Implementing the Minnesota Prairie Conservation Plan in Landscapes of Western Minnesota

A Final Report to the Legislative Citizens Commission on Minnesota Resources
in fulfillment of the reporting requirements for Grant LCCMR092C

Ordway Prairie ©Alison Mickelson/Greater Good Photography

The Nature Conservancy
1101 West River Parkway, Suite 200
Minneapolis, MN 55415-1291
612-331-0700
http://www.nature.org

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[1]The Nature Conservancy, 1101 West River Parkway, Suite 200, Minneapolis, MN, 55415-1291
[2]Institute on the Environment, University of Minnesota, 1954 Buford Ave., St. Paul, MN 55108

Executive Summary

The Minnesota Prairie Conservation Plan sets goals to: 1) protect the state's remaining native prairie, 2) create prairie core areas and connecting corridor complexes with at least 40% grassland and 20% wetland, 3) make the surrounding agricultural matrix more wildlife-friendly by maintaining at least 10% of land cover in native perennial vegetation, and 4) carry out this conservation work utilizing grass-based agriculture in ways that are cost effective and supported by local communities. The purpose of this project was to develop the information and techniques needed to achieve these four goals of the Prairie Plan. To address these issues, we studied two landscapes in western Minnesota: the 127,000 acre Agassiz Beach Ridges landscape located east of Moorhead and the 169,000 acre Glacial Lake landscapes located south of Glenwood.

Prairie Parcel Planning

The initial step in native prairie protection is to identify on what parcels of land the prairie is located and then prioritize parcels. Using Minnesota County Biological Survey native prairie data, we ran an analysis to map the areas of highest prairie density across the state. With a few exceptions, areas of highest density fell within the boundaries of the prairie core areas established by the Prairie Plan, but the exceptions of high density areas outside of any core area and core areas with no areas of high density suggest revisions for the next edition of the Prairie Plan. The same prairie-density methodology used for state-wide analysis was also used to identify conservation focal areas of exceptionally high native prairie density within prairie landscapes. Within the Agassiz Beach Ridges landscape, three focal areas, called Coordinated Landscape Management Areas (CLMAs), were defined for intensive conservation activities while two CLMAs were identified in in the Glacial Lakes landscape. These CLMAs ranged in size from 29,635 acres in the Felton Prairie CLMA to 13,447 acres in the Glacial Lakes State Park CLMA

For each of the five CLMAs, maps of key conservation-action parcels were developed that identify the private parcels with greater than 20 acres of native prairie and those with 1 to 20 acres of native prairie. In addition, key parcels that buffer and reconnect native prairie parcels were also mapped. In the five CLMAs covering a total of 124,476 acres, only 135 parcels with > 20 acres of native prairie, 124 with < 20 acres, and 145 buffer and reconnecting parcels will be the subject of land owner contact for future conservation work.

The 404 key conservation parcels covering 58,605 acres are the highest priority places for conservation work including restoration to natural habitat. Only 4.6% of key conservation parcels were classified as high quality native prairie. The low amount of native prairie is indicative of both degradation since the prairies were first inventoried in the 1980s and 1990s but also that much of the highest quality prairie has already been protected and was not included in the private key conservation parcels. In contrast, 21.1% of key conservation parcels were mixed native-invasive grassland, 25.3% was invasive perennial dominated grassland, and 23.9% was cropland. To achieve Prairie Plan goals, different restoration techniques (and associated costs) will be needed if

the starting point is grassland with desired native species to be retained, a heavily-invaded site requiring complete vegetation removal, or cropland on which restoration seeding can be readily initiated.

Since the Agassiz Beach Ridges and Glacial Lakes landscapes were originally surveyed for native prairie by the Minnesota County Biological Survey, there has been considerable change in the native prairie. Only in Bluestem Prairie CLMA is most of what was inventoried as native prairie still in a “mostly native prairie” class, likely due to the intensive history of prairie management and protection in this area. For the CLMAs in the Agassiz Beach Ridges landscape combined, 27.9% of the area inventoried as native prairie is now mostly native prairie, 36.1% is now classified as mixed native-invasive grassland and 30.1% is now invasive dominated grassland. The situation is worse in the Glacial Lakes landscape where values are 3.7% for mostly native prairie, 69.4% for mixed native-invasive, and 20% for invasive perennial dominated. These numbers indicate the need for increased prairie management to reverse the decline in native prairie quality.

Measures of Success

Clearly articulating goals and progress measures is a critical component of conversation planning, but it is particularly important and challenging in the context of landscape-scale conservation that seeks to integrate social and economic factors with more conventional conservation goals. Therefore, although much of this project deals with site-specific decisions for protection, restoration and/or land use change, we also want to define large-scale desired outcomes for both the Agassiz Beach Ridges and Ordway Glacial Lakes landscapes, as well as to develop measures and monitoring approaches aimed at tracking these outcomes. Outcomes for both landscapes include restoration and protection efforts that achieve the 40%-20%-40% breakdown of grassland, wetland, and other uses as laid out by the Minnesota Prairie Conservation Plan as well as measures that increase the quality of grassland by reducing woody cover and increasing cover of native plant communities.

Specific native wildlife outcomes were also developed for both landscapes and include stable or increasing populations of prairie obligate butterflies and birds. Greater Prairie-Chicken populations are good indicators of large areas of grassland habitat that includes a range of vegetation structure. In the Agassiz Beach Ridges landscapes where Greater Prairie-Chicken populations still persist, the goal is to maintain stable or increasing populations.

Minnesota’s grasslands are a matrix of grass and wetlands that are critical to sustaining all prairie species, and for each landscape, we specifically defined aquatic outcomes. In the Agassiz Beach Ridges, where calcareous fens are a prominent feature of the landscape, the goal is to maintain the diversity of indicator species specific to fen communities. In the Ordway Glacial Lakes landscape, where lakes are a prominent feature, the goal is to ensure compatible land use around key lake basins.

Social Analysis

Grassland conservation at broad, landscape scales requires leveraging conservation outcomes across land parcels owned and operated by a diverse array of stakeholders. We utilized ethnographic techniques, in-depth interviews, and qualitative system analyses to understand how key rural stakeholders view land use transitions in order to develop a grassland conservation strategy. The people we interviewed suggested that cultural divides and conflicts of interest among agricultural and conservation communities were unproductive. They voiced support for grassland conservation initiatives that were seen as simultaneously bolstering both conservation outcomes and rural socio-economic vitality.

Rural residents often perceived lands owned and managed by government agencies and conservation organizations for prairie or wetland conservation to be "wasted", both because economic return was limited and because these lands lacked necessary management. The growing recognition in the conservation community that ecosystems often exist in alternative states and need active management to maintain ecological function was found to be an important point of connection with the rural view that land is malleable and should be worked to promote desirable outcomes.

Interviewees voiced much stronger ownership of the goal of 'conservation of working grasslands,' as compared with the concepts of 'prairie restoration' or 'prairie connectivity'. Conservation approaches most effective in leveraging permanent protection of prairie remnants may involve tactics that alienate rural support for grassland conservation partnerships across larger landscape scales. To achieve outcomes associated with grassland conservation at broad scales, conservation agencies must invest significant resources in strategies focused on cross-boundary collaboration and sensitivity to integrated ecological, social, and economic outcomes.

While maintaining rural livelihoods through profitable economic returns from the land was seen as essential, interviewees voiced diverse and complex decision making strategies that were based only partially on economic considerations. In particular, relationships with local conservation personnel and effective partnerships among conservation organizations and agricultural entities were seen as essential. Interviewees voiced confusion about different conservation organizations and programs, often perceiving that these entities seemed to hold conflicting or competing goals. Pragmatic suggestions were offered for how conservation and agricultural entities could better cooperate to advance mutually beneficial outcomes in the future. With stakeholder input, we developed four value-added socioeconomic strategies to bolster grassland conservation: 1) integrated, independent crop and livestock operations, 2) coordinated conservation grazing and haying partnerships, 3) precision agriculture and conservation targeting, and 4) using cover crops to re-integrate crop and livestock systems.

The two grassland landscapes in which we worked exhibited markedly different ecological, economic, and social particulars, and we recommend overlapping but distinct strategies for working effectively with stakeholder groups in these two areas.

In the Agassiz Beach Ridges landscape, people were more suspicious and less aware of conservation programs and partnerships and land use decisions were concentrated in the hands of fewer, larger landowners and farmers. Strategic partnerships with key owners and operators handled with great sensitivity will be crucial to conservation success in this area. Comparatively, the Glacial Lakes landscape has had a long history of visible conservation activities and partnerships marked by conflict with agricultural entities and county government. In this landscape, increased collaboration between grazing and conservation interests focused on working grasslands is encouraging both sides to overcome historic differences. A variety of stakeholders voiced both the urgent need for cooperation around shared goals, but also suspicion of and hesitancy to trust the motivations of competing groups and interests. In the Glacial Lakes landscape, we recommend that conservation strategies focus on collaboration around shared goals among agencies, organizations, and stakeholder groups.

Restoration Planning

Landscape-scale restoration planning requires a method for incorporating restoration actions and costs into prioritization and decision-making; such methods and cost estimates have not previously been available for the Prairie Region of Minnesota. Incorporating restoration actions and costs into landscape-scale planning is challenging, because restoration decision making is often site- and project-specific, and detailed site assessments, project goals, and budgets are not easily or feasibly scaled up to landscape scales. Tools for landscape-scale restoration planning must therefore operate at a course resolution; they must reflect important site- and project-specific variability, but also be capable of being applied rapidly across large areas.

Our objectives were threefold: 1) Develop a coarse-resolution tool for estimating restoration actions and costs across a range of site conditions, project goals and budget constraints; 2) Create generalized restoration plans and seed mixes for common starting conditions and restoration targets to guide landscape-scale restoration in Minnesota; and 3) Generate estimates of restoration costs for common restoration transitions to serve as inputs into economic analyses and optimization models, and to inform decision-making by planners, policy-makers and private landowners.

Budgeting for landscape-scale projects requires a method for anticipating restoration prescriptions and costs that is sensitive to site and project variability, but can also be rapidly scaled-up large landscapes. To address this need, we developed a qualitative state-transition model as a coarse-resolution tool for landscape-scale restoration planning and applied it to two landscapes to guide implementation of restoration goals set forth in the Minnesota Prairie Conservation Plan. We specified common "start states" based on vegetation, and restoration "end states" distinguished by plant community, soil moisture, and project goals. We assessed which transitions from start to end states could be achieved through restoration, and for a subset, we developed generalized restoration plans based on best practices; created seed mixes reflecting commercial availability and regional differences; and surveyed restoration practitioners to estimate the costs of achieving each transition.

Based on the state-transition model, we produced 20 different generalized restoration plans based on best-practices reported in literature and interviews with 23 practitioners and experts in the Midwest. Each plan includes a brief overview, recommended protocol and rationale (covering vegetation removal, seed bed preparation, seeding, and management through the establishment phase); example seed mixes (reflecting soil moisture, project goals, and regional differences); cost estimates; and sources for more information.

Transition costs ranged widely (greater than three-fold), from $801/acre to restore Crop to Utility Prairie, to $2713/acre plus a $700 flat rate (minimum total: $3413) to restore Mixed Native-Invasive Grassland to Conservation Meadow. Differences in restoration costs generally reflect variability in seed cost and availability, and intensity of invasion management required; specifically: 1) Wet meadow restoration is more expensive than prairie restoration, due to more costly seed mixes and more intensive need for invasion management; 2) Restoration to Conservation end states is more expensive than restoration to Utility end states, due both to seed costs and the higher intensity of management required to maintain a high quality prairie/meadow with minimal invasive species cover; and 3) Invaded start states—e.g. invasive-perennial-dominated, mixed-native and invasive, and woody-invaded prairies—are more expensive to restore than crop fields and annual-dominated fields, reflecting the high costs of invasive species control and woody plant removal.

Start states were mapped for each landscape, and the transition costs will be used to inform prioritization in conservation planning. Restoration plans, seed mixes and cost estimates will also be distributed to conservation implementation teams to guide regional restoration planning and inform private landowners about restoration options.

Qualitative state-transition models are useful tools for landscape-scale restoration planning and cost-estimation. They can be developed rapidly at a scale appropriate for regional planning, reflecting common site conditions, restoration targets, and project goals; they can be integrated with social and economic analyses; and they produce results valuable for scenario planning, optimization models and outreach.

Economic Analysis

The potential economic viability of a transition from row-crop agriculture to any grass-based operation is highly dependent on the following four factors: the initial type of cropping system, current crop prices, underlying soil productivity, and, for grazing systems, the intensity of the grazing operation. Net returns from cropland operations were highest for corn and soybean in both landscapes on high productivity soils (land capability classes 1 and 2); returns for all annual crops declined rapidly on lower productivity soils (land capability class 3 or higher). Controlling for soil productivity class, cropland returns were higher in the Glacial Lakes landscape than the Agassiz Beach Ridges landscape. Net returns from grazing operations also declined with soil productivity levels, but showed significantly less variability with soil productivity than did cropland returns. Annual net returns per acre increased with the intensity of the grazing system due to modeled increases in stocking rates and utilization rates. Estimated annual net returns per acre for management intensive grazing systems are fairly comparable to returns from crops even on high productivity soils, with the exceptions being corn and soybeans, and these grazing returns in some cases exceed many crops on lower productivity soils.

However, these annual net return data do not include the costs of transitioning from one land cover and use to another, or the costs of establishing a new operation. Any comparison of operations based solely on the estimated annual return data is incomplete. Across soil productivity levels, our results suggest that landowners will need significant financial assistance with restoration and establishment costs for a transition to a grass-based system to be economically viable. Even with assistance on these one-time transition costs, opportunities are very dependent on the specific characteristics of their site and management practices. As a resource for land owners or other interested parties, we have included in our report a list of several programs which are designed to assist landowners with a one-time transition as well as ongoing maintenance costs.

Financial returns are not the only incentive driving land management decisions as the results of the social landscape analysis showed. Analysis of the impacts of land use practices on the provision of services which benefit the public and how to optimize implementation of the Prairie Plan for the maximum provision of private and public returns are ongoing.

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Prologue

The Agassiz Beach Ridges and Glacial Lakes areas of western Minnesota are special places. Even before the Minnesota Prairie Conservation Plan identified them as prairie core areas, naturalists knew that there were more native prairie remnants there than just about anywhere else in Minnesota. In both landscapes, farming practices are more diverse than in the flatter, row-crop dominated, regions surrounding them. Livestock grazing is still an important part of the rural economy. It is the combination of important prairie biodiversity and a diversified agriculture that gives conservationists hope that joint private and public actions driven by a "grass-based economy" can result in functioning prairie and grassland systems. The aim of functioning systems is to provide economic returns for local residents and promote thriving rural communities while at the same time maintaining viable populations of the area's native plant and animal species. In addition, functioning landscapes can offer other ecosystem services such as cleaner water, reduced soil erosion, and high-quality recreational opportunities that make the prairie landscapes of Minnesota places where people want to live and work.

Like all parts of Minnesota, the prairie landscapes face environmental threats. The conversion of prairie and grassland, the drainage of wetlands, and the deterioration of grasslands are the chief conservation threats in these areas. This report suggests an approach to meet those threats and others. The Minnesota Prairie Conservation Plan envisions the formation of local implementation teams composed of conservation groups and agencies that are active in the area. Our intention for this report is to provide information that the implementation teams and other interested parties can use in their work with key private landowners and public land managers to maintain or recreate functioning prairie systems.

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List of Abbreviations

ABR – Agassiz Beach Ridges (landscape area)
ADF – Annual-Dominated Field (start state)
AIPC – Agassiz Interbeach Prairie Complex
AUM – Animal Unit Month
CDL – Cropland Data Layer
CRP – Conservation Reserve Program
CSG – Cool Season Grass
FSG – Forage Suitability Group
IPDG – Invasive Perennial Dominated Grassland (start state)
LCC/LCCS – Land Capability Class/Subclass
LULC – Land Use/Land Cover
MLRA – Major Land Resource Area
MNIG – Mixed Native and Invasive Grassland (start state)
NPC – Native Plant Community
NPV – Net Present Value
GL – Glacial Lakes (landscape area)
PLS – Pure Live Seed
TNC – The Nature Conservancy
USFWS – United States Fish & Wildlife Service
WIP/M – Woody Invaded Prairie/Meadow (start state)
WPFO – Western Prairie Fringed Orchid
WSG – Warm Season Grass

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Chapter 1: Introduction

A. Original Extent of Native Prairie and Wetlands

The tallgrass prairie grasslands and wetlands that once covered most of the Prairie Region of western and southern Minnesota (Figure 1) are largely gone and the little that still remain are under threat. The numbers are daunting. Nearly 19 million of Minnesota's 44 million acres were once a vast network of prairie ecosystems (Wendt and Coffin 1988). Prairie ecosystems in

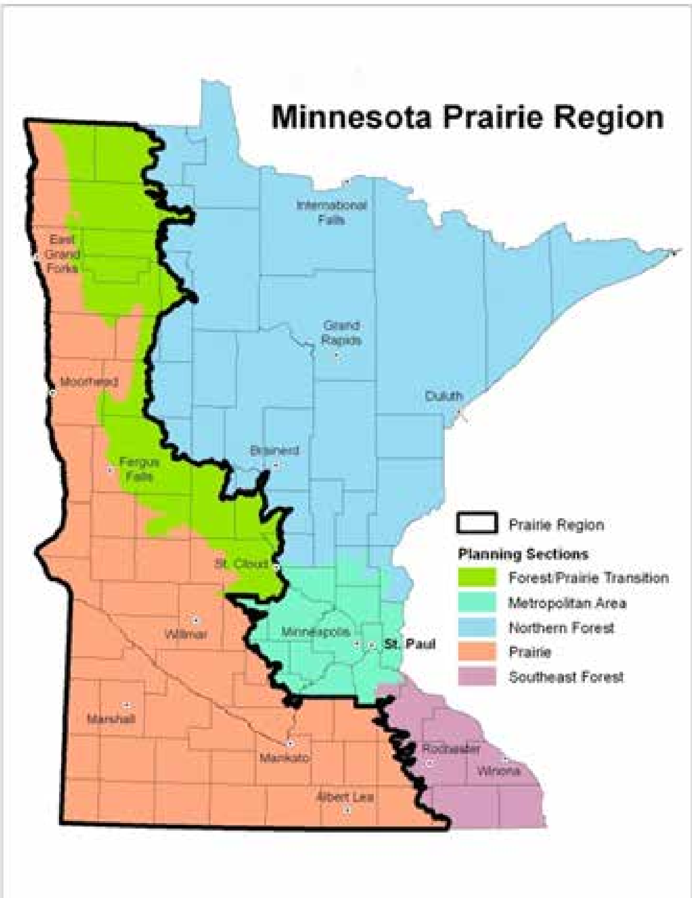

Figure 1. Minnesota's Prairie Region is located in the western and southern portion of the state. The Lessard-Sams Outdoor Heritage Council defined the boundaries which generally follow Ecological Province lines. The provinces included are the Prairie Parkland Province, Tallgrass-Aspen Parkland Province and a portion of the Eastern Broadleaf Province.

Minnesota included native prairie and other grasslands as well as temporary wetlands and shallow lakes. Defining native prairie as grassland that has never been plowed but retains most of its original native plant species, roughly 235,000 acres of native prairie remain in the entire state (Figure 2) (MBS 2010). The loss of over 98% of the native prairie in addition to the loss of nearly 92% of the original wetlands in 49 counties that cover most of the prairie region of Minnesota (Anderson and Craig 1984), demand a concerted effort to address questions of where and how best to preserve and restore functioning prairie ecosystems in the state. Any such analysis would be incomplete without incorporation of the costs and benefits of land use and land cover decisions to both humans and ecosystems.

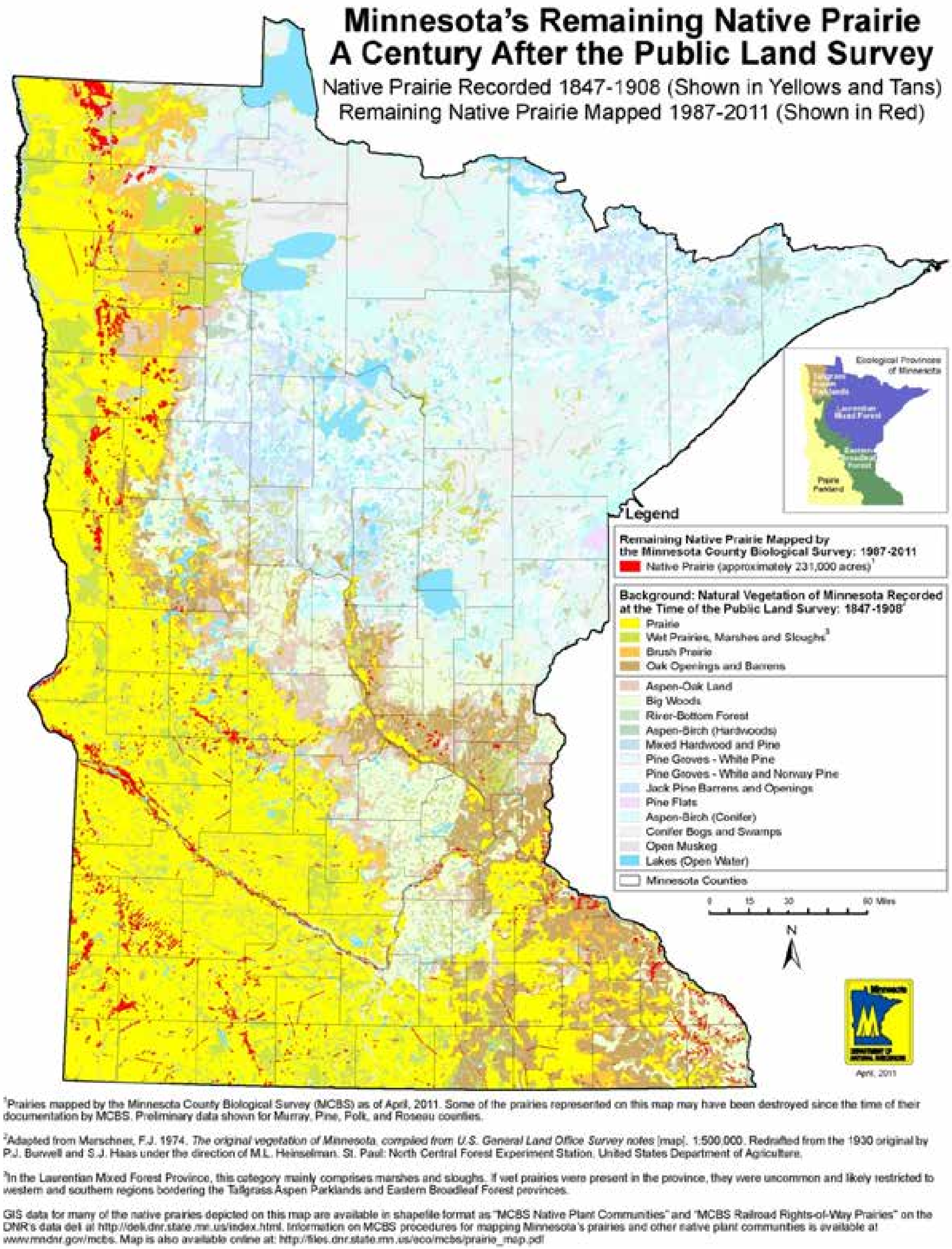

Figure 2. Native prairie currently in Minnesota. Native prairie (in red) was inventoried by the Minnesota Biological Survey between 1986 and 2010. The original extent of prairie is in yellow.

B. Minnesota Prairie Conservation Plan

The Minnesota Prairie Conservation Plan was created as a way of aligning prairie protection, management, and restoration efforts by multiple state agencies and non-profit groups. In the Minnesota Prairie Conservation Plan, hereafter the Prairie Plan, thirty-six prairie core areas were identified (Minnesota Prairie Plan Working Group 2011). These core areas capture 71% of the remaining native prairie acres in Minnesota (Figure 3). The Prairie Plan laid out an overall land cover goal within each core area of 40% prairie and grassland, 20% wetland, and 40% other uses. Three strategies were presented for reaching these overall land cover goals: protection, management, and restoration. By establishing core areas and outlining these three conservation strategies, the Prairie Plan begins to answer the questions of where and how efforts to address the loss of prairie ecosystems should be pursued.

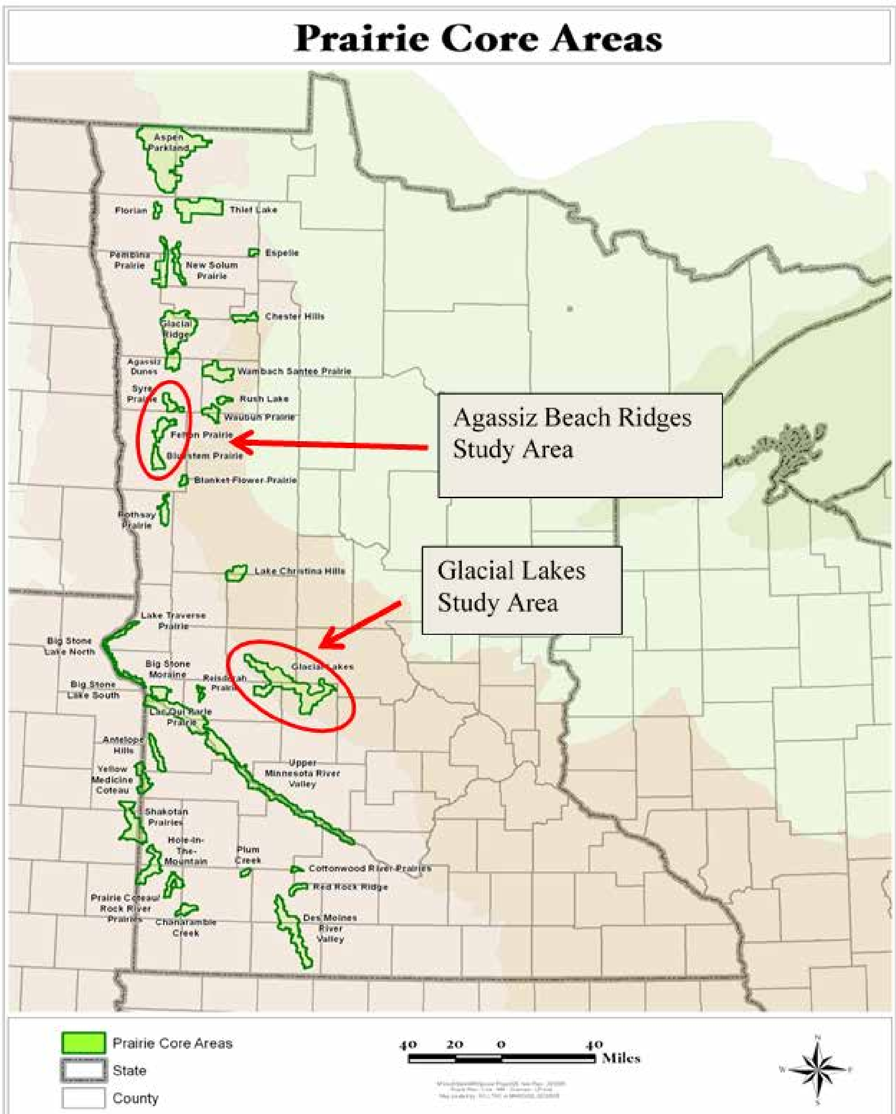

Figure 3. Locations of prairie core areas in Minnesota
Core areas were developed by the Minnesota Prairie Conservation Plan. The two study landscapes of this project Agassiz Beach Ridges (ABR) and Glacial Lakes (GL) are indicated.

1. Protection

The Prairie Plan calls for the protection of all remaining native prairie parcels on private land through the purchase of conservation easements or fee title from willing landowners. Currently, 49% of remaining native prairie in Minnesota is not permanently protected (Minnesota Prairie Plan Working Group 2011). Protecting the remaining native prairie in each core area will take a significant amount of time and coordination among conservation groups and private landowners.

In addition to protecting the remaining patches of native prairie, the Prairie Plan sets a goal of protecting, through acquisition or permanent easement, at least 50% of the other grasslands and wetlands included in the 40% grassland- 20% wetland land cover goal within each core area. There are many other types of grassland besides native prairie in Minnesota. In total there were 3,141,363 acres of grassland in CRP fields, pastures, hayfields, roadways, and other land uses as classified by the 2001 National Land Cover Data (Homer et al. 2007) and modified in 2010 by the US Fish and Wildlife Service's Habitat and Population Evaluation Team within the Prairie Pothole Region (USFWS HAPET 2010). The same dataset indicates a total of 2,238,740 wetlands acres. There will be substantial public resources available for restoration and enhancement on private lands but their use will require some sort of permanent protection in order to secure the public investment.

2. Management

Habitat management aimed at enhancing the quality of grasslands is one of the three approaches to grassland loss proposed in the Prairie Plan. In Minnesota, nearly every prairie, grassland, and wetland will be invaded by exotic pasture grasses, woody plants, or other invasive weeds unless there is regular disturbance provided by some combination of drought, grazing, haying, mowing, or fire. The Prairie Plan calls for disturbance or management on all the protected conservation lands and half the unprotected private lands every four years. On an annual basis, this amounts to 148,667 acres within the core areas annually and 812,053 total acres within the Prairie Region of Minnesota (Minnesota Prairie Plan Working Group 2011). Of these acres, 67,225 in core areas and 587,151 in total are private unprotected land. In the core areas, 45% of the management activities need to take place on private lands. Across the entire Prairie Region, the fraction increases, with over 72% of the management activities needing to take place on private lands.

Fire is the preferred management tool by many prairie biologists because it is a natural process that does not risk the introduction of invasive species or selective utilization of grazing or the potential habitat damage and nutrient removal of haying or brush removal. However, prescribed fire is an expensive tool and the time periods for the safe use of fire in the spring tend to be short and unpredictable. The result is that in many years a much smaller number of acres are actually burned than were planned or needed. In 2010, a better than average year for prescribed burning, only 104,361 acres were burned statewide in grassland habitat by the three principal entities in

Minnesota conducting prescribed fire: USFWS, Minnesota DNR, and The Nature Conservancy (MN DNR 2013b). This was less than 13% of the annual management needed since the need was calculated in the prairie region and the actual area burned was statewide. Since prescribed fire is unlikely to be ramped up to meet the total need, another widespread management tool is needed, especially one that private landowners are willing to implement on their own lands. The alternative management tool examined in this report is conservation grazing.

3. Restoration of Prairie Landscapes

Beyond protection and management of existing native prairie and high quality grasslands, additional grasslands will need to be restored in most core areas to reach the overall Prairie Plan land cover goal of 40% grassland and 20% wetlands. The magnitude of the conservation efforts needed to achieve the overall grassland and wetland goals is daunting and would be impossible to achieve if the only efforts were those of public and private conservation entities. Over 76% of the 36 core areas are privately owned based on protected lands data from a variety of sources (see Chapter 3 for further detail) but principally from the Minnesota DNR (MN DNR 2012). Of the private lands in the prairie core areas only 4% are protected via some type of conservation easement (based on GIS data available from the Minnesota Data Deli for state easements and directly from the USFWS for their easements). Because of this, most of the restoration actions needed to create and maintain functioning prairie ecosystems will have to take place on private lands.

Restoration actions will focus on restoring marginal cropland, degraded pastures, or weedy old fields to grassland or wetland communities with a higher proportion of native species. To achieve the desired conservation results on private lands at the scale envisioned by the Prairie Plan, management of restored grasslands will need to meet the economic needs of private landowners. The land use history of non-native and degraded grasslands is important in determining the methods used for prairie restoration and can help determine where restoration is most likely to succeed. Though some of these grasslands have never been plowed, they cannot be classified as native prairie because they no longer have most of the native plant species they once did due to past land uses such as overgrazing. These pastures are often dominated by introduced grasses, including non-native cool season pasture grasses such as smooth brome, reed canary grass, and Kentucky bluegrass, and herbaceous weeds. These introduced species invade native prairie through natural dispersal mechanisms or through direct seeding usually aimed at increasing pasture productivity. Conversely, there are grasslands that were plowed and cropped for a short period, but have regenerated native vegetation from the soil seed bank. Most of the rest of the “other grasslands” were cropped for a substantial period but ultimately were replanted to perennial grasses often through the Conservation Reserve Program (CRP).

C. Functioning Systems

The Prairie Plan outlines key features of functioning prairie ecosystems and functioning coupled human and natural systems. Ecologically, functioning ecosystems provide: the necessary diversity of habitats of sufficient quality to support a range of organisms, are resilient to change, and maintain hydrological and biogeochemical cycles. Indicator species and conservation priorities that reflect functioning prairie ecosystems are identified in the Prairie Plan. Coupled human and natural systems can provide both private and public returns. Private returns are assessed as economic returns from land use operations while public returns are assessed based on an ecosystem's provision of services such as: agricultural production, clean water, carbon sequestration, and wildlife habitat. These characteristics are discussed further in Chapter 8.

D. Project Overview

With the aim of informing the implementation of the Minnesota Prairie Plan, we focused on four core questions central to any approach taken to address the loss of grassland area and to reach the goals of the Plan: Where?, How?, At what cost?, and With what benefits?

WHERE?

- To determine where we are with respect to the Prairie Plan goals we show the current status of land use and cover for each landscape.
- To determine where within each landscape specific actions are best suited, we use two approaches. First we identify the private parcels with native prairie to meet the direct prairie protection and management goals. Second, we combine existing protection data and a prioritization process to identify areas optimal for grassland and wetland protection and management activities. To determine where restoration is best suited, we combine a state transition model, restoration plans, and both economic and social landscape analyses. An optimization process utilizes this data to highlight regions where specific conservation or land management approaches are most beneficial (economically and ecologically) and are culturally acceptable.

HOW?

- By determining the location of remnant native prairie patches, we can identify landowners for contact to determine their interest in protection and management of their prairies. We can also assess the potential for restoration of any adjacent non-prairie land.
- We explore how best to meet the Prairie Plan goals through an optimization process that accounts for economic constraints, through detailed restoration plans, and with an understanding of the priorities and aims of local stakeholders.

COSTS AND BENEFITS?

- We examine the social, economic and ecological costs and benefits of the dominant land use and cover transitions that are central to meeting the Prairie Plan goals.

The following diagram shows the relationships between the components of this report (Figure 4).

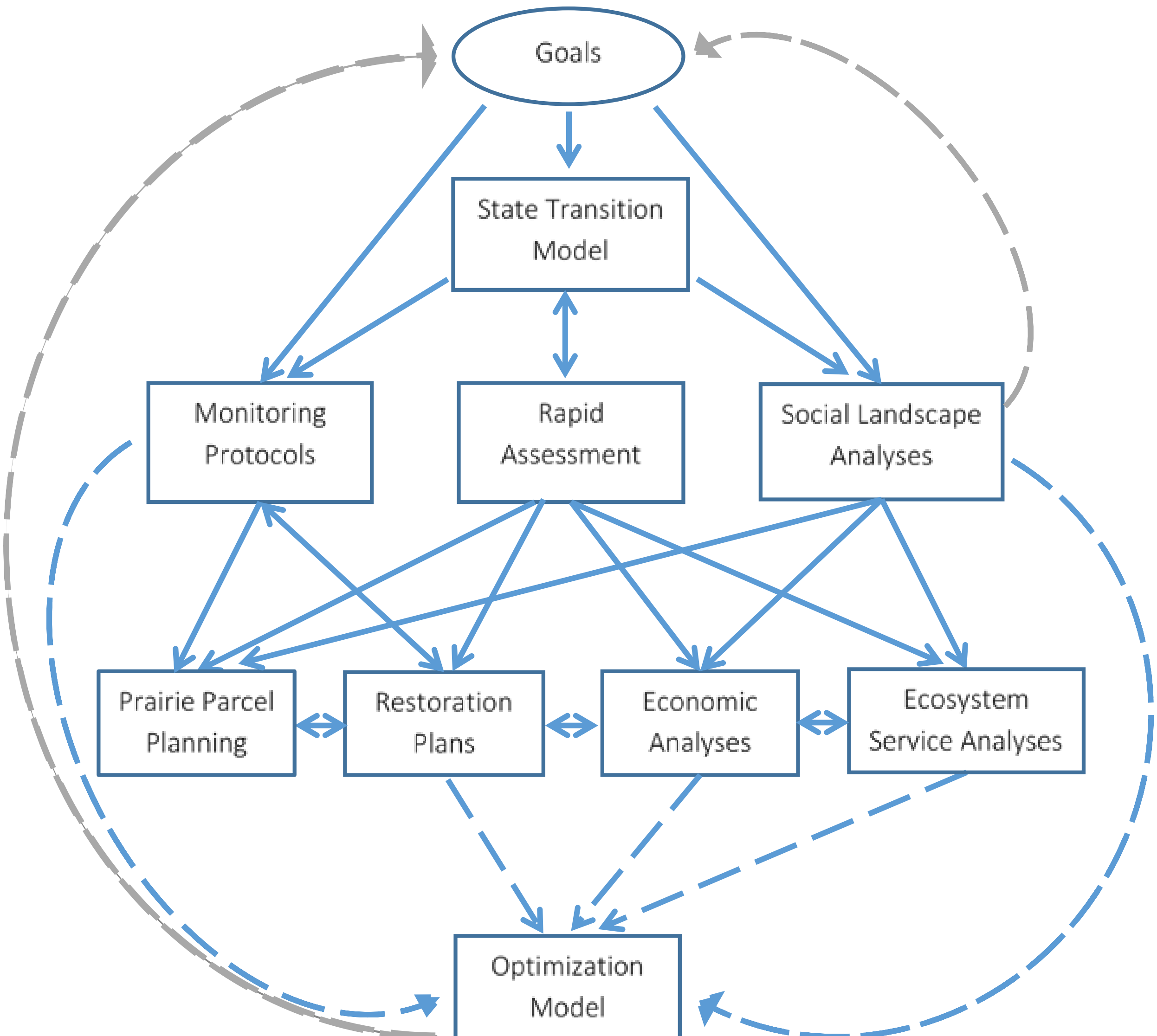

Figure 4. Regional landscape planning overview. Solid lines indicate relationships between research components presented in this report. Dashed lines indicate ongoing components of the work. Grey lines indicate potential future work.

One of the early steps in any landscape planning process is to define ecological goals and the metrics and protocols for evaluating progress toward those goals through monitoring. A transition model was developed to show the most common starting conditions and key land use and land cover transitions. Together, the goals and the transition model informed the rapid land cover assessment (Chapter 3), the start states for potential restoration on key private conservation parcels (Chapter 4), the development of long term monitoring protocols - used to determine the success of restoration efforts (Chapter 5), and the social landscape analysis (Chapter 6). The social landscape analysis identified key expectations that local residents have of their surroundings and of their livelihoods and is used to integrate these expectations with the ecological and economic potential of the landscapes. Restoration plans and transition costs (Chapter 7), combined with land use operation budgets (Chapter 8) and ecosystem service analyses (Chapter 9), inform our understanding of the private and public costs and benefits of land use (LU) and land cover (LC) transitions. While the focal area for this work was two landscapes, encompassing 4 of the 36 Prairie Plan core areas, the processes demonstrated here should serve as a general template for regional landscape planning efforts that cross agency and ownership divides.

1. Landscape Planning

There is a large body of research focused where to acquire land for conservation, and what size, shape, and configuration of managed areas is optimal (Soule and Simberloff 1986, Margules and Pressey 2000). In most conservation planning exercises, land acquisition efforts generally focus on protecting rare or important ecosystems or habitat types. In practice, acquisition decisions are often driven by opportunity and the cost of land first and only secondarily by the ecological values present.

We utilize two approaches to landscape planning which differ from traditional approaches by expanding the focus from only those parcels of land available for acquisition to all land within a designated area. This expansion is the first step in developing a landscape planning process that facilitates evaluation of a parcel’s conservation value in the context of its surroundings. First, we use a basic prioritization process to identify regions with high native prairie density. These regions are important for buffering and reconnecting remnant prairie parcels and are strong candidates for restoration to more diverse vegetation or for enhanced management to improve the viability of native plant and animal populations. We then identify the individual parcels of land that held native prairie and key parcels that buffer and connect the prairie parcels. These parcels are the highest priority of the Prairie Plan for protection but they often contain areas that need to be restored to allow continuous grassland habitat.

Second, we use an optimization process to examine the effects of economic, ecological and social values on larger landscape-scale planning. We aim to show the importance of integrating ecological and conservation goals with the social and economic realities of private landowners. Social analysis provides the opportunity to understand how cultural, historical, and economic factors influence landowner decision-making. Gaining an understanding of landowner objectives facilitates future collaboration and increases the potential success of any efforts requiring private landowner involvement. As any management or restoration effort includes opportunity costs over the period of transition and beyond, in our economic analysis we combine those costs with net land use operation returns to generate budgets which account for transitions. Through scenarios we combine economic, ecological, and social values to examine the effect of utilizing some or all of this information on landscape-scale optimization outcomes.

2. Restoration Planning

While landscape planning primarily addresses questions of where conservation actions are most beneficial, restoration planning is needed to inform what type of conservation actions are most appropriate (ecologically and economically) and to define the steps involved in restoration. We present restoration plans for a wide range of starting conditions and target end states. End states include working grasslands – those able to support grazing or haying – as well as restored high diversity native prairie communities. When public agencies encourage private landowners to restore native vegetation on their lands, recognition of the financial and personal factors affecting private landowner decisions about land use is required. Even when conservation agencies are considering restoration on their own lands, cost and practicality are key issues to consider. Within this report we quantify the costs of restoration associated with key land use and land cover transitions.

3. Informing Prairie Plan Implementation

As a resource for those implementing the Prairie Plan, we provide a process and a set of landscape specific analyses that can be adapted to all core areas. A key tool needed to reach the goal of protecting all native prairie are maps showing which land parcels have native prairie and which are important to buffer and reconnect the prairie remnants. The social analyses provide useful background on landowner priorities in each region that could help Prairie Plan Implementation Teams find a common language and purpose with landowners. Through interviews of key stakeholders we gained an understanding of the social landscape within which those implementing the Prairie Plan will be working. We present restoration plans that outline typical restoration procedures and seed mixes that can be adapted as needed for other core areas. Through economic and ecosystem service analyses we identify the potential alternative land use operations in each region. Our economic analyses can be used to identify regions where land use operations are most viable. In addition to the private costs and benefits of land use, the public costs and benefits are evaluated through the use of ecosystem service models. The basic approach used for the economic and ecosystem service analyses can be adapted to other core areas through substitution of region-specific data. The prioritization process described here could be replicated in other core areas to identify native prairie parcels for conservation activities and to identify prairie parcels that are most important for buffering and reconnecting other prairie remnants. Finally, the success of the Prairie Plan in creating functioning prairie ecosystems, and the provision of ecosystem services, could be monitored through utilization of the monitoring metrics described in this report.

Chapter 2: Landscape Descriptions *by Stephen J. Chaplin*

The Nature Conservancy

A. Landscape Selection

The Agassiz Beach Ridges (ABR) and Glacial Lakes (GL) areas are the two prairie landscapes chosen as study areas for this project (Figure 3). Both were identified as important native prairie locations by the Minnesota Prairie Conservation Plan (Minnesota Prairie Plan Working Group 2011). In the case of Agassiz Beach Ridges, the total landscape (126,774 acres) actually consists of three different prairie core areas identified within the Prairie Plan (Bluestem Prairie, Felton Prairie, and Syre Prairie). Glacial Lakes, however, coincides with a single large core area (169,305 acres). We combined the three core areas at ABR in this project to ensure that the two study areas were comparable in size.

The study areas were chosen to contrast different geomorphology, origin, current land use patterns, and social environment. We wanted to discover how conservation planning, restoration, and economics would differ in places where the factors influencing prairie and grassland preservation differed. ABR and GL were also practical selections because they were places where The Nature Conservancy had large preserves with experts that could help inform the project, and they provided the easiest logistics for a Twin Cities based project staff.

B. Landscape Descriptions

1. Geologic and Land Use History

After the last glacial advance reached its maximal extent about 14,000 years ago (Ojakangas and Matsch 1982) an interaction of climate and grassland vegetation began that, over time, produced the rich, deep soils we associate with prairies. Both the soils and topography of these core areas were shaped by their glacial history; leaving long, low sand and gravel beach ridges in ABR and numerous lakes and wetlands throughout GL. Although the native prairie in both areas has been mostly converted to row-crop agriculture, compared with the surrounding landscape, each retains substantial amounts of prairie and other grasslands.

Agassiz Beach Ridges

The Agassiz Beach Ridge landscape follows a series of parallel ridges about six miles wide that run north/south for 28 miles from just west of Twin Valley, MN in Norman County to just north of Downer, MN in Clay County. These ridges were created along the eastern shore of a large glacial lake. At its peak, Glacial Lake Agassiz and was larger than all of the modern Great Lakes combined (Sansome and Sansome 1983) and contained more water than all of the current lakes in the world (Perkins 2002). Lake Agassiz varied in size over time depending on the location and extent of the continental ice sheets that covered most of Canada. The lake finally disappeared about 8,500 years ago when the ice sheets retreated far enough that an outlet to

Hudson's Bay was created. The lake sediments and the following eight millennia history of mostly prairie vegetation resulted in deep organic soils with very little topographic relief on was the former lake bed. Along the shores of Lake Agassiz, beach ridges consisting of sand and gravel deposits developed as the lake was receding. These deposits make the beach ridges more difficult to farm. Their porous nature means that any rainfall rapidly flows through them leaving the surface layers dry. Many of these low, parallel, ridges still exist and support a substantial portion of the native prairie left in the region. Based on 2009 NRCS soil data, a total of 62,983 acres or 49.7% of ABR is classified as "non-prime soils" (Figure 5), i.e. soils that are unsuitable for row-crop agriculture (Soil Survey Staff NRCS 2009).

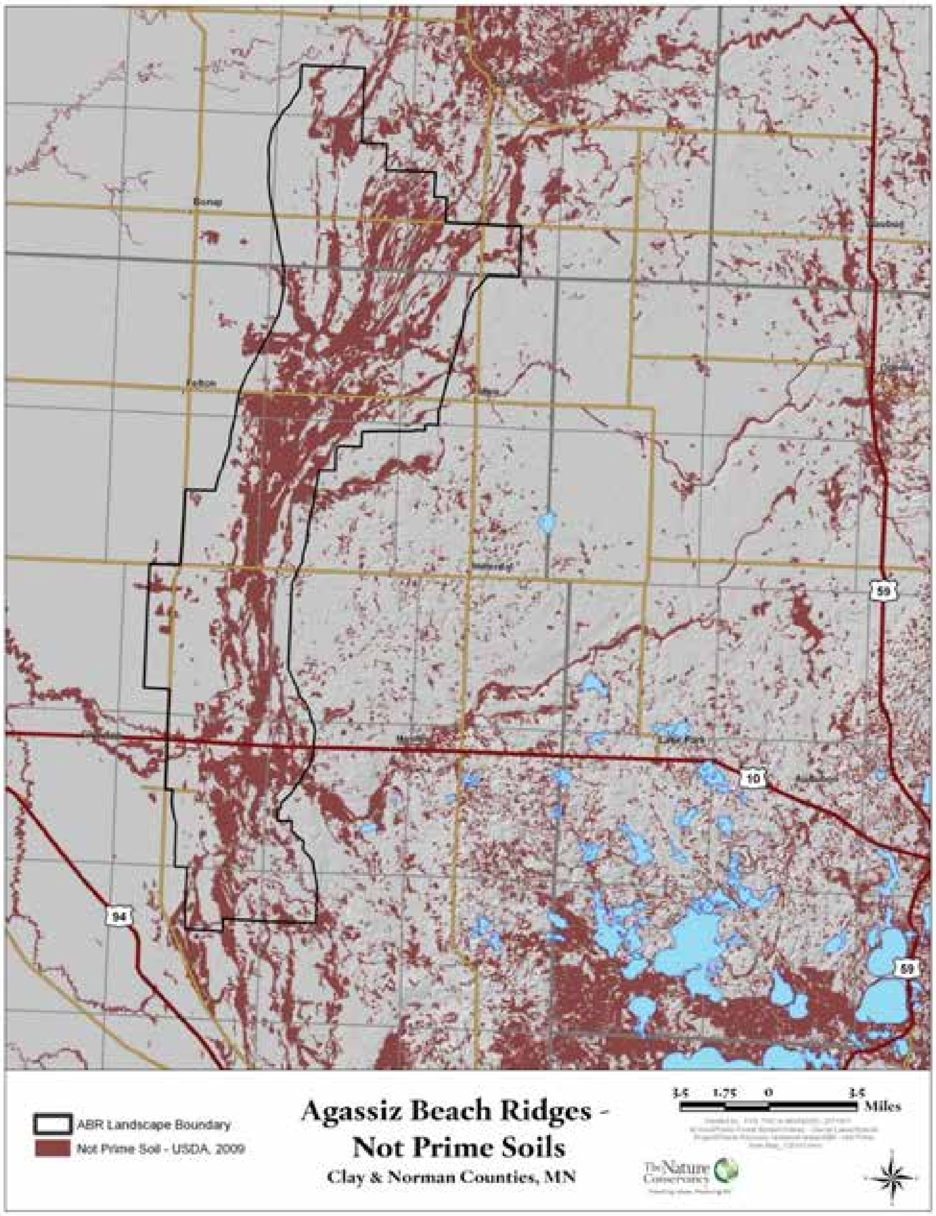

Figure 5. Extent of "not prime" soils in the ABR landscape. "Not prime" soils are those that do not easily support row-crop agriculture.

Glacial Lakes

The Glacial Lakes core area extends from near Starbuck to New London with extensions to towns of Regal and Swift Falls. The area is characterized by a rolling topography that becomes quite steep in places such as near Glacial Lakes State Park. Most of the lakes are ice debris features that were created when large blocks of ice within the glacial debris mixture of rock, sand, and silt melted leaving "potholes" on the surface of the land. Many of the hills are kames (conical mounds formed when melting holes in the ice filled with rocky and sandy debris), eskers (worm-like ridges formed under the ice in melt-water channels), or drumlins (elongated mounds formed as glacial ice flowed over the top of glacial debris). These features are characteristic of a larger geologic landform, the Alexandria Moraine, which was the result of the accumulation of materials at the terminus of the Wadena glacial lobe and later by the margins of the Des Moines lobe that extended from the main body of the continental glaciers in Canada to central Iowa (Whitehill 2002). The moraine runs the length of the Glacial Lakes core area.

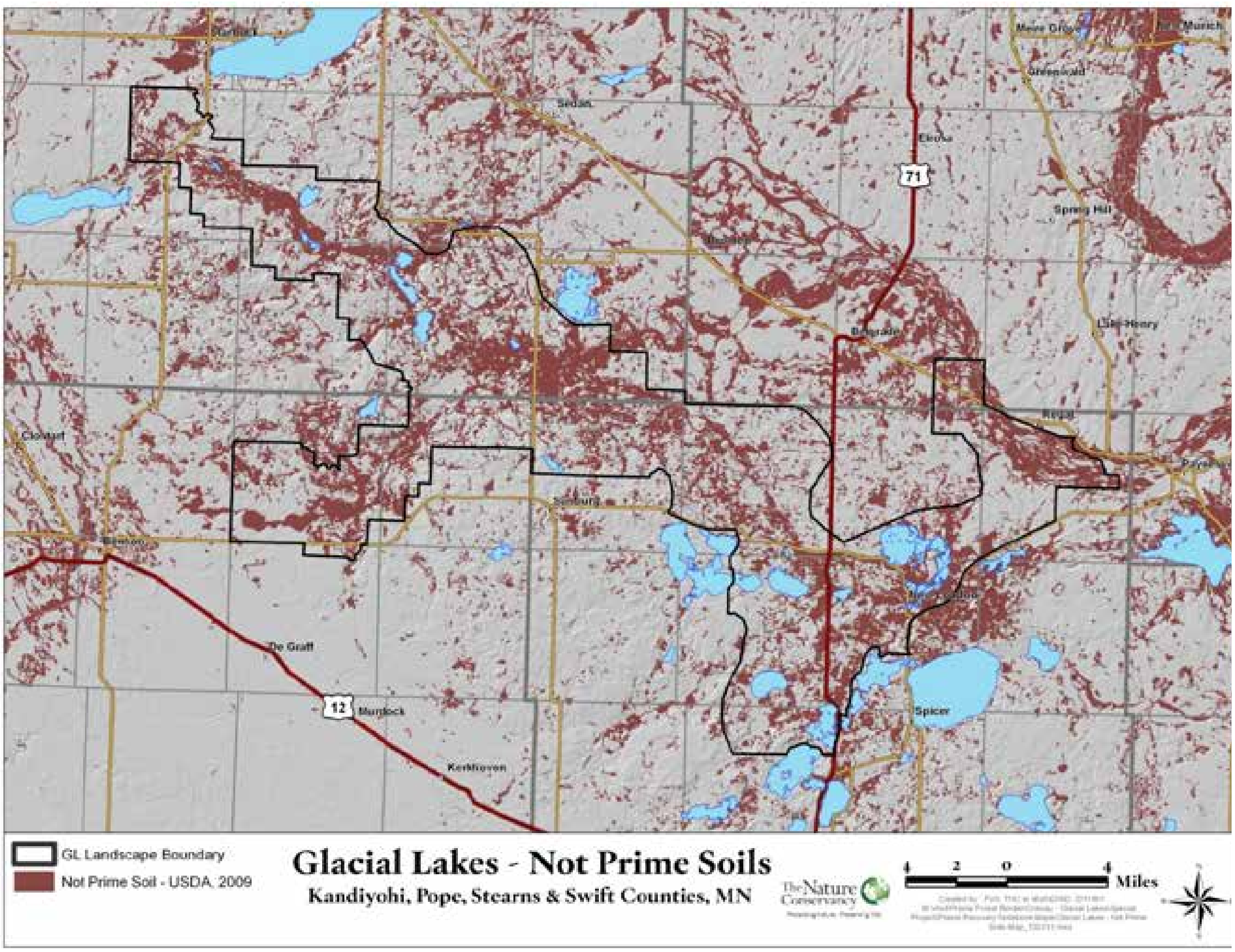

Figure 6. Extent of "not prime" soils in the Glacial Lakes landscape. **"**Not prime" soils are those that do not easily support row crop agriculture.

The primary reason that a relatively high amount of native prairie remains in the Glacial Lakes core area is that much of the area has been unsuitable for row cropping. Soils that are too rocky, steep, or wet to plow have remained in pasture. The Natural Resource Conservation Service has classified 64,713 acres (or 38.3%) of the Glacial Lakes core area as “not prime” soils (Soil Survey Staff NRCS 2009) (Figure 6). Within the Glacial Lakes core area, 5,539 acres of native prairie (76.5%) occur on “not prime” soils. In comparison, only 34.1% of other grasslands are found on “not prime” soils. When looked at the other way, 37.7% of the “not prime” soils are covered by native prairie or other grasslands.

2. Dominant Pre-Settlement Vegetation

a. Native Prairie

Native prairie consists of several types of fire dependent grassland communities. The vegetation that was found in any particular place was dependent on the soil, topography, and fire history of the area. These three factors vary substantially between the two landscapes and as a result, the type and pattern of prairie vegetation also differ.

Agassiz Beach Ridges

ABR represents a distinct zone between the nearly level expanse of the lake plain of Glacial Lake Agassiz to the west and the undulating to rolling morainal uplands to the east. A complex mosaic of natural prairie communities, ranging from marsh and calcareous seepage fens, through wet and mesic blacksoil prairies to dry sand and gravel prairies occurred across the transect (The Nature Conservancy 2012b). The glacial lake plain was covered mostly by marshes and wet to mesic prairies. Cattails, sedges and bulrush dominated the marshes while cordgrass transitioned to big bluestem and indian grass along the wet to mesic moisture gradient (MN DNR 2005). Water flowing out of the base of the beach ridges often created conditions suitable for fens and wet or seepage meadows dominated by sedges, reedgrass, and sphagnum moss. The beach ridges themselves were covered by drier prairies ranging from mesic prairie to dry sand-gravel prairie and dry hill prairies dominated by little bluestem and porcupine grass.

All of these prairie systems were prone to invasion by trees and shrubs when fire return intervals became prolonged. Brush prairies developed when prairie willow, American hazelnut, and scrubby burr oaks invaded drier sites while aspen, Bebb’s willow, juneberry, and bog birch entered wetter sites.

In total, the Minnesota County Biological Survey identified 15,965 acres of native prairie in the Agassiz Beach Ridges landscape (MBS 2010) (Figure 7). The native prairie is concentrated in three areas: Syre Prairie in the north, Felton Prairie in the middle of the landscape, and Bluestem/Buffalo River State Park in the south. All three of these areas have been important areas for prairie conservation since at least the 1970s.

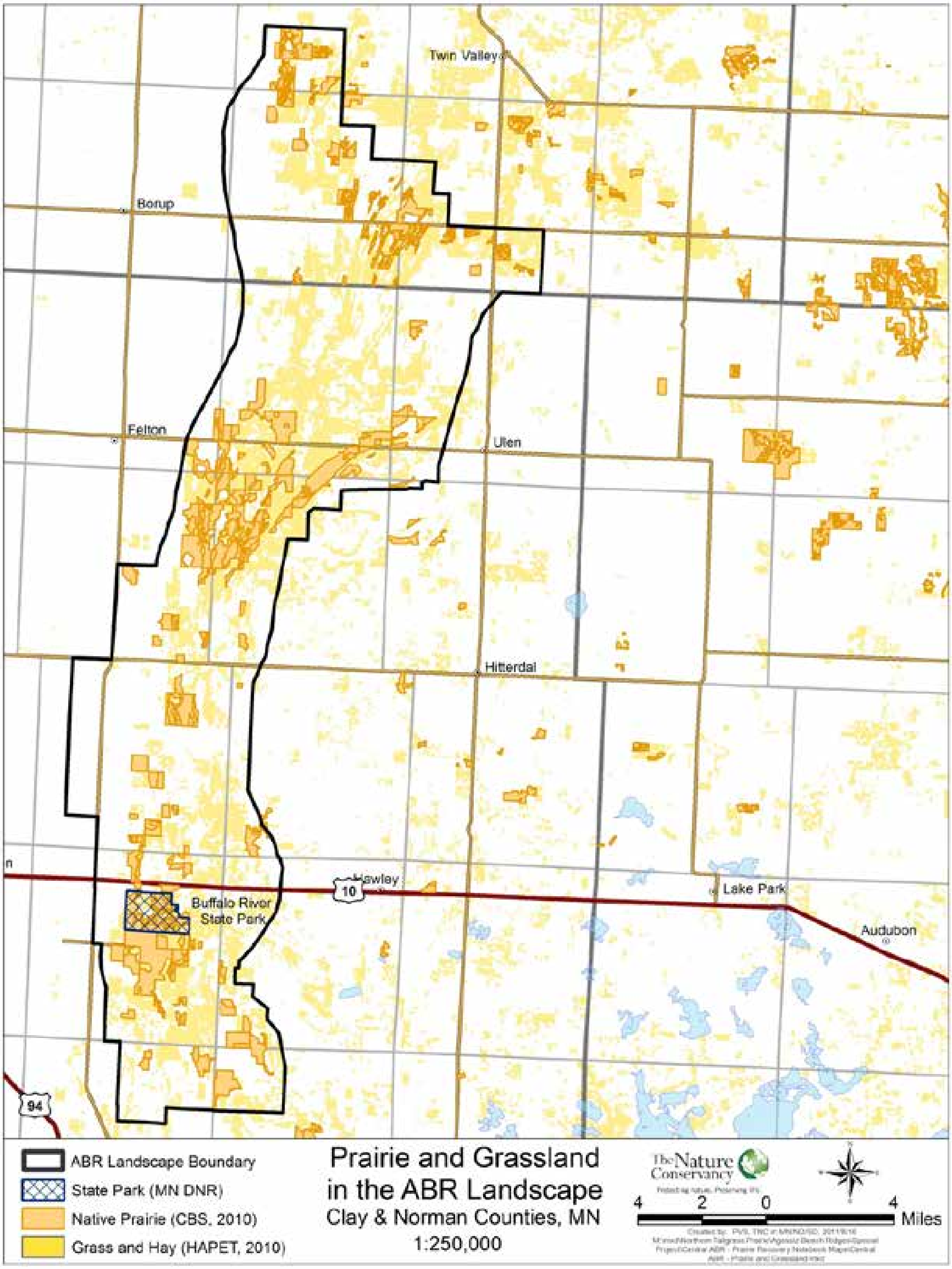

Figure 7. Extent of native prairie and other grasslands in ABR Landscape. Native prairie data was surveyed by the Minnesota County Biological Survey in the late 1980s.

Glacial Lakes

Not nearly as much remnant native prairie, 7,223 acres, was identified in the Glacial Lakes landscape (MBS 2010) as in ABR (Figure 8). At one time, most of the prairie found in the GL area would have been classified as mesic prairie. This highly productive prairie occurred in adequately drained upland areas with low to moderate slopes and over time tended to develop deep soils. It was here that big bluestem, Indian grass, and switch grass reached their peak of productivity and would send up seed stalks over eight feet in good years. These mesic prairies provided the ideal conditions for crop production and as a result nearly all mesic prairie of any size has been plowed and planted to row crops over the last 150 years.

On steeper slopes and drier habitats, a less-productive, shallower soil prairie was originally found. These hill prairies, sand prairies, and gravel prairies were often dominated by little bluestem and side-oats grama. Because they were less productive and difficult to farm, more of these prairie types were left as pasture and survive to this day. Finally, there were the prairies that grew in moister conditions along streams, around wetlands, and in swales of the mesic prairie. These wet prairies were often dominated by cord grass and sedges. At first these prairies survived as seasonal pastures because they were too wet to farm and too expensive to drain. As technology improved and the size of equipment increased, most of these wet prairies and sedge meadows have been drained and there are now very few high-quality examples remaining.

Within the GL core area, two places stand out: the area around Glacial Lakes State Park in the northwest portion of the core area and the Ordway Prairie/Randal WPA area in the central portion. Both areas have high densities of native prairie and have been focal areas of prairie conservation for decades. However, in both places, native prairie remains largely fragmented and both connection and buffering is needed to restore functioning.

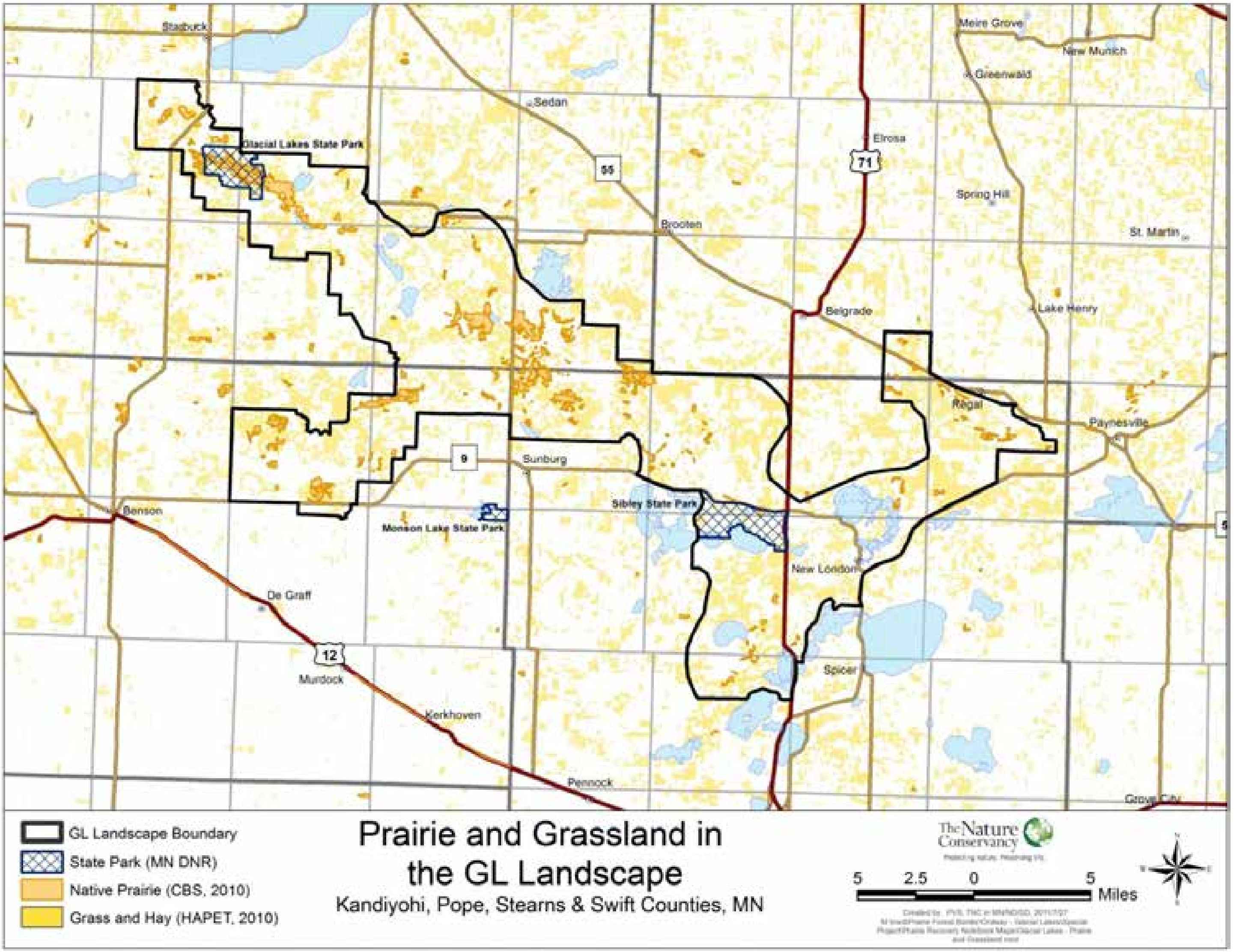

Figure 8. Extent of native prairie and other grasslands in the Glacial Lakes landscape. Native prairie data was surveyed by the Minnesota County Biological Survey in the mid to late 1990s.

b. Woodlands

Agassiz Beach Ridges

There was relatively little woodland and forest in the pre-European settlement ABR landscape except along rivers and streams. Floodplain forest such as that found along the Buffalo River, the south fork of the Wild Rice River, and Felton Creek was dominated by silver maple, cottonwood, green ash, and American elm (MN DNR 2005) . Broader zones of woodland or brushland were common along streams and other fire breaks; their size and configuration depended on prevailing wind and stream alignment (MN DNR 2013c). Within these fire-shadows and throughout the landscape where fire has been suppressed, quaking aspen, cottonwood, balsam poplar, burr oak, are found along with shrubs such as willows, bog birch, and hazelnut. Within the ABR study area only 0.6% or 719 acres, are currently classified as forest or woodland based on 2001 National Land Cover Data reclassified by the USFWS Habitat and Population Evaluation Team (USFWS HAPET 2010). Marschner's map of the original vegetation of Minnesota shows only slightly more acreage (3,436 acres or 2.7%) in river bottom forest at the time of the first land survey (MN Geospatial Information Office 2013).

Glacial Lakes

The Glacial Lakes core area sits within the Prairie/Forest transition area of Minnesota. To the west lies land extending into the Great Plains where trees were relatively uncommon, being found mostly along rivers and streams and in the lee of other types of fire breaks. To the east were deciduous and mixed forests, where prairies tended to exist as openings in the forest. In a transition area such as this, prairies tended to be found on higher and drier sites and any place where natural fires burned frequently. Within the GL core area there were significant amounts of open burr oak forest and woodland at the time of settlement around 1861. Public land surveys in the 1850s commonly mentioned "oak openings", "scattering oak", "grove of oak", "timber oak and aspen", and "prairie and timber oak" (Margoles, 2009). These woodlands and savanna were dominated by burr oak. With the settlement of the area by Europeans, the oaks probably declined initially due to harvest of timber and firewood and heavy grazing by cattle. There likely was also a decrease in fire that when coupled later with lower timber and firewood harvest led to the invasion of the woodlands and savannas by more aggressive species such as boxelder, green ash, and eastern red cedar. Today there are far more trees than were present as recently as the 1950s. Long term residents in the Ordway Prairie area speak of an open pasture environment with few trees that extended for miles along the top of the Alexandria moraine. Many of the former woodlands and savannas are now dense forests dominated by burr oak, green ash, box elder, and buckthorn.

Within the pre-settlement landscape there were large patches of dense forest. These forests were often the product of hilly topography with extensive wetlands and lakes that retarded the spread of fires driven by winds predominately from the west. These areas such as Moe Woods and the area around Sibley State Park were dominated by basswood, American elm, ironwood, green ash, black cherry, and oaks. As fires were suppressed, the forest patches have enlarged, probably covering more area now than they did in the past. In addition, buckthorn and other aggressive shrubs and small trees have invaded these native forests making them much denser and impenetrable. Currently, 10.2% of the Glacial Lakes core area (17,402 acres) is covered by woodlands or forest (USFWS HAPET 2010). In comparison, Marschner's interpretation of General Land Office records at the time of the original survey suggest that only about 5,890 acres were Aspen-Birch, Aspen-Oak, or Big Woods Hardwoods, but 27,412 acres were Oak Openings and Barrens (MN Geospatial Information Office 2013).

C. Wetlands, Streams, and Lakes

An important distinguishing feature between different types of wetlands is the source of water feeding the system. Surface-fed wetlands receive aboveground runoff from surrounding lands. They are greatly and immediately influenced by adjacent land use practices. If heavy loads of nutrients and other substances are being carried by the water, the wetland will be immediately impacted (Winter et al. 1998).

Groundwater wetlands are fed at least in part by below-ground water. Depending on the type of sediments and rocks that the groundwater flows through, the water can carry high levels of calcium and other minerals. Unique plant communities adapted to these unusual conditions often have rare and uncommon plant species. These groundwater wetlands tend to be small features on the landscape and imbedded within larger prairie, forest, or surface-water wetland communities. Because water moves slowly through below-ground sediments and rocks, there is often a long lag time between when water enters the groundwater system and when it exits in the groundwater wetlands (Alexander and Alexander 1989). Chemical pollutants such as agricultural herbicides applied to farm fields may take years before they reach groundwater wetlands, but once there can take years to flow through and be replaced by cleaner water (Winter et al. 1998).

Temporary wetlands, only wet a portion of the year, are extremely important to shorebirds, waterfowl, and other birds that require aquatic habitat. With increased tile drainage (the placement of underground plastic tubes), these temporary wetlands are increasingly rare (Galatowitsch 2012a). Draining allows farmers to get into their fields earlier in the spring but also removes seasonal wetland habitat and causes precipitation to run off farm fields much faster. The faster run off in turn makes streams much "flashier" and creates pulses of erosion and nutrient export that move through the lakes and rivers downstream.

Agassiz Beach Ridges

The nearly flat terrain and relatively rock free surface made ditching and tiling a feasible task in many places, even early in European settlement history. As a result many of the former wetlands and wet meadows in the ABR landscape have been drained and farmed. As a whole, Clay and Norman counties both have lost at least 95% of their original wetlands (Anderson and Craig

1984). GIS analysis of National Land Cover Data for the ABR landscape shows that there are 2,480 acres of permanent wetlands still remaining (USFWS HAPET 2010). Another 20,178 acres are classified as seasonal and temporary wetlands but many of these acres are actually crop fields or pastures that dry sufficiently to be used for production purposes later in the season.

Due to the influence of Glacial Lake Agassiz on the glacial remains left by the Des Moines lobe, most of the ice-debris features such as pothole lakes were destroyed in the ABR landscape. Analysis of 2010 land cover data (Homer et al. 2007) shows only 587 acres of open water in the study area. The few lakes now found in the landscape are often man-made, the result of sand/gravel mining, dugouts for watering livestock, impoundments, or oxbow lakes.

Glacial Lakes

The Glacial Lakes area name was given because of the large number and relatively high quality of lakes found there. In total there are 112 lakes larger than 10 acres in size comprising 10,556 acres of the total 11,753 acres of open water in the core area (MN DNR 2012). Some of these lakes such as Signalness, Hoff, Linka, Johnson, Kittelson, and Section 12 have high water clarity (MN DNR 2013a) due to their high position or relatively high amounts of perennial vegetation in their local watersheds. Other lakes have been impacted by excessive nutrient loads from their watersheds especially where they extend outside the prairie core area. The lakes that have large surrounding watersheds or are on a river or large creek (such as Lake Gilchrist on the East Branch of the Chippewa River) are especially vulnerable to eutrophication due to large amounts of phosphorous entering the lakes.

All lakes over time fill with sediment and eventually become marshes. The only reason there are so many lakes in the Glacial Lakes area is that it is still a very young place geologically. Less than 14,000 years ago, the area was covered by glaciers and glacial debris (Ojakangas and Matsch 1982). For most of the time since then, prairie vegetation has dominated the landscape reducing the sediment flowing into the lakes. The natural process of lake succession is still occurring in the Glacial Lakes area but has been accelerated with high levels of soil erosion coming off some farm fields and with excessive plant growth in lakes from added phosphorous.

In contrast to ABR, wetlands and lakes in GL were often deeper and located in hillier terrain. As a result, many more wetlands have survived to recent times. If you exclude the open water of lakes, 21.5% of the landscape or 36,326 acres is currently classified as permanent wetlands or open water (USFWS HAPET 2010). This number is an underestimate of total wetlands since there are many as 15,933 acres of seasonal or temporary wetland, mostly in the form of grasslands, pastures, or crop fields, that only hold water during the spring or other wet periods.

C. Key Threats to Functioning Prairie Systems

1. Loss of native prairie

The conversion of native prairie to agricultural crop fields has already caused the loss of over 98% of the native prairie in Minnesota. Remaining native prairie in Minnesota (shown in red, Figure 2, see page 2) is not randomly scattered across its former extent. Native prairie largely remains in sites where conversion to cropland has been too unprofitable in the past. However, as crop prices rise and the availability of farmland set-aside programs (such as CRP) decline, the regions where crop production can be profitable expand. As a result, remaining native prairie and other grasslands that are not currently protected are rapidly being converted to cropland (Faber et al. 2012, Wright and Wimberly 2013a).

New technologies, in addition to high crop prices, also contribute to the conversion of prairie and grasslands to cropland. Modern machinery is allowing tile drainage of wetlands that would have been impossible even 20 years ago. Other machinery can remove rocks from fields and level hills in ways that would have been impractical until recently. Besides the machinery, there have also been advances in crop breeding. Drought tolerant varieties of many crops allow them to be planted in sites that were previously too dry to produce a profitable crop. The new varieties have changed the definition of what is marginal cropland. Cropland that once was marginal is now productive and land that was too dry to be cropped is now marginal cropland.

Agassiz Beach Ridges
About 43.5% of the ABR landscape was in cropland in 2010 (USDA NASS 2011). Corn and soybeans are the dominant crops (yellow and green respectively in Figure 9) but sugar beets (purple) and other crops (pink) are also common in the area. There is clearly less cropland in the core area (delineated by the black line) than in the surrounding areas that are much more intensively farmed. Just west of the core area lies the heart of the Red River Valley agricultural zone. In that area, very little natural vegetation is left except along streams and rivers or in wetlands too deep to drain. Over half of the ABR landscape (65,595 acres) is still grassland or wetland (USFWS HAPET 2010), and most of that which is not in protected conservation lands is used for grazing.

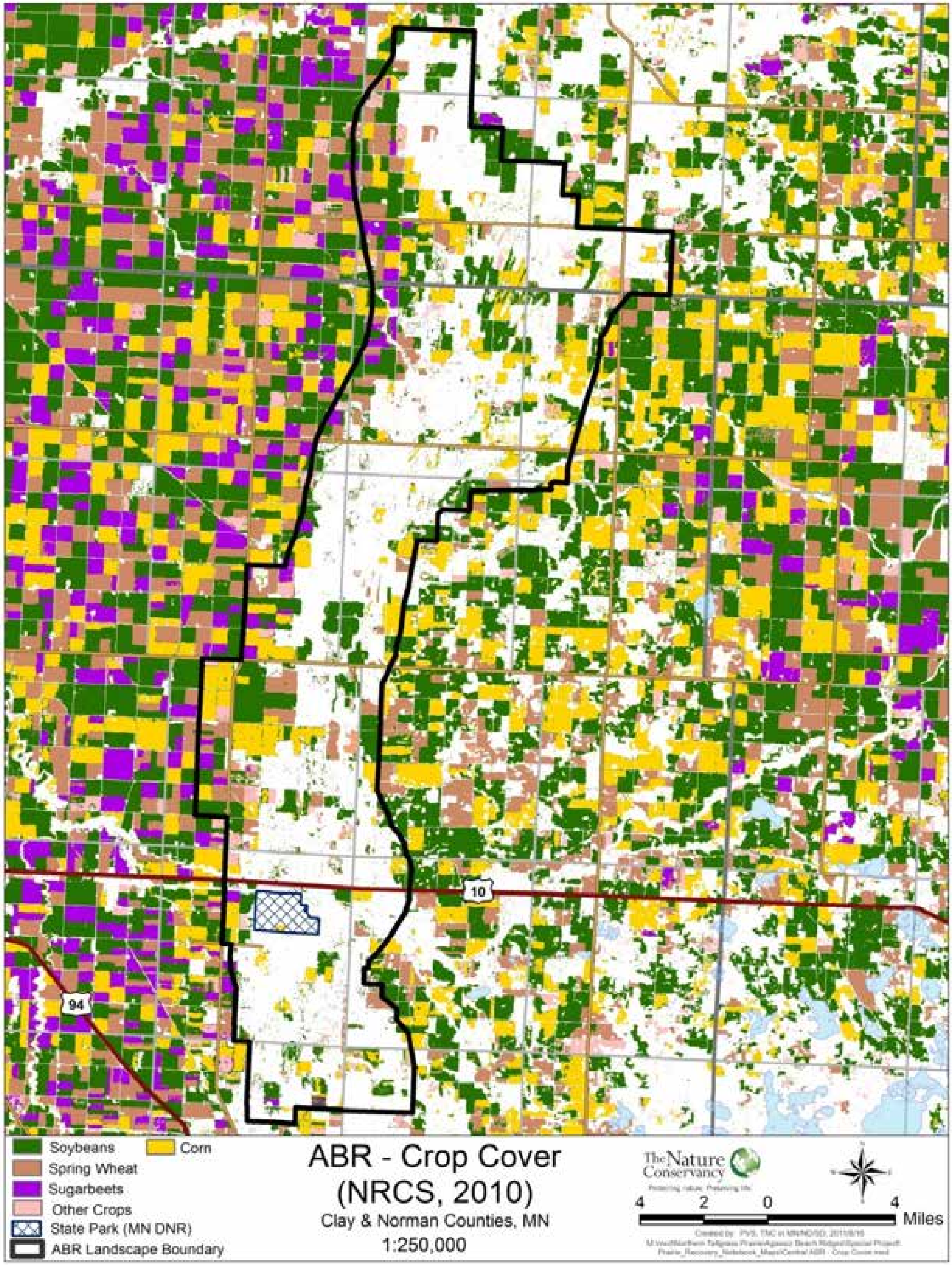

Figure 9. 2010 crop cover for the ABR landscape. Crop locations for the Agassiz Beach Ridges landscape are shown with the landscape boundary in black.

Glacial Lakes

Only 27,946 acres or 16.5% of the Glacial Lakes core area was in cropland agriculture in 2010. Figure 10 shows the area planted to corn (yellow), soybeans (green) and other crops (pink). Once again, there is clearly much less intensive row crop agriculture within the landscape than in the surrounding areas, particularly to the south and southwest where the Minnesota River plain lies. Some of the most intensive agriculture in Minnesota is located in Swift, Kandiyohi, Chippewa, and Renville counties. All of these counties are among the top eight in corn production in Minnesota (MDA 2013). It is in places like the Glacial Lakes and Agassiz Beach Ridges landscapes that the concept of a "grass-based" agriculture is still viable.

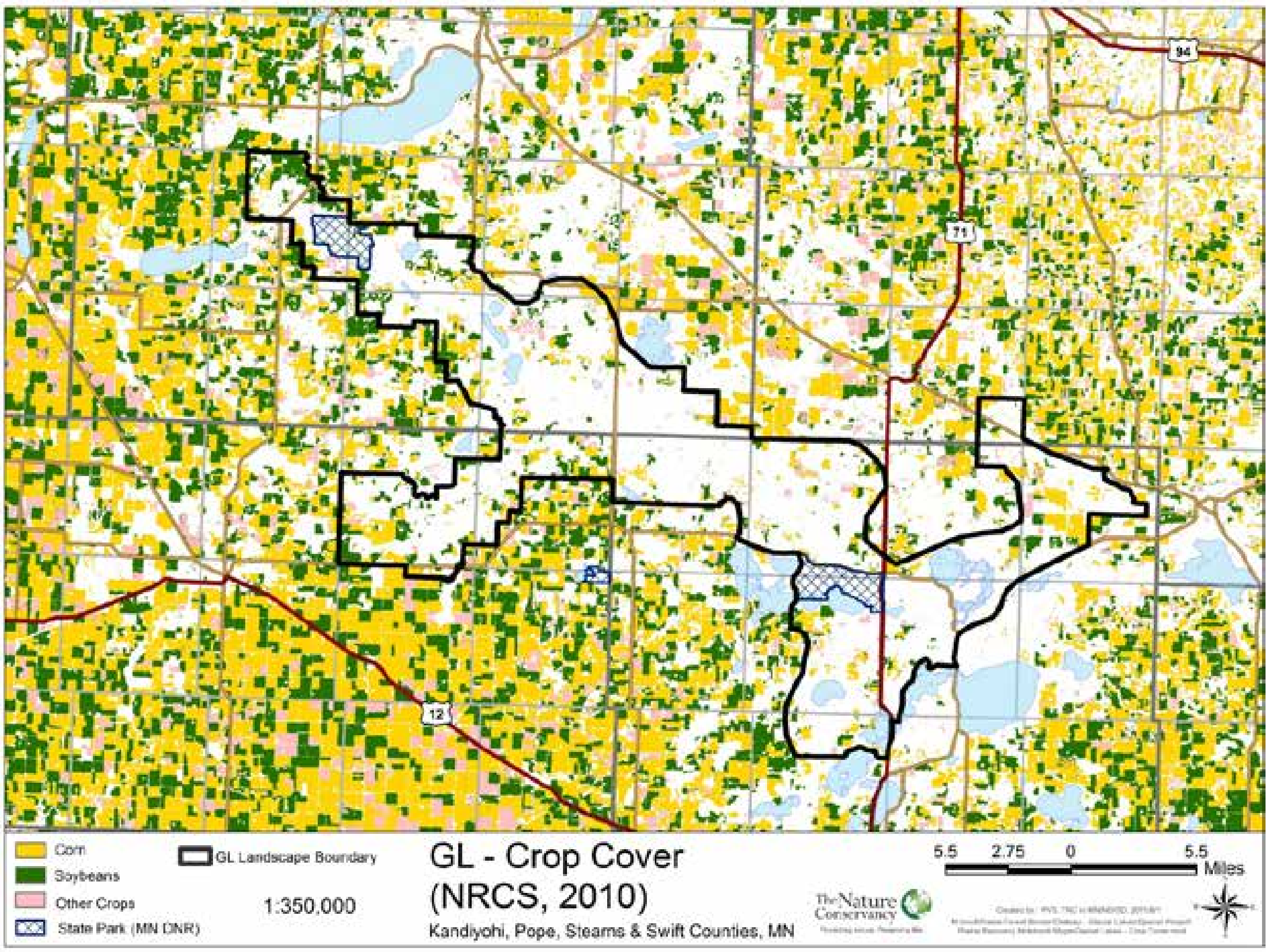

Figure 10. 2010 crop cover for the GL landscape. Crop locations for the Glacial Lakes landscape are shown with the landscape boundary in black.

