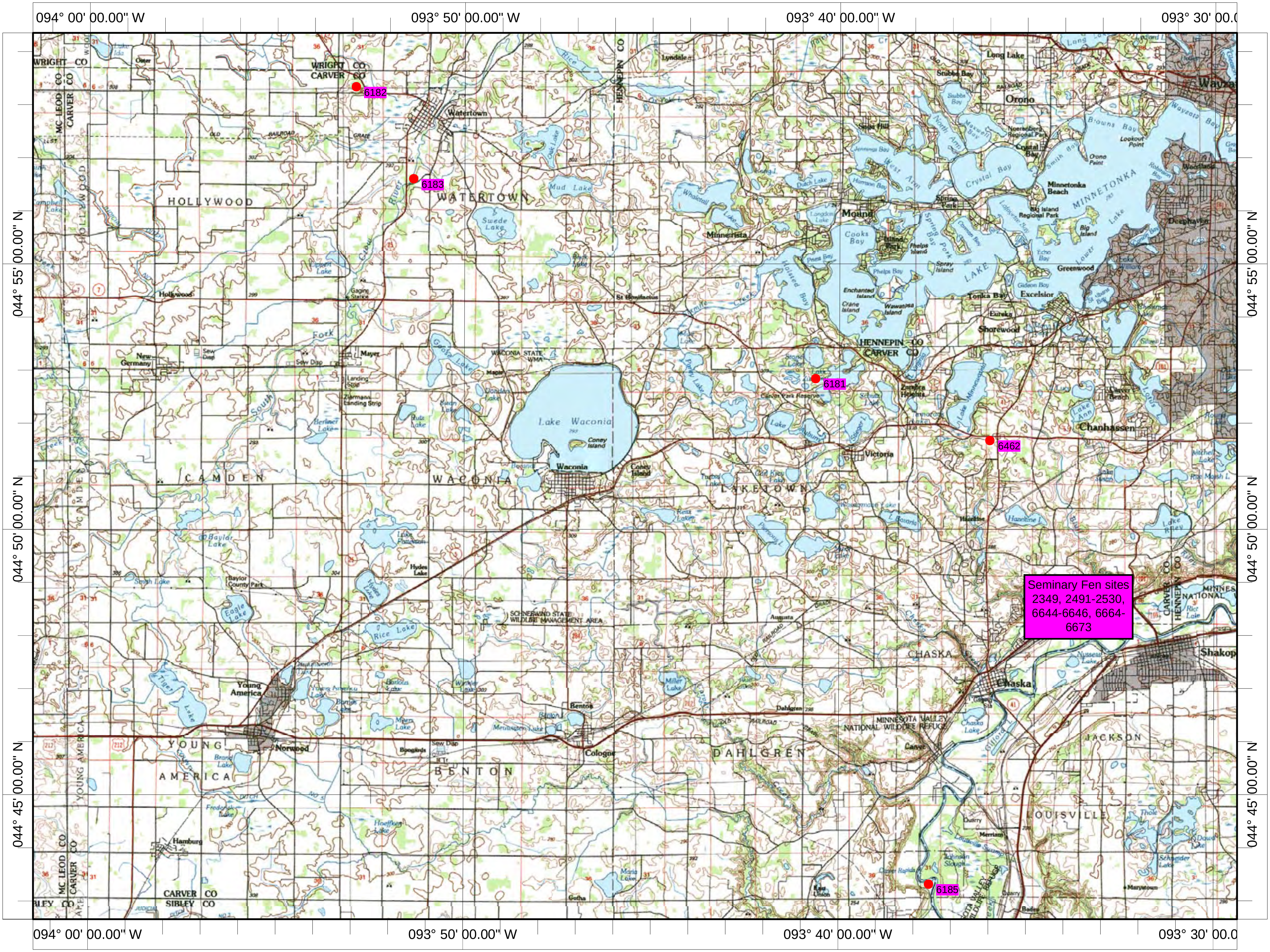
The bryophyte composition of comprehensive ecotopes is surveyed using a particular method adapted to its physiognomic character. Three general methods have been used: (1) the relevé method (MN DNR 2006) for ecotopes with near-continuous high bryophyte cover and easy ocular estimates of individual bryophyte-species cover (such as bogs and poor fens), (2) a point-intercept transect line method (Janssens 2006) for ecotopes with high to low total bryophyte cover but most of it hidden below a dense thatch cover (e.g., sedge meadows), and (3) a combination of line-intercept transect data and frequency estimates of bryophyte species per substrate type (Janssens 2006), most frequently used for mesohabitats in transitional and upland forests.

For Carver County all comprehensive sites (Seminary Fen) have been surveyed by method (2) listed above.

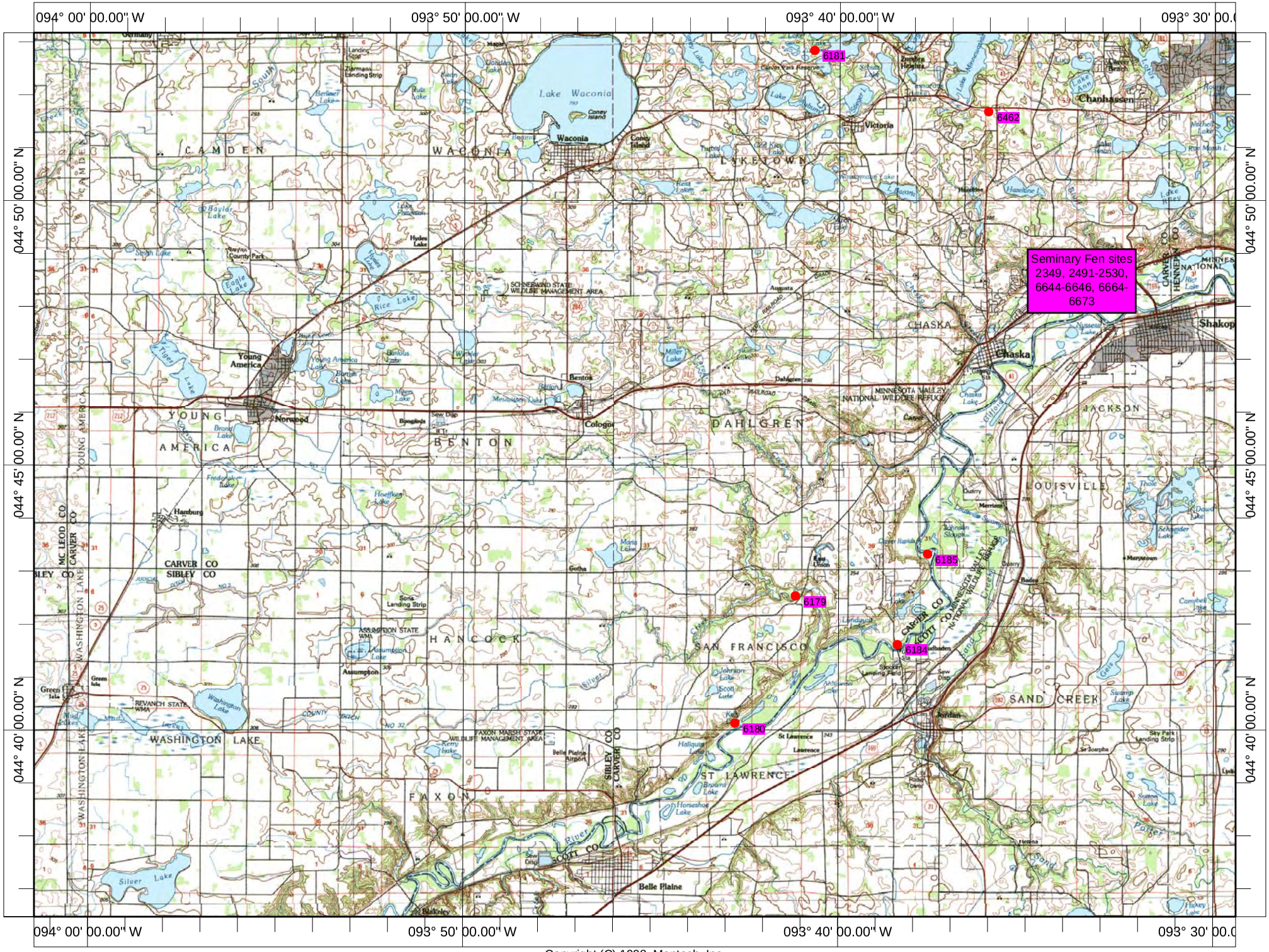
I have attempted to classify each one of the comprehensively surveyed bryophyte ecotopes using the Native Plant Community classification. I have restricted the typing of the ecotopes to the class level of the NPC classification. For more general information on the NPC classification see MN DNR (2005).

Wetland ecotopes are often characterized by their water chemistry. The methods described in Janssens (2006) were used.

The bryophyte vouchers (appendix) are deposited in the herbaria of Lambda-Max Ecological Research, Minneapolis (L-M), the Science Museum of Minnesota, St. Paul (SMM), and the University of Minnesota, St. Paul (MIN). The moss nomenclature is based on the County Atlas of Minnesota Mosses (Janssens 2000) and for the liverworts on Stotler & Crandall-Stotler (1977).



Copyright (C) 1998, Maptech, Inc.


094° 00' 00.00" W
093° 50' 00.00" W
093° 40' 00.00" W
093° 30' 00.0
044° 50' 00.00" N
044° 45' 00.00" N
044° 40' 00.00" N
6181
6462
6185
6179
6184
6180
Seminary Fen sites 2349, 2491-2530, 6644-6646, 6664-6673
Lake Waconia
Waconia
CAMDEN
WACONIA
LAKETOWN
Victoria
Chanhassen
CHASKA
Chaska
Shakopee
Young America
YOUNG AMERICA
Norwood
BENTON
Cologne
DAHLGREN
JACKSON
LOUISVILLE
Hamburg
CARVER CO
SIBLEY CO
HANCOCK
SAN FRANCISCO
SAND CREEK
Jordan
WASHINGTON LAKE
FAXON
ST LAWRENCE
Belle Plaine
Blakeley
MINNESOTA VALLEY NATIONAL WILDLIFE REFUGE
SCHNEEWIND STATE WILDLIFE MANAGEMENT AREA
ASSUMPTION STATE WMA
REVANCH STATE WMA
FAXON MARSH STATE WILDLIFE MANAGEMENT AREA
Belle Plaine Airport
Copyright (C) 1998, Maptech, Inc.

SITES 2349, 2491-2530, 6644-6646, & 6664-6673 (Seminary Fen)

Chaska Area: Seminary Fen, north of Highway 212 and between Bluff Creek Drive in the east and Audubon Road in the west, approximately 4 km northeast of Chaska: see table 1 below, and the topographic-map extract and aerial photo on following pages.

Table 1. Seminary Fen sites. The DMSlat and long (Degree, minute, second latitude and longitude coordinates) are using the NAD 27 datum, the UTM easting and northing the WGS 84 datum.

site	date established	DMSlat	DMSlong	elev (m)	UTM 15T	UTMy
2349	9/26/2002	44° 48' 35" N	93° 34' 00" W	229	455171	4961965
2491	6/9/2006	44° 48' 47.3" N	93° 33' 17.2" W	231	456115	4962340
2492	6/9/2006	44° 48' 45.8" N	93° 33' 19.1" W	229	456073	4962294
2493	6/9/2006	44° 48' 46.2" N	93° 33' 21.2" W	229	456026	4962306
2494	6/9/2006	44° 48' 45.1" N	93° 33' 20.7" W	229	456039	4962271
2495	6/9/2006	44° 48' 43.6" N	93° 33' 17.1" W	226	456115	4962225
2496	6/9/2006	44° 48' 42.0" N	93° 33' 20.0" W	226	456052	4962177
2497	6/9/2006	44° 48' 41.0" N	93° 33' 25.5" W	226	455932	4962146
2498	6/9/2006	44° 48' 44.6" N	93° 33' 23.9" W	229	455967	4962256
2499	6/9/2006	44° 48' 45.5" N	93° 33' 22.4" W	229	456000	4962283
2500	6/9/2006	44° 48' 45.4" N	93° 33' 23.4" W	229	455978	4962280
2501	6/9/2006	44° 48' 45.8" N	93° 33' 22.4" W	229	456001	4962292
2502	6/22/2006	44° 48' 47.3" N	93° 33' 17.2" W	230	456098	4962319
2503	6/22/2006	44° 48' 40.8" N	93° 33' 31.0" W	228	455810	4962140
2504	6/22/2006	44° 48' 40.3" N	93° 33' 33.5" W	228	455753	4962126
2505	6/22/2006	44° 48' 39.2" N	93° 33' 35.5" W	228	455711	4962092
2506	6/22/2006	44° 48' 38.1" N	93° 33' 32.8" W	227	455768	4962058
2507	6/22/2006	44° 48' 36.8" N	93° 33' 30.7" W	226	455816	4962018
2508	6/22/2006	44° 48' 35.6" N	93° 33' 41.2" W	225	455585	4961980
2509	6/22/2006	44° 48' 35.6" N	93° 33' 43.4" W	226	455536	4961965
2510	6/22/2006	44° 48' 35.3" N	93° 33' 48.1" W	227	455434	4961972
2511	6/22/2006	44° 48' 36.9" N	93° 33' 53.2" W	229	455321	4962024
2512	6/22/2006	44° 48' 35.5" N	93° 33' 53.9" W	229	455305	4961980
2513	6/22/2006	44° 48' 34.1" N	93° 33' 56.6" W	229	455247	4961937
2514	6/22/2006	44° 48' 32.3" N	93° 34' 01.1" W	229	455147	4961882
2515	8/10/2006	44° 48' 43.1" N	93° 34' 04.4" W	232	455076	4962215
2516	8/10/2006	44° 48' 39.8" N	93° 34' 03.8" W	230	455090	4962113
2517	8/10/2006	44° 48' 39.2" N	93° 34' 06.3" W	230	455034	4962095
2518	8/10/2006	44° 48' 38.3" N	93° 34' 02.9" W	230	455109	4962069
2518	8/10/2006	44° 48' 38.3" N	93° 34' 02.9" W	230	455109	4962069
2519	8/10/2006	44° 48' 35.6" N	93° 34' 07.7" W	229	455002	4961985
2520	8/10/2006	44° 48' 35.5" N	93° 34' 13.2" W	229	454882	4961984
2521	8/10/2006	44° 48' 32.2" N	93° 34' 12.1" W	228	454906	4961881
2522	8/10/2006	44° 48' 32.7" N	93° 34' 19.0" W	229	454754	4961898
2523	8/10/2006	44° 48' 31.2" N	93° 34' 24.4" W	229	454636	4961852
2524	8/10/2006	44° 48' 35.6" N	93° 34' 32.4" W	235	454460	4961989
2525	8/10/2006	44° 48' 37.6" N	93° 34' 28.6" W	236	454543	4962052
2526	8/10/2006	44° 48' 38.5" N	93° 34' 24.6" W	235	454631	4962077
2527	8/10/2006	44° 48' 39.7" N	93° 34' 19.9" W	233	454735	4962113
2528	8/10/2006	44° 48' 36.9" N	93° 34' 17.9" W	232	454780	4962028
2529	8/10/2006	44° 48' 40.9" N	93° 34' 14.3" W	232	454861	4962149
2530	8/10/2006	44° 48' 34.6" N	93° 34' 40.0" W	236	454293	4961960

Table 1. Cont'd.