2. Fragmentation of Contiguous Grassland

Besides the direct loss of prairie to cropland, prairie plants and animals are also impacted by the fragmentation of their habitat. Viable populations of all species require a minimal amount of habitat for their survival. Small areas can only support small populations. The reduced genetic diversity of small populations can lead to problems of inbreeding and small populations are more prone to random extirpations (Shaffer 1981). The actual amount of habitat required for a viable population varies with the species, but in general larger animals and animals higher in the food chain require larger areas. When that habitat is broken by barriers or unsuitable habitat such as roads or crop fields, the local grassland population may no longer have sufficient area to survive (Johnson 2014). A barrier such as a road may not pose a problem for grassland birds or butterflies, but it may be un-crossable for some mice, turtles, snakes or ground beetles (Forman and Alexander 1998). Similarly, a barrier of a mile-wide corn field that may be only an inconvenience for the most mobile species could prove insurmountable for others. Barriers are always species-specific, but if the goal is to provide habitat for the full array of species that inhabit Minnesota's prairie, there will need to be areas of effectively contiguous habitat for all of them.

A second impact of fragmentation is the increase of the amount of "edge" habitat in the landscape, for review see (Ries et al. 2004). Edges are considered favorable habitat for many generalist species such as white-tailed deer, pheasant, coyote, opossum, and others. High populations of these generalists in close proximity to native prairie tracts can lead to increased predation and competition with prairie obligate species. In addition, edges are often prime habitat for weeds in prairies. Many noxious weeds and other invasive plant species tend to spread through disturbed edge habitat and into more intact interior prairie locations.

3. Detrimental Grazing

Minnesota's prairies have been grazed by large herbivores for as long as they have existed. Prairies have adapted to the periodic grazing pressure that bison and elk provided in pre-settlement times. Domestic cattle can be used as surrogates for the type of disturbance once provided by bison; however, they are not as much of a grass specialist as bison and they tend to stay closer to water and shade. When grazing becomes a problem it is usually because cattle are confined to small pastures for long periods of time.

Most herds of beef cattle are relatively small in Minnesota. In Clay and Norman counties (ABR) the mean herd size per farm in 2007 averaged 36.8, while in Pope, Kandiyohi, and Swift counties (GL) the figure was even less at 27.8 (USDA NASS 2007). In addition, many pastures lack internal fencing. The result is that cattle are often left in undivided pastures for a substantial portion of the grazing season to harvest the available forage. Since cattle are selective feeders that graze preferred plant species when they are available, the outcome of long periods of grazing is that the most palatable plants get grazed multiple times as they attempt to regrow. The multiple bouts of grazing without sufficient time for regrowth between them will weaken the plant and over time cause the species to disappear from the pasture. The worst case grazing practice from a biodiversity perspective is season-long grazing. In this situation, cattle can choose to feed on only the most preferred species and remembering where they are, will return over and over again until the individual plant's carbohydrate reserves are depleted and it dies.

The result is that plant species diversity and productivity is lost and only those species that can tolerate repeated grazing or that cattle avoid survive.

Many over-grazed pastures wind up looking alike: mainly unpalatable plants such as thistles or milkweeds towering over closely-cropped introduced pasture grasses. With such simplified structure and limited diversity, these pastures offer little wildlife habitat and don't contribute much to maintaining the native prairie plants and animals of the area.

4. Invasive Species

There are many exotic weed species that are capable of living in grasslands and some that are capable of the more difficult task of invading even intact native prairie. The most abundant weeds in native prairies are introduced pasture grasses including smooth brome, Kentucky bluegrass, and reed canary grass. These weeds have been purposefully introduced from Europe and Asia to provide forage for livestock. In managed pastures they are valuable species, but they can dominate native prairies reducing the diversity of native plant species. At this point in time, introduced pasture grasses are abundant in nearly every native prairie parcel in both the Agassiz Beach Ridges and Glacial Lakes areas.

These introduced pasture grass species pose a threat to functioning prairie systems by their ability to spread into adjoining native prairies and displace native species (Cully et al. 2003). Most of these introduced pasture grasses evolved with cattle and other domestic livestock and are well adapted to frequent, intense grazing pressure. They are mainly cool-season grasses, meaning that they grow best in the cooler, wetter conditions of spring, early summer and fall. In some cases, native prairies are over-seeded with pasture grasses to increase forage early in the season before native warm-season grasses reach high productivity. Often in newly invaded prairies the highest densities of smooth brome and Kentucky bluegrass can be found around the perimeter boundaries and adjacent to roads.

In both the Agassiz Beach Ridges and Glacial Lakes areas there are hundreds of potential broadleaf weed species, but a few are especially problematic: leafy spurge, Canada thistle, and the biennial thistles (bull, plumeless, and musk thistle). ABR grasslands are additionally threatened by purple loosestrife, sow thistle, and garlic mustard (Clay County 2013). Glacial Lakes adds spotted knapweed, wild parsnip, Queen Anne's lace, and common toadflax as important weeds (Pope County Cooperative Weed Management Area 2008). All of these species are poisonous or non-palatable to cattle. Besides their detrimental effect on livestock they also can dominate local areas reducing the number of native species that can survive there (DiTomaso 2000).

5. Woody Plant Invasion

Both study landscapes are located in a part of North America that is capable of growing forest. Regular disturbance is needed either by fire, grazing, mowing, or drought to prevent the invasion of trees and shrubs into even native prairie. The most common invaders are the woody plants whose seeds are readily disbursed into grassland areas, either carried by birds (eastern red cedar, buckthorn, smooth sumac) or by the wind (Siberian elm, boxelder, aspen, and cottonwood). Regular fire can prevent establishment of all of these species, but once these species reach a certain size it is difficult for fire to remove them. It is important to control woody plants in these grasslands to prevent them from becoming dominant and shading out most herbaceous grassland species. This will reduce diversity and the amount of forage available for grazers and other grassland herbivores and can result in habitat conversion.

D. Current Conservation Status

1. Overall land cover goal

Due to the high levels of existing native prairie and other grasslands in the Agassiz Beach Ridges core areas, very little additional grassland habitat is needed to reach the 40% Prairie Plan grassland goal (Minnesota Prairie Plan Working Group 2011). That is not to say, that no grassland restoration is needed to maintain the viability of the grassland ecosystem. As parcels containing native prairie, other grasslands, and wetlands are protected some cropland or degraded natural habitats will also be protected on those same parcels. This land should be restored to a more diverse natural community. In addition, there will be key lands that are needed to buffer or reconnect native prairie parcels. These lands don't necessarily need to be restored to high diversity prairie plantings, but native grassland vegetation with the appropriate structure would provide value to prairie plants and animals currently using the high quality prairie.

Compared to grasslands, an additional 5,998 acres of wetlands are needed within the three core areas that compose the Agassiz Beach Ridges landscape to meet the 20% wetland goal (Minnesota Prairie Plan Working Group 2011). Most restoration work at ABR will be focused in the wetter habitats, especially in seasonal and temporary wetlands that were the easiest to drain and convert to cropland.

The Prairie Plan goes further in setting goals for wetlands. Beyond the overall 20% wetland goal is the requirement that 50% of the wetlands be seasonal or temporary in nature. Of the total 71,195 acres in the three ABR core areas, the Prairie Plan recommends that 7,120 acres should be seasonal or temporary wetlands. Land cover data from 2010 indicate that a majority (8,483 acres) of the wetlands in the ABR core areas are of seasonal and temporary wetlands in nature.

In contrast to ABR, the restoration situation is reversed in the Glacial Lakes landscape: there is at least a 5,137 acre shortfall in grassland habitat within the Glacial Lakes core area but no overall shortfall in wetland habitat (Minnesota Prairie Plan Working Group 2011). Here the need will primarily be to create new grassland habitat. Since there are only 16,194 acres of temporary or seasonal wetlands in the Glacial Lakes landscape, however, an additional 1,021 acres of wetlands that hold water only in the spring or after heavy rainfall events are needed.

2. Protected native prairie

The Prairie Plan calls for the permanent protection of all remaining native prairie. In the Agassiz Beach Ridges core areas there is a total of 15,965 acres of native prairie of which 8,253 acres are protected (Minnesota Prairie Plan Working Group 2011). That leaves 7,712 acres to be acquired by a conservation entity or protected via a conservation easement. Within the Glacial Lakes prairie core area, 2,813 acres of the 7,223 acres of native prairie are currently protected. The remaining 4,410 acres need some form of permanent protection.

3. Protected other grassland and wetland

In addition to native prairie, there are 23,926 acres of other grasslands in the three Agassiz Beach Ridges core areas (Figure 7, see page 14), with 28% of them protected (Minnesota Prairie Plan Working Group 2011). For wetlands, there are 9,474 acres with 42% protected. To reach the Prairie Plan protection goal of 50% of existing grasslands and wetlands, conservation easements or acquisition of about 5,306 additional acres of grasslands and 773 acres of wetland are needed.

In contrast, the protection shortfall at Glacial Lakes is much larger. About 55,362 acres of the Glacial Lakes core area is covered by grasslands other than native prairie (Figure 8, see page 16), but only 8,227 are protected (15%). An additional 36,326 acres are wetlands with 8,170 protected (22%). The Prairie Plan 50% goal requires protection of an additional 18,411 acres of grassland and 8,760 acres of wetlands. This is the largest combined protection shortfall of any prairie core area in the state.

4. Conservation Lands

Within the Agassiz Beach Ridges landscape, about 25,162 acres are protected land owned by public agencies, by The Nature Conservancy, or by private landowners with a permanent conservation easement (Figure 11) (Minnesota Prairie Plan Working Group 2011). Another 21,666 acres were enrolled in temporary 10-15 year contracts through the Conservation Reserve Program in 2008. Comparable numbers for Glacial Lakes are 25,340 acres of conservation lands and 26,216 acres of CRP) (Figure 12). As these CRP contracts expire, much of the enrolled grasslands could be plowed and returned to crop systems (Stubbs 2013).

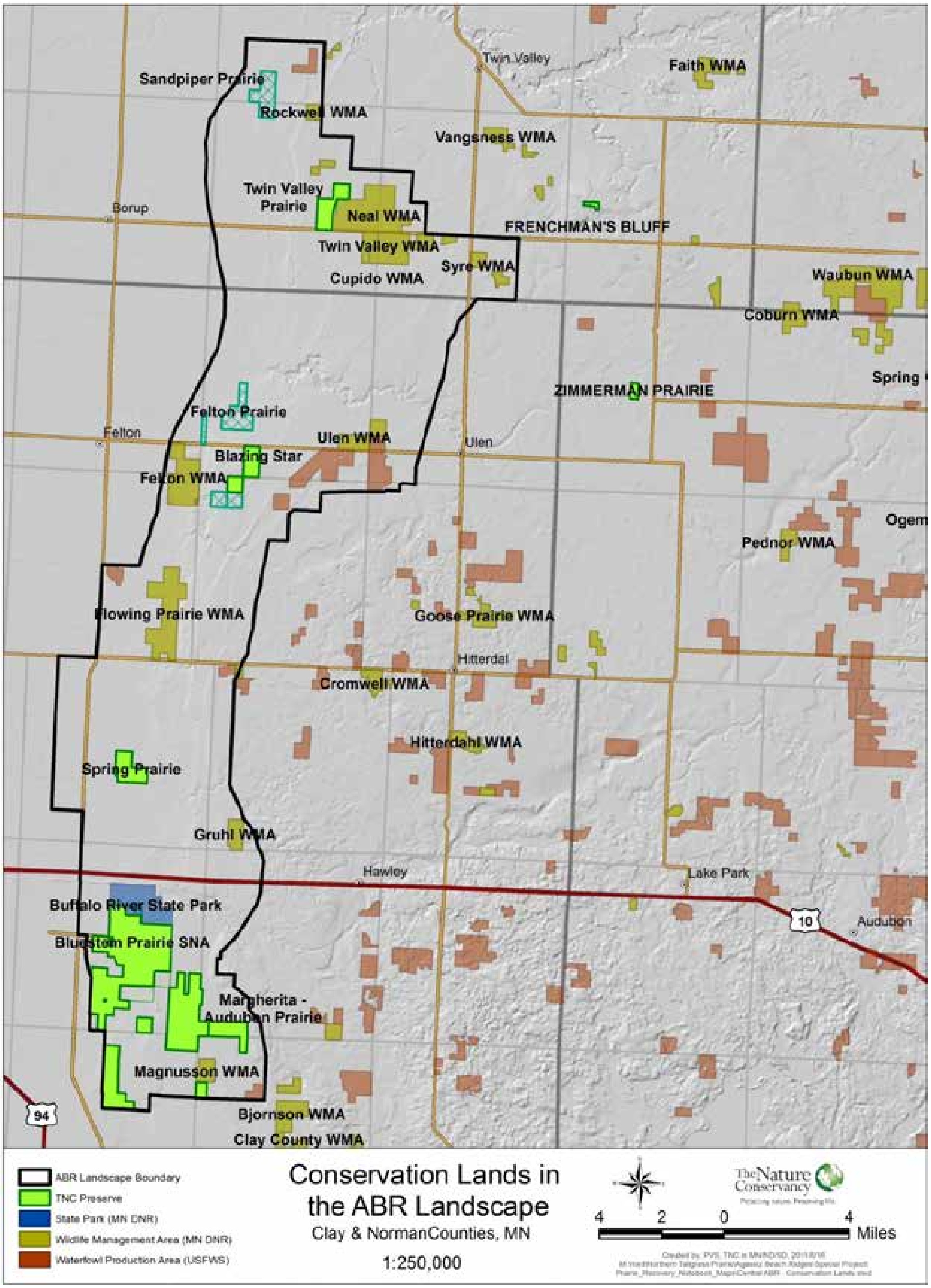

Figure 11. Protected conservation lands in the Agassiz Beach Ridges landscape.

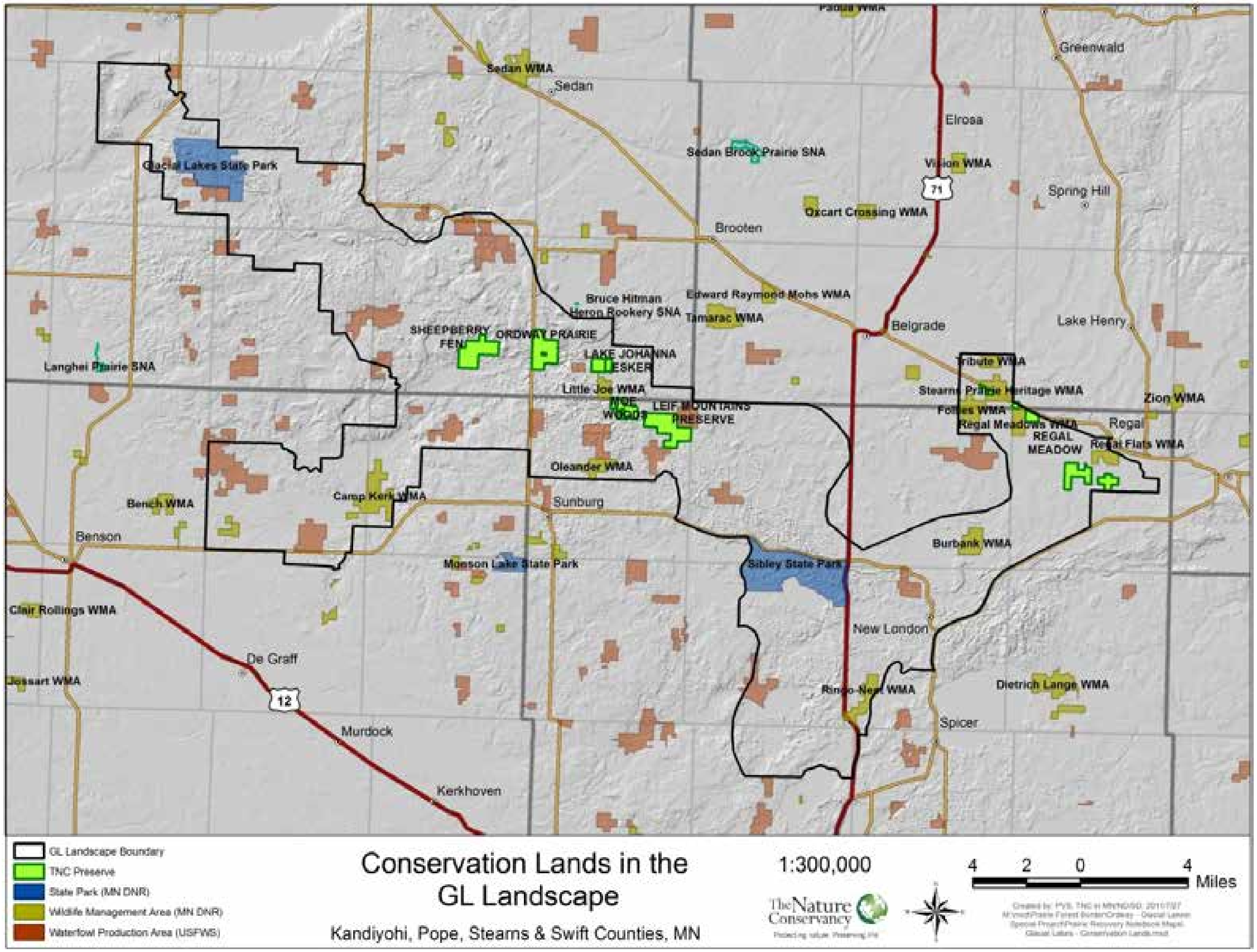

Figure 12. Protected conservation lands in the Glacial Lakes landscape.

The role of grasslands included in temporary conservation programs complicates the determination of how many acres need to be protected in order to meet the goals of the Prairie Plan. The Conservation Reserve Program signs up land for 10-15 year contracts providing an annual payment in return usually for placing the land in grassland cover. These CRP lands are temporarily protected grasslands that provide many of the conservation benefits that permanently protected grasslands do, including significant wildlife habitat for species such as pheasant (Laingen 2011). The Prairie Plan, however, did not count CRP lands towards the permanent protection goal since they can and are being plowed up when the contracts expire. If the CRP lands were counted towards the permanent protection goals, the CRP land would nearly fill the protection shortfalls leaving only 1,256 grassland acres (not counting native prairie protection) in Agassiz Beach Ridge's core areas and 5,230 acres in Glacial Lakes that would need to be protected beyond the amount permanently protected or enrolled in CRP in 2008. This result stresses the importance of maintaining and even expanding the amount of land enrolled in CRP.

Chapter 3: Current Land Use and Land Cover *by Harriet Van Vleck and Pieter Ver Steeg*

University of Minnesota and The Nature Conservancy

A. Mapping as a Component of Landscape Planning

Effective landscape planning begins with a clear understanding of the current patterns of land cover and land use in the landscape. These patterns serve as the starting point first for discussions about the goals of any landscape planning efforts, and second for any land cover or use transitions. The Minnesota Prairie Plan (Minnesota Prairie Plan Working Group 2011) provides the framework for a broad-based regional landscape planning effort that to be successful requires coordination among government agencies, non-profit conservation groups, and private landowners. The Prairie Plan focuses on protecting and restoring grasslands, typically the realm of government or non-profit conservation groups as well as increasing grass-based economic activities, typically the realm of the private land owner or operator. Current land use and land cover (LULC) maps developed for the two study landscapes, representing four of the prairie core areas identified in the Prairie Plan, are the foundation for the social, economic, and ecosystem service research presented in subsequent chapters. These maps informed the development of a state transition model and selection of priority restoration plans by identifying the most common existing LULC classes. These current conditions are the "start states" for restoration and management on key conservation parcels that the Prairie Plan recognized for conservation action (Chapter 4). Current LULC data also serve as a baseline for comparing economic returns from the current landscape with alternative future LULC scenarios and could be used to help identify areas where private grassland restoration efforts are most likely to be profitable (Chapters 8). Combining current LULC information with social (Chapter 6), economic (Chapter 8), and ecological constraints (Chapters 7 & 9) can help identify the optimal locations for restoration, protection, or enhancement activities outlined in the Prairie Plan (Chapter 10).

To determine which restoration plans to develop, or to compare economic returns and ecosystem service provision between the current landscape and alternative LULC scenarios, it is necessary to begin with a base map that captures adequate detail in the LULC classification. Unique LULC classes should distinguish between land use and land cover features which are most likely to impact restoration plans, potential returns, or ecosystem service provision, with a particular focus on those LULC classes that are subject to change in the alternative scenarios. With the aim of helping inform implementation of the Prairie Plan in two landscapes, the LULC classes needing the greatest detail were existing cropland and grassland types, areas that were most likely to be considered for grassland restoration or protection. In contrast, only coarse resolution was needed among land cover types such as forests, wetlands, and developed areas as these are unlikely targets for grassland restoration.

While several datasets of land use and land cover exist for Minnesota, none available have the detail needed to determine information about the grassland community, grassland quality (used hereafter to refer to the degree of invasion by non-native species and impact by land management), and likely grassland use. While the Cropland Data Layer (CDL) has complete coverage of our study areas, grasslands are very broadly classified as grassland/herbaceous, shrubland, or other hay/non-alfalfa (USDA NASS 2011). In contrast, Minnesota Biological Survey (MBS) data on native plant communities (NPC) provide detailed information on grassland communities, but are available only for those locations with patches of fairly high native species diversity and have little information on grassland use (MBS 2000). To generate a LULC map with more detailed information on grassland community, quality, and use than the CDL, and broader spatial coverage than the MBS native plant community data, LULC maps for two landscapes were generated through the combination of multiple existing LULC datasets.

In this chapter we present our base LULC maps for each landscape: the underlying datasets used to create these maps, how these datasets were combined, and the rapid assessment methods used to examine the accuracy of the composite maps. Figure 13 shows the general land cover classes mapped, including those where no change is anticipated in efforts to meet the Prairie Plan goals. Descriptions of the vegetation communities and the rationale behind the percent cover criteria for start states as well as an overview of our state transition model are presented with restoration approaches for common state transitions in Chapter 7. Detailed descriptions of the major land use activities considered for each start state are included in Chapter 8.

B. Land Use and Land Cover Map Development

1. General Methods

Methods for combining LULC datasets were largely derived from Mehaffey et al. (2011) and from personal communication with Sarah Hagen and Jan Slaats (TNC). The major steps are listed below and subsequently described; additional method details can be found in Appendix 1.

1. Starting with a single LULC map that covers the research area, identify the dominant LULC classes at a classification level similar to Anderson Level I (Anderson et al. 1976). Repeat this process with each additional dataset to be combined.
2. Determine which LULC classes need further division to provide the detail needed for the research focus. If further division of a particular LULC class is unnecessary, then leave this class at Level I.
3. For those LULC classes needing further division, identify the key features of ecosystems (vegetation type, land use, tree cover, etc.) that define those divisions. Broad land cover classes mapped for this project are shown as “start states” in the State Transition Model (Figure 13, discussed further in Chapter 7).
4. Identify datasets which could be utilized to make all necessary LULC divisions.

5. Reclassify each dataset to extract key LU and/or LC information needed. Give each dataset a unique set of values. For example, differentiate by the order of magnitude.
6. Sum the unique LULC values (with the raster calculator in ArcGIS) to produce a new dataset with unique identifiers which reflect the original LULC classification from each underlying dataset. Using different orders of magnitude for each dataset facilitates identification of the original LULC classification for any pixel and facilitates the final classification step.
7. Assign each unique value to a final LULC class according to a pre-determined set of hierarchy rules. Hierarchy rules should reflect not only the value of the information added, but also the accuracy and the collection date of the data (see for example, Mehaffey et al. 2011).
8. Use field sampling to assess the accuracy of the generated LULC map. The number of samples and sampling protocol must be determined on a project basis. For descriptions of the benefits and drawbacks of various sampling schemes see Congalton (1988) and Stehman (2009).

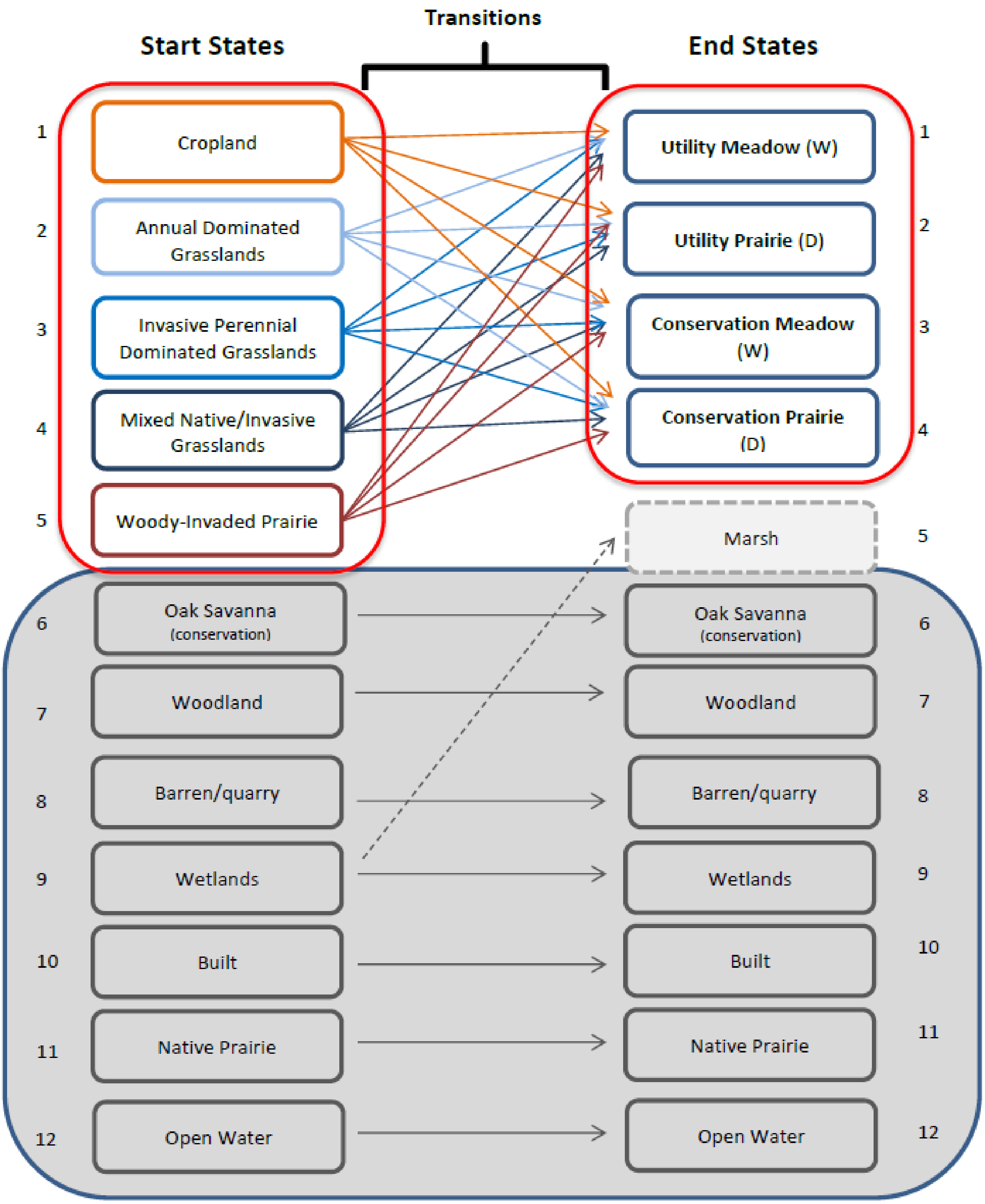

Figure 13. State Transition Model. Start and end states within the red circles are the focus of the restoration plans described in this report. States within the grey bubble represent additional major land cover types in each landscape that are not considered starting points for restoration.

2. Data Sources

What follows is a brief summary of the data sources and methods used to generate the spatial extent of each of the mapped land use and land cover classes. Each dataset used for the LULC mapping is included below with links to the data and a brief description.

Minnesota Biological Survey (MBS). Polygon data showing the locations and extent of native plant community (NPC) locations were the primary source of information the extent of distinct grassland, wetland, and woodland communities (MBS 2000). To assess the quality of the grassland NPCs, condition ranks assigned to the polygons (available for two of the six counties encompassing the focal landscapes) and older point element occurrence rank (EOR) data were combined. Where condition rank and EOR data overlapped, newer data was given priority. Where there were multiple EOR points in a NPC polygon, the lower rank was given priority. Both sets of ranking data reflect the quality, condition, and viability, of the plant community. Ranks of A, AB, and B translate into Excellent or Good occurrences of the NPC. Ranks of BC and C translate into Good/Marginal to Marginal NPC occurrences. Ranks of CD and D translate into Marginal/Poor and Poor NPC occurrences. Ranking data were used to identify grassland communities varying in the degree of invasion by non-native prairie species. NPC and condition rank data are available from the Minnesota Department of Natural Resources (DNR) (http://deli.dnr.state.mn.us/data_search.html). EOR data were obtained through personal communication with Fred Harris at the MN DNR (*personal communication* 2012).

Cropland Data Layer (CDL). The CDL, produced annually by the U.S. Department of Agriculture (USDA), is a national crop-specific land cover raster dataset for the U.S. generated from growing season satellite imagery and validated with Farm Service Agency (FSA) data (USDA NASS 2011). Since 2010 it has been produced with a resolution of 30 m^2, prior to that the resolution was 56m^2. The 2011 CDL data, which include the 2006 NLCD data for non-agricultural areas, were used to assign LULC classification (http://nassgeodata.gmu.edu/CropScape/).

National Wetlands Inventory (NWI). NWI data show the extent, location and type of wetlands as polygon data nationally (USFWS 2012). This dataset is produced by the U.S. Fish and Wildlife Service and is available for Minnesota from the DNR: http://deli.dnr.state.mn.us/data_search.html, and are available nationally through the U.S. Fish and Wildlife Service: Data are available online: http://www.fws.gov/wetlands/

LANDFIRE Existing Vegetation Cover (EVC) and Existing Vegetation Type (EVT). The LANDFIRE datasets were compiled by the USDA Forest Service Fire Lab, The Nature Conservancy (TNC), and the U.S. Geological Survey (USGS) (LANDFIRE 2011a, b). These data were primarily used to fill in gaps where we lacked MBS, NWI, and CDL data, though exceptions to this are outlined in the data compilation rules below. Data are available online: http://www.landfire.gov/vegetation.php or http://gisdata.usgs.net/website/landfire/.

National Hydrography Dataset (NHD). This national dataset includes polygons and lines reflecting lakes, ponds, swamps and marshes, and also rivers (USGS 2012). Data are produced by the U.S. Geological Survey and are available online: http://nhd.usgs.gov/data.html. These data were only used to further characterize wetlands as riparian or non-riparian.

CoreLogic ParcelPoint Data. This dataset includes parcel boundaries of properties within the focal landscapes as of 2010 and was utilized under the license of The Nature Conservancy primarily for development of a prioritization process described in Chapter 4 (CoreLogic 2010).

Protection Status. Whether a pixel was protected or not reflected it's inclusion within parcels under federal, state, or private ownership with some form of permanent protection. Temporary protection such as through the Conservation Reserve Program (CRP) was not included in this classification. A layer of permanently protected lands was compiled from U.S. Fish and Wildlife Service (USFWS) Waterfowl Productivity Areas (WPA) and other owned or easement protected USFWS lands; MN Department of Natural Resources Wildlife Management Areas (WMA), Scientific and Natural Areas (SNA), State Parks, and National Wildlife Refuges, private conservation land determined in the GAP 2008 analysis, and land with Prairie Bank easements (http://deli.dnr.state.mn.us/); easement or land owned by The Nature Conservancy (TNC) (http://maps.tnc.org/gis_data.html#TNClands); and easement land administered by the MN Board of Soil and Water Resources (BWSR). Protection status impacted the reclassification of grassland types where no MBS ranking data was available, and the potential land uses assigned to grasslands.

3. Data Compilation Rules

a. Land Cover Classification

Generalized land cover (LC) classifications were assigned to all underlying datasets. Fourteen LC classes were defined based on vegetation type and cover, these classifications allowed for the needed specificity, particularly as it related to grassland quality (Table 1). Of these fourteen, five were grassland LC classes: invasive perennial-dominated grassland (IPDG), mixed native/invasive grassland (MNIG), woody-invaded prairie (WIP), mostly-native prairie (MNP), and mostly-native savanna (MNS). Two woodland and two wetland LC classes were mapped: fire dependent oak woodland (FDOW), non-fire dependent woodland (NFDW), emergent wetland (EW), and forested/shrub wetland (FSW). The remaining five LC classes were: annual dominated fields (ADF), cropland, open water, developed, and barren/quarry.

The primary data sources for our base map were the Cropland Data Layer (CDL) and the joined MBS native plant community (NPC) and element occurrence rank (EOR) or condition rank data.

We viewed the MBS data as the best grassland quality data available, and the 2011 CDL as the best cropland data available (2011 was the most recent dataset available at the time of compilation). For non-cropland areas, the 2011 CDL utilizes data from the 2006 National Land Cover Dataset (NLCD). To address instances of consistent over or under-mapping of specific LULC classes discovered with initial field sampling, we determined rules for incorporating National Wetland Inventory (NWI) data and Landfire Existing Vegetation Type (EVT) and Existing Vegetation Cover (EVC) data. For example, we found that the extent of emergent wetlands seemed to be exaggerated in the 2011 CDL, so we gave open water and wetland extent data from the National Wetland Inventory data (NWI) priority over CDL data. Additionally, we gave the Landfire Existing Vegetation Type (EVT) data priority over CDL where the CDL classification was emergent wetland.

The unique values (step 6 above), representing each unique combination of the reclassified underlying datasets, along with the underlying data from each of those datasets were assigned to LC, LU, and LULC classes using the following rules. These rules were developed based on the year the data was collected, the accuracy of the dataset, our need for information provided by the dataset, and initial field sampling and discussions with others familiar with each dataset at the Minnesota Department of Natural Resources (Fred Harris) and The Nature Conservancy (Rich Johnson, Jan Slaats and Sarah Hagen).

1) If no MBS data, skip to rule 5.
2) If MBS data indicated “MNP or WIP” based on the EOR rank (A, AB, or B) as the land cover and the EVC was <10%, then the unique value was assigned to “MNP”. If the EVC was ≥10%, then the unique value was assigned to “WIP”.
3) If MBS data indicated “MNIG or IPDG” based on the EOR rank (BC or C) and the area was not protected, then the value was assigned to “IPDG”. If the area was protected, then the value was assigned to “MNIG”.
4) All other MBS classifications were assigned to the value without any modifications.
5) If no MBS data, and NWI data indicate anything other than “river” or “open water”, then skip to rule 7.
6) Where NWI data indicated “river” or “open water” these classifications were assigned to the value without any modifications.
7) If no CDL data, assign EVT classifications.
8) Unless CDL data indicated “cropland” or “wetland-emergent”, the CDL classifications were assigned to the unique values without any modifications.
9) Where CDL data indicated any type of cropland, and the area was not protected, the cropland type was assigned.
10) Where CDL data indicated any type of cropland and the area was protected, EVT data was used. If EVT data either was not available, or if they classified the area as “cropland”, then value was assigned to “ADF”. If available, and EVT was “MNIG or

IPDG" then "MNIG" was assigned. All other EVT classifications were assigned to the unique values without any modifications.

11) Where CDL data indicated "wetland-emergent", again EVT data was used with one exception. If EVT indicated "cropland" and the area was protected, then the value was assigned the CDL classification of "wetland-emergent". If EVT data indicated "MNIG or IPDG" the classification was determined by the protection status; if protected, then "MNIG" and if not protected, then "IPDG". Any other EVT classifications were assigned without any modifications. If there was no EVT data, and EVC was ≥30% then the classification was changed to "wetland-forested/shrub" from "wetland-emergent".

b. Land Use Classification

Nineteen land use (LU) classes were mapped (Table 1); the uses defined reflect known or potential differences in use and management of the dominant land cover classes. As with the LC mapping, the greatest LU detail needed was for grasslands and croplands. For a few LC classes where little detail on use was needed, the LU mapped was identical to the LC class (open water, emergent wetland, forested/shrub wetland, and barren/quarry). Similarly, a broad LU class, woodland, was assigned to each of the forested LC classes (NFDW and FDOW). Annual dominated grassland use was assumed to be old field/fallow. Areas classified as developed land cover were divided into two land use classes: open space-low intensity and medium-high intensity based on the four underlying NLCD developed classes that are carried over into the CDL (USDA NASS 2011) and Landfire EVT (LANDFIRE 2011b) datasets: open space, and low, medium, and high intensity.

For grasslands, the land cover class, tree cover, and protection status informed our assumptions about potential land use. Four groupings of potential grass-based land uses were defined based on whether grazing practices, if present, were likely to be continuous or rotational, and whether haying was likely to be possible on the land. Each land use class also includes "unmanaged" as a possibility to reflect those grasslands that are not actively managed. The four grass-based use classes are: grazed-continuous/hay/unmanaged, grazed-rotational/hay/unmanaged, grazed-continuous/unmanaged, and grazed-rotational/unmanaged. Four key assumptions drove the siting of these four land use groups to pixels of each grassland cover type: 1) where land was protected, any grazing was assumed to be rotational; 2) where tree cover was ≥30%, we assumed no haying was occurring; 3) if the LC type was MNP, any grazing was assumed to be rotational; 4) if the LC type was WIP, we assumed no haying was occurring.

Six cropland use classes were defined to reflect the dominant crop types in the landscapes and mapping was based on 2011 CDL data (USDA NASS 2011): corn, soybean, small grains, sugar beets, alfalfa hay, and other crops. Corn and soybean are the dominant crops in both landscapes (70-80% of all cropland area), followed by small grains in the ABR landscape and alfalfa hay in the GL landscape (each ~15% of the cropland area). Less common crops were lumped into an “other crop” class, this combined class represented 1% or less of the total cropland area in each of the two landscapes. Details on the CDL crop types reclassified as small grains and other crops are presented in Appendix 1 Land Use and Land Cover Classes.

In total twenty-eight LULC classes were mapped; the following table identifies the known or potential land uses combined with the land cover classes to generate a set of unique LULC classes (Table 1). Reflecting our need for detailed information on current cropland extent and both grassland quality and use, nearly half (twelve) of the LULC classes mapped are grassland types, another six are cropland types, and one represents old/fallow fields. The remaining eight LULC classes are open water, barren/quarry, two developed classes, two wetland classes, and two woodland classes.

Nine additional land cover classes were mapped: open water (OW), developed, barren/quarry, forested/shrub wetlands (FSW), emergent wetlands (EW), mostly native prairie (MNP), mostly native oak savanna (MNS), fire dependent oak woodland (FDOW), non-fire dependent woodland (NFDW). These additional classes are not included as start states in our state transition model as they are either rare in these landscapes or are not considered appropriate for restoration of grassland communities. Additional detail on the dataset compilation and LULC classification is provided in Appendix 1.

Prairie Plan Group	Start State & Land Cover	Land Use	LU Classification Notes
prairie	mostly native prairie (MNP)	grazed-rotational/hay	EVC <10%,
		grazed-rotational/no hay	EVC ≥10%
	woody-invaded prairie (WIP)	grazed-rotational/no hay	protected
		grazed-continuous/no hay	not protected
other grassland	mostly native savanna (MNS)	unmanaged/unknown	
	mixed native/invasive grassland (MNIG)	grazed-rotational/hay/unmanaged	protected and EVC <10%
		grazed-rotational/no hay/unmanaged	protected and EVC ≥10%
		grazed-continuous/hay/unmananged	not protected and EVC <10%
		grazed-continuous/no hay/unmananged	not protected and EVC ≥10%
	invasive perennial dominated grassland (IPDG)	grazed-rotational/hay/unmanaged	protected and EVC <10%
		grazed-rotational/no hay/unmanaged	protected and EVC ≥10%
		grazed-continuous/hay/unmananged	not protected and EVC <10%
		grazed-continuous/no hay/unmananged	not protected and EVC ≥10%
wetland	emergent wetland (EW)	EW	
	forested/shrub wetland (FSW)	FSW	
other land cover	cropland	corn	
		soybean	
		small grains	
		hay-alfalfa	
		sugar beets	
		other crop	
	annual dominated field (ADF)	old field/fallow	
	barren/quarry	barren/quarry	
	developed	open-low intensity	
		medium-high intensity	
	woodland/non-fire dependent (NFDW)	woodland	
	woodland/fire dependent oak (FDOW)	woodland	
	open water	open water	

Table 1. Land cover, potential land uses, and vegetative cover classes. Values used to define each class identified in the Agassiz Beach Ridges and Glacial Lakes landscapes are shown. Grey rows show land cover classes that are also start states for the transition model**.**

4. Rapid Assessment Methods

a. Sample Point Generation

To assess the accuracy of our combined LULC base map we used a stratified sampling approach with clustering to increase sampling efficiency. Combined land use, land cover, and protected lands datasets were in both polygon and raster formats and varied in resolution (30 and 56 m^2 raster data). Polygon data were converted to raster format and the generated LULC map (30m^2 resolution) was resampled to a resolution of 90 m^2 to reduce accuracy issues resulting from the combination of multiple datasets and from positional accuracy problems commonly associated with field sampling (personal communication, Dr. Joseph F. Knight, 2012; Knight and Lunetta 2003).

Primary and secondary sampling units (PSUs and SSUs), of 540m^2 cells and 90m^2 pixels were utilized to generate a random set of sample points for each LULC class in each landscape. DNR minor watersheds (HUC12) intersecting the landscape boundaries were used as strata (MN DNR 2009). Using a 540m^2 grid cell overlay, cells were assigned to the watershed within in which the majority of the cell/PSU fell. One PSU was randomly selected from each minor watershed (HUC12) allowing for geographic evenness of sampling across the landscapes as well as more efficient, clustered, sampling. To select PSUs for sampling, Geospatial Modeling Environment (GME) software and the r.sample tool (www.r-project.org/) were used to randomly sample input polygon features on a specified field. Selection of PSUs was limited to those cells falling completely within the landscape boundary. From the selected primary sampling units, a minimum of 15 secondary sampling units (90 m^2 blocks) per LULC class were randomly selected for sampling (simple random sample) in each landscape. If less than 15 blocks of a given LULC class were present across the selected primary sampling units, the remaining number were selected from those PSUs not initially selected. If less than 15 blocks of a given LULC class were present in the entire landscape, the maximum number of blocks present was sampled.

Agassiz Beach Ridges

The ABR landscape boundary overlaps two major watersheds (HUC08), the Buffalo River and Wild Rice River watersheds (MN DNR 2009). Within these two major watersheds there are 199 minor watersheds (HUC12) identified by the DNR; 42 of these are within or intersect the ABR landscape boundary. A total of 347 points were sampled in the ABR landscape (Figure 14).

Glacial Lakes

The GL landscape boundary overlaps three major watersheds, the North Fork Crow River, Minnesota River – Yellow Medicine River, and Chippewa River watersheds. Within these three major watersheds there are 377 minor watersheds; 29 of these are completely within or intersect the GL landscape boundary. A total of 340 points were sampled in the GL landscape (Figure 15).

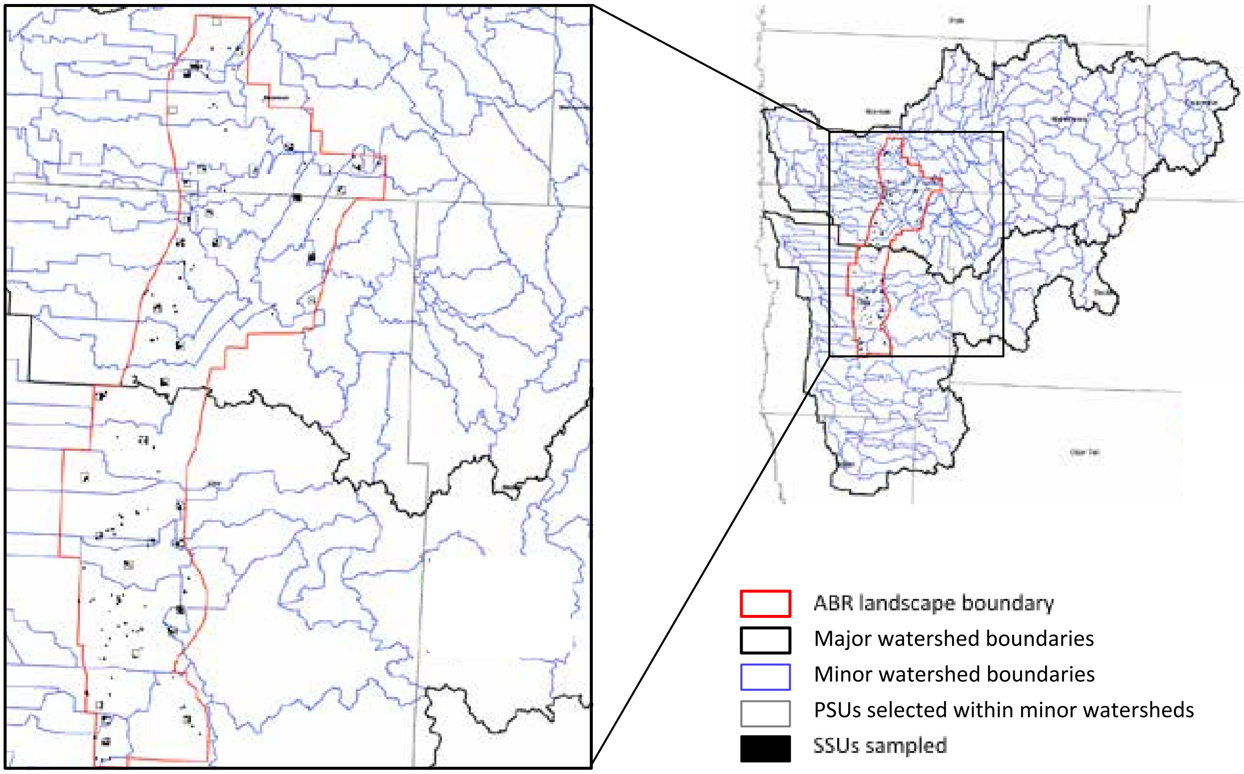

Figure 14. Agassiz Beach Ridges rapid assessment sample locations. At left, the location of primary sampling units (PSUs), shown as grey boxes and clustered secondary sampling units (SSUs) shown as solid black squares. The major watersheds the landscape falls within are shown at right.

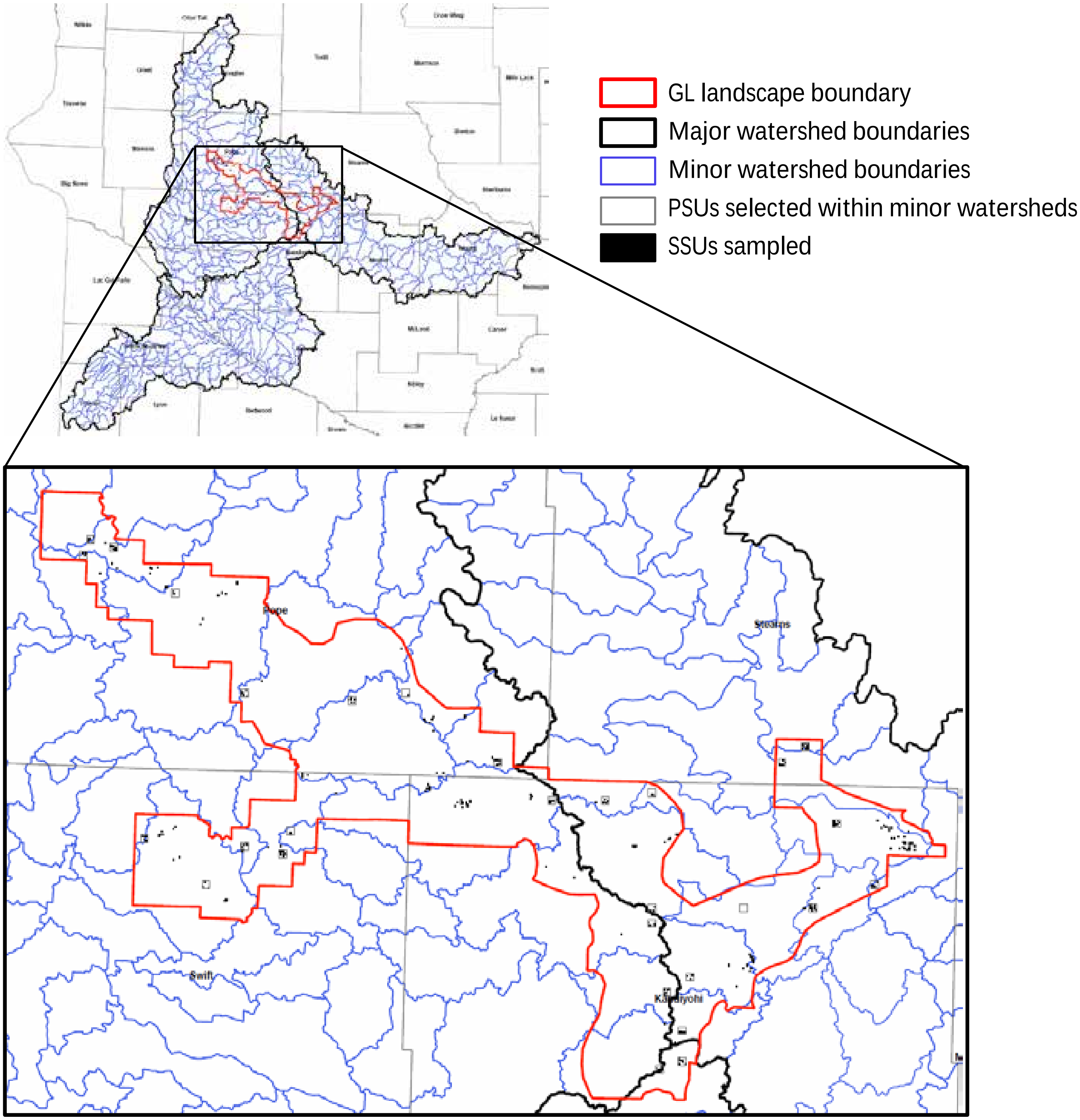

Figure 15. Glacial Lakes rapid assessment sample locations. The location of primary sampling units (PSUs) are shown as hollow grey boxes in the lower map, and clustered secondary sampling units (SSUs) shown as solid black squares. The major watersheds the landscape falls within are shown in the upper map.

b. Field Sampling

At each sample point, boundaries of the SSU were determined via a combination of aerial photography and latitude and longitude data derived from the GIS mapping. Notable landscape features (forest and grassland edges, lone large trees, fence lines, etc.) near or inside the boundary of the SSU were noted. Data on plant species composition, cover, and land use were entered into a datasheet with formulas that assigned the LULC classification to each point based on the entered data; these assignments were made based on vegetation criteria detailed in Chapter 7 (Table 20). Where sites fell on private land not easily observable from a road, ditch, or adjacent public land, landowners were approached for access. Most landowners approached were willing to grant access if they or a family member owned the property. If a landowner was not present, and sufficient data could not be gathered from a distance, new sample points representing the same LULC class were selected.

5. Accuracy Assessment Methods

Overall, user's, and producer's accuracy are three common statistics used to assess the quality of land cover maps. Overall accuracy reflects the average classification accuracy of the points sampled. User and producer accuracy data are specific to each LULC class. User's accuracy reflects errors of commission, showing the fraction of sites classified as class "X" that were correctly mapped as class "X". Put another way, this value reflects the probability that the observed LULC matches the mapped LULC class. Producer's accuracy reflects errors of omission, showing the fraction of sampled sites of class "X" that were accurately mapped as class "X" (Story and Congalton 1986). Put another way, this value reflects the probability that the mapped LULC matches the LULC class observed. These two statistics are generated using an error matrix with columns of data representing each of the sampled LULC classes (actual/reference LULC) and rows of data with the mapped LULC classes. Cells on the diagonal of this matrix represent the number of sampling points where there is agreement between the mapped and sampled LULC classes. These three metrics of accuracy were calculated for the base LULC map of each landscape.

$$\text{Overall accuracy} = \frac{\text{\# of correctly classified samples}}{\text{total \# samples}}$$

$$\text{User's accuracy} = \frac{\text{\# of correctly classified samples of class X}}{\text{total \# of samples classified as class X}}$$

$$\text{Producer's accuracy} = \frac{\text{\# of correctly classified samples of class X}}{\text{total \# of samples observed in class X}}$$

C. Results and Discussion

1. Current Land Use and Land Cover Mapped

a. Agassiz Beach Ridges Landscape

Grassland, wetland, and cropland represent 38, 12, and 43% of the land cover respectively in the ABR core area based on our LULC map (Figure 16). Land cover goals established in the MN Prairie Plan are 40% grassland, 20% wetland, and 40% other land cover (Minnesota Prairie Plan Working Group 2011). According to our mapping the grassland extent in ABR almost meets the Prairie Plan goal of 40% grassland cover while the wetland extent falls well short of the 20% cover goal. The fraction of the landscape mapped as mostly native prairie (MNP) or woody invaded prairie (WIP) is only 4% (Table 2). Grasslands degraded through invasion by non-native species or overuse represent 34% of the landscape (MNIG and IPDG). Comparisons between LULC in the ABR landscape and in the broader major watershed boundaries are shown in Figure 17 and summarized in Table 2.

Protection, as well as the extent, of both prairie and other grasslands in ABR falls short of the Prairie Plan goals for 100% protection of existing native prairie and 50% protection of "other grasslands" (Minnesota Prairie Plan Working Group 2011). Half of all land we classified as native-dominated prairie (MNP and WIP) is already protected (54%); permanently protecting the remaining native prairie would require protection of an additional 2,372 acres. Less than a third (28%) of lower quality prairie and other grasslands (MNIG and IPDG) are protected in ABR and only 15% of existing wetland acres mapped for this report are protected. In total, according to our classification, permanently protected grasslands (all classes) and wetlands represent only a small fraction of the ABR landscape, 12 and 3% respectively.

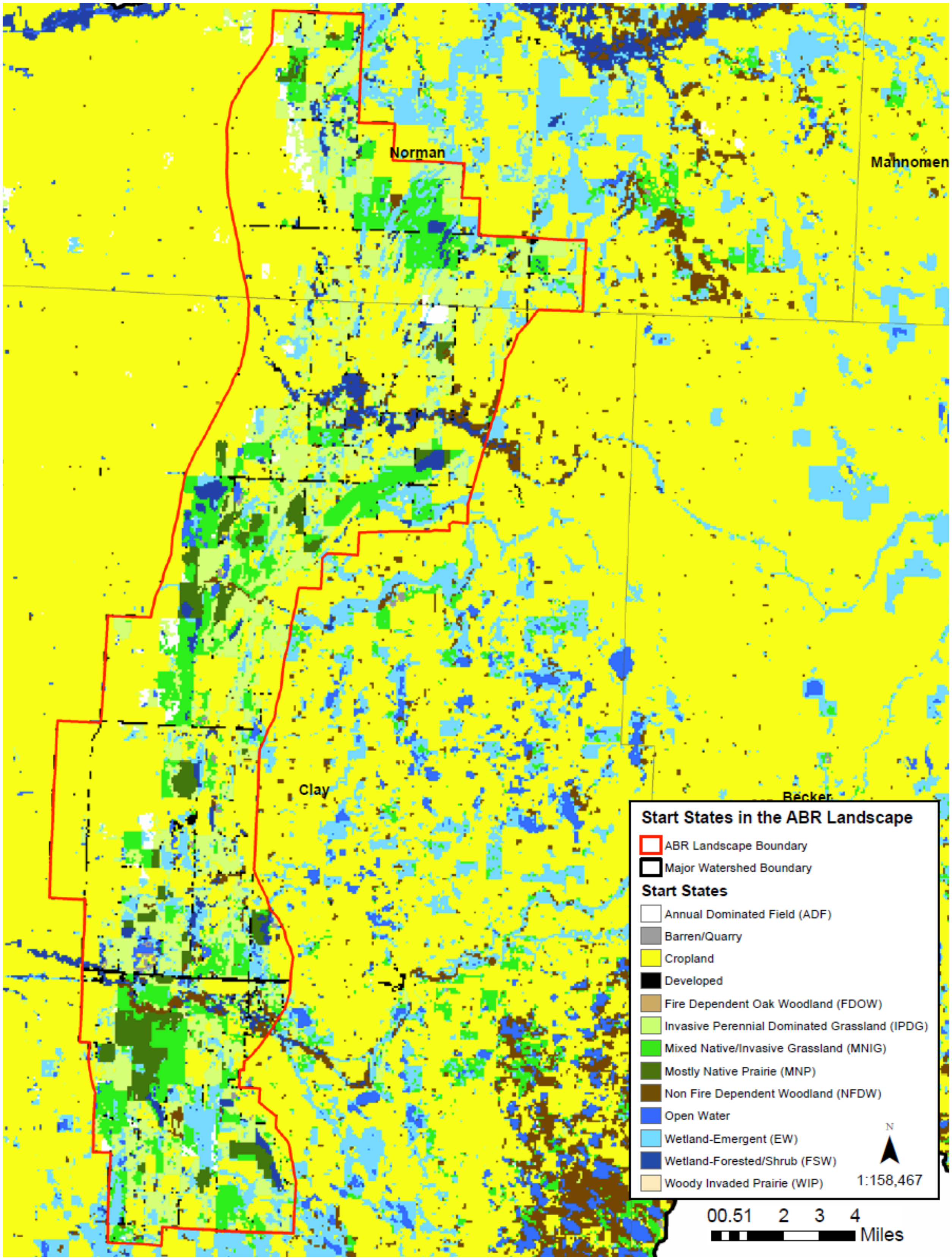

Figure 16. Start states in the Agassiz Beach Ridges landscape.

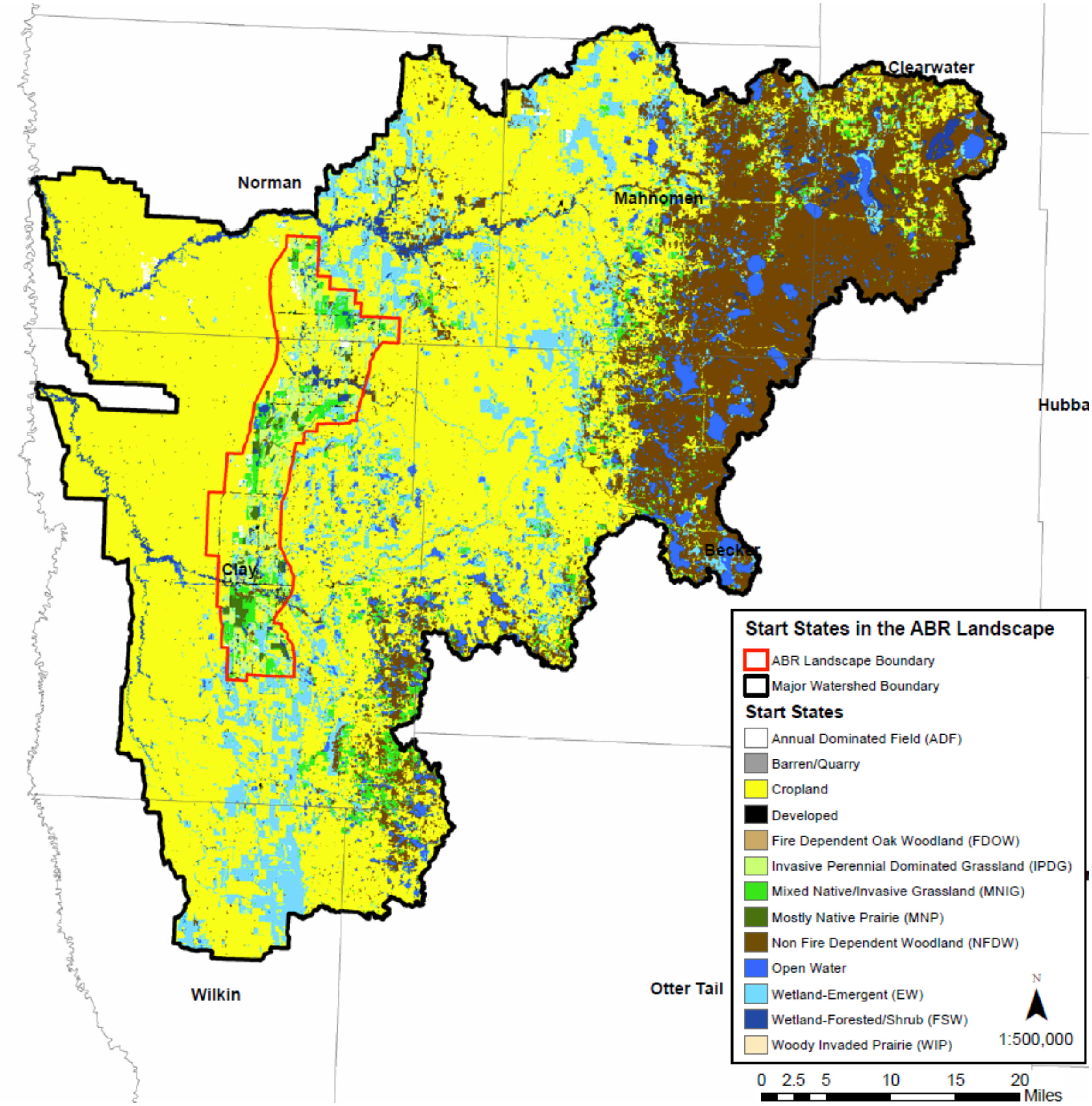

Figure 17. Start states within the ABR major watershed boundary. The external boundary of the two major watersheds is shown along with the dominant land use and land cover classes present.

Prairie Plan Group	Start State	Land Cover//Land Use	Landscape Acreage and Class Distribution						Watershed Acreage and Class Distribution	
			NP	P	Total	Landscape	Start State	Protected LULC	Total	Watershed
			Acres			%			Acres	%
prairie	MNP	MNP//grazed-rotational, hay, unmanaged†	2,370	2,780	5,152	4	100	54	5,961	<1
	WIP	WIP//grazed, unmanaged	2	18	20	<1	100	90		
other grassland	IPDG	IPDG//grazed, hay, unmanaged	26,155	1,163	27,318	22	100	4	36,829	2
		IPDG//grazed, unmanaged	26	12	38	<1	<1	32		
	MNIG	MNIG//grazed, hay, unmanaged	4,552	10,933	15,485	12	100	71	57,736	3
		MNIG//grazed, unmanaged	20	34	54	<1	<1	63		
wetland	wetland	wetland-emergent	7,624	2,933	10,557	8	69	28	179,322	10
		wetland-forested/shrub	3,811	939	4,750	4	31	20	29,115	2
other land cover	cropland	cropland//corn	12,419	–	12,419	10	23	0	281,906	16
		cropland//soybean	25,806	–	25,806	20	47	–	442,871	25
		cropland//small grains	8,834	–	8,834	7	16	–	199,651	11
		cropland//hay-alfalfa	4,471	–	4,471	4	8	–	51,571	3
		cropland//sugar beets	2,868	–	2,868	2	5	–	68,923	4
		cropland//other crop	464	–	464	<1	1	–	4,487	<1
	ADF	ADF//old field/fallow	2,286	632	2,918	1	100	42	4,641	<1
	barren/quarry	barren/quarry	336		336	<1	100	–	860	<1
	developed	developed//medium-high intensity	14		14	<1	1	–	530	<1
		developed//open space-low intensity	2,550		2,550	2	99	–	2,930	<1
	woodland	FDOW//woodland	–	4	4	<1	<1	100	337,3555	19
		NFDW//woodland	2,292	380	2,672	2	100	14		
	open water	open water	1,145		1,145	1	100	–	66,574	4
Total			106,848	19,976	126,824	100	–	16	1,771,264	100

†No pixels of MNP were mapped that would have been classified as "no hay" use so this LULC class was not included in this table.

Table 2. Land cover and land use in the Agassiz Beach Ridges landscape, and in the broader watershed area. For each land use and land cover grouping, the non-protected, protected and total acres are shown. Additionally, the LULC fraction of the total landscape area, the LULC class fraction of the corresponding start state area, and the fraction of the LULC class that is permanently protected are shown. The total area and fraction of the larger watershed area represented by each LULC class are also shown. Where grasslands are protected, any potential grazing is assumed to be rotational. For those classes where land cover and land use were the same, the information is only listed once, for example, open water//open.

b. Glacial Lakes Landscape

Grassland, wetland, and cropland represent 32, 21, and 25% of the land cover respectively in the GL core area based on our LULC map (Figure 18). As in ABR, the grassland extent in GL falls short of the Prairie Plan 40% goal while the wetland extent meets the 20% goal (Minnesota Prairie Plan Working Group 2011). The fraction of the landscape mapped as prairie (MNP and WIP) is only 0.5% of the total area, with the majority of grasslands in GL mapped as MNIG (27%) (Table 3). Comparisons between LULC in the GL landscape and in the broader major watershed boundaries are shown in Figure 19 and summarized in Table 3.

Nearly a quarter of the grassland and wetland acres we mapped in the GL landscape are protected (22 and 21% respectively). Protection rates for native-dominated prairie (MNP and WIP) and other grasslands (MNIG and IPDG) are very similar in GL at 24% and 21% respectively (Table 3). Due to the smaller total extent of native-dominated prairie in this landscape as compared with ABR, even though prairie protection is lower, only 651 additional acres of prairie in these classes need protection in GL. In total, permanently protected grasslands (all classes) and wetlands represent only a small fraction of the GL landscape, 7 and 0.1% respectively.

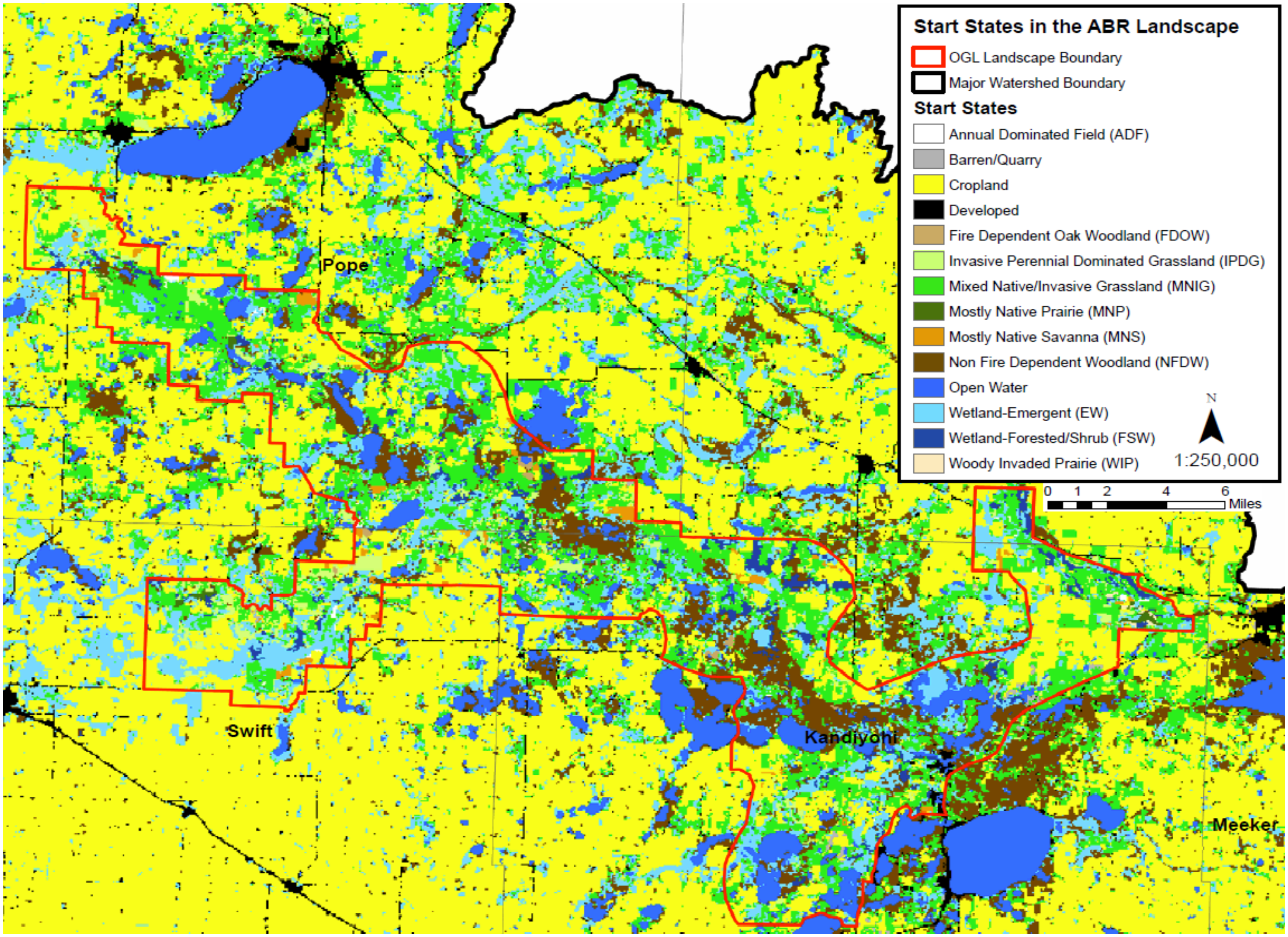

Figure 18. Start states in the Glacial Lakes landscape.

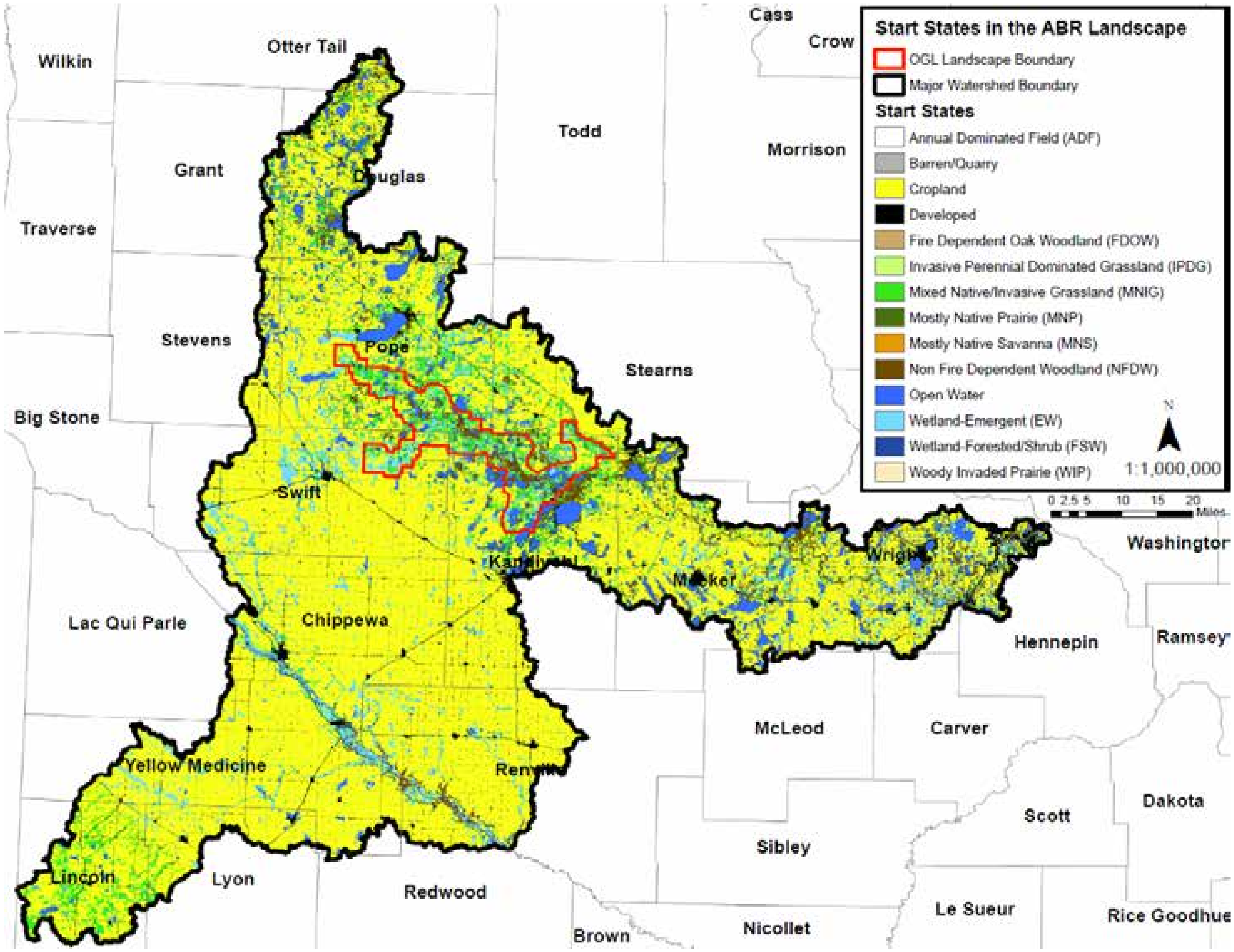

Figure 19. Start states within the GL major watershed boundary. The external boundary of the three major watersheds is shown along with the dominant land use and land cover classes present.

Prairie Plan Group	Start State	Land Cover//Land Use	Landscape Acreage and Class Distribution						Watershed Acreage and Class Distribution	
			NP	P	Total	Landscape	Start State	Protected LULC	Total	Watershed
			Acres			%			Acres	%
prairie	MNP	MNP//grazed-rotational, hay, unmanaged[†]	452	184	636	<1	74	29	2,024	<1
	WIP	WIP//grazed, unmanaged	198	26	224	<1	26	12		
other grassland	IPDG	IPDG//grazed, hay, unmanaged	8,232	168	8,400	5	97	2	21,252	1
		IPDG//grazed, unmanaged	246	12	258	<1	3	5		
	MNIG	MNIG//grazed, hay, unmanaged	33,142	11,295	44,436	26	98	25	233,077	6
		MNIG//grazed, unmanaged	536	204	741	<1	2	38		
wetland	wetland	wetland-emergent	21,282	6,167	27,449	16	77	22	343,944	10
		wetland-forested/shrub	6,871	1,285	8,156	5	23	16	12,055	<1
other land cover	cropland	cropland//corn	20,538	–	20,538	12	48	–	1,286,929	36
		cropland//soybean	13,693	–	13,693	8	32	–	930,611	26
		cropland//small grains	2,290	–	2,290	1	5	–	66,482	2
		cropland//hay-alfalfa	6,307	–	6,307	4	15	–	115,409	3
		cropland//sugar beets	156	–	156	<1	<1	–	76,765	2
		cropland//other crop	44	–	44	<1	<1	–	22,772	1
	ADF	ADF//old field/fallow	–	402	402	<1	100	100	434	<1
	barren/quarry	barren/quarry	516		516	<1	100	–	4,027	<1
	developed	developed//medium-high intensity	166		166	<1	42	–	107,303	3
		developed//open space-low intensity	232		232	<1	58	–	7,013	<1
	woodland	FDOW//woodland	326	108	434	<1	2	203,219	6	6
		NFDW//woodland	16,659	3,351	20,010	12	98	17		
	open water	open water	13,939		13,939	8	100	–	174,271	5
Total			145,827	23,202	169,029	100	–	100	3,607,589	3,607,589

[†]No pixels of MNP were mapped that would have been classified as "no hay" use so this LULC class was not included in this table.

Table 3. Land cover and land use in the Glacial Lakes landscape, and in the broader watershed area. For each land use and land cover grouping, the non-protected, protected and total acres are shown. Additionally, the LULC fraction of the total landscape area, the LULC class fraction of the corresponding start state area, and the fraction of the LULC class that is permanently protected are shown. The total area and fraction of the larger watershed area represented by each LULC class are also shown. Where grasslands are protected, any potential grazing is assumed to be rotational. For those classes where land cover and land use were the same, the information is only listed once, for example, open water//open water is listed as open water.

Grassland use observed in the two landscapes helps provide some understanding of the dominant grass-based land uses and how they align with grasslands of differing quality. The tables below indicate the fraction of observed grassland that showed evidence of grazing, haying, or showed no detectable signs of management (Table 4 and Table 5). Grazing was more common on lower quality grasslands (IPDG and MNIG) than on higher quality grasslands (WIP and MNP) in both landscapes. Heavy grazing pressure on protected grasslands was only observed on low quality grasslands in the GL landscape. Additionally, in GL, pastures where grazing impacts were relatively light were more common on MNIG parcels than IPDG parcels. Evident signs of management were absent an increasing number of parcels sampled as grassland quality increased in both landscapes: 44% of IPDG, 74% of MNIG, 97% of WIP, and 78% of MNP parcels. The most evident difference in grassland use between the two landscapes was the presence of grazing on MNP parcels in ABR. There was evidence of restoration on 5% of IPDG and MNIG parcels sampled in ABR and on 15% of MNIG parcels sampled in GL.

Grassland Use	IPDG			MNIG			WIP			MNP		
(% observations)	NP	P	Total	NP	P	Total	NP	P	Total	NP	P	Total
grazed	22	0	20	42	0	29	0	0	0	57	0	31
lightly grazed	0	15		4	6		0	0		0	16	
hay	33	5	25	0	0	0	0	0	0	36	0	13
undetected	31	80	45	54	94	71	100	100	100	7	84	56
other	14	0	10	0	0	0	0	0	0	0	0	0

Table 4. Observed grassland use in the ABR landscape. All data shown as a percentage of the total number of observations made at sample locations during the rapid assessment. The other land use was mowed lawn surrounding homes.

Grassland Use	IPDG			MNIG			WIP			MNP		
(% observations)	NP	P	Total	NP	P	Total	NP	P	Total	NP	P	Total
grazed	28	14	26	13	0	17	11	0	6	0	0	0
lightly grazed	0	0		13	11		0	0		0	0	
hay	31	43	33	0	11	7	0	0	0	0	0	0
undetected	42	43	42	74	78	76	89	100	94	100	100	100

Table 5. Observed grassland use in the GL landscape. All data shown as a percentage of the total number of observations made at sample locations during the rapid assessment.

2. Accuracy of LULC maps

a. Overall Accuracy

Eighty-five percent represents a commonly accepted target for the overall accuracy of LULC maps, with the additional goal of relatively even accuracy achieved across all LULC classes mapped (Foody 2002). Many mapping efforts fall short of one or both of these goals (Trodd

1995). We assessed the accuracy of our LULC maps for each landscape at three levels of resolution. The finest resolution includes the majority of the 28 LULC classes mapped. The mid-level resolution reflects dominant land cover classes, and matches the start states used in our transition model. The coarsest resolution reflects the land cover groupings used in the Prairie Plan.

Our overall accuracy for the two landscapes was very similar across the three levels of classification detail assessed. Overall accuracy was 75% in ABR and 76% in GL at the finest resolution and 79 and 78% at the mid-level resolution. At the coarsest resolution we approached or exceeded the target of 85% accuracy in the two landscapes. Both the user's and producer's accuracy varied widely among the individual LULC classes and unsurprisingly, both tended to be lowest for the grassland LULC classes where the greatest level of both cover and use detail was mapped.

b. Prairie Plan Group and Start State Accuracy

In ABR, the accuracy of our map was greater than 70% for each of the four land cover groups outlined in the Prairie Plan: prairie, other grassland, wetland, and other land cover. In GL, the accuracy of our map was 89% or greater for prairie, wetland, and other land cover. The fourth land cover group, other grasslands (MNIG and IPDG), had greater than 70% accuracy. In both landscapes, low producer's accuracy was found for other grasslands. This lower accuracy is a result of consistent under-mapping; other grassland classes were most often misclassified as cropland or annual dominated fields (ADF).

Within the grassland start states, accuracy tended to be higher for MNP than for WIP, MNIG or IPDG (Table 6 for ABR; Table 7 for GL). Confusion matrices are useful for clarifying the sources of inaccuracy in a LULC map; these matrices are presented at each level of resolution for the two landscapes in Appendix I (Table 51 through Table 56). In both landscapes, the IPDG class seems to underestimate the quality of the grasslands observed; several mapped IPDG points were observed to be MNIG, WIP, or MNP (see confusion matrices). In the ABR landscape, mapped MNIG points were observed to be higher quality (MNP or WIP) and lower quality (IPDG) grasslands in roughly equal numbers. In the GL landscape, mapped MNIG points seemed to slightly overestimate the grassland quality as indicated by the number of points mapped as MNIG but observed to be IPDG communities. Distinguishing between woody-invaded prairie and other grassland types and woodland was particularly challenging in the GL landscape. ADF user's accuracy was consistently low across the landscapes, with much of the area mapped as ADF observed to be active cropland or other grasslands (MNIG and IPDG, see confusion matrices).

c. LULC Accuracy

Accuracy data is shown for 17 of the 28 LULC classes originally defined. The reduction in classes assessed is largely a result of decisions to group LULC classes for differing reasons. Assessing the accuracy of crop-specific data from 2011 in 2012 would not be meaningful as most crops are grown in rotation; accordingly the six cropland classes were lumped into one class for the accuracy assessment. Grassland use classes were lumped into two use classes (from four) for MNIG and IPDG as the extent of these other grasslands where tree cover was thought to preclude haying was minimal (see Table 2 and Table 3). The result of this grouping is that protection status was the factor driving differences in land use on these two start states. As noted previously, grazing occurring on protected lands is assumed to be rotational while grazing occurring on unprotected lands is assumed to be continuous. Resampling the base LULC map to a resolution of $90m^2$ resulted in the remaining changes made to the number of LULC classes assessed. After resampling it became clear that the extent of the developed//open space-low intensity class was greatly exaggerated and pixels of this class were overwritten with the second most dominant class in each pixel. This developed class primarily represents roads and once resampled, it masked the land use and cover present on either side of roads. A second effect of resampling was that no pixels remained where MNS was the dominant LULC class.

Overall, several conclusions one can draw from the accuracy of these LULC classes are unsurprising. When the wrong grassland type or use was mapped, errors in grassland type were more common than errors in protection status (and therefore land use). Of 26 errors where the wrong grassland LULC class was mapped in ABR, only 6 were the result of errors in protection status alone, 18 were the result of errors in the grassland start state mapped, and 2 were the result of errors in both protection and start state mapped. In GL the results were similar; of 36 grassland mapping errors only 3 were the result of errors in protection status and 33 were the result of errors in the grassland start state mapped. Several reasons could explain the greater accuracy of the protection data. First, the protection data utilized is more current than much of the MBS ranking data utilized to determine grassland start states. Second, there is little room for subjectivity in recording the protection status of a parcel while determining the degree of invasion by non-native species is something that could vary among observers and over time.

d. Summary

Understanding the distribution of grasslands varying in quality and use was a central goal driving our mapping process. Given the lack of spatial data on either grassland quality, mapping grassland use required several assumptions and utilizing the information we knew about a parcel to rule out certain land uses and to suggest other land uses as more likely. The observational data collected during rapid assessment suggests that grazing is occurring on less than 20% of grasslands in these two landscapes. The observational data also suggest that grassland quality, at least in GL, may be a better indicator of the type of grazing practice utilized than protection status.

Overall, our accuracy data indicated that despite utilizing the MBS rank data, distinguishing among grasslands varying in quality is a significant challenge. In particular we found mapped transitional classes like woody-invaded prairie were often woodland or forested/shrub wetlands. We utilized percent tree cover to differentiate between MNP and WIP; though more time consuming to generate, a dataset utilizing tree cover over time would likely be the best way to determine areas of high quality grassland where woody-invasion is occurring. Grassland quality in ABR was more often underestimated than overestimated, while in GL, grassland quality was overestimated slightly more than it was underestimated. Satellite imagery has been used to distinguish between warm and cool season dominated grasslands in some locations (e.g., Wang et al. 2010). Once such data are broadly available they will significantly improve the accuracy of maps showing the extent of native versus invasive dominated grasslands in regions where the native and invasive grassland communities can be divided along these lines. While it is now possible to map broad scale changes in the extent of all grasslands (Wright and Wimberly 2013a), such data would allow mapping of changes in specific grassland types and thereby mapping of changes in habitat availability of species dependent on specific types of grasslands.

Prairie Plan Group	User's Accuracy	Producer's Accuracy	Start State	User's Accuracy	Producer's Accuracy	LULC class	No. Samples	User's Accuracy	Producer's Accuracy
prairie	**95**	**78**	**MNP**	100	77	**MNP//grassland**	15	93	100
						MNP//grassland, P	15	100	60
			WIP	80	80	**WIP//grassland**	1	100	100
						WIP//grassland, P	9	78	78
other grassland	**84**	**71**	**IPDG**	76	68	**IPDG//grassland**	31	90	57
						IPDG//grassland, P	31	61	95
			MNIG	68	51	**MNIG//grassland**	15	53	33
						MNIG//grassland, P	16	50	47
wetland	**71**	**71**	**wetland**	71	71	**emergent wetland**	14	43	60
						forested/shrub wetland	14	79	61
other land cover	**83**	**97**	**cropland**	87	93	**cropland//corn**	15	87	93
						cropland//soybean	15		
						cropland//small grains	15		
						cropland//hay-alfalfa	15		
						cropland//sugar beets	15		
						cropland//other crops	15		
			ADF	50	100	**ADF//old field/fallow**	30	50	100
			barren/quarry	63	75	**barren/quarry**	19	63	75
			developed	100	100	**developed//open space-low intensity**	.	.	.
						developed//medium-high intensity	15	100	100
			woodland	94	80	**FDOW//woodland**	2	0	0
						NFDW//woodland	15	93	74
			open water	60	90	**open water**	15	60	90
Overall	**84**		**Overall**	79		**Total No. Samples & Overall Accuracy**	347	75	

Table 6. Accuracy data for the ABR landscape. Acres of land and the fraction of total acres mapped for each Start State and for each LULC class in the ABR landscape. LULC class format is land cover//land use with a few exceptions, for example, barren/quarry//barren quarry is shortened to barren/quarry. Protection status (P) is indicated following the LULC class name.

Prairie Plan Group	User's Accuracy	Producer's Accuracy	Start State	User's Accuracy	Producer's Accuracy	LULC class	No. Samples	User's Accuracy	Producer's Accuracy
prairie	73	93	MNP	73	92	MNP//grassland	15	60	100
						MNP//grassland, P	15	87	87
			WIP	48	63	WIP//grassland	15	33	56
						WIP//grassland, P	6	83	71
other grassland	95	72	IPDG	65	65	IPDG//grassland	28	82	64
						IPDG//grassland, P	15	20	43
			MNIG	82	47	MNIG//grassland	17	65	48
						MNIG//grassland, P	17	94	44
wetland	97	91	wetland	97	91	emergent wetland	15	100	88
						forested/shrub wetland	15	93	93
other land cover	89	98	cropland	86	85	cropland//corn	15	86	85
						cropland//soybean	15		
						cropland//small grains	16		
						cropland//hay-alfalfa	16		
						cropland//sugar beets	15		
						cropland//other crops	7		
			ADF	5	100	ADF//old field/fallow	22	5	100
			barren/quarry	94	88	barren/quarry	16	94	88
			developed	100	94	developed//open space-low intensity	.	.	.
						developed//medium-high intensity	15	100	94
			woodland	100	91	FDOW//woodland	15	87	93
						NFDW//woodland	15	93	74
			open water	93	100	open water	15	93	100
Overall	89		Overall	78		Total No. Samples & Overall Accuracy	340	76	

Table 7. Accuracy data for the GL landscape. Acres of land and the fraction of total acres mapped for each Start State and for each LULC class in the GL landscape. LULC class format is land cover//land use with a few exceptions, for example, barren/quarry//barren quarry is shortened to barren/quarry. Protection status (P) is indicated following the LULC class name.

Chapter 4: Prairie Parcel Planning *by Stephen J. Chaplin and Pieter Ver Steeg*

The Nature Conservancy

Prairie landscape managers prioritize conservation work to ensure that available resources are focused in the most important areas and on the most important activities first. In this report, the approach we used to prioritize land for potential conservation action was based first on the extent of native prairie. The rationale for using prairie extent as an indicator of a functional system is the understanding that the most likely places to restore functionality are those that have retained the highest concentrations of surviving prairie. The surviving prairies are not only the home of native prairie plants and animals but they are also a potential source of genetically-appropriate colonists for surrounding lands. It is easier to restore ecosystem function if you start with a landscape that already contains fragments of high quality native habitat. The Minnesota Statewide Conservation and Preservation Plan (Swackhammer et al. 2008) recognized this when it made its first habitat recommendation to: “restore ecoregion-appropriate landscape-scale complexes of habitat centered on concentrations of existing remnant habitat”. The Minnesota Prairie Conservation Plan also made the protection of all native prairies its top priority.

Areas with high concentrations of native prairie also need less restoration to buffer and reconnect the native prairie to get the large areas of continuous grassland that many prairie animals need to maintain viable populations. Another way of thinking about this is that in places with a high extent of native prairie it should be easier to reverse the impacts of fragmentation.

A. Coordinated Landscape Management

Current land use decisions are made on a parcel by parcel basis. Each landowner decides independently how to manage his or her own property with little or no consideration for the status of surrounding properties or how they are being managed. Many neighboring landowners face the same economic pressures and environmental constraints while being influenced by local land use culture. The result is that most landscapes tend to be fairly homogenous with a limited number of land use/land cover combinations. An alternative approach to achieve conservation goals would be to coordinate management activities to not only ensure that adequate management occurs on each property but that the full range of natural habitat types and conditions are maintained within the landscape. There would likely be economic advantages as well with a coordinated approach. Potential cost sharing and efficiencies of scale could be employed for management activities including prairie restoration, prescribed fire, invasive weed and woody plant encroachment control, and conservation grazing. We assume that if landowners were to coordinate in their land use decisions and cooperate on cross-boundary activities, the efficiencies and cost sharing could be significant and the likelihood would increase that the existing prairie and grassland system become more functional.

B. Methods

1. Density of native prairie

In this study, prairie extent was measured by calculating the percentage of quarter-quarter sections (40 acre parcels) with at least five acres of native prairie within two miles for any point in Minnesota. We divided the state into a grid of square quadrats one-quarter mile on edge (these are the same as legal quarter-quarter sections of land equaling about 40 acres each). For each quarter-quarter section in the state we calculated the percentage of other quarter-quarter sections within two miles that contained at least five acres of native prairie. Figure 20 details the process to calculate the density of native prairie quarter-quarter sections around the central green quarter-quarter section.

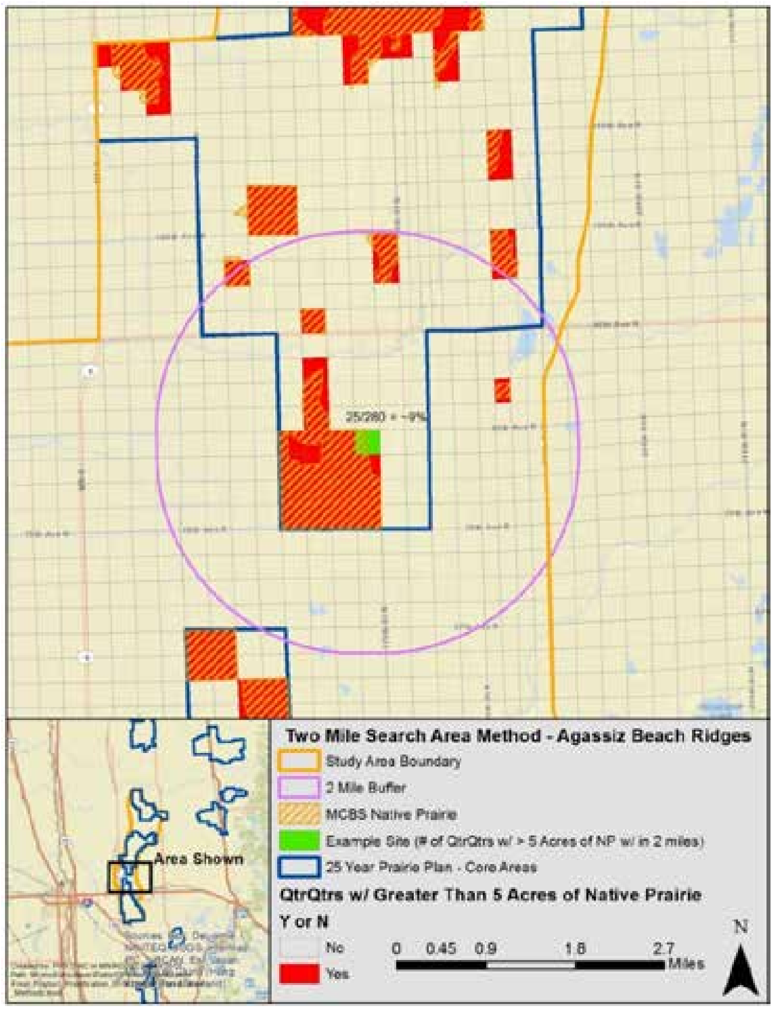

Figure 20. Prairie Density Methodology. Example in the Agassiz Beach Ridges landscape showing the percentage of quarter-quarter sections with at least 5 acres of native prairie within 2 miles. Native prairie delineated by the MCBS is shown in light blue.

In the example given, there were 36 other quarter-quarter sections (shown in red) with at least five acres of native prairie within two miles (large magenta circle). Since there are roughly 280 quarter-quarter sections within any area with a radius of two miles, the percentage of native prairie quarter-quarter sections within that area is 12.8%. The same calculation is done for each of the 1,352,014 quarter-quarter sections in the state and three categories were established: 10-20%, 20-40%, and more than 40%.

2. Identifying Coordinated Landscape Management Areas (CLMAs)

The same analysis used to measure the extent of prairie statewide can be used to delineate local areas with high concentrations of native prairie. These areas are the places we expect will have the greatest potential for prairie functionality and are often places that have been the subject of intense conservation activity for many decades. Using the same scores described earlier for each quarter-quarter section of land, we assigned the highest quarter-quarter score found within each land ownership tract as the score for the entire tract. Tracts that had scores greater than about 20% were then plotted on a map and the line drawn around that group of tracts roughly comprised the boundaries of the Coordinated Landscape Management Areas.

3. Coordinated Landscape Management Area Maps and Analysis

Using a Geographic Information System we intersected the native prairie layer provided by Minnesota's County Biological Survey with legal tract boundary (parcel) data. The parcel data came from a variety of sources including data from ParcelPoint©, a private data company, data directly from county governments, and digitization from tax records and published plat maps. The tracts that contained at least 20 acres of native prairie were identified along with those that had 1-20 acres. These were plotted and used to identify other tracts with little or no native prairie that were either immediately adjacent to areas of native prairie (buffer) or that were located in key positions between tracts with native prairie (connection).

C. Results

1. Native Prairie Density

The remaining native prairie of Minnesota is not distributed evenly across its former range. The Minnesota Prairie Conservation Plan recognized this pattern but used a different approach based on the expert opinion and the visual interpretation of aerial photography to locate prairie core areas. That plan delineated 36 prairie core areas (shown in blue in Figure 21) that capture 71% of the known native prairie acres in Minnesota within a landbase of 1.5 million acres. In comparison, the areas of high native prairie density (shown in yellow, orange, or red in Figure 21) capture 47% of the native prairie in 472,154 acres. The strong agreement between the two approaches is reassuring although perhaps not surprising since both approaches used the same native prairie dataset as their starting points. Six major native prairie concentrations are the most important in the state: the Aspen Parklands in Kittson County, Glacial Ridge in Polk County, the Agassiz Beach Ridges in Clay and Norman Counties, Lac Qui Parle in Swift and Chippewa

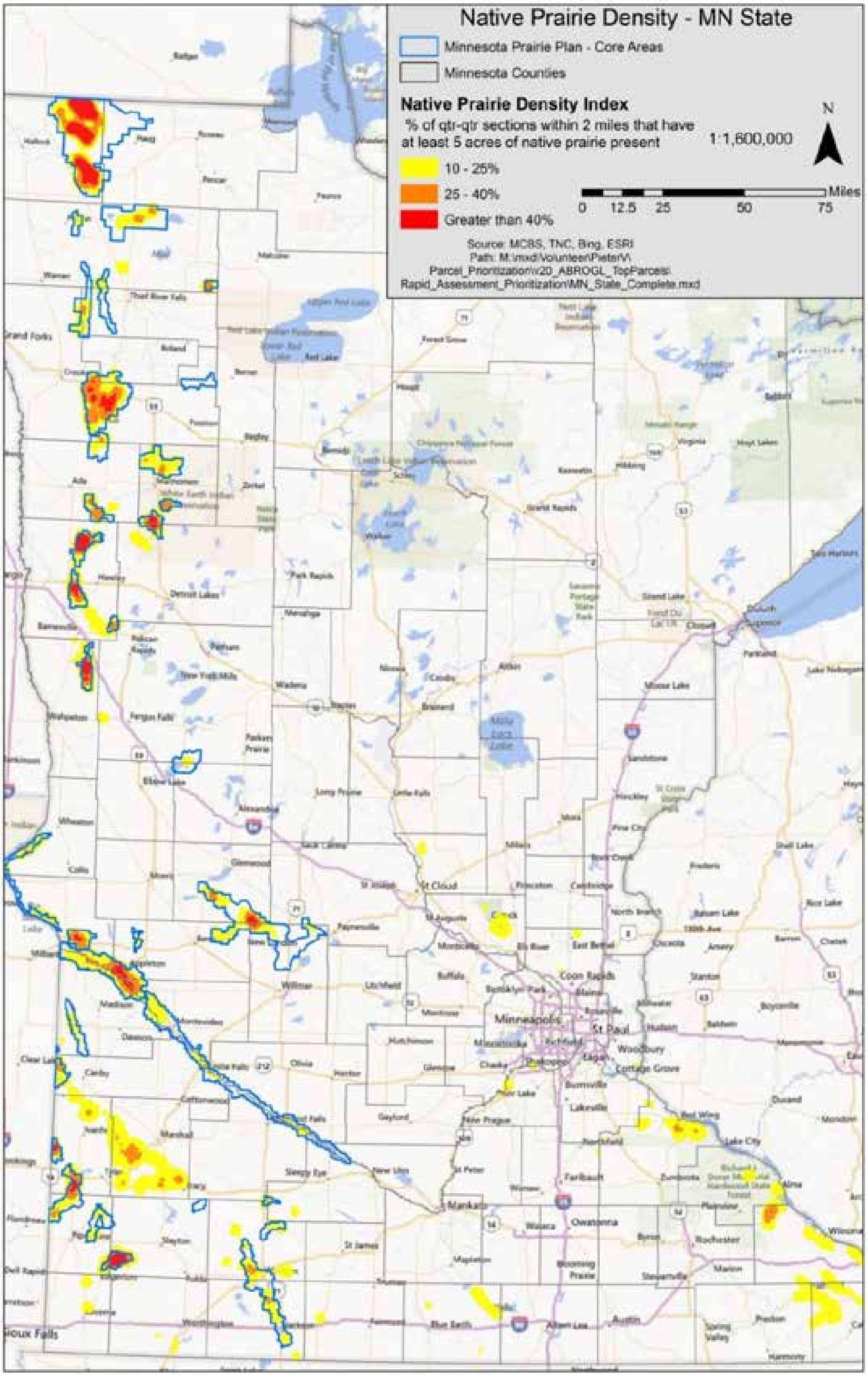

Figure 21. Prairie density methodology applied statewide.

Counties, the Prairie Coteau in Lincoln, Pipestone, and Murray Counties, and Glacial Lakes in Pope and Kandiyohi Counties. The differences between the prairie plan and the concentration of native prairie developed in this study do point out areas for additional consideration in the next iteration of the Prairie Plan. Some core areas had relatively low concentrations of native prairie including Plum Creek and Chester Hills that may need to be reconsidered. Other areas such as around Camden State Park in Lyon County had relatively high concentrations of native prairie but were not included as a core area in the original Prairie Plan.

2. Location of Coordinated Landscape Management Areas

When the same native prairie concentration analysis is performed at the ABR and GL landscape scale, the results are depicted in Figure 22 and Figure 23. The analysis revealed that there are three major concentrations of native prairie within the ABR landscape and two in GL. The line around each of these five concentrations shows the boundaries of the proposed CLMAs listed south to north: Bluestem Prairies, Felton Prairies, and Syre Prairies (each of which correspond to a prairie core area in the Prairie Plan, but with slightly different boundaries) in the Agassiz Beach Ridges landscape and Ordway Prairie and Glacial Lakes State Park area in the Glacial Lakes landscape. There has been a long history of conservation in these five CLMAs and this analysis helps confirm that past conservation activity has largely been focused in the right places.

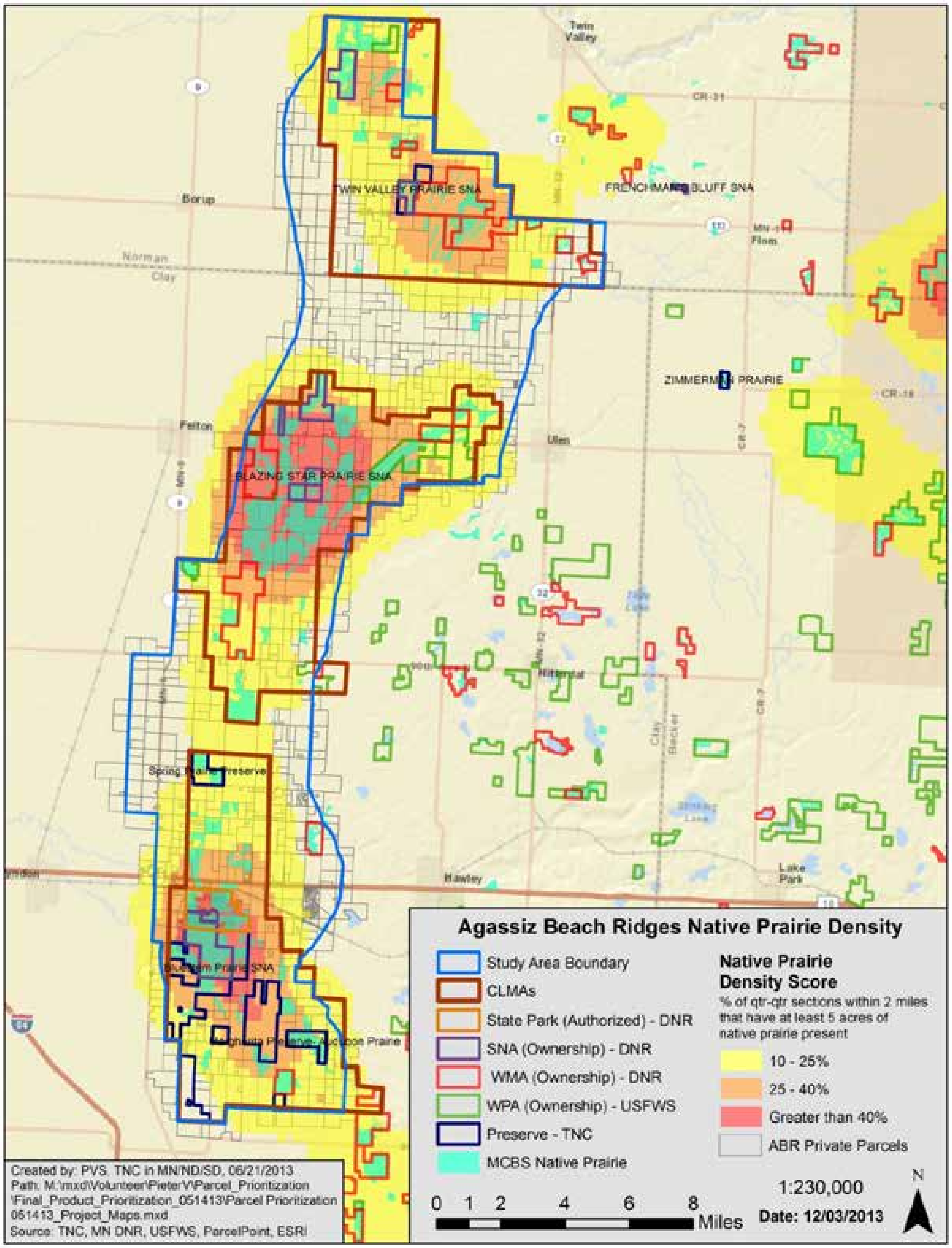

Figure 22. Native prairie densities within ABR. Coordinated Landscape Management Area boundaries in the Agassiz Beach Ridges landscape and their relation to native prairie densities.

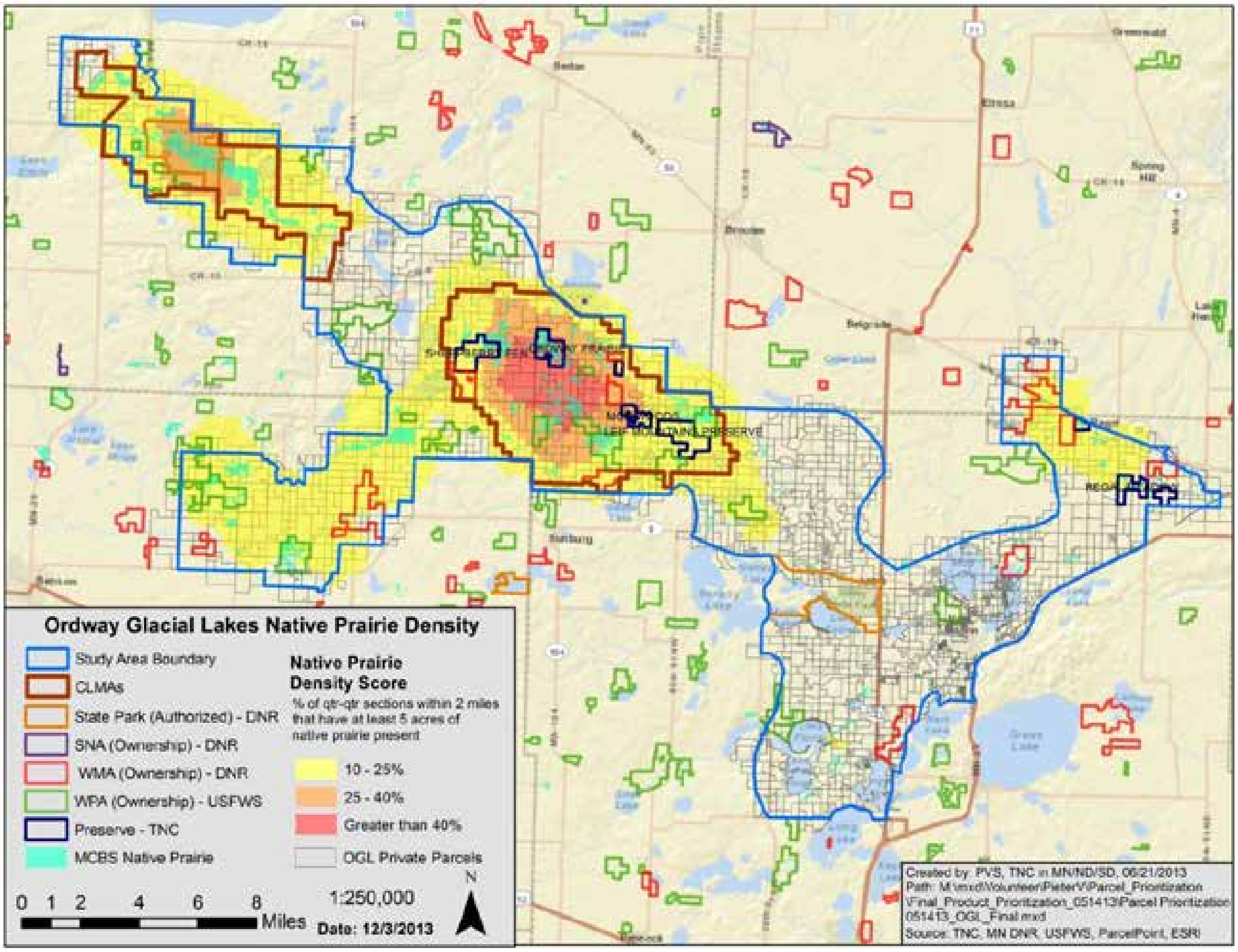

Figure 23. Native prairie densities in GL. Coordinated Landscape Management Area boundaries in the Agassiz Beach Ridges landscape and their relation to native prairie densities.

3. Coordinated Landscape Management Areas

a. Key Private Conservation Parcels

The final set of prairie parcel maps (Figure 24 through Figure 28) show the distribution of key conservation parcels: those with at least 20 acres of native prairie, those with 1-20 acres of native prairie, and those that lack native prairie but are important for buffering and reconnecting native prairie parcels in each CLMA. These key conservation parcels are the ones that the Prairie Plan Local Implementation Teams are studying for some combination of potential conservation actions including management, restoration, and protection. Landowners are being contacted to assess their interest in participating. These parcels are the most desirable places for conservation in the next 25 years and it is important to understand current land use/land cover as the potential starting point for action. Table 8 shows the number of tracts, acreage of those tracts, and the acres of native prairie in those tracts for each category in each CLMA.

CLMA Name	Total CLMA	CP with > 20 acres NP	CP with 1 – 20 acres NP	CP that Buffer and Connect	Combined CP
Bluestem	303/27,688/5,146	26/4,181/1,774	22/1,978/106	26/2,874/ 2	74/9,033/1,882
Felton	293/29,685/7,524	41/9,277/5,119	23/3,280/194	44/4,553/ 4	108/17,110/5,317
Syre	113/26,506/3,152	17/5,510/1,674	7/1,802/ 56	16/2,526/ 1	40/9,839/1,731
Ordway	304/27,150/2,747	33/4,879/1,233	51/5,002/377	44/3,432/ 0	128/13,313/1,610
Glacial Lakes SP	126/13,447/2,094	18/5,380/1,320	21/2,282/154	15/1,648/ 2	54/9,310/1,476
TOTAL	1,139/124,476/20,663	135/29,227/11,120	124/14,344/887	145/15,033/9	404/58,605/12,016

Table 8. Key private conservation parcel numbers for each CLMA. Number, acreage and native prairie extent of key private conservation parcels (CP) within Coordinated Landscape Management Areas (CLMAs). The format for each cell is: number of tracts / total acres / native prairie acres.

This analysis indicates that within the five CLMAs found in the two study landscapes, a combined total of only 135 tracts with more than 20 acres of native prairie, 124 tracts with 1 to 20 acres of native prairie, and 145 tracts important for buffering and connecting are key tracts for some combination of potential conservation actions (management, restoration, and/or protection). These 404 private tracts have a combined size of 58,605 acres and contain 12,016 acres of native prairie. These potential conservation parcels comprise 35% of the total parcels within the CLMAs although there is high variability among the CLMAs. Only 32.6 percent of the total CLMA have been identified as key private conservation parcels at Bluestem Prairie, mostly because of the high amounts of existing conservation lands already present there. In comparison, Felton Prairie and Glacial Lakes SP had the highest percentage of private conservation parcels with about 70% of the total CLMAs having been identified. All five CLMAs in total have 20,663 acres of native prairie but the private conservation parcels have only 12,016, meaning that 42% or 8,647 acres of native prairie are already protected on existing conservation lands (state, federal, and TNC).

The conservation parcel analysis shows some important differences between the CLMAs. Bluestem Prairie has the most native prairie on existing conservation land. Over 63% of the native prairie is found on state or TNC lands. In comparison, Felton Prairie CLMA located nearly adjacent within the Agassiz Beach Ridges landscape and Glacial Lakes SP CLMA are the least protected with more than 70% of the native prairie on private lands. Felton Prairie also has the most native prairie of the five CLMAs with 7,524 acres or 25% of the total 29,685 acres being classified as native prairie by the MCBS. Ordway Prairie has the lowest percentage of native prairie with only 10% (2,747 acres).

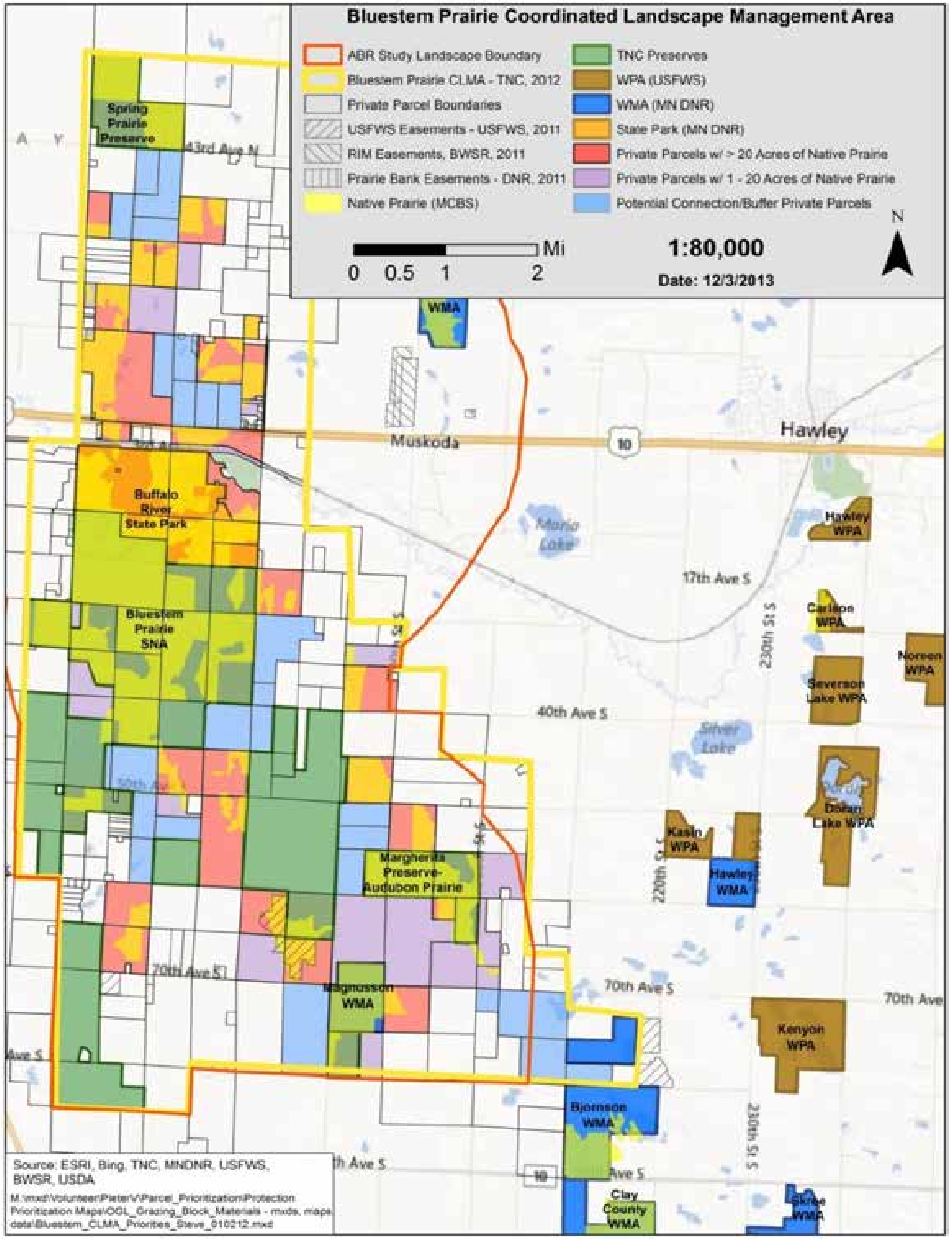

Figure 24. Key conservation parcels in the Bluestem Prairie CLMA. Bluestem Coordinated Landscape Management Area in the Agassiz Beach Ridges landscape showing key native prairie parcels.

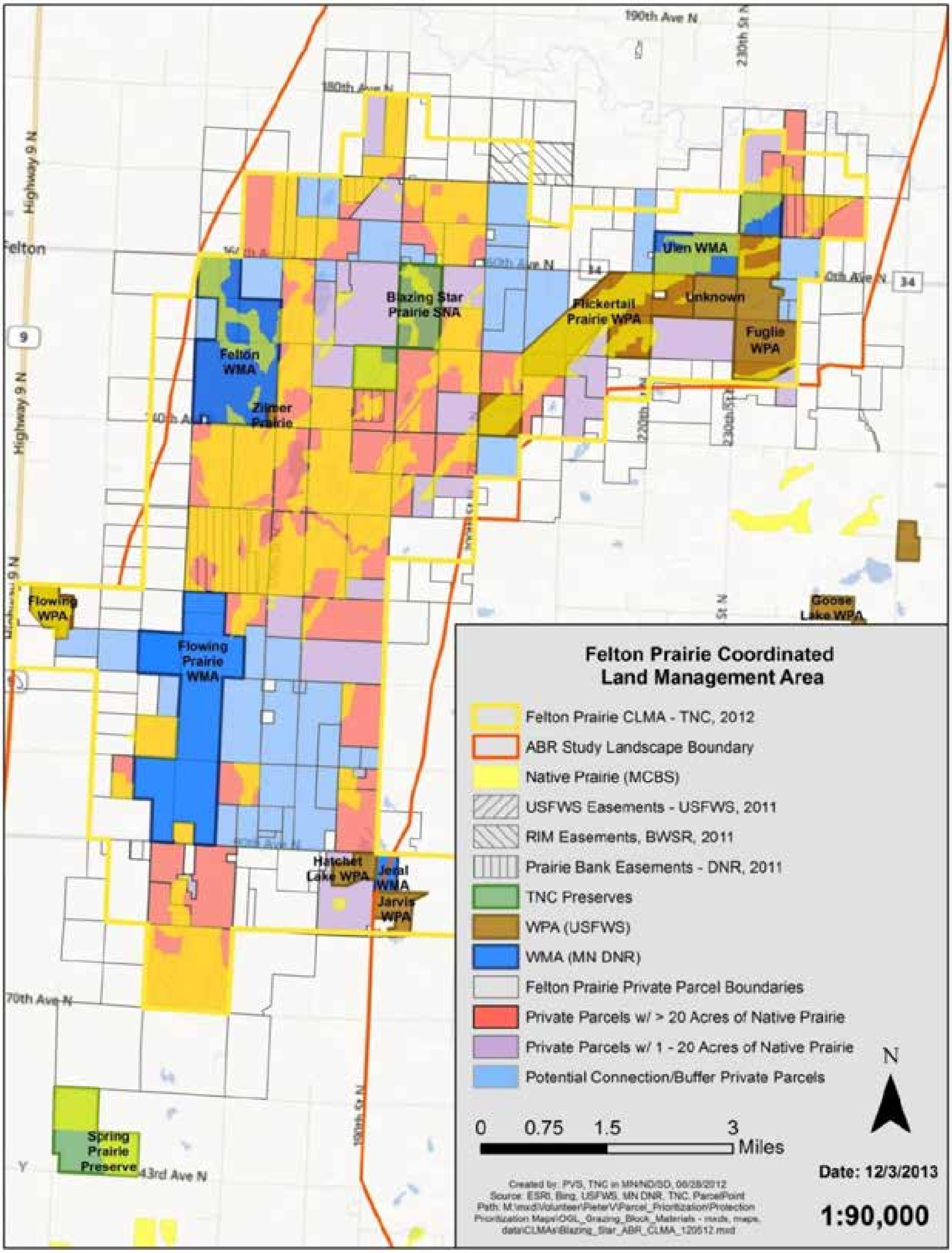

Figure 25. Key conservation parcels in the Felton Prairie CLMA. Felton Coordinated Landscape Management Area in the Agassiz Beach Ridges landscape showing key native prairie parcels.

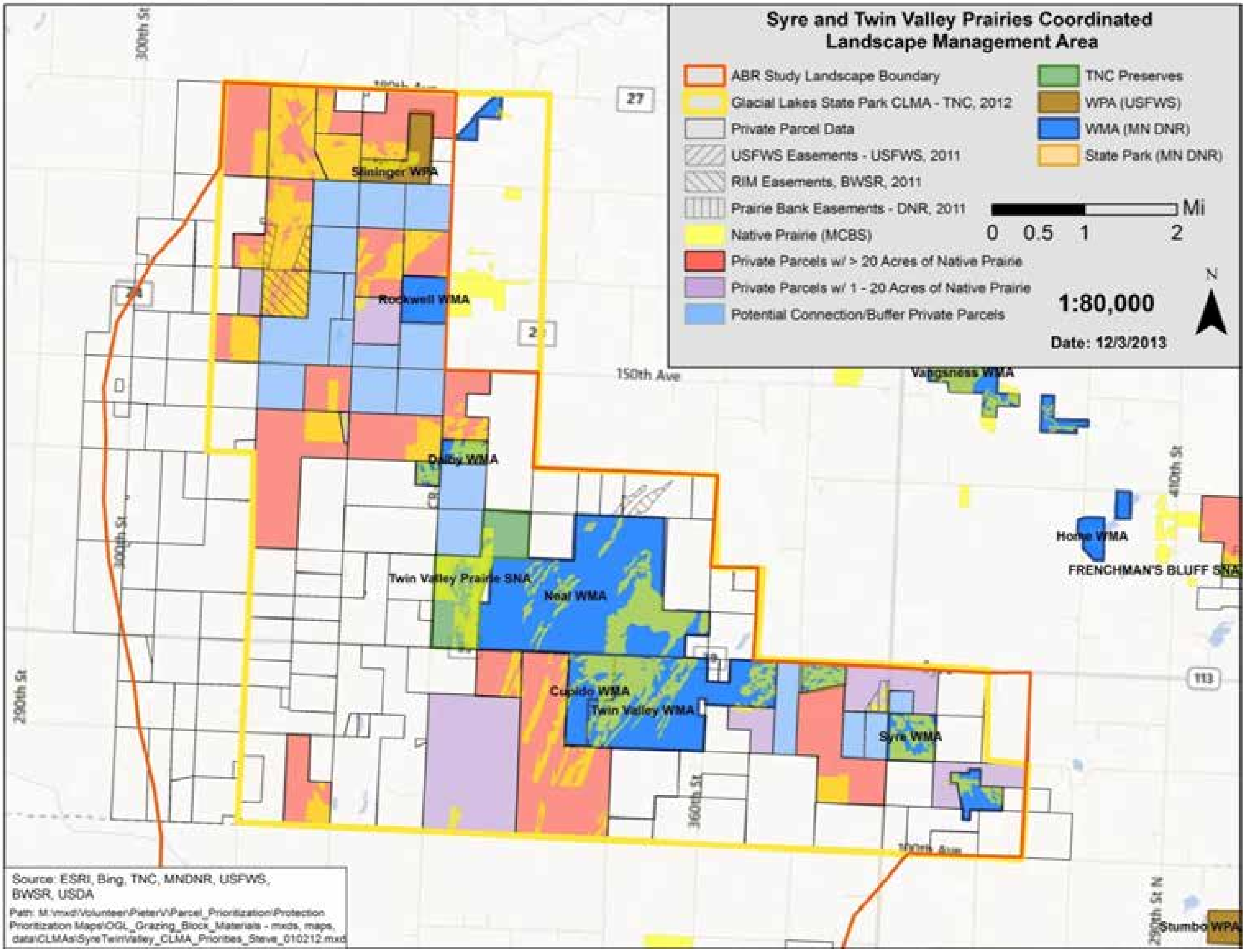

Figure 26. Key conservation parcels in the Syre Prairie CLMA. Syre Coordinated Landscape Management Area in the Agassiz Beach Ridges landscape showing key native prairie parcels.

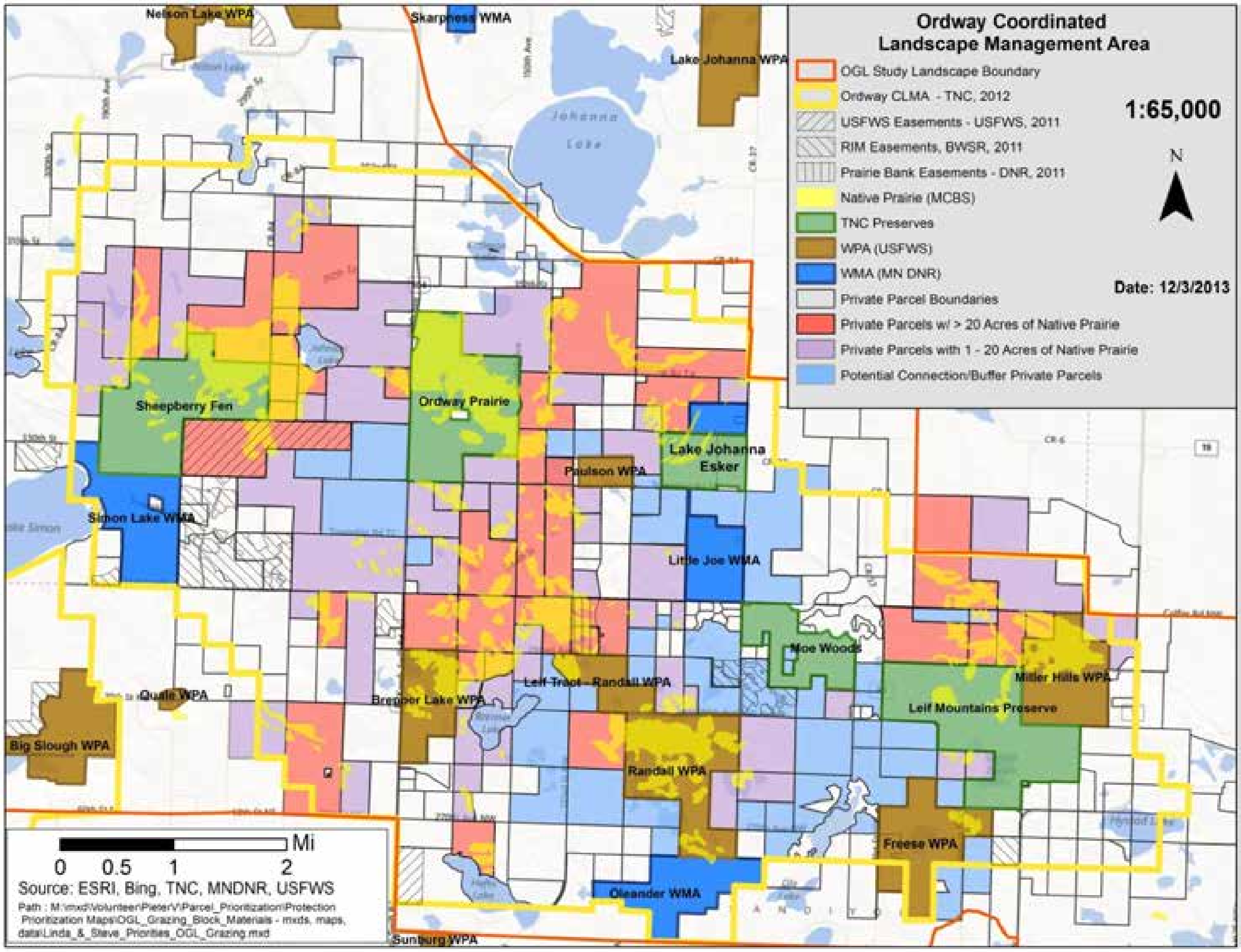

Figure 27. Key conservation parcels in the Ordway CLMA. Ordway Coordinated Landscape Management Area in the Glacial Lakes landscape showing key native prairie parcels.

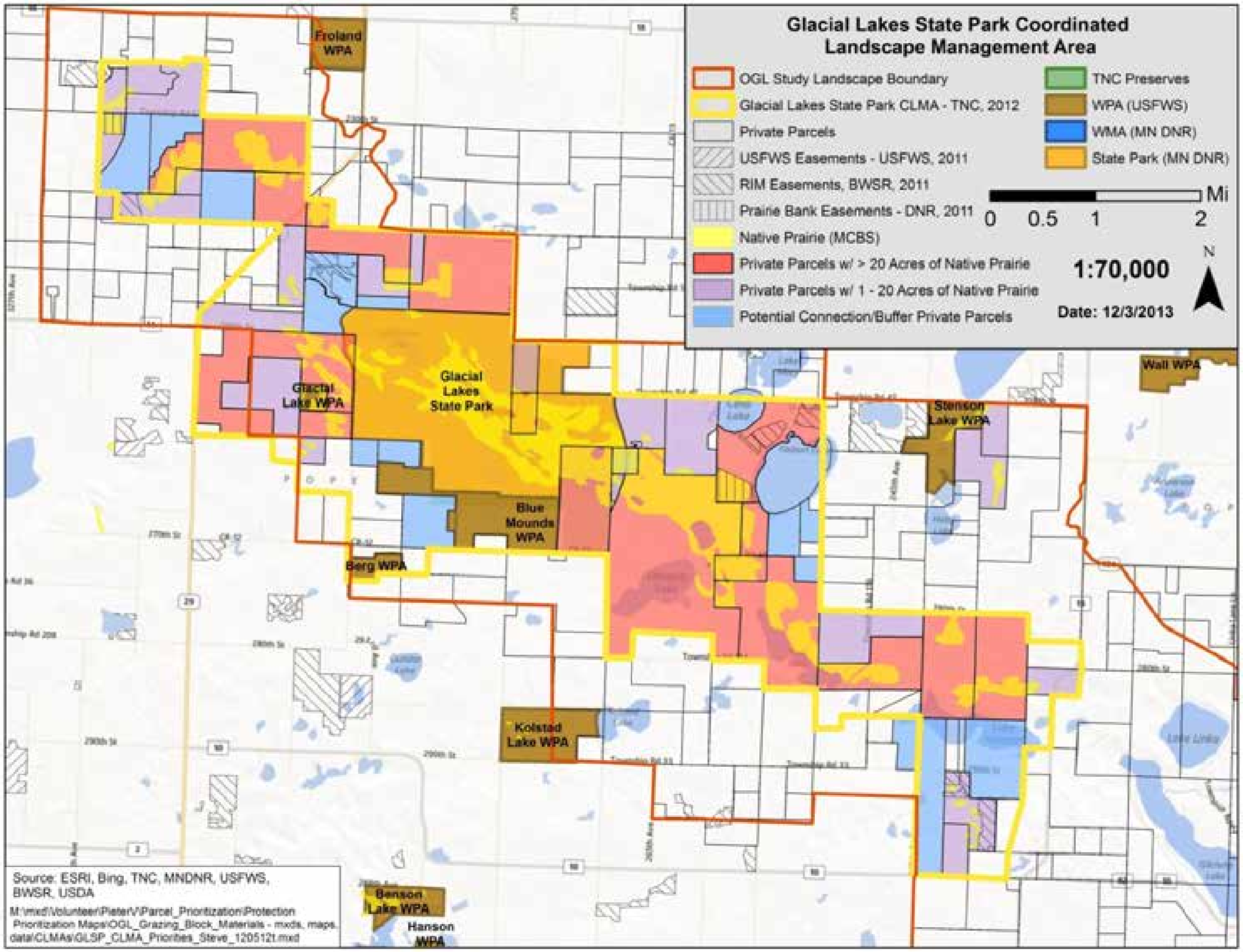

Figure 28. Key conservation parcels in the Glacial Lakes State Park CLMA. GLSP Coordinated Landscape Management Area in the Glacial Lakes landscape with key native prairie parcels.

The last important observation is that the 404 key private tracts are only 21% native prairie (as classified by the Minnesota County Biological Survey) suggesting that there is potentially a large need for restoration of the 79% of the key conservation parcels to high diversity grasslands. These tracts along with the existing conservation lands are the backbone for future grassland restoration and an expanded grass-based agricultural economy in the CLMAs.

b. Land use/land cover on key conservation parcels

Tables 9-13 offer a deeper look at what the starting transition states are on the key parcels within each Coordinated Landscape Management Area. Over 19% (1,739 acres) of the key private conservation parcels at Bluestem Prairie (parcels with > 20 acres of native prairie, 1-20 acres of native prairie, and <1 acres of native prairie but important for buffering and connecting) are currently in cropland. These cropland acres are potential candidates for restoration to diverse

Bluestem Prairie CLMA					
LULC Type	CP with > 20 Acres NP	CP with 1 - 20 Acres NP	Connection CP	Combined CP	Total CLMA
MNP	539.5	95.7	15.9	651.1	2,583.8
WIP	1.3	0.0	0.0	1.3	16.8
MNIG	716.8	80.1	139.0	935.9	4,744.3
IPDG	1,511.8	679.4	1,046.4	3,237.7	7,254.2
ADF	26.1	0.0	24.8	50.9	329.2
Woodland	191.9	15.3	19.6	226.8	747.1
Wetland	524.8	451.4	520.9	1,497.1	5,024.2
Open Water	117.1	34.4	36.9	188.4	381.6
Cropland	444.6	595.1	698.8	1,738.6	5,123.4
Bare and Quarry	91.6	2.3	31.1	125.0	188.1
Outside Study Area	15.6	24.1	340.5	380.3	1,296.3
TOTAL	4,181.0	1,978.0	2,874.0	9,033.0	27,689.0

Table 9. Bluestem Prairie CLMA LULC types on key private conservation parcels. Acres of each land use/land cover type are show for parcels with greater than 20 acres of native prairie (as classified by the MN Biological Survey), tracts with 1-20 acres of native prairie, key connection tracts, and the total CLMA.

grassland habitat. Another potential target for restoration on the key conservation parcels at Bluestem Prairie are the 3,238 acres of IPDG "invasive perennial dominated grasslands" that are mostly smooth brome and reed canary grass pastures and former fields. In comparison, native prairie in good condition (classified as LULC type MNP "mostly native prairie") makes up about 7.2% (651 acres) of the key conservation parcels suggesting that efforts will be needed to increase the native plant species diversity of many of the existing grasslands within the Bluestem Prairie CLMA. One explanation for the low levels of MNP is that only 36.6% of the total native prairie in the CLMA is located on private conservation parcels with 63.4% of the native prairie (including most of the highest quality) on protected conservation land.

Felton Prairie CLMA					
LULC Type	CP with > 20 Acres NP	CP with 1 - 20 Acres NP	Connection CP	Combined CP	Total CLMA
MNP	1,596.5	84.6	4.3	1,685.4	2,071.9
WIP	0.0	0.0	0.0	0.0	0.0
MNIG	1,689.9	292.7	341.0	2,323.6	5,746.1
IPDG	3,565.5	1,012.7	1,222.9	5,801.1	7,666.6
ADF	28.8	1.3	105.1	135.2	456.2
Woodland	134.6	32.6	68.6	235.9	299.2
Wetland	749.8	513.3	509.5	1,772.6	3,307.7
Open Water	159.5	48.7	32.2	240.5	446.8
Cropland	1,315.9	1,226.8	2,249.2	4,791.8	8,528.7
Bare and Quarry	36.0	24.7	18.3	79.0	100.5
Outside Study Area	0.4	42.7	1.8	44.9	1,062.2
TOTAL	9,277.0	3,280.0	4,553.0	17,110.0	29,686.0

Table 10. Felton Prairie CLMA LULC types on key private conservation parcels. Acres of each land use/land cover type are show for parcels with greater than 20 acres of native prairie (as classified by the MN Biological Survey), tracts with 1-20 acres of native prairie, key connection tracts, and the total CLMA.

Compared with Bluestem Prairie, the private conservation parcels at Felton have more cropland with 28% of the total in farm production. Potential restoration of these areas will require a large component of vegetation reconstruction from bare ground. Invasive perennial dominated grasslands IPDG is another large category (33.9%) that will also demand significant restoration. Less intensive restoration will be needed in the "mixed native-invasive grasslands" (13.6%) and "mostly native prairie" (9.9%) LULC types.

Syre Prairie CLMA					
LULC Type	CP with > 20 Acres NP	CP with 1 - 20 Acres NP	Connection CP	Combined CP	Total CLMA
MNP	188.4	1.3	0.0	189.7	194.0
WIP	0.0	0.0	0.0	0.0	0.0
MNIG	546.1	30.0	96.5	672.6	3,506.9
IPDG	2,173.7	799.7	1,384.1	4,357.5	7,419.7
ADF	274.3	44.6	83.2	402.1	571.3
Woodland	82.9	55.6	15.9	154.4	370.6
Wetland	493.9	283.4	398.9	1,176.2	3,535.2
Open Water	11.5	34.0	15.3	60.8	101.7
Cropland	1,714.5	529.7	530.7	2,774.9	8,629.5
Bare and Quarry	6.0	15.3	0.0	21.3	50.5
Outside Study Area	18.6	8.5	1.5	28.6	2,126.6
TOTAL	5,510.0	1,802.0	2,526.0	9,838.0	26,506.0

Table 11. Syre CLMA LULC types on key private conservation parcels. Acres of each land use/land cover type are show for parcels with greater than 20 acres of native prairie (as classified by the MN Biological Survey), tracts with 1-20 acres of native prairie, key connection tracts, and the total CLMA.

If all of the private conservation parcels were restored at Syre Prairie CLMA, it would require the biggest effort of any of the CLMAs studied. Over 72% of the combined private conservation parcels were either cropland (28.2%) or IPDG "invasive perennial dominated grassland (44.3%).

Ordway Prairie CLMA					
LULC Type	**CP with > 20 Acres NP**	**CP with 1 - 20 Acres NP**	**Connection CP**	**Combined CP**	**Total CLMA**
MNP	67.7	9.8	0.0	77.5	77.7
WIP	19.3	2.4	0.0	21.7	21.7
MNIG	1,845.8	1,809.8	1,353.3	5,008.9	9,403.6
IPDG	479.7	411.2	90.5	981.4	1,318.1
ADF	0.0	0.0	0.1	0.1	7.4
Woodland	622.9	1,106.7	634.2	2,363.9	4,828.8
Wetland	913.7	763.1	601.6	2,278.5	5,643.0
Open Water	62.8	171.3	193.7	427.9	1,610.2
Cropland	724.8	567.2	548.1	1,840.1	4,189.6
Bare and Quarry	0.0	0.0	4.0	4.0	5.5
Outside Study Area	142.2	160.4	6.4	309.0	44.5
TOTAL	4,879.0	5,002.0	3,432.0	13,313.0	27,150.0

Table 12. Ordway CLMA LULC types on key private conservation parcels. Acres of each land use/land cover type are show for parcels with greater than 20 acres of native prairie (as classified by the MN Biological Survey), tracts with 1-20 acres of native prairie, key connection tracts, and the total CLMA.

Fitting its location within the Prairie-Forest region and its morainal hill topography, Ordway Prairie CLMA had more wetlands and woodlands than any of the CLMAs in the Agassiz Beach Ridges landscape. It also had surprisingly little area classified as MNP “mostly native prairie” despite the fact that the CLMA was located in an area of relatively high native prairie density. Within the private conservation parcels, the most common LULC type was MNIG “mixed native invasive grassland” at 37.6%.

Glacial Lakes State Park CLMA					
LULC Type	CP with > 20 Acres NP	CP with 1 - 20 Acres NP	Connection CP	Combined CP	Total CLMA
MNP	109.6	4.0	0.0	113.7	149.6
WIP	2.0	2.0	0.0	4.0	4.0
MNIG	2,348.4	693.5	386.7	3,428.6	5,349.2
IPDG	320.5	121.7	36.3	478.5	492.8
ADF	0.0	5.1	1.7	6.9	91.2
Woodland	144.2	100.1	148.5	392.7	646.9
Wetland	436.0	357.7	276.7	1,070.4	1,659.5
Open Water	481.9	17.1	131.5	630.5	1,109.8
Cropland	1,290.1	906.2	705.4	2,901.8	3,485.7
Bare and Quarry	0.0	0.9	0.0	0.9	14.0
Outside Study Area	247.1	73.6	11.2	331.9	44.3
TOTAL	5,380.0	2,282.0	1,698.0	9,360.0	13,047.0

Table 13. Glacial Lakes State Park CLMA LULC types on key private conservation parcels. Acres of each land use/land cover type are show for parcels with greater than 20 acres of native prairie (as classified by the MN Biological Survey), tracts with 1-20 acres of native prairie, key connection tracts, and the total CLMA.

In the past, nearly all of the conservation work Glacial Lakes SP CLMA has taken place within Glacial Lakes State Park. However, only about 30% of the native prairie in the CLMA is within the park, the rest in private conservation parcels. The most commonly found LULC type on the key private conservation parcels was MNIG "mixed native-invasive grassland" indicating that the grasslands there are degraded somewhat from the MNP "mostly native prairie" but they still retain a recognizable native plant component. Like the Ordway Prairie, the other CLMA in the Glacial Lakes landscape, there is a sizable component of wetlands (11.4%), and open water (6.7%) on the private conservation parcels. Unlike Ordway, there is a large amount of cropland (31.0%) - more even than in the CLMAs of the Agassiz Beach Ridges landscape.

c. Current LULC types on lands classified as native prairie by the MBS

In CLMAs (chosen because of their high relative densities of native prairie) there was surprising little area classified as the LULC type "mostly native prairie". In the combined CLMA in each landscape only 18.9 % in the Agassiz Beach Ridges CLMAs and 11.9% Glacial Lakes CLMAs were designated native prairie by MCBS when they were originally surveyed. For the key private conservation parcels the ABR percentage was somewhat higher at 24.8% and the GL percentage was 13.6 percent. When the same areas were resurveyed as part of the land use/land cover work of this study 20-30 years later, the percentage of the combined CLMAs in the ABR landscape classified as LULC type "mostly native prairie" was 5.9% and even less at 0.5% for the GL landscape. The same numbers for the combined private conservation parcels were 7.0% for ABR and 0.8% for GL.

The surprisingly low numbers for the high quality "mostly native prairie" type in an area of relatively high native prairie density raises the question of what are the current LULC types for the lands that were originally classified as native prairie in 1980s for the Agassiz Beach Ridges area and in 1990s for the Glacial Lakes area.

	Native Prairie Area of ABR Landscape				Native Prairie Area of GL Landscape			
LULC Type	Total Combined CLMAs		Private Conservation Parcels in CLMAs		Total Combined CLMAs		Private Conservation Parcels in CLMAs	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
MNP	4,364.3	27.9%	2,247.4	25.2%	181.0	3.7%	152.9	4.9%
WIP	14.4	0.1%	0.8	0.0%	20.4	0.4%	20.4	0.7%
MNIG	5,650.9	36.1%	2,223.1	24.9%	3,358.3	69.4%	1,943.5	62.8%
IPDG	4,691.3	30.0%	3,948.6	44.2%	967.6	20.0%	765.8	24.7%
ADF	10.9	0.1%	6.1	0.1%	0.0	0.0%	0.0	0.0%
Woodland	136.3	0.9%	68.3	0.8%	63.8	1.3%	44.7	1.4%
Wetland	548.3	3.5%	249.3	2.8%	148.4	3.1%	80.2	2.6%
Open Water	13.8	0.1%	12.4	0.1%	38.0	0.8%	28.4	0.9%
Cropland	224.7	1.4%	167.7	1.9%	60.3	1.2%	58.7	1.9%
Disturbed	2.5	0.0%	1.9	0.0%	0.0	0.0%	0.0	0.0%
TOTAL	15,657.5	100.0%	8,925.7	100.0%	4,837.8	100.0%	3,094.6	100.0%

Table 14. LULC types on land designated as native prairie. Native prairie was identified by the Minnesota Biological Survey in the two study landscapes but in this study was classified in different land use/land cover types. Acres and percentage of each LULC type are shown for the native prairie areas at the Agassiz Beach Ridges and Glacial Lakes study areas.

The fate of native prairie in the CLMAs and on key conservation parcels since they were surveyed by MCBS varied between the two landscape study areas. In the Agassiz Beach Ridges, about a quarter has remained as mostly native prairie (27.9% in the entire CLMA and 25.2% on the private conservation parcels) whereas very little is currently classified as high quality prairie in the Glacial Lakes landscape (3.7% for the CLMAs and 4.9% for the conservation parcels). This suggests that at least 75% at ABR and 95% at GL of the MCBS surveyed native prairie has degraded or been destroyed although it is unclear how much of what is now classified as mixed native-invasive grassland would have been classified as native prairie in the original surveys. What is of interest is how the different CLMAs vary and how that corresponds with past prairie management. The ratio of mostly native prairie to mixed native-invasive prairie to invasive perennial dominated grassland or MNP:MNIG:IPDG is instructive. This ratio applies to all the native prairie in the CLMA on both protected conservation lands and private lands.

CLMA	MNP		MNIG		IPDG
Bluestem Prairie	2.6	:	1.9	:	1.0
Felton Prairie	1.0	:	1.4	:	1.4
Syre Prairie	1.0	:	8.3	:	7.3
Ordway Prairie	1.0	:	29.0	:	10.3
Glacial Lakes SP	1.0	:	13.1	:	2.7

Only Bluestem Prairie CLMA has maintained more of the lands designated as native prairie in a current LULC "mostly native prairie" type. A large part of the credit for this relative success is the intensive conservation activities that have taken place in the Bluestem/Buffalo River State Park area over the last 30 years. This area has been a focus of both The Nature Conservancy and the Minnesota DNR for prairie protection and management including regular prescribed fires on a substantial part of the area. Felton Prairie CLMA has probably had the second most intense prairie management history but a smaller percentage of the native prairie is in conservation land status (and thus included in the management).

The other three CLMAs have had a more recent and less intense history of prairie management and protection. In all three cases, far more of the land designated as native prairie is currently found in the MNIG "mixed native invasive grassland" type (8.3 to 29 times more). The Ordway Prairie CLMA has the highest amount of degradation with not only 29 times more in MNIG type but also 10.3 times more in the even more degraded type of IPDG "invasive perennial dominated grassland". Although there has been extensive prairie protection and an increase in prairie management in the last 10 years, compared to the Bluestem Prairie area work has been relatively recent. It will be interesting to see if the increased level of conservation work can reclaim the areas designated as native prairie by driving down the amount of the European pasture grasses to allow prairie forbs and native grasses to once again dominate.

D. Conclusions

The Minnesota Prairie Conservation Plan has two overriding goals. The first is to protect all remaining native prairie in the state and second to create functioning prairie systems at the places in Minnesota where there are high concentrations of native prairies, wetlands, and other grasslands. The conservation planning approach described in this chapter addresses these two goals within the Agassiz Beach Ridges and Glacial Lakes landscapes. Within this chapter we identified the places in Minnesota in general and within the study landscapes specifically (Coordinated Landscape Management Areas or CLMAs) that have the highest density of native prairie and which we suggest are the places that can be brought back to functioning prairie systems most readily. The second part of this planning effort was to identify what parcels of land are needed to protect all native prairie within the CLMAs. We also identified parcels needed to buffer and reconnect the prairie parcels thus helping to define the area that would be essential to recreate functioning prairie systems. Together these parcels (key private conservation parcels) are high priority for conservation activities that would not only protect and enhance the native prairie but also restore the surrounding lands to diverse grassland and wetland systems that complement the native prairie.

Although the Minnesota Prairie Conservation Plan is focused on native prairie, it also is concerned with the environmental wellbeing of the broader Prairie Region of western and southern Minnesota. The Prairie Plan sets goals for grassland and wetland protection, restoration, and management throughout the agricultural matrix that surrounds prairie core areas. This agricultural matrix covers over 21.6 million acres of the 24.9 million acres in the region. Conservation in the agricultural matrix, or for that matter the corridors and area outside the CLMAs within the prairie cores, must and will be multi-factorial. That is, conservation work will try to balance many values simultaneously including ecological services and wildlife. An approach that optimizes multiple goals is needed and that is the approach undertaken in Chapter 10 to prioritize lands beyond the CLMAs.

The analysis of the five CLMAs identified in this chapter revealed that each was different in its current land use/land cover, but several general themes emerged:

1. Considerable cropland exists (13.8 – 31.0%) within the key private conservation parcels generally and even in the subset of parcels with over 20 acres of native prairie (10.6 – 31.1%). This cropland is a key start state for potential restoration using the methods described in Chapter 7.
2. At the opposite end of the spectrum, more prairie is in relatively good condition on key private conservation parcels in the Agassiz Beach Ridges CLMAs than in the Glacial Lakes CLMAs. LULC type MNP "mostly native prairie" varies from 1.9 – 10.4% in ABR but only 0.6% and 1.2% in GL within areas classified as native prairie by the MBS.
3. The most common LULC type on key private conservation parcels in the Agassiz Beach Ridges landscape is IPDG "invasive perennial dominated grassland" (33.9% – 44.3% whereas the most common type in the Glacial Lakes landscape is MNIG "mixed native invasive grassland" (36.6% and 37.6%).

4. Where grasslands fall in the declining quality spectrum of MNP to MNIG to IPDG depends of the past conservation history of the CLMA. The Agassiz Beach Ridges CLMAs have a longer history of prairie protection and management that has in turn resulted in more protected native prairie but leaving the remaining key conservation parcels with more cropland and former cropland that is now IPDG “invasive perennial dominated grassland”.

Chapter 5: Measures of Success and Monitoring *by Meredith Cornett, Marissa Ahlering, and Phil Gerla*

The Nature Conservancy

The success of any plan rests on knowing what outcomes are desired. These desired outcomes should be agreed upon in advance by all parties working on conservation in the area. The outcomes also need to be described with sufficient precision that progress can be measured and it is clear when success is achieved. The desired outcomes can be modified as the plan is implemented and new knowledge and experience are gained, but there should be widespread agreement when the outcomes are modified. In this project, the measures and monitoring were developed for the desired conservation outcomes for the project and landscape as a whole and are not specific to any one piece (e.g., restoration plans, economic analysis, etc.). As such, these outcomes and indicators are broad in scope and attempt to capture the impacts of conservation activity at a scale larger than any one site-level restoration project.

To achieve conservation success at scales large enough to be meaningful to support diverse and functioning ecosystems, the conservation community needs to integrate with private landowners. The goal of this project is to design a framework that achieves conservation success while incorporating and sustaining the economic needs of local communities and private landowners. Although we need to incorporate private landowners and their economic considerations in our conservation plans, we still need to be sure our actions and the actions we promote across the landscape are having the desired impacts on the ecological communities. The scale of this framework and resulting on-the-ground projects is on the order of tens of thousands of acres. While this is crucial for conservation, it makes measuring success challenging. We need methods that will measure the ecological effectiveness of our actions, while also being efficient enough to be implemented across thousands of acres. The ultimate goal of these methods is to provide an effective but rapid assessment of progress towards success for each indicator and target. Throughout this process, we have tried to balance activity-oriented measures, such as acres protected, with ecosystem level measures, such as population size of greater prairie chickens (*Tympanuchus cupido*).

A. Conservation Targets

Before determining the desired outcomes for the project, we first identified which biological and/or ecological parts of the prairie ecosystem we were targeting. The conservation targets selected for this project come from Conservation Action Plans (The Nature Conservancy 2012a, 2012b) developed for each landscape by The Nature Conservancy and partners. While both the Ordway Glacial Lakes and the Agassiz Beach Ridges landscapes are tallgrass prairie, there are some important ecological differences between the landscapes, and these differences resulted in different targets for each landscape. The conservation targets are described separately for each landscape.

1. Agassiz Beach Ridges

The conservation targets of the ABR landscape include different components of the Prairie/Wetland system as a whole. We focused on three fine-scale system-based conservation targets, and we considered two taxa as targets from a connectivity perspective.

***Agassiz Interbeach Prairie Complex* (AIPC)** is a fine-scale target occurring as small patches embedded within the large-scale Prairie/Wetland System mosaic. This mosaic of plant communities is unique to the ABR landscape and should be managed and protected with this in mind. In light of climate change, management of the AIPC to allow for community migration will help maintain fine-scale biodiversity.

Dry prairie & oak savannas/barrens face different threats than mesic and wet prairies (the threat is primarily gravel mining rather than agriculture). These systems are also becoming increasingly uncommon in the ABR landscape. There are also reasons to believe these communities may be more resilient to climate change than many systems.

Calcareous fens generally lie at the slope break between the relict beach ridges of Glacial Lake Agassiz and the historical lake bed itself. The subsurface stratigraphy of the Felton and Pembina areas has relatively impermeable strata rising to the surface, forcing groundwater toward the surface where it discharges through the fen.

Grassland dependent birds are a conservation target in the ABR landscape and were initially a major reason why The Nature Conservancy focused its efforts in the ABR area. Fifteen species were chosen from both wetland and upland dependent species to act as surrogates for the entire suite of grassland and wetland bird species for the region (The Nature Conservancy 2012b). Grassland birds are declining faster than any other guild of birds in North America (Sauer and Link 2011). In the current project, grassland dependent birds are one of the targets for our connectivity goals with particular emphasis on the greater prairie chicken.

Prairie obligate butterflies are not specifically called out in the ABR Conservation Action Plan (The Nature Conservancy 2012b). The target for the ABR landscape in that plan is endemic prairie invertebrates. To narrow the scope of this target, we used the more specific nested target called out in the Glacial Lakes landscape, prairie obligate butterflies (see below). Similar to the grassland dependent birds, this target is also used to define and evaluate the connectivity goals for the project. Butterflies and birds represent opposite ends of the spectrum when it comes to mobility and needs for connectivity.

2. Glacial Lakes

In the GL landscape, we focused on three system-based conservation targets and one taxa-based target that overlap with the taxa targets for the ABR.

Fire dependent communities include nearly all of the upland vegetation types originally found in the area with the exception of true forests. The types ranged from prairies to savannas to open woodlands. All of these communities were influenced by and depended on the regular return of prairie fires. Without fire, all of these communities would have grown up into oak-elm-basswood forests. Patches that burned frequently enough to prevent the development of a closed-canopy forest but not as frequently as needed to maintain treeless prairies, developed into scrubby or bushy woodland communities (MN DNR 2005).

Surface water wetlands comprise most of the wetlands in the Glacial Lakes area and are fed by rain and snow runoff. At one time, wet and wet-mesic prairies that were flooded for brief periods in the spring and after heavy rain events were relatively common. Now nearly all of these seasonal or temporary wetlands have been drained and plowed. The surface water wetlands that remain tend to be at the wetter end of the wet-mesic to permanent wetland moisture gradient.

Ground water wetlands develop where mineral rich waters flow or seep from below ground. The type of ground water wetland depends on the type of rock or geologic deposits the water flows through, the substrate at the surface, and the amount of ground versus surface water that impacts the area at different times. Complete descriptions of all the types of ground-water wetlands and the environmental conditions associated with them have been have been developed by the Minnesota County Biological Survey (MN DNR 2005). All of the ground-water wetlands in the Glacial Lakes area tend to be smaller features in the landscape, usually less than just a few acres. As such they tend to be embedded in larger natural communities and will be affected by whatever conservation actions take place within the larger matrix.

Prairie obligate butterflies are among the prairie animals most sensitive to habitat conversion, fragmentation, and disturbance. The Poweshiek (*Oarisma poweshiek*), Dakota (*Hesperia dacotae*), Arogos (*Atrytone arogos*), and Pawnee (*Hesperia leonardus pawnee*) skippers all feed on native grasses as caterpillars while the regal fritillary's (*Speyeria idalia*) larval host plants are violets. All these species are now rare, but until recently could be found reliably on many large prairies in the Glacial Lakes Area (Selby 2005). In the last ten years, few if any of these species have been found. There is fear that the Poweshiek skipper may even be extirpated from the entire state of Minnesota.

B. Conservation Outcomes and Measures

We defined the ultimate outcomes we would like to see achieved in each landscape by 2020. These outcomes are based on goals set both by TNC's Conservation Action Plans and the Minnesota Prairie Conservation Plan. The goal of this project is to develop both restoration plans and economic feasibility analyses to help us achieve these goals. For each of the desired outcomes, we have developed indicators and methods of evaluating these indicators. Taken as a whole, these outcomes and indicators are meant to serve as measures of conservation success across each landscape. Below we outline these outcomes, indicators and methods for both landscapes. Where possible we attempted to identify where these targets and outcomes overlap with the state and transition model developed in the restoration plans (see Chapter 7). For brevity, several start states are hereafter referred to by their abbreviations: woody invaded prairie (WIP), mixed native/invasive grassland (MNIG), invasive perennial dominated grassland (IPDG), and annual dominated field (ADF).

1. Agassiz Beach Ridges

The following are the stated outcomes and current indicators chosen for the Agassiz Beach Ridges landscape. Below each indicator is the proposed assessment method (Appendix 2 for method details).

Permanently protect the last remaining unprotected 7,270 acres of native prairie (roughly doubling the number of acres of native prairie under protection by 2020 (8,253 acres currently protected; Prairie Plan Table 2, Table 3).

<u>Measure</u>: Number of acres protected
<u>Method</u>: Every-other-year GIS analysis of conservation status of native prairies identified by the Minnesota Biological Survey (MBS 2010)

Maintain stable or increasing populations (number and size of populations) of the western prairie fringed orchid, <u>Platanthera praeclara</u> (Prairie Plan Ecosystem Measure 8; ABR Conservation Action Plan)

<u>Method</u>: Inventories of WPFO populations using standard protocols

Permanently protect an additional 3,155 acres of wetland habitat (to address the protected wetlands shortfall by 2020; Prairie Plan Table 2). Priority should be given to lands that optimize protection of important calcareous fens and their ground watersheds. Within these acres we are assuming that no major restoration is required on wetlands protected.

Measure a: Number of acres Utility Prairie, IPDG, and MNIG protected
Measure b: Number of acres Conservation Meadow, Utility Meadow, and Marsh protected
Method a & b: Every-other-year GIS analysis for conservation lands/protection status

Reconstruct/restore 4,764 acres of Agassiz Inter-beach Prairie Complex wetlands (to address the wetland habitat shortfall of the ABR core areas; Prairie Plan Table 2). The category of wetland includes the continuum from open-water/marsh to wet prairies and fens. Restoration should be done in conjunction with native prairie and western fringed orchid protection above.

Transitions facilitated: Start States: Cropland, ADF, IPDG, or MNIG to End States: Utility Meadow, Utility Prairie, Conservation Meadow, or Conservation Prairie (Figure 13)

Measure: Number of basins and acres restored
Method: For low-diversity restoration, every-other-year GIS analysis for number of acres restored, and for high-diversity restoration, Grassland Monitoring Team Protocol (Vacek et al. 2012) or Extensive Assessment Protocol for Large-Scale Restorations.

Reduce woody species density and cover across all conservation prairie areas (For priority areas, trees are either absent or with a few shrub-like grubs of bur oak and/or quaking aspen; shrub layer is sparse to interrupted ranging from 5% to 75%**;** Ecological Land Classification Program 2005; ABR Conservation Action Plan.)

Transitions facilitated: Start State: WIP to End State: Conservation Prairie (Figure 13)

Measure: Number of acres treated/cut
Method: Digital Aerial Photo Analysis - before-and-after cover in treatment areas

Measure: Number of invaded acres in landscape
Method: Remote Sensing/Satellite Imagery to measure woody cover across landscape

***Native vegetation dominates conservation prairie* (>75% cover across approximately 16,000 acres of remnants) and *constitutes 25% to 50% of vegetation for Utility Prairie*;** Prairie Plan Ecosystem Measure 9; ABR Conservation Action Plan).

Transitions facilitated: Start States: Cropland, ADF, IPDG, or MNIG to End States: Utility Meadow, Utility Prairie, Conservation Meadow, or Conservation Prairie (Figure 13)

Measure: Proportion of field classified as predominantly native with increasing or stable trend toward native-dominated
Method: Grassland Monitoring Team Protocol (Vacek et al. 2012)

Stable or increasing populations of prairie obligate butterflies (e.g., Dakota skipper, Poweshiek skipperling, and regal fritillary detected on >50% of the Conservation Prairie acres; (Prairie Plan Ecosystem Measure 7, ABR Conservation Action Plan).

Measure: Number of individuals of each of 2-3 species of interest
Method: Pollard Counts (Pollard 1977)

Ensure 90% compatible land use within the recharge zones of calcareous fens (Prairie Plan Ecosystem Measure 9; ABR Conservation Action Plan).

Measure: Percent compatible land use/cover in the infiltration/recharge zone for each important calcareous fen recharge zone
Method: GIS assessment of land cover classes (states) on a recharge zone scale

Maintain diversity of indicator species for calcareous fens. (Prairie Plan Ecosystem Measure 9; ABR Conservation Action Plan).

Measure: An average of at least 50% of prairie extremely rich fen OPp93 (MN DNR 2005) indicator species should occur in each fen occurrence and native fen species constitute at least 25% of total wetland vegetation cover, which in turn is also native-dominated (75%).
Method: Fen plant inventories

Stable or increasing populations of greater prairie chickens (Prairie Plan Ecosystem Measure 2; ABR Conservation Action Plan).

Measure: Greater prairie chicken population size
Method: Annual Lek counts

2. Glacial Lakes

The following are the stated outcomes and current indicators chosen for the Glacial Lakes landscape. Below each indicator is the proposed assessment method (Appendix 2 for method details).

Permanently protect the last remaining 4,410 acres of native prairie roughly tripling the number of acres of native prairie under protection (2,813 acres currently protected) by 2020; (Prairie Plan Table 3). Assumes no major restoration required on the new lands protected.

Measure: Number of acres of Conservation Prairie protected

Method: Every-other-year GIS analysis for conservation lands/protection status for Conservation Prairie

Permanently protect integrated grassland and wetland habitats (Prairie Plan Table 2).

Transitions facilitated: Start States: IPDG or MNIG to End States: Conservation Meadow or Marsh (Figure 13)

Measure a: Number of acres of Utility Prairie, IPDG, and MNIG protected. Protect an additional 18,411 acres of grassland beyond the native prairie protected above through fee or permanent easement to address the protected grasslands shortfall (Prairie Plan Table 3). These acres may need restoration/enhancement depending on the state and desired use.)
Measure b: Number of acres of Conservation Meadow, Utility Meadow, and Marsh protected. Protect an additional 8,760 acres of wetland through fee or permanent easement to address the protected wetlands shortfall (Prairie Plan Table 3). The category of wetland includes the continuum from open-water/marsh to wet prairies and fens. Assumes no major restoration required on wetlands protected.
Method (a & b): GIS analysis biennially with most recent conservation lands ownership information for cumulative running totals.

Reconstruct/restore 5,137 acres of grassland to reach a full 40% of grassland habitat (To be determined what proportion in conservation prairie, utility prairie, and others are needed or desirable. Seek opportunities to do so in conjunction with 1 and 2 above.)

Transitions facilitated: Start States Cropland and ADF to End States: Conservation Meadow or Marsh (Figure 13)

Measure: Number and location of new acres prepped and planted
Method: A simple count of the number of acres restored

Measure: Composition of vegetation
Method: (Low Diversity Planting): Every-other-year GIS analysis for number of acres restored
Method (High Diversity Planting): Grassland Monitoring Protocol (Vacek et al. 2012) or Extensive Assessment Protocol for Large-Scale Restorations.

Remove mature woody vegetation and canopy trees for woody-invaded sites (GL Conservation Action Plan).

Transitions facilitated: Start State WIP to End States: Conservation Meadow, Conservation Prairie, or Oak Savanna as appropriate (Figure 13)

Measure: Juniper canopy cover in priority areas
Method: Digital aerial photo analysis of before-and-after cover in focused treatment areas

Measure: % Juniper cover in the landscape
Method: Lidar/SPOT/Landsat imagery analysis to measure juniper cover across landscape

Native vegetation dominates native Conservation Prairie with >75% cover on the 7,223 acres of native prairie and constitutes 25% to 50% of vegetation for Utility Prairie (Prairie Plan Ecosystem Measure 9, GL Conservation Action Plan).

Transitions facilitated: Start States: Cropland, ADF, IPDG, or MNIG to End States: Utility Meadow, Utility Prairie, Conservation Meadow, Conservation Prairie, or Marsh (Figure 13)

Measure: Proportion of site classified as predominantly native
Method: Grassland Monitoring Protocol (Vacek et al. 2012)

Stable or increasing populations of prairie obligate butterflies (e.g., Dakota skipper, Poweshiek skipperling, and regal fritillary detected on >50% of the Conservation Prairie acres (Prairie Plan Ecosystem Measure 7; GL Conservation Action Plan).

Measure: Number of individuals of each of 2-3 species of interest
Method: Pollard Counts (Pollard 1977)

Ensure key lake basins (to be determined but see Figure 29) are in 90% compatible land use/cover. Compatible land use includes any of seven end states including conservation prairie, conservation meadow, utility prairie, utility meadow, oak savanna, woodland, or wetlands.

Measure: Percent of each priority basin in compatible land use/cover
Method: Assessment of land cover classes (states) on a basin scale
Increase the clarity of 12 shallow lakes (about 10% of the shallow lakes in the landscape) by 33% over the next 10 years (Prairie Plan Ecosystem Measure 10, GL Conservation Action Plan).

Measure: Water clarity
Method: Secchi disc or transparency tube readings

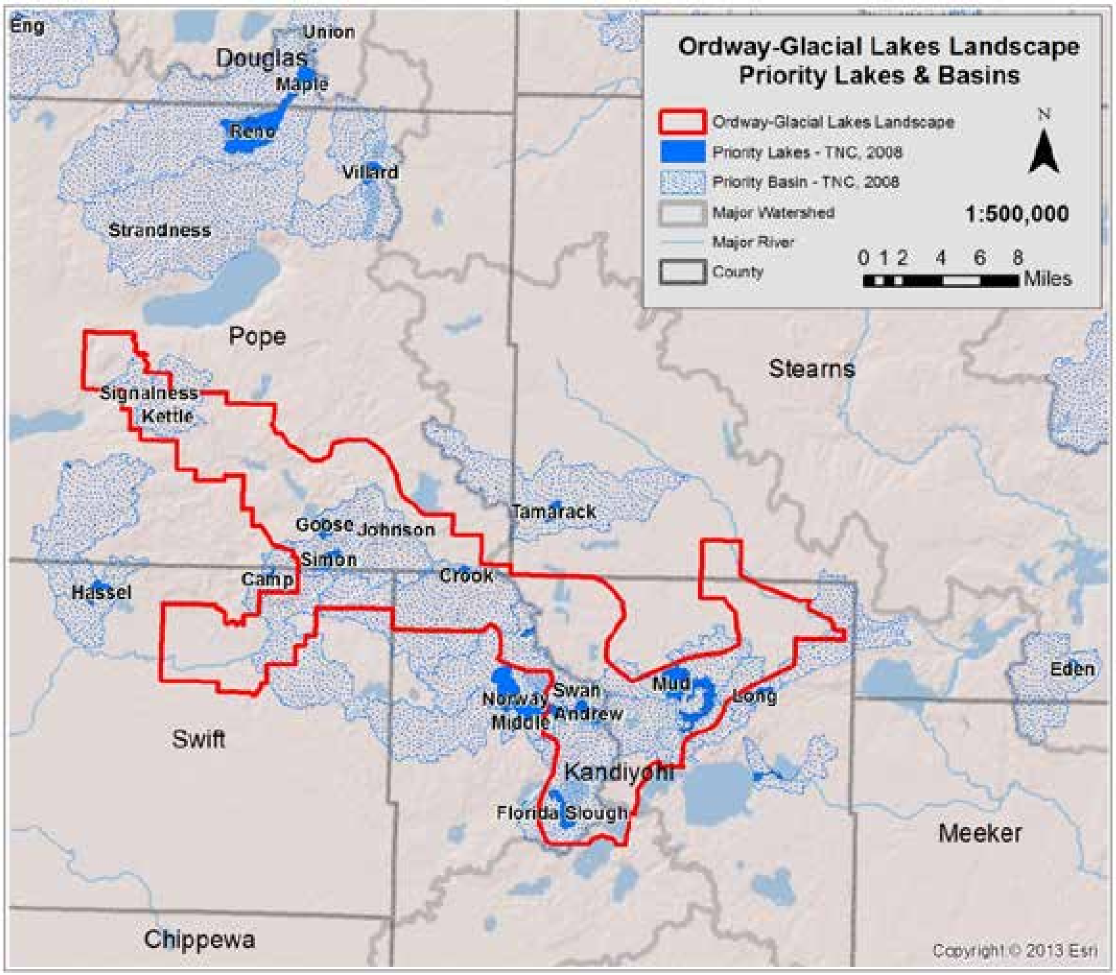

Figure 29. Priority lakes and basins in the Glacial Lakes landscape. Map shows the priority basins in stippled blue and the priority lakes in dark blue (Blann and Cornett 2008).