site	date established	DMSlat	DMSlong	elev (m)	UTM 15T	UTMy
6644	6/16/2005	44° 48' 44.7" N	93° 33' 18.1" W	227	456094	4962259
6645	6/16/2005	44° 48' 42.6" N	93° 33' 18.3" W	227	456089	4962195
6646	6/16/2005	44° 48' 42.4" N	93° 33' 22.4" W	227	456000	4962189
6664	6/16/2005	44° 48' 36.5" N	93° 33' 22.4" W	226	455998	4962006
6665	6/16/2005	44° 48' 38.5" N	93° 33' 23.2" W	227	455980	4962068
6666	6/16/2005	44° 48' 27.6" N	93° 33' 15.9" W	218	456138	4961729
6667	6/16/2005	44° 48' 26.6" N	93° 33' 26.5" W	220	455906	4961702
6668	6/16/2005	44° 48' 24.2" N	93° 33' 29.1" W	218	455849	4961628
6669	6/16/2005	44° 48' 19.4" N	93° 33' 40.5" W	216	455596	4961481
6670	6/16/2005	44° 48' 16.6" N	93° 33' 41.1" W	216	455583	4961395
6671	6/16/2005	44° 48' 16.9" N	93° 33' 45.3" W	216	455492	4961404
6672	6/16/2005	44° 48' 15.7" N	93° 33' 52.1" W	215	455342	4961370
6673	6/16/2005	44° 48' 35.8" N	93° 33' 19.4" W	223	456065	4961985

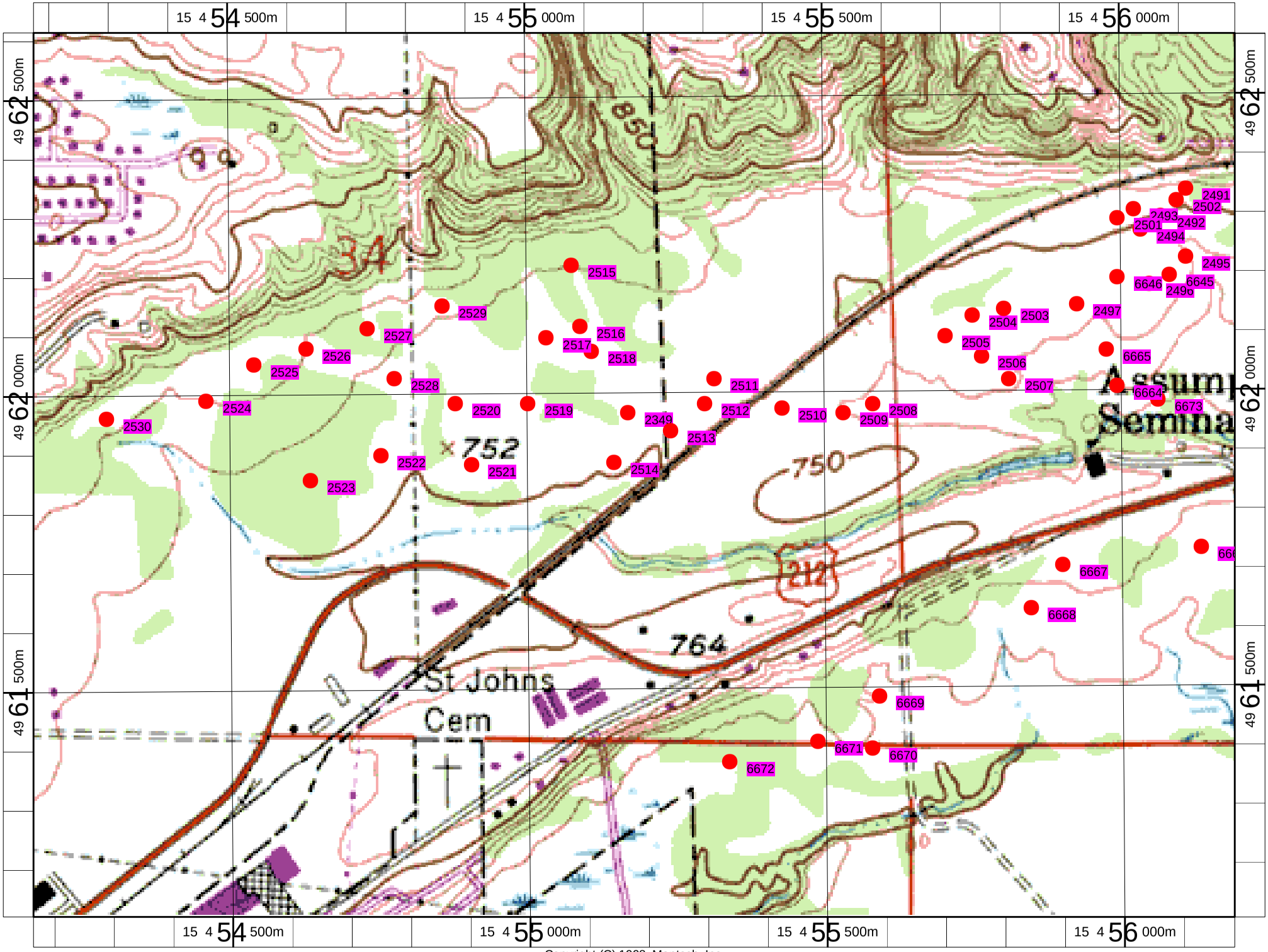
Ecotopes

Classification: Table 2 below lists all ecotopes that were surveyed at Seminary Fen. Those checked in the 'comp' column are considered comprehensively sampled (*i.e.*, an attempt was made to record all bryophyte species within them). Recorded also are (1) their tentative NPC class (DNR 2005), awaiting further analysis of the vascular-plant composition (D. Dejoode, pers. comm.), (2) water-chemistry parameters (see Janssens 2006 for detailed methodology), and (3) the number of bryophyte calcareous-fen indicators present (#Ind) and their total calcareous-fen bryophyte score (totCFscore), calculated using the procedure presented in Janssens (2005). Many ecotopes have also been sampled by point-intercept line (D. Dejoode, pers. comm., BotTr#; Janssens 2006). Their total % bryophyte cover is listed (4), and individual species covers, based on their proportional representation among the point-intercept hits and general collections (Janssens 2006), are given in table 3. Species from ecotopes not sampled by point intercept are listed in the appendix.

The total calcareous-fen score based on the bryophyte composition of the 50 ecotopes with calcareous-fen indicator species ranges from 17 to 346, 35 of them with a score over 109 and thus classified as calcareous fen based on the bryophyte criterion (Janssens 2005). Most of these calcareous-fen ecotopes are located in the northeastern and central parts of the fen complex (see the aerial photo extract with superimposed bubbles representing totCFscore). The score of 346 (ecotope 2515A, botanical transect 46) also equals the highest previous score obtained for any calcareous fen in the state (Ottawa Fen, Janssens 2005).

Some photos are added below to illustrate the varied physiognomy of the Seminary Fen calcareous-fen ecotopes.

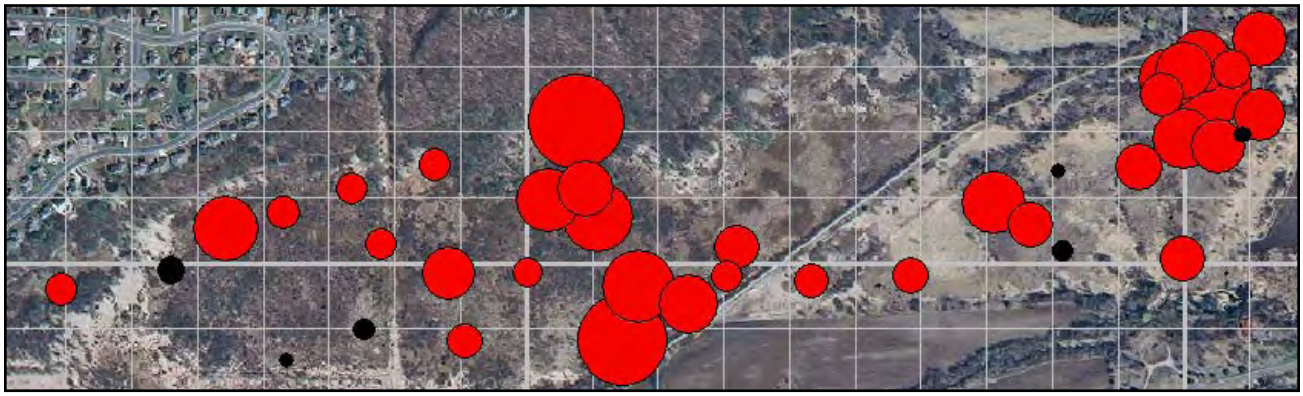
Bryophytes: Table 4 lists the collectors, collecting dates, and collection-number ranges of the 608 Seminary Fen bryophyte collections (1081 species vouchers). Voucher identifications are given in the appendix. All vouchers were identified by JAJ in the laboratory.



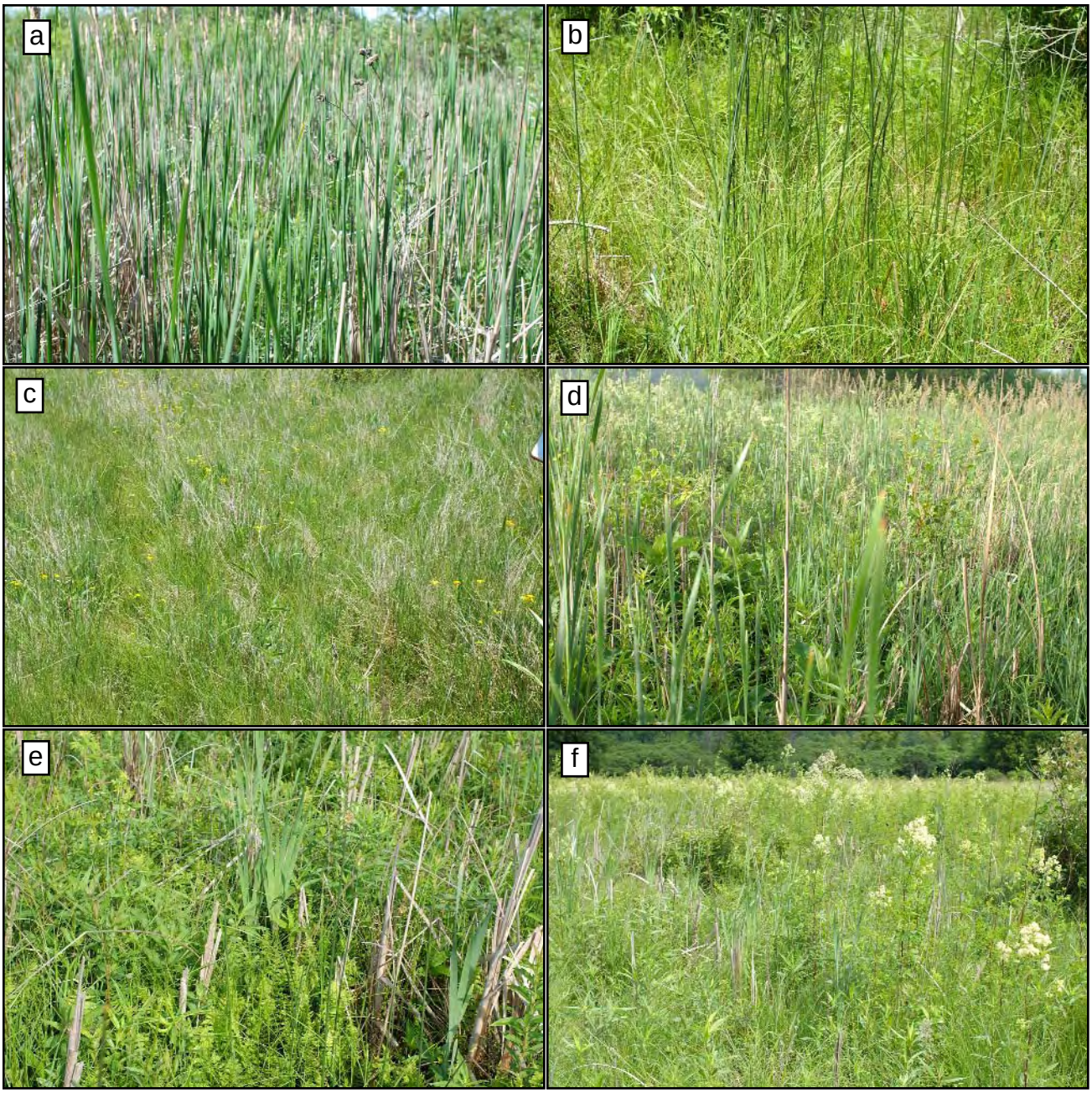
Copyright (C) 1998, Maptech, Inc.

Facing page: **Seminary Fen sites** 2349, 2491-2530, 6644-6646, & 6664-6673**.** Topographic map extract from the 1:24,000 Shakopee quad (UTM coordinates, see table 1).

Seminary Fen aerial photo, including the areas south of Highway 212.



Seminary Fen ecotopes north of Highway 212. The diameter of the bubbles represent the totCFscore, based on the presence of calcareous-fen indicators among the bryophytes (Janssens 2005). The red bubbles are ecotopes classified as calcareous fen mesohabitat (totCFscore >109, with a maximal value of 346). The black bubbles are ecotopes with an insufficient number of bryophyte indicator species to classify as calcareous fen, and for which the totCFscore is <109. (Grid is UTM, see map on facing page and table 1.)



Seminary Fen calcareous-fen ecotopes: a. ecotope 2493A, dominated by cattail and sedge; b. ecotope 2497A, dominated by tall sedges; c. ecotope 2498A, dominated by short sedges; d. ecotope 2503A, dominated by sedges and goldenrod; e. ecotope 2506A, dominated by marsh fern and cattail; and f. ecotope 2508A, dominated by sedges and meadow-rue.

Table 2. Seminary Fen ecotope characterization. See text for details.

		(1) NPC	(2) Water-chemistry Parameters				(3) CF validation		(4) Point Intercept	
ecotope	comp	class	M	pH	K	Abs_{350}	#Ind	totCFscore	BotTr#	%cover
2349A	x	WMs83	S	7.96	1020		6	263		
2491A	x	WMs83	S	7.5	458	0.012	4	199	01	60
2492A	x	WMs83	S	7.8	469	0.048	4	139	06	80
2493A	x	WMs83	S	7.6	284	0.065	6	227	08	30
2494A	x	OPn93	S	8.2	359	0.025	7	309	07	30
2495A	x	WMs83	S	7.7	527	0.062	5	189	04	30
2496A	x	WMs83					5	195	41	80
2497A	x	WMs83	D	7.9	435	0.160	4	171	18	100
2498A	x	WMs83					3	161	10	70
2499A		WMs83	S	8.9	349	0.061				
2500A	x	WMs83					5	224	09	50
2501A	x	WMs83	S	7.3	353	0.047	6	206	42	100
2502A		WMs83								
2503A	x	WMn82					2	56	21	50
2504A		WMn82								
2505A	x	WMs83					6	228	22	70
2506A	x	WMs83					4	164		
2507A	x	WMn82	S	8.7	380	0.055	2	79	23	30
2508A	x	WMs83					4	134	25	50
2509A	x	WMn82					1	17	26	10
2510A	x	WMs83					3	125	27	40
2511A	x	WMs83	D	7.5	310	0.100	4	164		
2512A	x	WMs83					3	118	38	30
2513A	x	WMs83					5	217	39	30
2514A	x	OPp93	D	7.7	326	0.146	8	327	40	40
2515A	x	OPp93					9	345	46	50
2516A	x	WMs83					6	206	44	90
2517A	x	WMs83					6	234	51	60
2518A	x	WMs83					7	253	43	50
2518B		WMs83								
2519A	x	WMs83					3	109	50	30
2520A	x	WMs83					5	195	55	30
2521A	x	WMs83					3	131	49	30
2522A	x	WMn82					2	78	56	60
2523A	x	WMn82					2	56	57	50
2524A	x	WMn82					3	102	58	60
2525A	x	WMs83					6	235	60	80
2526A	x	WMs83					3	118	59	80
2527A	x	WMs83					3	118	53	40
2528A	x	WMs83					3	118	54	10
2529A	x	WMs83					3	118	52	10
2530A	x	WMs83					3	118	61	100
6644A	x	WMn82					1	17	05	10
6645A	x	WMn82					2	64	12	80
6646A	x	WMs83					5	224	13	90
6664A	x	WMs83					4	163	16	70
6665A	x	WMn82					1	17	17	80
6666A		WMn82					2	79	28	40
6667A		WMn82							30	10
6668A		WMn82					2	79	31	100
6669A		WMn82					2	79	32	60
6670A		WMn82					1	17	33	20
6671A		WMn82					1	17	34	50
6672A		WMs83					4	170	36	90
6673A	x	WMn82					1	17	15	30