Chapter 6: Social Analysis *by Ryan Atwell*

A. Background

1. The challenge of conservation across privately owned working landscapes

Currently, high crop and land prices in the midst of an economic downturn create challenges for conservation of prairies, wetlands, and grassland throughout southern and western Minnesota. Long-term changes in technology, U.S. farm policy, and international markets – including federal subsidies/assistance for commodity production, crop insurance, and corn-based ethanol – are interacting to encourage increased conversion of grassland to corn and soybeans throughout the north-central U.S. (Claassen et al. 2011, Rashford et al. 2011, Wallander et al. 2011). Because return on many other economic investments is lower than normal, regional to global interest in cropland as an investment is high throughout the Corn Belt region of the Midwestern U.S. Simultaneously, public and private funding of conservation initiatives faces economic and political challenges, leading to a time of competitive disadvantage for conservation programs, easements, and land acquisitions. As a result, grasslands – including remnant prairies, pastures, and land formerly enrolled in initiatives such as the Conservation Reserve Program (CRP) – are being plowed and planted to cropland at a rapid rate (Figure 30).

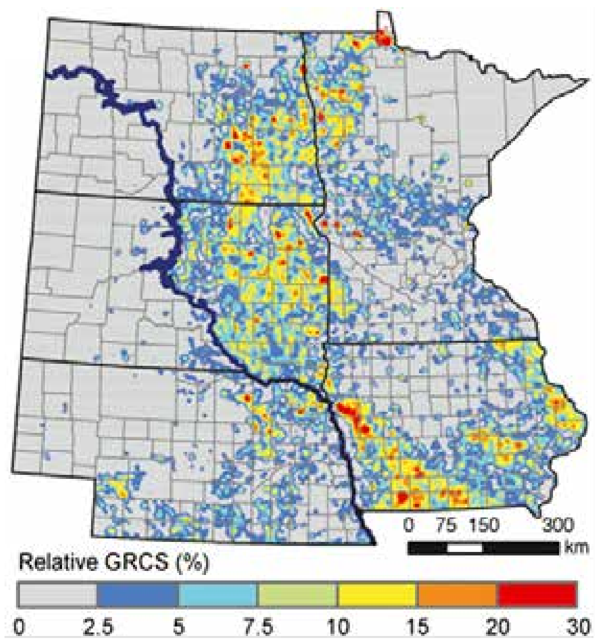

Figure 30. Loss of grassland to corn and soybeans. The relative rate of change from grassland in 2006 to corn and soybeans in 2011 (Wright and Wimberly 2013a).

In response to these challenges, the ten conservation agencies and organizations drafting the Minnesota Prairie Plan intend to leverage an estimated $3.5 billion to acquire or protect 2.2 million acres, creating a network of connected native and restored prairies, grasslands, and wetlands throughout the western part of the state. About two-thirds of these funds will come from federal and state agricultural conservation programs in order to leverage private investment on private lands. Because such programs are available to all agricultural producers across the state, roughly one-third of the land protection projected in the Minnesota Prairie Plan will occur within Prairie Core landscapes (see Figure 3, page 3) and two-thirds of the protected acreage will be more widely distributed.

Consequently, implementation of the Minnesota Prairie Plan is not only focused on acquisition and easement of remaining remnant prairie and wetland parcels, but also includes the ambitious goal of restoring landscape-level matrices of prairies, wetlands, and grasslands that are intended to function as an interconnected ecosystem. The conservation value, but also the economic, political, and socio-cultural challenges, of re-integrating perennial cover – in the form of pasture, wetlands, buffer strips, cropping systems, etc. – in a coordinated manner throughout working row-crop agricultural landscapes has been widely documented (Schulte et al. 2006, Nassauer et al. 2007, Atwell et al. 2009a, 2009b, 2010, Atwell et al. 2011). However, most of this research has been conducted in landscapes heavily dominated by row crop agriculture (>80% of total land use), and with low amounts of perennial cover (<10% of total land use).

In this project, analyses were focused around two landscapes deemed to have among the most contiguous networks of prairie, wetland, and grassland in Minnesota – the Agassiz Beach Ridges (ABR) and the Glacial Lakes (GL) landscapes. Due to the unique geologic history, soil types, and topography of these core prairie landscapes further described in Chapter 2, each is currently comprised of 50-60% perennial land cover, including native and restored prairies, wetlands, working grasslands used for pasture and hay, and land in conservation programs, such as the Conservation Reserve Program (CRP). These core areas are surrounded by landscapes more typical of the Corn Belt, with a higher density of row crop agriculture and lower density of perennial cover.

In order to complement the broad focus of the Minnesota Prairie Plan, the research in this project was designed to better understand and develop strategies for restoration and protection of high quality prairies, as well as conservation of working grassland landscapes – both within and surrounding the core landscapes (ABR and GL). The social landscape analysis component of this project focused primarily on better understanding stakeholder perspectives related to grassland conservation on privately owned working lands. A secondary focus was to learn more about the social feasibility of a suite of conservation options (land use transitions) that could be implemented on privately owned parcels of particular conservation value within core landscapes. Throughout these landscapes, we were interested in understanding the tradeoffs in farmers', landowners', and local leaders' values and decisions as they balance production of agricultural goods, economic return, conservation, small-town and rural socio-economic vitality, and other community, family, and personal considerations.

2. Incorporating stakeholder perspectives in social-ecological system models

The agro-ecosystems of focus in this study are facing increasing societal pressure to produce multiple outcomes including food and fiber, energy, sustainable rural livelihoods, recreation and aesthetic opportunities, water quality, flood control, and species conservation. Optimally managing these multifunctional agricultural landscapes is a dynamic and complex endeavor that involves understanding and evaluating tradeoffs related to variable agricultural, ecological, socio-cultural, economic, and political processes (Liu et al. 2007, Jordan and Warner 2010, Atwell et al. 2011). As such, the different project components of this study seek to integrate conservation research, models, and strategy development to most effectively manage these systems by optimizing combinations of desired outcomes.

Resilience theory in ecology proposes that, despite the underlying complexity inherent in such ‘social-ecological systems,’ key processes, thresholds, and feedback loops are often controlled by a handful of three to six key limiting variables (Walker et al. 2006). In many cases, some of these limiting variables are difficult to quantify because they involve human decision-making processes or cultural and political factors. Conservation scientists often neglect consideration of these variables, resulting in models that fail to illuminate the most pressing questions and meet timely needs of stakeholders, conservation managers, and decision-makers. Because our study is focused on landscapes comprised primarily of privately owned working agricultural lands, incorporating perspectives of rural stakeholders is particularly important. Prioritizing the incorporation of key socio-cultural and political variables, and stakeholders’ perspectives, in conservation strategy development presents new challenges for conservation efforts.

To address this challenge, we developed and implemented an approach called ‘social landscape analysis’ that utilizes ethnographic techniques, depth interviews, and qualitative and systems analyses to incorporate the socio-cultural, economic, and political perspectives of stakeholders into conservation strategy development. Social landscape analysis complements, builds on, provides further information for, and identifies ranges and limits of plausible variability for ecological, economic, and optimization models (Figure 31). This project component informs further development and implementation of the Minnesota Prairie Plan in several ways (Table 15).

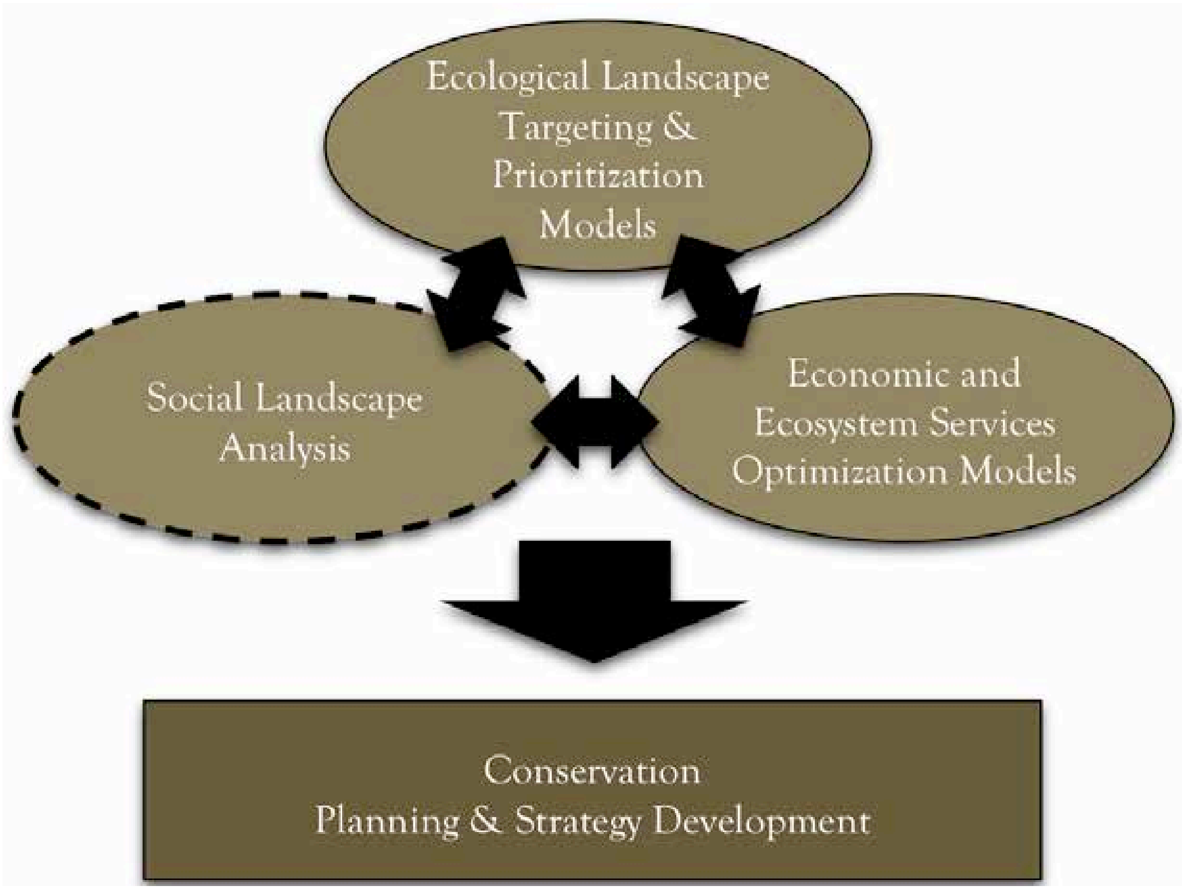

Figure 31. Social landscape analysis. An approach used to determine spatially explicit conservation priorities by both building upon and further refining ecological, economic, and ecosystem services models. Initial ecological and economic data can inform which stakeholder perspectives are most crucial to understand. In turn, as stakeholders' perspectives are elucidated through social landscape analysis, suites of plausible variability are honed, allowing models to more parsimoniously and accurately focus on parameters and possible outcomes that are most relevant and realistic.

Objectives of Social Landscape Analysis	
Where?	• Identify lands most & least culturally and politically feasible to protect at patch/field, landscape/community, and regional/institutional scales. • Understand who brokers and makes conservation decisions on priority parcels. • Analyze political and cultural factors and develop conservation strategies unique to the social, cultural, and political particularities of the ABR and OGL landscapes.
How?	• Investigate what rural stakeholders – including farmers, land owners, local opinion leaders, conservation personnel, and county decision makers – most value about their landscapes. • Identify cultural, economic, and political strategies most likely to promote cost-effective protection and expansion of prairie. • Identify leverage points to achieve desired outcomes. • Integrate stakeholder innovation into future conservation strategies.
At what costs, and with what benefits?	• Analyze social, cultural, economic, political, and strategic ***barriers to*** and ***opportunities for*** protection and expansion of grassland. • Identify key tradeoffs in decision making processes regarding land use transitions • Investigate the value of ecosystem services to rural stakeholders, and probe the tradeoffs involved in adoption of practices that would hinder or promote these services. • Inform policy and management tradeoffs about how to invest limited conservation dollars and resources.

Table 15. Objectives of Social Landscape Analysis. Social Landscape Analysis was used to further the Minnesota Prairie Plan's goal of conserving and enhancing networks of prairie, wetlands, and grassland across working agricultural landscapes across southern and western Minnesota in the following ways.

3. The science of conservation decision-making among rural stakeholders

The challenge of implementing broad-scale restoration goals across privately owned, working landscapes involves coordinating the decisions of large numbers of farmers, landowners, and other decision-makers. Much research has been done to try and better understand and leverage how landowner, farmer, and collective rural decisions are made. Here we provide a brief summary of the research that is most relevant to the social landscape analysis approach implemented in this study.

Flora's model of social influence applied to agroecosystem management. Rural sociologist Cornelia Flora (Flora and Flora 2013) developed a model to explain how different small towns do or do not take collective control of common pool resources(Figure 32). Her model suggests that collective decision-making is a multi-faceted and interactive process that can be explained only partially by any one type of social influence, but can be better understood through the interactions among different types of social influence. For example, individual values exert comparably stronger forces on decision-making than do top-down pressures such as regulation or economic cost-benefit tradeoffs. However, individual values often change very slowly and vary a great deal among individuals. If we think of Flora's model as an iceberg, individual values lie just below the water line and are difficult to "see," predict, and influence.

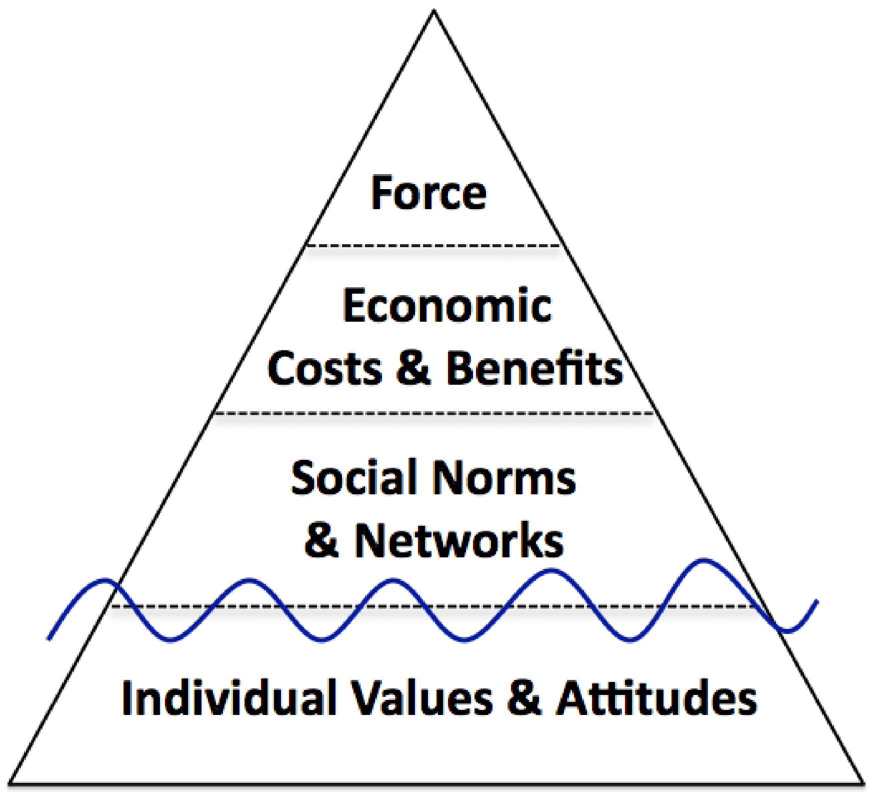

Figure 32. Flora's model of collective rural decision making. The model suggests that social norms and networks may be instrumental in mediating the influence of relatively weaker top-down drivers of behavior and the relatively stronger influence of individual values that can be difficult to predict and change. We added the water line to illustrate that, if we think of this figure as an iceberg, individual values may be difficult and time consuming to discern clearly and influence, but social norms and networks may be more helpful in accessing and influencing what can't be seen.

Flora's research showed that the most effective pathway for bridging the gap between individual values and top-down regulatory and economic pressures in order to leverage effective management of community resources was to understand and utilize community social norms and networks. Many of the small towns that Flora studied had a collective "low tax" ideology – that is, "if it ain't broke, don't fix it." However, "unseen" problems in rural infrastructure often caused municipal systems to deteriorate over time leading to depreciation of an unkempt investment. Other towns had a much different ideology of actively preparing for the future that led to maintenance of systems over time. In both instances economic and regulatory pressures were similar, but communities exhibited different social norms and networks, which explained differing long-term management choices.

Diffusion of innovations. Diffusion of innovations is a field of research focused on explaining how new ideas and practices spread through a population (Rodgers 2003) that posits theories complementary to those proposed by (Flora and Flora 2013). Diffusion theory emerged in the mid-twentieth century from studies in several disciplines, including seminal studies that sought to explain the relatively slow adoption of seemingly more profitable row crop agricultural production technologies by Corn Belt farmers (Ryan and Gross 1943). Results from diffusion research conducted for many decades across many societal sectors indicate that most people decide to adopt an innovation based primarily on subjective values and social norms, diffused through interpersonal networks, rather than on purely rational cost-benefit analyses (Rodgers 2003).

One particularly important theory that has been widely supported by empirical diffusion of innovation research is the adoption curve explaining the rate at which a new practice spreads across different segments of a population (Rodgers 2003), Figure 33**.**

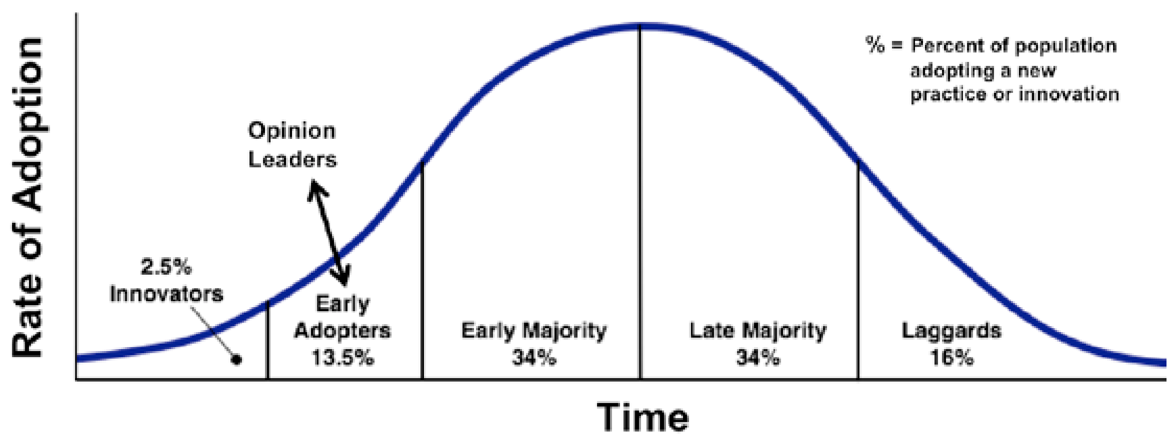

Figure 33. Diffusion of Innovations Theory. Research and theory in the field of Diffusion of Innovations explain how the rate of adoption changes as adoption of a new practice or technology spreads through segments of the population that have different characteristics. Success of adoption often hinges on a practice being adopted by roughly 15% of a population, at which point the rate of adoption often increases dramatically. Opinion leaders who are integrated into well-established social networks, both inside and outside of their local communities, often play a crucial role in brokering adoption across socio-cultural barriers, and their decisions are particularly influential in drawing adoption rates towards the 15% threshold (Rodgers, 2003).

This theory suggests that new practices are often first adopted by 'innovators,' a subset of the population that is very willing to experiment and try new things, in part because these innovators are strongly connected to the outside world and are only weakly influenced by the social norms and networks of the communities of which they are a part. In the Corn Belt, organizations focused on conservation and sustainable agriculture are often drawn to partner with farmers who are innovators because these farmers are eager to connect with them and are more willing to experiment with new practices. However, these innovators are often perceived as outsiders and viewed with suspicion and skepticism by peers within their local communities. As a result, their example may do as much to hinder as it does to help spread the adoption of an innovative practice throughout a broader population.

The adoption curve illustrates that the rate of adoption begins to rapidly increase when a beneficial new practice is implemented, not only among innovators, but also by local opinion leaders who often have connections both inside and outside a local community and who can serve to broker adoption across societal boundaries (Burt 1999, Rodgers 2003). Once these opinion leaders adopt a practice, the rate of adoption often increases as the practice becomes diffused throughout large sectors of a given societal group. In social landscape analysis, a high priority is placed on identifying opinion leaders in a population, understanding how their values and perspectives relate to an innovation of interest, and garnering their input and support to determine how this practice might be most beneficially and effectively implemented in a given context (Atwell et al. 2009b).

Current diffusion research on conservation practices has been largely built on retrospective, survey-based studies which link the timing of innovation adoption with social and demographic data (Fliegel and Korsching 2001, Wejnert 2002, Rodgers 2003). Yet because not all innovations are successfully diffused or found to be beneficial in their cultural contexts, it has been widely suggested that "positioning research" to better understand the cultural suitability of potential innovations is needed. These theorists also posit that such research might utilize either qualitative or systems approaches to understand the interplay among complex, multi-scale social drivers of change, which are often difficult to quantify and compare directly. Social landscape analysis has utilized such an approach to understand the socio-cultural, economic, and political efficacy of, and potential for, increasing perennial vegetation in Corn Belt agroecosystems (Atwell et al. 2009b).

B. Social Landscape Analysis

1. Target ecologically, target socially: synching landscape and interviewee characteristics

Spatial ecological prioritization models enable conservation planners both to identify landscape patterns and processes that are most critical in driving outcomes of interest and to target investment of limited conservation resources in a cost-effective manner. Similarly, social landscape analysis can be used to assess the social variability across different land parcels and landscape positions. Especially in privately owned working landscapes, understanding the social 'lay of the land' can elucidate a suite of cultural, economic, and political variability that can either constrain or enhance the suitability and feasibility of conservation outcomes.

For instance, land managers often seek to influence conservation decisions related to certain land uses and practices, such as maintenance of stream buffers, wetlands, or grasslands at strategic locations across a landscape. Identifying the landowners, farmers, or other managers who are most likely to make a decision regarding these important landscape positions and practices – as well as understanding the community values, norms, and networks that influence decision-making – can have important implications for what, where, and how practices are implemented. In addition, implementing conservation initiatives in ways that work with, rather than against, the cultural, economic, and political particularities and resources of a local social setting also bolsters the potential efficacy of conservation outcomes.

In this project, social landscape analysis was built upon the preliminary conservation prioritization maps for the ABR and GL landscapes (Chapter 4), as well as protocols and costs associated with a suite of key land use transitions that are integral to the implementation of the Minnesota Prairie Plan (Chapter 3). Prairie density analysis identified two to three priority areas (Coordinated Landscape Management Areas or CLMAs) within each landscape containing concentrations of land of high conservation value. Within each landscape, one of these priority areas was chosen to be the focus of landscape social analysis: the Felton Prairie CLMA in the Agassiz Beach Ridges Landscape and the Ordway CLMA in the Glacial Lakes Landscape (Figure 25 page 67 and Figure 27 page 69). Protocols were developed to prioritize the understanding of factors that influence conservation of these priority areas. However, secondary goals included exploring broader social patterns that influenced conservation decision-making – both across the priority areas comprised primarily of prairie, wetland, and grassland within core landscapes, as well as areas of more intensive agricultural production interwoven into and surrounding core landscapes.

With these goals in mind, we used an ethnographic approach (Neuman 2003) and leads from conservation partners to develop initial relationships in our study area. This included conducting preliminary interviews to determine what land managers already knew about key people and networks in these landscapes, as well as initiating informal conversations with local residents about our research through visits to grain elevators, agribusiness dealerships, local coffee spots, churches, and other gathering places. Based on insight gained from these discussions, we used purposive sampling (Neuman 2003) to seek out participants for depth interviews who represented a diversity of local perspectives within the following overlapping groups: crop farmers, livestock farmers, land owners, rural opinion leaders, and township/county policy makers. Among these groups, we prioritized interviewing opinion leaders (Figure 33 page 95) and civically active farmers whose behavior, decisions, and influence were recognized by other community members as impacting sizable portions of the landscape (>200 ha) or parcels of strategic conservation priority (Figure 25 and Figure 27, Table 16 and Table 17). We continued to initiate interviews until we reached "saturation" in relationship to major study questions—the point at which we begin to be able to predict subject responses based on previous interviews and analyses.

	ABR (acres)	GL (acres)
Total	126,774	169,305
Crop	65,595	27,946
Prairie	15,965	7,223
Wetland	2,480	36,326
Other Grassland	23,926	55,362
Protected Prairie	8,253	2,813
CRP (2008)	21,666	26,216
Total Protection	25,162	25,340
Private Ownership	≈101,000 (≈80.2%)	≈144,000 (≈85.0%)

Table 16. Amount of land by use, cover type, and protection status in the Agassiz Beach Ridges and Glacial Lakes landscapes.

	ABR	GL
Total interviewees	19	23
Crop farmers	8	8
Livestock farmers	8	13
Non-farm land owners	3	8
Opinion leaders	5	5
County commissioners	2	1
Township board	1	1
Total land owned	17,121 acres	11,245 acres
Total land rented	11,438 acres	5,615 acres
Cropland owned or rented	13,717 acres	7,576 acres
Pasture and hay owned or rented	6,955 acres	795 acres
Conservation Reserve Program (CRP) land owned or rented	636 acres	551 acres

Table 17. Characteristics of interviewees associated with the Agassiz Beach Ridges and Glacial Lakes landscapes.

Across the ABR and GL landscape study areas, we contacted 83 individuals, households, and/or parties requesting interviews. Of these, 52 agreed to participate, 15 declined, and 16 did not return our calls. We received a much higher rate of positive response to interview requests in the GL landscape in comparison to the ABR landscape (Table 18). Due to scheduling challenges, we were not able to interview everyone who agreed to participate.

Contact Response When Asked to Participate in an Interview	ABR Landscape	GL Landscape
Total contacts asked to participate in an interview	51	32
Yes, will participate in interview*	26	26
No, would prefer not to participate	12	3
Did not return our calls	13	3
**Due to scheduling challenges, we were not able to interview everyone who agreed to participate*		

Table 18. Interview response rates. When asked to participate in interviews, rates of response varied dramatically between our two landscape study sites.

In total, we conducted 43 depth interviews with 46 individuals (3 interviews involved interviewing two respondents simultaneously). Interviewees ranged in age from 25 to over 88 years old, with an average age of 53 (Table 19). Our interviewees fell into the following strategically chosen and overlapping categories (i.e. one interviewee could be counted in multiple categories): 21 livestock farmers, 16 crop farmers, 10 non-farm owners, 10 opinion leaders, 3 county commissioners, 2 township board representatives, and 6 conservation land managers.

Age	Number of Interviewees
20-29	2
30-39	7
40-49	8
50-59	13
60-69	13
70+	3

Table 19. Numbers of interviewees in different age classes.

Nineteen of our interviewees were connected with the ABR study area, and 23 were connected with the GL study area. Two of our interviewees were conservation land managers who were not directly connected with either study area, and one conservation land manager whom we interviewed worked in both study areas. Our interviewees owned and operated land that reflected land uses and cover types of the larger ABR and GL core landscapes (Table 16 and Table 17). Land ownership parcels in the ABR landscape tended to be larger than those in the GL landscape. As such we, conducted fewer interviews in ABR than in GL, but the 19 interviewees in ABR influenced a larger proportion of the core landscape area than the 26 interviewees in GL.

Interviewees represented groups such as: Farm Bureau, Farmer's Union, Cattleman's Association, Grazing Land Conservation Association, Minnesota Rural County Caucus, 4H, Lion's, chambers of commerce, county planning boards, and local booster organizations. The most common form of local involvement among interviewees was participation in church parishes.

2. In-depth interviews

Interviews followed an open-ended guide—while similar questions were asked and similar topics were covered in each interview, the exact wording and flow of questions varied among interviews. Interviews included three sections. The first section began with the broad question, "What is most important to you about this area?" referring to the landscape of interest (ABR or GL) that had been introduced at the start of the interview. We probed how interviewees perceived the natural landscape, how they viewed their neighbors and community, what challenges they saw facing their rural area, and what local assets and amenities they most valued.

In the second section of interviews, we explored tradeoffs in values that effect decision-making related to a number of land use transitions. We began this part of the interview by engaging participants in conversation using sets of pictures depicting several management practices and land use transitions related to the goals of the Minnesota Prairie Plan, including: seeding and managing for native grasses, removal of invasive species and woody vegetation, conservation grazing, controlled burns, native seed harvest, and savannah restoration. We then asked respondents to fill out two brief questionnaires in which they were asked to consider the importance of a) different ecosystem services and natural resources and b) factors influencing farm and conservation management decisions. These questionnaires were used to ask more probing questions about how farmers evaluate tradeoffs in farm and conservation decision-making.

The third section of each interview focused on reviewing our conversation and asking how each interviewee would envision desired landscapes of the future.

3. Qualitative data analysis

All interviews were recorded and transcribed. Text transcriptions were imported into the NVivo10 data management and analysis software package (QSR 2012). Interview data were coded in NVivo10 into descriptive and topical categories by the lead of the social landscape analysis project component. These codes were used to further analyze which themes in the data were strong or weak, how themes were related to one another and to study questions, and how the data reinforced themes and with what caveats. Validity in qualitative research is based on probing the plausibility, accumulation, and connectedness of themes as they emerge through iterative analysis of empirical data (Miles and Huberman 1994).

C. How Do Stakeholders Value Their Landscape?

1. Farming lifestyle, rural socio-economic vitality, and the conservation-agriculture divide

Agriculture is perceived by local stakeholders as both the primary economic activity in the communities across our study sites, as well as an important integrative aspect of rural culture. When asked what they valued about the places in which they lived, nearly all (42 out of 44) of our interviewees indicated that maintaining vibrant agricultural economies or lifestyles in rural communities was of great importance to them. Interviewees recognized that the small towns and rural communities spread across our study sites were facing pressing social, economic, and cultural challenges associated with consolidation of farming systems. While rural residents often questioned whether agribusiness companies and 'corporate agriculture' had the interests of rural communities in mind, the future socio-economic vitality of rural communities was seen as deeply interdependent with the success of farms and agricultural businesses. People recognized that over the last several decades farms have gotten bigger and the number of farmers and farmsteads has declined. This has led to fewer people in rural communities and less support for local services and businesses, leading to declines in rural social and economic vitality.

Maintaining high levels of agricultural production was generally voiced and accepted across interviewees as an important aspect of how their locales contributed to larger regional and global societal needs. Many interviewees mentioned that, with the increasing global population, it was crucial to maintain high levels of agricultural production on suitable cropland. Even if farmers at times questioned whether the external control exercised by agribusiness over local economies was in the best interests of local communities, they generally voiced a sense of pride in contributing to global food and energy needs.

Across both study areas, 30 of the 43 people we interviewed spoke of a recognized cultural divide and conflict of interest between agriculture and conservation. This divide was most strongly linked to a perceived clash between a) the agricultural economies that are foundational to rural culture and b) the desires of outside conservation interests to preserve idyllic environmental conditions on land that they do not directly own or manage. Often, environmental agendas and conservation initiatives were associated with external control and regulatory practices that lacked common sense in relation to the realities of farming practices and rural lifestyles. Rural residents and opinion leaders often perceived that urban decision-makers did not take time to really listen to rural perspectives and consider the impact of conservation decisions on rural livelihoods. Urban residents and conservation decision makers were often stereotyped among interviewees as valuing a romantic notion of ‘untouched’ nature, while at the same time not understanding the ecological footprint of their own lifestyles, including where their food comes from. One farmer and opinion leader put it this way,

“It seems as though the most extreme conservationists live in a city and are causing just as much harm by their lifestyle. They are going to the grocery store wanting cheap food and yet wanting us to produce that food on less acres. And they are coming out, driving hundreds of miles, to look at wildlife. If you were to track their footprint through their life versus our footprint as a farmer, I would really like to see that study on who is actually causing more disruption to the ecosystem.”

Despite this cultural divide, many interviewees emphasized that this conflict between agriculture and conservation was unfortunate, unnecessary, and unproductive. Twenty-six interviewees (including eight of the ten opinion leaders that we talked with) emphasized the importance of dialogue about shared values, suggesting that if cultural differences could be overcome, conservation and agriculture interests might have more in common than they expected. Interviewees also suggested pragmatic approaches to cooperation between agricultural and conservation entities, which are described in more detail later.

Several key terms were found to have different connotations depending on context. When our interviewees talked about conservation, stewardship, and sustainability, they were interested primarily in maintenance of farm viability and rural socio-economic vitality over time. However, when ‘conservation’ and ‘environment’ were perceived as a threat to sustaining farming lifestyles and rural socioeconomic vitality they were viewed with suspicion.

The farmers we talked with generally considered themselves to be interested in conservation, especially practices associated with soil and water stewardship within their farm fields. However, they questioned whether too much quality agricultural land was being taken out of production to advance unclear conservation ideologies being driven by Minnesota’s urban resident base. Alternatively, environmental stewardship tended to be viewed in a positive light when it was linked with sustainability of rural resources and the farming way of life. As one farmer and opinion leader said:

“It is about money [pause] – to a degree, I mean. If you don't make money, you are going to be gone, so you got to make money. So how do you get it all [agriculture and the environment] together? And the reality of it is, the secret of it is – yes you are worried about money, yes you are worried about the environment. So guess what? When you are worried about both, it's kinda like a bird in the hand where if you keep ‘em too tight you are going to crush them, and if you kinda leave them just a little bit [of wiggle room] they will probably stick around.

We can all talk and yippy-skippy around, but the bottom line is that, if money is not being made, or the potential for it, everyone might as well save their breath because it's just going to be a matter of years before everyone is burnt out and broke. Unacceptable. So part of sustainability is making money so you can be sustainable. One of the old FSA directors once said to me, 'to be green, you got to make green,' because if you are in the red, you can just forget it, it all goes out the window."

In sum, the opinion leaders, farmers, and other local residents with whom we talked generally voiced support of initiatives that were seen as bolstering the farm and local agricultural economies. Alternatively, they were suspicious and standoffish towards conservation and environmental agendas when these were perceived to be driven by outsiders – especially decision-makers and moneyed interests in Minneapolis, St. Paul, St. Cloud, and from out of state – that were seen as having little understanding of or appreciation for farming lifestyles and rural socioeconomic vitality. Within the ABR study site, the nearby urban center of Fargo-Moorhead was *not* viewed with the same distance and suspicion as was the Twin Cities.

2. Conservation wastelands

Few of the rural residents with whom we spoke identified with or valued prairie and wetland conservation on lands owned and managed by government agencies and conservation organizations. Sixteen of our interviewees (including 15 farmers and six out of the ten opinion leaders that we interviewed) volunteered that they perceived these lands to be “wasted,” both because economic return is limited and because these lands are perceived to lack necessary management to bolster desired species while keeping noxious weeds and woody encroachment at bay. In addition, management decisions on these lands are not well understood and are seen as driven by Minnesota’s metropolitan population who rarely visit these areas. Currently, no significant, locally influential subset of the rural population in either of our study areas takes ownership of the goals of conservation of native species and ecosystems. A lengthy quote from an interview with a livestock farmer and opinion leader illustrates the thoughts of many of our interviewees:

“You know, I have lived here my whole life and I like to hunt, and I'm a good advocate for the wildlife, and I think most all the farmers out there are. There is definitely some resentment out there against The Nature Conservancy for buying up land out here, and the DNR. And I was in a couple of dealings trying to buy land that I was interested in, and I lost them to the DNR, and you feel frustrated.

One of the biggest drawbacks is with the high price of corn and beans, anyone who has any kind of marginal ground for pasture is putting the plow to it. So that is one of the biggest limiting factors for us is grass... And the general consensus for a long time out there has been, you know, you drive past that DNR land, or The Nature Conservancy, and the grass is growing up, and it is getting brushy, and you know, there would be a lot of good eating for cows, and here, we are struggling to find forage....

So there is a real demand for grass. And I would like to see them [conservation agencies] do more with that. That would certainly help their image in the neighborhood, let me tell you [with emphasis]! 'Cause there is some heated discussion up here, and I'm sure a lot of places. You know, it gets kinda frustrating and it gets compounded on a year like this when we're dry and you have that wildlife [land] and the grass is this tall and you look across the road and your cows are eating dirt. The first thing I hear come out of peoples' mouth around here when they see those big chunks of grass is, 'What a waste!'"

3. Malleable land, utilitarian landscapes

The sense that many conservation lands are being "wasted" is synonymous with another strong theme that emerged across interviews. The majority (25 out of 44 interviewees, 22 out of 24 farmers, all 10 opinion leaders) of the rural people with whom we spoke saw land as something to be worked and managed, whether for agricultural or conservation purposes. This view contrasted sharply with the attitudes of some conservation land managers who saw conservation reserves as places where the integrity of historical ecological processes was being protected from overly intensive management practices associated with agriculture.

Attitudes towards the plowing of land formerly enrolled in the USDA Conservation Reserve Program (CRP) are illustrative of this theme. While nearly all of our interviewees felt that a lot of land was currently being plowed and put into crops that shouldn't be, most took the conversion from CRP to cropland in stride. For instance, many interviewees echoed the sentiment of one farmer and county commissioner who said,

"With crop prices up, some of that is going to come out, but if prices dip, some of that might go back in if prices come down or they decide to allow a guy to hay it. You know, it used to be competitive, but now it isn't."

The following exchange with another farmer who lives and farms crops in the gravelly ABR core area illustrates that changing crop and equipment technologies are also leading to changes in perceptions about what land is and isn't appropriate for crop farming:

Q. “Would you be more inclined to participate in conservation programs in the future if they allowed economic activity off of the land?”

A. “That still wouldn't match the value of the land for crop production. If it is good land, you ought to plow it. Use it for what it's good for.”

Q. “But a lot of the land in an around the [Agassiz] Beach Ridges is pretty gravelly, it is not very good for farming, is it?”

A. "Well, you should see what they are getting off of it nowadays, a lot of it is getting 200 bushel per acre."

Q. “Isn't some of it pretty rocky, almost impossible to till?”

A. "Well, not if you got the heavy machinery."

Land was seen as malleable, meaning that it could be changed over time through human management. Many of the positive and negative comments about CRP voiced by rural residents added a caveat to this viewpoint. Several interviewees voiced concern that, in the past, productive agricultural land was often put into CRP when it could have been growing crops. This was also seen as a current problem with the Wetland Reserve Program (WRP). Conversely, interviewees emphasized that non-productive land should be in CRP, pasture, or some other grass use, rather than in row crops. Thus, the importance of targeting conservation practices to marginal farmland, an approach increasingly used in the conservation community, was also important to rural residents. A young livestock farmer who preferred farming grassland compared to cropland nonetheless expressed the sentiment shared by many that good cropland should be tilled:
“If it is good tillable farm land, I think it is best off in farm ground, because I think a lot of that CRP just grows up in cottonwoods and thistles and ten years later they got to pay a big bill to pull that out, and it is not managed well. And crop farming is basically what you fall on if you can't manage the grass [chuckles]. You know, you just plant it in the spring and harvest in the fall and that is all there is to it.”

Another concern about CRP volunteered by the farmer above, as well as 16 other interviewees (representing a diverse cross-section of respondents including 13 of 24 farmers, five out of six conservation land managers, four out of five township and county leaders, and one non-farm rural resident) was that the land enrolled in this program was often poorly managed, or lacked necessary management altogether. While some conservation managers saw unmanaged land as existing in a safe and protected state, the majority of our interviewees emphasized that much

CRP was managed poorly, or not managed at all, leading to waste of conservation potential and economic return. Many observed that most CRP lands were never seeded properly due to insufficient government funds and voiced frustration that restrictions on management activities like haying and grazing resulted in CRP lands becoming overgrown with weeds and woody vegetation. One farmer who was also on the township board put it this way:

"Neglect, so much land owned by absentees in CRP. Trees growing up. There are no fences anymore, so there is no interest in grazing it. It creates a wildlife magnet, and then wildlife come out and eat crops. They need to rework the CRP system to be more user friendly for grazing. There needs to be something in those contracts that provides for fencing and grazing. All the idle land you see around here, much of it is CRP."

Building on the sentiments of the interviewee above, several farmers offered that the relaxation of restrictions to allow haying and grazing of CRP land during draught times without incurring a penalty in payments was a great positive. These interviewees wished that the program allowed similar activities during normal, non-draught times. Several interviewees pointed out, straightforwardly, that payments for CRP were no longer competitive with crop prices and that, given government budget deficits, this was unlikely to change in the future. As such, many interviewees across categories suggested that, in the future, program changes that would allow 'stacking' a CRP payment on top of other economic returns from grasslands would make grassland conservation programs more economically viable from a landowner and producer standpoint.

A few of our interviewees, including an influential county commissioner, liked several characteristics of the CRP program that lent themselves to the dynamic nature of working agricultural landscapes. First, this commissioner echoed the concerns voiced by many other interviewees that permanent easements constrain the options of future generations. Alternatively, he offered the 10-15 year contract length of the CRP program as an ideal timeframe for easements – long enough to implement consistent management practices, but short enough that farmers have options to adapt to changing social, economic, and ecological realities. Second, this county commissioner also liked that, in the CRP program, land remained in private ownership. The preference for conservation strategies that maintained land in private ownership and allowed for some type of continued economic productivity from the land was commonly voiced throughout interviews. This kept the land in the tax base and often kept a source of revenue flowing to a rural farm owner or operator.

County commissioners and township board members that we talked with all discussed the effect that conservation lands have on the rural tax base. Especially in the GL study area, these leaders perceived that a high density of conservation lands in certain tax jurisdictions leads to a burden on the shared tax base, because conservation agencies pay reduced and/or no taxes. In addition, these conservation lands were seen as posing a potential threat to continued expansion and growth of the agricultural economy. While all county and township leaders with whom we spoke indicated that they saw conservation in general, and prairie preservation in particular, as important and necessary on some lands, all begged the question, “How much is enough?” They felt that this question was an important one for public discussion among their local constituents, as well as at a state level.

As ecological scientists, conservation organizations, and environmental groups increasingly recognize that humans dominate earth ecosystems (Vitousek et al. 2009) and ecosystems often exist in alternative states (Beisner et al. 2003), and in such systems lack of conservation management usually leads to suboptimal conservation outcomes (Folke et al. 2004). As such, management activities are increasingly seen as necessary on all conservation lands, and especially in landscapes and ecosystems that have been highly altered in relationship to their historical counterparts. Within prairie landscapes, human activities have dramatically altered historical ecological processes to the extent that, when remnant prairies are left unmanaged, their vegetative communities are often dominated by invasive and woody species (Kettle et al. 2000).

This understanding of conservation land as needing management is an important point of connection between agricultural and conservation communities that has the potential to bring shared values to both communities. For instance, several of the farmers with whom we spoke volunteered that, given their familiarity with the land they farm and the use of heavy equipment, they would be happy to help restructure hydrologic systems and reseed conservation areas on their farmland and neighboring parcels voluntarily or under contract. One farmer and opinion leader told the following story:

“We are working with a landlord who is selling land to a WRP program, but they have been waiting two years now for funding. They signed the papers, they have come out and pounded the stakes in and advertised that they have gotten the land bought, but there is no money. NRCS wants the land in corn and beans for one year before you reseed, but no more than that. But the funding does not come through in a timely fashion, and then while that land sits there, the weed seeds get a foothold. And there is nothing in the program that includes a farmer mentality to say, ‘well today, we need to do this because the weather is right.’ Instead of having these plans ready and then waiting for the funding, we need to have the funding ready and then implement the plan. It has gotten backwards, and Mother Nature doesn't wait for politics and timing. When Mother Nature says it is time to go, it is time to go.

And if they had of let us farm one more year while they were waiting, the weed pressure would be down, the quality of the soil would be maintained for another year. And if done correctly, once that crop has taken off, it could be seeded no-till right into a soybean field or even corn trash. All that trash is good for the soil to increase residue, and with the heavier equipment we have available today, we can easily plant into pretty heavy trash [referring to stubble from the previous crop]. But they keep putting restrictions on us: ‘yes you can farm it, but don't do this and don't do that and we need a soybean crop.’ Well, the check has not even been written, why are we getting told how we should farm it? Once the transaction takes place, then we can make changes, because if there is no funding to buy it, there is no funding to plant the native grasses back to it.

If they said to us, you can farm it for two years for nothing, but all we need is for you to make sure that it is level and smooth and the ruts are out and seed it back to a certain native grass mix, I would buy the seed. And if it is done in a timely fashion, we can ensure that it is done properly, that the drainage is done appropriately, if they want to dam it up for wetland restoration, we have a small construction company sitting in the yard with scrapers and tractors and dozers. We will gladly do what needs to be done, but we just need a master plan. And if we can just farm it in lieu of land rent, we will do it, and we will do it in a timely fashion, and we can do it from the perspective of someone who knows the land.

Now that would be working together! Not, ‘this has got to come out of production and then, by the way, we got to find someone to do this and that, and then someone is implementing the plan who has never been around agriculture before.’ Or their plan is to see ten cattail sloughs and few ducks flying out of there and they are happy. When they acquire this land, it should be rented to someone who will work with the land continuously. You know, give me a three-year land contract and I'll have it how you want it by the end of the third year. So we can get the land into shape, and know what our goals are because we came up with a plan ahead of time, and get the stuff funded because it is self-funded [e.g., we bring in some revenue to offset our restoration cost]. You know, that would be a nice system to have. Cause then we are on the same team, we know what is coming, when it is coming, and what the final result is going to be, instead of always hanging on the end wondering what is going to happen next year.”

Appreciation of grassland and prairie as a natural resource of special importance was voiced most strongly among interviewees who had participated in partnerships in which both agriculture and conservation entities pooled resources to implement grassland management practices. Another farmer opinion leader’s story of how such a partnership started is illustrative of how a shared interest in land management can bring agricultural and conservation entities together:

“In this area, until [a local USFWS land manager] come along, I looked at the Fish and Wildlife Service, DNR, Nature Conservancy – you know all of them – CREP, REM, whatever... what a waste! You know, for 30 years, you know all they did was bought land and let it sit. And that was it! CRP was a great program for five years, but we didn't manage it, so it deteriorated. I first met [this same USFWS land manager] about six or seven years ago. He stopped here and asked to hunt down there. And dad and me came out. And I said, 'Go hunt your own land. You got all those damn acres out there, why don't you go and hunt out there? You got all those damn acres, and you come over here and ask me to hunt because all the wildlife is on mine. Why don't you go hunt on yours?'

I was up for an argument. I just said, 'I'm sick of you guys not doing anything with all of your grass. You buy up all of this and then it just sits here and it is junk.' And he said, 'I agree with you, it needs management.' And we started talking and one thing led to another, and we realized that we were on the same page and that our common interest was grass. I wanted it for cows and he wanted it for wildlife, and that's just kinda where we went with that. But [this same local USFWS land manager] is by far and away the rarity for government employees. Guys like him are few and far between."

This conversation was the beginning of an innovative conservation grazing partnership between this producer and this USFWS land manager.

4. Prairie and grassland

The prairie conundrum. Attitudes towards prairie varied across interviewees. Prairie rarely emerged early in interviews as an aspect of place that was valued by our interviewees. However, over the course of interviews and discussions of photos of management practices, 12 of our 44 interviewees expressed strongly positive associations with the concept of prairie. These 12 individuals included six out of ten non-farm rural residents, five out of six conservation personnel, and three out of five county leaders, but only three of 24 farmers and one out of ten opinion leaders. However, in response to questionnaires, most interviewees indicated that prairie was a natural resource of either primary or secondary importance.

Despite this overall lukewarm positive response to prairie, few interviewees voiced efficacy or interest in implementing prairie conservation or restoration management practices. When asked, most interviewees, including grazers, exhibited little understanding of or interest in implementing the types of management practices needed to bolster native grass species – although most interviewees also emphasized that they would be interested and willing to learn about or implement practices if technical support and cost-share assistance were readily available. Thirteen interviewees (including 11 farmers and seven out of ten opinion leaders) simultaneously voiced a measure of suspicion about prairie restoration as something being implemented by outside conservation interests in ways driven by abstract ideas that lacked 'common sense.'

Grassland as a unifying theme. In contrast to the mixed attitudes voiced towards prairie, the importance of grass, pasture, and grazing livestock on working grasslands was a theme voiced consistently and strongly by 39 out of 44 interviewees with whom we spoke. Where positive responses to prairie usually came out only through questioning and later in interviews, the importance of grassland was a theme volunteered early and often by many interviewees. Many farmers, opinion leaders, and local policymakers with whom we talked felt that grasslands in western Minnesota, and especially in core ABR and GL landscapes, could be much more efficiently utilized to increase conservation outcomes and economic return through haying, grazing, and other economic ventures.

Thirty of our 44 interviewees, many of whom were livestock farmers and local opinion leaders, voiced particularly strong values associated with the importance of grass, grassland, and grazing livestock as a lifestyle. Across interviews, both farmers and rural leaders perceived grasslands as a threatened natural resource, but also envisioned a future in which grasslands might be utilized more efficiently and managed more effectively to produce both economic and environmental benefits. One farmer opinion leader summed up the sentiments of many in this way:

"Well, I think in this area here, the saddest thing for me, and that is why I'm so excited for you being here and working with these [conservation organizations] is that this country used to be full of livestock. And now here we are facing a growing world, and everyone wants to eat, and food costs are going up, and it takes land to produce food, which I think is great. And what I would like to see is more livestock to come back into the area to utilize these lands that have just been sitting here in CRP or these publically owned lands.

And some of this USFWS land that I have grazed, I can tell that nobody has been on it since the 1980's, and I can tell because some of those fences are in pretty rough shape. That's a lot of land that didn't produce anything but a few ducks for someone to shoot in that entire time, in my opinion. So now I graze it for about 45 days, with about 28 cow/calf pairs. With them calves gaining about two lbs per day, that's 2500 lbs of cattle, times about 60%, that's about 1500 lbs of beef! That's on about 45 acres of grass. There's some wetland on that too, but I'm not counting that. Well, that created something better for mankind, it provided us with some food. Plus, we are benefiting the nest production and the wildlife. We are benefiting the land. And that is what I want to see more of. Let's feed the hungry people of the world!"
Another farmer opinion leader emphasized the potential for grass to unify politically divisive interests:

"Grassland is the most important natural resource in Minnesota that nobody is talking about. We think about lakes, and forests, and row crops, but no one thinks about grassland as a resource. We need to add this to the political conversation at a state level...

Remember with the users of grassland, their common thing is the livestock, and with tree huggers, their common thing is the grass. And it is what you do with the grass that can bring you together or pull you apart."

Grazing as prairie education. Of particular note is that, among the 15 interviewees who voiced the strongest interest in learning more about native species grass management, eight were livestock farmers who had been grazing conservation lands in partnership with either the US Fish and Wildlife Service, the Minnesota Department of Natural Resources, or The Nature Conservancy. These producers indicated that they had originally become involved in these partnerships because of the pragmatic benefits of obtaining an additional grazing opportunity, but that through these partnerships they had come to an increased appreciation for the value of native species in general and warm season grasses in particular. One farmer put it this way:

“I don't hunt, but I do like to see wildlife out in the pastures. So many pastures in this area are overgrazed bad, you know, Bluegrass. I'd like to see more natives. I graze some with the USFWS. And in a restoration deal, I've been running cattle on one section of it for about five years now, and that's come real nice, and now I understand and see the difference in natives. At first, I didn't understand it.

I actually hayed that section this summer for USFWS, and when I was out there, I could see there was a lot of difference, although I couldn't tell you what the species were, I don't know much about the grasses and flowers. So I guess I would like to see more of that on the [privately owned] land that I have got as well. If we could just somehow [thoughtful pause] – it just takes a lot of work with the cross fencing, and the watering systems. That's the biggest holdup, I think, is that it takes a lot of work to get it set up, but once it is done, you know, you can control the grass, and not overgraze, and enhance the wildlife.”

5. Value of other ecosystem services and natural resources

We asked each respondent to rank their perception of the value of several ecosystem services (described to interviewees as ‘benefits provided by natural systems’) or natural resource as either: very important, somewhat important, of minor importance, or not important. Interviewees were asked follow-up questions to better understand the values and reasoning underlying their rankings.

Pragmatic and aesthetic landscape diversity. When asked to respond to a written survey on the importance of natural amenities, 11 interviewees said aesthetics was of primary importance, and 20 said it was of secondary importance. Nine interviewees emphasized in interviews that they valued the more heterogeneous terrain, land cover types, and land uses of core prairie landscapes, both for aesthetic and pragmatic reasons. One farmer put it this way:

“Well, I love the variety of the land. We are always going to get something here – in wet years, we got the hills, in drought years we got the bottoms. Everything grows here. I like the hunting and fishing. And with smaller ground and hills, everyone knows everyone. The terrain keeps the bigger operators out, but that is starting to change.”

The very distinctive rolling hills of the GL core landscape were more often associated with aesthetic benefits than were the more subtle gravelly ridges of the ABR core landscape, which were more often associated with poor crop production and considered more aptly suited for livestock and gravel.

Hunting, fishing, and recreation. When asked to respond to a written survey on the importance of natural amenities, 12 interviewees said hunting was of primary importance, and 12 said it was of secondary importance, while ten said fishing was of primary importance, and 17 said it was of secondary importance. Six of our interviewees, and only one opinion leader, brought up hunting in interviews as an activity of strong importance. Comparatively, seven interviewees, including four opinion leaders, emphasized that hunting was primarily done by outsiders.

Among our interviewees, especially those in the GL core landscape, hunting was *not* seen as beneficial for local economies or an important motivating factor linked to conservation of prairie, grassland, and wetland habitats. The general consensus across interviewees was that most of the people who hunted on both private and publically owned conservation wetlands and grasslands were outsiders from the Twin Cities, or other urban areas, who were scantily invested in local social and economic systems. In addition, while our interviewees felt strongly connected to the land through agriculture and appreciated the aesthetics of a diverse countryside, few voiced an interest in recreational opportunities in rural landscapes.

Wildlife and prairie chickens. Twenty-three of our interviewees volunteered that seeing wildlife was important to them. When asked, most other interviewees agreed that wildlife was of some value, but did not consider this an amenity of primary value associated with their place. Wildlife species that most interviewees identified with included common and readily visible game species such as white-tailed deer, ring-necked pheasant, Canada geese, and wild turkey. Few interviewees associated specific wildlife species with prairie, wetland, or grassland, but some indicated approval that these habitats provide cover for birds. Some interviewees indicated concern that, without shrubs and trees, the birds in grassland conservation areas had nowhere to find cover from winter weather and predators. When asked, most interviewees in the ABR landscape [where prairie chickens are present] did not think that prairie chickens were of high value to themselves or other local residents. A few commented that advocacy for prairie chickens seemed to peak in the 1980's and 1990's, but concurred that they had not heard as much about this species in recent years.

Water quality. Water quality was rarely volunteered as either of great value or concern by the people we interviewed. However, when asked about its importance in questionnaires, almost all interviewees said that water quality was of high importance, with drinking water quality being most important, and quality of water in regional lakes, streams, and rivers also of high importance. Residents were mostly unconcerned about their own drinking water quality, but some voiced concern for the quality of water in lakes, streams, and rivers, including concerns about agricultural, industrial, and urban sources of pollution.

Gravel. Gravel was seen as a resource important for local economic development as well as urban growth, especially in the ABR landscape. Interviewees recognized that tradeoffs had to be made between gravel production and prairie conservation in the Beach Ridges.

Soil formation. Interviewees generally spoke of soil quality as being of very high importance and associated grasslands and other type of perennial cover on marginal farmland as important in minimizing erosion. Most interviewees felt that, depending on farmers' soil stewardship practices, conventional and industrial approaches to crop farming could be implemented in ways that improved soil quality. Most interviewees did not feel like organic farming was synonymous with better soil quality.

Trees and woodlands. Our interviews spoke very highly of the value of trees, and most interviewees also appreciated woodlands as a limited resource in their areas. A few interviewees who were more invested in grassland and prairie conservation expressed concern that woodlands have spread in the last several decades.

Wetlands. Most interviewees saw wetlands as a positive component of the landscape, citing importance for habitat, water filtration and regulation, and historical value. A few interviewees mentioned that, in some instances, isolated 'farmable wetlands' that they were penalized for plowing had little ecological value. These respondents concurred it would be of greater benefit to all parties involved if these wetlands were allowed to be farmed in exchange for restoring or conserving wetlands in more valuable conservation locations.

Pollination and bees. When asked to respond to a written survey on the importance of natural amenities, 17 interviewees said having bees for pollination was of primary importance, and 14 said it was of secondary importance. Eight interviewees volunteered that they, or someone that they knew, kept bees. Bees seemed of particular importance to interviewees living and farming within the GL core landscape.

Climate. Reactions to the importance of farmland for carbon sequestration varied markedly across interviewees and showed no patterns by interviewee type or across our two study landscapes.

D. Value-based Tradeoffs in Land Use Decision Making

In addition to asking interviewees about the importance of ecosystem services and natural resources, we also asked landowners, farm operators, and rural policy makers about the importance of a number of factors that might influence land use decision-making. We also showed interviewees a number of pictures illustrating common land use transitions and management practices of interest in prairie, grassland, and wetland conservation and restoration. We asked these interviewees to share their positive and negative impressions of these transitions and practices, and probed what decision-making factors would lead them to be more or less interested in implementing specific practices.

Flora's (2004) model of social control emerged as helpful in explaining how interviewees conceptualized their land use decision-making processes (Figure 32). Our data highlight two decision-making thresholds in Flora's model that should be of primary importance to policy makers and conservation land managers working to leverage conservation outcomes across privately owned agricultural landscapes: a) social norms and networks as a bridge to understanding, identifying with, and leveraging individual values, and b) profit thresholds.

1. Social norms and networks as a bridge

Much research into conservation decision-making on farms and other privately owned lands suggests that individual values vary a great deal among individuals, are difficult to predict, and have a strong influence on land use decision-making and quality of land care. This was true of our interviewees, who voiced very different decision-making frameworks that did not correspond with interviewee type (e.g., crop and livestock farmers, non-farm residents and owners, policy makers). This variety in decision- making strategies raises great potential challenges for conservation. However, almost all of our interviewees indicated that they value local social cohesion and indicated that involvement in these networks influences their decision-making.

One of the strongest themes voiced by interviewees was the efficacy of a personal relationship with a local conservation land manager in motivating implementation of practices that lead to conservation outcomes. Alternatively, interviewees also indicated that lack of connection, ineffective connections, negative interactions, and unhelpful relationships with local conservation personnel had the effect of inhibiting a conservation decision. In addition, local conservation land managers emphasized that, on a given piece of property, many different factors might motivate a conservation decision by either a landowner or farm operator. But it was emphasized that these factors could only be known through getting to know the owner and/or the operator of an individual piece of property.

Many farm owners and operators indicated an interest in implementing additional conservation practices and learning about sources of technical and economic assistance and advice. However, many interviewees acknowledged that implementing these conservation practices was currently a secondary priority and that, in reality, they were unlikely to implement a practice unless conservation personnel guided them through the process. One non-farm landowner and opinion leader clearly expressed the importance of establishing relationships between conservation personnel and agricultural stakeholders:

"That grass on my land really needs to be redone. But when the landowner sees the cost of it, he backs away from it. And I know that there are programs out there to show me and help me, but I haven't taken advantage of them. Somebody has got to take me by the hand and help me to get it done...

I think a lot of the landowners don't take advantage of the programs because they are not educated. There are good FSA employees that do a very good job and explain things to you real well, and then there are bad ones who are very poor. It depends what county you are in...

These individuals [speaking of the land managers that have been most helpful] stand out because they take the time to 'stroke my ego' [laughing].

Call me. Check in. Help out."

Some farmers suggested that they weren't really interested in participation in government programs regardless of potential economic gain because they did not want to mess with the hassle, red tape, and potential loss of control over their land. However, several of these farmers indicated willingness to implement voluntary practices if they could enter into relationships of dialogue and mutuality with conservation personnel who might be able to advise them on how to manage subprime cropland. Interviewees also indicated that participation and involvement in local social networks in ways that led to improved socio-economic vitality was important to them. They indicated a desire to work with conservation personnel and programs that were similarly connected.

The interviewees that we talked to voiced appreciation for the interview process, asked many good questions, engaged in lengthy conversations about conservation practices and programs, and suggested that conservation efforts should include more conversations such as those that had occurred in the interviews. While interviewees valued their landscapes differently and voiced many different values related to land use decision-making, over the course of the interviews, many connections between what interviewees valued and conservation outcomes emerged. We consistently documented that interviewees expressed more positive attitudes toward, and a greater interest in implementing, conservation practices at the end of interviews when compared to the beginning of interviews.

2. Profit thresholds

Across interviews, profit did *not* emerge as one of the primary factors driving decision-making. When asked to describe the importance of profit in their decision-making processes, less than half of our interviewees (including ten out of 22 farmers that were asked this question) described profit as a primary influence in their land use decisions. However, these and many other respondents who described profit as of secondary or minor importance agreed that profit still mattered. The majority of our interviewees who relied on farm income for a substantial portion of their livelihood – as well as the policy makers who represent them – viewed profit as a threshold that had to be met, but above which other decision-making factors played more important roles. As one farmer simply stated,

“Profitability has to stay because that is what keeps you in business.”

Many livestock farmers emphasized that they could be making more money and working fewer hours as crop farmers, but indicated that they enjoyed the lifestyle and working with animals. One put it:

“Doing what I like is important. I like the animal side. I'm drawn to the challenges and variety of livestock. You know, it’s different than planting a bag of corn, spraying it, and then sitting around your house all summer and watching the sky, before combining it and hauling it to town in the fall.”

Another said,

"Well, I don't do everything to make a big amount of money. I do it for enjoyment, too. I’d hate to be let down all the time [laughing].”

Interviewees told stories that illustrate how their management decisions were framed through the ‘profit as threshold’ lens in conjunction with other themes. For instance, several farmers and landowners discussed the choice to plow land that was coming out of CRP very straightforwardly, in similar terms to this farmer,

“My CRP land came out of CRP, and last year I bid to put it in CRP and it didn’t get accepted, so I asked a renter who lives next door to break it up and put it in soybeans.”

Farmers indicated that CRP was no longer a cost competitive program on all but the most unproductive land. Similar to the manner in which city drivers might complain about having to commute long distances in a gas-guzzling automobile to and from work, many farmers indicated that they didn’t really want to plow sub-prime cropland, but they would not hesitate to use their land resource in order to balance their farm budget and support their family. Another struggling livestock farmer discussed a historic woodlot on his family’s property that was currently enrolled in a CRP contract that was ending soon. This farmer was afraid that this parcel might not re-qualify for enrollment in the CRP program. He loved these trees and respected his family’s decision not to plow this land, but he also expressed that this land needed to generate revenue in order for him to keep the farm viable and support his family's continued ownership of the farm. This led him to consider logging and plowing the land.

A second economic threshold became apparent in our data among a small, but distinctive, portion of our interviewees who owned land for reasons other than income generation. Six of the interviewees we spoke with who owned land in the core priority areas indicated a strong interest in promoting conservation outcomes on their land, but indicated an interest in generating just enough income from the land to pay the taxes and/or cover the cost of land improvement and conservation projects on their property. This included both farm and non-farm rural residents who lived on the land they owned as well as absentee landowners who had a primarily non-monetary interest in their land for recreation or conservation purposes.

3. Responses to specific management practices and land use transitions

Interviewees were shown photographs of and asked specific questions about the following land use transitions.

Managing to promote warm season grasses and other native prairie species. Most interviewees who owned or managed working grasslands indicated that, while grass was important to them and had some conservation and agricultural benefits over crops, they had *not* considered managing for native grass species. Thirteen of the twenty-one livestock farmer interviewees with whom we spoke indicated that they were not very interested in managing for native grass species. The other eight indicated varying levels of interest in presumed benefits in forage quality and quantity that they suspected they could receive through greater rotation and other management practices to support warm season grasses. Many indicated that if they were part of a conservation grazing partnership with a conservation entity, the availability of additional grass on conservation land would allow them to rest their own grass and experiment with managing for native and warm season grasses on their own pastures. Farmer interviewees who had already participated in a conservation grazing partnership were much more likely to voice interest in, and a sense of efficacy to promote, implementation of warm season grasses on their property. A small, but passionate, minority of livestock producers and conservation land managers with whom we spoke (centered in the GL landscape) were already very interested and involved in managing for native grasses and other prairie species using livestock grazing as a management tool.

Conservation grazing. Conservation grazing was also a popular idea across interviews, especially among livestock producers. In certain parts of Minnesota, conservation agencies have been leasing land to livestock producers for rotational grazing for over a decade. Both conservation land managers and livestock producers who have participated in these partnerships perceive that conservation grazing has bolstered quality of native plant species on conservation lands while allowing grazers to rest private grasslands and boost forage yield. Some land managers are even experimenting with using very high stocking densities of livestock for very short durations to prepare unrestored prairies for additional seeding and management.

Removal of woody encroachment. Almost all interviewees responded positively to pictures depicting removal of woody shrub and small tree species from the landscape, such as cedar and Siberian elm. In the GL landscape, the USFWS has been pursuing an aggressive cedar removal program for several years. Interviewees who had participated in or observed the results of this program all viewed it as a benefit for the area. A few interviewees indicated that they hated to see cedars and other small trees and shrubs removed from the landscape because it reduced deer habitat, but they still understood and supported the program overall. Several interviewees indicated that, although they did not share this sentiment, they knew people who hunted who were opposed to removal of woody vegetation. In the ABR landscape, USFWS had implemented a different program of removing large and old cottonwood trees from its lands in order to eliminate the perches of predators that might attack Prairie Chickens. This program was very unpopular, because of loss of old trees from an area largely devoid of them.

Controlling invasive and undesirable species. The importance of managing weedy and woody species in both conservation reserves and privately owned grassland resonated across interviewees. Several grazers suggested that management of woody and invasive species was a logical nexus for conservation agencies and programs to begin connecting with farmers.

Fire. All of our interviewees responded either positively or neutrally to fire. Some indicated that they perceived fire to be a much more publicly acceptable land management tool than it was a couple of decades ago, although the county commissioners that we interviewed said that they still got calls of complaint from some constituents whenever prescribed fires were implemented. Many interviewees who owned grasslands indicated that, if neighboring conservation agencies were burning their own conservation land, they would be interested in implementing a simultaneous burn on their own grassland as well. Several other interviewees indicated that, while they did not have a problem with fire, they hated to see all that good forage go up in smoke and would rather see grazing used as a restoration tool.

Native prairie seed harvest. Interviewees were less interested in economic and agricultural return from prairie seed harvest than they were from grazing, however many land owners who had native prairie on their land indicated some interest depending on the market and who was implementing the harvesting. Several landowners suggested that they would be willing to allow conservation organizations to harvest seed without payment or as a swap for implementation of various prairie management activities, such as fire, on their land.

Oak savannah restoration and conservation. Across categories, many interviewees were unfamiliar with just what an oak savannah was, but all expressed interest (including strong interest from many) once the concept was explained. Trees in general, and oak trees in particular, resonated as having high value, and interviewees liked the idea that such a beautiful tree species could be consistent with the idea of prairie. Many respondents commented on the aesthetic beauty of oak savannah, indicated that they had oak forests on their properties that were encroached, and expressed interest in programs that would provide technical and cost assistance for savannah restoration.

Easement length. Most of the interviewees that we talked with were opposed to implementation of permanent easements on the landscape, especially easements that prohibited grazing and haying. Interviewees commonly cited growing world population, changes in agricultural technologies and markets, and hesitancy to limit the options of future generations as reasons for opposing permanent contracts. Interviewees indicated that 5-15 years was an ideal tradeoff between permanence and flexibility, with a few respondents indicating that they would consider contracts lasting as long as 30 years.

E. Social Landscape-scale Conservation Strategies

Analysis of interview data in response to the goals of the Minnesota Prairie Plan, as well as the findings of other project areas, reveal many important implications for conservation strategy, management, and policy which are laid out in the following sections.

1. What are we restoring? Rural perspectives on prairie conservation

Connectivity of different habitat and land cover types is an important ecological concept that influenced the landscape-scale focus of this interdisciplinary project and the goals of the Minnesota Prairie Plan. The perspectives of rural stakeholders through interviews add clarity and caveat to the social and ecological efficacy of thinking about conservation and connectivity of prairie and grassland landscapes. The regions of Minnesota formerly comprising prairie ecosystems have been dramatically altered by European settlement and production agriculture. One of the many challenges involved in prairie restoration is that the function of ecological processes such as hydrologic and disturbance regimes, animal movements, and trophic cascades have been fundamentally changed in comparison to their historical counterparts.

While many of the changes induced by humans, such as extensive tillage, channelization of hydrologic features, and eradication of species deemed to compete with agriculture were once thought to have net societal benefits, but the long-term sustainability of Corn Belt agro-ecosystems has increasingly been called into question (Nassauer et al. 2007, Atwell et al. 2011, Liebman et al. 2013). Interest in restoration of prairies and grasslands across landscape scales is motivated by many factors. These include interest in preserving species, history, and culture. In addition, ecological and agronomic research suggests that restoration of perennial vegetation at strategic landscape locations may bolster healthy functioning ecological processes at local, to regional, to continental scales (Schulte et al. 2006, Nassauer et al. 2007, Liebman et al. 2013).

Especially when talking about restoring and conserving grassland and prairie across broad landscape scales, these issues beg the question of: 'restoration of and to what?' The monitoring goals for this project (Chapter 5) offer some possible starting points when considering what type of ecological indicators might correspond with healthy prairie systems in core landscapes, post-European settlement. With the exception of prairie chicken populations in the ABR landscape and lake water quality in the GL landscape, many of these monitoring goals are more focused on working within parcel management, rather than on objectives that cross broad landscape scales. While target butterfly habitat and pollination of key plant species might be improved through management of practices on adjacent parcels, few of these targets entail cross-boundary considerations or connectivity of corridors across landscape scales.

2. Prairie restoration vs. conservation of working grasslands

As stated above, many indicators of functioning prairie ecosystems do not necessarily require landscape scale connectivity. Yet many goals of the Minnesota Prairie Plan focus on maintaining and increasing both the density and connectivity of grassland, wetland, and prairie at landscape scales. The social component of this project offers valuable stakeholder insight into how the broad, landscape-scale visionary goals and the parcel scale ecological monitoring objectives of this initiative do and do not fit together.

Among the rural stakeholders that we interviewed in the ABR and GL landscapes, there is broad potential support for both small-scale prairie conservation and broader-scale grassland conservation. However, our conversations with rural stakeholders suggest critical distinctions between these categories. While the rural stakeholders with whom we spoke exhibited some resonance with the historical, aesthetic, and cultural value of prairie, these values were not strongly voiced across interviewees and generally came out only in response to pictures and questions. Our interviewees rarely showed understanding of the species that make prairie unique or appreciation of the types of management practices and approaches needed to move towards our monitoring goals for each landscape (Chapter 5). In addition, interviewees expressed broad-scale distaste for large tracts of unutilized conservation land devoted to conservation of rare and threatened plant or bird species.

Alternatively, interviewees voiced very strong support for the conservation and expansion of working grasslands on non-productive cropland across broad landscape scales. "Grassland" was a term capable of garnering rural support for a broad-scale vision in ways that "prairie" did not. While stakeholders showed some support for, and little opposition to, enhanced conservation goals – such as restoration of native species or maintenance of water quality through grassland conservation – the value of grassland was based much more on social, economic, and cultural factors. One livestock farmer and opinion leader put the sentiments of many boldly:

"Have a livestock plan to go along with the prairie plan. We need to see that conservation organizations are willing to support all types of farmers, including row crop farmers. The Minnesota Prairie Plan is a great idea, but my fear is that it is going to end up with a whole bunch of shit land that we can't use. We need a comprehensive, holistic idea of how to use land so it doesn't devolve into everybody has their own idea of what prairie is supposed to be in each agency."

In some instances, the convenience and potential flexibility offered to livestock producers through grazing cattle on neighboring conservation lands does suggest some cultural efficacy to the potential importance of adjacency of conservation grasslands parcels. However, while farmers showed support for working grasslands at large scales, analysis of interview data suggests that broad scale rural support for 'prairie connectivity' is lacking for a number of reasons.

First, in a privately owned and operated working landscape, connecting patches of conservation land is difficult to coordinate. Second, the rural people that we interviewed voiced concern about what they perceived as imperialistic and romantic conservation ideals of outsiders – including urbanites and wealthy out of state donors – resulting in large-scale or systematic removal of land from agricultural production and the tax roll. Third, interviewees voiced concern that current conservation lands, including prairie remnants, in both the ABR and GL landscapes are often of fairly low quality. In relationship to the monitoring goals laid out in Chapter 5, rural perspective may not be too far off.

This lack of rural support for connectivity in prairie and grassland landscapes suggests that conservation land managers should carefully consider when, where, and to what degree parcel adjacency is necessary to achieve desired outcomes.

3. Tradeoffs in investment of limited conservation resources and staff

One farmer and county commissioner whom we interviewed suggested that conservation organizations might direct their limited resources towards better management of the land that they currently own, rather than acquiring new land only to let it sit idle and become encroached by weeds and woody vegetation. Given the current rapid conversion of grassland to cropland, conservation organizations might disagree and prioritize increased protection over improved management. However, this commissioner's comments align closely with many of the monitoring goals developed in this project (Chapter 5). What interview data does make clear is that there is a tradeoff in management of staff and resources among a) acquiring and placing additional prairie under protection, b) enhancing management of grassland and prairie currently under protection, and c) building the types of cross-boundary partnerships and collaborative efforts needed to support landscape-scale networks of working grassland, wetland, and prairie. Conservation agencies are currently perceived to be much more capable of a) acquisition and easements than b) effective management, while c) landscape scale collaboration is perceived to be largely lacking.

Implementing landscape-scale networks of working grasslands across privately owned lands in western Minnesota can only happen through broad-scale partnerships and cooperation among multi-level stakeholder groups. This entails implementation of a different set of strategies and resources than those commonly used for parcel by parcel acquisition and restoration. First and foremost, interview data suggests that on the ground conservation personnel are needed who are skilled and well trained in working with land owners, farm operators, opinion leaders, and local decision-makers to accomplish mutually beneficial cross-boundary objectives.

In the past, many conservation land managers have primarily worked to implement practices on lands owned by conservation organizations. Interviews indicate that many farmers in and around core landscapes are eager to partner with conservation personnel and assist in actual implementation of conservation management practices – both on a voluntary and contract basis. Across interview categories, rural people do *not* feel that the primary duty of conservation personnel should be to implement practices. They often feel that, given proper support and guidance, they or the people who farm for them, are better prepared to implement management practices than are conservation personnel. Rather, they want conservation personnel who are skilled in the following characteristics of facilitative leadership:

a) Investment in forming local relationships marked by a give and take flow of knowledge
b) Willingness to work flexibly with individuals to adapt programs to fit the agricultural and conservation particulars of certain pieces of land and the values of land owners and operators.
c) Awareness of how coupled social, economic, and ecological challenges are impacting rural communities
d) Technical assistance and guidance
e) Knowledge of how to access program benefits and cost-share opportunities
f) Facilitation of dialogue and collaborative partnerships between agricultural and conservation entities
g) Scientific and adaptive monitoring expertise to help individuals and communities determine if the practices that they are implementing are working

Building this skill set within the conservation community will entail investment in additional strategy, training, and personnel in conservation organizations. These organizations should carefully consider the resources needed to successfully accomplish broad, landscape-scale cross-goals. In some landscapes, parcel-by-parcel initiatives focused on acquisitions, easements, and management of the highest quality parcels may be sufficient to achieve most objectives. In other landscapes, objectives may justify the additional investment needed to conserve broad networks of working grasslands (see discussion of comparative landscape strategies below).

4. Connecting with individual values through social norms and networks

Among the facilitative leadership qualities listed above, the most significant factor voiced by farmers for making a positive conservation decision is supportive local personnel who invest in relationships and provide customized service and technical support. Despite general rural distaste for federal government control over local resources, interviewees in our study areas consistently pointed to the work of local USFWS personnel as being particularly helpful for a number of different reasons.

First, the 'private lands biologists' who work in these areas have reached out to stakeholders on a person-to-person basis and formed relationships characterized by reciprocal sharing of information. This allows formation of local social knowledge among land managers, which is particularly important in informing conservation in privately owned landscapes where it can be difficult to know which owner or operator might make a conservation decision on any given parcel of land without developing personal relationships with the parties involved.

Second, the USFWS personnel in our study areas had longer-term tenure in an area compared to personnel in other agencies, which allows them to get to know the producers over time. Often interviewees spoke of getting to know conservation personnel by running into them in indirect ways, such as this farmer and township board member's perspective on his relationship with a local USFWS land manager:

"[Local USFWS land manager] has been here a long time, and the reason that I know him is that he has been counting ducks here for about the last 25 years, so I have gotten to know him pretty well."

Third, USFWS easement programs were seen as being flexible to meet the needs of individual landowners and farm operators and their particular pieces of land. One livestock producer and opinion leader commented on his experience:

"Ease and complexity – if it is going to create me more headaches than what it is worth, then I would rather just go out there and do it myself. I'd rather be out working than sitting here trying to do the paperwork. I'll just pay for it myself!

I like working with [USFWS land manager] because he is flexible, and tries to minimize it, and keeps everything pretty simple. You know, and he does all the paperwork, and all you have to do is go in and you know, 'Here, does it look all right? OK, sign it and give me some cows!' I've done some EQUIP work with some of these water projects, and some of that stuff just gets to be so...[sigh], and then it has been done to their specs."

Finally, USFWS has implemented programs on private lands across landscape scales, such as removal of encroaching cedars, which are popular with the public and are seen as having both socio-economic and ecological benefits for rural communities.

Just the process of listening to perspectives of rural stakeholders through interviews led to sharing of mutual understanding and trust, and opened the door to possible future connections. For instance, one skeptical rural resident and landowner declined to be interviewed at the beginning of a phone conversation and began a litany of complaints about how conservation organizations were operating in his locale. The interviewer listened attentively and expressed interest in understanding this resident's perspective. Ten minutes later, at the end of the conversation, the resident invited,

"I'm just telling you how I see it. Stop by whenever you are out here and I'd be happy to give you another earful (laughing)."

A relationship was formed that could lead to a future conservation partnership.

5. Agency coordination: synching strategies and presenting a common front

Interviews reveal a number of different ways in which increased coordination among conservation organizations groups could more efficiently utilize collective resources to leverage mutually beneficial conservation outcomes. Landowners and producers currently voice confusion and frustration about the lack of coordination among conservation entities and programs. In particular, programs and personnel differ in their encouragement of haying, grazing, and other management practices that provide economic return on conservation lands. One producer's comment echoes the challenges of many to understand what conservation options are available on his land across agencies and programs:

"Some conservation agents with the DNR have been out trying to get me to do a prairie bank easement. In the past, I have worked with USWFS more than DNR. You get $200 more per acre if you don't keep the grazing option in the prairie bank easement and the DNR people seemed to be against grazing. They wanted just prairie. But now USFWS and TNC seem to be in favor of grazing... I kinda feel caught between all these different organizations."

Other interviewees expressed frustration that individual land managers, even within the same organization, often seem more motivated by personal pet projects and philosophies rather than interfacing with landowners and producers to meet the unique needs of their lands and operations. A livestock farmer and grassland owner put it this way,

"Well, the DNR Land Owner Incentive Program, the idea is to help people who have native prairie take better care of it. And Brice [alias for a DNR conservation agent] is the one I work with, and he is real nice, but I didn't always agree with some of the things that he is trying to push, because he would listen to somebody [meaning somebody else's set philosophy or approach], and then he would think, well that is what we have to do. And I would be, 'Now wait a minute, this isn't going to work.' But you can't tell him anything!

Originally, what I wanted out of the deal was leafy spurge control, because I got leafy spurge everywhere, and it is just overwhelming. Well, we ended up doing just about anything but that. And I did, eventually, get some help with that, but we got into a lot of other things that just didn't work out.

In the DNR... everyone has their own ideas, and they argue back and forth, and the USFWS has their own ideas, and they argue back and forth with the DNR about how things should be done."

In addition, different agencies have different strengths and weakness and better and worse connections with different types of stakeholders in different areas. However, agencies may not understand the relative advantages and disadvantages of their unique missions, capabilities, reputations, and jurisdictions. This leads stakeholders to express a sense of unnecessary competition and lack of coordination among management entities. The result is that stakeholders become confused about who to talk with, who to trust, and what conservation options are available on their lands. Conservation resources could be better implemented if organizations worked together to identify relative strengths and weaknesses, as well as to understand what tools and approaches each organization can offer constituents and what gaps in local and regional conservation toolboxes need to be filled.

In particular, interviewees voiced frustration that many incentives associated with conservation easements reward restriction of economic activity and management practices (such as limited haying and grazing), but these easements currently cannot come close to competing with returns from cropland. A wide variety of both permanent and fixed term (e.g., 3, 5, 12, and 30 year) easement programs were desired that allow economic and management activities that are agreed to be mutually beneficial by land owners, farmers, and conservation personnel.

Farmers indicate willingness to share the cost of technologies, practices, and infrastructure necessary to implement conservation grazing management practices at rates inversely proportional to potential economic return. USDA EQUIP and USFWS Working Land Initiative programs currently fund many practices. Greater awareness of these programs is needed among landowners, farmers, and conservation personnel. Additional cost-share programs are needed to cover practices deemed beneficial at local levels that do not qualify for federal assistance.

6. Strategic coalitions between agriculture and conservation entities

Across interviewee categories, but especially among rural opinion leaders and farm operators, a strong desire was expressed to overcome historical divides between agricultural and conservation interests through mutual understanding of differences and greater collaboration around shared goals. Interviewees expressed that working grassland landscapes, and the livelihoods, cultures, and ecological outcomes that depend upon grass, are in all jeopardy. The timely sense of this crisis was expressed repeatedly, as was the awareness that there was much work to be done. Interviewees emphasized the sentiment that such partnerships must begin with extensive dialogue and mutual listening, but move quickly towards shared, collaborative, and even experimental plans of action. While such partnerships presented risks and challenges to both camps, several emphasized that the grassland crisis put both livestock producers and conservation entities in a situation where innovative and potentially risky avenues must be found to accomplish desired goals. It was felt that only by pooling resources and working together could conservation and agricultural entities hope to accomplish mutual goals. Three young crop and livestock farmers and local opinion leaders we talked with expressed the following similar sentiments:

"Yes, I think that there is an opportunity there, but people don't realize what the opportunity is. It is an untapped resource. It is something that is different than what your current business is. You don't realize – 'Hey, this land that was in CRP could be utilized better as another business entity for our farm.' If you don't see that potential, there aren't too many people actively driving around the country saying, 'Oh wow, that is a beautiful piece of grassland, maybe I could do such and such with this land.' They just see – 'Duck, pheasant, wasteland, no public return, no return to the tax base.' They see a much different picture. But if you can bring a different perspective to that, well then, 'Let's take a look at that again, let's go for another drive and see what we see'...

The biggest thing is to work together to make sure you get all the team members at the table who have a stake in what is going on, because if you don't include all the members at the table, you are just going to continue to fight and butt heads. It's got to be a compromise and a team approach."

"I'll bet you, if you put a bunch of Concerned Citizens [an environmental group] in a room, and made them write down their concerns, and then you took a bunch of guys like me and did the same thing and said, you know, 'write down your concerns,' and then you took both lists and mix them up so that you didn't know which one was which, I'll bet you would have a hell of a hard time figuring out which one was which, and whose was what. Because we all have the same thing, you know, they don't want pollution, we don't want pollution.

So O.K. then, what is the big problem? We are on the same page I would say, so then why all the problem? Is it just a lack of understanding or discussion on both sides? What is the problem? Because, I don't think it is an insurmountable issue. You know, you get the hard line super-hunters who go, 'Jeeze, you can't have a [domestic animal] track out here till I show up for hunting [in the fall] because you are going to disturb the wildlife.' Well, I'm gonna say that that is not right. But then you got the other side that says, 'Whatever you do [with your agriculture operation] doesn't matter.' Well, you know, it is somewhere in the middle, guys. And I think that the more they just kinda get together.

And the more successful situations that you get going – see, you got to have a situation you can point to. And there might be some wrong moves made in that situation, but the whole time you are moving forward and you are moving ahead. So at some point you can say, look at here. Yep, we might have grazed a little too long when it was dry, and we got to learn better what to do with some of those times. But look at this, look at what is happening. We are getting benefits. We are keeping down invasive species, woody species, things like that.

And the other thing is, everybody has got to be realistic about what we are trying to do. Because I have heard, you know, we want to all get this back to how it was prior to settlers here. OK, well, here is a goofy thing. Whenever you see an old time picture, whether you are down in the cities, or go to Glenwood, or wherever you are at, the one thing I have started noticing the last few years is how few trees there were. I mean, down by the cities, they have all the old mansions of the day, and they are all on the bluff of the river, so in the background, you can see a long way, and there is like no trees! The ones that were there are just little dinky... it was the prairie! And then you start putting two and two together and read the geological stuff, and there just weren't many trees. Yes, you had the oak savannah, but you didn't have box elders, you didn't have a lot of maple trees down in this area. It was really pretty desolate really.

So what I'm getting at is, what are we looking for? If we have, quack grass out in the grazing area, is that OK? Or should it be a warm season Indian grass? What really are we shooting for here?"

"I think a lot of the push back [against conservation and environmental concerns in the agricultural community] that you get is fear. Conservation has a history of being completely at opposite point of view from what productive agriculture is. And it seems like it is too extreme. And there hasn't been willingness for both parties to come together and sit down at the same table and discuss it. And I think that there tends to be the extremists who speak publically, but don't understand where the food source comes from. You know, we want cheap food, but we don't want it on every acre. And those two things just don't go together."

"We are working for a common goal, and that's where I think that both the conservation side and the mid-sized farmer don't understand that. We need to get that line out of the sand and start working together. You know, our generation needs to do that."

The grassland management goals of farm owners/operators and conservation personnel overlap, but are different. Both of these groups emphasized the need for clear goals and plans that utilize adaptive knowledge and practices tailored to conditions, climates, technologies, and economics that are dynamic and locally variable. Flexibility and adaptive management at grassroots levels were considered necessary characteristics of conservation partnerships where conservation objectives may need to change over time and where dependable economic return is required to maintain farmer livelihoods.

Many farmers indicated a desire to become more involved in implementation of conservation practices, and often considered themselves better equipped than conservation personnel to implement large-scale restoration and management activities. What they needed to make such partnerships successful were available local personnel with whom they could dialogue to develop mutually beneficial farm and landscape level management plans.

7. The role of conservation reserves in grassland landscapes

Rural stakeholders and conservation personnel that we spoke with often talked about the very different and antagonistic roles of working agricultural lands compared with conservation reserves. However, many of our respondents in both camps expressed interest in more integrated landscapes where some conservation reserves were used for appropriate forms of agricultural production (e.g., haying and grazing) and some private working agricultural lands included more conservation benefits. It has been proposed that working models of integrated production and conservation activities on reserves may act as catalysts and experimental crucibles for cross-boundary landscape management initiatives (Miller et al. 2012). Our interview data supports the efficacy of such an approach. Interviewees who grazed cattle on USFWS, Minnesota DNR, or TNC conservation lands spoke highly of these partnerships and often shared increased interest in grassland, wetland, and prairie conservation objectives on both their own lands and across the broader landscape as a result of these partnerships. While conservation reserves of particularly high quality or containing sensitive and threatened species may be better managed for purely conservation objectives, goals on many reserves should include catalyzing and developing practices and partnerships that can be implemented throughout surrounding landscapes.

8. Reverse education

While conservation organizations often see outreach and education aimed at increasing understanding of conservation objectives among stakeholders as part of their mission, our interviewees repeatedly spoke of education in a different way. Interviewees considered locals and farmers to be the 'first conservationists' and have the necessary local knowledge to successfully implement conservation objectives. When asked what conservation organizations could do to help accomplish mutually beneficial grassland goals, our interviewees spoke of the importance of conservation entities 'educating' their urban constituents and broader donor base about the potential compatibility of agricultural and ecological outcomes. Rural people generally felt that they were often blamed for environmental issues that were also perpetrated by urbanites and/or larger sectors of consumer-oriented American society. The rural people we spoke with generally voiced enthusiasm for conservation-agricultural partnerships, but felt that many non-rural environmental constituents had negative stereotypes towards agriculture that partner conservation organizations could work to change.

F. Value-added Socioeconomic Strategies to Bolster Grassland Conservation

Among the landowners and producers with whom we spoke, we found varying levels of interest in adopting new and innovative practices associated with land use transitions. While some producers voiced resistance to making large changes in their operations, several others indicated excitement and willingness to forge new partnerships and experiment with new practices. Among our interviewees, younger farmers, larger more business-oriented producers, and farmers who had livestock were the most likely to express interest in experimenting with new management practices and changes in their operation. The following strategies emerged as particularly promising ways to simultaneously bolster conservation objectives while also advancing rural socio-economic vitality in culturally feasible ways.

1. Value to the community of integrated, independent crop & livestock farms

Among our interviewees, livestock producers were the subset of the rural population most invested in maintenance of grassland. The economic challenges facing grassland conservation similarly affect farmers who are heavily invested in grazing to bring livestock to weight on grass, a practice which is increasingly cost effective compared to feeding corn. Historically, the pasture base utilized by these producers has been concentrated on marginal cropland. However, current crop prices and land rates offer incentives for landowners to make a short-term economic gain by renting these marginal lands to crop farmers. As a result, livestock producers are being outbid on land and are losing access to pasture. Without enough land to maintain an economically viable herd, these producers are being pushed to either liquidate their cattle assets or to increase stocking density on remaining pastures and increase use of purchased feed.

Many interviewees, including but not limited to livestock farmers, mourned the loss of dairy and livestock industries because they see these entities as buying more local inputs and services per unit land area than crop farmers. They also argue that livestock/dairy tends to support more independent farmers or family incomes per unit land than does crop farming. Several interviewees argued that integrated crop and animal operations benefit rural communities much more than crop farming, at least on a per unit land basis. Consider the logic of one farmer and opinion leader:

“Livestock has such a tremendous return for the community compared to grain. Livestock is so labor intensive that you are not going to have absentee landowners. You are going to have operators who need to be around the livestock 100% of the time, spending money locally, buying their products locally. If you look at how many times a dollar turns over for a livestock operation in the community: equipment, feed purchases, veterinary bills. You have stable families, people aren't just coming in, farming a chunk of land, going over to the next county, farming a chunk of land there. That equipment can be mobile. But you bring livestock into a community, you have got to be around. That means you are planting a family in a community, putting kids in your schools, and shopping locally. Plus, environmentally, you are utilizing manure as a fertilizer, which helps with water quality and soil retention. It is a much more positive environmental impact versus commercial fertilizer in that respect.”

Many interviewees also suggested that once a community loses a certain threshold of animal producers, the infrastructure to support these producers dries up and is hard to get back, and many producers feel as though western Minnesota’s agricultural communities have either crossed or are precipitously close to crossing this threshold. Another farmer told a story about the importance of livestock for local communities and emphasized the timely crisis affecting the livestock industry:

“Dad and I used to drive feeder pigs out across five states: Minnesota, North Dakota, South Dakota, Iowa, and Wisconsin. In South Dakota, no matter what time you got there, even in the middle of the night, they would help you and feed you. But in Iowa, they didn't help at all; Iowa had already got more cropland. And you could see the trend – the more cropland, the more competitive, whereas the more livestock, the more neighborly it was. From my point of view, that still holds true. If you are doing livestock, you like the work to some extent or another or you wouldn't do it...

The problem is, cattle producers are getting squeezed from both sides. On one hand, we got the conservation community trying to buy prime grasslands and take them out of production. On the other hand, we got row crop producers buying up land left and right at prices that grazers can't afford, in order to plow the land under and put it into row crop. Then there are government programs like CRP that give people from the city incentive to buy land to set it aside for private hunting reserves. All we have left is a bunch of piecemeal grazing land, and whenever a piece of land comes up for sale, it gets snatched up right away.

Once you lose the base of cattle producers on the land, and the infrastructure for that industry, that segment of the social fabric and economy of rural communities is not going to come back. We have a limited window of time. This is happening now. With current trends in corn prices and land coming out of CRP, we don't have a few years; the time to act is now."

It is important to note that these interviewees are not talking about purely pasture-based animal systems. Rather, they are talking about an integrated combination of pasture, feed-lot, and mid-sized CAFO operations. This is important, because often groups interested in conservation, environment, and sustainable agriculture concerns stereotype and lump farms and farmers into much different categories: with rotational pasture systems on one end of the spectrum and CAFO/feedlot/crop farms on the other. But the rural stakeholders that we talked with in this study make a different distinction that is more economic/social in nature, but still quite meaningful. For them, the important characteristic of the integrated animal-crop systems is not the scale of operations, but rather that are independently owned. Their point is not only the bottom line associated with economic return per acre, but also how much of the lifecycle of the revenue stays local and goes to independent producers and local business.

The opportunity and question that really intrigues interviewees who valued integrated crop and livestock operations is based on their perception that the livestock business is teetering on the brink right now – both of potential demise, but also, for some of them, a potential revival. These producers all see both crop and livestock agriculture in a time of unknown transition. And when they think of all the grassland in core landscape areas and add to that the increasingly prohibitive high price of feeding grain to cattle, these interviewees think, 'what if we were using that grassland more efficiently and effectively.'

Research is needed that further investigates the full lifecycle benefits and future socio-economic feasibility of integrated crop and livestock systems for rural communities, as are conservation strategies that augment the potential of such operations.

2. Coordinated conservation grazing and haying partnerships

Eighteen of the twenty-one livestock producers that we talked with voiced an interest in partnerships with conservation organizations that would allow access to leasing additional grazing land. In return, these producers indicate willingness to implement better conservation grazing practices on their privately owned and rented lands. Of the ten non-farm landowners that we talked with, nine indicated an interest in partnerships that would enable conservation grazing on their privately owned lands. Currently, grazing practices, rental agreements, and access to conservation lands vary on a case-by-case basis. Both landowners and producers who rent land voiced a need for an entity that could develop conservation grazing plans and broker cooperative grazing partnerships that span landscape boundaries. One producer described the need this way:

“I would like someone who you could get a hold of in those agencies to help a guy out with being able to graze or pasture grassland. You know me, I'd jump through just about any hoop they wanted me to jump through, just as long as there was someone there who told me what hoops needed to be jumped through! You know, even if there was like one guy you could go to in the whole state, who could go to local land managers, or whoever, who could show them what the state was thinking, and that maybe this isn't all bad, instead of getting a flat 'No,' because it's too involving for them, or they don't know where to go, or they are afraid they will get into trouble. ‘Cause if I had one of them jobs, and someone was pestering me to put cattle on this grass, I might think well, that's extra work for me, and I might get in trouble for it, you know, ‘I ain't going there.’ You kinda need someone to go to, you know, a guy who knows how to get it done. You know, a third party could go and talk to the local Conservancy people to show them that what they are doing is not out of the bounds where, you know, they'll get in trouble. And then go to that local rancher and tell him, you know, these are some of the things you need to do to make it work.

In fact, I think that is the only way that some of these things are going to work out, because, people in these government positions are just scared to do anything, or else they don't want to do anything. Because, if their burning practices are working for all the higher ups on their chain of command, then why would you want to do something more involving? Because if you are going to work with a rancher to put cattle out there, then that is going to require more of your time. To me, that third party guy would be helping the rancher, but he would also be knowledgeable about the answers to make it work for both sides, someone that can show you the hoops, you know, the do's and don'ts of what does and doesn't work.”

Outcomes of conservation grazing could include more acres in quality grassland, less acres plowed, and increased support among rural residents for grassland conservation. Among interviewees, current participants in conservation grazing programs were among the most invested in grassland and prairie conservation and the most knowledgeable about native prairie species and warm season grasses. Our interviewees envisioned the following considerations as an important part of successful conservation grazing partnerships.

Cooperative vs. coordinated grazing. Many non-farm landowners indicated that it would be helpful to have a third party entity coordinating relationships with livestock farmers who rented their land for grazing in order to help push grazers to more conservation-oriented grazing plans. Other landowners who did not currently have cattle on their land also responded positively to the idea that a conservation organization might help broker partnerships between grazers and landowners to achieve conservation outcomes.

Livestock producers had more nuanced ideas about such third party management and the concept that multiple owners might pool cattle in a common herd on the same land. Some producers liked the idea of a third party entity managing partnerships, while others indicated that it was simpler and easier to manage partnerships on their own. No livestock producers that we interviewed were comfortable pooling cattle with a number of different owners and leaving management decisions to a third party entity. Producers indicated that part of what kept them in the livestock industry was the challenges and unique approaches that they had developed to manage their herd over time. In addition, producers pointed to different breeds of cattle and varied timing of breeding and calving strategies as factors that would make pooling cattle difficult. Most producers did not want to compromise the uniqueness of their operation to accommodate more cooperative models of conservation grazing in which herds might be pooled. Instead, producers preferred small partnerships where one to three producers might partner with one to several landowners or conservation organizations to coordinate timing of rotation across several properties, parcels, or management units. In several instances, producers volunteered that they would be willing to partner with one to two specific producers with whom they were confident they could work compatibly to meet the grazing needs of conservation organizations.

Duration of grazing. Livestock producers emphasized that, in order to make it worth their while to move cattle into an area, they needed to be able to count on at least 30-45 days of grazing on that parcel, although being in an area for a whole growing season was deemed ideal. Most producers indicated that they would be willing to subdivide and rotate cattle within a parcel once every few days to once every week. Several producers who owned land adjacent to conservation land indicated a willingness to turn cattle out into this land for shorter durations if necessary to meet the goals of conservation managers.

Fencing and water. Most livestock producers indicated that high quality outer fences and watering systems were key to the success of grazing partnerships. Producers usually preferred that the landowner provide the fencing materials, install, and own the original exterior fence. Nearly all producers indicated a willingness to install and move temporary electric interior fences and maintain outer fences in trade for reduced rates on grazing leases. Some producers said that they would be willing to do all the fencing work in return for reduced grazing lease rates. A few of the producers that we talked to had obtained technical and financial assistance through consultation with NRCS grazing specialists and cost-share funding through USDA's EQUIP program that enabled them to implement fencing and watering systems. However, many other producers were unaware or only vaguely aware of these resources.

Transportation. Producers voiced varying levels of comfort with and willingness to truck cattle or drive them down rural highways and gravel roads. Some said that moving cattle at all was just too much hassle. Many producers were willing to move cattle 15-30 miles if they could graze cattle for at least 30-45 days. Others, including a couple of producers who owned their own trucks and trailers, indicated a willingness to move their own or others' cattle longer distances. Some producers were very comfortable herding cattle down rural back roads or even down county highways. Others were very hesitant to herd cattle even short distances. A few producers emphasized that, if cattle were going to be moved in and out of areas for short durations on a regular basis, some type of corral would be desirable.

Rotation. Livestock producers often discussed rotational grazing as a new and spreading agricultural 'technology.' Many producers indicated an interest in implementing greater rotational practices on their own land, but had not yet been sufficiently motivated to spend the time, effort, and expense to act on their interest. Other producers with whom we talked had recently implemented rotational systems and talked positively or optimistically about benefits to their operation. Common positive outcomes of rotational grazing mentioned by farmers included greater forage quality and yield, disease control, and nutrient cycling.

Contract length. Livestock producers indicated that, in order to best plan the size and timing of their herds, it would be ideal to enter into 3-5 year contracts with landowners who want conservation grazing on their land. When contracts were implemented on a seasonal or yearly basis, farmers felt that it was difficult to plan for the next year. Contracts longer than five years were seen as placing too much burden on both owners and operators.

Flexibility. Both conservation managers and agricultural producers indicated that grazing agreements needed to have flexibility built in so that both parties can respond to changing climatic conditions, management feedback loops, and adaptive producer and conservation goals. As such, both parties emphasized that while contracts were necessary, they were no substitute for working partnerships based around on the ground relationships of trust and open communication about the shared and competing goals of conservation land managers and producers.

Marketing. Most livestock producers with whom we talked sell their calves to be fattened to finishing weight somewhere else. This approach allows them more flexibility in responding to seasonal, weather-related, and market changes in feed availability. None of the livestock producers with whom we spoke were interested in selling their cattle through niche markets such as 'grass fed' or 'organic' for premium prices. This was, in part, due to the elitist stigma associated with these markets in rural culture.

Research. Both livestock producers and conservation land managers voiced the need for more adaptive management research to help determine approaches that would allow maximal forage opportunity for producers while achieving desired conservation outcomes.

3. Precision agriculture and conservation targeting

In this study, a few of the larger crop farmers with whom we talked identified an important potential connection between conservation targeting and precision agriculture. One young farmer and opinion leader who ran a large farming operation and business dedicated to risk-management strategies associated with row-crop farming spoke particularly eloquently about this opportunity. This farmer suggested that he and other farmers like him have a lot of data from precision and GPS approaches to agriculture that were not available a decade ago. These data allow farmers to understand, across very small spatial scales, which land produces a good yield consistently, and which land does not. Because operators who farm a lot of land often have high input costs and slim profit margins on a per acre basis, it is increasingly important to 'mitigate risk' by only farming land that meets certain probability thresholds for good yield. This producer indicated that, in and around prairie core areas, there is plenty of land that is below ideal thresholds. This farmer indicated that he personally had no interest in participating in government conservation programs because of associated restrictions and red tape regardless of potential financial gain. However, he indicated that he would be happy to work with conservation personnel to help himself and his landowner clients better understand what the most ecologically and culturally appropriate uses for these suboptimal lands might be. This farmer emphasized the future importance of maximizing agricultural production on good cropland and using subprime land to mitigate the environmental and social damage or risk that will continue to occur due to high-production approaches to agriculture. In this producer's words:

"And what we want to do is take out the best land and make it even more efficient, and then mitigate [our environmental impact] on the marginal land. Mitigation is the number one tool that we need to work successfully with conservation and change the idea that somebody is winning and somebody is losing – mitigation of farmable wetlands, or stuff like that where, basically, we can take marginal land that yes, we can farm through every year, but we are raising a zero to seventy-five percent crop. We need to be able to go to a wetland bank, or take one of our own pieces of land and say, OK, we are going to create a wetland here, and then we are going to have a farmable wetland on this field [that can be farmed through]. And then we are going to have a quarter or a half section, or a forty that is just conservation. And that is in an area where we can create buffer zones of the water coming through so that we can have some benefit from it."

This farmer also emphasized that it is often not in a producer's best interest to farm marginal cropland. However, many producers receive pressure from landowners who want to receive rent off of all of their acres. This producer told the following story and emphasized that one role of conservation organizations might be to help producers justify alternative uses for sub-prime farmland:

"A piece of a landowner's CRP comes out and they won't accept it back in, so he goes to the tenant and says, 'if you are going to give me $150 per acre for my good land, I need $100 per acre for that CRP ground.' So the farm operator is forced to farm land that shouldn't be farmed. And they aren't excited about it. There are a few guys out there chasing anything they can to break up, but the average guy is sitting here going, 'As soon as things get dry again or the winds come up, this land that has been in CRP should be in CRP.' That is the biggest concern I see is just funds available to renew CRP contracts, because if they were just competitive – they don't even have to be top dollar – that land would stay there... And it is forcing a farmer to take more risk on a lower productive ground that he doesn't necessarily want, just so he can have acres... Because what the landowner says to the tenant is that, if I give this to someone else to farm, next thing that guy is going to come after all the rest of your land [it is a veiled threat]. As a defensive mechanism, it forces you to take on lower productivity land for risk management, knowing good and well that that land is not something that you want or need in your operation."

4. Using cover crops to re-integrate crop and livestock systems

Several producers with whom we talked indicated that high crop prices were ushering in a period of transition that was leading to decentralization of the livestock industry. They perceived that, into the future, it might be more beneficial to producers to bring cattle to weight on grass and alternative feed stocks rather than feeding grain in large feedlots. Among the strategies being considered by producers to re-integrate livestock into their operations, one that was perceived to be most promising economically and ecologically, was creative use of cover crops to maximize off-season forage for livestock.

For instance, two interviewees who were large crop and livestock farmers had been experimenting with inter-seeding a cover crop such as winter rye into a mid-season corn crop with a cultivator/planter or into late-season corn via airplane. This would allow a winter cover crop to become established without competing with the corn crop that already had a competitive advantage. But once the corn was harvested the already established winter cover crop would quickly release and mature, creating a viable level of forage for winter grazing. Once harvest was complete, these producers would graze cattle on corn stubble and the cover crop. By spreading supplemental feed in areas most in need of manure fertilizer, these producers controlled where the cattle spent more time and distributed nutrients. Both utilized byproducts such as distilled grains from ethanol plants or beet pulp to meet cattle's nutritional requirements.

These farmers envisioned that, into the future, this solution of winter grazing might create a dynamic winter complement to conservation grazing during the growing season. One of these producers was also experimenting with a two-year rotation that included shorter duration cash crops such as sweet corn and peas in order to allow more time for inter-seeded cover crops to mature in preparation for winter grazing. Such approaches to using cover crops to provide winter forage for cattle may help provide viable, cost-effective ways to graze cattle year-round, especially on nearby highly perennial prairie core landscapes with abundant summer grazing opportunities.

G. Comparative Social-Ecological Targeting Strategies in the ABR and GL Landscapes

Social landscape analysis revealed differences in socio-economic and cultural makeup between the two landscapes compared in this project that have implications for conservation strategy and management. Here we discuss these differences as well as their management implications in conjunction with findings from other project sections.

1. Agassiz Beach Ridges (ABR) landscape

The gravelly soils of the beach ridges in the ABR landscape are known to local farmer owners and operators as areas often more suitable to livestock production and gravel quarries than to crop farming. However, the beach ridges do not stand out visually from their surrounding landscapes and seem to go largely unnoticed by others in the area. The larger public has some knowledge of the conservation importance of the prairie chicken population and the hiking trails through prairies at Buffalo River State Park, but the conservation value of remnant prairies and gravely ridges in this area were not widely known or valued by those who do not farm or own land in their midst.

While the gravely ridges have historically been considered largely un-tillable and crop agriculture has been confined to troughs between ridges and the surrounding landscape, new seed stocks, larger farming equipment, and high crop prices are leading to more attempts to farm beach ridge land. Many interviewees recognized and were concerned that much land in the beach ridges and throughout surrounding landscapes that used to be grazed or in the Conservation Reserve Program (CRP) is now being transitioned into crop production. Several producers and opinion leaders in this area complained that the federal Farm Bill crop insurance program is encouraging farmers to take short-term risks on farming marginal cropland that would have higher long-term ecological and economic value if left in grass.

Compared to the GL landscape, people in the ABR area were much more difficult to get a hold of by phone, less likely to return calls, and refused more often to be interviewed (Table 18). In addition, we talked with more interviewees in this region who were both very critical of conservation organizations' approaches while simultaneously expressing less understanding of conservation objectives and strategies. As one producer exclaimed when asked if he saw conservation organizations doing anything positive to manage land in the area:

"You tell me, what *are* they doing!? Put it [conservation land] back in the general fund [by this he means the tax base] and start paying for it! Give it back to the people. It would be nice to see that land getting grazed or used for something. It's no good, it's not helping anyone!"

In addition, interviewees tended to be less active in agricultural and conservation organizations than in the GL landscape.

While attitudes towards conservation in the ABR landscape were generally more negative or skeptical than in the GL landscape, ABR had much higher densities of remnant prairie, both in and out of permanent protection (Table 16 and Table 17). Landholdings per owner and parcel size tended to be significantly larger in the ABR landscape. Notably, a significant proportion of sizable prairie remnants not currently in permanent protection were owned by about a dozen owners, and three landowners accounted for nearly half of the unprotected remnant prairie in the Felton Prairie CLMA Area (Figure 25 see page 67). Many of the other unprotected prairie remnants were owned or rented by livestock producers who expressed varying levels of interest in conservation grazing partnerships.

Our analysis suggests that, currently, conservation resources in the ABR landscape would be best invested in trying to develop relationships with key landowners and farm operators rather than forming more broad scale partnerships with stakeholder groups focused on 'prairie conservation.' Local perception that conservation organizations are targeting this area for future prairie initiatives may lead to concern about additional land being taken out of production and suspicion of the goals of outsiders. Conservation entities should coordinate efforts to avoid multiple agencies 'over-contacting' and jeopardizing sensitive relationships with key landowners.

In the ABR landscape, investing in relationships with carefully chosen landowners, farm operators, and opinion leaders in conservation partnerships may increase the cultural understanding surrounding, and acceptability of, prairie conservation goals. Over time, this may increase cultural readiness for more visible collaboration between agricultural and conservation entities. Comparatively, working more visibly with crop farmers and farm organizations to develop 'working grassland conservation' initiatives that offer more flexible options and less restriction of grazing and haying than is currently the case with the Conservation Reserve Program would likely be well-received in this area.

2. Glacial Lakes (GL) core landscape

Although the GL landscape has less protected and privately owned acres of remnant prairie than does the ABR landscape, it's rolling glacial hills, lakes, and diverse terrain were much more readily recognized as having great aesthetic and pragmatic value among interviewees. Parcels and landholding are smaller in GL than in ABR (Table 16 and Table 17), meaning that there are many more farm owners and operators with whom conservation mangers need to work to meet conservation objectives.

In addition, where conservation efforts seem little known or understood in the ABR landscape, in GL there is a long and politically charged history of both antagonistic and cooperative relationships between agricultural and environmental groups. This history dates back to lawsuits and county policies pushed by a group of citizens concerned about the impacts of livestock production on local water quality beginning in the 1980's. This history and public recognition of the value of the area's natural resources have led to highly organized agricultural and conservation groups who have mobilized over the past two decades to protect their interests. Especially in Pope County, concern is high over the increasing density of non-productive and poorly managed conservation land in certain townships. Many interviewees perceive that local farmers are being outbid on land by conservation organizations and absentee buyers who want the land for hunting and recreation. Concern is also abundant that land is being taken off the tax role at the same time that small towns face dwindling populations and commerce, effectively increasing the tax burden on fewer residents.

Despite these challenges, different types of partnerships between two distinctive groups of local stakeholders present significant potential opportunities for broad gains in prairie and grassland conservation. First, a small but growing and highly active and organized group of local livestock producers and conservation personnel have been building conservation grazing partnerships over the last decade throughout this area. Both conservation and agricultural entities perceive these partnerships to have been quite successful in meeting mutual goals and express readiness and desire to move beyond past differences. Currently, there is much momentum around promoting conservation grazing more broadly throughout protected and privately owned grasslands across the GL core landscape area. While a growing number of landowners and producers whom we interviewed, including several young farmers, express interest in becoming more involved, the effort lacks organization and future vision, especially on the conservation side. Many land owners and producers in this area express confusion about which conservation organization is which and what programs and options are available and most suitable for their land.

In this area, publically visible and well-organized landscape-scale coordination and collaboration within and between agricultural and conservation organizations is greatly needed. Since many landowners and farm operators express interest in becoming more involved, wide-scale cultural and political support of prairie and grassland conservation might be best encouraged through strategies that facilitate a number of smaller partnerships among land owners, producers, and conservation agencies. Because of the complex and contentious history between agricultural and conservation interests in this area, it is imperative that conservation organizations work together in ways that present a common front and are sensitive to the distinct capacities, limitations, and positive and negative reputations of respective organizations. It is also important that organizations pay property taxes wherever possible and operate in ways that demonstrate sensitivity to and interest in bolstering declining rural socio-economic vitality.

Second, especially within the Ordway CLMA (Figure 27, see page 69), there are a number of absentee landowners and rural residents who do not expect or desire significant economic return from their lands (except to pay the taxes in many cases) and who express strong interest in becoming more highly involved in conservation management activities on their lands. These interviewees emphasized that, while conservation is a priority, they are often overwhelmed by the number of conservation entities and programmatic options in the area and are too busy to figure out what to do on their own without guidance and technical assistance. Many of these interviewees voiced a strong desire for personal relationships with local conservation personnel who could work closely with them to better understand and implement management options. Interest was high among these interviewees in practices such as prairie, savannah, and wetland restoration, conservation grazing, prescribed fire, control of woody and invasive species, prairie seed harvest, and other practices that promote wildlife and native species.

Across opportunity types and stakeholder groups, there is a strong need for greater coordination and public transparency in the GL landscape among and between conservation entities.

Chapter 7: Landscape-Scale Restoration Analysis *by Laura Phillips-Mao and Susan M. Galatowitsch*

University of Minnesota

A. Introduction

The importance of landscape-scale restoration planning is gaining recognition, as land managers, natural resource agencies and conservation organizations strive to address threats that operate at regional and global scales. In an increasingly fragmented, homogenized and warming world, landscape-scale restoration planning may provide synergistic results that exceed the potential of conventional site-level planning. Strategically interconnected networks of natural areas may not only effectively increase wildlife habitat but also support dispersal, migration and gene flow, thereby enabling native species to respond and adapt to climate change and other threats. Elements of regional restoration planning include protecting and enhancing existing native remnants; acquiring and restoring additional land to buffer and connect natural areas; and shifting land use in the surrounding matrix to practices that support conservation goals, while also meeting the economic needs of local communities.

A critical question in developing regional restoration plans is where on the landscape to locate protection and restoration efforts. Prioritization models that aim to maximize conservation benefit are one approach, but these models typically fail to take into restoration costs into account. Prioritization models that include land acquisition costs may be sufficient for landscape planning that focuses on purchasing and protecting existing natural areas, but will not be sufficient for planning large-scale restoration efforts, where the expected costs of plant community restoration are more complex than land purchase prices. In order for planners to make cost-effective decisions that maximize conservation benefit per investment, and to develop realistic project budgets, expected restoration actions and costs need to be incorporated into planning models.

Landscape-scale restoration planning is inherently challenging, however, because restoration actions and costs are largely dependent on site- and project-specific characteristics that are not easily scaled up to regional levels. The actions required to restore a given parcel of land will vary based on physical and ecological conditions (e.g. existing vegetation or degree of physical and hydrologic disturbance), as well as the target plant communities, project goals, and budget constraints. For site-level planning, detailed site assessments and establishment of project goals and budgets are critical steps in developing a restoration plan (Galatowitsch 2012b). However, attempting to conduct individual site assessments across large landscape areas and incorporate the goals and budgets of individual landowners and conservation stakeholders would be cost-and time-prohibitive. Therefore, a coarse-resolution tool for estimating restoration actions and costs across a range of site conditions, project goals and budget constraints, is needed in order to plan restorations more effectively at the landscape-scale.

In this project, we aimed to develop a course-resolution tool to aid in implementing the Minnesota Prairie Conservation Plan, which establishes broad restoration and conservation goals to protect and expand prairie communities in western Minnesota (Minnesota Prairie Plan Working Group 2011). Implementing Prairie Plan goals will involve identifying, protecting and enhancing native prairie remnants that may be vulnerable to land use conversion; restoring strategically-located parcels to high-quality prairie to buffer and connect existing prairies; and restoring larger areas to moderate-quality prairie that can support economic activities such as grazing, haying, and native seed harvest, while also providing ecosystem services and supporting conservation goals. This project investigates strategies for implementing the Prairie Plan within two landscape areas: Agassiz Beach Ridges (ABR) in northwestern Minnesota, and Glacial Lakes (GL) in west-central Minnesota. Our goal was to inform decision-making about where to prioritize restoration activities by creating a tool to estimate restoration actions and costs that could be applied to landscape scales and integrated with economic analyses, scenario planning and spatially-explicit prioritization/optimization modeling.

To this end, we developed a qualitative state transition model that characterizes common site conditions (“start states”), restoration targets (“end states”), and the transitions between start and end states that could reasonably be achieved by restoration actions (Figure 34). For a priority set of transitions (Figure 13), we developed generalized restoration plans describing the actions that would be required to shift a site from a given start state to the desired end states. We estimated costs of implementing the restoration plans by surveying restoration service providers across the state of Minnesota. Additionally, we created example seed mixes for each of the restoration end states, reflecting commercial availability, project goals and regional differences. Seed mix costs were included in the estimates of restoration costs.

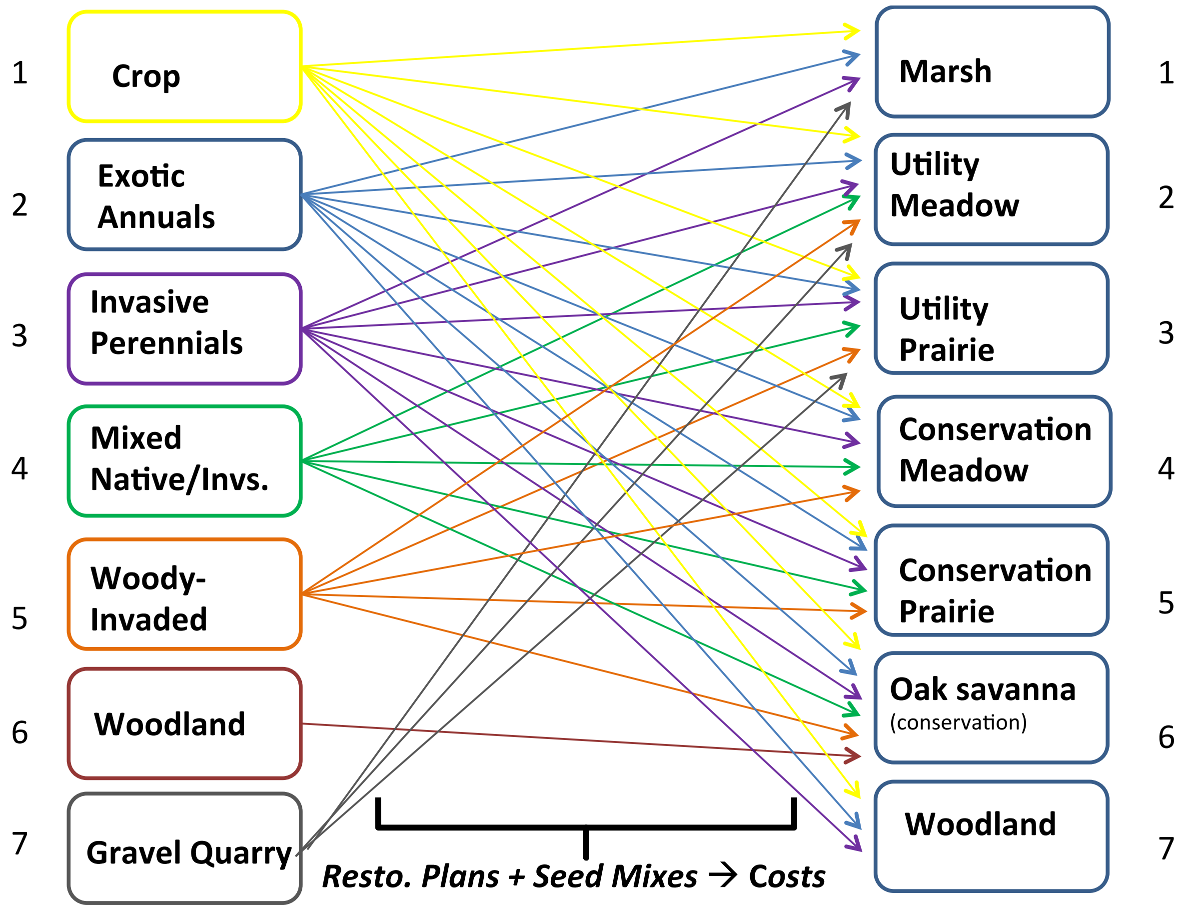

Figure 34. Qualitative restoration state transition model. Arrows represent transitions from start to end states that could reasonably be achieved via ecological restoration. Generalized restoration plans and example seed mixes were developed for a priority set of transitions; associated costs were estimated via a survey of restoration practitioners.

Our goal was to generate cost inputs for the economic analyses and optimization models (Chapters 8 and 9), as well as to produce resources that would support prairie restoration planning in western Minnesota. Additionally, we aimed to develop an approach to regional restoration planning that would be applicable to other landscape regions within the upper Midwest. More specifically, our objectives were to:

- Develop an approach to restoration planning that accounts for site- and project-specific variables and can be integrated with planning maps and models to prioritize restoration planning at the landscape scale;
- Create generalized restoration plans and seed mixes for a variety of common starting conditions and restoration targets for the purpose of cost-estimation and to serve as a resource for Minnesota Prairie Plan Implementation Teams as they work with local landowners to encourage restoration (Appendices 3 and 4);

- Generate estimates of restoration costs for a variety of common starting conditions and restoration targets to serve as inputs into economic analyses and optimization models, as well as to inform decision-making by planners, policy-makers and private landowners.

B. Restoration State Transition Model

We developed a qualitative state transition model as a coarse-resolution tool to incorporate site characteristics and project goals that influence restoration strategies and costs into landscape-scale conservation planning (Figure 34). In the model, we characterize common starting conditions in the Glacial Lakes and Agassiz Beach Ridges landscape areas according to their current vegetative cover, and identify restoration targets, or "end states", that reflect ecological constraints (e.g. potential vegetation, soils, and hydrology) as well as project goals (Figure 35). We assessed which transitions from start to end states could be achieved through restoration, and for a subset, we developed generalized restoration plans based on best practices (Appendix 3); created seed mixes reflecting commercial availability and regional differences (Appendix 4); and surveyed restoration practitioners to estimate the costs of achieving each transition.

To develop the model, we identified common start states (Table 20) and restoration targets (Table 21) in the Glacial Lakes and Agassiz Beach Ridges landscape areas based on site visit observations, conversations with local TNC field staff, and native plant community data from GIS data layers and the Field Guide to Native Plant Communities of Minnesota (MN DNR 2005). We mapped current land cover within each project area (Figure 16 and Figure 18, see pages 45 and 49) to characterize current conditions generally, and more specifically, to locate and quantify the specific start states that would likely be priorities for restoration activities, i.e. the start states included in the state transition model (Table 20).

The selection of end states within the model was based on potential native plant communities for the region, as well as economic, ecosystem service and conservation goals (Figure 35) identified within the Prairie Plan (Minnesota Prairie Plan Working Group 2011), 2005 conservation action plans (The Nature Conservancy 2012a, 2012b), and through discussions with conservation and economic analyses professionals familiar with the areas. We then applied restoration knowledge to identify transitions between the start and end states that could reasonably be accomplished via restoration actions. We selected a priority set of 20 transitions as the focus of the analysis described in this report, with the future intention of further refining both potential end states and priority transitions based on input from local landowners and conservation groups (Chapter 6). The selected start states (Table 20), end states (Table 21) and restoration transitions (Figure 34) included in this priority set are described below.

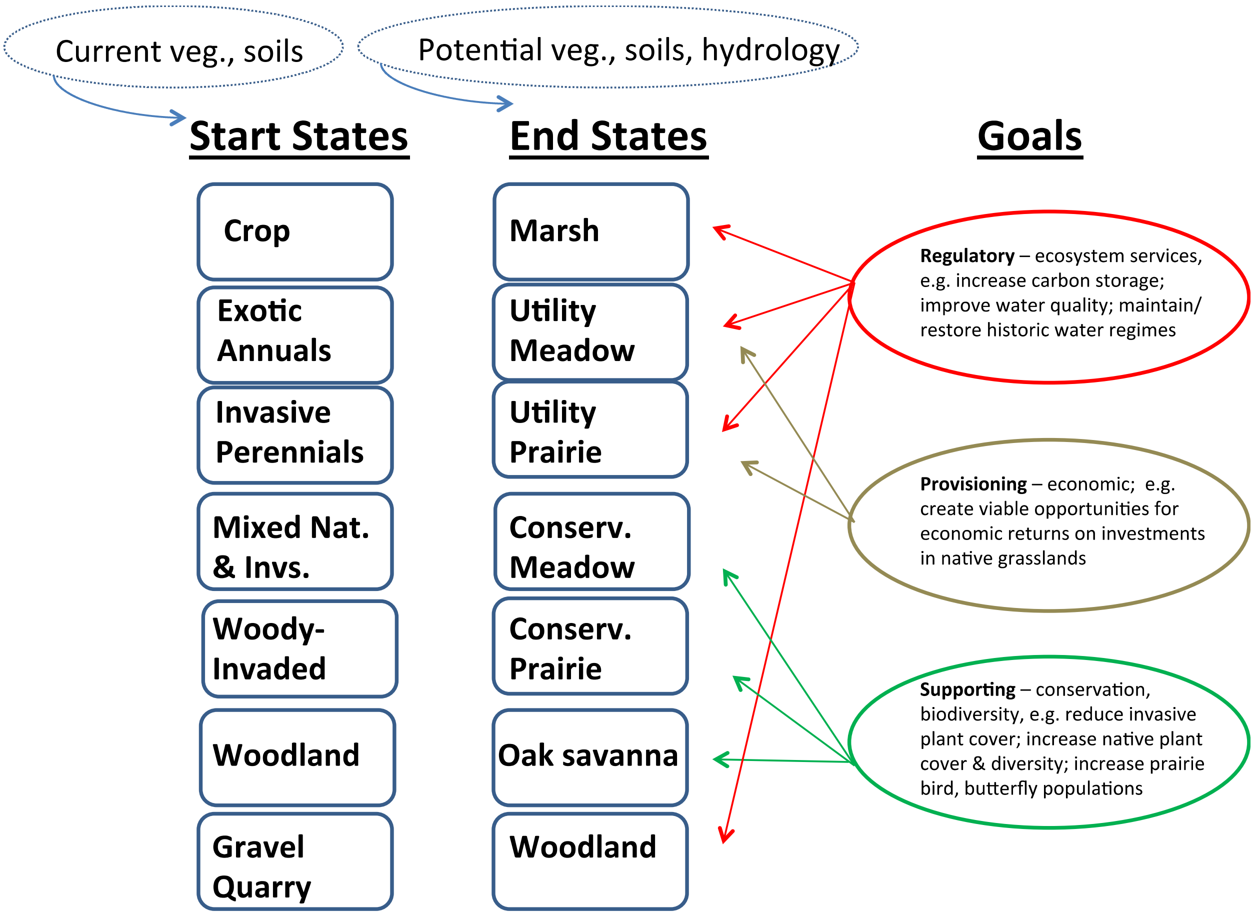

Figure 35. Driving factors that influence the selection of start and end states in the restoration state transition model. Start states were characterized based primarily on current vegetation and soils; end states were defined by target vegetation, soil moisture and project goals, including regulatory, provisioning and supporting ecosystem services. Note: provision of each category of ecosystem services is not exclusive to the specified end states; for example: regulatory services would be provided by all of the end states, however given the anticipated higher costs of restoring to conservation systems, they are only likely to be selected as restoration targets if supporting services are important project goals for a given site. The arrows therefore represent reasonable restoration targets for situations in which the primary goal for a site falls within the specified category of ecosystem services.

States	Land Use(s)	Herbaceous Cover	Woody Cover
Cropland	Corn; Soybean; Small grains; Sugarbeets; Hay (alfalfa); Other crops	Crop; Crop residue; Bare ground; Minimal weeds; No natives	Absent
Annual Dominated Field	Old field/fallow	>75% annual weeds; <25% other; Minimal natives	Absent
Invasive Perennial Dominated Grassland	Conservation; Grazing (continuous & rotational)/Hay; Perennial grass crop/non-alfalfa hay	>75% invasive perennials; <25% other; Minimal natives	< 10% cover mature trees; Possible oak canopy (savanna): 10 - 50% cover; Tree seedlings (< 5 cm diameter) included with invasive perennials (>75%)
Mixed Native Invasive Grassland	Conservation; Grazing (continuous & rotational)/Hay	25-75% natives; 25-75% invasive perennials	< 10% cover mature trees; Tree seedlings (< 5 cm) included with invasive perennials (25-75%)
Mostly Native Prairie	Conservation; Grazing (rotational)/Hay; Native Seed Harvest	>75% prairie natives; <25% exotic annuals/invs. perennials	< 10% cover mature trees; Tree seedlings (<5 cm) included with invasive perennials (<25%)
Mostly Native Savanna	Conservation	>75% prairie/savanna natives (understory)	10-50% oak overstory; < 25% invasive tree seedlings (< 5 cm diameter)
Woody Invaded Prairie	Conservation; Grazing (continuous & rotational)/Hay	Understory >75% native (likely sparse); <25% exotic annuals/invasive perennials	>10% canopy cover by mature (invasive) trees or dense shrub thickets; Tree seedlings (< 5 cm diameter) also likely present--included with invasive perennials but may exceed 25%
Fire Dependent Oak Woodland	Woodland	Understory: 1) shrubs & shade-tolerant herbs; 2) prairie/woodland edge species; or 3) invasive perennials (e.g. brome)	Tree canopy >50%; oaks dominant
Forest & Non-fire-dependent woodland	Woodland	Woodland herbs	Tree canopy >50%
Wetland Emergent	Wetland-emergent	Wetland herbs, sedges, rushes	Shrubs, trees <10 %
Wetland Forested/Shrub	Wetland-forested/shrub	Wetland herbs, sedges, rushes	Shrubs, trees >10%
Open Water	Open water		
River	River		
Developed	Low-intensity/open-space (includes roads); Med-high intensity		
Gravel Quarry	Barren/quarry	bare ground; minimal veg	

Table 20. Start States identified in the Agassiz Beach Ridges and Glacial Lakes landscape areas; typical land uses; and vegetative cover classes used to define each start state.

Land-scape	Native Plant Community	NPC Code	End State	Graminoid Cover	Forb Cover	Shrub Cover	Tree Cover
ABR	Northern Dry Prairie	UPn12	Prairie	50-100% patchy to continuous	5-50% sparse to patchy	0-50% sparse to patchy	absent, or occaisional small bur oak; other trees indicate fire suppression
GL	Southern Dry Prairie	UPs13	Prairie	50-100% patchy to continuous	5-50% sparse to patchy	<5% sparse	absent, or occaisional small bur oak; other trees indicate fire suppression
ABR	Northern Mesic Prairie	UPn23	Prairie	75-100%; usually continuous	5-50% sparse to patchy	5-75% sparse to interrupted	absent; if present indicate fire suppression
GL	Southern Mesic Prairie	UPs23	Prairie	75-100% usually continuous	5-50% sparse to patchy	5-25% sparse	absent; if present indicate fire suppression
ABR	Northern Wet Prairie	WPn53	Meadow	75-100% usually continuous	5-50% sparse to patchy	0-75% absent to interrupted	absent
GL	Southern Wet Prairie	WPs54	Meadow	75-100% usually continuous	5-50% sparse to patchy	0-25% absent to sparse	absent
GL & ABR	Prairie Wet Meadow/Carr	WMp7 3	Meadow	50-100% interrupted to continuous	<50% variable	<5% sparse; Salix spp.	absent
ABR	Northern Dry Savanna	UPn13	Savanna	25-100% patchy to continuous	5-50% sparse to patchy	5-50% sparse to patchy	10-70%, but typically 25-50%; scattered or in clumps; bur oak common; aspens/ash indicate fire suppression
ABR	Northern Mesic Savanna	UPn24	Savanna	50-100% interrupted to continuous	5-50% sparse to patchy	25-75% patchy to interrupted	10-70%, but typically 25-50%; bur oak common
GL	Southern Dry Savanna	UPs14	Savanna	25-100% patchy to continuous	5-50% sparse to patchy	5-50% sparse to patchy	<70%; typically 25-50%; scattered or in clumps; bur oak most common, but also northern pin oak...
GL	Southern Mesic Savanna	UPs24	Savanna	50-100% interrupted to continuous	5-50% sparse to patchy	50-75% patchy to interrupted	<70%; typically 25-50%; scattered or in clumps; bur oak most common, but also northern pin oak...other tree species increase with fire suppression
				Groundlayer (sedges & forbs)			
ABR	Northwestern Dry-Mesic Oak Woodland	FDw24	Savanna/ Woodland	25-50% patchy		25-75% patchy to interrupted	canopy: 25-75% patchy to interrupted; bur oak most common; aspen and balsam popular may be present but not common; subcanopy: 5-25% sparse
GL	Southern Dry-Mesic Oak Woodland	FDs37	Savanna/ Woodland	25-100% patchy to continuous		25-100% patchy to continuous	canopy: 50-100%; interrupted to continuous; bur oak and northern pin oak most common; older trees open grown; subcanopy 25-75%

Table 21. Minnesota Native Plant Communities in the, Agassiz Beach Ridges and Glacial Lakes landscapes. Native plant communities are aligned with end states in the Restoration State Transition Model, and their vegetative cover as presented in the Field Guide to the Native Plant Communities of Minnesota: The Prairie Parkland and Tallgrass Aspen Parklands Provinces (MN DNR 2005).

C. Start States - Descriptions

The state transition model includes seven initial site conditions that represent common restoration starting points in the Agassiz Beach Ridges and Glacial Lakes landscapes: Crop fields; Exotic Annual-Dominated Fields (ADF); Invasive Perennial-Dominated Grasslands (IPDG); Mixed Natives & Invasive Grasslands (MNIG); Woody-Invaded Prairie/Meadow (WIP); Woodland; and Gravel Quarry (Figure 34). These start states are a subset of a more comprehensive list of land cover categories that we developed to inform GIS map work for the economic analysis and optimization models (Figure 13). States that are unlikely to be selected for restoration actions under the Minnesota Prairie Conservation Plan, such as developed land, are not included in the model. Similarly, high quality states, such as native prairie with minimal invasive species presence ("mostly-native" prairie), are excluded from the model; although ongoing management may be required to maintain high quality conditions, restoration actions are not required to transition to a new end state.

We expected restoration actions and costs to be strongly influenced by the level of vegetation removal and management required to restore native prairie species; therefore we defined start states primarily by their vegetative cover. A key distinction between start states are whether native prairie species are generally absent (crop; ADF; IPDG; woodland and quarry), which allows for non-selective management strategies but requires substantial native seed investments, or whether native prairie species are already present (MNIG and WIP/M), providing an on-site propagule source but requiring (costlier) selective weed management strategies. Start states are further distinguished by the types of undesired (non-native prairie) vegetation present, as this influences the control efforts needed to trigger the transition. Crops and exotic annuals are relatively easy to remove, whereas invasive perennials and woody invaders (e.g. cedars) require greater investment of time and resources and different removal strategies.

To more precisely define the start states, we established percent cover categories (Table 20) that are consistent with vegetative cover descriptions of Minnesota Native Plant Communities (Table 21) and with prairie vegetation monitoring protocols (Vacek et al. 2012). The cover category definitions allow for rapid and consistent identification of start states in the field, which will enable restoration planners to readily assign a given parcel to a start state and assess the reasonable transitions and restoration actions required. The cover categories also served as the basis of "rules" used to develop landscape maps of land use and land cover in our project regions (Chapter 2). Field-applicability of the start state definitions was demonstrated during the Rapid Assessment survey work (Chapter 3) to inform map development and the economic analysis/optimization models. Start states and current land cover were mapped and quantified within ABR (Figure 16) and GL (Figure 18) and acreages of the priority start states for transitions are shown in Table 22.

Landscape Areas	Start States				
	Crop	Annual-Dominated	Invasive Perennial -Dominated	Mixed Native & Invasive	Woody-Invaded Prairie/Meadow
Agassiz Beach Ridges	54,862	1,877	27,356	15,539	20
Glacial Lakes	43,027	402	8,659	45,177	224

Table 22. Start states quantified by project landscape area (in acres). Calculations are based on GIS analysis and ground-truthing conducted in 2012 (Chapter 3).

It should be noted that individual sites considered for restoration may not neatly fit a given start state definition, or may contain multiple start states. In either case, elements from multiple restoration plans and seed mixes may be combined to create a site-specific plan. However, for the purposes of landscape-scale planning, these categories are designed to be broad enough that most sites can be assigned to a single start state.

1. Crop Fields

Crop fields are essentially a bare-ground start state with no native species present, minimal weeds, intact soils, and ready-to-seed seedbed. We assume that crops have been harvested prior to initiating restoration; crop residue may be present on site and, if substantial (e.g. corn residue) disking may be required to break down the residue prior to seeding. Corn-soybean rotations are common in the ABR and GL landscape regions. When possible, it is recommended to end on a soybean rotation prior to initiating restoration, so that the field requires minimal preparation for seeding. Although we assume corn-soybean rotations in our restoration plans, these plans and cost estimates are appropriate for other common annual crops in the region as well. For perennial crops (e.g. alfalfa), it will be more appropriate to refer to the ADF and/or IPDG restoration plans, which include methods for controlling existing herbaceous vegetation. Wetter crop sites have likely been drained via drainage tiles or ditches to allow for cultivation; restoring hydrology by breaking tiles and/or plugging ditches, and—in some cases—installing water control devices will be an important step in restoring crop sites to wet meadow.

2. Annual Weed-Dominated Fields

Annual-dominated fields (>75% annual weeds) are typically previously cropped fields that have been left fallow and have subsequently been colonized by exotic annual weeds, such as foxtail (*Setaria spp*.), barnyard grass (*Echinochloa crus-galli*) and lambs-quarters (*Chenopodium album*). Native weedy annuals such as ragweed (*Ambrosia spp*.) may also be present, but desirable native prairie species are either absent or comprise very minimal cover. Controlling annual weeds and their seed bank will be an important step in restoration, and seedbed preparation is typically required prior to seeding. Annual-dominated fields represent a relatively small area within the GL and ABR landscapes (Table 22), due to their transitive nature and the high price of corn (few fields are left fallow for long), however, we included this start state in the transition model because it represents a moderate level of vegetation control in contrast to the more aggressive measures required for the IPDG start state. Wet crop fields may also become annual-dominated if soil moisture conditions frequently prevent access for weed management, leading to an accumulation of annual weed seeds in the soil seed bank, or if restoration is delayed for 1-2 years following harvest, resulting in colonization by annual weeds.

3. Invasive Perennial-Dominated Grasslands

Invasive perennial-dominated grasslands (>75% invasive perennials) are one of the most problematic start states from a restoration perspective, as they require substantial investment of time and resources in vegetation management both before and after seeding prairie species. Often used as pasture or hay fields, these sites are dominated by aggressive species that persist in seed and rhizome banks for many years, and if uncontrolled, can quickly outcompete and suppress planted natives. Common and problematic invasive perennials in the GL and ABR landscape include smooth brome (*Bromus inermis*), reed canary grass (*Phalaris arundinacea*), and birdsfoot trefoil (*Lotus corniculatus*). Wet sites, in particular, are often dominated by reed canary grass, which can be particularly difficult to control, often requiring multiple years of repeated treatments. In some cases, invasive woody species may be present on site and require additional removal strategies, which are described in more detail in the woody-invaded prairie restoration plans. Restoring invasive perennial-dominated sites often requires multiple seasons of vegetation control prior to seeding, and attentive management through the seedling establishment phase and beyond in order to maintain a competitive advantage for native prairie plants. When possible, cropping these fields (essentially converting them to the Crop Field start state) is an increasingly popular and more affordable option for achieving the level of weed control required for successful restoration outcomes.

4. Mixed Native & Invasive Grasslands

The Mixed Native and Invasive start state is defined as having 25-75% of native prairie species, and 25-75% invasive perennials and other undesired species. These sites include degraded prairie remnants (never plowed; original prairie vegetation); low-diversity prairie plantings (e.g. CRP land) that have become invaded; native grasslands that were over-seeded with exotic perennials for pasture; and restored or native prairie wetlands that have become degraded and invaded through insufficient management. The challenge of restoring the MNIG start state is to reduce the cover of invasive species while retaining the existing native species and increasing their abundance and diversity. This process is sometimes referred to as “stand enhancement” as opposed to “stand replacement” (Williams 2010e).

Selective vegetation control measures must be used to reduce the cover and competitiveness of invasive species while avoiding damage to the natives present; this is particularly important on prairie remnants, where preserving original prairie vegetation and native genotypes is of paramount importance. To enhance existing vegetation and increase native cover and diversity, prairie species are sown into the existing vegetation as opposed to into a prepared seedbed; this planting strategy is referred to as "interseeding" or "overseeding". Special considerations must be made to species selection to avoid polluting the native gene pool or otherwise harming existing natives.

Our cutoff of 25% native vegetation serves only as a guideline when applying this tool to specific sites. Landowners may choose to employ more selective measures even if native species represent less than 25%, particularly if rare species or species of high conservation value are present on site. Alternatively, if existing native vegetation is planted (non-remnant), poor quality, or of questionable native status (e.g. cultivars, or southern ecotypes), landowners may choose to treat the site as an invasive perennial-dominated grassland and employ non-selective methods of control in order to start the restoration with a "blank slate".

5. Woody-Invaded Prairies & Meadows

Woody-Invaded Prairie and Meadows are mostly-native grasslands that have become invaded by woody species, typically resulting from insufficient fire frequency. We specified a canopy cover of > 10% trees and shrub thickets, and an understory dominated by native species (>75% cover) although this native understory may be sparse as a result of shading by trees and shrubs. Woody-invaded prairies are distinguished from oak savannas (Table 20), which have a mature oak canopy, prairie and savanna understory, and are another rare and highly-valued conservation target (Nuzzo 1986, MN DNR 2005).

Fire-suppressed prairies are commonly invaded by native prairie-colonizers, such as eastern red cedar (*Juniperus virginiana*), sumac (*Rhus spp*.) and boxelder (*Acer negundo*), as well as exotic species such as Siberian elm (*Ulmus pumila*). Shrubs such as prairie rose (*Rosa arkansana*), red-osier dogwood (*Cornus sericea*), and willows (*Salix spp*.) are a native component of Minnesota's wet prairie communities (MN DNR 2005). Though typically sparse in southern Minnesota's wet prairies, they can be quite abundant in northern wet prairie communities. Shrub and tree cover in wet prairies is tied to fire frequency. Continued fire suppression can lead to increased cover of native shrubs (e.g. sandbar willow, *Salix interior*, in ABR), invasion by native trees (e.g. quaking aspen, *Populus tremuloides*, and balsam poplar, *P. balsamifera*), and ultimately succession to wet brush prairie or even woodlands. Returning fire to such plant communities to restore herbaceous dominance may be a desired strategy for those with a goal of increasing native grass cover across the landscape for either conservation or utility purposes.

It is important to emphasize that not all trees in prairie communities are invasive, and not all of the woody species that are considered invasion problems are exotics. In fact, colonization by woody species is a natural phenomenon that historically occurred along the prairie-forest border, which shifted over time with climate variation and resulting changes in fire frequency (Davis

1977). As light-tolerant woody species (e.g. sumac) colonized, they created shadier conditions more suitable for other woody species and less suitable for prairie species, resulting in a successional shift from prairie to woodland vegetation. Halting this natural succession process by controlling woody invasion in prairies is a decision based on values, reflecting our conservation goals to protect and maintain remaining prairie ecosystems.

Woody seedlings and saplings may be controlled by herbicide applications and fire, in a manner similar to herbaceous invasive perennials, but larger trees and dense shrub thickets require mechanical removal. Bare or sparsely-vegetated patches left behind after woody species removal are vulnerable to invasion by exotic species. Reintroducing prescribed burns will help encourage prairie species biomass production and spread; interseeding may further decrease the site's invasibility by more quickly filling in the gaps left behind by tree removal.

Fire-suppressed prairies and meadows are often also invaded by herbaceous perennial weeds. For the purposes of this restoration plan, we are assuming that woody invasion is the greater threat and that invasive herbaceous species represent < 25% of the herbaceous community. However, if herbaceous invasive perennials are present, their control is strongly recommended as well (see Mixed Native-Invasive start state for more details).

D. End States – Descriptions & Compatible Land Use

Native grassland end states are distinguished both by soil moisture (meadows and wet prairie vs. mesic-to-dry prairie) and by goals. "Utility" meadows and prairies are those for which the primary goal is to provide economic returns (i.e. provisioning services), while "conservation" meadows and prairies are restored primarily for conservation purposes (i.e. supporting services) (Figure 35). Although we have developed separate restoration plans for prairie and meadow communities, it is important to remember that these communities commonly co-occur on a site, and therefore restoration at the site level may require merging elements from multiple appropriate restoration plans and seed mixes. Wet meadow communities in particular often occur as part of a continuum, transitioning from deeper emergent marshes, to sedge meadow, wet prairie, and mesic to dry uplands, sometimes within very narrow bands. Wet prairie is intermediate in nature between sedge meadows and mesic prairie, and includes many species and restoration challenges in common with both plant communities. Wet prairie and sedge meadow communities may occur as isolated moist depressions within a mesic prairie matrix, or as more extensive components of a wet prairie/marsh matrix. In the ABR region in particular, wet and mesic prairie communities occur together in a mosaic, with upland prairie occurring along the beach ridges. If restoration sites include poorly-drained, saturated, wet to wet-mesic soils as well as well-drained, mesic to dry uplands, strategies from both the meadow and prairie restoration plans are recommended.

1. Utility Prairie

The utility prairie end state is an economical dry to mesic tallgrass prairie community designed to maximize biomass production and palatability for forage, while still supporting basic conservation goals. It is distinguished from conventional grassland production fields by its emphasis on regionally appropriate native species and greater diversity. Compatible land uses include moderate levels of cattle or bison grazing, hay production, commercial seed harvest, and potentially biofuels, as well as recreational activities (e.g. hunting). Anticipated conservation benefits and other ecosystem services include habitat for nesting birds and insects, soil stabilization and improved water quality (MN BWSR 2012a)

Utility prairie differs from Utility meadow in its soil moisture conditions. The utility prairie end state spans dry to mesic soil conditions, whereas utility meadow covers wet to wet-mesic conditions. Utility prairie and conservation prairie communities are generally found on the same soil types and environmental conditions. Compared to conservation prairie, utility prairie features a lower diversity seed mix, fewer forbs, greater emphasis on palatable, productive, and grazing-tolerant species, and avoidance of toxic or highly sensitive species. Restoration plans for the utility prairie include less intensive exotics control, options for incorporation of grazing, haying, and harvest into management practices, and less emphasis on "natural appearances". Use of locally-sourced seed is still strongly encouraged to maximize restoration outcomes on site and to prevent genetic outcrossing with native prairie species in the area.

Utility prairie will be a particularly desirable end-state for highly degraded and altered start states, where the transition to conservation prairie might be unfeasible, as well as for landowners for whom economic returns on restoration investments is a primary goal. Utility prairie is not a recommended end state for native prairie remnants since conservation prairie is better suited to the high conservation value of these rare sites. Utility prairie may also be ideal for sites adjacent to other prairies. They can connect and buffer high-quality prairies from land uses that are less supportive of conservation and generally increase the habitat area for prairie-obligate wildlife species while generating an economic return to landowners.

2. Conservation Prairie

The conservation prairie end state is a diverse, high quality, dry to mesic tallgrass prairie community designed to maximize species diversity and provide a wide range of ecosystem services, including soil stabilization, improved water quality, wildlife habitat, grassland bird nesting sites, and support of local pollinators (MN BWSR 2012c). The primary goal of restoring conservation prairie is to achieve high conservation value, therefore, this end state is generally not compatible with continuous grazing, haying and commercial seed harvesting, or high-impact recreational activities such as ATV use. Limited and carefully-managed grazing, haying or and native seed harvest may be supported by conservation prairie, but conservation prairie is unlikely to be a restoration target when economic returns are the primary goals. Low-impact recreation, such as hiking, photography, and limited pheasant/duck hunting may also be supported by conservation prairie. Conservation prairies provide excellent opportunities to engage the public and showcase the benefits of a diverse prairie community via educational and community-building events such as public outreach, citizen science, and hands-on participation in restoration and management activities.

Conservation prairie differs from the conservation meadow end state by their soil moisture conditions. Conservation prairie occurs on mesic to dry soils, whereas conservation meadow occurs on wet to wet-mesic soils. Conservation prairie and utility prairie communities are generally suitable for the same soil types and environmental conditions. Compared to utility prairie, conservation prairie features a higher diversity seed mix, more forb species, and a higher level of customization for creating habitat/food sources for native insects and wildlife. Restoration plans for the conservation prairie place include more intensive exotics control, greater emphasis on burning to achieve management goals (vs. grazing, haying), and on achieving natural appearances. Relative to utility prairies, there may also be greater emphasis on using local ecotypes, matching quality and composition of reference sites, and preserving the genetic integrity of remnant native populations on site.

Conservation prairie may be a particularly desirable end-state for degraded prairie remnants or sites that are adjacent to existing high quality prairies (e.g. TNC preserves, Scientific and Natural Areas). They might also serve as strategic connections for existing high-quality prairie, as well as for land owners who value the aesthetics and wildlife of a diverse prairie community.

3. Utility Meadow

The utility meadow end state is an economical wet prairie and sedge meadow community designed to maximize biomass production and palatability for forage, while still supporting basic conservation goals. It is distinguished from conventional grassland production fields by its emphasis on regionally appropriate native species and greater diversity. Compatible land uses include moderate levels of cattle or bison grazing, hay production, commercial seed harvest, and potentially biofuels, as well as recreational activities (e.g. hunting). Anticipated conservation benefits and other ecosystem services include habitat for wetland birds and insects, flood control, and improved water quality (MN BWSR 2012b).

The suitability of utility meadow for supporting cattle grazing will depend to some extent on the relative amounts of wet prairies and sedge meadow on the site. Sedges are not preferred forage for cattle, and very wet sites may be more vulnerable to damage by trampling. If a site is likely to be dominated by primarily sedge meadow and marsh, it may not be suitable for grazing. Sites that are primarily wet prairie or a mix of wet and upland prairie will be more suitable for grazing because they have more palatable forage species and a balance of cool and warm season grasses to sustain season-long usage. However, utility meadows will be an appropriate restoration target for wet depressions and wetter sites within these larger matrices of wet and mesic prairie.

Utility meadow is distinguished from utility prairie by its soil moisture conditions. Utility meadow is suitable for wet to wet-mesic conditions, while utility prairie is more appropriate for mesic to dry soils. Wet meadows typically occur on poorly-drained soils that are saturated for up to 8 weeks following snow-melt, as well as temporarily throughout the year following large precipitation events. Like mesic and dry prairies, the vast majority of wet prairie and sedge meadow in western Minnesota has been converted to agriculture or other developed land uses, and what little remains is threatened by hydrologic alterations and plant invasions. Nearly all former wet meadow in western Minnesota has been drained to some degree via ditches or drainage tile; restoration of natural hydrology is therefore a critical component of wet meadow restoration. In these restoration plans, we assume all wet meadow start states have been partially drained, and as a result, current soil moisture conditions may not reflect the historic conditions. Assessing soil types and hydrology will therefore be an important step in selecting appropriate restoration targets and actions.

Compared to conservation meadow, utility meadow features a lower diversity seed mix, fewer forbs, greater emphasis on palatable, productive, and grazing-tolerant species, and avoidance of toxic and highly sensitive species. Restoration plans for the utility meadow include less intensive exotics control and options for incorporation of grazing, haying, and harvest into management practices. Use of locally-sourced seed is still strongly encouraged, to maximize restoration outcomes on site and to prevent genetic outcrossing with native meadow genotypes in the area.

Utility meadow will be a particularly desirable end-state for highly degraded and altered start states, from which transitioning to conservation meadow might be unfeasible, as well as for landowners for whom economic returns on restoration investments is a primary goal. Utility meadow is not a recommended end state for remnant wet prairie and sedge meadow; conservation meadow is better suited to the high conservation value of these rare sites. Utility meadow may also be ideal for sites adjacent to other restored prairies and wet meadows, as it can connect and buffer high-quality prairie communities from land uses that are less supportive of conservation, and generally increase the habitat area for prairie-obligate wildlife species, while generating an economic return to landowners.

4. Conservation Meadow

The conservation meadow end state includes diverse, high quality, wet prairie and sedge meadow communities, designed to maximize species diversity and provide a wide range of ecosystem services, including soil stabilization, improved water quality, wildlife habitat, grassland bird nesting sites, and support of local pollinators (MN BWSR 2012b). The primary goal of restoring conservation meadow is to achieve high conservation value, therefore, this end state is generally not compatible with frequent or intensive grazing, haying and commercial seed harvesting, or high-impact recreational activities such as ATV use or horseback riding. Limited and carefully-managed grazing, haying or and native seed harvest may be supported by conservation meadow, but conservation meadow is unlikely to be a restoration target when economic returns are the primary goals. Grazing value may be particularly limited in very wet sites dominated by sedges; sedges have low palatability, and saturated sites may be more vulnerable to trampling damage. Low-impact recreation, such as hiking, photography, and limited waterfowl hunting may also be supported by conservation meadow. Conservation meadows may also provide excellent opportunities to engage the public and showcase the benefits of diverse wetland communities via educational and community-building events such as public outreach, citizen science, and hands-on participation in restoration and management activities.

Conservation meadow differs from the conservation prairie end state in hydrology and soil moisture. The conservation meadow end-state is suitable for wet to wet-mesic conditions, whereas prairie suitable for mesic to dry soil conditions. Wet meadows will typically occur on poorly-drained soils that are saturated for up to 8 weeks following snow-melt, as well as temporarily throughout the year following large precipitation events. Like mesic and dry prairies, the vast majority of wet prairie and sedge meadow in western Minnesota has been converted to agriculture or other developed land uses, and what little remains is threatened by hydrologic alterations and plant invasions. Nearly all former wet prairie/sedge meadow in western Minnesota has been drained to some degree via ditches or tile; restoration of natural hydrology is therefore a critical component of wet meadow restoration. In our restoration plans, we assume all wet meadow start states have been partially drained and, as a result, current soil moisture levels may not reflect historic conditions. Assessing soil types and hydrology will therefore be an important step in selecting the appropriate restoration targets and actions.

Conservation and utility meadow communities are generally suitable for the same soil types and environmental conditions. Compared to utility meadow, conservation meadow features a higher diversity seed mix, more forbs and cool-season graminoids (e.g. sedges), and a higher level of customization for creating habitat/food sources for native insects and wildlife. Restoration plans for the conservation meadow include more intensive exotics control, greater emphasis on burning and selective herbicide treatments to achieve management goals (vs. grazing, haying), and greater emphasis on achieving natural appearances. Relative to utility meadows, there may also be greater emphasis on using local ecotypes, matching quality and composition of reference sites, and preserving the genetic integrity of remnant native populations on site.

Conservation meadow may be a particularly desirable end-state for degraded remnant wet prairies and sedge meadows, or sites adjacent to existing high quality native grassland communities (e.g. TNC preserves, Scientific and Natural Areas). They may also be valuable as strategic connections between existing prairie and meadow, and appeal to land owners who value the aesthetics and wildlife in a diverse native grassland/wetland habitat.

E. Restoration Transitions

Transitions from start to end states that could reasonably be achieved via restoration are shown in Figure 34. In this context, "restoration" refers to deliberate efforts to move a site from one state to another. Maintenance of existing states (e.g. high quality prairie) is not included in the state-transition model, as it does not represent a transition from one state to another; however, management prescriptions developed for conservation end states may be applied to maintaining high-quality sites. Our assessment of feasibility in selecting reasonable transitions considered the anticipated effort and cost required for a given transition, the likelihood of achieving satisfactory outcomes, and the likely conservation and economic goals that might drive land use/land cover decisions. For example, while it may be technically possible to restore a crop field to mature woodland, the time and expense required to plant forest trees and understory and allow a full forest community to develop would be prohibitive. Furthermore, it is unlikely that many people will be interested in transitioning from crop to woodland, given the value of native grassland for both conservation and economic purposes within our project areas. (A possible exception might be a transition from crop field to woodland plantation, but that would not be considered restoration, as the end state is not a native plant community.)

One of the strengths of the state transition model is the recognition that for any current site or start state, there may be multiple feasible and appropriate restoration targets, depending on ecological factors (e.g. soils and hydrology), goals, and budget constraints. Including these multiple potential trajectories and their associated costs into economic analyses and landscape planning allows us to compare more nuanced and precise land use/land cover scenarios than would otherwise be possible. At the individual site-planning level, land-owners and restoration practitioners must evaluate site conditions and identify specific project goals in order to choose a suitable restoration end state (Galatowitsch 2012b). While we do not describe site assessment and restoration project planning in detail within this report, the start and end state descriptions and plant cover categories (Table 20 and Table 21), and general restoration plans and estimated costs can serve as a guide to landowners as they face these decisions.

The restoration plans (Appendix 3) provide a description of the actions, rationale, and important considerations involved in achieving a transition from selected start state to end state. They are organized by end state, and within each priority end state (Utility Prairie, Conservation Prairie, Utility Meadow and Conservation Meadow), there are separate plans for transitions from each priority start state (Crop, ADF, IDPG, MNIG, and WDP/M). Each restoration plan includes recommended actions for site preparation (e.g. vegetation removal and seed bed preparation), seeding, and post-seeding management. Restoration plans were developed based on review of published restoration resources, scientific journal articles, and interviews with restoration practitioners in Minnesota and the Midwest. Restoration plans were further enhanced by data on common restoration actions, equipment and costs, gathered via a survey of restoration experts.

1. Utility & Conservation Prairie

Herbaceous-dominated start states (e.g. crop, annual and invasive-dominated fields, and woody-invaded prairie) can all reasonably be restored to utility or conservation prairie (Figure 34). Crops and annual-dominated fields will require less site preparation and intensive weed control than sites dominated by invasive perennials. Woody-invaded prairies require an initial investment in labor to mechanically remove unwanted trees and shrub thickets, but thereafter are relatively easily maintained with appropriate burn regimes. Utility prairie may be a particularly suitable end state for sites that are heavily invaded by extremely aggressive invaders (e.g. reed canary grass), given the likelihood of persistent weed management problems. Utility prairie may also be a reasonable target for gravel quarries, due to the highly disturbed nature of this start state (e.g. altered topography and loss of topsoil). The costs, resources and engineering required to reconstruct gravel quarries make utility prairie a more feasible and cost-effective target than conservation prairie.

Neither utility prairie nor conservation prairie is likely to be a reasonable restoration target for woodlands as defined in this project. Although a prairie may transition to woodland due to long-term fire suppression, we are distinguishing such woody-invaded prairies from woodlands. Oak savanna is a reasonable restoration target for fire-dependent woodlands that show evidence of being degraded savanna (e.g. presence of open-grown oak trees, burn scars, remnant savanna understory species, or historical records).

Mixed native-invasive and woody-invaded prairies present particular challenges in restoration that influence whether utility or conservation prairie will be the most appropriate end states. Appropriate restoration targets and strategies for these end states depend in part on the origins of the native species present on the site. If the site is an original unplowed, unplanted prairie remnant, it is extremely important to avoid disturbing the native soils, to minimize adverse effects on remnant vegetation, and to avoid diluting native gene pools (i.e. outcrossing depression). Because of their rare status and high conservation value, we recommend that degraded native remnants be restored to conservation prairie. Conservation prairie restoration plans for MNIG and WIP/M assume that the start state is a remnant. The goal on such sites is to increase diversity by 1) controlling invaders that may spread, out-compete and displace native plants; 2) if necessary: reducing cover of native dominants (often grasses) to encourage establishment of new native species; and 3) adding seed to increase species richness and native cover.

If the site is not a remnant, but a degraded, low-diversity restoration or native grassland planting, the concerns about avoiding soil disturbance and diluting the gene pools are less applicable. However, it is still desirable to use selective control measures and interseeding methods, because it is economical to take advantage of the native species that are already established on site. The utility prairie restoration plans assume that the start state is a planted, non-remnant site. The goal on such sites is to increase diversity by 1) controlling invaders that may spread, out-compete and displace native plants; 2) if necessary: reducing cover of native dominants (often grasses) to encourage establishment of new native species; and 3) adding seed to increase native cover and biomass (for utility purposes), and species richness (for conservation purposes).

2. Utility & Conservation Meadow

Herbaceous-dominated start states (e.g. crop, annual and invasive-dominated fields, and woody-invaded wet prairie) can all reasonably be restored to utility and conservation meadow, provided the soil type and moisture is suitable and the hydrology can be restored as necessary (Figure 34). Tiled/drained fields will require filling ditches and/or removing or breaking tiles to restore original soil moisture and hydrological regimes. Timing these actions appropriately with seeding is an important but challenging aspect of wet meadow restoration. Crops and annual-dominated fields will require less intensive pre-seeding weed control than sites dominated by invasive perennials. However, wet meadows are highly vulnerable to invasion by the aggressive perennial reed canary grass (*Phalaris arundinaceae*); therefore, regardless of start state, all sites will require ongoing monitoring to detect and respond to reed canary grass invasion. If sites are heavily invaded by such extremely aggressive exotic perennials, utility meadow may be a more reasonable restoration target, given the likelihood of persistent weed management problems. Similarly, utility meadow may be a more suitable target for gravel quarries, given the highly disturbed nature of this start state (e.g. altered topography; lost topsoil). The costs, resources, and engineering required to reconstruct gravel quarries make utility meadow a more feasible and cost-effective target.

Wet meadow is not likely to be a reasonable restoration target for woodlands as defined in this project. Although shrub-dominated and forested wetlands do occur in the project landscape areas (Table 20), they are not among the primary conservation targets identified in the Minnesota Prairie Conservation Plan, and therefore we have not developed restoration plans for these plant communities at this time. Some aspects of our wet meadow restoration plans would apply, with the addition of planted tree and shrub species as potted seedlings or bare rootstock.

For the invaded meadow start states (MNIG and WDP/M), appropriate restoration targets and strategies depend in part on the origins of the native species present on the site. If the site is an original wet prairie/sedge meadow remnant, with intact hydrology and soils (i.e. never drained or plowed) and native, non-planted prairie and sedge meadow species, it is extremely important to avoid disturbing the native soils, minimize adverse effects on remnant vegetation, and avoid diluting native gene pools (i.e. outcrossing depression). Because of their rare status and high conservation value, it is recommended that degraded native remnants be restored to conservation meadow. The conservation meadow restoration plans for MNIG and WIP/M assume that the start state is a remnant. The goal on such sites is to increase diversity by 1) controlling invaders that may spread, out-compete and displace native plants; 2) if necessary: reducing cover of native dominants (often grasses) to encourage establishment of new native species; and 3) adding seed to increase species richness and native cover.

If the site is not a remnant, but a degraded, low-diversity restoration (i.e. natives were planted; site previously plowed or drained), the concerns about avoiding soil disturbance and diluting the gene pools are less applicable. However, it is still desirable to use selective control measures and interseeding methods, because it is economical to take advantage of the native species that are already established on site. The utility meadow restoration plans assume that the start state is a planted, non-remnant site. The goal on such sites is to increase diversity by 1) controlling invaders that may spread, out-compete and displace native plants; 2) if necessary: reducing cover of native dominants (often grasses) to encourage establishment of new native species; and 3) adding seed to increase native cover, biomass (for utility purposes), and species richness (for conservation purposes).

F. Seed Mixes for Prairie & Meadow Restoration

For each of the selected restoration end states, we developed seed mixes as examples for the Minnesota Prairie Conservation Plan Implementation Teams, public land managers, and interested private landowners (Appendix 4). The seed mixes are not intended to be prescriptive, but instead to provide an accurate estimate of seed costs and to serve as a guide for developing site-specific seed mixes when planning restorations on individual sites. When planning on-the-ground restorations, these seed mixes can serve as a base mix; species substitutions and modifications to seeding rates and ratios can be made to accommodate individual project goals, site conditions, budgets, and seed availability. We do, however, encourage seed mix designers to pay close attention to diversity and seeding rate recommendations. Substantially reducing species richness (particularly forbs) and seeding rate may decrease upfront seed costs, but at risk of increasing erosion and weed invasion, and reducing resilience and provision of ecosystem services. For more information on designing effective seed mixes for a variety of site conditions and project goals, several resources are available for prairies (Diboll 1997, Williams 2010a) and wet meadows (Jacobson 2006). The Minnesota State Seed Mixes and Seed Mix Design Tool are also excellent resources (MacDonagh and Hallyn 2010, MN BWSR 2011).

Our approach to seed mix design was to start with readily available “tried and true” mixes and modify them as needed to more precisely fit the specified end states. With the exception of the Utility Prairie Mix, we used Minnesota State Seed Mixes (MN BWSR 2011) as the core of each seed mix. For the Utility Prairie Mix, we selected an economical native CRP mix (Shooting Star

Native Seeds CP25 Economy Mix—2012 recipe) that included a balance of species suitable for supporting grazing. To enhance diversity (particularly for conservation mixes), we selected “add-on” species using the Minnesota State Seed Mix Design tool (MacDonagh and Hallyn 2010), which contains “Pick Lists” of species suitable for a variety of plant community types. For each species, the Seed Mix Design Tool includes useful characteristics such as guilds, soil moisture tolerances, pollinator/wildlife value and regional suitability (by Ecological Section). Additionally, we referred to the Species Frequency and Cover Tables from the Field Guide to Native Plant Communities to guide species selection and relative seeding rates (MN DNR 2005).

Estimated seed costs were calculated based on 2013 pricing from several native plant nurseries serving Minnesota. Rather than costing out each list “from scratch”, we obtained 2013 prices for the State Seed Mixes, and then added on the prices of individual species added to each mix. We contacted 17 nurseries requesting pricing information for State Seed Mixes, and we obtained prices from four nurseries: Shooting Star Native Seeds (Spring Grove, MN; recently combined with Feder Prairie Seed Co., Blue Earth, MN), IonXchange (Harpers Ferry, IA), Agassiz Seeds (West Fargo, ND), and Twin Cities Seed Co. (Edina, MN). Price differences between nurseries ranged from $88/acre for the Dry-Swale Mix (33-262) to $287.50/acre for the Wet Prairie Mix (34-262). For the sake of consistency, we used prices from Shooting Star Native Seeds for the State Mixes and CP25 CRP mix in our seed cost calculations. Relative to the other nurseries, Shooting Star generally reported lower to average costs. Add-on species costs were calculated based on the 2013 price lists of Prairie Moon Nursery (Winona, MN), Shooting Star Native Seeds, and, to a limited extent, IonXchange. It should be noted that seed prices and availability are subject to change annually, so restoration planners are encouraged to compare prices for their seed mixes when selecting a vendor. Seed mix prices were higher in 2013 than in 2012, because the summer 2012 drought limited seed availability; for example, the price/acre for the selected CP25 mix increased by $75/acre due to the drought. We were unable to average seed prices over multiple years, however, so the provided cost estimates reflect 2013 prices.

For the sake of cost estimation, we assumed that seeds would be purchased from a local native plant vendor, although in some cases, harvesting seeds from existing prairies and remnants may be an option as well. Harvesting native prairies for restoration seeding is a common practice within TNC, USFWS and other conservation organizations with substantial prairie holdings. Seeds from locally-harvested prairies may be more affordable and more locally-adapted to the restoration site conditions than nursery-produced seeds. Prairies can be combine-harvested to produce a bulk seed mix containing many of the species present in the harvested prairie. This is a relatively quick approach to harvesting seeds, however if weeds or invasive species are present on site, there is a risk of including these undesired species in the bulk mix. Additionally, bulk-harvested mixes are typically biased toward late-season flowering species; cool-season grasses, sedges, and early-flowering forbs tend to be under-represented in these mixes. Seeds can also be hand-harvested, which allows for more precise species selection and more careful evaluation of ripeness. Hand-harvesting is significantly more time-consuming, but makes a great volunteer activity when volunteer labor is available. Harvesting seeds requires specialized knowledge of species identification, appropriate collection methods and evaluation of ripeness, as well as rodent- and moisture-proof storage options to protect the seeds until time of seeding.

Both combined and hand-harvested seeds tend to be less “clean” than purchased seeds. A pound of bulk-harvested seed may contain substantially more chaff and non-viable seeds than a pound of nursery seeds, which are typically sold as “pure live seed”. For this reason, we recommend that the seeding rate of harvested seeds be increased by as much as 30-40 lbs/acre compared to clean, purchased seed (Diboll 1997). Additionally, when harvesting seeds from native populations, it is important to avoid depleting the local seed source. No more than 10-50% of a population’s seeds should be collected (proportional to species rarity), and individual populations should be harvested infrequently enough to prevent species decline and loss of local diversity (Shirley 1994, Diboll 1997, Houseal 2010). Current research indicates that combine-harvesting three out of ten years has little impact on species composition, but annual harvesting may cause substantial declines in some species (J. Meissen, personal communication). Regardless of whether seed is purchased from a nursery or wild-harvested, it is important to use local ecotype seed sources from within 175 miles of the restoration site (MN BWSR 2011).