Table 3. Seminary Fen ecotope bryophyte composition. The highlighted ecotopes are considered calcareous fen mesohabitat based on the bryophyte criterion (see text for further detail). The calcareous-fen bryophyte indicators and their presence or percent cover are highlighted in green. See further on page to the right.

ecotope	2491A	2492A	2493A	2494A	2495A	2496A	2497A	2498A	2500A	2501A	2503A	2505A	2507A	2508A	2509A	2510A	2512A	2513A	2514A	2515A	2516A	2517A	2518A	2519A	2520A
BotTr#	01	06	08	07	04	41	18	10	09	42	21	22	23	25	26	27	38	39	40	46	44	51	43	50	55
% total bryo cover	60	80	30	30	30	80	100	70	50	100	50	70	30	50	10	40	30	30	40	50	90	60	50	30	30
totCFscore	199	139	227	309	189	195	171	161	224	206	56	228	79	134	17	125	118	217	327	345	206	234	253	109	195
Amblystegium serpens																		x							
Amblystegium varium			10		15	24				4	10	37	22	6	10	10	12	4	11	x	5	6	5	15	11
Aneura pinguis		7	x	x					5										x	2		6			3
Aulacomnium palustre									5																
Brachythecium acuminatum												x				x									
Brachythecium oedipodium																									
Brachythecium rivulare	x		x	x	x							x				x		x	x	x					
Brachythecium salebrosum	10		20	15			23		10	18	40	21	7	12	x	20	6	12	x	14	45	33	15	7	3
Brachythecium velutinum														x											
Bryum pseudotriquetrum	5			x		8	x	8	10	4				6				x	11	8	11	x	5	x	3
Calliergonella cuspidata							x			4										x	5		x		
Campylium chrysophyllum										x				x					x						
Campylium polygamum		7	x	x	x	x			10	13		x		25					11	x	5	x	x		x
Campylium radicale														x	x					x	x				
Campylium stellatum		36		x	7	40		61	5			x		x					x	x			x		
Cratoneuron filicinum	x		x	x	x		x																		
Drepanocladus aduncus	5		x	15	x	x	28	x	5	13		5	x			10	6	4	x	8	5	x	5		3
Eurhynchium hians	10		x			x				4	x	x													
Fissidens adianthoides		29			7	8				4									5	x	x		5		
Hypnum lindbergii	x								x												x				
Hypnum pratense			x				9			4		x								2	x		x		
Leptodictyum humile	x																								
Limprichtia cossonii		x																							
Plagiomnium cuspidatum											x	x				x			x			6	10	x	3
Plagiomnium ellipticum	30		x	x			38			27	x	5					6	8	x	11	11	6	5	7	
Thuidium delicatulum							x												x						
Thuidium recognitum																				x					

Table 3. Cont'd. The values are either percent cover, or presence in case the species was not recorded along the point-intercept transect itself but only during the general ecotope survey. The vouchers are listed in table 4 by ecotope. Species identifications of individual vouchers are given in the appendix.

ecotope	2521A	2522A	2523A	2524A	2525A	2526A	2527A	2528A	2529A	2530A	6644A	6645A	6646A	6664A	6665A	6666A	6667A	6668A	6669A	6670A	6671A	6672A	6673A
BotTr#	49	56	57	58	60	59	53	54	52	61	05	12	13	16	17	28	30	31	32	33	34	36	15
% total bryo cover	30	60	50	60	80	80	40	10	10	100	10	80	90	70	80	40	10	100	60	20	50	90	30
totCFscore	131	78	56	102	235	118	118	118	118	118	17	64	224	163	17	79		79	79	17	17	170	17
Amblystegium serpens																							
Amblystegium varium	12		16	22		16	11	10	10	12		30			43	11		9	42	20	50	50	20
Aneura pinguis													4	7									
Aulacomnium palustre																							
Brachythecium acuminatum																							
Brachythecium oedipodium															21								
Brachythecium rivulare				7																			
Brachythecium salebrosum	12	42	5	30	20	32	17			37		10		7	14	5	10	72	8				10
Brachythecium velutinum																							
Bryum pseudotriquetrum	x				16								13	7								5	
Calliergonella cuspidata					13																		
Campylium chrysophyllum																							
Campylium polygamum		x			6						10		27	28									
Campylium radicale		8			x																		
Campylium stellatum					6							30	22	21									
Cratoneuron filicinum																							
Drepanocladus aduncus	6	8			13	16	11	x	x	8			4			11		9	8			5	
Eurhynchium hians												10				11							
Fissidens adianthoides		x			3								13										
Hypnum lindbergii													4										
Hypnum pratense					x													9					
Leptodictyum humile																							
Limprichtia cossonii																							
Plagiomnium cuspidatum				x						8													
Plagiomnium ellipticum			27	x	x	16	x	x	x	33												28	
Thuidium delicatulum																							
Thuidium recognitum																							

Table 4. Next page. Seminary Fen bryophyte collections. The voucher identifications are given in the appendix.

ecotope	collector	date	first	last
2349A	Janssens, J.A.	26-Sep-02	JAJ47434	JAJ47475
2491A	Dejoode, D.R.	18-Jun-05	DRD00001	DRD00008
2491A	Janssens, J.A.	09-Jun-06	JAJ52053	JAJ52059
2491A	Leete, J.H.	09-Jun-06	JHL00949	JHL00949
2492A	Dejoode, D.R.	28-Jun-05	DRD00051	DRD00060
2492A	Janssens, J.A.	09-Jun-06	JAJ52060	JAJ52066
2493A	Dejoode, D.R.	17-Jun-05	DRD00072	DRD00080
2493A	Janssens, J.A.	09-Jun-06	JAJ52067	JAJ52073
2493A	Leete, J.H.	09-Jun-06	JHL00950	JHL00955
2494A	Dejoode, D.R.	17-Jun-05	DRD00068	DRD00070
2494A	Janssens, J.A.	09-Jun-06	JAJ52074	JAJ52088
2494A	Leete, J.H.	09-Jun-06	JHL00956	JHL00956
2495A	Dejoode, D.R.	18-Jun-05	DRD00033	DRD00039
2495A	Janssens, J.A.	09-Jun-06	JAJ52089	JAJ52093
2495A	Leete, J.H.	09-Jun-06	JHL00957	JHL00957
2496A	Dejoode, D.R.	28-Jun-05	DRD00401	DRD00410
2496A	Janssens, J.A.	09-Jun-06	JAJ52094	JAJ52095
2496A	Leete, J.H.	09-Jun-06	JHL00958	JHL00959
2497A	Dejoode, D.R.	17-Jun-05	DRD00171	DRD00180
2497A	Janssens, J.A.	09-Jun-06	JAJ52096	JAJ52101
2497A	Leete, J.H.	09-Jun-06	JHL00960	JHL00962
2498A	Dejoode, D.R.	28-Jun-05	DRD00094	DRD00100
2498A	Janssens, J.A.	09-Jun-06	JAJ52102	JAJ52104
2499A	Leete, J.H.	09-Jun-06	JHL00963	JHL00963
2500A	Dejoode, D.R.	17-Jun-05	DRD00081	DRD00086
2500A	Janssens, J.A.	09-Jun-06	JAJ52105	JAJ52110
2500A	Leete, J.H.	09-Jun-06	JHL00964	JHL00965
2501A	Dejoode, D.R.	17-Jun-05	DRD00411	DRD00420
2501A	Leete, J.H.	09-Jun-06	JHL00966	JHL00970
2502A	Janssens, J.A.	22-Jun-06	JAJ52141	JAJ52143
2503A	Dejoode, D.R.	18-Jun-05	DRD00202	DRD00208
2503A	Janssens-Verbelen, E.	22-Jun-06	EJV00529	EJV00534
2503A	Leete, J.H.	22-Jun-06	JHL00971	JHL00972
2504A	Janssens, J.A.	22-Jun-06	JAJ52131	JAJ52131
2505A	Dejoode, D.R.	18-Jun-05	DRD00211	DRD00220
2505A	Janssens, J.A.	22-Jun-06	JAJ52132	JAJ52139
2505A	Janssens-Verbelen, E.	22-Jun-06	EJV00535	EJV00539
2505A	Leete, J.H.	22-Jun-06	JHL00973	JHL00975
2506A	Janssens, J.A.	22-Jun-06	JAJ52140	JAJ52140
2506A	Janssens, J.A.	22-Jun-06	JAJ52144	JAJ52144
2506A	Janssens-Verbelen, E.	22-Jun-06	EJV00540	EJV00546
2506A	Leete, J.H.	22-Jun-06	JHL00976	JHL00978
2507A	Dejoode, D.R.	17-Jun-05	DRD00222	DRD00227
2507A	Janssens, J.A.	22-Jun-06	JAJ52145	JAJ52146
2507A	Janssens-Verbelen, E.	22-Jun-06	EJV00547	EJV00547
2507A	Leete, J.H.	22-Jun-06	JHL00979	JHL00980
2508A	Dejoode, D.R.	17-Jun-05	DRD00242	DRD00250
2508A	Janssens, J.A.	22-Jun-06	JAJ52147	JAJ52155
2508A	Janssens-Verbelen, E.	22-Jun-06	EJV00548	EJV00551
2508A	Leete, J.H.	22-Jun-06	JHL00981	JHL00984
2509A	Dejoode, D.R.	17-Jun-05	DRD00259	DRD00259
2509A	Janssens, J.A.	22-Jun-06	JAJ52156	JAJ52156
2509A	Janssens-Verbelen, E.	22-Jun-06	EJV00552	EJV00554
2509A	Leete, J.H.	22-Jun-06	JHL00985	JHL00987
2510A	Dejoode, D.R.	17-Jun-05	DRD00264	DRD00269
2510A	Janssens, J.A.	22-Jun-06	JAJ52157	JAJ52161
2510A	Janssens-Verbelen, E.	22-Jun-06	EJV00555	EJV00558
2510A	Leete, J.H.	22-Jun-06	JHL00988	JHL00991
2511A	Janssens, J.A.	22-Jun-06	JAJ52162	JAJ52165
2511A	Janssens-Verbelen, E.	22-Jun-06	EJV00559	EJV00560
2511A	Leete, J.H.	22-Jun-06	JHL00992	JHL00995
2512A	Dejoode, D.R.	18-Jun-05	DRD00371	DRD00374
2512A	Janssens, J.A.	22-Jun-06	JAJ52166	JAJ52166
2512A	Leete, J.H.	22-Jun-06	JHL00996	JHL00998

ecotope	collector	date	first	last
2513A	Dejoode, D.R.	18-Jun-05	DRD00381	DRD00388
2513A	Janssens, J.A.	22-Jun-06	JAJ52167	JAJ52168
2513A	Leete, J.H.	22-Jun-06	JHL00999	JHL01002
2514A	Dejoode, D.R.	18-Jun-05	DRD00393	DRD00397
2514A	Janssens, J.A.	22-Jun-06	JAJ52169	JAJ52182
2514A	Leete, J.H.	22-Jun-06	JHL01003	JHL01010
2515A	Dejoode, D.R.	15-Jun-06	DRD06125	DRD06129
2515A	Janssens, J.A.	10-Aug-06	JAJ52271	JAJ52280
2515A	Janssens-Verbelen, E.	10-Aug-06	EJV00561	EJV00563
2516A	Dejoode, D.R.	15-Jun-06	DRD06115	DRD06123
2516A	Janssens, J.A.	10-Aug-06	JAJ52281	JAJ52292
2516A	Janssens-Verbelen, E.	10-Aug-06	EJV00564	EJV00568
2517A	Dejoode, D.R.	10-Jun-06	DRD06109	DRD06114
2517A	Janssens, J.A.	10-Aug-06	JAJ52293	JAJ52297
2517A	Janssens-Verbelen, E.	10-Aug-06	EJV00569	EJV00571
2518A	Dejoode, D.R.	10-Jun-06	DRD06101	DRD06105
2518A	Janssens, J.A.	10-Aug-06	JAJ52298	JAJ52301
2518A	Janssens-Verbelen, E.	10-Aug-06	EJV00572	EJV00575
2518B	Janssens, J.A.	10-Aug-06	JAJ52302	JAJ52305
2519A	Dejoode, D.R.	10-Jun-06	DRD06106	DRD06108
2519A	Janssens, J.A.	10-Aug-06	JAJ52306	JAJ52308
2519A	Janssens-Verbelen, E.	10-Aug-06	EJV00576	EJV00576
2520A	Dejoode, D.R.	15-Jun-06	DRD06134	DRD06136
2520A	Janssens, J.A.	10-Aug-06	JAJ52309	JAJ52313
2520A	Janssens-Verbelen, E.	10-Aug-06	EJV00577	EJV00579
2521A	Dejoode, D.R.	15-Jun-06	DRD06130	DRD06132
2521A	Janssens, J.A.	10-Aug-06	JAJ52314	JAJ52315
2521A	Janssens-Verbelen, E.	10-Aug-06	EJV00580	EJV00580
2522A	Dejoode, D.R.	15-Jun-06	DRD06138	DRD06143
2522A	Janssens-Verbelen, E.	10-Aug-06	EJV00581	EJV00581
2523A	Dejoode, D.R.	15-Jun-06	DRD06144	DRD06148
2523A	Janssens, J.A.	10-Aug-06	JAJ52316	JAJ52316
2523A	Janssens-Verbelen, E.	10-Aug-06	EJV00582	EJV00582
2524A	Dejoode, D.R.	16-Jun-06	DRD06154	DRD06158
2524A	Dejoode, D.R.	16-Jun-06	DRD06185	DRD06185
2524A	Janssens, J.A.	10-Aug-06	JAJ52317	JAJ52322
2524A	Janssens-Verbelen, E.	10-Aug-06	EJV00583	EJV00583
2525A	Dejoode, D.R.	16-Jun-06	DRD06167	DRD06174
2525A	Janssens, J.A.	10-Aug-06	JAJ52323	JAJ52330
2525A	Janssens-Verbelen, E.	10-Aug-06	EJV00584	EJV00586
2526A	Dejoode, D.R.	16-Jun-06	DRD06159	DRD06166
2526A	Janssens, J.A.	10-Aug-06	JAJ52331	JAJ52338
2526A	Janssens-Verbelen, E.	10-Aug-06	EJV00587	EJV00587
2527A	Dejoode, D.R.	16-Jun-06	DRD06150	DRD06153
2527A	Janssens, J.A.	10-Aug-06	JAJ52339	JAJ52341
2528A	Dejoode, D.R.	15-Jun-06	DRD06137	DRD06137
2528A	Janssens, J.A.	10-Aug-06	JAJ52342	JAJ52343
2529A	Dejoode, D.R.	16-Jun-06	DRD06149	DRD06149
2529A	Janssens, J.A.	10-Aug-06	JAJ52344	JAJ52344
2529A	Janssens-Verbelen, E.	10-Aug-06	EJV00588	EJV00588
2530A	Dejoode, D.R.	16-Jun-06	DRD06175	DRD06184
2530A	Janssens, J.A.	10-Aug-06	JAJ52345	JAJ52350
6644A	Dejoode, D.R.	18-Jun-05	DRD00050	DRD00050
6645A	Dejoode, D.R.	18-Jun-05	DRD00122	DRD00130
6646A	Dejoode, D.R.	28-Jun-05	DRD00111	DRD00120
6664A	Dejoode, D.R.	28-Jun-05	DRD00151	DRD00160
6665A	Dejoode, D.R.	17-Jun-05	DRD00161	DRD00170
6666A	Dejoode, D.R.	29-Jun-05	DRD00271	DRD00279
6667A	Dejoode, D.R.	29-Jun-05	DRD00298	DRD00298
6668A	Dejoode, D.R.	29-Jun-05	DRD00301	DRD00310
6669A	Dejoode, D.R.	29-Jun-05	DRD00311	DRD00319
6670A	Dejoode, D.R.	29-Jun-05	DRD00327	DRD00330
6671A	Dejoode, D.R.	29-Jun-05	DRD00334	DRD00340
6672A	Dejoode, D.R.	29-Jun-05	DRD00351	DRD00360
6673A	Dejoode, D.R.	28-Jun-05	DRD00143	DRD00148

REFERENCES

Janssens, J.A. 2000. County Atlas of Minnesota Mosses. Website by Ecological Services, Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, Minnesota 55155, @ http://www.dnr.state.mn.us/plants/flm/mossatlas/index.html.

Janssens, J.A. 2005. Classification of the Bryophyte Assemblages of Minnesota's Extreme Rich Fens and the Bryophyte Criterion for the Evaluation of Potential Calcareous-Fen Ecotopes, update October 2005. Report to the Minnesota Department of Natural Resources, Division of Waters. Available from the author janss008@tc.umn.edu.

Janssens, J.A. 2006. Methods for the study of bryophyte ecology. Update 2006. Available from the author janss008@tc.umn.edu.

Janssens, J.A. and E.E. Orf. 1999. Liverworts of Minnesota: county records based on Schuster's Boreal Hepaticae, and on additional authenticated specimens of the MIN herbarium (UofM St. Paul). Submitted to the Minnesota County Biological Survey, Department of Natural Resources, 500 Lafayette Road, St. Paul, Minnesota 55155, February 1999.

Minnesota Department of Natural Resources. 2005. Field Guide to the Native Plant Communities of Minnesota: the Eastern Broadleaf Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program. MNDNR St. Paul, MN.

Minnesota Department of Natural Resources. 2006. A Handbook for Collecting Relevé Data in Minnesota, 2nd Edition, in preparation. Minnesota Natural Heritage and Nongame Research Program and Minnesota County Biological Survey. Minnesota Department of Natural Resources, St. Paul.

Schuster, R.M. 1977 (1953). Boreal Hepaticae, a manual of the liverworts of Minnesota and adjacent regions. American Midland Naturalist 49: 257 684 and republished as Bryophytorum Bibliotheca by J. Cramer, Band 11.

Stotler, R.E. and B. Crandall-Stotler. 1977. A checklist of the liverworts and hornworts of North America. The Bryologist 80: 405-428.

APPENDIX: COUNTY CHECKLIST

Site information and ecotope habitat descriptions

See table 1 above for the Seminary Fen sites 2349, 2491-2530, 6644-6646, & 6664-6673.

Other Carver County sites (see county maps on pages 4 and 5):

Site 6179: Carver Area, 44° 42’ 32” N, 93° 41’ 11” W
ecotope 6179X: no habitat description provided

Site 6180: Carver Area, 44° 40’ 08” N, 93° 42’ 48” W
ecotope 6180X: no habitat description provided

Site 6181: Victoria Area, 44° 52’ 51” N, 93° 40’ 39” W
ecotope 6181X: no habitat description provided

Site 6182: Watertown Area, 44° 58’ 21” N, 93° 52’ 54” W
ecotope 6182X: no habitat description provided

Site 6183: Watertown Area, 44° 56’ 37” N, 93° 51’ 22” W
ecotope 6183X: no habitat description provided

Site 6184: Carver Area, 44° 41’ 37” N, 93° 38’ 29” W
ecotope 6184X: no habitat description provided

Site 6185: Carver Area, 44° 43’ 19” N, 93° 37’ 40” W
ecotope 6185X: no habitat description provided

Site 6462: Chanhassen Area: along Bog Trail at UofM Arboretum, 44° 51’ 41” N, 93° 36’ 01” W
ecotope 6462X: no habitat description provided

Site 6674: Chaska Area, no precise locality information provided
ecotope 6674X: no habitat description provided

Site 6675: Waconia Area, no precise locality information provided
ecotope 6674X: no habitat description provided

Voucher lists for all bryophyte species recorded in county ecotopes

Amblystegium serpens
***ecotope* 2513A:** Leete, 6/21/2006, 1000A1, **ecotope 6179X:** Wheeler, 7/31/1999, 20166A1, 20168A1

Amblystegium varium
***ecotope* 2493A:** Dejoode, 6/16/2005, 75A1, Leete, 6/8/2006, 953A2, **ecotope 2495A:** Dejoode, 6/17/2005, 37A1, 39A1, Janssens, 6/8/2006, 52090A1, 52092A1, 52093A1, **ecotope 2496A:** Dejoode, 6/27/2005, 405A1, 408A1, 410A1, **ecotope 2501A:** Dejoode, 6/16/2005, 411A1, Leete, 6/8/2006, 967A4, 969A2, **ecotope 2503A:** Dejoode, 6/17/2005, 202A1, Janssens-Verbelen, 6/21/2006, 532A1, **ecotope 2505A:** Dejoode, 6/17/2005, 211A2, 212A1, 214A1, 215A1, 216A2, 219A1, 220A1, Janssens, 6/21/2006, 52137A1, 52138A1, Janssens-Verbelen, 6/21/2006, 539A1, Leete, 6/21/2006, 973A3, 974A2, **ecotope 2506A:** Janssens-Verbelen, 6/21/2006, 541A1, 542A3, 545A3, **ecotope 2507A:** Dejoode, 6/16/2005, 222A1, 223A1, 227A2, Janssens, 6/21/2006, 52145A1, Janssens-Verbelen, 6/21/2006, 547A1, Leete, 6/21/2006, 979A1, 980A1, **ecotope 2508A:** Dejoode, 6/16/2005, 250A2, Janssens, 6/21/2006, 52149A2, 52154A3, **ecotope 2509A:** Dejoode, 6/16/2005, 259A1, Janssens-Verbelen, 6/21/2006, 553A2, **ecotope 2510A:** Dejoode,

6/16/2005, 269A1, Janssens, 6/21/2006, 52161A2, Janssens-Verbelen, 6/21/2006, 555A3, 557A2, Leete, 6/21/2006, 988A1, 989A1, 990A1, **ecotope 2511A:** Janssens, 6/21/2006, 52162A1, Leete, 6/21/2006, 994A1, 995A1, **ecotope 2512A:** Dejoode, 6/17/2005, 372A1, 374A1, Janssens, 6/21/2006, 52166A1, Leete, 6/21/2006, 996A1, 997A1, 998A1, **ecotope 2513A:** Dejoode, 6/17/2005, 388A2, Janssens, 6/21/2006, 52167A3, **ecotope 2514A:** Dejoode, 6/17/2005, 395A1, 397A1, Leete, 6/21/2006, 1005A3, **ecotope 2515A:** Janssens, 8/9/2006, 52274A3, **ecotope 2516A:** Dejoode, 6/14/2006, 6121A1, **ecotope 2517A:** Dejoode, 6/9/2006, 6111A2, **ecotope 2518A:** Dejoode, 6/9/2006, 6103A1, **ecotope 2519A:** Dejoode, 6/9/2006, 6107A2, 6108A1, Janssens, 8/9/2006, 52306A2, 52308A1, **ecotope 2520A:** Dejoode, 6/14/2006, 6134A3, 6135A3, 6136A2, Janssens, 8/9/2006, 52310A2, 52312A1, 52313A3, **ecotope 2521A:** Dejoode, 6/14/2006, 6130A1, 6131A2, **ecotope 2523A:** Dejoode, 6/14/2006, 6144A2, 6145A1, 6147A2, Janssens-Verbelen, 8/9/2006, 582A1, **ecotope 2524A:** Dejoode, 6/15/2006, 6154A2, 6155A1, 6156A1, Janssens, 8/9/2006, 52317A1, **ecotope 2526A:** Dejoode, 6/15/2006, 6161A1, 6162A1, 6166A3, **ecotope 2527A:** Dejoode, 6/15/2006, 6150A3, 6151A1, Janssens, 8/9/2006, 52341A1, **ecotope 2528A:** Dejoode, 6/14/2006, 6137A1, Janssens, 8/9/2006, 52342A2, **ecotope 2529A:** Dejoode, 6/15/2006, 6149A1, Janssens, 8/9/2006, 52344A2, **ecotope 2530A:** Dejoode, 6/15/2006, 6177A3, 6182A1, 6183A3, Janssens, 8/9/2006, 52348A2, **ecotope 6645A:** Dejoode, 6/17/2005, 122A1, 127A1, 128A1, **ecotope 6665A:** Dejoode, 6/16/2005, 161A1, 162A2, 167A1, 168A2, 169A1, 170A1, **ecotope 6666A:** Dejoode, 6/28/2005, 273A1, 274A3, **ecotope 6668A:** Dejoode, 6/28/2005, 306A1, **ecotope 6669A:** Dejoode, 6/28/2005, 311A2, 312A1, 316A1, 317A1, 318A1, **ecotope 6670A:** Dejoode, 6/28/2005, 327A1, 330A1, **ecotope 6671A:** Dejoode, 6/28/2005, 334A1, 335A1, 338A1, 339A1, 340A1, **ecotope 6672A:** Dejoode, 6/28/2005, 351A1, 352A1, 353A2, 354A1, 355A1, 356A2, 357A1, 359A1, 360A2, **ecotope 6673A:** Dejoode, 6/27/2005, 143A1, 145A1

Aneura pinguis

***ecotope* 2349A:** Janssens, 9/25/2002, 47448A1, 47469A1, **ecotope 2492A:** Dejoode, 6/27/2005, 51A1, **ecotope 2493A:** Janssens, 6/8/2006, 52071A3, **ecotope 2494A:** Janssens, 6/8/2006, 52076A1, Leete, 6/8/2006, 956A1, **ecotope 2500A:** Dejoode, 6/16/2005, 85A1, **ecotope 2514A:** Janssens, 6/21/2006, 52175A2, 52176A1, **ecotope 2515A:** Dejoode, 6/14/2006, 6129A3, Janssens, 8/9/2006, 52277A1, **ecotope 2517A:** Dejoode, 6/9/2006, 6114A1, **ecotope 2520A:** Dejoode, 6/14/2006, 6134A1, **ecotope 6646A:** Dejoode, 6/27/2005, 120A1, **ecotope 6664A:** Dejoode, 6/27/2005, 160A1

Anomodon attenuatus

***ecotope* 6179X:** Wheeler, 7/31/1999, 20158A1, **ecotope 6184X:** Wheeler, 6/5/1998, 18922A1

Anomodon minor

***ecotope* 6180X:** Wheeler, 6/23/1998, 19357A1, 19394A1, **ecotope 6184X:** Wheeler, 6/5/1998, 18921A1

Anomodon rostratus

***ecotope* 6183X:** Wheeler, 8/17/1999, 20327A1

Aulacomnium palustre

***ecotope* 2500A:** Dejoode, 6/16/2005, 86A1

Barbula unguiculata

***ecotope* 6181X:** Wheeler, 6/11/1999, 19995A1

Brachythecium acuminatum

***ecotope* 2505A:** Janssens, 6/21/2006, 52136A1, **ecotope 2510A:** Janssens-Verbelen, 6/21/2006, 555A2, **ecotope 6180X:** Wheeler, 6/23/1998, 19358A1

Brachythecium erythrorrhizon

***ecotope* 6179X:** Wheeler, 6/23/1998, 19343A1, 7/31/1999, 20161A1

Brachythecium oedipodium

***ecotope* 6665A:** Dejoode, 6/16/2005, 165A1, 168A1, 169A2

Brachythecium rivulare

***ecotope* 2349A:** Janssens, 9/25/2002, 47437A2, 47440A1, 47447A2, 47448A3, 47455A3, 47456A3, 47467A1, 47468A2, 47474A1, **ecotope 2491A:** Janssens, 6/8/2006, 52053A1, 52054A1, **ecotope 2493A:** Janssens, 6/8/2006, 52067A1, 52068A2, 52072A1, 52073A2, Leete, 6/8/2006, 950A3, 952A1, **ecotope 2494A:** Janssens, 6/8/2006, 52074A1, **ecotope 2495A:** Janssens, 6/8/2006, 52091A1, **ecotope 2505A:** Janssens-Verbelen, 6/21/2006, 536A1, 538A1, **ecotope 2510A:** Janssens, 6/21/2006, 52158A1, 52159A1, Janssens-Verbelen, 6/21/2006, 557A1, **ecotope 2511A:** Janssens, 6/21/2006, 52163A1, Janssens-Verbelen, 6/21/2006, 560A1, **ecotope 2513A:** Leete, 6/21/2006, 1001A1, **ecotope 2514A:** Leete, 6/21/2006, 1005A1, **ecotope 2515A:** Janssens, 8/9/2006, 52274A1, **ecotope 2524A:** Dejoode, 6/15/2006, 6158A1, Janssens, 8/9/2006, 52322A1

Brachythecium salebrosum

***ecotope* 2491A:** Dejoode, 6/17/2005, 6A1, 7A2, Janssens, 6/8/2006, 52056A2, 52057A3, 52059A2, **ecotope 2493A:** Dejoode, 6/16/2005, 72A1, 80A1, Leete, 6/8/2006, 950A2, 953A3, **ecotope 2494A:** Dejoode, 6/16/2005, 68A1, 69A1, Janssens, 6/8/2006, 52075A1, 52076A3, 52079A1, 52081A3, 52082A2, **ecotope 2497A:** Dejoode, 6/16/2005, 173A1, 175A2, 176A1, 177A2, 180A1, Janssens, 6/8/2006, 52097A2, 52099A3, 52100A3, Leete, 6/8/2006, 960A2, 961A3, **ecotope 2500A:** Dejoode, 6/16/2005, 84A1, 85A3, **ecotope 2501A:** Dejoode, 6/16/2005, 412A1, 413A1, 414A3, 415A4, Leete, 6/8/2006, 966A2, 967A3, 968A3, **ecotope 2503A:** Dejoode, 6/17/2005, 204A1, 206A1, 207A1, 208A1, Janssens-Verbelen, 6/21/2006, 530A1, 531A1, 533A1, Leete, 6/21/2006, 972A1, **ecotope 2505A:** Dejoode, 6/17/2005, 211A1, 212A2, 216A1, 219A2, Janssens, 6/21/2006, 52132A1, 52133A2, 52135A2, Janssens-Verbelen, 6/21/2006, 535A2, 539A2, **ecotope 2506A:** Janssens, 6/21/2006, 52140A2, 52144A1, Janssens-Verbelen, 6/21/2006, 540A2, 543A1, 544A2, 545A2, Leete, 6/21/2006, 978A2, **ecotope 2507A:** Dejoode, 6/16/2005, 227A1, **ecotope 2508A:** Dejoode, 6/16/2005, 242A1, 243A1, Janssens-Verbelen, 6/21/2006, 550A1, 551A1, **ecotope 2509A:** Janssens, 6/21/2006, 52156A1, Janssens-Verbelen, 6/21/2006, 552A1, 553A1, 554A1, Leete, 6/21/2006, 985A1, 986A1, **ecotope 2510A:** Dejoode, 6/16/2005, 264A1, 267A1, Janssens, 6/21/2006, 52157A1, 52160A1, 52161A1, Janssens-Verbelen, 6/21/2006, 556A2, 558A1, **ecotope 2511A:** Leete, 6/21/2006, 992A2, 993A1, **ecotope 2512A:** Dejoode, 6/17/2005, 371A3, Leete, 6/21/2006, 996A2, 998A2, **ecotope 2513A:** Dejoode, 6/17/2005, 381A1, 387A1, 388A4, Janssens, 6/21/2006, 52167A4, Leete, 6/21/2006, 999A1, 1002A2, **ecotope 2514A:** Janssens, 6/21/2006, 52170A3, 52172A2, 52173A2, 52174A3, 52176A2, Leete, 6/21/2006, 1007A1, 1008A2, **ecotope 2515A:** Dejoode,