Because of the very large landscape areas intended for restoration under the Minnesota Prairie Conservation Plan, it is unlikely that sufficient seed sources will be available to use locally harvested seeds for all restoration areas, and many landowners do not have access to high quality prairie from which to harvest seeds. Thus, most of the prairie restoration specified by the Prairie Plan will likely will likely require seed purchased from local vendors.

1. Target Plant Communities

The native plant communities that represent appropriate restoration targets within the ABR and GL landscapes are outlined in Table 21. Species frequency and cover data for each plant community served as a guide for seed mix creation (MN DNR 2005), although only a portion of the species naturally occurring in these plant communities are available commercially. If specific species are desired and not commercially available, harvesting from existing natural areas may be an option for conservation agencies with prairie/meadow landholdings. Similarly, bulk combine-harvested seed may be purchased from some local seed vendors, particularly in the ABR region. Some species that are not currently available through nursery production may be obtained through such bulk harvesting techniques.

2. Utility Mixes

Species included in the utility seed mix should have broad soil moisture tolerances, ranging from wet to wet mesic for the meadow mix, and from mesic to dry for the prairie mix. Although the richness levels are lower than those recommended for conservation end states, all major prairie functional groups (i.e. warm and cool season grasses, forbs and legumes) should ideally be represented (although few legumes occur in saturated soils). A diversity of vegetation heights (e.g. tall, medium and short grasses) is also recommended. No specific guidelines are available for grass:forb or warm:cool season ratios for native grazing systems, but ultimately, species composition will be influenced by timing and intensity of grazing and other management activities, so initial seeding ratios are not definitive.

The seed mix for the utility prairie and meadow should contain a balance of cool- and warm-season native grasses to sustain grazing and haying operations throughout the growing season. Cool season grasses are typically used in conventional grazing systems and generally provide better forage quality than warm season grasses, but their production declines dramatically in the hot, mid-summer months. Warm season grasses, the dominant species in Minnesota's tallgrass prairies, reach maximum biomass in the mid-summer months and can thus support grazing during the periods when cool-season grasses are in decline.

Forbs should include palatable and relatively grazing-tolerant species and nutrient-rich legumes. Grazing-sensitive and toxic species (e.g. *Delphinium*) should be avoided, although toxic forbs are unlikely to be a problem unless they are present in high densities or cattle stocking rates are very high (in which case, cattle will eat non-preferred species).

A suitable seed mix for utility prairies is the Minnesota CP25 Economy Mix (Shooting Star Native Seeds – 2012 recipe. Developed as a Minnesota CRP native seed mix, the CP25 Economy Mix includes cool-season native grasses, warm-season grasses, legumes and forbs (Appendix 4, Table 60). Tall, mid-height, and short grasses are represented within the warm-season component. Species in this mix are tolerant of dry to mesic conditions, with the exception of *Elymus virginicus* (Virginia wild rye), which is a mesic to wet-mesic species. If planting on dry to dry-mesic sites, this species may be excluded from the mix (with proportional increases of the other species) or substituted with another species.

We selected two Minnesota State Seed Mixes for the Utility Meadow end states: Seed mix 33-262 - *Dry Swale/Pond* is suitable for sites with 3-4 weeks of soil saturation/year and can be planted as an economical wet prairie mix (Appendix 4,Table 61). Seed Mix 33-261 - *Stormwater South & West* will be suitable for sites with soil saturation approximately 6-8 weeks/year and some ponding; this will be an economical mix for wetter sedge meadow sites (Appendix 4,Table 62). Restoration planners and seed mix designers should avoid the temptation to reduce the seeding rate to save money! Low seeding rates will increase both the risk of invasion of exotic species (and thus management costs), as well as the time until native grasses exert dominance and are capable of supporting grazing.

3. Conservation Mixes

Seed mixes for conservation prairies and meadows have high diversity (i.e. 40+ species) to support nesting birds and other wildlife and provide a variety of ecosystem services (MN BWSR 2012b). Benefits of diversity in plant communities include increased productivity (Tilman et al. 2001, Hooper et al. 2005), stability/resilience (Tilman et al. 2006), invasion resistance (Naeem et al. 2000, Fargione and Tilman 2005), food and habitat resources for pollinators, birds and other wildlife, as well as aesthetic value. Although it is difficult to specify "how much is enough" when it comes to species numbers in restorations, a diverse restoration in Minnesota may have 50-100 species or more.

Forbs contribute much of the species richness of a diverse prairie and meadow community. These flowering species are important nectar sources for pollinators and butterflies and have high aesthetic value. Relative to the dominant warm-season grasses and the common forbs included in the utility prairie mix, many prairie forbs are more expensive, more limited in supply, and can be difficult to establish, with more precise germination requirements and narrower ranges of tolerance for environmental conditions such as soil moisture. Conservation meadow mixes also tend to have a higher ratio of cool-season grasses and sedges, which are often more limited in availability and challenging to establish from seed. To avoid wasting valuable seed, it is important to tailor the species and seeding methods to the appropriate environmental conditions.

Although the restoration plans included herein are appropriate for a fairly broad range of soil conditions (mesic to dry conditions for prairie, and wet to wet mesic for meadow), for conservation end states it will be important to design mixes that are suitable for the specific moisture levels of the site and region. We have included four example seed mixes for conservation prairie—a dry and mesic mix suitable for each project landscape area—using Minnesota Native Seed Mixes 35-421, 35-441, 35-521, and 35-541 (Appendix 4, Table 63-Table 66). We have also included example seed mixes for conservation meadow—wet prairie and sedge meadow mixes suitable for western Minnesota—using Minnesota Native Seed Mixes 34-262 and 34-271 (Appendix 4, Table 67 and Table 68). Supplemental species are selected from the MN State Native Seed Mix Design Tool "Pick Lists" based on regional appropriateness, soil moisture tolerances, and conservation value. These are examples for the purpose of cost-estimation; restoration planners are encouraged to design their own site-specific mix for individual projects.

4. Seed Mixes for Interseeding

Interseeding (also referred to as overseeding) is the process of sowing seeds into existing vegetation, as opposed to a site from which all vegetation is removed. Although the term can be used to refer to seeding natives directly into an exotic-dominated pasture, in the context of this project, we use it to refer to seeding into a site that contains at least 25% native vegetation (e.g.

mixed native-invasive and woody-invaded start states), such that selective control methods are required to remove invasive species, and some native vegetation is present on site to contribute propagules for revegetation. The goals of interseeding typically include enrichment (i.e. adding diversity to an otherwise low-diversity restoration/degraded remnant) and biotic resistance to invasion (i.e. adding native species to occupy a site, reduce bare ground, and reduce invasibility). Species selection for interseeding will depend both on the goals and on site characteristics.

If the primary goal is enrichment, the seed mix will generally not include species already present/common on the site, since that would not increase species richness. If the primary goal is invasion resistance, it may be more important to select competitive, fast-growing natives. Both of these goals may be applicable to utility and conservation end states, but for utility end states there will likely be greater emphasis on adding relatively affordable, fast-growing and competitive native species than on enriching the site with more conservative species.

For native remnants, there is an additional reason to avoid adding species already present on site, beyond the objective to increase species richness. To avoid contaminating the local native gene pool via out-crossing, it is recommended that you avoid adding new genetic material to the site and instead encourage the plants already present to spread. Some restoration practitioners argue even against adding new species (Smith 2010b), however many seem to accept adding locally-sourced, regionally-appropriate species that are not currently present on the remnant (but likely did occur there in the past).

For low diversity, degraded restorations and planted grasslands, there is less concern about outcrossing and genetic contamination (although use of locally-sourced seeds is still strongly encouraged). Adding new species to reach a basic threshold of diversity (e.g. ~15 species for Utility end states) is a reasonable goal, but simultaneously, species that already occur on the site might be added following invasive species control to rapidly add cover and biomass (for grazing and biofuel production) and prevent reinvasion. One could argue that species already occurring on the site are "proven performers" for the site conditions. That said, if the site is heavily dominated by just a few highly competitive species, we do not advise adding more of those same species; doing so will not result in an increase in diversity, and may in fact inhibit other species from establishing.

For Utility Prairie and Meadow, we assume a low-diversity restoration start state (i.e. not a native remnant) with a primary goal of filling in gaps after invasive species removal with productive natives, and a secondary goal of increasing species richness to a modest level. For this reason, we generally recommend the same seed mixes for interseeding Utility Prairies as specified for the other start states, regardless of the current vegetation composition. However, if the site is currently dominated by 1-3 species present in the Economy mix, we recommend removing those species from the seed mix order and/or substituting with other less-dominant species. For cost estimation purposes, we assume use of the Utility Prairie, Utility Wet Prairie, and Utility Meadow mixes without substitutes.

For conservation prairie and meadow, we assume a native remnant start state and focus on adding species not already present on site. We also assume that the goals are both to enrich diversity and to fill in gaps and prevent reinvasion following invasive species control. Again, for cost estimation purposes, we assume the same species mixes as specified for the non-remnant start states, but we caution restoration planners to conduct a thorough vegetation assessment prior to purchasing a seed mix to avoid adding species already present on site. Species that occur on site can be subtracted from the conservation mixes presented herein.

G. Restoration Cost Estimation

To estimate the costs of achieving each restoration transition, we collaborated with a graduate research assistant, Jodi Refsland, to create and administer a survey of Minnesota restoration professionals and service providers. In the survey, we provided respondents with four start state scenarios based on our priority set of start states for the restoration transitions analysis (for efficiency's sake, the Mixed Native & Invasive and Woody-Invaded Prairie start states were combined into a single degraded, invaded prairie scenario). Two versions of the survey were created—one that focused on Utility end states and another that focused on Conservation end states. In each, we asked respondents to assume a 40-acre site, adjacent to either a working farm (Utility) or a conservation reserve, such as a Scientific and Natural Area (Conservation). We then queried practitioners about the specific actions and associated costs for restoring both mesic prairie and wet prairie/sedge meadow end states. For each scenario, we provided a table of common restoration actions and asked respondents to indicate the actions and equipment they would typically use for the specified restoration transition, and to provide an estimate of average costs and labor (person hours) per acre for each action.

The survey was developed as a fillable PDF form and emailed to 111 restoration practitioners and service providers in Minnesota, including representatives from private restoration companies, non-profit organizations, and government agencies (i.e. Minnesota Department of Natural Resources, U.S. Fish & Wildlife, Watershed Districts, and Soil & Water Conservation Districts). We stratified contacts by geographic region (Northwest, Southwest, and Beyond) in order to evenly distribute Utility and Conservation surveys in our study areas and across the state. Because we knew that not all restoration providers would be likely to undertake a "conservation restoration" as we had defined it, we prioritized contacts within each region to receive Conservation surveys and used random survey distribution for the remaining contacts. As an added incentive to completing the survey, we offered $20 Holiday Gift Cards to the first 50 respondents. Following receipt of the surveys, Jodi conducted follow-up phone interviews with a subset of survey respondents to clarify responses and ensure data validity.

To calculate transition costs, we averaged the cost estimates provided for specific restoration actions, and then summed the total costs of actions specified in our restoration plans, including vegetation removal, seed bed preparation, seeding, and post-seeding management up 4 years after seeding. To these, we added the average cost of seed mixes for the relevant end state. Costs are reported per acre, with the exception of hydrologic restoration costs (described below), which are added on to project estimates as a flat rate. All transition costs assume that services are purchased from a local restoration service provider and seed mixes purchased from a native seed vendor. Project planning and management, site assessment, and monitoring activities are not included in these restoration cost estimates.

For the wet meadow end states, we added an estimated cost of hydrologic restoration, which we obtained in consultation with Tom Wenzel of the Minnesota Board of Water and Soil Resources. Factors that influence hydrologic restoration costs include drainage type (tile or ditch), tile size and depth, soil type, sediment deposits (i.e. whether sediment needs to be removed via excavation), and whether management of wetland discharge is required (i.e. by constructing an outlet). Total site area does not directly influence hydrologic restoration costs; therefore, we chose to include this cost estimate as a flat rate, as opposed to a per acre cost. To generate a low-end baseline cost, we considered a relatively straightforward scenario; specifically, we assumed a 10-acre, class 2-3 depressional wetland within a 40-acre parcel; sapric and hemic peat soils; current vegetation of reed canary grass (wetland) and corn (upland); a watershed: wetland area of about 8:1; and site drained with tile in a set of 6-inch parallel lines collected on a 10-inch main line that is relatively shallow (8 feet or less) at the point where it leaves the wetland basin. In this scenario, restoration typically will not require removal of the entire length of tile, but can be achieved by placing a single well-placed tile block at the wetland's outlet, e.g. beginning at or just downstream of the wetland and continuing for 100 feet downstream. We assumed that construction of an outlet was not required, due to the wetland size and watershed area. Estimated costs are approximately $500–600 to excavate, remove tile, seal ends, and backfill and compact the trench (T. Wenzel, personal communication). Mobilization costs might add $200–400 to the project cost, depending on contractors and site location. We included a flat rate of $700/project for wetland restoration cost estimates, representing this low-cost scenario with modest mobilization costs. Actual costs of hydrologic restoration may be higher, depending on the factors described above.

The results of the cost estimation analysis are shown in Figure 36. Transition costs ranged widely, from $801/acre to restore Crop to Utility Prairie, to $2713/acre plus a $700 flat rate (minimum total: $3413) to restore Mixed Native-Invasive Grassland to Conservation Meadow. Overall, wet meadow restoration was more expensive than prairie restoration, due in part to the more costly seed mixes, and in part to the need for more intensive management of invasive perennials (i.e. reed canary grass). Restoration to Conservation end states was, not surprisingly, more expensive than restoration to Utility end states—again, due both to seed costs and the higher intensity of management required to maintain a high quality prairie/meadow with minimal invasive species cover. Invaded start states, e.g. invasive-perennial-dominated, mixed-native and invasive, and woody-invaded prairies were more expensive to restore than crop fields and annual-dominated fields, reflecting the high costs of invasive species management and woody plant removal.

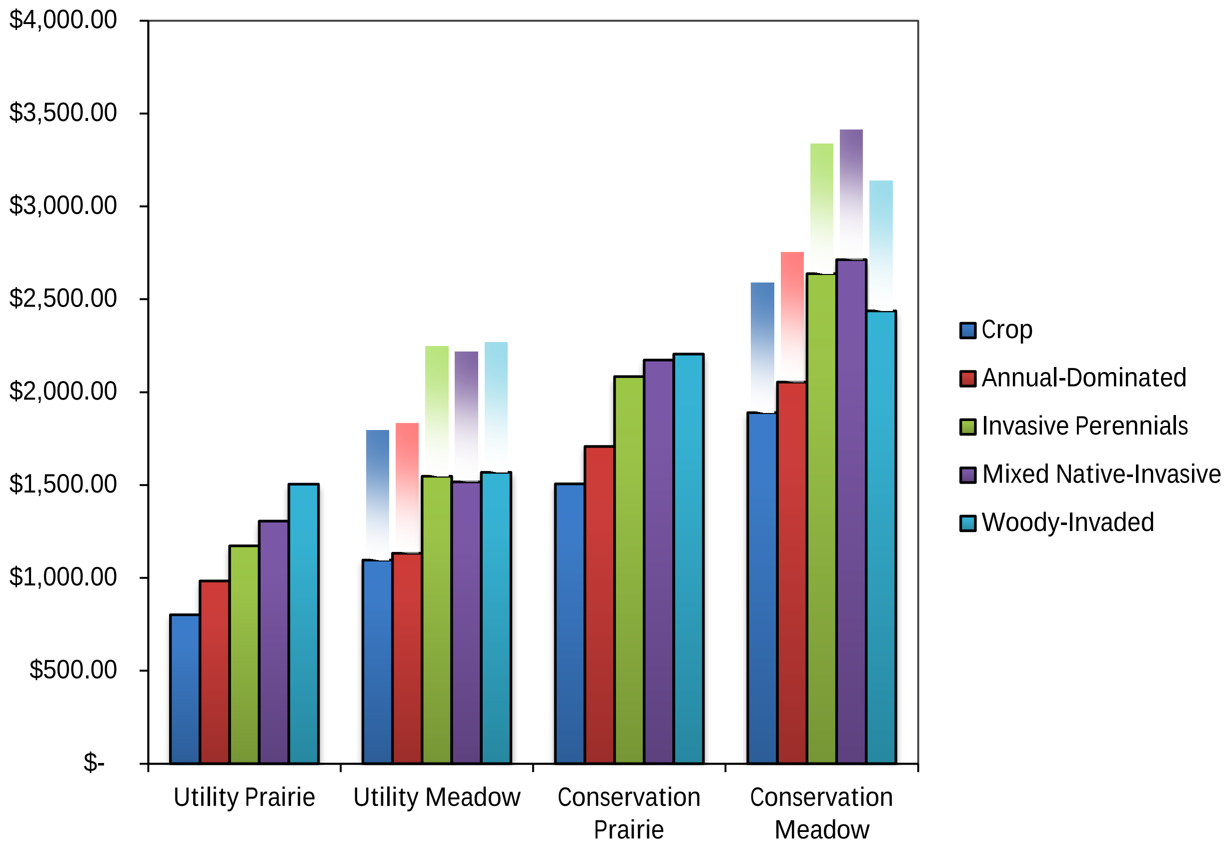

Figure 36. Estimated costs per acre of restoration transitions from five different start states to Utility and Conservation versions of Upland Prairie and Wet Meadow end states. Vegetation removal, seed bed preparation, seeding and three years of post-seeding management are included in the cost estimates. Not included are project planning and management, site assessment, and monitoring activities. Shadow bars above the Utility and Conservation Meadow bars represent the estimated additional cost of hydrologic restoration ($700 flat rate per project, representing a low-end estimate for tile removal and modest mobilization charges). Costs assume purchased services and seed material.

H. Conclusion

The restoration state transition model and cost analysis has provided more nuanced and accurate estimates of the restoration actions and costs that will be required to implement Minnesota Prairie Conservation Plan goals. Because these cost estimates reflect multiple common starting conditions and restoration targets, they can be effectively used for scenario planning, conservation optimization models, and other landscape-scale restoration planning strategies. Within this project, restoration cost estimates were incorporated into economic analyses as the upfront costs of state transitions (Chapter 8) and affect the tradeoffs between private and public returns (Chapter 9).

Social analysis (Chapter 6) can inform the future expansion of the restoration analysis by guiding and refining the selection of potential restoration targets and prioritization of transitions to include in the analysis. For example, participants in the social analysis expressed a strong interest in seeing more oak trees on the landscapes; expanding the restoration analysis to include the oak savanna end state would therefore be a reasonable future step.

The restoration plans, seed mixes, and cost estimates will be distributed to Minnesota Prairie Conservation Plan implementation teams to guide outreach to private landowners interested in planting prairies and meadows to support grazing, haying, seed harvest, and other native grassland-based activities. The Utility end states will be of particular interest to these parties. Both the Utility and Conservation restoration plans will be valuable to conservation agencies tasked with planning and implementing restoration to achieve the specific conservation goals and targets specified in the Minnesota Prairie Conservation Plan and the Measures and Monitoring protocol developed in Chapter 5. Although the restoration transition model was developed specifically for the Agassiz Beach Ridges and Glacial Lakes landscape areas, the restoration plans are generalized and thus will be applicable to other prairie core landscapes identified in the Prairie Plan. Landscape areas that contain prairie and meadow plant communities beyond those that occur in the ABR and GL areas may require additional seed mix development, but otherwise the cost estimates can be easily applied to landscape-scale restoration planning across western Minnesota.

Chapter 8: An Economic and Ecosystem Service Comparison of Row Crop and Grass-Based Land Use *by Harriet Van Vleck and Stephen Polasky*

University of Minnesota

A. Introduction

Agriculture is an essential contributor to the economic vitality of families and communities western Minnesota. Land cover maps highlight the extent of agricultural activity statewide, and particularly in the southern and western portions of the state. Approximately 44% of the land area in Minnesota, as of 2000, was used for agricultural production (Remote Sensing and Geospatial Analysis Laboratory 2000a, Remote Sensing and Geospatial Analysis Laboratory 2000b), with over 80% of this area used for crop production and only 6% used for pasture (USDA NASS 2009). However, the agricultural legacy of the region includes a long history of livestock grazing. In recent years, the trend of decreasing grazing activity has continued as prices of both crops and land have risen (USDA ERS 2012, Center for Farm Financial Management 2013). Combined, these two factors have led to a marked reduction in the extent of grassland in the Upper Midwest (Wright and Wimberly 2013b). Similar trends are evident nationally; pastureland decreased by roughly 12 million acres, or 9%, between 1982 and 2007 (NRCS National Resources Inventory 2013) and corn and soybean planting rates have been steadily increasing (USDA NASS 2013).

The development of the Minnesota Prairie Plan has provided an opportunity for state agencies, non-profit conservation organizations, researchers, and Minnesota landowners to join together in a concerted effort to address threats to grasslands in the state, including the ongoing conversion of grassland to cropland (Minnesota Prairie Plan Working Group 2011). Through examination of economic returns from current cropland use and existing or potential grass-based land uses we assess the viability of alternatives to row crop agriculture in two Minnesota landscapes. Grass-based alternatives to row crops could reduce rates of grassland conversion and encourage ongoing maintenance or restoration of high quality grassland. The focal areas for these analyses are two landscapes which incorporate five of the prairie core areas defined by the Minnesota Prairie Conservation Plan (Figure 3).

For most landowners, a primary goal of land management is to increase the provision of benefits from their unit of land. Management-derived benefits can be divided into two categories, those that accrue solely to the land owner or operator, and those that accrue to the general public. Hereafter, we refer to the former as *private benefits*, defined as the economic benefit from a management operation that is realized by a land manager (owner or operator). The latter are *public benefits*; a term used to encompass the societal benefit in the form of ecosystem services that is gained through a particular management approach. Ecosystem services refer to those ecosystem processes or functions which enhance human well-being (*sensu*, Polasky et al. 2011). Land management decisions are typically made based on a combination of factors including personal experience, economic potential, economic risk, and regional land use patterns. Currently, the economic value of public benefits is infrequently quantified and rarely factors into management decisions made on private land. The economic cost or benefit of changes in water quality, for example, is borne by the public through tax-payer support of public utilities and loss of recreational benefits among other costs. Rising awareness of the value of ecosystem services (public benefits) and greater understanding of managements' potential to impact the provision of public benefits can help inform land use planning and land management decisions at a variety of spatial scales have the potential to significantly alter the provision of both private and public benefits in positive or negative directions.

The Minnesota Prairie Plan calls for an increase in the extent of working grasslands in Prairie Core Areas to buffer and connect the remaining native prairie patches. With over 80% of the land area in each landscape in private ownership, achieving the goals of the prairie plan will require collaboration with private landowners to identify and support the implementation of land management practices which generate the needed public benefits while also generating sufficient private benefits to meet the needs of the land owner.

In this chapter we focus on the provision of private benefits (net returns) from select start states and restoration transitions described in Chapter 7. Additionally, we present a framework for understanding the changes in public costs and benefits (ecosystem service provision and value) associated with potential land use transitions. We focus on management practices which reflect the dominant land use and land cover composition of two landscapes. Landscape composition has been shown to greatly influence the provision of public benefits, and analyses focusing on both landscape composition and configuration have the potential to encourage coordinated land management actions that cross land owner boundaries (Goldman et al. 2007).

The public benefits of maintaining or increasing grassland in highly modified landscapes include benefits to water quality, soil carbon storage, and wildlife habitat. For example, model results showed the potential for a significant public benefit, decreased phosphorous loading in two watersheds by 71–75% resulting from the conversion of 7–14% of cropland in Minnesota to grassland (Boody et al. 2005). Other studies have also shown lower rates of nutrient loss and sediment erosion from areas with grassland cover compared with cropland (Moore and Palmer 2005, Tangen and Gleason 2008, The Center for Integrated Agricultural Systems 2013).The conversion of grassland and wetland into cropland has resulted in significant reductions in soil organic carbon (C) stocks (e.g., Mann 1986); these declines in soil C appear to be at least partially reversible upon conversion of cropland back to grassland (McLauchlan et al. 2006).

Numerous studies have shown the greater benefits of grassland as compared to cropland for bird and other animal habitat (e.g., Polasky et al. 2011).

B. Methods

1. Economic Model

a. Overview

We generate estimates of the economic returns for land use and land management by computing the benefits and costs associated with each land use and land management combination. We combine these return estimates with the restoration costs from Chapter 7 and Appendix 3 to highlight the role of transition costs in determining the economic viability of state transitions, with a focus on cropland to grassland transitions (Figure 13). Among grazing operations in particular, there is significant variability in the management practices utilized by land managers. Our analyses reflect some of this variability by including multiple operation sizes, grazing intensities, and levels of grassland productivity. The latter reflects both variability in grassland composition and in the underlying regional soils and climate. Budget data in this chapter reflect average data often at the county level and may not fully reflect site specific variation in yield, management practices or economic data.

b. Operation Budgets

For start and end state land use/land cover (LULC) types that were the focus of the restoration plans in Chapter 7 (see Figure 16 for ABR start states and Figure 18 for GL start states) we generated estimates of economic returns based on county or region specific yield, price, and production cost data. Net returns were separated into two groups, net returns to the land and net returns to the operator. Net returns to both land and operator were further separated based on land ownership, with net returns per acre estimated for both owned and rented land. Returns to the operator include per acre production costs as well as the cost of labor, insurance, land rent or property tax, and both government and insurance payments. Returns to the land differ in that they do not include government or insurance payments, and also do not include the costs of owning or renting the land making this the most relevant value to compare across state transitions. For clarity, we focus on the net returns on owned land. Net returns presented are returns to the operator unless otherwise noted. Note that net returns presented only reflect the potential returns from a single operation. These returns do not represent a complete financial analysis for a farm or farming family for which there are typically multiple sources of on and off farm income as well as multiple farming operations.

The general equation for calculating annual net returns was $NR_{mlt} = Y_{mlt} * P_{mlt} + R_{mlt} - C_{mlt}$, where NR is the annual net return, Y is yield per acre, P is price per unit yield, R is other revenue per acre associated with the management practice, C is the cost per acre of producing the yield, *m* represents the commodity type grown in LCCS class *l* in the year *t*. Given the variability of crop prices, cropland returns are presented for two five-year periods, 2002-2006 and 2007-2011, and to reflect recent high prices, returns are also reported for the year 2011. Returns for all other operations are only presented for the 2007-2011 period.

c. Transition Costs

Using the restoration plans and transition costs presented in Chapter 7 and Appendix 3, we identified the annual expenses and potential revenue associated with state transitions (Figure 34). Three assumptions were needed for inclusion of the transition budgets in our economic model.

1) If a management protocol included a range of timeframes for a given action, we made the conservative assumption that the maximum amount of time would be required thus erring on the side of overestimating the total time needed for transitions. For example, when pre-seeding management timeframes vary depending on site conditions, requiring either a full growing season or only the fall, we made a conservative assumption that the full growing season would be required. This assumption precludes returns from any income generating activities occurring on the start state prior to the transition.

2) The recommended management protocols for many of the end states suggest burning on a 3-5 year rotation, and dividing the area into either 2 or 3 units such that only one unit is burned within a given growing season. To incorporate these suggestions into our economic model, we assumed that burns happened on a 4 year rotation and assumed burn costs were spread across either 2 or 3 years depending on the transition specific management protocols (see Appendix 3). Similarly when the recommended burn rotation was 4-7 years, we assumed a 5 year rotation. Assuming a longer period between burns would reduce annual maintenance costs, but these reduced costs would quickly be offset if the longer burn rotation allowed for invasion by non-native species requiring additional management actions such as spot spraying herbicide.

3) Establishment costs for end state operations were compiled from other studies are presented in this chapter but these costs were not included in the transition analysis.

2. Cropland Budgets

a. Description

Operation yield, price, and cost data were compiled for each year, county, and tenure type. Both tables and maps presented in this chapter show patterns of *potential* net returns based on the five year average financial data and estimated yields. Data shown represent average returns reported for a region. The exact location; soils, topography, management history, and current management will each influence an operator’s actual net return. Further, net returns presented reflect individual operations and do not reflect the combined outcome of multiple revenue streams or off-farm income.

b. Budget Components

(1) Yield

In order to get annual estimates of yield for each county and each tenure type, annual county-level yield data from FINBIN was collected for a ten year period, from 2002 through 2011 (Center for Farm Financial Management 2013). FINBIN data is available as an average by county, but cropland yields vary significantly with soil productivity. The benefit of FINBIN data is that it is based on information collected from producers and therefore represents actual yield data. Yield data that reflects the variability in soil productivity is available from SSURGO, but these data are expected yields rather than actual yields and are only available as an average over time (Soil Survey Staff et al. 2013).

SSURGO crop yields are reported by soil productivity groupings called land capability classes (LCC) and subclasses (LCCS) for each county (Soil Survey Staff et al. 2013). LCC classes 1–8 reflect soil productivity levels, with 1 being the highest productivity and 8 being the lowest. In Minnesota, LCC 1–3 soils are generally viewed as suitable for crop production, while LCC 4 soils are marginal for crop production and are often highly prone to erosion. LCC 5–8 soils are infrequently used for commercial crop production and are best suited to grass-based uses (Table 23). LCC subclasses identify those characteristics of soils within an LCC class that may constrain productivity (Table 24). To distinguish areas where there are no yield data due to the presence of a water body versus none due to the absence of a particular LCCS within a county, we assigned an LCCS value of 10 to water bodies and a null value (shown as ".") to unrepresented LCCS groups. Where there was no SSURGO crop yield reported for a particular soil map unit, the average for the land capability subclass (LCCS) in that county was used. In those instances where there were no yield data for an LCCS within a county, the average yield for that LCCS across the major watershed area was utilized.

Class	Land Capability Class Description
1	Few limitations that restrict use.
2	Some limitations that reduce the choice of plants or require moderate conservation practices.
3	Severe limitations that reduce the choice of plants or require special conservation practices, or both.
4	Very severe limitations that reduce the choice of plants, require very careful management, or both.
5	Little to no erosion hazard, but other limitations that are impractical to remove limit use.
6	Very severe limitations, generally unsuited to cultivation and use is limited primarily to pasture, etc.
7	Very severe limitations, unsuited to cultivation and use restricted to grazing, etc.
8	Limitations that preclude use for commercial plant production and restrict use.

Table 23. Land capability class descriptions. Table summarizes information from the domain descriptions of SSURGO data (Soil Survey Staff 2013).

Subclass	Land Capability Subclass Description
e	erosion
s	soil limitations within the rooting zone
w	excess water
c	climate condition

Table 24. Land capability subclass descriptions. Table summarizes information from the domain descriptions of SSURGO data (Soil Survey Staff 2013).

The estimated yields used to generate net returns in our budgets reflect the variability in soil productivity from the SSURGO data and the variability in yields over time from the FINBIN data. To generate yield estimates, we multiplied SSURGO crop yield data for each LCCS within each county by the ratio of FINBIN yield data for a given year to the average of FINBIN yield for 2002-2011 for a given county, year, and tenure type. For example, to estimate yield for a given crop, county, and tenure type in 2010 on soils classified as LCCS 2e, SSURGO data for LCCS 2e was multiplied by the ratio of the 2010 FINBIN yield to the ten year average FINBIN yield for that crop, county, and tenure type.

Major crop types in the two landscapes include: corn, soybean, small grains, alfalfa hay, and sugar beets. As spring wheat is the dominant small grain grown in these landscapes, spring wheat enterprise budgets were considered representative of other small grain budgets. Farmers growing small grains other than spring wheat will need to adjust these budgets accordingly. Crops representing less than 1% of the cropland area based on data from the 2011 CDL (USDA NASS 2011) were combined into an "other crop" category represented by oat enterprise budgets for both landscapes. For our analysis of public benefit provision, cropland types were combined into two classes, row crop and alfalfa hay.

(2) Prices and Production Costs

For each county within the study area, enterprise budgets for each crop were compiled from FINBIN (2013a) for each year of two five year intervals, 2002–2006 and 2007–2011. Where FINBIN data on specific costs were missing for a county, average values across the counties within each landscape by tenure type (own versus rent), and by year were used where possible, or by 5-year average where necessary.

FINBIN costs for each operation were adjusted in the following manner to generate returns to land and returns to operators. Returns to land excluded revenue or costs not directly tied to the productivity of the land. It is assumed that expenses such as land rent or property taxes will remain constant regardless of the land management operation in place. For this reason, returns to land are best suited for comparing potential returns across management operations. Returns to land further do not include hedging gains or losses per acre, crop insurance per acre (revenue or cost), farm insurance, dues and professional fees, or government payments. Returns to the operator do include land costs as well as each of the items listed above. Both estimates of net return include the cost of labor and other revenue sources associated with the operation (such as the sale of crop residue). Thus net returns to land and to the operator were estimated using the following general approach: Net Return/acre = [Price/unit * Yield (estimate) + other revenue/acre_land or other revenue/acre_operator] – [Costs_land or Costs_operator]. All profits and costs presented have been converted to 2011 dollars using the consumer price index (U.S. Department of Labor 2013).

3. Grassland Budgets

a. Description

Operation yield, price, and cost data were compiled for each year, and county. For grass-based operations, all land is assumed to be owned as insufficient data was available for distinguishing between tenure types. As with cropland data, tables and maps presented in this chapter show patterns of *potential* net returns based on the five year average financial data (2007-2011) and estimated yields. As was stated about the cropland budgets, data shown represent average returns reported for a region. The exact location; soils, topography, management history, and current management will each influence an operator's actual net return. Further, net returns presented reflect individual operations and do not reflect the combined outcome of multiple revenue streams or off-farm income.

The potential to use grazing as a grassland management tool has received a lot of attention in recent years. Conservation grazing can be defined as grazing by livestock to accomplish specific conservation goals by providing the disturbance native prairie and other grasslands need. Specifically conservation grazing: 1) maintains or improves the composition of the plant community by increasing native plant species diversity while discouraging the spread of invasive weeds and woody plants, 2) provides a diversity of vegetation structure at all time periods, and 3) allows natural ecological processes to occur. To accomplish these goals, grazing will have to be rotational in nature and conducted in a way that allows all native plant species ample recovery time following defoliation.

We generated budgets for six types of grazing operations. The focus of our analysis was on beef cow-calf operations, though research on pasture-raised dairy operations in Wisconsin show promising results. Large operations represent an additional 38% percent, and the remainder is comprised of operations with 500 or more head which are unlikely to be pasture based systems. Grazing operations modeled varied in size, small (1-100 head) or large (101-200 head), and in stocking rate (the number of animal units per acre over the growing season) with stocking rate increasing from conventional (CON), to rotational (ROT), and ultimately to management intensive (MIG) grazing systems. In practice, there is tremendous variability in the implementation of each of these three grazing systems based on operator experience, site history, and local markets. Several assumptions were necessary in order to generate estimates of the potential economic returns from a "typical" farm utilizing each grazing system.

Management decisions differ depending on whether one is trying to maximize system productivity per head or per acre (Figure 37). For farmers with limited land for grazing, rotational systems have the potential to increase net returns on a per acre basis, whereas continuous grazing systems tend to have higher net returns per cow or cwt.

As modeled, management intensity affects net returns per acre through differences in estimated grassland productivity and forage utilization rates. Combined, productivity and utilization rate controlled differences in potential stocking rates among operations. Grassland productivity and utilization rates varied from 0.30 to 0.65% and were based on Forage Suitability Group data described in greater detail below and in Table 25 (Soil Survey Staff 2012).

Increasing grazing intensity is typically characterized by increasing stocking rates and number of paddocks, but decreasing grazing duration and paddock size. The result is greater forage utilization rates by livestock. The right combination of cool and warm season grasses for an operation will depend on the desired length of the grazing season and the effect of local climate on the relative growth rates of cool versus warm season grasses. For this analysis we assumed a 5 month grazing season (154 days, from roughly May 1 to October 1). Though many managers find it optimal to plant a mix of cool and warm season grasses to maximize their overall forage production and grazing season length, for our analysis we calculate unique net returns for systems dominated by either warm season grasses or a mix of cool season grasses and legumes. In both rotational and management intensive systems, paddocks are typically only grazed one time per season, systems should be designed to allow grazers to alternate the timing of grazing on paddocks over time. If maintaining grassland diversity is an objective of the grazing operation, haying should occur between mid-July and early August (Jarchow and Liebman 2011).

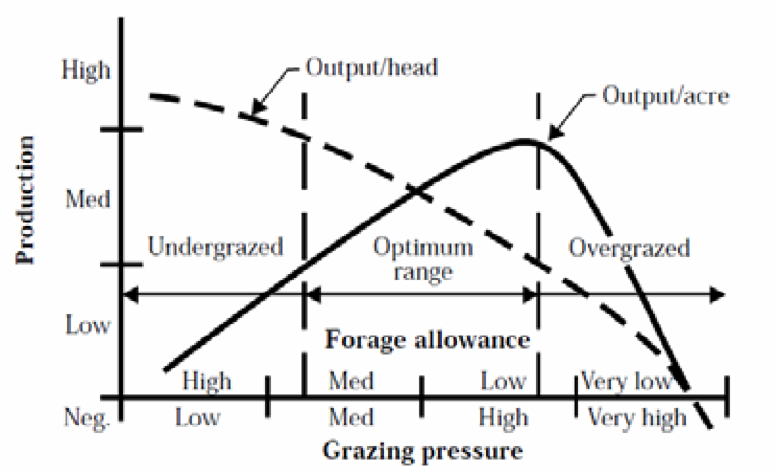

Figure 37. Effect of grazing pressure on grass productivity. Relationship between grazing pressure (animal units per unit lb dry matter) and two measures of grazing production levels, output/head and output/acre. Forage allowance is the inverse of grazing pressure (lbs dry matter per animal unit). This image from the NRCS Range and Pasture Handbook (NRCS 2003) was adapted from Barnes et al (1995).

b. Budget Components

(1) Yield

Forage suitability group (FSG) data were used to estimate grass yields for specific start and end states. FSG grassland yield data are produced at the state level for each major land use resource area (MLRA) (Soil Survey Staff 2012). Species specific FSG data can be grouped by species type/group: cool season grasses, mixed cool season grasses and legumes, legumes, or warm season grasses. Average yield data for mixes common in each of the landscapes were used to estimate yields for the IPDG start state. Most of the cool season grasses in this start state are non-native, and both trefoil and clover are common in these communities. Average yield data for warm season grasses (WSG) were used to estimate yields for the MNIG, WIP and MNP start states as well as the UP and UM end states. Yield can vary significantly with grassland community, soils, and management (particularly fertilization). Operators should utilize site and management specific yield data, not the estimates used here, to calculate potential returns for grazing or haying operations on a particular site.

Cool season grasses within the FSG dataset for the ABR and GL regions include: smooth bromegrass (*Bromis inermis*), tall fescue (*Festuca arundinacea*), timothy (*Phleum pretense*), Kentucky bluegrass (*Poa pratensis*), creeping foxtail (*Alopecurus arundinaceus*), orchardgrass (*Dactylis glomerata*), reed canarygrass (*Phalaris arundinacea*), intermediate and tall wheatgrass (*Thinopyrum intermedium* and *Thinopyrum ponticum*), and Western wheatgrass (*Pascopyrum* *smithii*). Legumes in this dataset include birdsfoot trefoil (*Lotus corniculatus*), cicer milkvetch (*Astragalus cicer*), crownvetch (*Securigera varia*), alfalfa (*Medicago sativa*), and five types of clover (alsike - *Trifolium hybridum*, kura - *Trifolium ambiguum*, ladino - *Trifolium repens*, red - *Trifolium pratense*, and white - *Trifolium repens*). Mixes are primarily non-native cool season grass/clover mixtures in ABR and grass/clover, trefoil/clover/grass, alfalfa/clover/grass, or bromegrass/orchardgrass mixtures in GL. Warm season grasses included in this dataset are: big bluestem (*Andropogon gerardii*), indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), little bluestem (*Schizachyrium scoparium*), and sideoats grama (*Bouteloua curtipendula*).

Yield data are included in the FSG dataset for three levels of productivity reflecting differences in fertilization assumptions, and most importantly, differences in utilization rates when grazed. A summary of the characteristics of production levels within the FSG dataset follows (Table 25).

	High	Medium	Low
Lime and Fertilizer	optimum nutrient levels	75% of optimum nutrient levels	50% of optimum nutrient levels
Pest Control	Controlled	Most controlled	Only noxious controlled
Species Planted	Maximize and balance quantity and quality	Maximize long term stand persistence	Low cost or tradition
Harvest	Mechanical to optimize number of cuttings per season	Mechanical, limited to 2-3 cuttings per season	Mechanical, completed near species maturity
Grazing Management	Management Intensive	Rotational	Continuous
Utilization Rate	65%	45%	30%

Table 25. Management assumptions in the Forage Suitability Group data.

For our model, grazing management and assumed FSG grass type influenced potential net returns through utilization rates and yields of grass available as forage per acre. FSG yields are available as pounds of dry matter per acre (lb DM/ac) and as animal unit months per acre (AUM/ac). For each combination of grassland start or end state and grazing system, we had to make assumptions about which FSG data to use, Table 26 summarizes our use of the FSG data.

FSG Grass Type	FSG Management	Start / End State	Grazing system
Mix	Low	IPDG	grazed
	Medium		grazed-rotational
WSG	Low	MNIG	grazed
	Medium		grazed-rotational
	Low†	WIP	grazed-rotational
	Medium	MNP	grazed-rotational
	High		grazed-mig
	Medium	UP	grazed-rotational
	High		grazed-mig
	Medium	UM	grazed-rotational
	High		grazed-mig

†Though this is a rotationally grazed system, we assumed lower potential yields due to the presence of invasive woody plants.

Table 26. Use of Forage Suitability Group data to estimate start and end state grassland yields. Forage suitability group (FSG) data for mixed cool season and legume grasslands (Mix) and for warm season dominated grasslands (WSG) were the basis for our estimates of grassland productivity for each of the perennial grassland start states and the utility end states.

(2) Prices and Production Costs

As done for the crop budgets, cow-calf operation price and production cost data was gathered from FINBIN (Center for Farm Financial Management 2013) and net returns to the operator on owned land are presented for both landscapes and the intersecting major watersheds. FINBIN livestock budgets are available on a per cow unit or per hundredweight (cwt) basis. Potential stocking rates for each management system were utilized to convert the returns per cow unit to returns per acre. To make budgets reflect the availability of forage, we adjusted the costs associated with pasture in the budgets to reflect the additional feed needed or the surplus feed available based on the FSG yield data. Adjustments to the budgets were small, ranging from a reduction in costs of $6.40/ac to an additional cost of $25.70/ac for ABR, and a similar magnitude for GL.

4. Ecosystem Service Analysis

a. Services Modeled

We quantified land use impacts on the following processes and benefits: soil carbon storage, and water and nutrient retention. Utilizing knowledge of both private and public consequences of decision making has the potential to improve regional quality of life and lead to more effective regional land use planning. Prior studies describe in detail the benefits of incorporating ecosystems service information into land use planning, as well as the data requirements and methods of using InVEST to model ecosystem service provision (e.g., Polasky et al. 2008, Polasky et al. 2011, Johnson et al. 2012).

(1) Carbon

At multiple stocking levels, grazing in semi-arid regions has been shown to increase soil carbon (C) storage as compared to ungrazed grasslands (Schuman et al. 2002), but in regions with annual precipitation similar to Minnesota, there appears to be no net effect of grazing on soil C storage to a depth of 105 cm (Henderson 2000). We used the same C storage input data for grazed and ungrazed grasslands, making the focus of our analysis the difference between croplands and grasslands rather than the differences between grass-based land uses. Future analysis will examine whether differences in management of grasslands have a significant impact on C storage through differences in productivity between grassland communities or management practices such as burning. On tallgrass prairies, annual burning can lead to increased soil C storage; likely a result of the generation of charcoal which is slow to decompose (Rice and Owensby 2000).

(2) Water Quality

Annual vegetation and draining of cropland alters the hydrologic patterns contributing increased quantities of water to surface flow, and increasing both nutrient and sediment concentrations in surface water due to high rates of nutrient application and increased soil erosion with annual cover (Goolsby et al. 1999, Oquist et al. 2007, Donner and Kucharik 2008).

The InVEST water model runs as two steps, the first computes the water yield from each LULC pixel (90 x 90 m2) based on input layers including precipitation and potential evapotranspiration. The second step utilized user defined export and retention coefficients for each LULC class to determine the fraction of nitrogen (N) or phosphorous (P) retained on the landscape. Nutrients are then routed across the landscape and the amount of nutrient exiting watersheds can be compared under land use change scenarios.

C. Results

1. Land Capability Class Distribution and Yield Estimates

Generally, the LCC distribution within the ABR landscape and within the broader watershed boundary are very similar, with 82–84% of the area classified as LCC 1–4, 12–15% classified as LCC 5–8, and 3–4% undefined, LCC 10 or "." (Table 27). In contrast, the LCC distribution between the GL landscape and the surrounding watershed area do differ with the extents of LCC 1–4, 5–8, and undefined classes as a percent of the total landscape area being: 69%, 23% and 8%, while corresponding values for the watershed area are: 87%, 8%, and 5% (Table 28). LCC and LCCS spatial distribution is shown in Figure 38–Figure 40 for each landscape and for the broader watershed areas encompassing each landscape (Chapter 3).
Crop yields within the landscapes and the broader watershed areas differ dramatically among LCC classes as can be observed in the tables and maps of crop yields for both landscapes presented in Appendix 5. On average, crop yields within the landscapes were lower than for the watershed area which, especially for GL, reflects the underlying soil characteristics (see

Appendix 5 for yields by LCCS and county, Table 78–Table 83 for ABR and Table 84–Table 89 for GL).

	Landscape Boundary						Watershed Boundary					
LCC	c	e	s	w	Total	% Total	c	e	s	w	Total	% Total
1	.	.	.	.	**4,209**	**3**	.	.	.	.	**57,146**	**3**
2	.	4,969	20,506	11,437	**36,912**	**29**	1,865	316,787	395,333	294,127	**1,008,111**	**57**
3	.	1,038	16,964	16,731	**34,734**	**27**	.	162,500	73,249	66,414	**302,163**	**17**
4	.	5,370	17,305	5,659	**28,333**	**22**	.	48,639	57,210	14,595	**120,445**	**7**
5	.	.	.	647	**647**	**1**	.	.	.	11,570	**11,570**	**1**
6	.	.	8,867	7,921	**16,789**	**13**	.	28,372	29,122	77,481	**134,975**	**8**
7	.	.	5	.	**5**	**<1**	.	2,568	2,078	13,602	**18,247**	**1**
8	.	.	.	1,069	**1,069**	**1**	.	.	415	49,680	**50,095**	**3**
10	.	.	.	.	**104**	**<1**	.	.	.	.	**52,548**	**3**
.	.	.	.	.	**3,972**	**3**	.	.	.	.	**15,865**	**1**
Total	.	**11,377**	**63,648**	**43,464**	**126,774**	**100**	**1,865**	**558,866**	**557,407**	**527,469**	**1,771,165**	**100**
% Total	.	**9**	**50**	**34**	**100**		**<1**	**32**	**31**	**30**	**100**	

Table 27. Land capability class (LCC) and subclass extent, ABR. Distribution of each class and subclass shown as acres and as a fraction of the total landscape or watershed area.

	Landscape Boundary					Watershed Boundary				
LCC	e	s	w	Total	% Total	e	s	w	Total	% Total
1	.	.	.	**1,055**	**1**	.	.	.	**241,233**	**7**
2	14,006	5,491	8,749	**28,246**	**17**	783,553	317,689	849,270	**1,950,528**	**54**
3	25,573	22,713	16,726	**65,012**	**38**	316,897	194,768	299,975	**811,679**	**22**
4	15,043	7,212	229	**22,484**	**13**	96,365	46,965	6,489	**149,832**	**4**
5	.	.	362	**362**	**<1**	.	.	29,184	**29,184**	**1**
6	3,041	6,483	10,377	**19,901**	**12**	28,727	25,537	66,479	**120,754**	**3**
7	2,610	5,371	252	**8,233**	**5**	23,558	15,496	1,273	**40,331**	**1**
8	.	.	10,826	**10,826**	**6**	.	1,415	84,934	**86,355**	**2**
10	.	.	.	**12,048**	**7**	.	.	.	**158,090**	**4**
.	.	.	.	**894**	**1**	.	.	.	**19,892**	**1**
Total	**60,273**	**47,270**	**47,521**	**169,061**	**100**	**1,249,100**	**601,869**	**1,337,603**	**3,607,879**	**100**
% Total	**36**	**28**	**28**	**100**		**35**	**17**	**37**	**100**	

Table 28. Land capability class (LCC) and subclass distribution, GL. Distribution of each class and subclass shown as acres and as a fraction of the total landscape or watershed area.

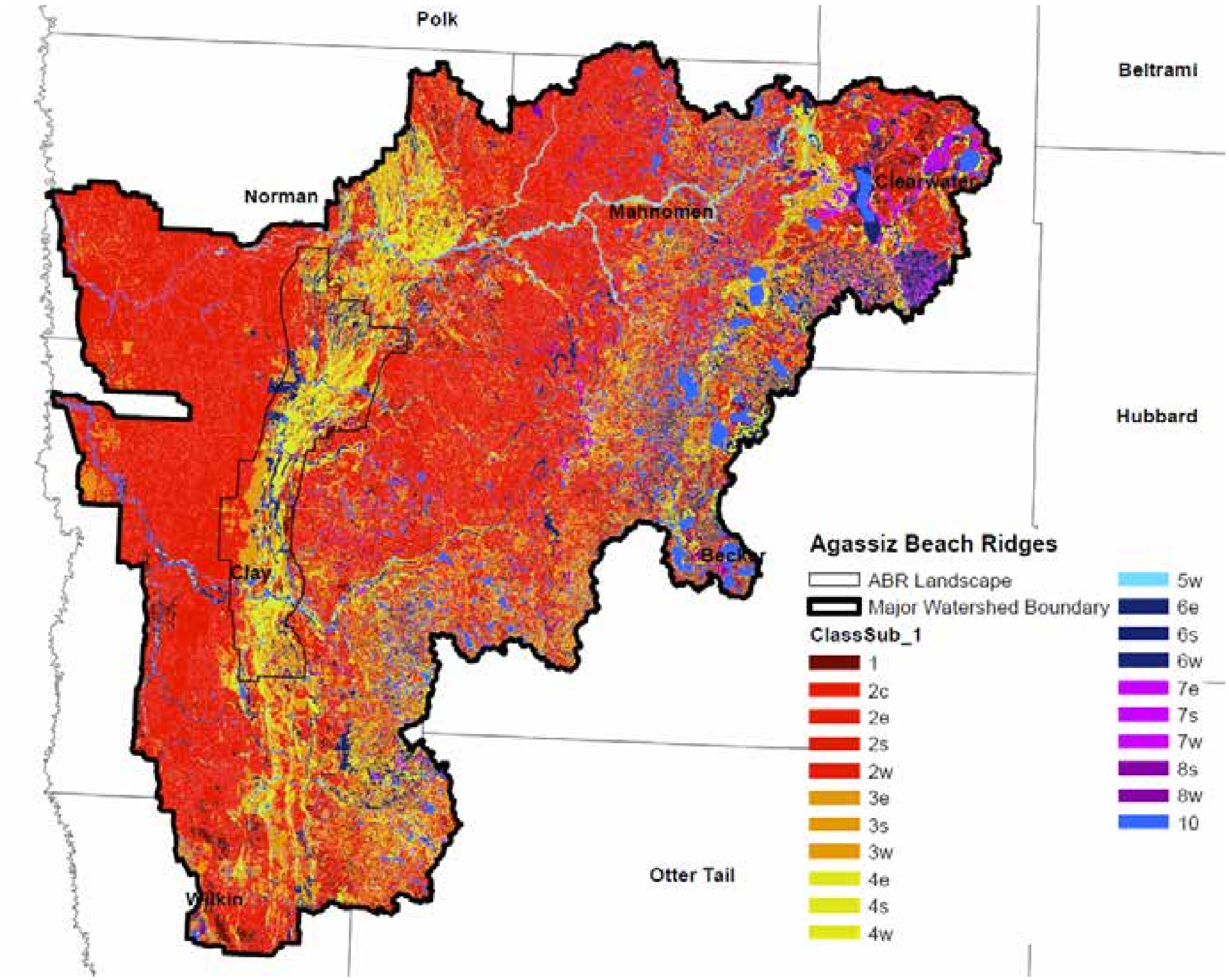

Figure 38. Land capability class and subclass within the ABR major watershed boundaries. The external boundary represents the boundary of three major watersheds which intersect the Agassiz Beach Ridges landscape.

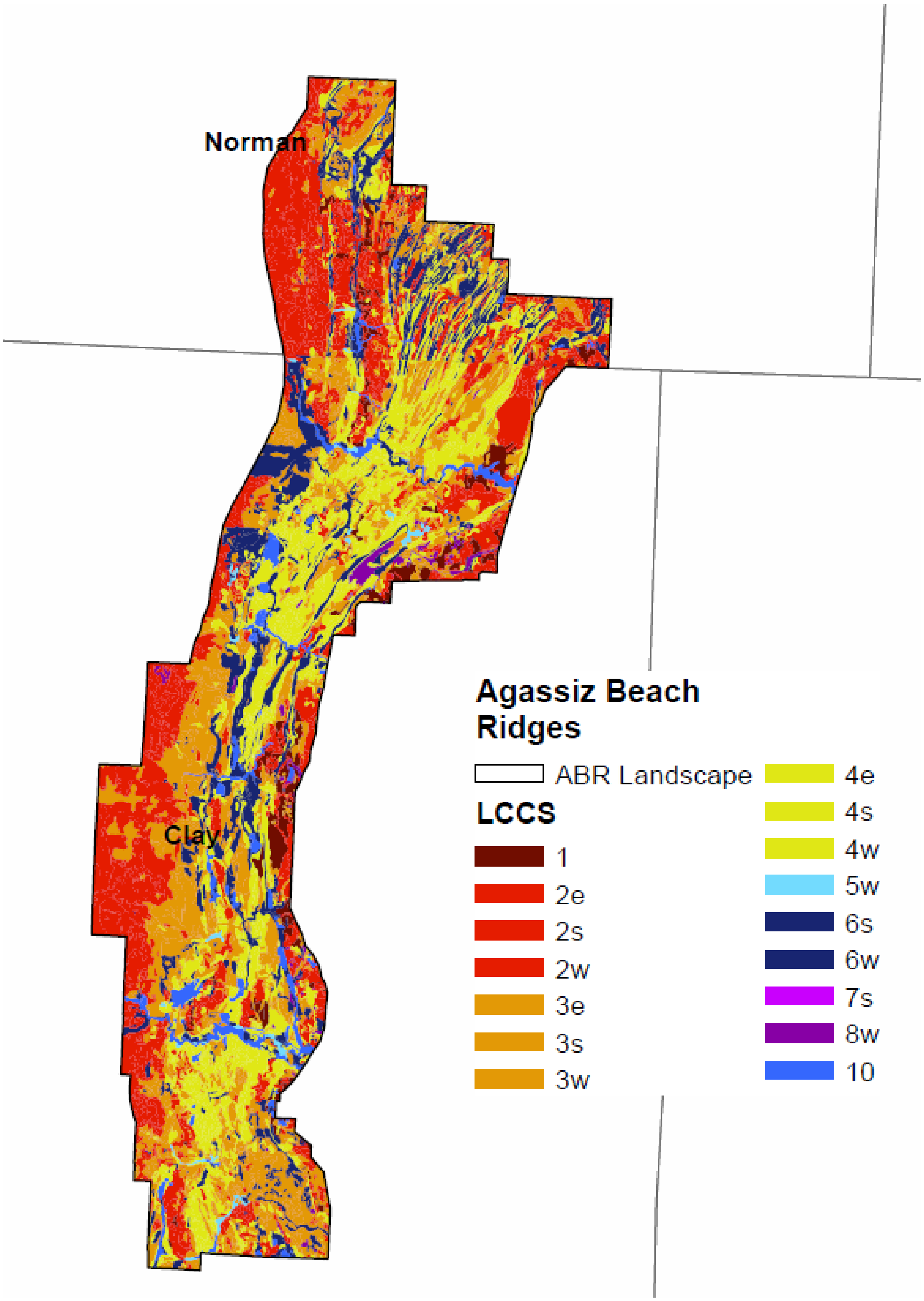

Figure 39. Land capability class and subclass within the ABR landscape.

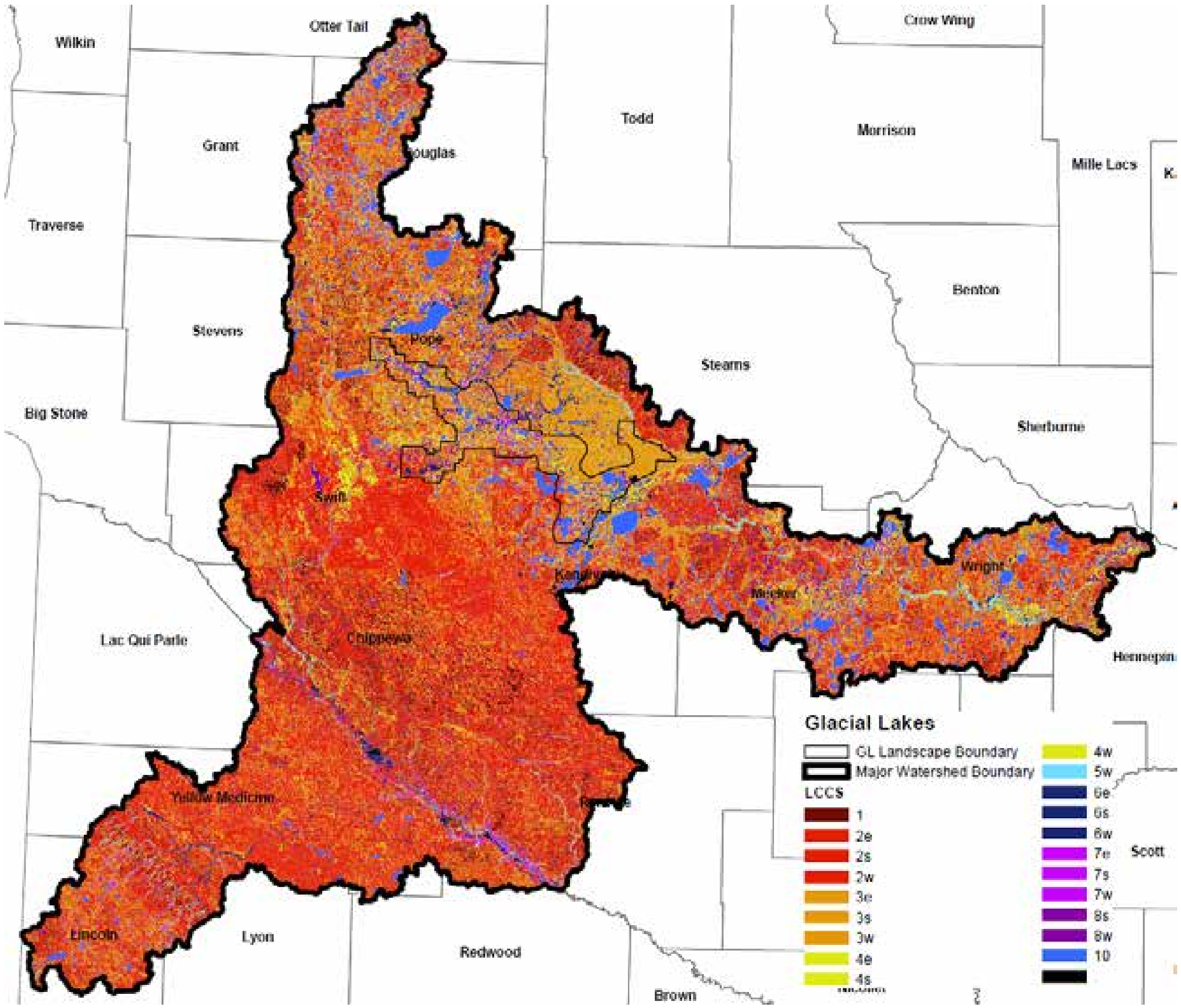

Figure 40. Land capability class and subclass within the GL major watershed boundaries. The external boundary of the three major watersheds which intersect the landscape is shown.

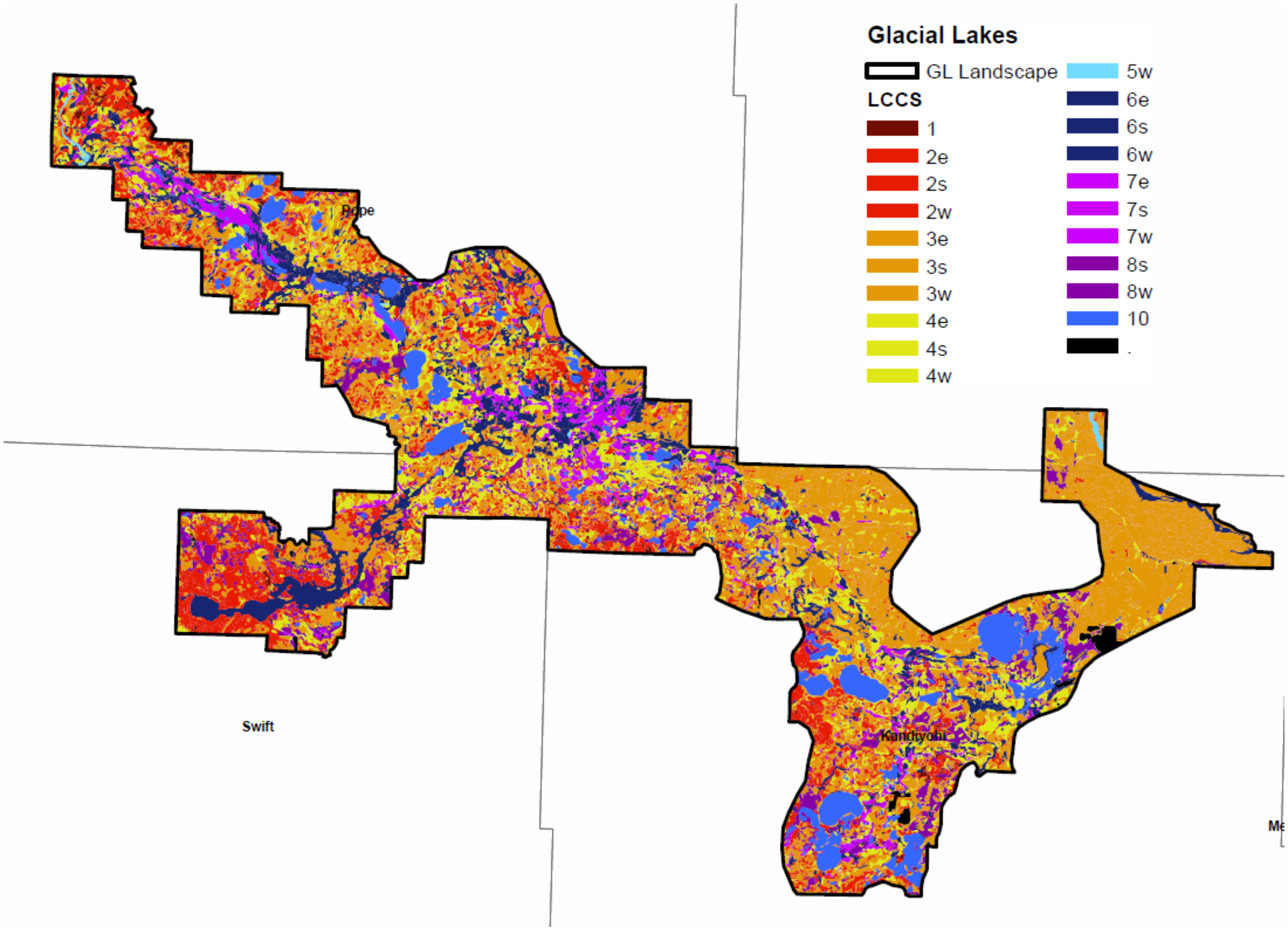

Figure 41. Land capability class and subclass within the GL landscape.

Grassland yields varied significantly with both land capability class and with management practices (reflected in the high, medium, and low productivity groupings, Table 29 and Table 30). Warm season grass yields for the two landscapes ranged from 1,000–8,400 lbs DM/acre (pounds dry matter per acre) based on Forage Suitability Group data (Soil Survey Staff 2012). Average yields for warm season grasslands, at a medium level of productivity, were 4,122 for the ABR landscape and 5,377 lbs DM/acre for the GL landscape. These average yield data are comparable to estimates from high diversity grassland restorations in Minnesota 4,000-6,000 lbs DM/acre (Mangan et al. 2011). A summary of grassland yields is shown in Table 29 for the two landscapes and Table 30 for the two watershed defined regions. Yield data are shown by land capability class and subclass in Appendix 5 (Table 73–Table 76).

Grassland Productivity		Warm Season Grass		Cool Season Grass Mix	
		ABR	GL	ABR	GL
lb DM/acre	high	5,766 (3,000 – 7,400)	7,507 (4,000 – 8,400)	7,320 (3,600 – 9,733)	8,168 (3,882 – 10,333)
	medium	4,122 (2,000 – 5,400)	5,377 (2,800 – 6,000)	5,223 (2,600 – 7,067)	5,843 (2,809 – 7,400)
	low	2,100 (1,000 – 2,800)	2,676 (1,400 – 3,000)	2,135 (800 – 2,800)	2,497 (1,294 – 3,200)
Potential AUM/ac	high	4.7 (2.5 – 6.1)	6.2 (3.3 – 6.9)	6.0 (3.0 – 8.0)	6.7 (3.2 – 8.5)
	medium	2.3 (1.1 – 3.1)	3.1 (1.6 – 3.4)	3.0 (1.5 – 4.0)	3.3 (1.8 – 4.2)
	low	0.8 (0.4 – 1.1)	1.0 (0.5 – 1.1)	0.8 (0.3 – 1.1)	0.9 (0.4 – 1.2)
Modeled Stocking Rate CCpr/acre, 5 months	high	0.8 (0.4 – 1.0)	1.0 (0.5 – 1.1)	1.0 (0.5 – 1.3)	1.1 (0.5 – 1.4)
	medium	0.4 (0.2 – 0.5)	0.5 (0.3 – 0.6)	0.5 (0.2 – 0.7)	0.5 (0.3 – 0.7)
	low	0.1 (0.1 – 0.2)	0.2 (0.1 – 0.2)	0.1 (0.1 – 0.2)	0.2 (0.1 – 0.2)

Table 29. Landscape grassland productivity estimates for warm season grasses and cool season grass mixes in Agassiz Beach Ridges and Glacial Lakes. Ranges reflect differences in yield estimates between forage suitability groups and the underlying variability in soil productivity and climate.

Grassland Productivity		Warm Season Grass		Cool Season Grass Mix	
		ABR	GL	ABR	GL
lb DM/acre	high	6,534 (2,762 – 7,400)	8,079 (3,977 – 8,400)	8,517 (3,600 – 9,733)	9,582 (4,509 – 10,523)
	medium	4,712 (1,994 – 5,400)	5,786 (2,781 – 6,000)	6,111 (2,600 – 7,067)	6,852 (3,263 – 7,373)
	low	2,472 (1,004 – 2,800)	2,883 (1,382 – 3,000)	2,579 (917 – 3,177)	2,976 (1,188 – 3,179)
Potential AUM/ac	high	5.4 (2.3 – 6.1)	6.6 (3.3 – 6.9)	7.0 (3.0 – 8.0)	7.9 (3.7 – 8.5)
	medium	2.7 (1.1 – 3.1)	3.3 (1.6 – 3.4)	3.5 (1.5 – 4.0)	3.9 (1.9 – 4.2)
	low	0.9 (0.4 – 1.1)	1.1 (0.5 – 1.1)	1.0 (0.3 – 1.1)	1.3 (0.5 – 1.1)
Modeled Stocking Rate CCpr/acre, 5 months	high	0.9 (0.4 – 1.0)	1.1 (0.5 – 1.1)	1.2 (0.5 – 1.3)	1.3 (0.6 – 1.4)
	medium	0.4 (0.2 – 0.5)	0.5 (0.3 – 0.6)	0.6 (0.2 – 0.7)	0.6 (0.3 – 0.7)
	low	0.2 (0.1 – 0.2)	0.2 (0.1 – 0.2)	0.2 (0.1 – 0.2)	0.2 (0.1 – 0.2)

Table 30. Watershed grassland productivity estimates for warm and cool season grass mixes surrounding both the ABR and GL landscapes. Ranges reflect differences in yield estimates between forage suitability groups and the underlying variability in soil productivity and climate.

Like the other prairie core areas identified in the MN Prairie Plan, the two focal landscapes, Agassiz Beach Ridges and Glacial Lakes, have a greater proportion of grassland cover than the surrounding landscapes (Chapter 3). Particularly in GL, this is a result of soil productivity influencing land use decisions. Within the ABR and GL landscapes, 82% and 69% of soils respectively are categorized as land capability classes (LCC) 1–4; these soils are suitable for annual crop production, though class 4 soils are marginal (Soil Survey Staff et al. 2013). The remaining soils are categorized as LCC classes 5–10, with 5–8 suitable for grazing or other land uses with perennial cover and class 10 (added here) representing water bodies. In the broader regions representing the boundary of all major watersheds that intersect the ABR and GL landscapes, as much as 84% and 87% of soils respectively are classified as LCC 1–4 (Table 27and Table 28). As a result, net returns on these lower productivity soils tend to be lower than those for the broader region surrounding the landscape.

2. Start and End State Budgets

a. Operation Budgets

Net returns per acre for individual crops are presented in Appendix 5. Returns for several of the crop types, particularly corn, show rapid declines with LCC (Table 78–Table 86). Net returns per acre for grazing operations on each of the grassland start states are shown in Table 31 (ABR) and Table 34 (GL). These returns are reported in 2011 dollars and are the returns per acre to the land owner. More so than with cropland operations, generating grazing operation budgets involves numerous assumptions, which are detailed in the methods section. Each of these assumptions has the potential to influence net returns. Landowners considering transitioning to grazing operations, or intensifying their existing operations, should carefully develop their own budgets based on the details of their planned management. These budgets will be useful in identifying regions of each landscape where cow-calf grazing systems are most likely to be profitable.

LCC	corn	soy	spring wheat	alfalfa hay	sugar beets	oats
1-2	130	169	43	124	-34	116
3-4	-81	30	-64	18	-184	9
5-6	-153	-20	-129	-68	.	-77
7-8	.	.	-141	-67	.	-76
10	.	.	.	.	.	.
.	.	.	.	.	.	.
Average	-31	86	-61	19	.	11

Table 31. Annual net returns per acre for cropland operations, ABR landscape. Returns are averaged by land capability subclass (LCCS) and presented by LCC groups.

Agassiz Beach Ridges	MNP				WIP		MNIG				IPDG				UP / UM			
	Management Intensive		Rotational		Rotational		Rotational		Continuous		Rotational		Continuous		Management Intensive		Rotational	
LCC	small	large	small	large	small	large	small	large	small	large	small	large	small	large	small	large	small	large
1-2	32	-75	-72	-123	-148	-158	-72	-123	-148	-158	-64	-120	-148	-158	32	-75	-72	-123
3-4	4	-79	-93	-123	-167	-156	-93	-123	-167	-156	-88	-121	-166	-156	4	-79	-93	-123
5-6	-26	-82	-120	-121	-191	-152	-120	-121	-191	-152	-117	-120	-191	-152	-26	-82	-120	-121
7-8	-26	-82	-120	-121	-191	-152	-120	-121	-191	-152	-118	-120	-191	-152	-26	-82	-120	-121
10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average	9	-66	-75	-104	-138	-132	-75	-104	-138	-132	-70	-102	-138	-132	9	-66	-75	-104

Table 32. Annual net returns per acre for grazing operations on start and end states, ABR landscape. Returns are averaged and presented by LCC group.

LCC	corn	soy	spring wheat	alfalfa hay	sugar beets	oats
1-2	190	191	61	160	40	64
3-4	-29	38	-12	-4	-93	16
5-6	-112	-18	-73	-118	.	-9
7-8	.	.	.	-105	.	-47
10	.	.	.	.	.	.
.	.	.	.	.	.	.
Average	47	78	1	13	13	22

Table 33. Annual net returns per acre for cropland operations on start and end states, GL landscape. Returns are averaged and presented by LCC group.

Glacial Lakes	MNP				WIP		MNIG				IPDG				UP / UM			
	Management Intensive		Rotational		Rotational		Rotational		Continuous		Rotational		Continuous		Management Intensive		Rotational	
LCC	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**	**small**	**large**
1-2	53	31	-60	-16	-113	-38	-60	-16	-113	-38	-47	-3	-102	-21	53	31	-60	-16
3-4	49	26	-62	-20	-116	-42	-62	-20	-116	-42	-52	-9	-103	-23	49	26	-62	-20
5-6	45	23	-63	-21	-117	-43	-63	-21	-117	-43	-54	-11	-103	-22	45	23	-63	-21
7-8	39	10	-69	-32	-124	-53	-69	-32	-124	-53	-58	-16	.	.	39	10	-69	-32
10	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average	51	28	-61	-18	-114	-40	-61	-18	-114	-40	-49	-6	-103	-22	51	28	-61	-18

Table 34. Annual net returns per acre for grazing operations on start and end states, GL landscape. Returns are averaged by land capability subclass (LCCS) and presented by LCC groups.

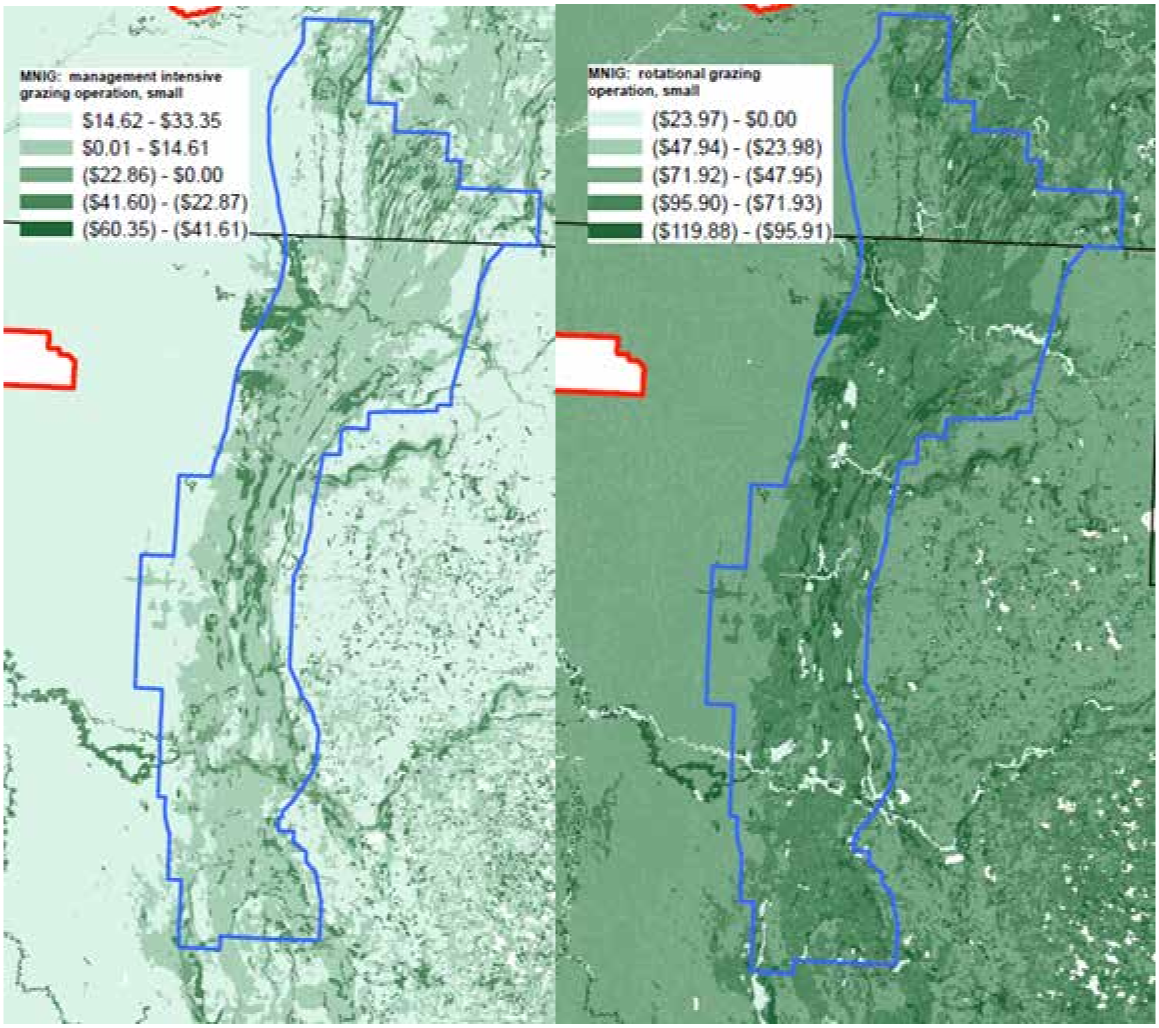

Figure 42. Spatial distribution of net returns/acre from grazing operations on the MNIG start state, ABR landscape.

Other studies with comparable stocking rates and in similar climates have shown returns from rotational grazing systems ranging from $75-110/acre without the inclusion of labor costs (Moore and Gerrish 2013). Labor costs for our two focal landscapes averaged $46/ac and $50/ac for ABR and GL respectively. With labor costs included, the only positive net returns estimated were for management intensive grazing systems reflecting greater potential grassland yields and stocking rates. Without labor costs, Figure 42 shows that the maximum returns/acre for MIG operations on the MNIG start state would be roughly $61/ac-$79/ac, similar to the Moore and Gerrish estimate.

By combining the prioritization maps presented in Chapter 4, and our economic analysis it is clear that a significant fraction of those regions in the two landscapes that were identified as high priority for grassland conservation are already in some type grass-based use with very low economic return potential from current or potential future grazing operations. This suggests that these areas are best suited for grassland protection unless restoration costs are highly subsidized. Using the example of returns from grazing operations on MNIG lands with LCC 5-8 (Table 34. Annual net returns per acre for grazing operations on start and end states, GL landscape range from -$21 to -$124/ac among the four modeled grazing operations in these LCC classes. To examine the viability of transitions from MNIG to alternative grazing systems on restored utility grasslands, compare the NPV of modeled returns from current grazing operations on MNIG (no transition) with the potential NPV of returns for alternative grazing operations on utility prairie or utility meadow. Table 35 and Table 36 show the NPV for end state utility grassland grazing operations, while Table 37 shows the NPV of the restoration costs. Combined, data from these three tables was used to generate the NPV data shown in (Table 41–Table 43) which includes the costs of restoration with the costs and revenue of the end state land use. With the costs of restoration included, a transition to utility grasslands provides little if any economic benefit. Note that in this example, the returns from grazing operations are negative, so the comparison becomes which operation has the lower overall loss. Figure 43 and Figure 44 show the overlap between high priority grassland areas and areas with MNIG or IPDG start states that fall on land with LCC 1-4 for the ABR and GL landscapes. These areas of overlap are likely better suited to protection or restoration actions by a state or non-profit entity rather than a private landowner.

Areas more suited to state transitions, with greater potential for economic returns from grazing, often fall within areas indicated as moderate priority, making them well placed as buffers surrounding higher priority areas. Figure 43 and Figure 45 show the extent of IPDG and MNIG start states on LCC 5-8 as well as marginal croplands on LCC 3-6. Based on our economic analysis these areas show the greatest potential for positive returns from grazing operations on restored utility grasslands, but only if restoration costs are subsidized.

1% discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	1,291	158	(1,063)	(1,063)
	large	(3,016)	(3,193)	(3,279)	(3,279)
ROT	small	(2,878)	(3,741)	(4,819)	(4,819)
	large	(4,934)	(4,943)	(4,874)	(4,874)

4 % discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	722	89	(594)	(594)
	large	(1,687)	(1,786)	(1,834)	(1,834)
ROT	small	(1,610)	(2,093)	(2,695)	(2,695)
	large	(2,760)	(2,765)	(2,726)	(2,726)

7% discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	475	58	(391)	(391)
	large	(1,111)	(1,176)	(1,207)	(1,207)
ROT	small	(1,060)	(1,378)	(1,774)	(1,774)
	large	(1,817)	(1,820)	(1,795)	(1,795)

Table 35. Net present value of potential end state grazing operations, ABR landscape. Net present value (NPV) shown for 3 discount rates and calculated over a 50 year time horizon. NPV shown for each LCC group and both small and large size management intensive grazing (MIG) and rotational grazing (ROT) systems assuming grassland productivity and utilization rates associated with utility grasslands.

1% discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	2,144	1,977	1,805	1,555
	large	1,242	1,044	938	407
ROT	small	(2,429)	(2,507)	(2,517)	(2,769)
	large	(648)	(794)	(837)	(1,282)

4% discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	1,199	1,106	1,010	869
	large	695	584	524	227
ROT	small	(1,359)	(1,402)	(1,408)	(1,549)
	large	(363)	(444)	(468)	(717)

7% discount rate

Utility Prairie/Meadow		LCC 1-2	LCC 3-4	LCC 5-6	LCC 7-8
MIG	small	789	728	665	572
	large	457	384	345	150
ROT	small	(894)	(923)	(927)	(1,019)
	large	(239)	(292)	(308)	(472)

Table 36. Net present value of potential end state grazing operations, GL landscape. Net present value (NPV) shown for 3 discount rates and calculated over a 50 year time horizon. NPV shown for each LCC group and both small and large size management intensive grazing (MIG) and rotational grazing (ROT) systems assuming grassland productivity and utilization rates associated with utility grasslands.

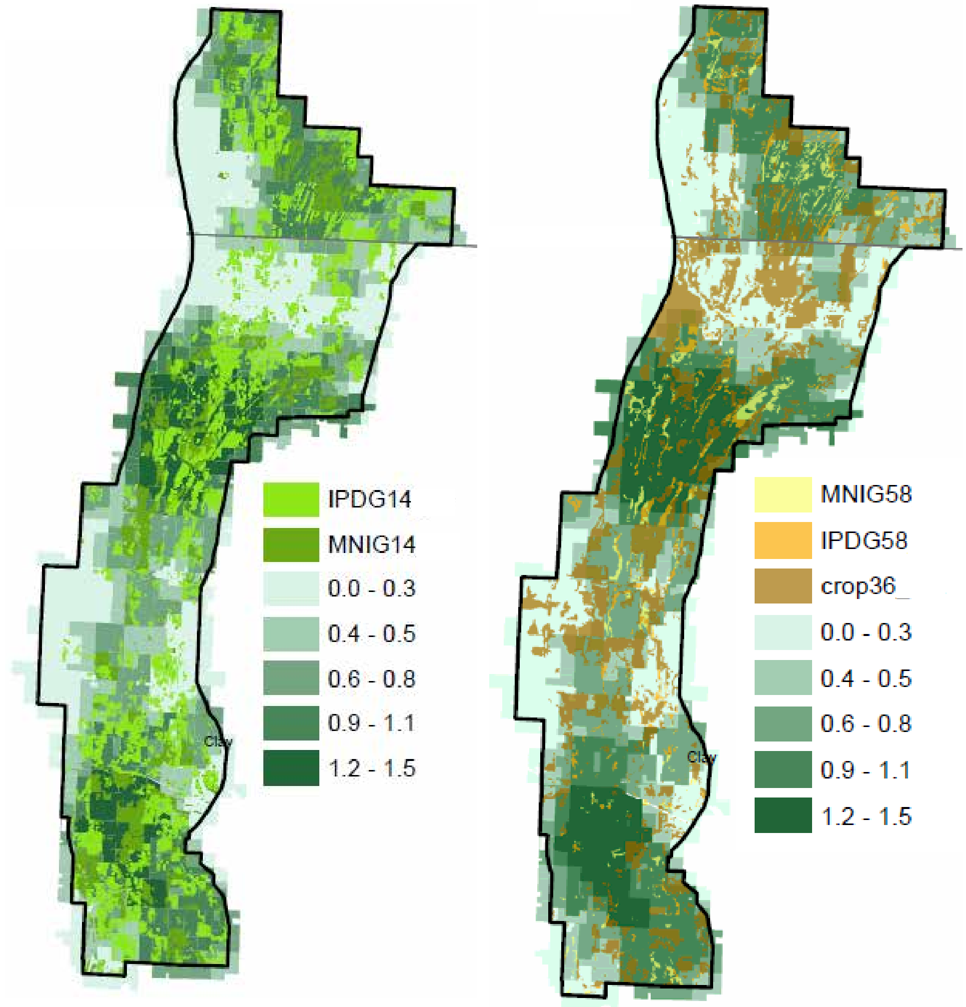

Figure 43. Existing grasslands best suited for protection or for restoration transitions, ABR landscape. An index of grassland priority (darker colors indicating higher priority) underlays areas identified as either the MNIG or IPDG start state on LCC 5-8 soils.