6/14/2006, 6125A2, 6126A2, 6127A2, 6128A3, 6129A4, Janssens, 8/9/2006, 52276A1, 52280A2, **ecotope 2516A:** Dejoode, 6/14/2006, 6115A1, 6116A1, 6117A1, 6118A1, 6119A1, 6120A3, 6122A2, 6123A1, Janssens, 8/9/2006, 52281A1, 52282A3, 52283A2, 52284A1, 52285A1, 52288A3, 52290A1, 52291A2, Janssens-Verbelen, 8/9/2006, 565A1, 567A1, **ecotope 2517A:** Dejoode, 6/9/2006, 6109A1, 6110A1, 6112A2, 6113A1, 6114A2, Janssens, 8/9/2006, 52295A1, 52297A1, Janssens-Verbelen, 8/9/2006, 569A1, 570A1, **ecotope 2518A:** Dejoode, 6/9/2006, 6101A1, 6102A2, 6105A4, Janssens-Verbelen, 8/9/2006, 573A3, 575A1, **ecotope 2518B:** Janssens, 8/9/2006, 52303A2, 52304A1, 52305A1, **ecotope 2519A:** Dejoode, 6/9/2006, 6107A1, Janssens, 8/9/2006, 52306A1, Janssens-Verbelen, 8/9/2006, 576A2, **ecotope 2520A:** Dejoode, 6/14/2006, 6134A2, Janssens, 8/9/2006, 52309A1, 52310A1, 52311A1, 52312A2, 52313A2, Janssens-Verbelen, 8/9/2006, 579A2, **ecotope 2521A:** Dejoode, 6/14/2006, 6131A1, 6132A2, Janssens, 8/9/2006, 52314A3, 52315A1, Janssens-Verbelen, 8/9/2006, 580A1, **ecotope 2522A:** Dejoode, 6/14/2006, 6138A1, 6139A1, 6140A1, 6141A1, 6142A1, **ecotope 2523A:** Dejoode, 6/14/2006, 6146A1, Janssens, 8/9/2006, 52316A1, **ecotope 2524A:** Dejoode, 6/15/2006, 6154A1, 6156A2, 6157A1, 6185A1, Janssens, 8/9/2006, 52317A2, 52318A2, 52319A1, 52320A1, Janssens-Verbelen, 8/9/2006, 583A2, **ecotope 2525A:** Dejoode, 6/15/2006, 6168A1, 6170A2, 6171A2, 6172A3, 6173A1, 6174A1, Janssens, 8/9/2006, 52324A3, 52325A1, 52326A3, 52327A2, 52330A2, Janssens-Verbelen, 8/9/2006, 584A1, 586A1, **ecotope 2526A:** Dejoode, 6/15/2006, 6159A1, 6160A1, 6163A1, 6164A1, 6165A2, 6166A1, Janssens, 8/9/2006, 52331A1, 52333A1, 52334A2, 52335A1, 52337A1, **ecotope 2527A:** Dejoode, 6/15/2006, 6150A1, 6152A1, 6153A1, Janssens, 8/9/2006, 52339A3, 52341A2, **ecotope 2530A:** Dejoode, 6/15/2006, 6175A2, 6176A1, 6177A1, 6178A1, 6179A2, 6180A1, 6181A2, 6183A1, 6184A2, Janssens, 8/9/2006, 52345A1, 52346A2, 52347A2, 52348A1, 52350A2, **ecotope 6180X:** Wheeler, 6/23/1998, 19362A1, **ecotope 6185X:** Wheeler, 6/9/1998, 18994A1, **ecotope 6645A:** Dejoode, 6/17/2005, 130A1, **ecotope 6664A:** Dejoode, 6/27/2005, 159A2, **ecotope 6665A:** Dejoode, 6/16/2005, 162A1, 164A1, **ecotope 6666A:** Dejoode, 6/28/2005, 279A1, **ecotope 6667A:** Dejoode, 6/28/2005, 298A1, **ecotope 6668A:** Dejoode, 6/28/2005, 301A1, 302A1, 303A1, 304A1, 305A1, 307A1, 308A1, 310A1, **ecotope 6669A:** Dejoode, 6/28/2005, 311A1, **ecotope 6673A:** Dejoode, 6/27/2005, 148A1

Brachythecium velutinum

***ecotope* 2508A:** Janssens, 6/21/2006, 52154A2, Leete, 6/21/2006, 982A1

Bryohaplocladium microphyllum

***ecotope* 6180X:** Wheeler, 6/23/1998, 19360A1

Bryum pseudotriquetrum

***ecotope* 2349A:** Janssens, 9/25/2002, 47439A3, 47445A3, 47446A1, 47447A3, 47461A3, 47463A2, 47464A3, **ecotope 2491A:** Dejoode, 6/17/2005, 1A2, **ecotope 2494A:** Janssens, 6/8/2006, 52076A2, 52082A1, 52084A2, 52087A2, **ecotope 2496A:** Dejoode, 6/27/2005, 404A2, Janssens, 6/8/2006, 52094A2, Leete, 6/8/2006, 958B2, **ecotope 2497A:** Leete, 6/8/2006, 960A1, **ecotope 2498A:** Dejoode, 6/27/2005, 98A2, Janssens, 6/8/2006, 52103A1, **ecotope 2500A:** Dejoode, 6/16/2005, 83A2, 84A2, Janssens, 6/8/2006, 52105A2, 52107A2, **ecotope 2501A:** Dejoode, 6/16/2005, 414A1, Leete, 6/8/2006, 968A5, 970A2, **ecotope 2508A:** Dejoode, 6/16/2005, 242A2, Janssens, 6/21/2006, 52147A1, 52151A1, Janssens-Verbelen, 6/21/2006, 549A1, Leete, 6/21/2006, 983A1, 984A1, **ecotope 2513A:** Janssens, 6/21/2006, 52167A1, **ecotope 2514A:** Dejoode, 6/17/2005, 395A2, 396A2, Janssens, 6/21/2006, 52171A1, 52174A2, 52176A3, 52177A2, 52182A2, Leete, 6/21/2006, 1009A1, **ecotope 2515A:** Dejoode, 6/14/2006, 6127A4, 6128A4, 6129A1, Janssens, 8/9/2006, 52279A2, **ecotope 2516A:** Dejoode, 6/14/2006, 6116A2, 6117A2, Janssens, 8/9/2006, 52282A2, 52285A2, 52286A3, Janssens-Verbelen, 8/9/2006, 565A2, 566A3, 568A1, **ecotope 2517A:** Janssens, 8/9/2006, 52294A2, **ecotope 2518A:** Dejoode, 6/9/2006, 6105A3, Janssens-Verbelen, 8/9/2006, 575A3, **ecotope 2518B:** Janssens, 8/9/2006, 52303A3, **ecotope 2519A:** Janssens, 8/9/2006, 52306A3, 52307A2, **ecotope 2520A:** Dejoode, 6/14/2006, 6135A2, Janssens, 8/9/2006, 52309A2, Janssens-Verbelen, 8/9/2006, 577A2, 577B1, 578A2, 579A1, **ecotope 2521A:** Janssens, 8/9/2006, 52314A2, **ecotope 2525A:** Dejoode, 6/15/2006, 6167A1, 6168A2, 6169A2, 6170A4, 6173A3, Janssens, 8/9/2006, 52329A3, Janssens-Verbelen, 8/9/2006, 586A3, **ecotope 6646A:** Dejoode, 6/27/2005, 112A4, 114A1, 118A2, **ecotope 6664A:** Dejoode, 6/27/2005, 156A1, **ecotope 6672A:** Dejoode, 6/28/2005, 352A2

Calliergon cordifolium

***ecotope* 6182X:** Wheeler, 6/13/1999, 20055A1

Calliergonella cuspidata

***ecotope* 2497A:** Janssens, 6/8/2006, 52098A1, **ecotope 2499A:** Leete, 6/8/2006, 963A1, **ecotope 2501A:** Dejoode, 6/16/2005, 417A1, Leete, 6/8/2006, 966A1, 968A2, **ecotope 2515A:** Janssens, 8/9/2006, 52276A4, **ecotope 2516A:** Dejoode, 6/14/2006, 6121A2, Janssens, 8/9/2006, 52281A2, 52282A1, 52288A2, 52291A1, **ecotope 2518A:** Janssens-Verbelen, 8/9/2006, 572A1, 573A1, 574A1, **ecotope 2518B:** Janssens, 8/9/2006, 52304A2, **ecotope 2525A:** Dejoode, 6/15/2006, 6167A2, 6169A1, 6170A3, 6173A2, Janssens, 8/9/2006, 52324A2, **ecotope 6182X:** Wheeler, 6/13/1999, 20054A1, 20056A1

Campylium chrysophyllum

***ecotope* 2501A:** Leete, 6/8/2006, 970A1, **ecotope 2508A:** Janssens, 6/21/2006, 52150A1, **ecotope 2514A:** Janssens, 6/21/2006, 52169A1, 52174A1, 52177A1

Campylium polygamum

***ecotope* 2349A:** Janssens, 9/25/2002, 47434A2, 47435A1, 47441A1, 47442A2, 47443A1, 47444A1, 47445A2, 47446A2, 47447A1, 47448A2, 47455A2, 47456A2, 47457A1, 47459A2, 47460A2, 47461A2, 47462A1, 47463A1, 47464A2, 47465A1, 47466A1, 47467A2, 47468A3, 47469A2, 47470A2, 47471A2, 47472A1, 47473A1, 47475A1, **ecotope 2492A:** Dejoode, 6/27/2005, 52A1, Janssens, 6/8/2006, 52066A1, **ecotope 2493A:** Janssens, 6/8/2006, 52071A1, Leete, 6/8/2006, 955A1, **ecotope 2494A:** Janssens, 6/8/2006, 52076A4, **ecotope 2495A:** Janssens, 6/8/2006, 52089A2, **ecotope 2496A:** Janssens, 6/8/2006, 52094A1, Leete, 6/8/2006, 958B1, 959A2, **ecotope 2499A:** Leete, 6/8/2006, 963A3, **ecotope 2500A:** Dejoode, 6/16/2005, 81A2, 85A2, Janssens, 6/8/2006, 52108A2, 52109A1, Leete, 6/8/2006, 964A2, **ecotope 2501A:** Dejoode, 6/16/2005, 414A4, 415A1, 417A4, **ecotope 2505A:** Janssens-Verbelen, 6/21/2006, 535A1, **ecotope 2508A:** Dejoode, 6/16/2005, 243A2, 244A1, 246A1, 250A1, Janssens, 6/21/2006, 52148A1, 52149A1, 52152A1, 52153A1, 52155A1, Janssens-Verbelen, 6/21/2006, 548A1, 550A2, 551A2, Leete, 6/21/2006, 981A1, 984A2, **ecotope 2514A:** Dejoode, 6/17/2005, 393A1, 396A3, Janssens, 6/21/2006, 52179A1, 52180A3, 52182A4, Leete, 6/21/2006, 1004A1, 1005A2, 1006A1, 1010A1, **ecotope 2515A:** Janssens, 8/9/2006, 52277A3, 52278A1, **ecotope 2516A:** Dejoode, 6/14/2006, 6121A3,

Janssens-Verbelen, 8/9/2006, 564A1, 566A1, 568A2, **ecotope 2517A:** Janssens, 8/9/2006, 52296A1, **ecotope 2518A:** Janssens, 8/9/2006, 52301A2, Janssens-Verbelen, 8/9/2006, 572A2, 575A4, **ecotope 2520A:** Janssens, 8/9/2006, 52311A2, **ecotope 2522A:** Janssens-Verbelen, 8/9/2006, 581A1, **ecotope 2525A:** Dejoode, 6/15/2006, 6167A3, 6168A3, Janssens, 8/9/2006, 52323A1, 52326A4, 52327A3, **ecotope 6644A:** Dejoode, 6/17/2005, 50A1, **ecotope 6646A:** Dejoode, 6/27/2005, 111A2, 112A2, 113A1, 114A2, 116A2, 120A2, **ecotope 6664A:** Dejoode, 6/27/2005, 151A1, 152A1, 155A1, 156A2

Campylium radicale

***ecotope* 2508A:** Janssens, 6/21/2006, 52154A1, Leete, 6/21/2006, 982A2, **ecotope 2509A:** Leete, 6/21/2006, 987A1, **ecotope 2515A:** Janssens, 8/9/2006, 52280A4, **ecotope 2516A:** Janssens, 8/9/2006, 52287A1, **ecotope 2522A:** Dejoode, 6/14/2006, 6143A1, **ecotope 2525A:** Janssens, 8/9/2006, 52329A1

Campylium stellatum

***ecotope* 2492A:** Dejoode, 6/27/2005, 51A2, 53A2, 55A1, 57A2, 60A1, Janssens, 6/8/2006, 52060A2, 52061A1, 52062A2, 52063A2, 52064A1, 52065A2, **ecotope 2494A:** Janssens, 6/8/2006, 52085A2, 52086A1, Leete, 6/8/2006, 956A2, **ecotope 2495A:** Dejoode, 6/17/2005, 33A2, **ecotope 2496A:** Dejoode, 6/27/2005, 401A1, 403A2, 404A1, 406A1, 407A1, Janssens, 6/8/2006, 52095A1, **ecotope 2498A:** Dejoode, 6/27/2005, 94A1, 95A1, 96A1, 97A1, 98A1, 99A1, 100A1, Janssens, 6/8/2006, 52102A1, 52103A3, **ecotope 2500A:** Dejoode, 6/16/2005, 83A1, Janssens, 6/8/2006, 52105A1, 52106A1, **ecotope 2505A:** Janssens, 6/21/2006, 52133A1, **ecotope 2506A:** Leete, 6/21/2006, 977A1, **ecotope 2508A:** Janssens, 6/21/2006, 52151A2, **ecotope 2514A:** Janssens, 6/21/2006, 52175A1, **ecotope 2515A:** Janssens, 8/9/2006, 52279A1, **ecotope 2518A:** Janssens, 8/9/2006, 52300A1, **ecotope 2525A:** Dejoode, 6/15/2006, 6169A5, 6172A1, Janssens, 8/9/2006, 52328A1, Janssens-Verbelen, 8/9/2006, 586A4, **ecotope 6645A:** Dejoode, 6/17/2005, 124A1, 125A1, 126A1, **ecotope 6646A:** Dejoode, 6/27/2005, 111A1, 112A3, 117A2, 118A1, 119A1, **ecotope 6664A:** Dejoode, 6/27/2005, 153A1, 159A1, 160A2

Ceratodon purpureus

***ecotope* 6180X:** Wheeler, 6/23/1998, 19400A1, **ecotope 6181X:** Wheeler, 6/11/1999, 19994A1

Climacium dendroides

***ecotope* 6182X:** Wheeler, 6/13/1999, 20058A1

Conocephalum conicum

***ecotope* 6183X:** Wheeler, 8/17/1999, 20331A1

Cratoneuron filicinum

***ecotope* 2491A:** Janssens, 6/8/2006, 52055A1, 52057A2, Leete, 6/8/2006, 949A1, **ecotope 2493A:** Janssens, 6/8/2006, 52068A1, Leete, 6/8/2006, 951A1, **ecotope 2494A:** Janssens, 6/8/2006, 52077A1, 52081A2, 52083A1, 52084A1, 52085A1, 52087A1, 52088A1, **ecotope 2495A:** Janssens, 6/8/2006, 52089A1, Leete, 6/8/2006, 957A1, **ecotope 2497A:** Janssens, 6/8/2006, 52101A1

Dicranella varia

***ecotope* 6181X:** Wheeler, 6/11/1999, 19996A1

Drepanocladus aduncus

***ecotope* 2349A:** Janssens, 9/25/2002, 47440A2, 47444A2, **ecotope 2491A:** Dejoode, 6/17/2005, 6A3, Janssens, 6/8/2006, 52053A2, 52057A1, 52059A1, **ecotope 2493A:** Janssens, 6/8/2006, 52067A2, 52070A1, 52071A2, 52072A2, 52073A1, Leete, 6/8/2006, 950A1, **ecotope 2494A:** Dejoode, 6/16/2005, 69A2, 70A1, Janssens, 6/8/2006, 52074A2, 52075A2, 52076A5, 52077A2, 52078A1, 52079A2, 52080A1, 52081A1, **ecotope 2495A:** Janssens, 6/8/2006, 52091A2, **ecotope 2496A:** Janssens, 6/8/2006, 52095A2, **ecotope 2497A:** Dejoode, 6/16/2005, 172A1, 173A3, 174A1, 177A4, 178A2, 179A1, Janssens, 6/8/2006, 52098A3, 52099A1, 52101A3, Leete, 6/8/2006, 961A1, 962A1, **ecotope 2498A:** Janssens, 6/8/2006, 52103A2, 52104A1, **ecotope 2499A:** Leete, 6/8/2006, 963A2, **ecotope 2500A:** Dejoode, 6/16/2005, 81A1, Janssens, 6/8/2006, 52106A2, 52108A1, 52110A1, Leete, 6/8/2006, 964A1, **ecotope 2501A:** Dejoode, 6/16/2005, 413A2, 415A3, 420A1, Leete, 6/8/2006, 967A1, 968A4, 969A1, **ecotope 2505A:** Dejoode, 6/17/2005, 212A3, Janssens, 6/21/2006, 52139A1, Leete, 6/21/2006, 973A2, 975A1, **ecotope 2506A:** Leete, 6/21/2006, 976A2, 977A3, 978A1, **ecotope 2507A:** Janssens, 6/21/2006, 52146A1, **ecotope 2510A:** Dejoode, 6/16/2005, 265A1, Leete, 6/21/2006, 991A1, **ecotope 2511A:** Janssens, 6/21/2006, 52164A1, 52165A1, Janssens-Verbelen, 6/21/2006, 559A1, 560A2, **ecotope 2512A:** Dejoode, 6/17/2005, 371A1, **ecotope 2513A:** Dejoode, 6/17/2005, 388A1, **ecotope 2514A:** Janssens, 6/21/2006, 52180A2, 52182A1, Leete, 6/21/2006, 1003A2, 1004A2, 1006A2, **ecotope 2515A:** Dejoode, 6/14/2006, 6126A1, 6127A3, 6129A5, Janssens, 8/9/2006, 52275A1, 52276A2, 52277A2, 52278A2, Janssens-Verbelen, 8/9/2006, 561A3, **ecotope 2516A:** Dejoode, 6/14/2006, 6120A2, Janssens, 8/9/2006, 52286A1, 52289A2, Janssens-Verbelen, 8/9/2006, 564A2, 565A3, 566A2, 567A2, **ecotope 2517A:** Janssens, 8/9/2006, 52293A1, 52294A1, 52295A2, Janssens-Verbelen, 8/9/2006, 569A2, 571A1, **ecotope 2518A:** Dejoode, 6/9/2006, 6105A5, Janssens, 8/9/2006, 52300A2, **ecotope 2520A:** Dejoode, 6/14/2006, 6135A1, Janssens, 8/9/2006, 52309A3, 52313A1, **ecotope 2521A:** Dejoode, 6/14/2006, 6132A1, Janssens, 8/9/2006, 52314A1, **ecotope 2522A:** Dejoode, 6/14/2006, 6138A2, **ecotope 2525A:** Dejoode, 6/15/2006, 6169A3, 6170A1, 6171A1, 6172A2, Janssens, 8/9/2006, 52323A2, 52324A1, 52326A2, 52328A2, Janssens-Verbelen, 8/9/2006, 586A2, **ecotope 2526A:** Dejoode, 6/15/2006, 6159A2, 6164A2, 6165A3, Janssens, 8/9/2006, 52331A2, 52332A1, 52333A2, 52334A1, 52335A2, 52336A1, 52337A2, 52338A1, Janssens-Verbelen, 8/9/2006, 587A1, **ecotope 2527A:** Dejoode, 6/15/2006, 6150A2, 6153A2, Janssens, 8/9/2006, 52339A2, 52340A1, **ecotope 2528A:** Janssens, 8/9/2006, 52342A1, 52343A2, **ecotope 2529A:** Janssens, 8/9/2006, 52344A1, Janssens-Verbelen, 8/9/2006, 588A2, **ecotope 2530A:** Dejoode, 6/15/2006, 6176A3, 6182A3, Janssens, 8/9/2006, 52345A2, 52347A1, 52349A1, **ecotope 6182X:** Wheeler, 6/13/1999, 20064A1, **ecotope 6646A:** Dejoode, 6/27/2005, 117A1, **ecotope 6666A:** Dejoode, 6/28/2005, 271A1, 274A2, **ecotope 6668A:** Dejoode, 6/28/2005, 309A1, **ecotope 6669A:** Dejoode, 6/28/2005, 319A1, **ecotope 6672A:** Dejoode, 6/28/2005, 360A1

Entodon cladorrhizans

***ecotope* 6179X:** Wheeler, 6/23/1998, 19344A1, 7/31/1999, 20164A1, **ecotope 6180X:** Wheeler, 6/23/1998, 19359A1, **ecotope 6184X:** Wheeler, 6/5/1998, 18923A1

Eurhynchium hians

***ecotope* 2349A:** Janssens, 9/25/2002, 47442A1, **ecotope 2491A:** Dejoode, 6/17/2005, 1A1, 2A2, **ecotope 2493A:** Leete, 6/8/2006, 954A1, **ecotope 2496A:** Leete, 6/8/2006, 958A1, **ecotope 2501A:** Dejoode, 6/16/2005, 417A3, **ecotope 2503A:** Leete, 6/21/2006,

971A1, **ecotope 2505A:** Janssens, 6/21/2006, 52135A1, Leete, 6/21/2006, 973A1, **ecotope 6181X:** Wheeler, 6/11/1999, 20000A1, **ecotope 6645A:** Dejoode, 6/17/2005, 129A1, **ecotope 6666A:** Dejoode, 6/28/2005, 273A2, 274A1

Fissidens adianthoides

***ecotope* 2349A:** Janssens, 9/25/2002, 47434A1, 47439A2, 47442A3, 47444A3, 47445A1, 47449A1, 47450A1, 47451A1, 47455A4, 47456A1, 47458A1, 47459A1, 47461A1, 47464A1, 47466A2, 47468A1, 47471A1, **ecotope 2492A:** Dejoode, 6/27/2005, 53A1, 57A1, 58A1, 59A1, **ecotope 2495A:** Dejoode, 6/17/2005, 33A1, **ecotope 2496A:** Dejoode, 6/27/2005, 403A1, Janssens, 6/8/2006, 52095A3, Leete, 6/8/2006, 959A1, **ecotope 2501A:** Dejoode, 6/16/2005, 414A2, Leete, 6/8/2006, 968A1, **ecotope 2506A:** Leete, 6/21/2006, 977A2, **ecotope 2514A:** Dejoode, 6/17/2005, 396A1, Janssens, 6/21/2006, 52170A1, 52173A1, 52180A1, 52182A3, Leete, 6/21/2006, 1003A1, 1008A1, 1009A2, 1010A2, **ecotope 2515A:** Janssens, 8/9/2006, 52272A1, Janssens-Verbelen, 8/9/2006, 561A2, 562A1, **ecotope 2516A:** Janssens, 8/9/2006, 52283A1, **ecotope 2518A:** Dejoode, 6/9/2006, 6102A1, Janssens, 8/9/2006, 52301A1, **ecotope 2522A:** Janssens-Verbelen, 8/9/2006, 581A2, **ecotope 2525A:** Dejoode, 6/15/2006, 6169A4, Janssens, 8/9/2006, 52329A2, 52330A1, **ecotope 6646A:** Dejoode, 6/27/2005, 111A3, 116A1, 119A2

Frullania eboracensis

***ecotope* 6182X:** Wheeler, 6/13/1999, 20065A1

Funaria hygrometrica

***ecotope* 6181X:** Wheeler, 6/11/1999, 19992A1

Hypnum lindbergii

***ecotope* 2349A:** Janssens, 9/25/2002, 47436A1, 47437A1, 47439A1, 47449A2, 47451A2, 47460A1, 47470A1, **ecotope 2491A:** Janssens, 6/8/2006, 52056A1, **ecotope 2500A:** Janssens, 6/8/2006, 52107A1, **ecotope 2516A:** Janssens, 8/9/2006, 52289A1, 52292A1, **ecotope 2518B:** Janssens, 8/9/2006, 52302A1, 52303A1, **ecotope 6181X:** Wheeler, 6/11/1999, 19997A1, **ecotope 6646A:** Dejoode, 6/27/2005, 112A1

Hypnum pratense

***ecotope* 2493A:** Janssens, 6/8/2006, 52069A1, **ecotope 2497A:** Dejoode, 6/16/2005, 176A3, 177A1, Janssens, 6/8/2006, 52096A1, 52100A2, Leete, 6/8/2006, 961A4, **ecotope 2501A:** Dejoode, 6/16/2005, 418A1, **ecotope 2505A:** Janssens, 6/21/2006, 52134A1, Leete, 6/21/2006, 974A1, **ecotope 2515A:** Dejoode, 6/14/2006, 6128A1, Janssens, 8/9/2006, 52271A1, 52280A3, **ecotope 2516A:** Janssens, 8/9/2006, 52286A2, **ecotope 2518A:** Janssens, 8/9/2006, 52299A1, **ecotope 2525A:** Janssens, 8/9/2006, 52326A1, 52327A1, 52330A3, Janssens-Verbelen, 8/9/2006, 584A2, 585A1, **ecotope 6668A:** Dejoode, 6/28/2005, 304A2

Leptodictyum humile

***ecotope* 2491A:** Janssens, 6/8/2006, 52058A1, Leete, 6/8/2006, 949A2

Leskea gracilescens

***ecotope* 6184X:** Wheeler, 6/5/1998, 18924A1

Leskeella nervosa

***ecotope* 6185X:** Wheeler, 6/9/1998, 18996A1

Limprichtia cossonii

***ecotope* 2492A:** Janssens, 6/8/2006, 52060A1, 52062A1, 52063A1, 52065A1, 52066A2, **ecotope 2502A:** Janssens, 6/21/2006, 52141A1, 52142A1, 52143A1

Lindbergia brachyptera

***ecotope* 6179X:** Wheeler, 7/31/1999, 20167A1, **ecotope 6180X:** Wheeler, 6/23/1998, 19395A1

Lophocolea heterophylla

***ecotope* 6182X:** Wheeler, 6/13/1999, 20066A1

Marchantia polymorpha

***ecotope* 6675X:** Ballard, no date, 704A1

Orthotrichum pumilum

***ecotope* 6182X:** Wheeler, 6/13/1999, 20067A1, **ecotope 6185X:** Wheeler, 6/9/1998, 18993A1

Physcomitrium pyriforme

***ecotope* 6181X:** Wheeler, 6/11/1999, 19993A1

Plagiomnium cuspidatum

***ecotope* 2503A:** Janssens-Verbelen, 6/21/2006, 529A1, 530A2, **ecotope 2505A:** Janssens-Verbelen, 6/21/2006, 537A1, Leete, 6/21/2006, 975A2, **ecotope 2510A:** Janssens-Verbelen, 6/21/2006, 555A1, 556A1, **ecotope 2514A:** Janssens, 6/21/2006, 52171A2, 52172A1, 52181A1, **ecotope 2517A:** Dejoode, 6/9/2006, 6112A1, **ecotope 2518A:** Dejoode, 6/9/2006, 6104A1, 6105A2, Janssens, 8/9/2006, 52298A1, **ecotope 2519A:** Janssens, 8/9/2006, 52307A1, **ecotope 2520A:** Dejoode, 6/14/2006, 6136A1, Janssens-Verbelen, 8/9/2006, 577A1, 577B2, 578A1, **ecotope 2524A:** Janssens, 8/9/2006, 52318A1, **ecotope 2530A:** Dejoode, 6/15/2006, 6175A1, 6177A2, **ecotope 6179X:** Wheeler, 7/31/1999, 20157A1, **ecotope 6180X:** Wheeler, 6/23/1998, 19361A1

Plagiomnium ellipticum

***ecotope* 2349A:** Janssens, 9/25/2002, 47447A4, 47455A1, **ecotope 2491A:** Dejoode, 6/17/2005, 1A3, 2A1, 3A1, 6A2, 7A1, 8A1, Janssens, 6/8/2006, 52054A2, **ecotope 2493A:** Leete, 6/8/2006, 953A1, **ecotope 2494A:** Janssens, 6/8/2006, 52079A3, 52080A2, 52082A3, **ecotope 2497A:** Dejoode, 6/16/2005, 171A1, 172A2, 173A2, 175A1, 176A2, 177A3, 178A1, 180A2, Janssens, 6/8/2006, 52096A2, 52098A2, 52099A2, 52100A1, 52101A2, Leete, 6/8/2006, 960A3, 961A2, **ecotope 2501A:** Dejoode, 6/16/2005, 415A2, 416A1, 417A2, 418A2, 419A1, 420A2, Leete, 6/8/2006, 966A3, 967A2, **ecotope 2503A:** Janssens-Verbelen, 6/21/2006, 534A1, **ecotope 2505A:** Dejoode, 6/17/2005, 215A2, **ecotope 2506A:** Janssens, 6/21/2006, 52140A1, Janssens-Verbelen, 6/21/2006, 540A1, 541A2, 542A1, 543A2, 544A1, 545A1, 546A1, Leete, 6/21/2006, 976A1, **ecotope 2511A:** Leete, 6/21/2006, 992A1, 993A2, **ecotope 2512A:** Dejoode, 6/17/2005, 371A2, **ecotope 2513A:** Dejoode, 6/17/2005, 387A2, 388A3, Janssens, 6/21/2006, 52167A2, 52168A1, Leete, 6/21/2006, 1002A1, **ecotope 2514A:** Janssens, 6/21/2006, 52170A2, **ecotope 2515A:** Dejoode, 6/14/2006, 6125A1, 6127A1,

6128A2, 6129A2, Janssens, 8/9/2006, 52273A1, 52274A2, 52276A3, 52280A1, Janssens-Verbelen, 8/9/2006, 561A1, **ecotope 2516A:** Dejoode, 6/14/2006, 6120A1, 6122A1, Janssens, 8/9/2006, 52288A1, **ecotope 2517A:** Dejoode, 6/9/2006, 6111A1, **ecotope 2518A:** Dejoode, 6/9/2006, 6105A1, Janssens, 8/9/2006, 52299A2, Janssens-Verbelen, 8/9/2006, 573A2, 575A2, **ecotope 2519A:** Dejoode, 6/9/2006, 6106A1, Janssens-Verbelen, 8/9/2006, 576A1, **ecotope 2523A:** Dejoode, 6/14/2006, 6144A1, 6145A2, 6146A2, 6147A1, 6148A1, Janssens, 8/9/2006, 52316A2, **ecotope 2524A:** Janssens, 8/9/2006, 52321A1, Janssens-Verbelen, 8/9/2006, 583A1, **ecotope 2525A:** Janssens-Verbelen, 8/9/2006, 585A2, **ecotope 2526A:** Dejoode, 6/15/2006, 6159A3, 6165A1, 6166A2, Janssens, 8/9/2006, 52331A3, 52333A3, 52336A2, 52337A3, Janssens-Verbelen, 8/9/2006, 587A2, **ecotope 2527A:** Janssens, 8/9/2006, 52339A1, 52340A2, **ecotope 2528A:** Janssens, 8/9/2006, 52343A1, **ecotope 2529A:** Janssens-Verbelen, 8/9/2006, 588A1, **ecotope 2530A:** Dejoode, 6/15/2006, 6176A2, 6178A2, 6179A1, 6180A2, 6181A1, 6182A2, 6183A2, 6184A1, Janssens, 8/9/2006, 52346A1, 52347A3, 52350A1, **ecotope 6672A:** Dejoode, 6/28/2005, 351A2, 353A1, 354A2, 356A1, 357A2

Platygyrium repens

***ecotope* 6179X:** Wheeler, 7/31/1999, 20156A1, **ecotope 6182X:** Wheeler, 6/13/1999, 20053A1

Rhodobryum ontariense

***ecotope* 6179X:** Wheeler, 7/31/1999, 20155A1

Ricciocarpos natans

***ecotope* 6674X:** Ballard, no date, 62A1

Sphagnum teres

***ecotope* 6462X:** Hofstetter, 10/6/1967

Steerecleus serrulatus

***ecotope* 6179X:** Wheeler, 7/31/1999, 20165A1

Taxiphyllum deplanatum

***ecotope* 6179X:** Wheeler, 7/31/1999, 20162A1, **ecotope 6183X:** Wheeler, 8/17/1999, 20326A1

Thuidium delicatulum

***ecotope* 2497A:** Janssens, 6/8/2006, 52097A1, Leete, 6/8/2006, 960A4, **ecotope 2514A:** Janssens, 6/21/2006, 52178A1

Thuidium recognitum

***ecotope* 2349A:** Janssens, 9/25/2002, 47438A1, 47452A1, 47453A1, 47454A1, **ecotope 2504A:** Janssens, 6/21/2006, 52131A1, **ecotope 2515A:** Janssens-Verbelen, 8/9/2006, 563A1, **ecotope 6179X:** Wheeler, 7/31/1999, 20160A1

Timmia megapolitana

***ecotope* 6179X:** Wheeler, 7/31/1999, 20163A1, **ecotope 6183X:** Wheeler, 8/17/1999, 20328A1

Weissia controversa

***ecotope* 6179X:** Wheeler, 7/31/1999, 20159A1

ANALYSIS OF THE BRYOPHYTE COMMUNITIES OF SEMINARY FEN, CARVER COUNTY, MINNESOTA

Update September 2006

Joannes A. Janssens

Lambda-Max Ecological Research
1061 25th Ave SE
Minneapolis, MN 55414-2637
janss008@tc.umn.edu

Cite as: J.A. Janssens. 2006. Analysis of the bryophytes of Seminary Fen, Carver County, Minnesota. Update September 2006.