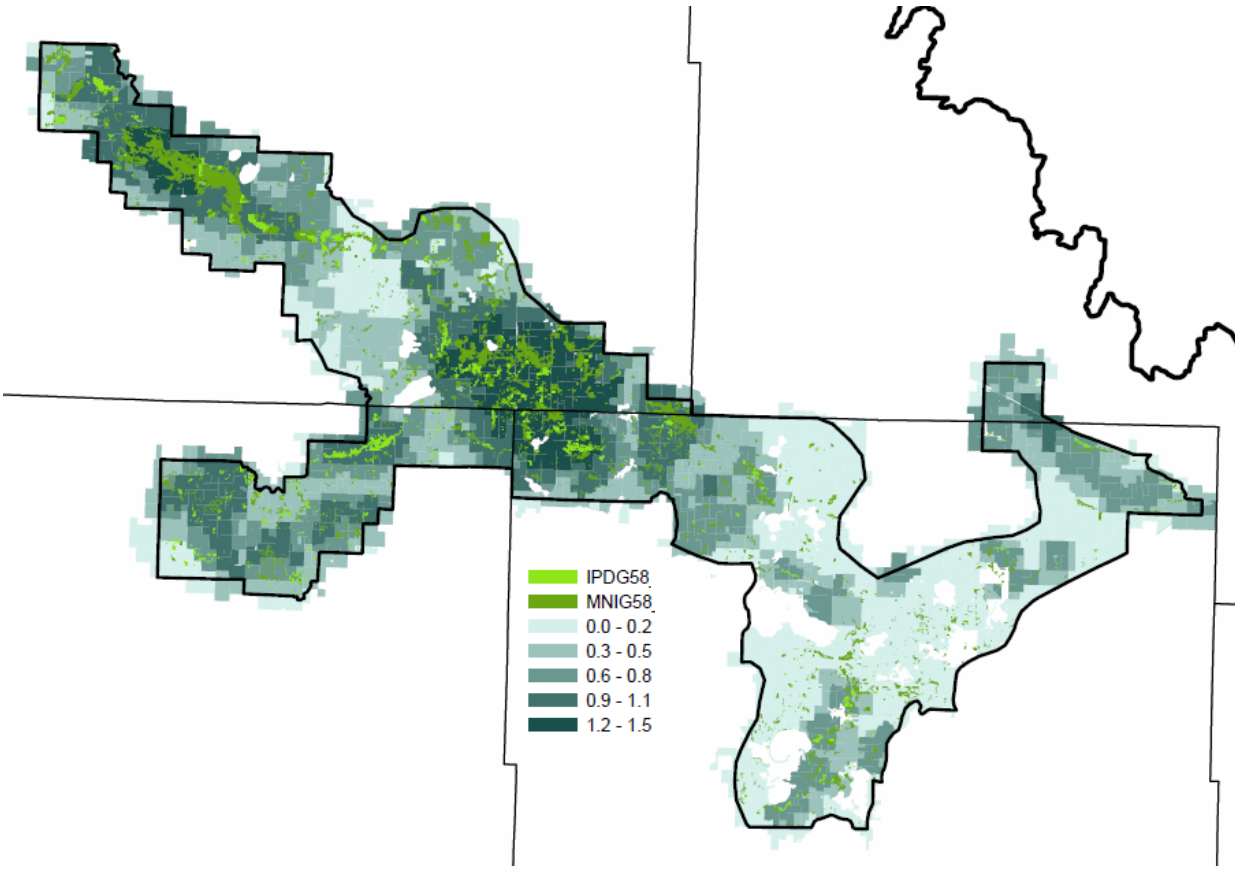

Figure 44. Existing grasslands best suited for protection, GL landscape. An index of grassland priority (darker colors indicating higher priority) underlays areas identified as either the MNIG or IPDG start state on LCC 5-8 soils.

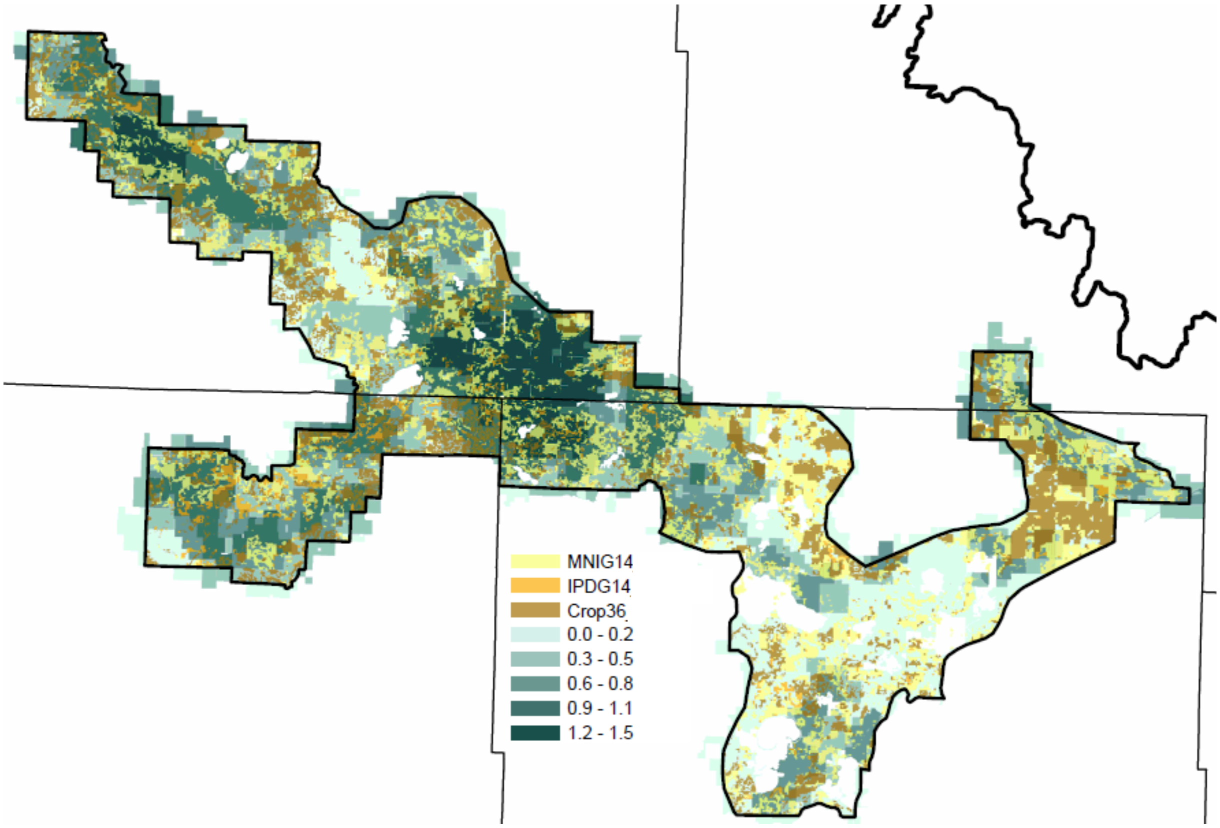

Figure 45. Existing grasslands and cropland best suited for restoration transitions, GL landscape. An index of grassland priority (darker colors indicating higher priority) underlays areas identified as the MNIG or IPDG start state on LCC 1-4 soils, or those identified as croplands on LCC 3-6 soils.

b. Transition Budgets

(1) Establishment Costs

Establishment of grazing system infrastructure, not including the cost of purchasing cattle, has been estimated to be between $500 and $600/ac by others (Moore and Gerrish 2013). Our transition analysis does not incorporate establishment costs for grazing operations such as purchasing of livestock, fencing or watering systems, but do include all costs associated with the conversion of land use from cropland start states to utility prairie and utility meadow end states (Chapter 7). Average establishment costs vary greatly with a landowners' current practice and must be factored into any decision about land use transitions.

(2) Transition Costs

With the objective of understanding the economic realities of transitions from cropland to various grass-based land uses, it is necessary to examine the costs and timeframes of each transition. The transition costs associated with restoration were presented in Chapter 7 and Appendix 3. Here we incorporate those costs with estimated net returns from end state land uses. All costs are reported as net present value, calculated at three different discount rates: 1, 4, and 7%.

The total costs of restoration associated with the transitions to the utility and conservation meadow end states differ slightly from those presented in Chapter 7 and Appendix 3 for two reasons. First, when restoration actions such as burns were described as occurring on multiple units (2 or 3), some of the costs included as maintenance costs in Chapter 7, were included as establishment costs here. These shifts were needed to ensure that all restoration actions needed prior to or during the final year of the establishment period were accounted for in the establishment period costs even though the action (e.g. annual spot spray) might be something that is an annual cost during the maintenance period as well as the establishment period. Doing so allowed for a clear distinction between establishment costs and ongoing maintenance costs incurred once the restoration is complete. Second, costs reported here are the net present value (NPV) calculated using a 10% discount rate. The duration and costs of the establishment and maintenance phases of restoration varied greatly across the transition as shown in Table 37. Restoration costs assumed in the Prairie Plan are $500/acre for grasslands or wetlands (Minnesota Prairie Plan Working Group 2011); costs estimated in Chapter 7 tend to higher than the Prairie Plan estimate.

	1% discount rate			4% discount rate			7% discount rate		
Start State	UP	UM	UM_hydro	UP	UM	UM_hydro	UP	UM	UM_hydro
Cropland	3178	3305	4005	1957	2185	2885	1425	1696	2396
IPDG	3545	3944	4637	2313	2723	3396	1771	2156	2811
MNIG	3680	3925	4619	2450	2705	3378	1910	2139	2793
WIP	3879	3778	4478	2652	2661	3361	2115	2175	2875

Table 37. Net present value of restoration costs per acre. Costs are discounted at three rates (1, 4 and 7%) over a 50 year time period. Transitions to utility prairie (UP), utility meadow (UM) and utility meadow with hydrologic restoration (UM_hydro) are shown.

Agassiz Beach Ridges Landscape, 4% discount rate		No Change				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT small			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	2,918	(1,814)	(3,431)	.	(1,235)	(1,868)	(2,551)	(2,551)	(3,644)	(3,743)	(3,791)	(3,791)	(3,567)	(4,050)	(4,652)	(4,652)	(4,717)	(4,722)	(4,683)	(4,683)
	soy	3,789	668	(440)	.																
	small grains	958	(1,437)	(2,895)	(3,173)																
	alfalfa hay	2,607	205	(1,730)	(1,703)																
	sugar beets	(754)	(4,139)	.	.																
	other crop	2,105	727	(2,051)	.																
IPDG	rotational, small	(1,441)	(1,975)	(2,624)	(2,648)	(1,591)	(2,224)	(2,907)	(2,907)	(4,000)	(4,099)	(4,147)	(4,147)	(3,923)	(4,406)	(5,008)	(5,008)	(5,073)	(5,078)	(5,039)	(5,039)
	rotational, large	(2,697)	(2,721)	(2,700)	(2,709)																
	continuous, small	(3,329)	(3,736)	(4,296)	(4,293)																
	continuous, large	(3,558)	(3,506)	(3,408)	(3,407)																
MNIG	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)	(1,728)	(2,361)	(3,044)	(3,044)	(4,137)	(4,236)	(4,284)	(4,284)	(4,060)	(4,543)	(5,145)	(5,145)	(5,210)	(5,215)	(5,176)	(5,176)
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																
	continuous, small	(3,337)	(3,745)	(4,301)	(4,301)																
	continuous, large	(3,562)	(3,509)	(3,410)	(3,410)																
WIP	rotational, small	(3,337)	(3,745)	(4,301)	(4,301)	(1,930)	(2,563)	(3,246)	(3,246)	(4,339)	(4,438)	(4,486)	(4,486)	(4,262)	(4,745)	(5,347)	(5,347)	(5,412)	(5,417)	(5,378)	(5,378)
	rotational, large	(3,562)	(3,509)	(3,410)	(3,410)																
MNP	management intensive, small	722	89	(594)	(594)																
	management intensive, large	(1,687)	(1,786)	(1,834)	(1,834)																
	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)																
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																

Agassiz Beach Ridges Landscape, 4% discount rate		No Change				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT, large				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	2,918	(1,814)	(3,431)	.	(1,462)	(2,096)	(2,779)	(2,779)	(3,872)	(3,970)	(4,019)	(4,019)	(3,794)	(4,277)	(4,880)	(4,880)	(4,944)	(4,949)	(4,911)	(4,911)
	soy	3,789	668	(440)	.																
	small grains	958	(1,437)	(2,895)	(3,173)																
	alfalfa hay	2,607	205	(1,730)	(1,703)																
	sugar beets	(754)	(4,139)	.	.																
	other crop	2,105	727	(2,051)	.																
IPDG	rotational, small	(1,441)	(1,975)	(2,624)	(2,648)	(2,000)	(2,634)	(3,317)	(3,317)	(4,410)	(4,508)	(4,557)	(4,557)	(4,332)	(4,815)	(5,418)	(5,418)	(5,482)	(5,487)	(5,449)	(5,449)
	rotational, large	(2,697)	(2,721)	(2,700)	(2,709)																
	continuous, small	(3,329)	(3,736)	(4,296)	(4,293)																
	continuous, large	(3,558)	(3,508)	(3,408)	(3,407)																
MNIG	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)	(1,982)	(2,616)	(3,299)	(3,299)	(4,392)	(4,490)	(4,539)	(4,539)	(4,314)	(4,797)	(5,400)	(5,400)	(5,464)	(5,469)	(5,431)	(5,431)
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																
	continuous, small	(3,337)	(3,745)	(4,301)	(4,301)																
	continuous, large	(3,562)	(3,509)	(3,410)	(3,410)																
WIP	rotational, small	(3,337)	(3,745)	(4,301)	(4,301)	(1,938)	(2,572)	(3,255)	(3,255)	(4,348)	(4,446)	(4,495)	(4,495)	(4,270)	(4,753)	(5,356)	(5,356)	(5,420)	(5,425)	(5,387)	(5,387)
	rotational, large	(3,562)	(3,509)	(3,410)	(3,410)																
MNP	management intensive, small	722	89	(594)	(594)																
	management intensive, large	(1,687)	(1,786)	(1,834)	(1,834)																
	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)																
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																

Table 38. Net present value with a 1% discount rate of returns to the operator for utility prairie and meadow transitions, Agassiz Beach Ridges. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

Agassiz Beach Ridges Landscape, 4% discount rate		No Change				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT small			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	2,918	(1,814)	(3,431)	.	(1,235)	(1,868)	(2,551)	(2,551)	(3,644)	(3,743)	(3,791)	(3,791)	(3,567)	(4,050)	(4,652)	(4,652)	(4,717)	(4,722)	(4,683)	(4,683)
	soy	3,789	668	(440)	.																
	small grains	958	(1,437)	(2,895)	(3,173)																
	alfalfa hay	2,607	205	(1,730)	(1,703)																
	sugar beets	(754)	(4,139)	.	.																
	other crop	2,105	727	(2,051)	.																
IPDG	rotational, small	(1,441)	(1,975)	(2,624)	(2,648)	(1,591)	(2,224)	(2,907)	(2,907)	(4,000)	(4,099)	(4,147)	(4,147)	(3,923)	(4,406)	(5,008)	(5,008)	(5,073)	(5,078)	(5,039)	(5,039)
	rotational, large	(2,697)	(2,721)	(2,700)	(2,709)																
	continuous, small	(3,329)	(3,736)	(4,296)	(4,293)																
	continuous, large	(3,558)	(3,506)	(3,408)	(3,407)																
MNIG	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)	(1,728)	(2,361)	(3,044)	(3,044)	(4,137)	(4,236)	(4,284)	(4,284)	(4,060)	(4,543)	(5,145)	(5,145)	(5,210)	(5,215)	(5,176)	(5,176)
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																
	continuous, small	(3,337)	(3,745)	(4,301)	(4,301)																
	continuous, large	(3,562)	(3,509)	(3,410)	(3,410)																
WIP	rotational, small	(3,337)	(3,745)	(4,301)	(4,301)	(1,930)	(2,563)	(3,246)	(3,246)	(4,339)	(4,438)	(4,486)	(4,486)	(4,262)	(4,745)	(5,347)	(5,347)	(5,412)	(5,417)	(5,378)	(5,378)
	rotational, large	(3,562)	(3,509)	(3,410)	(3,410)																
MNP	management intensive, small	722	89	(594)	(594)																
	management intensive, large	(1,687)	(1,786)	(1,834)	(1,834)																
	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)																
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																

Agassiz Beach Ridges Landscape, 4% discount rate		No Change				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT, large				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	2,918	(1,814)	(3,431)	.	(1,462)	(2,096)	(2,779)	(2,779)	(3,872)	(3,970)	(4,019)	(4,019)	(3,794)	(4,277)	(4,880)	(4,880)	(4,944)	(4,949)	(4,911)	(4,911)
	soy	3,789	668	(440)	.																
	small grains	958	(1,437)	(2,895)	(3,173)																
	alfalfa hay	2,607	205	(1,730)	(1,703)																
	sugar beets	(754)	(4,139)	.	.																
	other crop	2,105	727	(2,051)	.																
IPDG	rotational, small	(1,441)	(1,975)	(2,624)	(2,648)	(2,000)	(2,634)	(3,317)	(3,317)	(4,410)	(4,508)	(4,557)	(4,557)	(4,332)	(4,815)	(5,418)	(5,418)	(5,482)	(5,487)	(5,449)	(5,449)
	rotational, large	(2,697)	(2,721)	(2,700)	(2,709)																
	continuous, small	(3,329)	(3,736)	(4,296)	(4,293)																
	continuous, large	(3,558)	(3,506)	(3,408)	(3,407)																
MNIG	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)	(1,982)	(2,616)	(3,299)	(3,299)	(4,392)	(4,490)	(4,539)	(4,539)	(4,314)	(4,797)	(5,400)	(5,400)	(5,464)	(5,469)	(5,431)	(5,431)
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																
	continuous, small	(3,337)	(3,745)	(4,301)	(4,301)																
	continuous, large	(3,562)	(3,509)	(3,410)	(3,410)																
WIP	rotational, small	(3,337)	(3,745)	(4,301)	(4,301)	(1,938)	(2,572)	(3,255)	(3,255)	(4,348)	(4,446)	(4,495)	(4,495)	(4,270)	(4,753)	(5,356)	(5,356)	(5,420)	(5,425)	(5,387)	(5,387)
	rotational, large	(3,562)	(3,509)	(3,410)	(3,410)																
MNP	management intensive, small	722	89	(594)	(594)																
	management intensive, large	(1,687)	(1,786)	(1,834)	(1,834)																
	rotational, small	(1,610)	(2,093)	(2,695)	(2,695)																
	rotational, large	(2,760)	(2,765)	(2,726)	(2,726)																

Table 39. Net present value with a 4% discount rate of returns to the operator for utility prairie and meadow transitions, Agassiz Beach Ridges. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

Agassiz Beach Ridges Landscape, 7% discount rate		No Change				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT small			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	1,921	(1,194)	(2,259)	.	(950)	(1,387)	(1,817)	(1,817)	(2,536)	(2,601)	(2,633)	(2,633)	(2,485)	(2,803)	(3,200)	(3,200)	(3,242)	(3,245)	(3,220)	(3,220)
	soy	2,494	440	(290)	.																
	small grains	631	(946)	(1,906)	(2,089)																
	alfalfa hay	1,716	135	(1,139)	(1,121)																
	sugar beets	(497)	(2,725)	.	.																
	other crop	1,386	479	(1,350)	.																
IPDG	rotational, small	(949)	(1,300)	(1,728)	(1,743)	(1,296)	(1,713)	(2,163)	(2,163)	(2,882)	(2,947)	(2,979)	(2,979)	(2,831)	(3,149)	(3,546)	(3,546)	(3,588)	(3,591)	(3,566)	(3,566)
	rotational, large	(1,776)	(1,791)	(1,777)	(1,783)																
	continuous, small	(2,191)	(2,459)	(2,828)	(2,826)																
	continuous, large	(2,343)	(2,308)	(2,243)	(2,243)																
MNIG	rotational, small	(1,060)	(1,378)	(1,774)	(1,774)	(1,435)	(1,852)	(2,302)	(2,302)	(3,021)	(3,086)	(3,118)	(3,118)	(2,970)	(3,288)	(3,685)	(3,685)	(3,727)	(3,730)	(3,705)	(3,705)
	rotational, large	(1,817)	(1,820)	(1,795)	(1,795)																
	continuous, small	(2,197)	(2,466)	(2,831)	(2,831)																
	continuous, large	(2,345)	(2,310)	(2,245)	(2,245)																
WIP	rotational, small	(2,197)	(2,466)	(2,831)	(2,831)	(1,639)	(2,056)	(2,506)	(2,506)	(3,225)	(3,290)	(3,322)	(3,322)	(3,174)	(3,492)	(3,889)	(3,889)	(3,931)	(3,935)	(3,909)	(3,909)
	rotational, large	(2,345)	(2,310)	(2,245)	(2,245)																
MNP	management intensive, small	475	58	(391)	(391)																
	management intensive, large	(1,111)	(1,176)	(1,207)	(1,207)																
	rotational, small	(1,060)	(1,378)	(1,774)	(1,774)																
	rotational, large	(1,817)	(1,820)	(1,795)	(1,795)																

Agassiz Beach Ridges Landscape, 7% discount rate		No Change				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT, large				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	1,921	(1,194)	(2,259)	.	(1,221)	(1,638)	(2,088)	(2,088)	(2,807)	(2,872)	(2,904)	(2,904)	(2,756)	(3,074)	(3,471)	(3,471)	(3,513)	(3,516)	(3,491)	(3,491)
	soy	2,494	440	(290)	.																
	small grains	631	(946)	(1,906)	(2,089)																
	alfalfa hay	1,716	135	(1,139)	(1,121)																
	sugar beets	(497)	(2,725)	.	.																
	other crop	1,386	479	(1,350)	.																
IPDG	rotational, small	(949)	(1,300)	(1,728)	(1,743)	(1,681)	(2,098)	(2,548)	(2,548)	(3,267)	(3,332)	(3,364)	(3,364)	(3,216)	(3,534)	(3,931)	(3,931)	(3,973)	(3,976)	(3,951)	(3,951)
	rotational, large	(1,776)	(1,791)	(1,777)	(1,783)																
	continuous, small	(2,191)	(2,459)	(2,828)	(2,826)																
	continuous, large	(2,343)	(2,308)	(2,243)	(2,243)																
MNIG	rotational, small	(1,060)	(1,378)	(1,774)	(1,774)	(1,663)	(2,081)	(2,530)	(2,530)	(3,250)	(3,315)	(3,346)	(3,346)	(3,199)	(3,517)	(3,913)	(3,913)	(3,956)	(3,959)	(3,934)	(3,934)
	rotational, large	(1,817)	(1,820)	(1,795)	(1,795)																
	continuous, small	(2,197)	(2,466)	(2,831)	(2,831)																
	continuous, large	(2,345)	(2,310)	(2,245)	(2,245)																
WIP	rotational, small	(2,197)	(2,466)	(2,831)	(2,831)	(1,699)	(2,117)	(2,566)	(2,566)	(3,286)	(3,351)	(3,382)	(3,382)	(3,235)	(3,553)	(3,949)	(3,949)	(3,992)	(3,995)	(3,970)	(3,970)
	rotational, large	(2,345)	(2,310)	(2,245)	(2,245)																
MNP	management intensive, small	475	58	(391)	(391)																
	management intensive, large	(1,111)	(1,176)	(1,207)	(1,207)																
	rotational, small	(1,060)	(1,378)	(1,774)	(1,774)																
	rotational, large	(1,817)	(1,820)	(1,795)	(1,795)																

Table 40. Net present value with a 7% discount rate of returns to the operator for utility prairie and meadow transitions, Agassiz Beach Ridges. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

Glacial Lakes Landscape, 1% discount rate		No Transition				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)		(1,034)	(1,201)	(1,373)	(1,623)	(1,906)	(2,134)	(2,240)	(2,771)	(5,607)	(5,685)	(5,695)	(5,947)	(3,820)	(3,972)	(4,015)	(4,400)
	soy	7,471	1,309	(432)																	
	small grains	2,409	(435)	(1,610)																	
	alfalfa hay	6,286	(132)	(2,899)	(1,219)																
	sugar beets	1,561	(621)																		
	other crop	2,501	546	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(1,401)	(1,568)	(1,740)	(1,990)	(2,300)	(2,501)	(2,607)	(3,138)	(5,974)	(6,052)	(6,062)	(6,314)	(4,193)	(4,339)	(4,382)	(4,827)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)																	
	continuous, large	(862)	(918)	(891)																	
MNIC	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,536)	(1,703)	(1,875)	(2,125)	(2,438)	(2,636)	(2,742)	(3,273)	(6,109)	(6,187)	(6,197)	(6,449)	(4,328)	(4,474)	(4,517)	(4,962)
	rotational, large	(648)	(794)	(837)	(1,282)																
	continuous, small	(4,546)	(4,645)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,735)	(1,902)	(2,074)	(2,324)	(2,637)	(2,835)	(2,941)	(3,472)	(6,308)	(6,386)	(6,396)	(6,648)	(4,527)	(4,673)	(4,716)	(5,161)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,805	1,555																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,282)																

Glacial Lakes Landscape, 1% discount rate		No Transition				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT small				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)		(1,161)	(1,328)	(1,500)	(1,750)	(2,063)	(2,261)	(2,367)	(2,898)	(5,734)	(5,812)	(5,822)	(6,074)	(3,953)	(4,099)	(4,142)	(4,587)
	soy	7,471	1,309	(432)																	
	small grains	2,409	(435)	(1,610)																	
	alfalfa hay	6,286	(132)	(2,899)	(1,219)																
	sugar beets	1,561	(621)																		
	other crop	2,501	546	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(1,800)	(1,967)	(2,139)	(2,389)	(2,702)	(2,900)	(3,006)	(3,537)	(6,373)	(6,451)	(6,461)	(6,713)	(4,592)	(4,738)	(4,781)	(5,226)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)																	
	continuous, large	(862)	(918)	(891)																	
MNIC	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,781)	(1,948)	(2,120)	(2,370)	(2,683)	(2,881)	(2,987)	(3,518)	(6,354)	(6,432)	(6,442)	(6,694)	(4,573)	(4,719)	(4,762)	(5,207)
	rotational, large	(648)	(794)	(837)	(1,282)																
	continuous, small	(4,546)	(4,645)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,634)	(1,801)	(1,973)	(2,223)	(2,536)	(2,734)	(2,840)	(3,371)	(6,207)	(6,285)	(6,295)	(6,547)	(4,426)	(4,572)	(4,615)	(5,060)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,805	1,555																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,282)																

Table 41. Net present value with a 1% discount rate of returns to the operator for utility prairie and meadow transitions, Glacial Lakes. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

Glacial Lakes Landscape, 4% discount rate		No Transition				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)	-	(758)	(851)	(947)	(1,068)	(1,262)	(1,373)	(1,433)	(1,730)	(3,316)	(3,359)	(3,305)	(3,506)	(2,320)	(2,401)	(2,425)	(2,674)
	soy	7,471	1,309	(432)	-																
	small grains	2,409	(435)	(1,610)	-																
	alfalfa hay	6,280	(132)	(2,899)	(1,219)																
	sugar beets	1,581	(621)	-	-																
	other crop	2,501	546	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(1,114)	(1,207)	(1,303)	(1,444)	(1,618)	(1,729)	(1,789)	(2,086)	(3,672)	(3,715)	(3,721)	(3,862)	(2,676)	(2,757)	(2,781)	(3,030)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)	-																
	continuous, large	(862)	(918)	(891)	-																
MNIG	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,251)	(1,344)	(1,440)	(1,581)	(1,755)	(1,866)	(1,926)	(2,223)	(3,809)	(3,852)	(3,858)	(3,999)	(2,813)	(2,894)	(2,918)	(3,167)
	rotational, large	(648)	(794)	(837)	(1,262)																
	continuous, small	(4,546)	(4,645)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,453)	(1,546)	(1,642)	(1,783)	(1,957)	(2,068)	(2,128)	(2,425)	(4,011)	(4,054)	(4,060)	(4,201)	(3,015)	(3,096)	(3,120)	(3,309)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,806	1,555																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,262)																

Glacial Lakes Landscape, 4% discount rate		No Transition				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT small				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)	-	(986)	(1,079)	(1,175)	(1,316)	(1,490)	(1,601)	(1,661)	(1,958)	(3,544)	(3,587)	(3,593)	(3,734)	(2,548)	(2,629)	(2,653)	(2,902)
	soy	7,471	1,309	(432)	-																
	small grains	2,409	(435)	(1,610)	-																
	alfalfa hay	6,286	(132)	(2,899)	(1,219)																
	sugar beets	1,581	(621)	-	-																
	other crop	2,501	548	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(1,524)	(1,617)	(1,713)	(1,854)	(2,028)	(2,139)	(2,199)	(2,496)	(4,082)	(4,125)	(4,131)	(4,272)	(3,088)	(3,167)	(3,191)	(3,440)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)	-																
	continuous, large	(862)	(918)	(891)	-																
MNIG	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,506)	(1,599)	(1,695)	(1,836)	(2,010)	(2,121)	(2,181)	(2,478)	(4,064)	(4,107)	(4,113)	(4,254)	(3,068)	(3,149)	(3,173)	(3,422)
	rotational, large	(648)	(794)	(837)	(1,262)																
	continuous, small	(4,546)	(4,045)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,462)	(1,555)	(1,651)	(1,792)	(1,968)	(2,077)	(2,137)	(2,434)	(4,020)	(4,063)	(4,069)	(4,210)	(3,024)	(3,105)	(3,129)	(3,378)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,806	1,555																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,262)																

Table 42. Net present value with a 4% discount rate of returns to the operator for utility prairie and meadow transitions, Glacial Lakes. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

Glacial Lakes Landscape, 7% discount rate		No Transition				Utility Prairie, MIG, small				Utility Prairie, MIG, large				Utility Prairie, ROT small				Utility Prairie, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)	.	(636)	(697)	(760)	(853)	(968)	(1,041)	(1,080)	(1,275)	(2,319)	(2,348)	(2,352)	(2,444)	(1,664)	(1,717)	(1,733)	(1,897)
	soy	7,471	1,309	(432)	.																
	small grains	2,409	(435)	(1,610)	.																
	alfalfa hay	6,286	(132)	(2,899)	(1,219)																
	sugar beets	1,581	(621)	.	.																
	other crop	2,501	546	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(982)	(1,043)	(1,106)	(1,199)	(1,314)	(1,387)	(1,426)	(1,621)	(2,665)	(2,694)	(2,698)	(2,790)	(2,010)	(2,063)	(2,079)	(2,243)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)	.																
	continuous, large	(862)	(918)	(891)	.																
MNIG	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,121)	(1,182)	(1,245)	(1,338)	(1,453)	(1,526)	(1,565)	(1,760)	(2,804)	(2,833)	(2,837)	(2,929)	(2,149)	(2,202)	(2,218)	(2,382)
	rotational, large	(648)	(794)	(837)	(1,282)																
	continuous, small	(4,546)	(4,645)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,326)	(1,387)	(1,450)	(1,543)	(1,658)	(1,731)	(1,770)	(1,965)	(3,009)	(3,038)	(3,042)	(3,134)	(2,354)	(2,407)	(2,423)	(2,587)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,806	1,556																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,282)																

Glacial Lakes Landscape, 7% discount rate		No Transition				Utility Meadow, MIG, small				Utility Meadow, MIG, large				Utility Meadow, ROT small				Utility Meadow, ROT, large			
Start State	LULC	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8	1-2	3-4	5-6	7-8
Cropland	corn	7,437	(1,007)	(2,758)	.	(907)	(968)	(1,031)	(1,124)	(1,239)	(1,312)	(1,351)	(1,546)	(2,590)	(2,619)	(2,623)	(2,715)	(1,935)	(1,988)	(2,004)	(2,168)
	soy	7,471	1,309	(432)	.																
	small grains	2,409	(435)	(1,610)	.																
	alfalfa hay	6,286	(132)	(2,899)	(1,219)																
	sugar beets	1,581	(621)	.	.																
	other crop	2,501	546	(290)	(208)																
IPDG	rotational, small	(1,892)	(2,073)	(2,154)	(2,314)	(1,367)	(1,428)	(1,491)	(1,584)	(1,699)	(1,772)	(1,811)	(2,006)	(3,050)	(3,079)	(3,083)	(3,175)	(2,395)	(2,448)	(2,464)	(2,628)
	rotational, large	(125)	(348)	(427)	(644)																
	continuous, small	(4,102)	(4,158)	(4,131)	.																
	continuous, large	(862)	(918)	(891)	.																
MNIG	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)	(1,350)	(1,411)	(1,474)	(1,567)	(1,682)	(1,755)	(1,794)	(1,989)	(3,033)	(3,062)	(3,066)	(3,158)	(2,378)	(2,431)	(2,447)	(2,611)
	rotational, large	(648)	(794)	(837)	(1,282)																
	continuous, small	(4,546)	(4,645)	(4,686)	(4,970)																
	continuous, large	(1,534)	(1,675)	(1,734)	(2,142)																
WIP	rotational, small	(4,546)	(4,645)	(4,686)	(4,970)	(1,386)	(1,447)	(1,510)	(1,603)	(1,718)	(1,791)	(1,830)	(2,025)	(3,069)	(3,098)	(3,102)	(3,194)	(2,414)	(2,467)	(2,483)	(2,647)
	rotational, large	(1,534)	(1,675)	(1,734)	(2,142)																
MNP	management intensive, small	2,144	1,977	1,806	1,556																
	management intensive, large	1,242	1,044	938	407																
	rotational, small	(2,429)	(2,507)	(2,517)	(2,769)																
	rotational, large	(648)	(794)	(837)	(1,282)																

Table 43. Net present value with a 7% discount rate of returns to the operator for utility prairie and meadow transitions, Glacial Lakes. Net returns shown here discounted over 50 years. The net present value (NPV) of start state land uses is presented as no transition which can then be compared with the NPV of both small and large management intensive (MIG) and rotational (ROT) grazing systems for the Utility Prairie end state.

3. Ecosystem Service Provision

To examine the potential impacts of state transitions associated with the implementation of the Minnesota Prairie Plan, we ran the InVEST model for two LULC maps within each landscape. The difference between the two maps was solely a change in the number of acres of grassland such that the grassland shortfall would be met, 1805 acres for ABR and 5137 acres for GL. For ABR, lands with LCC 4e and 5e soils with a start state of row crops or alfalfa hay were converted to utility grassland. For GL, land with LCC 4 and with a start state of row crops or alfalfa hay, as well as land with LCC 3 and a start state of alfalfa hay were converted to utility grassland. The extent of the land cover changed is shown in Figure 46. Preliminary analysis of both nitrogen and phosphorous export was conducted for the LULC change scenario, for both landscapes. These results suggest that at the scale of change required to meet the MN Prairie Plan grassland goals, the impact on N and P export from the major watershed in each landscape will be minimal. The result of changing ~1,800 acres in ABR and ~5,100 acres in GL resulted in a change in N and P export of less than <1% in each of the five major watersheds (ABR: Buffalo River and Wild Rice River; GL: North Fork Crow River, Minnesota-Yellow Medicine River, and the Chippewa River). Due to the greater proportion of grassland and woodland already in the ABR and GL landscapes, baseline C sequestration rates are already higher within the landscapes than in the broader watershed areas (see Figure 47 for GL). The transition of row crop and alfalfa hay land to utility grassland increased C sequestration in both landscapes (data not shown).

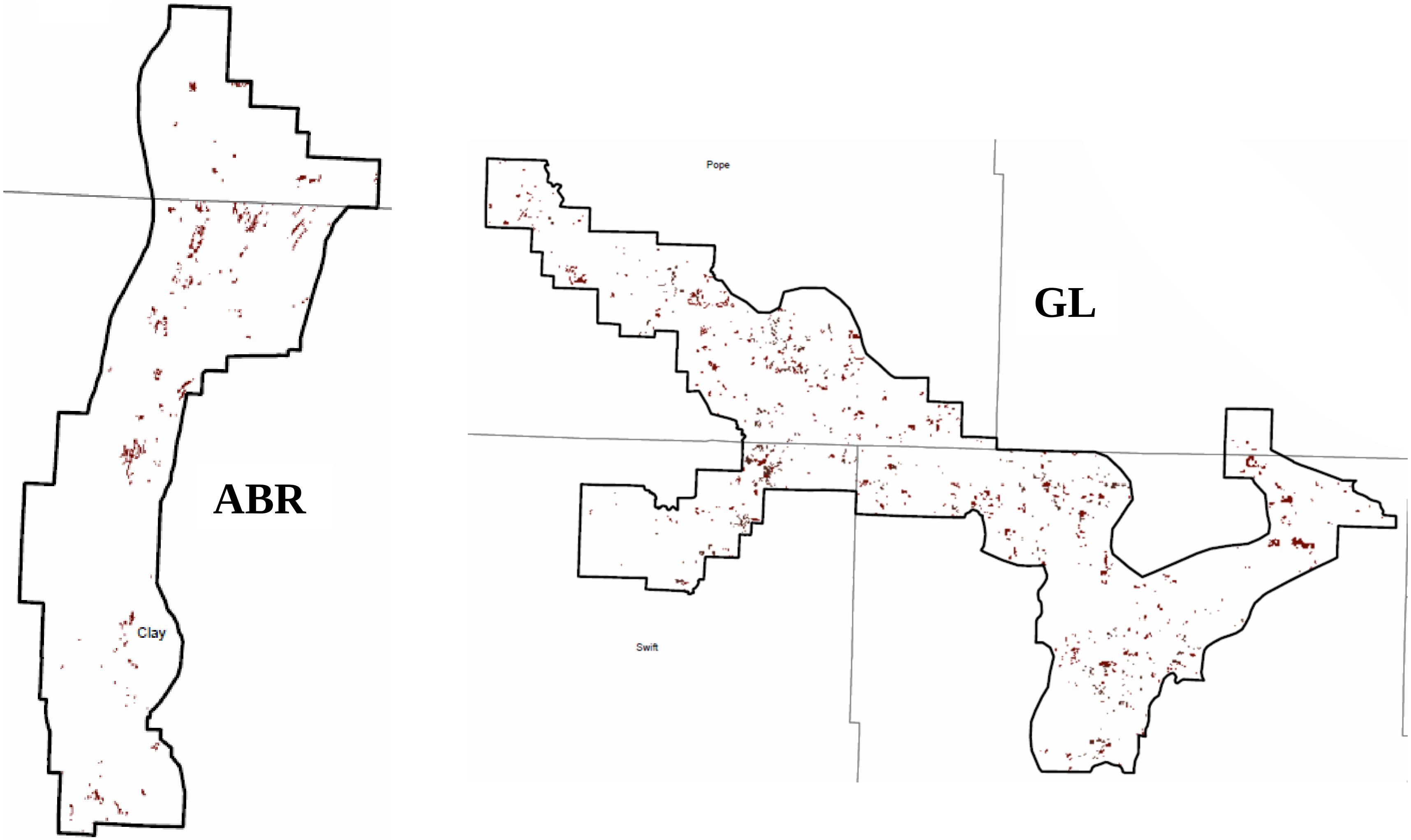

Figure 46. Extent of cropland transition to utility grasslands for preliminary ecosystem service analyses in both landscapes.

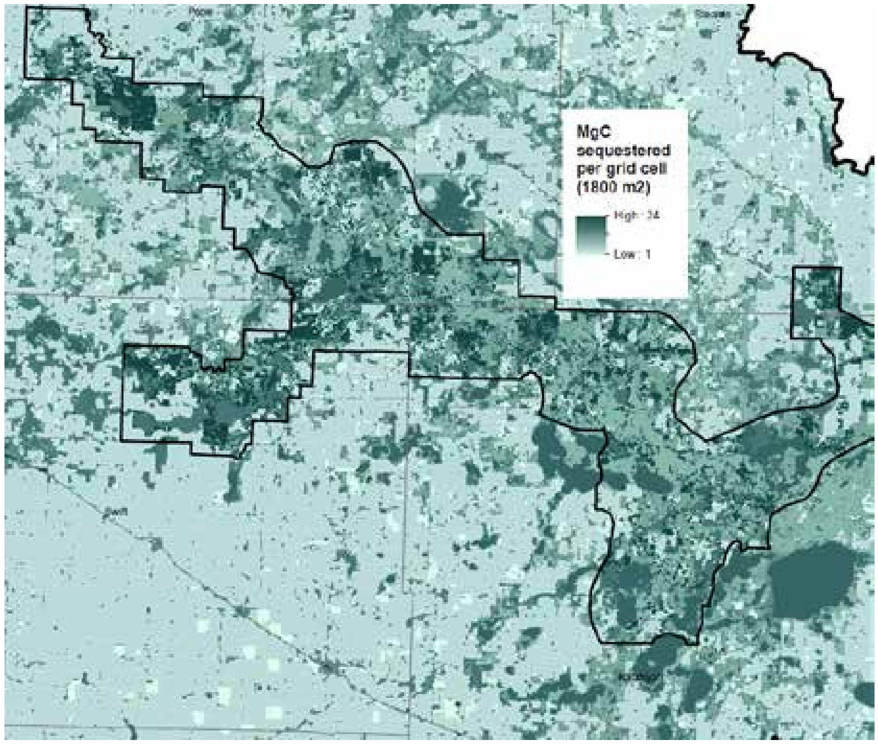

Figure 47. Carbon sequestration under current LULC.

D. Conclusions

The potential economic viability of a transition from row-crop agriculture to any grass-based operation is highly dependent on the following four factors: the initial type of cropping system, the current crop prices, and the underlying soil productivity, and for grazing systems – the intensity of the grazing operation. Net returns from cropland operations were highest for corn and soybean in both landscapes on high productivity soils (land capability classes 1 and 2); returns for all annual crops declined rapidly on lower productivity soils (land capability class 3 or higher). Controlling for soil productivity class, cropland returns were higher in the in the Glacial Lakes landscape than the Agassiz Beach Ridges landscape. Net returns from grazing operations also declined with soil productivity levels, but showed significantly less variability with soil productivity than did cropland returns. Annual net returns per acre increased with the intensity of the grazing system due to modeled increases in stocking rates and utilization rates. Estimated annual net returns per acre for management intensive grazing systems are fairly comparable to returns from crops even on high productivity soils, with the exceptions being corn and soybeans, and these grazing returns in some cases exceed many crops on lower productivity soils.

However, these annual net return data do not include the costs of transitioning from one land cover and use to another, or the costs of establishing a new operation. Any comparison of operations based solely on the estimated annual return data is incomplete. Across soil productivity levels, our results suggest that landowners will need significant financial assistance with restoration and establishment costs for a transition to a grass-based system to be economically viable. Even with assistance on these one-time transition costs, opportunities are very dependent the specific characteristics of their site and their management practices.

E. Ongoing Analyses

Financial returns are not the only incentive driving land management decisions as the results of the social landscape analysis showed. Through ongoing analyses we are analyzing the impact of a range of scenarios for implementing the goals of the Minnesota Prairie Plan on the provision of public and private benefits. The optimization model, still in development will allow for the combination of data from the social landscape analysis with the economic and ecosystem service data to identify optimal locations for state transitions defined within this report. Optimal locations will differ by scenario, with three scenarios planned. The first will maximize economic returns (private benefits) to landowners. The second will maximize the ecosystem service provision (public benefits) while meeting both the grassland and wetland acreage shortfalls noted in the Minnesota Prairie Plan. The third will utilize social preferences for land use patterns, identified through the interviews described in Chapter 6 that have been refined into a set of land use and transition “rules” that will constrain where state transitions are allowed. Within these constraints both economic and ecosystem service provision will be maximized. This works is currently underway and results will be provided to the implementation team and upon request.

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Appendix 1: Land Use and Land Cover Map Development

A. Preparing Datasets for Compilation

This appendix provides additional detail on the methods used to create the land use and land cover maps for the Agassiz Beach Ridges (ABR) and Glacial Lakes (GL) landscapes. By providing baseline information on land use and land cover (LULC) in these landscapes, the LULC maps provided a basis for designing and executing the social, economic, and ecological analyses described elsewhere in this report. These maps informed not only our understanding of the two landscapes, but also allowed for comparisons with the surrounding regions. Differences in mapping steps undergone within the landscapes versus in the surrounding regions will also be described.

The first step in compilation was to reassign LULC classes in each of the underlying datasets to a common set of LULC classes. To do this, all datasets were clipped to the landscape boundaries and attribute columns were then added to each dataset to reflect either generalizations or to highlight specific attributes of the data. For example, a general land cover (LC) attribute (Anderson Level I, Anderson et al. 1976) was added to the CDL data identifying LULC classes as: cropland, grassland, woodland, wetland, water or developed. Similarly, ten original Existing Vegetation Cover classes in the Landfire dataset were grouped into four classes: <10%, ≥10 to <30%, ≥30 to <50%, and ≥50%. These very broad LULC classes were then subdivided as needed, and as allowed by the level of detail in each dataset, to best address our research questions. Most dataset classifications were generalized, combining multiple crop, grassland, or wetland classes for example. By combining information from multiple reclassified datasets using a predetermined set of hierarchy rules we defined LULC classes which captured the necessary detail in grassland type and use. Spatial data processing was completed using ESRI ArcGIS 10.0 (ESRI 2013).

To facilitate reclassification and combination of datasets, all were converted to raster format with a resolution of 30 m^2 to match the resolution of the Cropland Data Layer (CDL, USDA NASS 2011). Converting the native plant community (NPC) data to raster format required the most extensive preparation. Once NPC types were reclassified as general land cover types (Level I), element occurrence rank point data (EOR) data was joined to the polygon data with the minimum value assigned in all cases where multiple rank points were present in a polygon. The point EOR data was obtained through correspondence with Fred Harris at the Minnesota Department of Natural Resources (*personal communication* 2012). The age of the EOR data varied from 1985–2010 in the ABR core areas and from 1990–2002 in the GL core area. These rank data combined with newer condition rank polygon data (available for a portion of each landscape as part of the NPC dataset) were used to delineate grasslands varying in quality.

Grassland quality is used hereafter to refer to the combined effects of invasion by non-native species and land use on the native plant community. Determination of how to use the rank data for grassland quality ranking evolved through communications between Laura Phillips-Mao, Harriet Van Vleck, and Susan Galatowitsch at the University of Minnesota, and Fred Harris at the MN DNR. EOR ranks range from A through D and include transitions such as AB or BC ranks as well as both a “not ranked” (NR) class and an extant (E) class. Ranks were assigned an EOR number to facilitate further processing described in more detail below (1 for A and AB, 2 for B, 3 for BC, 4 for C, 5 for CD, 6 for D, and 7 for NR and E). To convert the joined polygon and point data to a raster, multiple rasters were created for unique combinations of land cover types and EOR numbers (see LC_Reclass column in Table 55). These rasters were then merged resulting in a single raster with both land cover and rank data. There were some important differences between our reclassification of the MBS native plant community data and reclassification of these data for the MN Prairie Plan; these differences are described in section C of this appendix.

Table 44 through Table 49 show the reclassification of the USDA Cropland Data Layer (USDA NASS 2011), the Landfire Existing Vegetation Cover and Type data (LANDFIRE 2011a, b), the National Wetland Inventory data (USFWS 2012), the Minnesota Biological Survey native plant community data (MBS 2000) and the National Hydrography Dataset (USGS 2012).

B. Dataset Compilation

1. LULC within the Landscapes

With all datasets in raster format and reclassified to highlight key differences in land cover and land use (see “Values” column in Table 44 through Table 49), all datasets were merged by using the raster calculator to sum the assigned values. In doing so it was important to ensure that all “No Data” cells within the landscape boundaries were reclassified to have a value of zero to ensure these areas were included in the raster calculator extent. This can be done by checking the attribute settings and changing the mask under Raster Analysis to the corresponding landscape boundary when reclassifying.

Summing the values resulted in one raster for each landscape with nearly 4000 values in ABR and nearly 8000 values in GL; each value represents a unique combination of values assigned to the underlying datasets. As described in Chapter 3 a set of hierarchy rules was used to assign all of these values to a set of unique LULC classes. These rules were implemented through a series of If/Then statements in Excel. A table summarizing the unique value generated by the raster calculator and LULC classification assigned to each value was joined to the rasters for each landscape and both were then reclassified to reduce the number of values to the number of unique land use and land cover combinations.

To reduce errors of positional accuracy and issues arising from combining multiple datasets we resampled this combined $30m^2$ LULC raster to generate a raster at a larger spatial resolution, $90m^2$ (Dr. Joe Knight, University of Minnesota, *personal communication*, 2012). Once resampled, the number of unique LULC classes in both landscapes dropped from 28 to 26. The developed//open space-low intensity class which primarily represents roads, was exaggerated at the coarser resolution, masking the land cover and land use on either side of even small roads. To address this over-representation of roads, in preparing our expected LULC class map for rapid assessment we generated a map with this developed class removed. Conversely, mostly native savanna was only mapped at the $30m^2$ resolution; this LULC class disappeared at the coarser resolution.

Name	ID	Reclass_Value	Reclass_LC	Reclass_LU
open water	111	9	open water	open water
herbaceous wetlands	195	18	emergent wetland or forested/shrub wetland†	emergent wetland
woody wetlands	190	17	forested/shrub wetland	forested/shrub wetland
developed/open space developed/low intensity	121 122	10	developed	developed/open-low intensity
developed/medium intensity developed/high intensity	123 124	11	developed	developed/medium-high intensity
barren	131	12	barren/quarry	barren/quarry
corn sweet corn	1 12	1	cropland	corn
soybeans	5	3	cropland	soybean
sorghum barley spring wheat winter wheat oats millet	4 4 23 24 28 29	2	cropland	small grains
alfalfa	36	5	cropland	hay-alfalfa
sugar beets	41	7	cropland	sugar beets
sunflower dry beans canola other crops peas clover/wildflowers	6 42 31 44 53 58	4	cropland	other crop
fallow/idle cropland	61	8	ADF	old field/fallow
other hay/non-alfalfa sod/grass seed	37 59	6	IPDG	other hay/non-alfalfa
grassland herbaceous	171	16	MNIG	If protected and EVC <10%, then grazed-rotational/hay; if protected and EVC ≥10%, then grazed-rotational/no-hay; if not protected and EVC <10%, then grazed/hay; if not protected and EVC ≥10%, then grazed/no hay.
shrubland	152	15	WIP	If protected, then grazed-rotational/no hay; if not protected, then grazed/no hay.
deciduous forest evergreen forest mixed forest	141 142 143	14	NFDW	woodland

†If EVC <30% then emergent wetland; if EVC ≥30% then forested/shrub wetland.

Table 44. USDA cropland data layer (CDL) LULC reclassification. Based on the 2011 CDL classes: CDL class name and ID, unique reclass value assigned to differentiate between data source and unique LULC combinations, reclassified land cover (LC) and land use (LU).

Name	ID	Reclass_Value	Reclass_cover
Tree Cover < 10%	.	0	0 – 10% cover
Tree Cover >= 10 and < 20%	101	100,000,000	≥10 – <30% cover
Tree Cover >= 20 and < 30%	102		
Tree Cover >= 30 and < 40%	103	200,000,000	≥30 – <50% cover
Tree Cover >= 40 and < 50%	104		
Tree Cover >= 50 and < 60%	105	300,000,000	≥50 – 100% cover
Tree Cover >= 60 and < 70%	106		
Tree Cover >= 70 and < 80%	107		
Tree Cover >= 80 and < 90%	108		
Tree Cover >= 90 and <= 100%	109		

Table 45. LULC reclassification of Landfire Existing Vegetation Cover (EVC) tree cover classes (ID numbers 101-109). Tree cover was used to distinguish between MNP and WIP land cover types, between emergent and forested-shrub wetlands, and to identify grasslands with the potential for haying operations.

Name	ID	Reclass_Value	Reclass_LC	Reclass_LU
Open Water	11	300	open water	open water
Herbaceous Wetlands	95	2000	emergent wetland	emergent wetland
Recently Burned Herbaceous Wetlands	2198			
Western Great Plains Depressional Wetland Systems	2495			
Central Interior and Appalachian Shrub-Herbaceous Wetland Systems	2493	6000	forested/shrub wetland	forested/shrub wetland
Developed-Upland Deciduous Forest	13	400	developed	developed/open-low intensity
Developed-Upland Evergreen Forest	14			
Developed-Upland Mixed Forest	15			
Developed-Upland Herbaceous	16			
Developed-Upland Shrubland	17			
Developed-Roads	25			
Recently Disturbed Developed Upland Mixed Forest	2543			
Recently Disturbed Developed Upland Herbaceous	2544			
Recently Disturbed Developed Upland Shrubland	2545			
Developed-Medium Intensity	23	500	developed	developed/medium-high intensity
Developed-High Intensity	24			
Barren	31	600	barren/quarry	barren/quarry
Quarries-Strip Mines-Gravel Pits	32			
NASS-Row Crop-Close Grown Crop	63	700	cropland	defer to CDL data
NASS-Row Crop	64			
Agriculture-Cultivated Crops and Irrigated Ag.	82			
NASS-Fallow/Idle Cropland	66	800	ADF	old field/fallow
North-Central Interior Oak Savanna	2394	4000	MNS	unmanaged
Herbaceous Semi-dry	75	900	IPDG or MNIG†	‡
Herbaceous Semi-wet	76			
Northwestern Great Plains Mixedgrass Prairie	2141			
Recently Burned-Herb and Grass Cover	2195			
North-Central Interior Sand and Gravel Tallgrass Prairie	2412			
Great Plains Prairie Pothole	2482			
Eastern Great Plains Wet Meadow-Prairie-Marsh	2488			
Modified-Managed Northern Tall Grassland	2539			
NASS-Pasture and Hayland	67	1000		
Agriculture-Pasture and Hay	81			
Recently Disturbed Pasture and Hayland	2549			
Western Great Plains Floodplain Systems	2162	3000	NFDW	woodland
Boreal Aspen-Birch Forest	2301			
North-Central Interior Maple-Basswood Forest	2314			
Eastern Great Plains Tallgrass Aspen Parkland	2331			
Northern Tallgrass Prairie	2420			
Eastern Great Plains Floodplain Systems	2469			
Central Interior and Appalachian Floodplain Systems	2471			
North-Central Interior Dry-Mesic Oak Forest and Woodland	2310	5000	FDOW	woodland

†If protected, then MNIG; if not then IPDG.

‡If protected, then rotational grazing assumed, otherwise continuous grazing assumed; if EVC <10%, hay is a potential use.

Table 46. Landfire Existing Vegetation Type (EVT) LULC reclassification. EVT class name and ID, unique reclass value assigned to differentiate between data source and LULC combinations, reclassified land cover (LC) and land use (LU).

Name	ID	Reclass_Value	Reclass_LC	Reclass_LU
Lake	L1UBG, L1UBH, L1UBHh, L1UBHx, L2ABG, L2ABH, L2EMG, L2UBG, L2UBH	300,000	open water	open water
Freshwater Pond	PABFx, PUB/EMF, PUBF, PUBFd, PUBFh, PUBFx, PUBG, PUBGh, PUBGx, PUBH, PUBHx, PUBKFx			
Riverine	R2UBG, R2UBH, R2USA	400,000	open water (river)	open water (river)
Freshwater Emergent Wetland	PEM/ABF, PEM/FO1A, PEM/FO1B, PEM/FO1C, PEM/FO1C, PEM/FO1Cd, PEM/FO1Ch, PEM/SS1Ad, PEM/SS1B, PEM/SS1Bd, PEM/SS1Bdg, PEM/SS1Bg, PEM/SS1C, PEM/SS1Cd, PEM/SS1F, PEM/SS1FD, PEM/UBF, PEM/UBFB, PEM/UBFD, PEM/UBFH, PEM/UBFx, PEM/UBG, PEM5A, PEMA, PEMAd, PEMB, PEMBd, PEMBdg, PEMBg, PEMC, PEMCd, PEMCDx, PEMCh, PEMCx, PEMF, PEMFB, PEMFd, PEMFh, PEMFx, PEMG, PEMKFx, PEMU, PEMUB, PEMUd	100,000	emergent wetland	emergent wetland
Freshwater Forested/Shrub Wetland	PFO/SS1B, PFO/SS1Bg, PFO/SS1C, PFO/SS1Cd, PFO1/4B, PFO1/EMA, PFO1/EMB, PFO1/EMBD, PFO1/EMBg, PFO1/EMC, PFO1/EMCd, PFO1/EMCx, PFO1/EMF, PFO1/SS1B, PFO1/SS1BD, PFO1/SS1C, PFO1/SS1CD, PFO1/SSC, PFO1A, PFO1Ad, PFO1Ax, PFO1B, PFO1Bd, PFO1Bg, PFO1C, PFO1Cd, PFO1Cx, PFO1U, PFO4B, PFO4Bg, PFO5/EMC, PFO5/EMF, PFO5/SS5F, PFO5E, PFO5F, PFO5FB, PSS/EM1Ad, PSS/FO1A, PSS/FO1B, PSS/FO1Bg, PSS/FO1C, PSS/FO1CD, PSS1/EMB, PSS1/EMBd, PSS1/EMBg, PSS1/EMC, PSS1/EMCd, PSS1/EMCx, PSS1/EMF, PSS1A, PSS1Ad, PSS1B, PSS1Bd, PSS1Bg, PSS1C, PSS1Cd, PSS1Cx, PSS1F, PSS5/EMF, PSS5/EMFD, PSS5F	200,000	forested/shrub wetland	forested/shrub wetland

Table 47. National Wetland Inventory (NWI) LULC reclassification. NWI class name and ID, unique reclass value assigned to differentiate between data source and unique LULC combinations, reclassified land cover (LC) and land use (LU).

Name	ID	Reclass_Value	Reclass_LC	Reclass_LU
Other Water Body	OW	.	open water	open water
Meadow - Marsh - Fen-Swamp Complex	MMS_CX	30,000	emergent wetland (forested/shrub wetland if EVC reclass value is ≥ 200,000,000)	emergent wetland (forested/shrub wetland if EVC reclass value is ≥ 200,000,000)
Cattail - Sedge Marsh (Northern)	MRn83a			
Bulrush Marsh (Northern)	MRn93a			
Prairie Mixed Cattail Marsh	MRp83			
Cattail - Sedge Marsh (Prairie)	MRp83a			
Cattail Marsh (Prairie)	MRp83b			
Arrowhead Marsh (Prairie)	MRp93c			
Graminoid - Sphagnum Rich Fen (Basin)	OPn92b			
Rich Fen (Mineral Soil)	OPp91a			
Prairie Extremely Rich Fen	OPp93			
Calcareous Fen (Northwestern)	OPp93a			
Calcareous Fen (Southwestern)	OPp93b			
Willow - Dogwood Shrub Swamp	WMn82a	40,000	forested/shrub wetland	forested/shrub wetland
Oak Woodland-Brushland (Central)	OWCEXX	20,000	FDOW	woodland
Pin Oak - Bur Oak Woodland	FDs37b			
Northwestern Mesic Aspen-Oak Woodland	FDw34			
Northwestern Wet-Mesic Aspen Woodland	FDw44	10,000	NFDW	woodland
Aspen - (Cordgrass) Woodland	FDw44a			
Basswood - Bur Oak - (Green Ash) Forest	MHs38b			
Green Ash - Bur Oak - Elm Forest	MHw36a			
Lowland Aspen Forest	WFs55a			
Dry Sand - Gravel Oak Savanna (Southern)	UPs14b	50,000	MNS if A, AB,B rank	unmanaged
Agassiz Beach Ridge Complex	ABR_CX			Dependent on protection status and percent cover ‡
Agassiz Interbeach Prairie Complex	AIP_CX			
Prairie Wetland Complex	PWL_CX			
Dry Sand - Gravel Prairie (Northern)	UPn12b			
Dry Hill Prairie (Northern)	UPn12d			
Mesic Prairie (Northern)	UPn23b	60,000	MNP or WIP if rank = A, AB, or B.	
Dry Sand - Gravel Prairie (Southern)	UPs13b			
Dry Hill Prairie (Southern)	UPs13d			
Mesic Prairie (Southern)	UPs23a			
Sedge Meadow	WMn82b	80,000	MNIG if rank = BC or C	
Sedge Meadow: Beaked Sedge Subtype	WMn82b3			
Sedge Meadow: Lake Sedge Subtype	WMn82b4			
Prairie Meadow/Carr	WMp73a	70,000	IPDG if rank = CD or D	
Seepage Meadow/Carr	WMs83a			
Seepage Meadow/Carr Tussock: Sedge Subtype	WMs83a1			
Basin Meadow/Carr	WMs92a	90,000	MNIG or IPDG if rank = NR, E or no data †	
Wet Seepage Prairie (Northern)	WPn53a			
Wet Brush-Prairie (Northern)	WPn53b			
Wet Prairie (Northern)	WPn53c			
Wet Saline Prairie (Northern)	WPn53d			
Wet Seepage Prairie (Southern)	WPs54a			
Wet Prairie (Southern)	WPs54b			

†LC classification dependent on grassland rank data, tree cover (%), and protection status. If grassland rank = A, AB, or B then grassland was classified as mostly native prairie (MNP) with one exception. If the existing vegetation cover (EVC) was ≥10% on grasslands with A, AB, or B rank, woody-invaded prairie (WIP) was assigned. If rank = BC or C then grasslands were classified as mixed native-invasive grassland (MNIG). If rank = CD or D then grasslands were classified as invasive perennial dominated grassland (IPDG). If rank = NR, E, or no data, then grasslands were classified as IPDG if the pixel was not protected and MNIG if the pixel was protected.

‡Potential LU classification included grazing (continuous or rotational), haying, or unmanaged; classification was dependent on protection and tree cover (%). If protected potential grazing was assumed to be rotational, if non-protected, continuous grazing was assumed. If EVC was <10%, haying was a potential use, if EVC was ≥10% haying was deemed unlikely. Any of these grassland parcels could be unmanaged. Protection status and tree cover were combined to determine which uses were possible, for example if a parcel was not protected and EVC <10%, then grazed, hay, or unmanaged were potential uses, if not protected and EVC ≥10%, then grazed or unmanaged were both possible. These rules were applied with two exceptions: hay was not a potential use on WIP and rotational grazing was assumed regardless of protection status for all MNP parcels.

Table 48. Minnesota Biological Survey (MBS) LULC reclassification. MBS name and ID, unique reclass value assigned to differentiate between data source and unique LULC combinations, reclassified land cover (LC) and land use (LU).

Dataset	Class	Reclass_Value
Protection Status	Non-protected	1,000,000
	Protected	2,000,000
NHD	Non-river	0
	River	10,000,000
CRP	Non-CRP	0
	CRP	1,000,000,000

Table 49. Reclassification of additional datasets. Shown are protection status, National Hydrography Dataset (NHD), and 2007 Conservation Reserve Program (CRP) data.

2. LULC within the Major Watershed Boundaries

The process used to map the land use and land cover of the area extending from the boundary of each landscape to the boundary of the major watersheds was significantly simpler than that described above and in Chapter 3 for the area within the landscape boundaries. A simpler process is justified for these surrounding areas because in all scenarios used for economic and ecosystem service modeling we assumed no change in either LU or LC outside of the landscape boundaries. All LULC changes modeled in Chapters 8 and 9 reflect changes within the landscape boundaries. Therefore, in surrounding areas, we utilized only the USDA CDL data (USDA NASS 2011). The reclassification of CDL data in surrounding areas was much the same as it was within the landscape boundaries with the exception that in surrounding areas no additional datasets were used in the reclassification process, so neither protection status nor tree cover impacted reclassification. Differences between the reclassification within the landscape boundaries Table 44 and the surrounding areas are shown in bold in Table 50.

A summary of the accuracy data from our rapid assessment sampling was presented in Chapter 3. The full confusion matrices, for each level of resolution: LULC classes, Start State groups, and Prairie Plan groups are shown for each landscape in Table 51 through Table 56 below.

Name	ID	Reclass_Value	Reclass_LC	Reclass_LU
open water	111	9	open water	open water
herbaceous wetlands	195	18	**emergent wetland**	**emergent wetland**
woody wetlands	190	17	forested/shrub wetland	forested/shrub wetland
developed/open space developed/low intensity	121 122	10	developed	developed/open-low intensity
developed/medium intensity developed/high intensity	123 124	11	developed	developed/medium-high intensity
barren	131	12	barren/quarry	barren/quarry
corn sweet corn	1 12	1	cropland	corn
soybeans	5	3	cropland	soybean
sorghum barley spring wheat winter wheat **rye** oats millet	4 4 23 24 **27** 28 29	2	cropland	small grains
alfalfa	36	5	cropland	hay-alfalfa
sugar beets	41	7	cropland	sugar beets
sunflower **flaxseed** canola **camelina** dry beans **potatoes** other crops peas herbs clover/wildflowers **apples** **cantaloupes** **squash** **vetch**	6 **32** 31 **38** 42 **43** 44 53 57 58 **68** **209** **222** **224**	4	cropland	other crop
fallow/idle cropland	61	8	ADF	old field/fallow
other hay/non-alfalfa sod/grass seed **switchgrass**	37 59 **60**	6	IPDG	other hay/non-alfalfa
grassland herbaceous	171	16	MNIG	**grazed/hay/unmanaged**
shrubland	152	15	WIP	**grazed/hay/unmanaged**
Christmas trees deciduous forest evergreen forest mixed forest	**70** 141 142 143	14	NFDW	woodland

Table 50. CDL reclassification in areas surrounding landscape boundaries. Additional CDL classes present only in the surrounding areas are shown in bold. Differences in the Reclass_LC and Reclass_LU columns between this and Table 44 are also shown in bold.

LULC_mapped (down) LULC_observed (across)		MNP		WIP		IPDG		MNIG		wetland		cropland	ADF	barren/ quarry	developed	woodland		open water	No. Mapped	User's Accuracy (%)
		NP	P	NP	P	NP	P	NP	P	EW	FSW	all types	old field/ fallow	.	medium-high	NFDW	FDOW	.		
MNP	NP	14	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	93
	P	.	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	15	100
WIP	NP	.	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	1	100
	P	.	.	.	7	.	1	.	.	.	1	.	.	.	.	.	.	.	9	78
IPDG	NP	.	.	.	.	28	.	2	.	.	.	1	.	.	.	.	.	.	31	90
	P	.	6	.	.	.	19	.	4	2	.	.	.	.	.	.	.	.	31	61
MNIG	NP	.	1	.	.	3	.	8	.	.	.	.	.	3	.	.	.	.	15	53
	P	.	1	.	1	1	.	5	8	.	.	.	.	.	.	.	.	.	16	50
wetland	EW	.	.	.	.	2	.	4	.	6	2	.	.	.	.	.	.	.	14	43
	FSW	.	.	.	1	.	.	.	.	1	11	.	.	.	.	1	.	.	14	79
cropland	all types	.	.	.	.	10	.	.	.	.	.	78	.	1	.	1	.	.	90	87
ADF	old field/ fallow	.	.	.	.	5	.	5	1	.	.	3	15	.	.	1	.	.	30	50
barren/ quarry	.	.	.	.	.	.	.	.	4	1	.	.	.	12	.	1	.	1	19	63
developed	medium-high	.	.	.	.	.	.	.	.	.	.	.	.	.	15	.	.	.	15	100
woodland	NFDW	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	1	.	15	93
	FDOW	.	1	.	.	.	.	.	.	.	.	.	.	.	.	1	0	.	2	0
open water	.	.	.	.	.	.	.	.	.	.	4	2	.	.	.	.	.	9	15	60
No. Observed		14	25	1	9	49	20	24	17	10	18	84	15	16	15	19	1	10	347	<--Total No.
Producer's Accuracy (%)		100	60	100	78	57	95	35	56	67	61	93	100	75	100	74	0	90		
No. Correct		260																		
Overall		75%																		

Table 51. Confusion matrix for the ABR landscape, LULC classes. Grey boxes indicate the number of sample points where the observed LULC class matched the mapped LULC class. The total number of points sampled and mapped per LULC class in presented along with the user and producer's accuracy.

mapped (down) observed (across)	MNP	WIP	IPDG	MNIG	wetland	cropland	ADF	barren/ quarry	developed	woodland	open water	No. Mapped	User's Accuracy (%)
MNP	30	.	.	.	.	.	.	.	.	.	.	30	100
WIP	.	8	1	.	1	.	.	.	.			10	80
IPDG	6	.	47	6	2	1	.	.	.	.	.	62	76
MNIG	2	1	4	21	.	.	.	3	.	.	.	31	68
wetland	.	1	2	4	20	.	.	.	.	1	.	28	71
cropland	.	.	10	.	.	78	.	1	.	1	.	90	87
ADF	.		5	6	.	3	15	.	.	1		30	50
barren/ quarry	.	.	.	4	1	.	.	12	.	1	1	19	63
developed	.	.	.	.	.	.	.	.	15	.	.	15	100
woodland	1	.	.	.	.	.	.	.	.	16	.	17	94
open water	.	.	.	.	4	2	.	.	.	.	9	15	60
No. Observed	39	10	69	41	28	84	15	16	15	20	10	347	**<--Total No.**
Producer's Accuracy (%)	77	80	68	51	71	93	100	75	100	80	90		
No. Correct	271												
Overall	78%												

Table 52. Confusion matrix for the ABR landscape, start state groups.

mapped (down) observed (across)	prairie	other grassland	wetland	other land cover	No. Mapped	User's Accuracy (%)
prairie	38	1	1	.	40	95
other grassland	9	78	2	4	93	84
wetland	1	6	20	1	28	71
other land cover	1	25	5	155	186	83
No. Observed	49	110	28	160	347	**<--Total No.**
Producer's Accuracy (%)	78	71	71	97		
No. Correct	291					
Overall	84%					

Table 53. Confusion matrix for the ABR landscape, Prairie Plan groups.

LULC_mapped (down) / LULC_observed (across)		MNP		WIP		IPDG		MNIG		wetland		cropland	ADF	barren/ quarry	developed	woodland		open water	No. Mapped	User's Accuracy (%)
		NP	P	NP	P	NP	P	NP	P	EW	FSW	all types	old field/ fallow	.	medium-high	NFDW	FDOW	.		
MNP	NP	9	.	3	.	.	.	2	.	1	.	.	.	.	.	.	.	.	15	60
	P	.	13	.	2	.	.	.	.	.	.	.	.	.	.	.	.	.	15	87
WIP	NP	.	.	5	.	2	.	3	.	1	1	.	.	.	.	3	.	.	15	33
	P	.	.	.	5	.	1	.	.	.	.	.	.	.	.	.	.	.	6	83
IPDG	NP	.	.	1	.	23	2	2	.	.	.	.	.	.	.	.	.	.	28	82
	P	.	2	.	.	.	3	.	10	.	.	.	.	.	.	.	.	.	15	20
MNIG	NP	.	.	.	.	5	.	11	.	.	.	1	.	.	.	.	.	.	17	65
	P	.	.	.	.	.	.	1	16	.	.	.	.	.	.	.	.	.	17	94
wetland	EW	.	.	.	.	.	.	.	.	15	.	.	.	.	.	.	.	.	15	100
	FSW	.	.	.	.	.	.	.	1	.	14	.	.	.	.	.	.	.	15	93
cropland	all types	.	.	.	.	6	.	4	.	.	.	72	.	2	.	.	.	.	84	86
ADF	old field/ fallow	.	.	.	.	.	1	.	9	.	.	11	1	.	.	.	.	.	22	5
barren/ quarry	.	.	.	.	.	.	.	.	.	.	.	.	.	15	1	.	.	.	16	94
developed	medium-high	.	.	.	.	.	.	.	.	.	.	.	.	.	15	.	.	.	15	100
woodland	NFDW	.	.	.	.	.	.	.	.	.	.	.	.	.	.	14	1	.	15	93
	FDOW	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2	13	.	15	87
open water	.	.	.	.	.	.	.	.	.	.	.	1	.	.	.	.	.	14	15	93
No. Observed		9	15	9	7	36	7	23	36	17	15	85	1	17	16	19	14	14	339	<-- Total No.
Producer's Accuracy (%)		100	87	56	71	64	43	48	44	88	93	85	100	88	94	74	93	100		
No. Correct		258																		
Overall		76%																		

Table 54. Confusion matrix for the GL landscape, LULC classes. Grey boxes indicate the number of sample points where the observed LULC class matched the mapped LULC class. The total number of points sampled and mapped per LULC class in presented along with the user and producer's accuracy.

mapped (down) observed (across)	MNP	WIP	IPDG	MNIG	wetland	cropland	ADF	barren/ quarry	developed	woodland	open water	No. Mapped	User's Accuracy (%)
MNP	22	5	.	2	1	.	.	.	.	.	.	30	73
WIP	.	10	3	3	2	.	.	.	.	3	.	21	48
IPDG	2	1	28	12	.	.	.	.	.	.	.	43	65
MNIG	.	.	5	28	.	1	.	.	.	.	.	34	82
wetland	.	.	.	1	29	.	.	.	.	.	.	30	97
cropland	.	.	6	4	.	72	.	2	.	.	.	84	86
ADF	.	.	1	9	.	11	1	.	.	.	.	22	5
barren/ quarry	.	.	.	.	.	.	.	15	1	.	.	16	94
developed	.	.	.	.	.	.	.	.	15	.	.	15	100
woodland	.	.	.	.	.	.	.	.	.	30	.	30	100
open water	.	.	.	.	.	1	.	.	.	.	14	15	93
No. Observed	24	16	43	59	32	85	1	17	16	33	14	340	**<--Total No.**
Producer's Accuracy (%)	92	63	65	47	91	85	100	88	94	91	100		
No. Correct	264												
Overall	78%												

Table 55. Confusion matrix for the GL landscape, start state groups

mapped (down) observed (across)	prairie	other grassland	wetland	other land cover	No. Mapped	User's Accuracy (%)
prairie	37	8	3	3	51	73
other grassland	3	73	.	1	77	95
wetland	.	1	29	.	30	97
other land cover	.	20	.	162	182	89
No. Observed	40	102	32	166	340	**<--Total No.**
Producer's Accuracy (%)	93	72	91	98		
No. Correct	301					
Overall	89%					

Table 56. Confusion matrix for the GL landscape, Prairie Plan groups.

C. Comparison with Prairie Conservation Plan Mapping of Grasslands

1. Methodological Differences

With any dataset, there is the potential for different interpretations by users. The acres of native prairie in the Minnesota Prairie Plan map and grassland in our base LULC maps for the ABR and GL landscapes differed. The difference in grassland extent is primarily a result of choices made during reclassification of the Minnesota Biological Survey (MBS) native plant community dataset. This MBS dataset is polygon data representing the locations of native plant communities (NPC), from forest to prairie and wetland types, with a NPC code assigned to each polygon. The NPC class, type, and subtype data reflect local environmental conditions such as soil physical and chemical characteristics and disturbance regimes. The NPC codes reclassified as grassland differed between the two mapping efforts. Those reclassification differences are summarized in the table below (Table 57) showing all NPC types coded as native prairie for the Prairie Plan and as grassland for our mapping. NPC descriptions can be obtained from the MN Department of Natural Resources: (http://www.dnr.state.mn.us/npc/index.html).

A second difference in our use of the data is that in contrast to the designation of all selected grassland NPCs as native prairie – as done for the Prairie Plan maps, we divided the grassland NPCs selected into classes reflecting grassland quality (MBS ranking data reflects the degree of invasion by non-native species and the impacts of land use practices). Based on these ranking data, grasslands were divided into 5 classes: mostly native savanna (MNS), mostly native prairie (MNP), woody-invaded prairie (WIP), mixed native/invasive grassland (MNIG), or invasive perennial dominated grassland (IPDG). This means that same MBS data used for the identification of 1 grassland class in the Prairie Plan, was utilized to map 5 grassland classes for our mapping. All areas reclassified as grassland based on the MBS data were included in our base LULC map. However, for all grassland classes other than the mostly native prairie class, the extent of the class reflected data from MBS as well as other data sources.

To identify the reason for differences between the native prairie extent in the Prairie Plan map and the grassland extent in our base maps, we examined those differences resulting solely from use of the MBS NPC data. In ABR, this comparison required looking a geographic subset of the landscape we mapped (~127,000 acres) representing the three prairie core areas (~71,000). It also required looking only at the mapped grasslands derived from the MBS dataset and excluding those grasslands mapped based on CDL or EVT data.

NPC Name	NPC No.	ABR		GL	
		MPP	IMPP	MPP	IMPP
Oak Woodland-Brushland (Central)	OWCEXX	☐	☐	☐	☐
Pin Oak - Bur Oak Woodland	FDs37b	☐	☐	☐	☐
Northwestern Mesic Aspen-Oak Woodland	FDw34	☐	☐	☐	☐
Northwestern Wet-Mesic Aspen Woodland	FDw44	☐	☐	☐	☐
Aspen - (Cordgrass) Woodland	FDw44a	☐	☐	☐	☐
Basswood - Bur Oak - (Green Ash) Forest	MHs38b	☐	☐	☐	☐
Green Ash - Bur Oak - Elm Forest	MHw36a	☐	☐	☐	☐
Lowland Aspen Forest	WFs55a	☐	☐	☐	☐
Cattail - Sedge Marsh (Northern)	MRn83a	☒	☐	☐	☐
Bulrush Marsh (Northern)	MRn93a	☒	☐	☐	☐
Prairie Mixed Cattail Marsh	MRp83	☒	☐	☐	☐
Cattail - Sedge Marsh (Prairie)	MRp83a	☒	☐	☐	☐
Cattail Marsh (Prairie)	MRp83b	☐	☐	☐	☐
Arrowhead Marsh (Prairie)	MRp93c	☐	☐	☐	☐
Graminoid - Sphagnum Rich Fen (Basin)	OPn92b	☐	☐	☐	☐
Rich Fen (Mineral Soil)	OPp91a	☐	☐	☐	☐
Prairie Extremely Rich Fen	OPp93	☐	☐	☒	☐
Calcareous Fen (Northwestern)	OPp93a	☒	☐	☐	☐
Calcareous Fen (Southwestern)	OPp93b	☐	☐	☐	☐
Willow - Dogwood Shrub Swamp	WMn82a	☒	☐	☐	☐
Sedge Meadow	WMn82b	☐	☐	☐	☒
Sedge Meadow: Beaked Sedge Subtype	WMn82b3	☒	☒	☐	☐
Sedge Meadow: Lake Sedge Subtype	WMn82b4	☒	☒	☐	☐
Prairie Meadow/Carr	WMp73a	☒	☒	☒	☒
Seepage Meadow/Carr	WMs83a	☐	☒	☐	☒
Seepage Meadow/Carr Tussock: Sedge Subtype	WMs83a1	☐	☒	☐	☐
Basin Meadow/Carr	WMs92a	☒	☒	☐	☐
Wet Seepage Prairie (Northern)	WPn53a	☐	☒	☐	☐
Wet Brush-Prairie (Northern)	WPn53b	☒	☒	☐	☐
Wet Prairie (Northern)	WPn53c	☒	☒	☐	☐
Wet Saline Prairie (Northern)	WPn53d	☒	☒	☐	☐
Dry Sand - Gravel Oak Savanna (Southern)	UPs14b	☐	☐	☐	☒
Wet Seepage Prairie (Southern)	WPs54a	☐	☐	☒	☒
Wet Prairie (Southern)	WPs54b	☐	☐	☒	☒
Agassiz Beach Ridge Complex	ABR_CX	☐	☒	☐	☐
Agassiz Interbeach Prairie Complex	AIP_CX	☒	☒	☐	☐
Prairie Wetland Complex	PWL_CX	☒	☒	☒	☒
Dry Sand - Gravel Prairie (Northern)	UPn12b	☒	☒	☐	☐
Dry Hill Prairie (Northern)	UPn12d	☒	☒	☐	☐
Dry Sand - Gravel Prairie (Southern)	UPs13b	☐	☐	☒	☒
Dry Hill Prairie (Southern)	UPs13d	☐	☐	☒	☒
Mesic Prairie (Northern)	UPn23a	☒	☒	☐	☐
Mesic Prairie (Southern)	UPs23b	☐	☐	☒	☒

Table 57. Reclassification of MBS data. Checked boxes indicate native prairie classification in the Prairie Plan (MPP) or ranked grassland classification for our base LULC maps (IMPP).

2. Effects of Methodological Differences

In both landscapes, the Prairie Plan mapping tended toward inclusion of marsh, fen and swamp vegetation communities which we reclassified as wetland types, while we tended toward inclusion of seepage meadow and seepage prairie communities not classified as native prairie for the Prairie Plan. Additionally, in the GL landscape we included oak savanna as a grassland class, though with less than 6 acres of savanna this difference contributes minimally to the overall differences.

The mapping differences were greatest in the three ABR core areas (Bluestem Prairie, Felton Prairie, and Syre Prairie). In total, 15,523 acres of native prairie were mapped across these core areas for the Prairie Plan; this extent was composed of those NPCs identified in Table 57. We mapped a slightly larger extent of all grasslands (based only on the MBS data), 16,845 acres. The primary differences in the overall extent of grasslands reflects six NPC classes mapped as native prairie for the Prairie Plan but mapped as either emergent or forested wetland in our map (1,176 acres) and four classes included as grasslands in our map but excluded from the Prairie Plan native prairie map (2,789 acres). The difference in the overall extent of grassland based on the MBS data was relatively small in comparison to the differences in our estimates of native prairie extent. Of the nearly 17,000 acres of grassland we mapped based on the MBS data, roughly 31% of the grassland acres were classified as mostly native prairie or woody-invaded prairie, over 43% were classified as mixed native-invasive grassland, and a 26% were classified as invasive perennial-dominated grassland. Thus, our estimate of native prairie extent in the ABR core areas based on MBS data (5,152 acres) was roughly a third of the Prairie Plan estimate.

The extent of native prairie in the GL core area mapped by the Prairie Plan was 7,223 acres, while 8,239 acres of grassland were mapped based on our reclassification of the MBS NPC data. The three classes we included as grassland that were not also included as native prairie for the Prairie Plan comprised 1,040 acres. One class mapped as native prairie for the Prairie Plan was classified as emergent or forested wetland for our base LULC map, this class covered only 24 acres. As in the ABR core areas, this difference in our estimates of overall grassland extent is significantly less than the differences in our estimates of native prairie extent. In GL, the ranking data indicated that the majority of MBS mapped grasslands were mixed-native invasive grasslands (roughly 6,700 acres), while less than 800 acres each were mapped as invasive perennial-dominated grasslands and either mostly native prairie or woody-invaded prairie. Thus, our estimate of native prairie extent in the GL core area based on MBS data (740 acres) was roughly a tenth of the Prairie Plan estimate.