Analysis of the Bryophyte Communities of Seminary Fen, Carver County, Minnesota

Introduction

The graphs, results, discussion, and conclusions in this report are based on the bryophyte data presented in the August 2006 update of 'Bryophytes of Carver County, Minnesota', submitted to the Minnesota Department of Natural Resources, County Biological Survey (Janssens 2006a), and also available from the author.

The ecotopes (Janssens 2006b) studied at Seminary Fen are listed with precise coordinates in the above mentioned county report. Only th area north of Highway 212 are mapped on figures 1 to 3.

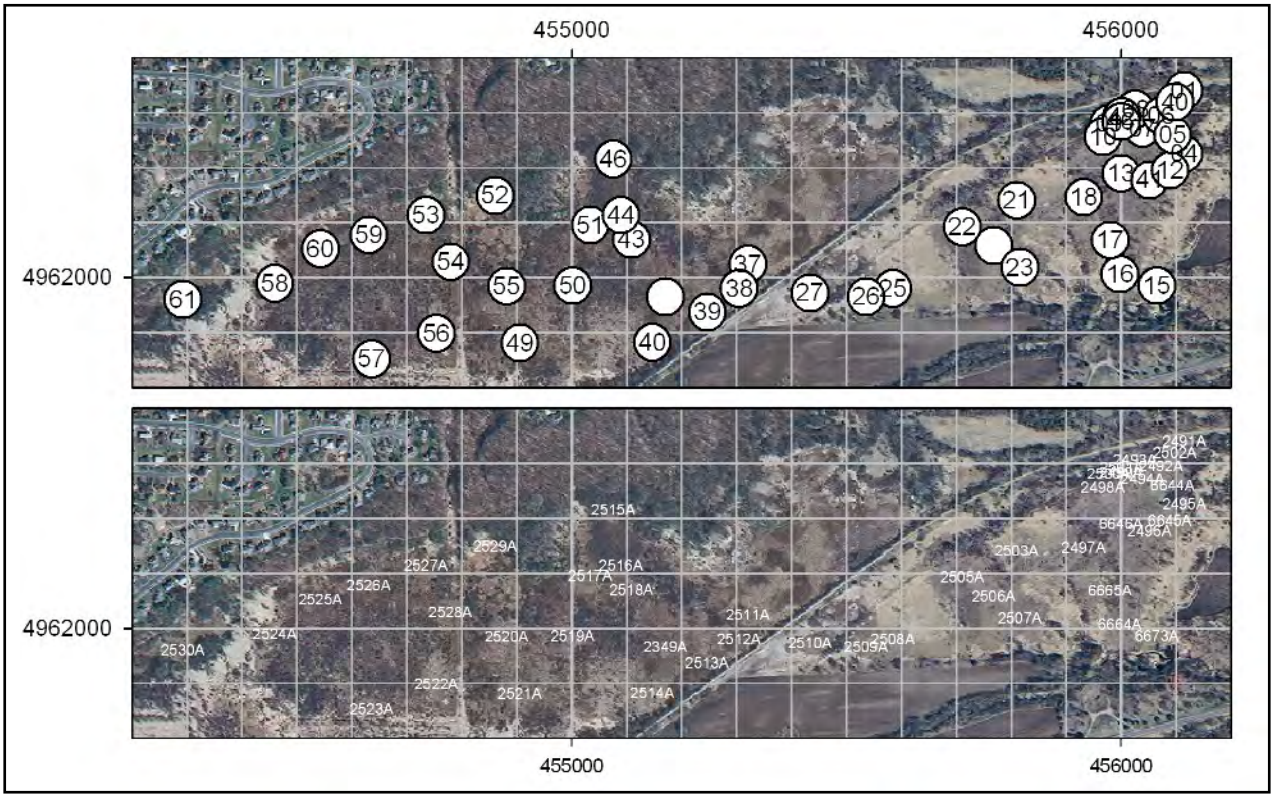


Figure 1. Seminary fen bryophyte-survey sites and ecotopes. The sites shown are those north of Highway 212. The upper panel gives the approximate location of the botanical transects (D.R. Dejoode, pers. comm.). The lower panel are the ecotope IDs as assigned in the Minnesota bryophyte database. The grid are along 100-m UTM coordinates (WSG 1984 datum). For more detailed locality information see 'Bryophytes of Carver County, Minnesota', submitted to the Minnesota Department of Natural Resources, County Biological Survey.

Results

For each ecotope, the number of calcareous-fen bryophyte indicator species and its total calcareous-fen score is calculated (totCFscore, figure 2). These scores range from 17 to 346. Those ecotopes with a score >109 are classified as calcareous-fen mesohabitat based on the bryophyte criterion (Janssens 2005). Most of these calcareous-fen ecotopes are located in the northeastern and central parts of the fen complex. The highest concentration of high-quality calcareous-fen mesohabitat appears to be along the NNW to SSE drainage in the center of the fen complex between the UTM easting of 455000 and 455200). Another large node is obvious in the northeastern corner, and a small one in the west (figure 3).

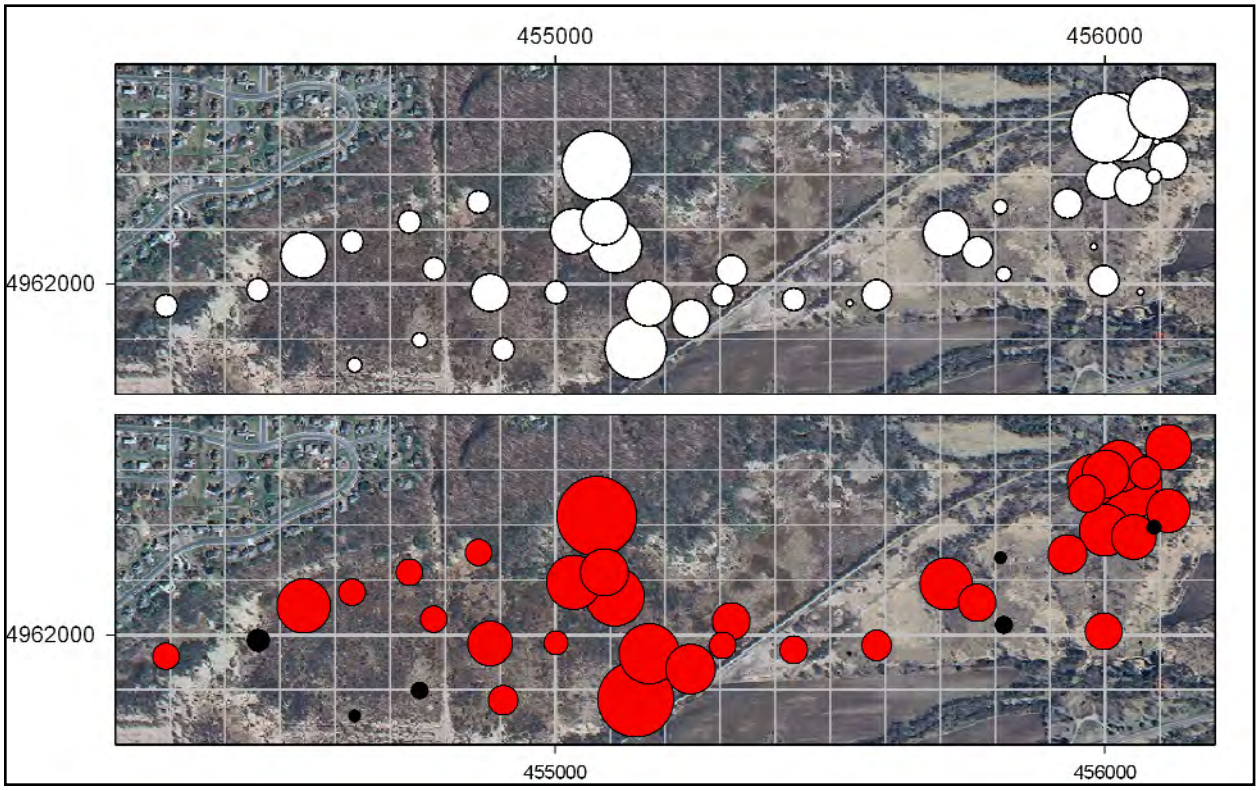


Figure 2. Seminary fen bryophyte-survey results. The upper panel illustrates the number of calcareous-fen bryophyte indicator species recorded during the surveys. The size of the bubbles is relative to the number of indicator species, ranging from 1 to 9. The diameter of the bubbles on the lower panel reflect the total calcareous-fen bryophyte score (Janssens 2005). The bubbles in red range from 109 to 346, and mark ecotopes typed as calcareous fen using the bryophyte criterion. The black bubbles are ecotopes with an insufficient number of bryophyte indicator species to classify as calcareous fen, and for which the totCFscore is <109.

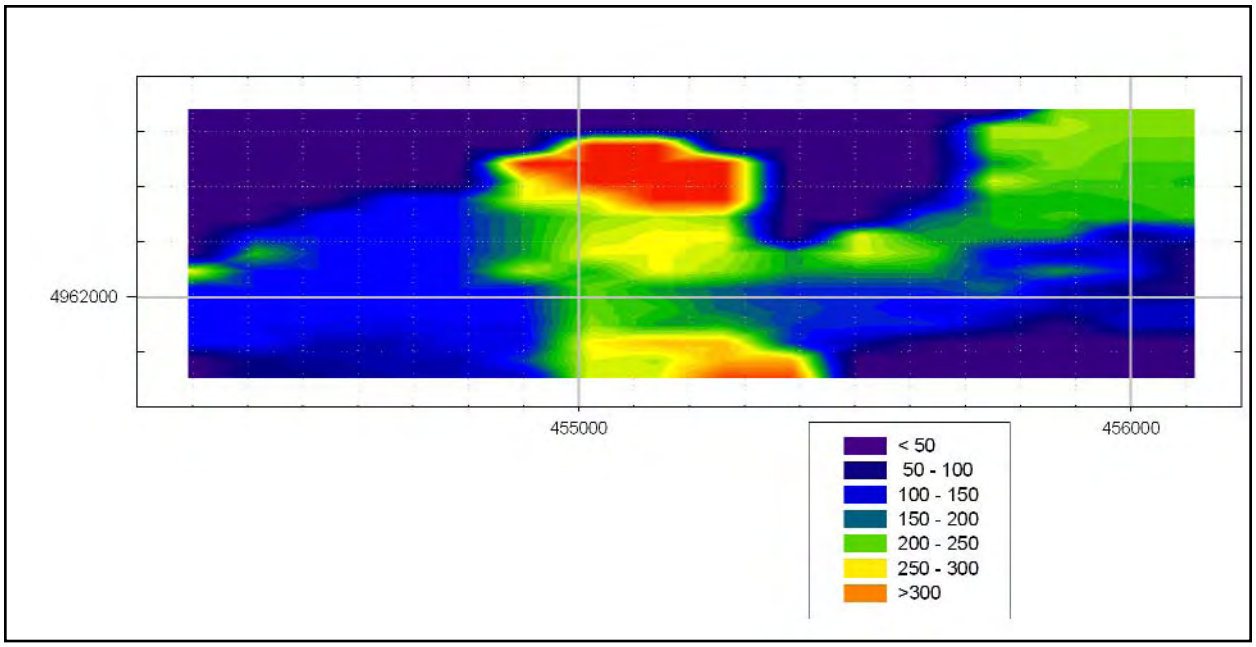


Figure 3. Seminary fen bryophyte-survey results. Filled smoothed contour plot across the ecotopes based on totCFscore (see legend; areas colored by a score of 100 could be considered as minimal calcareous-fen mesohabitat). The highest-quality areas of calcareous fen extend from the NNW to the SSE in the central portion of the fen, and in the northeastern corner. A small node exists in the western extreme of the fen complex.

Discussion and Conclusions

Figure 4 presents the results of the bryophyte records of the Seminary Fen ecotopes (including those south of Highway 212, see the Carver County checklist report), in the form of a matrix. The matrix squares are shaded based on the relative abundance of the species in its ecotope. The calcareous-fen ecotopes are highlighted with red ID labels, while the matrix squares underneath the calcareous-fen bryophyte indicators are outlined in green. There are no geographically-delineated blocs of species x ecotopes with more than 2 ecotopes to be derived from the two-way clustering of ecotopes and bryophytes (compare the clustering with the maps in the county report and figure 1). This suggests to me that all ecotopes are potentially belonging to the same complex of calcareous-fen mesohabitat and the low score of some of them reflects their more ruderal or disturbed aspect. This is probably caused by low through-flow of calcareous-fen water and the oxidation of drying peat in some areas of the fen complex.

Figures 5-6 reinforce this evidence of non-delineation of distinctive calcareous-fen mesohabitat and partial drying with its accompanying ruderal aspect. These figures are based on a nonmetric multidimensional scaling (NMS) ordination analysis of the same data as the ones presented in the two-way cluster analysis of figure 4. (Except for the elimination of a single outlier, ecotope 6668A.)

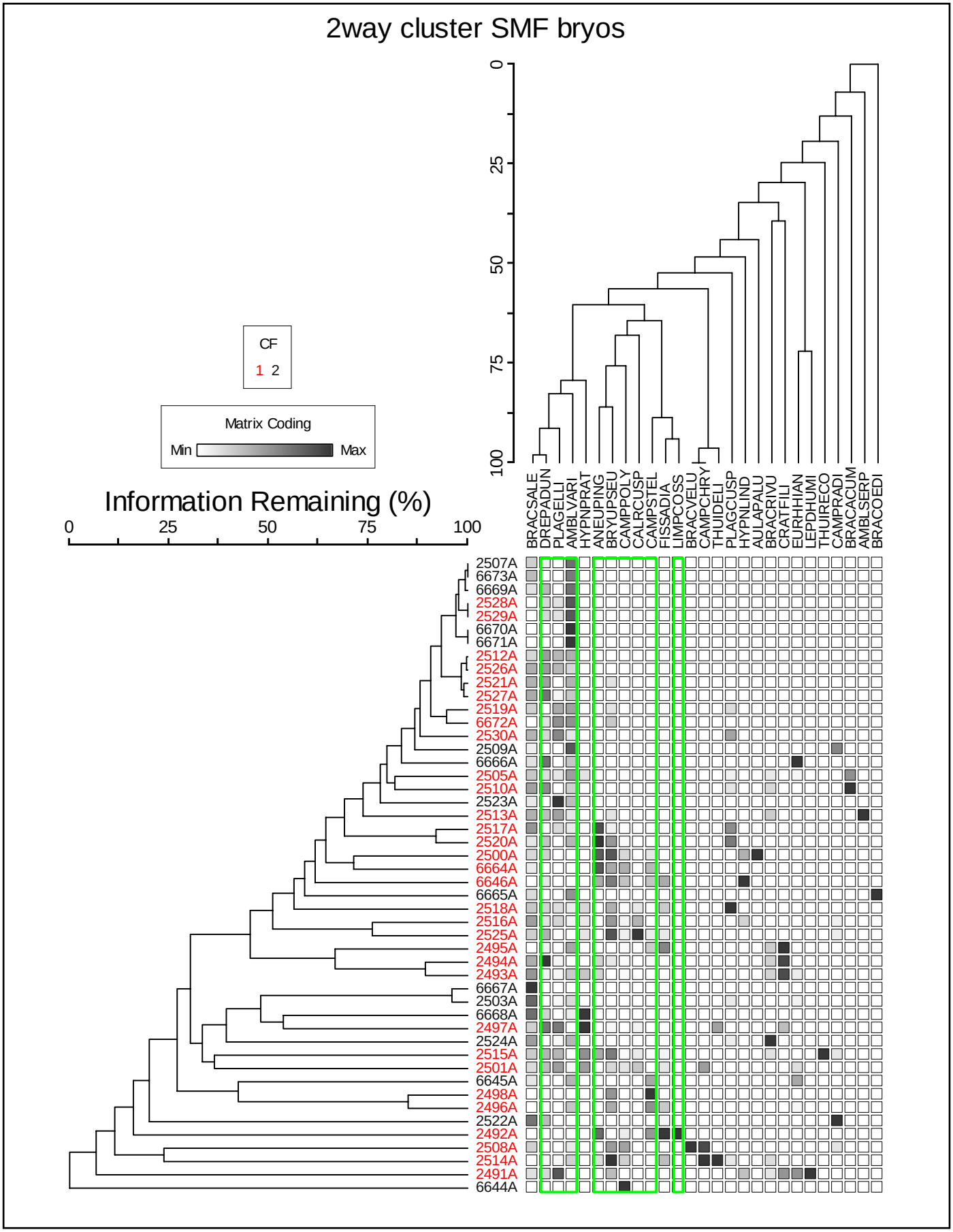

2way cluster SMF bryos
0
25
50
75
100
BRACSALE
DREPADUN
PLAGELLI
AMBLVARI
HYPNPRAT
ANEUPING
BRYUPSEU
CAMPPOLY
CALRCUSP
CAMPSTEL
FISSADIA
LIMPCOSS
BRACVELU
CAMPCHRY
THUIDELI
PLAGCUSP
HYPNLIND
AULAPALU
BRACRIVU
CRATFILI
EURHHIAN
LEPDHUMI
THUIRECO
CAMPRADI
BRACACUM
AMBLSERP
BRACOEDI
CF
1 2
Matrix Coding
Min
Max
Information Remaining (%)
0
25
50
75
100
2507A
6673A
6669A
2528A
2529A
6670A
6671A
2512A
2526A
2521A
2527A
2519A
6672A
2530A
2509A
6666A
2505A
2510A
2523A
2513A
2517A
2520A
2500A
6664A
6646A
6665A
2518A
2516A
2525A
2495A
2494A
2493A
6667A
2503A
6668A
2497A
2524A
2515A
2501A
6645A
2498A
2496A
2522A
2492A
2508A
2514A
2491A
6644A

Figure 4 (opposite page). Seminary fen bryophyte assemblages: two way clustering. The matrix of shaded squares represents the ecotopes x bryophyte matrix. The intensity of shading (matrix coding) is proportional to the abundance of the species in the ecotope. The dendrograms cluster the ecotopes and species using the Sorensen (Bray-Curtis) distance measure and nearest neighbor linkage method (PC-ORD 5, McCune & Mefford 2006). The ecotopes identified with red labels are those that have a totCFscore of >109 and can be considered as calcareous-fen mesohabitat using the bryophyte criterion (Janssens 2005). The matrix squares belonging to the calcareous-fen bryophyte indicators are outlined in green.

Specifics about the ordination are given in the caption to figures 5-6.

There is no distinct nodal clustering of ecotopes in the ordination, nor a distinct gradient of the totCFscore > 109 with the axes, except that the non-calcareous fen mesohabitat is rotated to the negative side of axis 1. Significant positive correlations ($p<0.01$) of species abundances with axis one are found for **Aneura pinguis*, **Bryum pseudotriquetrum*, **Campylium polygamum*, * *C. stellatum*, *Fissidens adianthoides*, *Hypnum lindbergii*, and **Limprichtia cossonii*. (The species marked by an asterisk are calcareous-fen indicators.) **Amblystegium varium* is the only calcareous-fen indicator negative correlated with axis 1, which emphasizes its well-known ruderal character. Similarly *Brachythecium salebrosum*, another ruderal species, is negatively correlated with axis 2. **Amblystegium varium* is again negatively correlated with axis 3, but the main remaining calcareous-fen indicators, **Drepanocladus aduncus* and **Plagiomnium ellipticum*, are highly significant along the positive direction of axis 3. Both of these latter two species are usually more in association with either dense thatch or shrub cover, while the species positively correlated with axis 1 are found rather in more open or short-sedge fens and wet meadows. The UTMx (easting) and UTMy coordinates (northing) are correlated positively with axis 1, which underscores the presence of better-quality calcareous-fen mesohabitat on the upslope (north) and less disturbed (east) side of the fen complex.

Generally, the entire Seminary Fen complex appears to be a suitable system for the preservation of calcareous-fen bryophytes and associated species. Its internal differentiation appears to be more related to distance from the main seepage areas immediately to the south of the upland bluffs and thus the length of the drainage systems, and local factors of disturbance.

References

Janssens, J.A. 2005. Classification of the Bryophyte Assemblages of Minnesota's Extreme Rich Fens and the Bryophyte Criterion for the Evaluation of Potential Calcareous-Fen Ecotopes, update October 2005. Report to the Minnesota Department of Natural Resources, Division of Waters. Available from the author janss008@tc.umn.edu.

Janssens, J.A. 2006a. Bryophytes of Carver County, Minnesota, update August 2006. Report to the Minnesota Department of Natural Resources, County Biological Survey. Available from the author janss008@tc.umn.edu.

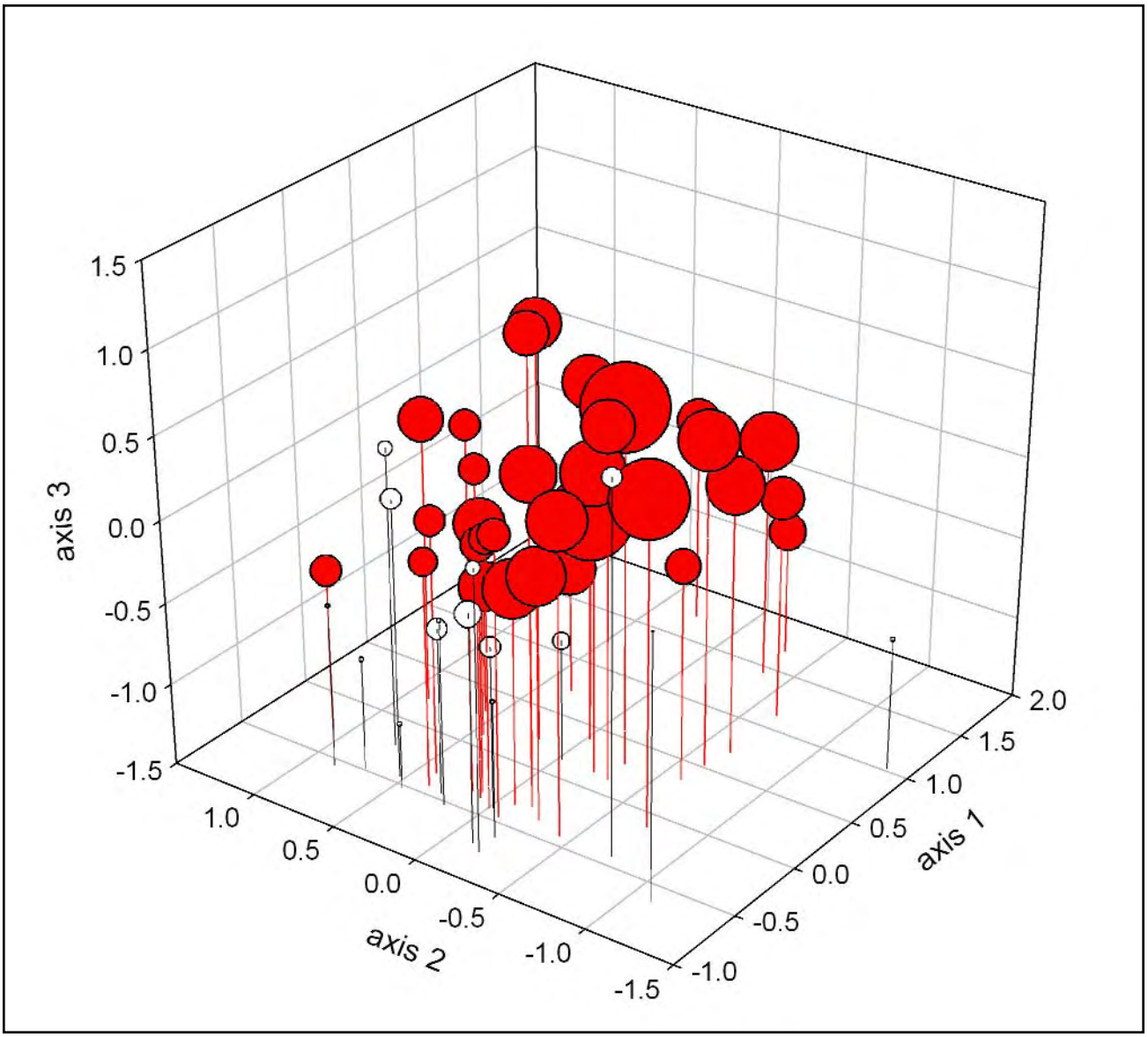
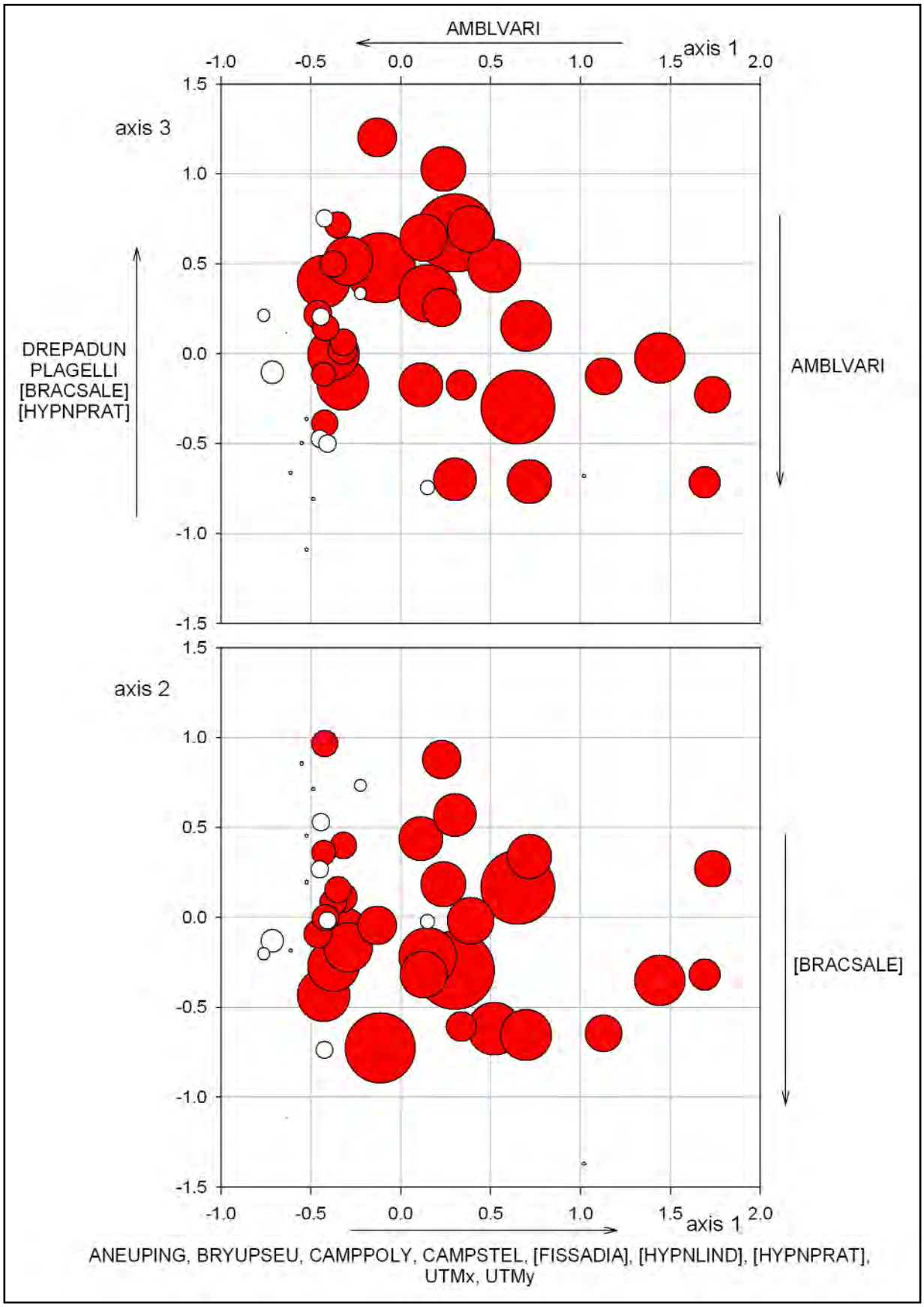


Figure 5 (above) and 6 (facing page). Seminary fen bryophyte assemblages: nonmetric dimensional scaling ordination (PC-ORD 5, McCune & Mefford 2006). The optimum number of dimensions are presented by the three axes, after 50 runs with real data and 50 with randomized data, using the Sorensen distance measure and random starting configuration (14.5 = final stress for 3-dimensional solution, 0.00112 = final instability, 200 = number of iterations). The ordination has been rotated to maximize totCFscore along axis 1. This results in most of the assemblage scores of <109 (small white bubbles) to be located on the left side of axis one. The red bubbles mark the ecotopes typed as calcareous-fen mesohabitat. Their diameter is proportional to their totCFscore based on the bryophyte criterion (as in figure 2, bottom panel). Correlations between ordination distances and distances in the original n-dimensional space (proportion of variance, r^2) are 0.410 for axis 1, 0.205 for axis 2, and 0.218 for axis 3 (cumulative total equals 0.834). Figure 6 also indicates the significant correlation ($p<0.01$) and direction of individual bryophyte abundance along the three axes. Species that are not considered to be calcareous-fen indicators have their acronyms listed in brackets. In addition, the northing and easting UTM coordinates are positively correlated with axis 1.


AMBLVARI
axis 1
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
axis 3
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
DREPADUN
PLAGELLI
[BRACSALE]
[HYPNPRAT]
AMBLVARI
axis 2
[BRACSALE]
axis 1
ANEUPING, BRYUPSEU, CAMPPOLY, CAMPSTEL, [FISSADIA], [HYPNLIND], [HYPNPRAT],
UTMx, UTMy

Janssens, J.A. 2006b. Methods for the study of bryophyte ecology. Update 2006. Available from the author janss008@tc.umn.edu.

McCune, B. and M.J. Mefford. 2006. PC-ORD. Multivariate Analysis of Ecological Data, Version 5. MjM Software Design, Gleneden Beach, Oregon, USA.