Our aim in highlighting the differences between our mapping and the Prairie Plan mapping is to show the potential impact of classification decisions on evaluation of our current status with respect to Prairie Plan goals. The differences resulting solely from use of MBS data are summarized in Table 58 and can be noted by examining differences in the current status data reported in Chapter 2 (based on the Prairie Plan data) and that reported in Chapter 3 (based on our LULC data). The implications of differing extents for native prairie and other grasslands quickly becomes evident when one considers the goal of 100% native prairie protection and 50% other grassland protection. Though the total grassland extent mapped is similar between the two approaches, the protection goal (if zero current protection is assumed) would be 15,523 acres based on Prairie Plan data versus 10,999 (1*5,152 + 0.5*11,693) acres based on our data. This example calculation is for illustrative purposes only as this is only a subset of the data utilized to map grasslands during the development of both the Prairie Plan and our base map. Other grasslands were mapped as part of the Prairie Plan, but the extent of these other grasslands was not derived from MBS data and therefore the data is not included in Table 58 below.

Classification Source, Type	ABR (Bluestem, Felton, Syre)	GL (Glacial Lakes)
MPP, Native Prairie	15,523	7,223
IMPP, Native Prairie	5,152	740
IMPP, Other Grasslands	11,693	7,499

Table 58. Effects of classification on native prairie extent. The extent of native prairie within the core areas as reported by the MN Prairie Plan (MPP) and as mapped for this report (IMPP). The comparison is based exclusively on the MBS data utilized to generate the Prairie Plan data.

Appendix 2: Method details for proposed indicators

A. Agassiz Beach Ridges landscape

1. Permanently protect remaining unprotected 7,270 acres of native prairie

Indicator: Number of acres protected (baseline completed – MPP 2011)
Methods: Annual GIS analysis with most recent conservation land ownership information for cumulative running totals.
Trends: Steadily increasing trend over next 10 years with acreage goal achieved by 2020.

Indicator: Number and size of Western Prairie Fringed Orchid (WPFO) populations (MPP EM8; ABR CAP). WPFO is highly correlated with high quality prairie, intact hydrology, and intact below-ground processes (fungal associates). Additionally, Minnesota has the world's largest populations of this species and a large, robust data set available for analysis and evaluation.
Methods: Regular inventories of Western Prairie Fringed Orchid (WPFO) population locations using standard protocols for WPFO monitoring. For the purposes of this project, every 3 to 5 years request GIS data for WPFO populations from the MN Natural Heritage Data Base and do spatial analysis for WPFO.
Trends: Stable or increasing population trend over the next 10 years.

2. Permanently protect an additional 3,155 acres of wetland (fee or easement)

Indicator:
a. Number of acres Utility Prairie, Invasive Perennial, Mixed Native/Invasive protected
b. Number of acres Conservation Meadow, Utility Meadow, and Marsh protected (baseline completed – MPP 2011)
Methods (a & b): Annual GIS analysis with most recent conservation land ownership for cumulative running totals.
Trends (a & b): Steadily increasing trend over next 10 years with acreage goal achieved by 2020.

3. Reconstruct/restore 4,764 acres of AIPC wetlands (and/or wetland system)

Indicator: Number of basins and acres restored (e.g., transitions from Cropland Start State to Utility or Conservation Meadow End States)
Methods: Annual GIS analysis with most recent conservation land ownership for cumulative running totals.
Trends: Steadily increasing trend over next 10 years with acreage goal achieved by 2020.

a. For restored Utility Meadow (low diversity):

Methods: Only a portion (TBD) of the reconstructed wetlands in each landscape will aim to reestablish diverse Conservation Meadow.

- For low diversity reconstructions, an in-depth survey of the plant diversity would not be appropriate or necessary. However, we may still be concerned about the cover of native versus invasive vegetation on the site. A simple count of the number of acres restored is the easiest and best option.
- If some assessment of composition is desired, a modified rapid assessment version of the Grassland Monitoring Team Protocol is recommended. The degree of native versus invasive cover would be assessed for more dispersed transects (<1 transect per 10 acres) with only native/exotic cover estimates along whole transects or at a radius around a random point rather than averaging across individual plots as in the Grassland Monitoring Team Protocol. For low diversity plantings, this measure is not worth a large investment of time.

Trends: Steadily increasing trend over next 10 years with acreage goal achieved by 2020.

b. For restored Conservation Meadow (or Marsh) (high diversity):

Methods: Grassland Monitoring Protocol (see #5) - for overall sense of change in native vs. exotic cover over time within and across sites or the Extensive Assessment Protocol for Large-Scale Restorations- for better information about species recovery across a large planted area
Trends: Individual sites should be at >75% native cover or show improving trend over next 10 years with dominance outcome achieved by 2020.

4. Reduce woody species density and cover across all Conservation Prairie areas

For priority areas, trees are either absent or with a few shrub-like grubs of bur oak and/or quaking aspen; shrub layer is sparse to interrupted ranging from 5% to 75% (Ecological Land Classification Program 2005; ABR CAP). Woody encroachment can be addressed with different types of management actions, (e.g., cutting or burning). Keeping track of the number of acres of trees cut or brush treated is one way to measure success, but would only account for the cutting types of management. A better measure would assess woody cover at a larger scale and would account for all types of management that could affect woody cover.

Indicator a: # acres treated/cut
Methods a: Rapid assessment aerial photo analysis and field checking of total tree density and cover in the landscape. For areas specified in the indicator above, tracking the number of acres of woody-invaded acres, and then the number cut is probably the best option for measuring success because this is a fairly small scale assessment. To determine the number of acres that need to be cut to achieve <10% cover, you will need an initial assessment of the number of acres in priority areas covered by woody vegetation. Digitizing the woody cover of the priority acres

from aerial photography would be a fairly easy and quick way to assess current cover. The estimate of current cover would be used to determine the number of acres that need to be cut. The measure of success then is simply how many acres you have cut in relation to the number that need to be cut.

Indicator b: # invaded acres in landscape
Methods b: Tracking the woody encroachment at the scale of the entire landscape of interest would need to involve a more coarse-scale and probably longer-term analysis. The goal here would be to track woody cover over time across the entire landscape where multiple management approaches are being used (cutting, burning, grazing, etc.). This would allow a big-picture assessment of whether activities on the landscape are favoring or hindering woody encroachment (precipitation patterns through time should also be considered here).

Remote sensing using 30X30 m LANDSAT images could be used. Images are free and taken every 16 days. Woody cover should be assessed on an annual basis using images taken at the same time of year. Ideally, images should be acquired when the woody vegetation is fully leafed out (not a problem for juniper). July would probably be best for other species. Once the initial analysis is done with the images, the process should be able to be automated for subsequent years and analyses. Initially, analyses should be done every year to determine the best interval to use to measure change in woody cover over time.

Trends (a & b): Steady decline in number of woody-invaded acres, attaining goal of <10% in priority areas, <20% elsewhere.

5. Native vegetation dominates conservation prairie (>75% cover; across ~16,000 acres)

There are numerous standardized methods for assessing vegetation; however, many of them are quite time intensive. Because we need a protocol that is effective but rapid, two approaches are proposed.

Indicator: Proportion of site classified as predominantly native
Methods: Representative sub-sample of the different physical conditions across the landscape for prairies (and high quality restorations). Site selection should be stratified by topography, ownership and dominant soil type at the minimum. Size and shape of prairies might also be considered given these could influence the level of invasive species at a site. A power analysis could be done to determine the number of sites to sample depending on the effect size that we hope to detect, and GIS could be used to identify and select the actual sites.

a. Grassland Monitoring Protocol (for overall sense of change in native vs. exotic cover over time within and across sites) developed by TNC, USFWS and MN DNR. This protocol is already being used extensively by partners and would facilitate the sharing and comparing of data across the state. The simple version of the protocol is relatively rapid and is designed to yield a cover of native vegetation at the pasture/field level. If it was desired to make this protocol even more rapid, the indicator species and structural vegetation measurements could be dropped. The belt transect with the categories developed is all you would need to determine the cover of native vegetation. However, if all the data could be collected, this could be contributed to the larger GMT model, which would also help us learn about the impact of management on native prairie condition. The advantage of this is that some of the conservation prairies in both of these landscapes are already being monitored with this protocol by various partners, reducing the number of sites that need to be sampled by any one team. The original project is focused on native prairie, but the protocol can be used on non-native grasslands as well.

b. Extensive Assessment Protocol for Large-Scale Restorations (for better information about species recovery across a large planted area). This protocol is better suited for yielding species richness type information instead of cover, but diversity categories are assigned at points along transects and cover of native vegetation could be included in this assessment. Because of the species richness component to this protocol, it is better for assessing success of high diversity restorations as species richness could be compared with richness of seed mixes used to evaluate success.

Trends (a & b): Increasing or stable trend toward native-dominated.

6. Stable or increasing populations of prairie obligate butterflies

Indicator: The number of individuals of each of 2-3 species of interest. This indicator initially arose because of the conservation targets defined in the GL landscape. However, it may be a good measure to implement across all prairie landscapes. While complete butterfly diversity surveys would take very skilled and experienced individuals in identifying all species of butterflies, it would be possible to choose a few easily identifiable yet grassland obligate species to survey. The primary species we suggest including in all surveys is the Regal Fritillary (*Speyeria idalia*), but which species are surveyed might vary depending on the landscape

Methods:

Due to major declines in prairie butterflies, a survey is getting underway in 2012 (Minnesota Zoo) focusing on visual counts of the abundance of all butterflies with an emphasis on rare and declining species, specifically the Poweshiek Skipperling, Dakota Skipper, Ottoe Skipper, Arogos Skipper, and Regal Fritillary. Researchers will conduct surveys throughout the summer across likely native tallgrass prairie habitats, especially those where today's rare species were once historically abundant. This group met with members of this project on 4/12/2012 and we discussed opportunities to collaborate. The 2012/2013 extensive surveys are geared toward re-locating rare species. We suspect that their findings will point toward areas where we should focus our efforts/Pollard-walk transects in future years to assess effectiveness in our conservation strategies for maintaining butterfly populations and helping them recover.

The most common method for conducting butterfly surveys is known as a Pollard count (Pollard 1977). These are essentially transects that are walked weekly to get an abundance estimate for butterflies at a site. Transects are usually walked weekly because they are trying to capture all the species at a site, and therefore, need to cover the summer because different species have different flight times. With just 2-3 species chosen that have similar peak flight times, a survey once during the peak flight time would probably be sufficient over time. Pollard surveys should be combined with the Grassland Monitoring Team (GMT) transect described in number 5 and 3 above. They can be laid out connecting the vegetation transects and could be conducted as the surveyors walk from one transect to the next.

The following components constitute the typical protocol for transects (see Pollard 1977 for further details):

- Done between 11 am and 4 pm – butterflies are most active during the warmest part of the day.
- Transects not usually wider than 5 m on either side
- Transects divided up into habitat segments if habitat associations are of interest
- All species (or 2-3) and individuals are recorded as transect is walked
- An abundance is obtained by summing all individuals of each species seen along the transect (divided by habitat if desired)

7. Ensure 90% compatible land use within the recharge zones of calcareous fens

The water quality and hydrological resilience of seepage fens, springs, and seeps provide an integrated measure of prairie conservation in areas where these wetland waters are captured as infiltration and recharge. In the glacial Lake Agassiz beach ridges, cultivation in capture zones (i.e. Start State 1) can lead to significant increases in recharge and perhaps a reduction of groundwater hardness (i.e., diminished calcareous conditions) because of increased hydraulic head and flow rates. Mining of aggregate (i.e. Start State 7) can lead to complete removal of unsaturated carbonate-rich beach sediments. This loss reduces the time that infiltrating subsurface water has in contact with carbonate minerals, which is critical to creating calcareous conditions.

Conservation lands (e.g., End States Conservation Prairie, Conservation Meadow, Marsh, Oak Savanna, and Woodland) constitute a compatible land use that tends to generate calcareous recharge, especially when it is maintained in ways that increase the acidity of infiltrating waters. This may include any management practice that enhances storage of labile organic carbon in the soil profiles. Sustainable grazing should be fully compatible (e.g., on Utility Prairie or Meadow or any of the Conservation End States). Aggregate mining (Start State 7) may be compatible, as long as sand and gravel is not removed from critical recharge areas and that restoration of the mined site is completed as soon as possible, with organic-rich soils returned to the surface and revegetated.

Incompatible land use includes aggregate extraction where pits remain open, exposing unmined coarse sediment. This increases recharge potential through decreased head loss. Similarly, cultivation of coarse textured soils in capture zones may lead to enhanced infiltration and recharge. In contrast, water diversion from beach aquifers (Lindgren 1996) will decrease recharge and is therefore an incompatible land use.

Indicator: % compatible land use/cover in fen recharge zones
Methods: Identify important calcareous fens. Initially, fens listed in the Natural Heritage Database will be mapped within and closely adjacent to the CABR project area. Potential new calcareous fen locations will be delineated by using a combination of National Wetland Inventory, LiDAR point returns, and NRCS SSURGO maps. Depending on accessibility, these locations will be field checked and, if warranted, may be added to a list of critical wetlands.

Variable-distance buffers will be delineated around important fens and calcareous seeps. At a minimum, these buffers will extend a fixed distance (recommended by experts) and expanded in areas where the direct surface watershed above the fen exceeds the buffer width.

Land cover inventories within buffers will be maintained and updated on a yearly basis to determine if significant changes in land use / land cover have occurred. Changes in crop-type, drainage conditions, aggregate mining, among others, within the buffers will likely cause greatest alteration in fens. These will be monitored closely using GIS and evaluated.

A challenging part of the effort will be to characterize and delineate groundwater capture zones. This will be done using a combination of the following methods:

- Sample the water and determine the electrical conductance, pH, hardness, and stable O and H isotopic composition for each season for at least a year. Results will provide a relative measure of path-line length and general location of infiltration and recharge.
- Deep groundwater, recharged millennia ago, may be discharging from fens. If so, then the effects of any conservation project may not be observed for centuries or more. Attempts will be made to date groundwater discharged from the fens by using use of chlorofluorocarbons, H-3/He-3 ratio, and other techniques (e.g. Bethke and Johnson 2008). Lawrence Livermore National Laboratory (2012) provides information applications, laboratory capabilities, and technique references.

- Georesistivity imaging will be used to characterize the subsurface "plumbing" of the fens. This should help reveal the presence or absence of deep, confined aquifers. If deeper connections are indicated, then additional evaluation of stratigraphy (based on Minnesota Department of Health well bore data) will be needed to delineate potential recharge areas. It is uncertain, however, if sufficient state agency data exist for most areas.
- Once the stratigraphy and hydraulic potential related to the seepage zones is reasonably well known, then standard GIS raster analysis tools will be used to delineate flow accumulation and estimate capture zones.

8. Maintain diversity of indicator species for calcareous fens

Calcareous fens are classified as Prairie Extremely Rich Fen (OPp93) within the Open Rich Peatland System, Prairie Floristic Region (Ecological Land Classification System, 2005). Calciphilic wetland species are generally rare plants that are either restricted to or tend to greatly favor wet locations with unusually hard water. In northwestern Minnesota, rare fen species include the state-endangered *Fimbristylis puberula* (Hairy fimbristylis), state-threatened *Carex sterilis* (Sterile sedge), *Rhynchospora capillacea* (Fen beak-rush), *Scleria verticillata* (Nut-rush) *Eleocharis rostellata* (Beaked spike-rush), and *Valeriana edulis* Valerian, and, finally, two species of special concern, *Cladium mariscoides* (Twig-rush) and *Cypripedium candidum* (Small white lady's slipper) (MN DNR 2011). The goal of this measure is to determine that calcareous fen areas themselves are sufficiently protected from external disturbances caused by local changes in land cover and land cover compatibility.

Indicator: An average of at least 50% of OPp93 indicator species occurs in each fen occurrence and native fen species constitute at least 25% of total wetland vegetation cover, which in turn is also native-dominated (75%).
Methods: Basin-wide inventories for each calcareous fen (up to 20 occurrences) will be conducted every three years to document presence /absence and cover estimates of OPp93) species, along with a biannual evaluation of key indicator species (Table 59). Selection of these monitoring sites will be based on results from item 7 (above), with a goal of selecting fen sites with the greatest hydroecological diversity. The boundary of each fen will be assumed to correspond to the extent of SSURGO hydric soils at individual monitoring sites.
Trends: Number of indicator species stable to increasing (50% or greater of possible species).

Common	**Latin**	**Frequency**
Sage-leaved willow	*Salix candida*	78
Sterile sedge	*Carex sterilis*	76
Spotted Joe pie weed	*Eupatorium maculatum*	71
Mat muhly grass	*Muhlenbergia richardsonis*	69
Flat-topped aster	*Aster umbellatus*	67
American grass-of-Parnassus	*Parnassia glauca*	58
Narrow reed grass	*Calamagrostis stricta*	54
Big Bluestem	*Andropogon gerardii*	49
Northern bedstraw	*Galium boreale*	47
Aquatic sedge	*Carex aquatilis*	46
Prairie sedge	*Carex prairea*	45
Riddell's goldenrod	*Solidago riddellii*	45
Tufted Bullrush	*Scirpus cespitosus*	41
Hardstem and Slender bulrush-	*Scirpus* sp.	41
Marsh arrowgrass	*Triglochin palustris*	38
Hair-like beak rush	*Rhynchospora capillacea*	28
Lead-colored sedge	*Carex livida*	24

Table 59. Examples of indicator species (in order of commonness within OPp93 communities).

9. Stable or increasing populations of Greater Prairie Chickens

This outcome arose because of the focus on Prairie-Chickens in the ABR region and its mention as an ecosystem measure in the Minnesota Prairie Plan (2011). In landscapes where prairie chickens occur (e.g., CABR, Northern Agassiz Beach Ridges, Tallgrass Aspen Parkland, etc.), population size is likely a good indicator of landscape connectivity for non-migratory wildlife.

Indicator: The primary indicator is greater prairie chicken population size.
Methods: Lek counts. Partner organizations such as the MN Prairie Chicken Society have conducted lek counts for decades. Lek counts are the most common method for monitoring Prairie-Chicken populations. This project can use annual data from ongoing lek counts to track Prairie-Chicken success in the landscapes where we are working. If there are a number of known lek sites that are not regularly counted in an area within the CABR, it might be worth conducting supplemental surveys to track success across the entire landscape of interest. After an initial survey of the landscape in any given year, conducting the lek counts should be relatively simple as Prairie-Chickens tend to be fairly faithful to their lek sites.
Trends: Greater Prairie Chicken population targets are maintained for the long-term.

B. Ordway Glacial Lakes landscape

1. Permanently protect the last remaining 4,410 acres of native prairie

Indicators: # acres Conservation Prairie protected (baseline completed – MPP 2011)
Methods: GIS analysis annually with most recent conservation lands ownership information for cumulative running totals.
Trends: Should show steadily increasing trend over next 10 years with acreage goal achieved by 2020.

2. Permanently protect integrated grassland and wetland habitats

Indicators:

a. # acres Utility Prairie, Invasive Perennial, Mixed Native/Invasive protected
b. # acres Conservation Meadow, Utility Meadow, and Marsh protected (baseline completed – MPP 2011)

Methods: GIS analysis annually with most recent conservation lands ownership information for cumulative running totals.
Trends: Should show steadily increasing trend over next 10 years with acreage goal achieved by 2020.

3. Reconstruct/restore 5,137 acres of grassland to reach a full 40% of grassland habitat

Indicators: Number and location of new acres prepped, planted (e.g., transitions from Crop to Conservation Prairie or Utility Prairie) (for all plantings)
Methods a: (Low Diversity Plantings) Only a portion (TBD) of the reconstructed prairies in each landscape will aim to reestablish diverse Conservation Prairie. For low diversity reconstructions, an in-depth survey of the plant diversity would not be appropriate or necessary. However, we may still be concerned about the cover of native versus invasive vegetation on the site. A simple count of the number of acres restored is the easiest and best option.
If some assessment of composition is desired, a modified rapid assessment version of the Grassland Monitoring Team Protocol is recommended. The degree of native versus invasive cover would be assessed for more disperse (<1 per 10 acres) with only native/exotic cover estimates along whole transects or at a radius around a random point rather than averaging across individual plots as in the Grassland Monitoring Team Protocol. For low diversity plantings, this measure is not worth a large investment of time.
Trends a: Should show steadily increasing trend over next 10 years with acreage goal achieved by 2020.

Methods b: (High Diversity Plantings) Grassland Monitoring Protocol (see #5; for overall sense of change in native vs. exotic cover over time within and across sites) or the Extensive

Assessment Protocol for Large-Scale Restorations (for better information about species recover across a large planted area).
Trends b: Individual sites should be at >75% native cover or show improving trend over next ten years with dominance goal achieved by 2020.

4. Remove mature woody vegetation and canopy trees for Woody-invaded sites

Woody encroachment, whether of juniper or other canopy trees, can be dealt with through different types of management actions, (e.g., cutting or burning). Keeping track of the number of acres of juniper cut would be one way to measure the success, but would only account for the cutting types of management. A better measure would assess woody cover at a larger scale and would account for all types of management that could affect woody cover.

Indicators: Juniper canopy cover in priority areas and/or % Juniper cover in the landscape
Methods:
a. Rapid assessment aerial photo analysis and field checking of total juniper in the landscape. For the priority areas specified in the indicator above, tracking the number of acres of Juniper-invaded acres, and then the number cut is probably the best option for measuring success because this is a fairly small scale assessment. To determine the number of acres that need to be cut to achieve <10% cover, you will need an initial assessment of the number of acres covered by juniper or woody vegetation. Digitizing the woody cover of the priority acres from digitized aerial photography would be a fairly easy and quick way to assess current cover. The estimate of current cover would be used to determine the number of acres that need to be cut. The measure of success then is simply how many acres you have cut in relation to the number that need to be cut.

b. Tracking the woody encroachment at the scale of the entire landscape of interest would need to involve a more course-scale and probably longer-term analysis. The goal here would be to track woody cover over time across the entire landscape where multiple management approaches are being used (cutting, burning, grazing). This would allow a big-picture assessment of whether activities on the landscape are favoring or hindering woody encroachment (precipitation patterns through time should also be considered here). Remote sensing using 30X30 m LANDSAT images could be used. Images are free and taken every 16 days. Woody cover should be assessed on an annual basis using images taken at the same time of year. Ideally, images should be acquired when the woody vegetation is fully leafed out (not a problem for juniper). July would probably be best for other species. Once the initial analysis is done with the images, the process should be able to be automated for subsequent years and analyses. Initially, analyses should be done every year to determine the best interval to use to measure change in woody cover over time.

Trends: Steady decline in number of Juniper-invaded acres, attaining goal of <10% in priority areas, <20% elsewhere.

5. Native vegetation dominates Conservation Prairie (>75% cover; 7,214 remnant acres)

There are numerous standardized methods for assessing vegetation; however, many of them are quite time intensive. Because we need a protocol that is effective but rapid, two approaches come to mind.

Indicators: Proportion classified as predominantly native with increasing or stable trend toward native-dominated.

Methods: Representative sub-sample of the different physical conditions across the landscape for prairies (and high quality restorations). Site selection should be stratified by topography, ownership and dominant soil type at the minimum. Size and shape of prairies might also be considered given these could influence the level of invasive species at a site. A power analysis could be done to determine the number of sites to sample depending on the effect size that we hope to detect, and GIS could be used to identify and select the actual sites.

a. Grassland Monitoring Protocol (see #3) (for overall sense of change in native vs. exotic cover over time within and across sites) developed by TNC, USFWS and MN DNR. This protocol is already being used extensively by partners and would facilitate the sharing and comparing of data across the state. The simple version of the protocol is relatively rapid and is designed to yield a cover of native vegetation at the pasture/field level. If it was desired to make this protocol even more rapid, the indicator species and structural vegetation measurements could be dropped. The belt transect with the categories developed is all you would need to determine the cover of native vegetation. However, if all the data could be collected, this could be contributed to the larger GMT model, which would also help us learn about the impact of management on native prairie condition. The advantage of this is that some of the conservation prairies in both of these landscapes are already being monitored with this protocol by various partners, reducing the number of sites that need to be sampled by any one team. The original project is focused on native prairie, but the protocol can be used on non-native grasslands as well.

b. Extensive Assessment Protocol for Large-Scale Restorations (for better information about species recover across a large planted area). This protocol is better suited for yielding species richness type information instead of cover, but diversity categories are assigned at points along transects and cover of native vegetation could be included in this assessment. Because of the species richness component to this protocol, it is better for assessing success of high diversity restorations as species richness could be compared with richness of seed mixes used to evaluate success.

6. Stable or increasing populations of prairie obligate butterflies

While complete butterfly diversity surveys would take very skilled and experienced individuals in identifying all species of butterflies, it would be possible to choose a few easily identifiable yet grassland obligate species to survey. The primary species we suggest including in all surveys is the Regal Fritillary (*Speyeria idalia*), but which species are surveyed might vary depending on the landscape.

Indicators: Number of individuals of each of 2-3 species of interest
Methods:

a. **-** Due to major declines in prairie butterflies, a survey is getting underway in 2012 (Minnesota Zoo) focusing on visual counts of the abundance of all butterflies with an emphasis on rare and declining species, specifically the Poweshiek Skipperling, Dakota Skipper, Ottoe Skipper, Arogos Skipper, and Regal Fritillary. Researchers will conduct surveys throughout the summer across likely native tallgrass prairie habitats, especially those where today's rare species were once historically abundant. This group met with members of this project on 4/12/2012 and we discussed opportunities to collaborate. The 2012/2013 extensive surveys are geared toward re-locating rare species. We suspect that their findings will point toward areas where we should focus our efforts/Pollard-walk transects in future years to assess effectiveness in our conservation strategies for maintaining butterfly populations and helping them recover.
b. The most common method for conducting butterfly surveys is known as a Pollard count(Pollard 1977). These are essentially transects that are walked weekly to get an abundance estimate for butterflies at a site. Transects are usually walked weekly because they are trying to capture all the species at a site, and therefore, need to cover the summer because different species have different flight times. With just 2-3 species chosen that have similar peak flight times, a survey once during the peak flight time would probably be sufficient over time.

Pollard surveys should be combined with the Grassland Monitoring Team (GMT) transect described in #s 5&3 above. They can be laid out connecting the vegetation transects and could be conducted as the surveyors walk from one transect to the next.

The following components constitute the typical protocol for transects (see Pollard 1977 for further details):

- Done between 11 am and 4 pm – butterflies are most active during the warmest part of the day.
- Transects not usually wider than 5 m on either side
- Transects divided up into habitat segments if habitat associations are of interest
- All species (or 2-3) and individuals are recorded as transect is walked

- An abundance is obtained by summing all individuals of each species seen along the transect (divided by habitat if desired)

7. Ensure key basins (TBD but see map 1) are in 90% compatible land use/cover

This objective was included to address ensure adequate recharge potential, reduce nutrient transport, and lower surface water run-off. Land cover and management generally control the peak flow, volume, and water quality of storm runoff. Natural prairie managed for habitat and biodiversity tends to not only retain rain and snowmelt, but likely stores water deep in the soil profile during drought (Brye et al. 2000).

Indicator: % of each priority basin in compatible land use/cover
Methods:
1. *Key basins* will be selected from watersheds defined by the Minnesota Department of Natural Resources catchment / watershed protocol (Vaughn 2010). Watersheds defined as key basins will be selected through a two-tier stratification, with the 7th defined level in the Minnesota DNR watershed unit hierarchy chosen as smaller units of the broader-scale HUC12 watersheds.

2. *Criteria to select key basins* include (1) grassland cover as a percent of the entire basin area (2) percentage of the basin within the study area project boundary, and (3) potential for effective water quality monitoring (i.e., presence of lakes and permanent streams). Selection will also factor in priority basins identified in the Minnesota Lake Conservation Portfolio (Blann & Cornett 2010) and priority areas for terrestrial protection and restoration within the GL area (Chapter 4). Each of these will be weighted equally, with the first two scored as a fraction ranging from 0 to 1, and potential water quality monitoring assessed as an indicator value of either 1 or 0. The stratified basins with scores in the upper 10 percentile will be selected as the key basins.

3. In the context of this project, *compatible land cover* includes all start and end states in Figure 34 with two exceptions: Crop and Exotic Annuals. Pasture is included as a compatible land use where there is a sufficiently protective buffer, roughly 30 m wide (e.g. Welsch 1991, Castelle et al. 1994), separating grazed areas and stock from streams, lakes, and wetlands. Farmsteads, roads, aggregate pits and excavations, cultivated agricultural land, clear-cut forest, and commercial land use (buildings, towers, parking lots, etc.) are considered *non-compatible.*

4. The key basins selected in the first two steps will be assessed biannually for compatible land use using most recent NAIP or FSA imagery. Results will be field checked, tabulated, and screened for increasing, decreasing, or stable compatible land use.

5. Where practical, key basins will be monitored for basic water quality (total phosphorus, electrical conductivity, suspended sediment or turbidity, and organic carbon)* at the outlets or lowest lake within both HUC12 and DNR level 7 key basins. Sampling and analysis of waters, collected using standard protocol (ASTM or other standard), will be carried out semi-annually (at base-flow conditions in late winter and fall) on a biannual basis.

*rationale: total P should be at concentrations below lake eutrophication threshold, electrical conductivity and suspended sediment should be stable or decreasing, and increasing organic carbon a possible signal of increasing storage of C in basin soils

8. Increase the clarity of 12 shallow lakes (10%) by 33% over the next ten years

Water clarity of selected lakes and ponds will be measured using a Secchi disc or transparency tube (U.S. EPA 2012) twice per year (spring and fall). This simple metric provides a convenient and definitive way to monitor localized effects of increasing compatible land use in the Reconnect project area. This method is straight-forward and opens an opportunity to involve local residents and the public in an effort that will likely establish a greater sense of ownership of the condition of aquatic resources (Carlson and Simpson 1996).

Indicator: Water clarity
Methods: At least 12 shallow lakes (roughly 10% of the lakes in the area) will be selected from key basins for intensive and long-term monitoring of water clarity. Baseline trends of water quality will be obtained from online resources (e.g., MN Lake Finder).
Enlist local residents and land owners as volunteers to regularly monitor water (recruited through public meetings, mailings, TNC's volunteer newsletter, watershed district websites, and word-of-mouth. It may require that 3-4 people be selected per lake to make sure we do not lose critical data because of participant attrition. Yearly recognition might be helpful, such as a dinner, lunch, and lake awards.
Trends: A non-parametric measure of trend, such as the Mann-Kendall test (Gilbert 1987), will be used to relate changes in lake water clarity to effects of this study's land use compatibility measures.

Appendix 3: Restoration Plans

The following restoration plans describe the recommended steps and estimated costs required to achieve the transitions from start to end state, described in Chapter 7 of this report. They represent a summary of information gathered from relevant literature and experienced restoration professionals in Minnesota and the Midwest and are intended to serve as a general guide for restoration planning purposes. Planners can characterize the starting conditions of potential restoration sites, select their restoration target(s), and refer to this guide for the recommended restoration protocols for the given transition. These generalized plans were written for the purpose of landscape-scale planning; conservation planners and Minnesota Prairie Conservation Plan Implementation Teams can characterize potential restoration sites by starting conditions, select their restoration target(s), and use the recommended restoration protocols and costs in this guide to prioritize potential restoration sites and develop reasonable budgets for project implementation. Additionally, these restoration plans will be a useful resource for individual landowners interested in restoring land to utility or conservation prairie and wet meadow. These plans are not site-specific, however, and the precise sequence of restoration actions required will vary by site, budget and specific goals. Thus, when applying these restoration plans and seed mixes to a specific restoration site, we advise land-owners to consult with their local Minnesota Prairie Conservation Plan Implementation teams and restoration service providers for more detailed guidance.

The restoration plans are organized into sets by broad plant community end states ("Upland and Mesic Prairie" and "Wet Prairie and Sedge Meadow"); and within these are plans for each start state to both Utility and Conservation versions of the end state. Following each set of restoration plans, we have provided example seed mixes appropriate for the end states (described in Chapter 7). The individual restoration plans focus primarily on vegetation management and species addition; they include the following restoration phases: Vegetation Removal; Seedbed Preparation; Seeding; and Post-Seeding Management. Additionally, for each restoration plan we have provided a cost estimate (described in Chapter 7) and cited literature resources that will provide more detailed guidance in developing and implementing a restoration plan.

The restoration plans presume that a site assessment will be conducted prior to initiating restoration actions. Characterizing the existing vegetation is required to identify the start state, but additionally, planners should evaluate the site's soil, hydrology, wildlife, land use history, and factors in the surrounding landscape that may impact restoration goals, strategies and outcomes. Site assessment protocol is not included in these restoration guides; general background on conducting site assessments is provided in (Galatowitsch 2012b), and an example site assessment protocol can be found in the Minnesota Native Seed Mix Design tool (MacDonagh and Hallyn 2010). Similarly, general guidelines are suggested for hydrologic restoration in the Wet Meadow restoration plans, but restoration engineering and earth moving are beyond the scope of these restoration plans; we encourage planners to consult with professional restoration service providers or local Soil and Water Conservation District representatives (http://www.maswcd.org) for more information on this aspect of wetland restoration. Additionally, a guide to wetland restoration is forthcoming and will be accessible via the Minnesota Board of Water and Soil Resources website (expected release January 2014). A draft version (currently in review) is available at: http://www.bwsr.state.mn.us/publications/WRG/.

We are grateful to the following restoration professionals, resource managers and scientists who provided information and insights that were invaluable to the development of these restoration plans and seed mixes. In addition to those listed below, we also gained useful information from 17 Minnesota restoration professionals and service providers who generously shared their experiences and advice via the restoration cost estimation summary. Presenters and participants at the 2012 Prairie Restoration Network workshop at Neal Smith National Wildlife Refuge, Prairie City, IA also provided valuable information on restoration strategies for the Upper Midwest.

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Pauline Drobney	US Fish & Wildlife
Stephanie Frischie	The Nature Conservancy/Northwestern University
Matt Graeve	The Nature Conservancy
Fred Harris	Minnesota Dept. of Natural Resources
Larry Hanson	US Fish & Wildlife
Chris Helzer	The Nature Conservancy
Greg Hoch	Minnesota Dept. of Natural Resources
Laura Jackson	University of Northern Iowa
Rhett Johnson	The Nature Conservancy
Justin Meissen	University of Minnesota
Jason Nordmann	The Nature Conservancy
Dennis Pederson	Habitats Forever/Pheasants Forever
Erik Runquist	Minnesota Zoo
Derek Scasta	Oklahoma State University
Dan Shaw	Minnesota Board of Water and Soil Resources
Mark Udstuen	Shooting Star Native Seeds
Brian Winter	The Nature Conservancy
Steve Winter	US Fish & Wildlife
Dave Williams	University of Northern Iowa
Tom Wenzel	Minnesota Board of Water and Soil Resources

A. Upland & Mesic Prairie Transitions

1. Crop to Utility Prairie

a. Vegetation Removal

Vegetation removal is not necessary on annual crop fields, provided restoration is initiated immediately following harvest. If the crop field is left fallow for one or more growing seasons and has become dominated by annual weeds, see Annual Dominated Field to Utility Prairie restoration plan.

b. Seedbed Preparations

Crop fields require little seedbed preparation, unless heavy crop residue is present that might interfere with seeding. Soybean fields are the preferred crop "start state" for restoration, because they are essentially ready to seed (Rowe 2010). The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Williams 2010e). For this utility prairie restoration plan, no-till drills are the assumed seeding method.

Recommended Protocol:

- If light crop residue is present (e.g. soybean field):
    - No site preparation needed if no-till drilling
    - (Lightly harrow if broadcast seeding)
- If heavy crop residue is present (e.g. corn field):
    - Mow stalks
    - Disk site multiple times (3+) to incorporate residue into soil
    - Cultipack if possible
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance may bring weed seeds to the soil surface; herbicide applications may be required prior to native seed establishment (see Annual-Dominated to Utility Prairie restoration plan for more details).

c. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (Rowe 2010, Williams 2010d). This Utility Prairie restoration plan assumes the use of no-till drills; seed drills ensure efficient, even site coverage and good seed-soil contact, and they are particularly effective at seeding native prairie grasses. If a no-till drill is unavailable, broadcast seeding also produces excellent results with a more natural appearance (i.e. no persistent row lines), increased capacity to access difficult site conditions (e.g. rocky soils). Broadcast seeding may be less efficient than drilling; consider increasing the seeding rate, particularly if broadcasting onto slopes or other erodible sites.

Recommended Protocol:

- Drill seeds directly into crop residue (or prepared seedbed) using no-till drill (e.g. Truax)

  - Alternative option: broadcast seeds, then cultipack if possible
- When to seed: any season except summer
  - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
  - Spring seeding promotes warm season grasses
- Design: seed single Utility Prairie seed mix (Table 60) in an even distribution across site provided soil moisture ranges from dry to mesic
  - If soil moisture is highly variable and ranges to wet-mesic/wet, combine mix with Utility Wet Prairie and Utility Wet Meadow mixes (Table 61 and Table 62) as appropriate and seed evenly across site OR seed individual mixes into appropriate seed zones (i.e. "mosaic seeding")
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 40 seeds/sq. foot (8-10 lbs/acre) to reduce risk of weed invasion
  - If minimal weed pressure and excellent site preparation, can reduce to 30 seeds/sq. foot
  - Increase rate to 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Prairie establishment generally takes 3-5 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing, and displacing establishing natives. Annual weeds are the biggest management problem in the early stages of restoration from crop field, as they can quickly overtop and shade prairie seedlings, resulting in decreased growth and survival. Frequent mowing can prevent annuals from forming a dense canopy and building up thatch that can further suppress native seedlings (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

Year 2:

- Mow field to 12-inch height every 1-2 months, or as needed.
- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses have achieved dominance.
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 3-4 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat

- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody invasions continue to increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Crop start state to Utility Prairie end state is $801 per acre (Figure 36). This cost estimate assumes the site is seeded with a no-till drill, and post-seeding management includes a total of eight mowing treatments and a controlled burn on each of two management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

2. Crop to Conservation Prairie

a. Vegetation Removal

Vegetation removal is not necessary on annual crop fields, provided restoration is initiated immediately following harvest. If the crop field is left fallow for one or more growing seasons and has become dominated by annual weeds, see Annual Dominated Field to Utility Prairie restoration plan.

b. Seedbed Preparations

Crop fields require little seedbed preparation, unless heavy crop residue is present that might interfere with seeding. Soybean fields are the preferred crop "start state" for restoration, because they are essentially ready to seed (Rowe 2010). The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Williams 2010e). This conservation prairie restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- If light crop residue is present (e.g. soybean field):
    - Lightly harrow (e.g. with spike tooth harrow)
    - (No site preparation needed if frost seeding or no-till drilling)
- If heavy crop residue is present (e.g. corn field):
    - Mow stalks
    - Disk site multiple times (3+) to incorporate residue into soil
    - Cultipack if possible
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance may bring weed seeds to the soil surface; herbicide applications may be required prior to native seed establishment (see Annual-Dominated to Conservation Prairie restoration plan for more details).

c. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using a spreader mounted to a tractor or ATV (Rowe 2010, Williams 2010d). Broadcast seeding is typically recommended for conservation prairies, because it produces a more natural appearance (no persistent rows) and favors forb species, which contribute much of the diversity and cost in a conservation mix. Broadcasting equipment is also easy to operate and maintain, and allows access into difficult site conditions (e.g. rocky or uneven soils) and is more conducive to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. No-till drills, on the other hand, provide efficient site coverage, excellent seed-soil contact, and are particularly effective for seeding prairie grasses. Some practitioners opt to drill in grass seeds, and then broadcast forb seeds over the drilled seed bed, or even open the drill seed tubes that contain the forbs and allow them to essentially broadcast while drilling the grasses (P. Bockenstedt, personal communication). If drills are used to seed conservation prairies, the persistence of drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d).

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost seeding (late fall/early winter), snow seeding (late winter/early spring) or ash seeding (sowing into ash immediately following a burn), mechanical incorporation may not be needed; freeze-thaw, snowmelt- and rainfall action may naturally incorporate seeds into the soil.
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
    - Spring seeding promotes warm season grasses
- Design: use mosaic seeding design to tailor seed mixes to their most suitable site conditions to prevent costly seed losses, e.g. sow dry conservation prairie mix (Table 63 or Table 65) onto dry ridge tops and a mesic mix (Table 64 or Table 66) into mesic soil conditions.
    - Note: if the site is relatively homogeneous (e.g. either dry or mesic soils throughout), a single seed mix can be sown evenly across the site.
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in “nodes” located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
- Seed rate: minimum 40-60 seeds/sq. foot (10-12 lbs/acre); as high as 100 seeds/sq. foot
    - Minimum 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Establishment of a diverse conservation prairie with typically takes 5-7 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing, and displacing establishing natives. Annual weeds are the biggest management problem in the early stages of restoration from crop field, as they can quickly overtop and shade prairie seedlings, resulting in decreased growth and survival. Frequent mowing can prevent annuals from forming a dense canopy and building up thatch that can further suppress native seedlings (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

Year 2:

- Mow field to 12-inch height every 1-2 months, or as needed.
- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- To promote rapid establishment of prairie species, may burn at an interval of 1-2 years from years 3-5 (optional); thereafter burn at an interval of 3-5 years.
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Crop start state to Conservation Prairie end state is $1506 per acre (Figure 36). This cost estimate assumes the site is harrowed, broadcast-seeded and cultipacked; post-seeding management includes a total of eight mowing treatments and a controlled burn on each of three management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

3. Exotic Annual-Dominated Field to Utility Prairie

a. Vegetation Removal

Annual weeds are common in disturbed sites, such as fallow crop fields. If not properly managed, annual weeds can overtop and shade newly planted prairie seedlings, resulting in reduced survival and growth (Williams et al. 2007). Controlling annual weeds and reducing their seed bank prior to seeding and in the early establishment phase will typically result in faster and more complete establishment of planted natives. Annual weeds are commonly controlled with combinations of mowing/burning and herbicide applications (Williams 2010e).

Recommended Protocol:

- Burn (if fuel load is sufficient to carry a fire) or mow site to remove thatch
- When weed regrowth reaches 4-6 inches (2-4 weeks), apply appropriate herbicide, e.g. glyphosate
    - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
- Reapply herbicide (broadcast or spot-treatment) to remaining green vegetation after 2 weeks
- Wait at least another 2 weeks to seed
- Alternate option: harrow or disk the site to bring seeds to soil surface and then apply repeated herbicide applications to emerging vegetation and regrowth.
    - This risks bringing the seeds of additional undesired species (e.g. invasive perennials) to the soil as well.
    - Not recommended for highly erodible sites

b. Seedbed Preparations

The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Williams 2010e). For this utility prairie restoration plan, no-till drills are the assumed seeding method.

Recommended Protocol:

- No site preparation is needed if seeding with no-till drill, unless:
    - If soil surface is uneven (e.g. numerous soil clods), lightly harrow to create a smoother surface for drilling
    - If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance will likely result in a flush of annual weeds, as seeds are brought to the soil surface; additional herbicide applications may be required prior to native seed establishment.

  - If the site was not burned to remove thatch (e.g. due to insufficient fuel), tilling, disking and harrowing can be used to clear and smooth the seedbed.

c. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (Rowe 2010, Williams 2010d). This Utility Prairie restoration plan assumes the use of no-till drills; seed drills ensure efficient, even site coverage and good seed-soil contact, and they are particularly effective at seeding native prairie grasses. If a no-till drill is unavailable, broadcast seeding also produces excellent results with a more natural appearance (i.e. no persistent row lines), increased capacity to access difficult site conditions (e.g. rocky soils). Broadcast seeding may be less efficient than drilling; consider increasing the seeding rate, particularly if broadcasting onto slopes or other erodible sites.

Recommended Protocol:

- Drill seeds with no-till drill (e.g. Truax)
  - Alternative option: broadcast seeds (then cultipack if possible)
- When to seed: any season except summer
  - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
  - Spring seeding promotes warm season grasses
- Design: seed single Utility Prairie mix (Table 60) in an even distribution across site provided soil moisture ranges from dry to mesic
  - If soil moisture is highly variable and ranges to wet-mesic/wet, combine mix with Utility Wet Prairie and Utility Wet Meadow mixes (Table 61 and Table 62) as appropriate and seed evenly across site OR seed individual mixes into appropriate seed zones (i.e. “mosaic seeding”)
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 40 seeds/sq. foot (8-10 lbs/acre) to reduce risk of weed invasion
  - If minimal weed pressure and excellent site preparation, can reduce to 30 seeds/sq. foot
  - Increase rate to 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Prairie establishment generally takes 3-5 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing, and displacing establishing natives. Reinvading annual weeds are the biggest management problem in the early stages of restoration from an annual-dominated field; they can quickly overtop and shade prairie seedlings, resulting in decreased growth and survival. Frequent mowing can prevent annuals from forming a dense canopy and building up thatch that can further suppress native seedlings (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

Year 2:

- Mow field to 12-inch height every 1-2 months, or as needed.
- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses have achieved dominance.
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 4 & Beyond:
Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs

- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 3-4 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
  - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining
  - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
  - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
  - Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody invasions continue to increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Annual-Dominated Field start state to Utility Prairie end state is $983 per acre (Figure 36). This cost estimate assumes vegetation removal includes two broadcast herbicide applications and one mowing treatment; the site is seeded with a no-till drill; post-seeding management includes a total of eight mowing treatments and a controlled burn on each of two management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

4. Exotic Annual-Dominated Field to Conservation Prairie

a. Vegetation Removal

Annual weeds are common in disturbed sites, such as fallow crop fields. If not properly managed, annual weeds can overtop and shade newly planted prairie seedlings, resulting in reduced survival and growth (Williams et al. 2007). Controlling annual weeds and reducing their seed bank prior to seeding and in the early establishment phase will typically result in faster and more complete establishment of planted natives. Annual weeds are commonly controlled with combinations of burning/mowing and herbicide applications (Williams 2010e).

Recommended Protocol:

- Burn site to remove thatch (if fuel load is insufficient to carry a fire, mow instead)
- When weed regrowth reaches 4-6 inches (2-4 weeks), apply appropriate herbicide, e.g. glyphosate
    - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
- Reapply herbicide (broadcast or spot-treatment) to remaining green vegetation after 2 weeks
- For maximum weed control, repeat herbicide applications as needed throughout growing season
- Wait 2 weeks following last herbicide application to seed
- Alternate option: harrow or disk the site to bring seeds to soil surface and then apply repeated herbicide applications to emerging vegetation and regrowth.
    - This risks bringing the seeds of additional undesired species (e.g. invasive perennials) to the soil as well.
    - Not recommended for highly erodible sites

b. Seedbed Preparations

The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Williams 2010e). This conservation prairie restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Lightly harrow site (e.g. with a spike-tooth harrow) to loosen the soil and remove thatch
- If site was burned (thatch removed) and if planning to frost-seed, no site preparation is necessary
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance will likely result in a flush of annual weeds, as seeds are brought to the soil surface; additional herbicide applications may be required prior to native seed establishment.

C. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using a spreader mounted to a tractor or ATV (Rowe 2010, Williams 2010d). Broadcast seeding is typically recommended for conservation prairies, because it produces a more natural appearance (no persistent rows) and favors forb species, which contribute much of the diversity and cost in a conservation mix. Broadcasting equipment is also easy to operate and maintain, and allows access into difficult site conditions (e.g. rocky or uneven soils) and is more conducive to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. No-till drills, on the other hand, provide efficient site coverage, excellent seed-soil contact, and are particularly effective for seeding prairie grasses. Some practitioners opt to drill in grass seeds, and then broadcast forb seeds over the drilled seed bed, or even open the drill seed tubes that contain the forbs and allow them to essentially broadcast while drilling the grasses (P. Bockenstedt, personal communication). If drills are used to seed conservation prairies, the persistence of drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d).

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost seeding (late fall/early winter), snow seeding (late winter/early spring) or ash seeding (sowing into ash immediately following a burn), mechanical incorporation may not be needed; freeze-thaw, snowmelt- and rainfall action may naturally incorporate seeds into the soil.
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
    - Spring seeding promotes warm season grasses
- Design: use mosaic seeding design to tailor seed mixes to their most suitable site conditions to prevent costly seed losses, e.g. sow dry conservation prairie mix (Table 63 or Table 65) onto dry ridge tops and a mesic mix (Table 64 or Table 66) into mesic soil conditions.
    - Note: if the site is relatively homogeneous (e.g. either dry or mesic soils throughout), a single seed mix can be sown evenly across the site.
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in “nodes” located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.

- Seed rate: minimum 40-60 seeds/sq. foot (10-12 lbs/acre); as high as 100 seeds/sq. foot
  - Minimum 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Establishment of a diverse conservation prairie with typically takes 5-7 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing, and displacing establishing natives. Reinvading annual weeds are the biggest management problem in the early stages of restoration from an annual-dominated field; they can quickly overtop and shade prairie seedlings, resulting in decreased growth and survival. Frequent mowing can prevent annuals from forming a dense canopy and building up thatch that can further suppress native seedlings (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

Year 2:

- Mow field to 12-inch height every 1-2 months, or as needed.
- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- To promote rapid establishment of prairie species, may burn at an interval of 1-2 years from years 3-5; thereafter burn at an interval of 3-5 years.
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Annual-Dominated Field start state to Conservation Prairie end state is $1707 per acre (Figure 36). This cost estimate assumes vegetation removal includes two broadcast herbicide applications and one controlled burn; the site is broadcast-seeded and cultipacked; post-seeding management includes a total of eight mowing treatments and a controlled burn on each of three management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

5. Invasive Perennial-Dominated Grassland to Utility Prairie

a. Vegetation Removal

Unmanaged invasive perennials (e.g. reed canary grass, birdsfoot trefoil, smooth brome) can outcompete even otherwise dominant native prairie species. Thorough and repeated control is critical prior to planting in order to minimize re-invasion, particularly because post-seeding control methods can negatively impact planted natives. The significant control effort and costs required to produce a successful restoration outcome may be unfeasible for some project areas. When possible, many practitioners prefer instead to crop the fields for 2-3 years prior to initiating restoration, in order to exhaust the seed/rhizome bank and essentially convert the site from an extremely difficult restoration start state to the relatively easy cropland start state (Rowe 2010). Otherwise, the most common approach to control of invasive perennials is repeated herbicide applications combined with mowing/haying or burning to remove thatch (Williams 2010e). The frequency of herbicide applications required will depend on the vigor and persistence of the invasive species; for example, for a weak stand of smooth brome growing in sub-optimal conditions, a single herbicide application may provide a sufficient level of control. In most cases, however, a minimum of two herbicide applications is recommended prior to seeding. The better the pre-seeding control achieved, the less long-term management will be required in the post-establishment phase and beyond. We recommend a minimum of one full growing season of invasion control prior to seeding Utility Prairie.

Recommended Protocol:

- Mow/hay (to 4 in. height) or burn site in spring or early summer
- When weed regrowth reaches 4-6 inches (2-4 weeks), apply appropriate herbicide, e.g. glyphosate (broadcast application, i.e. with tractor-mounted boom sprayer)
    - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
- Repeat herbicide applications (broadcast or spot-treatment) to regrowth monthly or as needed throughout the summer and into early fall
- Wait at least 2 weeks following last herbicide application to seed
- If invasive woody species are present, see "Woody-invaded Prairie to Utility Prairie restoration plan; saplings < ½ in. diameter can be herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- If reed canary grass (*Phalaris arundinacea*) is present, apply glyphosate in September for maximum effect (Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Jacobson 2006); see Invasive Perennial-Dominated Grassland to Utility Meadow for more information.
- Alternate option 1: Crop field for 1-4 years to deplete invasive perennial seed bank, ending on a rotation of Roundup Ready soybeans; then refer to Crop to Utility Prairie Restoration Plan

- Alternate option 2: after spring mowing/burn, and herbicide application, disk the site repeatedly (every 3-4 weeks) throughout the growing season to maximize control of invasive perennial rhizomes; follow with additional herbicide applications as needed
    - This risks bringing additional invasive seeds and rhizomes to the soil surface and should be done in conjunction with multiple herbicide treatments to control regrowth
    - Not recommended for highly erodible sites

b. Seedbed Preparations

The appropriate method of seedbed preparation in an invasive perennial-dominated site is influenced by the site conditions, the amount of resources available for continued vegetation management, and the intended seeding method (Williams 2010e). If the soil surface is uneven or severely compacted, harrowing or disking may be required to prepare the site, which often results in a flush of new invasive perennial growth, as seeds and rhizomes are brought to the soil surface. If such soil cultivation is required, invasive perennial regrowth should be treated with repeated herbicide applications prior to native seedling establishment. Alternatively, several rounds of deep tillage may be used intentionally to break up rhizomes and bring them to the surface for winter kill (Morgan 1997). Whenever possible, however, most practitioners prefer to avoid soil disturbance to prevent bringing seeds and rhizomes to the soil surface and minimize both reinvasion and the need for continued intensive management. For this utility prairie restoration plan, no-till drills are the assumed seeding method.

Recommended Protocol:

- No site preparation is needed if seeding with no-till drill, unless:
    - If soil surface is too uneven for effective drilling (e.g. numerous soil clods), lightly harrow to create a smoother surface; treat invasive regrowth with repeated herbicide applications prior to native seedling establishment
    - If soils are severely compacted, multiple rounds of tilling and disking (4-inch depth) may be used to loose soil and break up invasive rhizomes; finish soils by harrowing to break up soil clods; treat invasive regrowth with repeated herbicide applications prior to native seedling establishment.

c. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (Rowe 2010, Williams 2010d). This Utility Prairie restoration plan assumes the use of no-till drills; seed drills ensure efficient, even site coverage and good seed-soil contact, and they are particularly effective at seeding native prairie grasses. If a no-till drill is unavailable, broadcast seeding also produces excellent results with a more natural appearance (i.e. no persistent row lines), increased capacity to access difficult site conditions (e.g. rocky soils). Broadcast seeding may be less efficient than drilling; consider increasing the seeding rate, particularly if broadcasting onto slopes or other erodible sites.

Recommended Protocol:

- Drill seeds with no-till drill (e.g. Truax)
  - Alternative option: broadcast seeds (then cultipack if possible)
- When to seed: any season except summer
  - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
  - Spring seeding promotes warm season grasses
- Design: seed single Utility Prairie mix (Table 60) in an even distribution across site provided soil moisture ranges from dry to mesic
  - If soil moisture is highly variable and ranges to wet-mesic/wet, combine mix with Utility Wet Prairie and Utility Wet Meadow mixes (Table 61 and Table 62) as appropriate and seed evenly across site OR seed individual mixes into appropriate seed zones (i.e. "mosaic seeding")
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 40 seeds/sq. foot (8-10 lbs/acre) to reduce risk of weed invasion
  - Increase rate to 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Prairie establishment generally takes 3-5 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing, and displacing establishing natives. Maintaining control of invasive perennials is the primary management concern in restorations from invasive perennial-dominated fields; annual weeds may also rapidly colonize the restoration site and suppress native seedling establishment (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives (e.g. dormant season application; spot-treatment with backpack sprayer or wick applicator; avoid applying on windy days to prevent drift)

Year 2:

- Mow field to 12-inch height every 1-2 months, or as needed.
- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.
- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses have achieved dominance.
- Mowing should no longer be needed; spot-treat invasive perennials as necessary
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 3-4 year burn rotation (Smith 2010a).

- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
  - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining
  - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
  - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
  - Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody invasions continue to increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Invasive Perennial-Dominated Grassland start state to Utility Prairie end state is $1172 per acre (Figure 36). This cost estimate assumes vegetation removal includes two broadcast herbicide applications and one mowing treatment; the site is seeded with a no-till drill; post-seeding management includes a total of eight mowing treatments, two selective herbicide treatments (spot-spray), and a controlled burn on each of two management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

6. Invasive Perennial-Dominated Grassland to Conservation Prairie

a. Vegetation Removal

Unmanaged invasive perennials (e.g. reed canary grass, birdsfoot trefoil, smooth brome) can outcompete even otherwise dominant native prairie species. Thorough and repeated control is critical prior to planting in order to minimize re-invasion, particularly because post-seeding control methods can negatively impact planted natives. This is especially important for conservation prairies; seeding diverse and costly seed mixes is not advised if there are insufficient funds for thorough and complete invasion control. When planning a restoration from the invasive perennial-dominated start state, the level of vegetation management anticipated should be proportional to the quality, diversity and cost of the seed mix to be planted. The significant control effort and costs required to produce a successful restoration outcome may be unfeasible for some project areas. When possible, many practitioners prefer instead to crop the fields for 2-3 years prior to initiating restoration, in order to exhaust the seed/rhizome bank and essentially convert the site from an extremely difficult restoration start state to the relatively easy cropland start state (Rowe 2010). Otherwise, the most common approach to control of invasive perennials is repeated herbicide applications combined with mowing/haying or burning to remove thatch (Williams 2010e). The frequency of herbicide applications required will depend on the vigor and persistence of the invasive species; for example, for a weak stand of smooth brome growing in sub-optimal conditions, a single herbicide application may provide a sufficient level of control. In most cases, however, a minimum of two herbicide applications is recommended prior to seeding. The better the pre-seeding control achieved, the less long-term management will be required in the establishment phase and beyond. We recommend a minimum of two full growing seasons of invasion control prior to seeding Conservation Prairie.

Recommended Protocol:

Year 1:

- Burn site in spring or early summer
    - If burning is not possible, mow to remove thatch instead
- When weed regrowth reaches 4-6 inches (2-4 weeks), apply appropriate herbicide, e.g. glyphosate (broadcast application, i.e. with tractor-mounted boom sprayer)
    - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
- Repeat herbicide applications (broadcast or spot-treatment) to regrowth monthly, or as needed, throughout the summer and into early fall

Year 2:

- Repeat the spring burn and repeated spraying sequence above monthly or as necessary throughout the growing season
- Wait at least 2 weeks following last herbicide application to seed

Additional notes:

- If invasive woody species are present, see "Woody-invaded Prairie to Utility Prairie restoration plan; saplings < ½ in. diameter can be herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- If reed canary grass (*Phalaris arundinacea*) is present, apply glyphosate in September for maximum effect (Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Jacobson 2006); see Invasive Perennial-Dominated Grassland to Utility Meadow for more information.
- Alternate option 1: Crop field for 1-4 years to deplete invasive perennial seed bank, ending on a rotation of Roundup Ready soybeans; then refer to Crop to Utility Meadow Restoration Plan
- Alternate option 2: after spring burn, and herbicide application, disk the site repeatedly (every 3-4 weeks) throughout the growing season to maximize control of invasive perennial rhizomes; follow with additional herbicide applications as needed
    - Risks bringing additional invasive seeds and rhizomes to the soil surface; best results if part of a comprehensive, long-term approach to invasion control with a minimum of two seasons of repeated disking, herbicide applications and burns
    - Not recommended for highly erodible sites.

b. Seedbed Preparations

The appropriate method of seedbed preparation in an invasive perennial-dominated site is influenced by the site conditions, the amount of resources available for continued vegetation management, and the intended seeding method (Williams 2010e). If the soil surface is uneven or severely compacted, harrowing or disking may be required to prepare the site, which often results in a flush of new invasive perennial growth, as seeds and rhizomes are brought to the soil surface. If such soil cultivation is required, invasive perennial regrowth should be treated with repeated herbicide applications prior to native seedling establishment. Alternatively, several rounds of deep tillage may be used intentionally to break up rhizomes and bring them to the surface for winter kill (Morgan 1997). Whenever possible, however, most practitioners prefer to avoid soil disturbance to prevent bringing seeds and rhizomes to the soil surface and minimize both reinvasion and the need for continued intensive management. This conservation prairie restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Forgo site preparation to minimize soil disturbance and subsequent reinvasion (frost-seeding, snow seeding or ash seeding may help incorporate seeds into soil). Exceptions:
    - If soil surface is very uneven (e.g. numerous soil clods), lightly harrow to create a smoother surface; treat invasive regrowth with repeated herbicide applications prior to native seedling establishment

- If soils are severely compacted, multiple rounds of tilling and disking (4-inch depth) may be used to loose soil and break up invasive rhizomes; finish soils by harrowing to break up soil clods; treat invasive regrowth with repeated herbicide applications prior to native seedling establishment.

c. Seeding

Upland prairies may be seeded either using a no-till drill or broadcasting using a spreader mounted to a tractor or ATV (Rowe 2010, Williams 2010d). Broadcast seeding is typically recommended for conservation prairies, because it produces a more natural appearance (no persistent rows) and favors forb species, which contribute much of the diversity and cost in a conservation mix. Broadcasting equipment is also easy to operate and maintain, and allows access into difficult site conditions (e.g. rocky or uneven soils) and is more conducive to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. No-till drills, on the other hand, provide efficient site coverage, excellent seed-soil contact, and are particularly effective for seeding prairie grasses. Some practitioners opt to drill in grass seeds, and then broadcast forb seeds over the drilled seed bed, or even open the drill seed tubes that contain the forbs and allow them to essentially broadcast while drilling the grasses (P. Bockenstedt, personal communication). If drills are used to seed conservation prairies, the persistence of drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d).

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost seeding (late fall/early winter), snow seeding (late winter/early spring) or ash seeding (sowing into ash immediately following a burn), mechanical incorporation may not be needed; freeze-thaw, snowmelt- and rainfall action may naturally incorporate seeds into the soil.
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
    - Spring seeding promotes warm season grasses
- Design: use mosaic seeding design to tailor seed mixes to their most suitable site conditions to prevent costly seed losses, e.g. sow dry conservation prairie mix (Table 63 or Table 65) onto dry ridge tops and a mesic mix (Table 64 or Table 66) into mesic soil conditions.
    - Note: if the site is relatively homogeneous (e.g. either dry or mesic soils throughout), a single seed mix can be sown evenly across the site.

    - If some forb seed quantities are insufficient to seed entire site, cluster these species in "nodes" located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
- Seed rate: minimum 40-60 seeds/sq. foot (10-12 lbs/acre); as high as 100 seeds/sq. foot
    - Minimum 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Post-Seeding Management

Establishment of a diverse conservation prairie with typically takes 5-7 years but will vary depending on soil moisture and climate conditions. Early management is critical to preventing re-invading weeds and woody species from out-competing and displacing establishing natives. Maintaining control of invasive perennials is the primary management concern in restorations from invasive perennial-dominated fields; annual weeds may also rapidly colonize the restoration site and suppress native seedling establishment (Williams et al. 2007, Williams 2010c). Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Management strategies include mowing annual weeds (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1: Mow field to a height of 4-6 inches every 3-4 weeks, or when annual weed canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

- Locate and spot-treat invasive perennials using either hand-pulling or selective herbicide application methods that minimize damage to natives (e.g. dormant season application; spot-treatment with backpack sprayer or wick applicator; avoid applying on windy days to prevent drift)

Year 2: Mow field to 12-inch height every 1-2 months, or as needed.

- If annual weeds are limited to individual patches, may spot-mow (e.g. with string trimmer) instead of mowing whole field.
- If there is flush of annual/biennial noxious weeds (e.g. Canada thistle; Wild Parsnip), mow, pull, or spot-treat prior to flowering to prevent seed-set.
- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- To promote rapid establishment of prairie species, may burn at an interval of 1-2 years from years 3-5; thereafter burn at an interval of 3-5 years.
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Invasive Perennial-Dominated Grassland start state to Conservation Prairie end state is $2084 per acre (Figure 36). This cost estimate assumes vegetation removal includes four broadcast herbicide applications and two controlled burns (whole site); the site is broadcast-seeded and cultipacked; post-seeding management includes a total of eight mowing treatments, three selective herbicide treatments (spot-spray), and a controlled burn on each of three management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

7. Mixed Native & Invasive Grassland to Utility Prairie

a. Vegetation Removal

For the Mixed Native & Invasive Grassland start state (i.e. invaded, low-diversity prairie), the primary challenge of vegetation removal is to control aggressive invasive perennials with minimal harm to the existing native vegetation. If the native vegetation includes only a few very competitive native species, it may also be important to reduce their cover of these species to allow for the addition of new species and increase the site's diversity vegetation management will free existing sub-dominant natives from competition and open microsites for native seed establishment. Management will typically include a fall burn or mowing and selective vegetation removal or disturbance to allow interseeded natives to establish (Williams 2010e, MN BWSR 2012a). When invasive species are minimal, it is possible to dormant-seed directly into recently-burned soils and conduct all vegetation management as repeated mowing during the seedling establishment phase (Williams et al. 2007). Direct interseeding is quick and cheap, though establishment may be delayed and reduced due to competition from dominant vegetation, and invasive species may persist for many years (Williams 2010e). When invasive species are present on site, as in the mixed native-invasive grassland start state, we recommend controlling these species prior to seeding to prevent their further spread and minimize impacts to planted native species.

Recommended Protocol:

- Burn (spring or fall) or mow/hay (summer) entire site to remove thatch
- When regrowth of invasive perennials reaches 4-6 in. height, selectively treat with appropriate herbicide (e.g. glyphosate)
    - To minimize damage to natives, herbicide can be "spot-sprayed" into larger patches using ATV-mounted sprayers; applied to smaller patches with backpack sprayers; or applied with a wicking device to individual plants.
    - When possible, dormant-season applications of herbicide can be applied to cool-season exotics without damaging warm-season native grasses (MN BWSR 2012a); caution is advised if native cool-season grasses and sedges are present on site.
    - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
- Repeat selective herbicide application when invasive perennial vegetation regrowth again reaches 4-6 in. height.
- Wait at least 2 weeks following last herbicide application to seed
- If invasive woody species are present, see "Woody-invaded Prairie to Utility Prairie restoration plan; saplings < ½ in. diameter can be burned or herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- If reed canary grass (*Phalaris arundinacea*) is present, apply glyphosate in September for maximum effect (Adams and Galatowitsch 2004, Adams and Galatowitsch 2006,

Jacobson 2006); see Invasive Perennial-Dominated Grassland to Utility Meadow for more information.

- Alternate approach: lightly disk 25-50% of the site to 4-in. depth in nodes or strips to reduce competition from both invasive perennials and dominant natives (Grygiel et al. 2009, Williams 2010e).
    - Caution: soil disturbance risks bringing additional invasive species seeds to the surface, which can result in an even greater invasion problem.
- Cropping is not recommended for Mixed Native-Invasive Grassland start states.

b. Seedbed Preparations

When interseeding into existing vegetation, seedbed preparations are often minimized to avoid disturbing established natives and bringing additional weed seeds and rhizomes to the soil surface. If invasive species are minimal, selective disking or tilling (i.e. in nodes or strips covering 25-50% of the site) is sometimes used to reduce competition from established natives (Grygiel et al. 2009, Williams 2010e). However, in an invaded site with mixed natives and invasive species present, we recommend avoiding soil disturbance and instead drilling seeds into newly burned ground after a spring or fall burn (Williams 2010e, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn or mow prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Upland prairies may be interseeded either using a no-till drill or broadcasting using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (Rowe 2010, Williams 2010d, MN BWSR 2012a). This Utility Prairie restoration plan assumes the use of no-till drills; seed drills ensure efficient, even site coverage and good seed-soil contact, and they are particularly effective at seeding native prairie grasses. However, drilling into an untilled site can be hard on the drill; if the site is very rough, rocky or has numerous gopher mounds, the equipment wear and tear may outweigh the efficiency of drilling, in which case broadcast seeding may be a better alternative. Broadcast seeding also produces excellent results with a more natural appearance (i.e. no persistent row lines), although it may be less efficient than drilling; consider increasing the seeding rate, particularly if broadcasting onto slopes or other erodible sites. (See Mixed Native-Invasive Grassland to Conservation Prairie restoration plan for more details on broadcast seeding.)

Recommended Protocol:

- Drill seeds into existing vegetation with no-till drill (e.g. Truax) following a burn or mowing to remove thatch
    - Alternative option: broadcast seeds

- When to seed: any season except summer
  - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
  - Spring seeding promotes warm season grasses
- Design: seed single Utility Prairie mix (Table 60) in an even distribution across site provided soil moisture ranges from dry to mesic
  - If soil moisture is highly variable and ranges to wet-mesic/wet, combine mix with Utility Wet Prairie and Utility Wet Meadow mixes (Table 61 and Table 62) as appropriate and seed evenly across site OR seed individual mixes into appropriate seed zones (i.e. "mosaic seeding")
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009), rest paddocks (Jackson 1999), or bare patches resulting from invasive species removal.
- Seed rate: minimum 40 seeds/sq. foot (8-10 lbs/acre)
  - Increase rate to 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are not recommended for interseeding

d. Post-Seeding Management

Interseeded prairie species will require at least 3-5 years to establish, depending on competitive pressure, soil moisture and climate conditions. Early management is critical to reduce competition from existing vegetation and prevent reinvasion of weeds and woody species that might otherwise displace establishing natives. Maintaining control of invasive perennials is the primary management concern in restorations from invaded low-diversity prairies; however, existing native vegetation should also be carefully managed to promote rapid establishment of planted natives. Management strategies include frequent mowing or haying to reduce competition (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c, MN BWSR 2012a), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:
Year 1:

- Mow vegetation to a height of 4-6 inches weekly to bimonthly to reduce competition from established natives and minimize thatch build-up.
- OR: Hay the site monthly (removing mowed material to prevent thatch build-up); expect low yields.

- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives (e.g. dormant season application; spot-treatment with backpack sprayer or wick applicator; avoid applying on windy days to prevent drift)

Year 2:

- Mow/hay field to 12-inch height twice, once in late spring, and again in mid-summer
- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses have achieved dominance.
- Mowing should no longer be needed for vegetation control; spot-treat invasive perennials as necessary
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 3-4 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses

- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining
  - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
  - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
  - Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody invasions continue to increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Mixed Native-Invasive Grassland start state to Utility Prairie end state is $1306 per acre (Figure 36). This cost estimate assumes vegetation removal includes two selective herbicide applications and one controlled burn (whole site); the site is seeded with a no-till drill; post-seeding management includes a total of ten mowing treatments, two selective herbicide treatments (spot-spray), and a controlled burn on each of two management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

8. Mixed Native & Invasive Grassland to Conservation Prairie

a. Vegetation Removal

When restoring invaded prairie remnants, the primary challenge of vegetation removal is to control aggressive invasive perennials with minimal harm to the existing native vegetation. If the native vegetation includes only a few very competitive native species, it may also be important to reduce their cover of these species to allow for the addition of new species and increase the site's diversity. Vegetation management will free existing sub-dominant natives from competition and open microsites for native seed establishment. Management will typically include a fall burn or mowing and selective vegetation removal to allow interseeded natives to establish (Williams 2010e, MN BWSR 2012a). When invasive species are minimal, it is possible to dormant-seed directly into recently-burned soils and conduct all vegetation management as repeated mowing during the seedling establishment phase (Williams et al. 2007). Direct interseeding is quick, cheap, and minimally disruptive to remnant natives, but seedling establishment may be delayed and reduced due to competition from dominant vegetation, and invasive species may persist for many years (Williams 2010e). An intriguing non-chemical approach to vegetation management currently being tested at Fermi National Accelerator Laboratory (IL) is sowing native hemiparasites (e.g. *Castilleja* spp.; *Commandra* spp.) to reduce the cover of dominant native grasses and create gaps for forb establishment (R. Campbell, personal communication). Due to limitations in seed availability, this method is probably not feasible at large scales, but could be considered in sensitive locations where herbicide poses too great a risk to species of high conservation value. When invasive species are abundant on site, as in the mixed native-invasive grassland start state, we recommend chemically controlling these species prior to seeding to prevent their further spread and minimize impacts to planted native species.

Recommended Protocol:

- Divide remnant into multiple burn units in order to preserve local habitat refugia for resident wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002); avoid burning more than ½ of the site in any one season.
- On each management unit, conduct the following sequence:
- Burn management unit in spring or fall to remove thatch
- When regrowth of invasive perennials reaches 4-6 in. height, selectively treat with appropriate herbicide (e.g. glyphosate)
    - To minimize damage to natives, herbicide can be "spot-sprayed" into larger patches using ATV-mounted sprayers; applied to smaller patches with backpack sprayers; or applied with a wicking device to individual plants.
    - When possible, dormant-season applications of herbicide can be applied to cool-season exotics without damaging warm-season native grasses (MN BWSR

2012a); caution is advised if native cool-season grasses and sedges are present on site.
  - See (Williams 2010e) and (Solecki 1997) for lists of recommended herbicides
  - In highly sensitive sites, and/or if sufficient labor is available, consider hand-pulling invasive species to minimize non-target effects.
- Repeat selective herbicide application when invasive perennial vegetation regrowth again reaches 4-6 in. height.
- Wait at least 2 weeks following last herbicide application to seed
- If invasive woody species are present, see "Woody-invaded Prairie to Conservation Prairie restoration plan; saplings < ½ in. diameter can be burned or herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- If reed canary grass (*Phalaris arundinacea*) is present, apply glyphosate in September for maximum effect (Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Jacobson 2006); see Invasive Perennial-Dominated Grassland to Conservation Meadow for more information.
- Cropping and disking should NOT be used on native remnants! Avoid soil disturbance.

b. Seedbed Preparations

When interseeding remnants, seedbed preparations are minimized to avoid disturbing native soil communities and established natives, and to prevent bringing additional weed seeds and rhizomes to the soil surface. Native remnants should never be tilled or disked; instead, seeds should be broadcast directly into established vegetation following a burn (Smith 2010b, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Seeding prairie remnants should be undertaken with caution to avoid negatively impacting remnant vegetation, soil communities, and wildlife (Smith 2010b, MN BWSR 2012a). Seed mixes should be tailored specifically to the site to avoid introducing aggressive species that may outcompete existing vegetation; in general, species already present on site should not be planted unless the seed is harvested on site. Whenever possible, locally-harvested seed should be used, and species selection should be based on historical records and/or reference sites. We have provided example conservation prairie seed mixes with this restoration plan (Table 63–Table 66) with the expectation that species already present on a given site (or not appropriate for a given site) will be eliminated from the list; relative rates of conservative to common species will be increased; and locally-harvested seeds will be prioritized over commercially-produced seed.

Upland prairie remnants may be interseeded either by no-till drill or broadcasting with a spreader mounted to a tractor or ATV, or by hand (Rowe 2010, Smith 2010b, Williams 2010d, MN BWSR 2012a). However, broadcasting is the preferred seeding method for remnant prairies because it minimizes soil disturbance, produces a more natural appearance, allows for selectively seeding and favors forb species, which contribute much of the diversity and cost in a conservation mix. Broadcasting also allows access into difficult site conditions (e.g. rocky or uneven soils) and is more conducive to selectively seeding targeted areas and mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. Additionally, broadcast seeding allows for the use of raw, uncleaned seeds, which can be helpful when using wild-harvested seed. The use of no-till drills on remnants should be limited to large, extremely low-diversity sites with few remaining native species (Smith 2010b).

Recommended Protocol:

- Broadcast seeds into recently-burned soils using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (or by hand if selectively seeding small patches)
- Incorporate the seeds into the soil with a drag harrow or piece of chain link fence pulled behind the tractor/ATV while broadcasting
    - Note: if frost seeding (late fall/early winter), snow seeding (late winter/early spring) or ash seeding (sowing into ash immediately following a burn), mechanical incorporation may not be needed; freeze-thaw, snowmelt- and rainfall action may naturally incorporate seeds into the soil.
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs and is therefore the preferred option for interseeding to increase diversity
    - Spring seeding promotes warm season grasses
- Design: use mosaic seeding design to tailor seed mixes to their most suitable site conditions to prevent costly seed losses, e.g. sow dry conservation prairie mix (Table 63 or Table 65) onto dry ridge tops and a mesic mix (Table 64 or Table 66) into mesic soil conditions.
    - Note: if the site is relatively homogeneous (e.g. either dry or mesic soils throughout), a single seed mix can be sown evenly across the site.
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in "nodes" located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.

    - Low cost/conservative interseeding option: selectively broadcast into bare patches resulting from invasive species removal and/or specific areas of low cover/diversity
- Seed rate: minimum 40-60 seeds/sq. foot (10-12 lbs/acre); as high as 100 seeds/sq. foot
    - Minimum 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are not recommended for interseeding.
- Conservative option: seed remnants in two phases:
    1) Sow only seeds collected on site; in conjunction with management to encourage recovery of existing vegetation (e.g. prescribed fire); monitor vegetation response to determine additional seeding needs
    2) Add new species using local-ecotype seed, collected from a nearby reference site (or, locally-sourced nursery seed)

d. Post-Seeding Management

Establishment of interseeded prairie species, particularly conservative forbs, may take at least 5-7 years, though this will vary depending on competitive pressure, soil moisture and climate conditions. Early management is critical to reduce competition from existing vegetation and prevent reinvasion of weeds and woody species that might otherwise displace establishing natives. Maintaining control of invasive perennials is the primary management concern in restorations of invaded native remnants; however, existing native vegetation should also be carefully managed to promote rapid establishment of planted natives. Management strategies include frequent mowing or haying to reduce competition (Williams et al. 2007), selective use of herbicide to control invasive perennials (Solecki 1997, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a, b). The restoration site should continue to be burned on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:
Year 1:

- Selectively mow vegetation to a height of 4-6 inches weekly to bimonthly to reduce competition from established natives and minimize thatch build-up
    - Mow in strips or nodes representing 25-50% of site (Grygiel et al. 2009)
    - Note: if conservative species are present on site, protect from mowing or forgo mowing treatments entirely and expect lower and slower establishment of interseeded species

- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives (e.g. dormant season application; spot-treatment with backpack sprayer or wick applicator; avoid applying on windy days to prevent drift)

Year 2:

- Locate and spot-treat invasive perennials using appropriate herbicides and application methods that minimize damage to natives

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- To promote rapid establishment of prairie species, may burn at an interval of 1-2 years from years 3-5; thereafter burn at an interval of 3-5 years.
- Spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Mixed Native-Invasive Grassland start state to Conservation Prairie end state is $2173 per acre (Figure 36). This cost estimate assumes vegetation removal includes four selective herbicide applications and one controlled burn on each of two management units (two burns total); the site is broadcast-seeded and cultipacked;

post-seeding management includes a total of ten mowing treatments, two selective herbicide treatments, and a controlled burn on each of three management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

9. Woody-Invaded Prairie to Utility Prairie

a. Vegetation Removal

Woody-invaded prairies typically require a combination of mechanical removal, selective herbicide treatments, and prescribed fire to control invasive trees and shrubs and prepare the site for interseeding native prairie species (Pauly 1997, Solecki 1997, Smith 2010a, b, Williams 2010e). Tree seedlings and smaller saplings (diameter < ½ in.) can often be managed by reintroducing controlled burns, but larger trees require mechanical removal and, in most cases, chemical stump treatment to prevent resprouting. Equipment options include brush hogs, slashers, brush cutters and chain saws; the most efficient and effective methods of tree and shrub removal will depend on the species, size, density and spatial pattern of the targeted species. Degraded prairies that are invaded by trees and shrubs will often also have some herbaceous invasive perennials and other weed problems as well; if invasion is minimal (as we will assume for this restoration plan), they may also be controlled effectively with reintroduced fire. However, if invasive perennials are vigorous and spreading, they may require selective herbicide treatments (see Mixed Native-Invasive to Utility Prairie restoration plan for details.) In most cases, tree and shrub removal can be carried out in a single season prior to interseeding Utility Prairie.

Recommended Protocol:

- Cut dense brush thickets (e.g. with brush cutter) that are unlikely to be controlled by fire alone
- Cut trees > 5cm diameter (e.g. with chainsaws or slashers)
- Treat stumps with appropriate herbicide, e.g. Triclopyr (Garlon 4), Picloram (Tordon), and glyphosate (Roundup)
    - Exception: eastern red cedar (*Juniperus virginiana*) does not resprout; stump treatment is not needed.
- Haul and pile woody slash using tractor-mounted skid steers or grapple attachments
- If woody invasion is more extensive, slash should be piled and burned, or chipped in a woodchipper and removed
    - If woody cover is relatively low (<10%), slash may be distributed and left to rot or burn during a prescribed fire
- Burn or mow/hay (4 in. height) site to kill woody seedlings and remove thatch (fall or spring prior to seeding).
- Invading stands of clonal species, such as aspen, may be controlled more gradually by girdling.
- Cropping and disking are not recommended for woody-invaded prairies.

b. Seedbed Preparations

When interseeding into existing vegetation, seedbed preparations are often minimized to avoid disturbing established natives and bringing additional weed seeds and rhizomes to the soil surface. If invasive species are minimal, selective disking or tilling (i.e. in nodes or strips covering 25-50% of the site) is sometimes used to reduce competition from established natives (Grygiel et al. 2009, Williams 2010e). However, a more conservative approach is to avoid soil disturbance and instead drill seeds into newly burned ground after a spring or fall burn (Williams 2010e, MN BWSR 2012a). (Note: drilling into an untilled site can be hard on the drill; if the site is very rough, rocky or has numerous gopher mounds, the equipment wear and tear may outweigh the efficiency of drilling, in which case broadcast seeding may be a better alternative; see Mixed Native-Invasive Grassland to Conservation Prairie restoration plan for more details.)

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Upland prairies may be interseeded either using a no-till drill or broadcasting using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (Rowe 2010, Williams 2010d, MN BWSR 2012a). This Utility Prairie restoration plan assumes the use of no-till drills; seed drills ensure efficient, even site coverage and good seed-soil contact, and they are particularly effective at seeding native prairie grasses. However, drilling into an untilled site can be hard on the drill; if the site is very rough, rocky or has numerous gopher mounds, the equipment wear and tear may outweigh the efficiency of drilling, in which case broadcast seeding may be a better alternative. Broadcast seeding also produces excellent results with a more natural appearance (i.e. no persistent row lines), although it may be less efficient than drilling; consider increasing the seeding rate, particularly if broadcasting onto slopes or other erodible sites. (See Mixed Native-Invasive Grassland to Conservation Prairie restoration plan for more details on broadcast seeding.)

Recommended Protocol:

- Drill seeds into existing vegetation with no-till drill (e.g. Truax) following a burn or mowing to remove thatch
    - Alternative option: broadcast seeds
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs
    - Spring seeding promotes warm season grasses
- Design: seed single Utility Prairie mix (Table 60) in an even distribution across site provided soil moisture ranges from dry to mesic

  - If soil moisture is highly variable and ranges to wet-mesic/wet, combine mix with Utility Wet Prairie and Utility Wet Meadow mixes (Table 61 and Table 62) as appropriate and seed evenly across site OR seed individual mixes into appropriate seed zones (i.e. "mosaic seeding")
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009), rest paddocks (Jackson 1999), or bare patches resulting from woody species removal.
- Seed rate: minimum 40 seeds/sq. foot (8-10 lbs/acre)
  - Increase rate to 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are not recommended for interseeding.

d. Post-Seeding Management

Interseeded prairie species will require at least 3-5 years to establish, depending on competitive pressure, soil moisture and climate conditions. During the establishment phase, management efforts should focus on reducing competition from existing vegetation and preventing reinvasion of woody species that degrade prairie vegetation and reduce habitat over time. Management strategies include frequent mowing or haying to reduce competition from existing native vegetation (Williams et al. 2007), selective mechanical or chemical control of resprouting woody species (Solecki 1997, Smith 2010a, Williams 2010c), and prescribed fire to promote native prairie species and discourage further woody invasion (Pauly 1997, Smith 2010a). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Mow vegetation to a height of 4-6 inches weekly to bimonthly to reduce competition from established natives and minimize thatch build-up.
- OR: Hay the site monthly (removing mowed material to prevent thatch build-up); expect low yields.
- If resprouting woody trees and brush are too dense to control via mowing, spot-control with brush cutters or cut-stump treatments

Year 2:

- Mow/hay field to 12-inch height twice, once in late spring, and again in mid-summer
- Spot-control resprouting woody species as necessary

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.

- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses have achieved dominance.
- Mowing should no longer be needed for vegetation control; spot-control woody species as necessary
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 3-4 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody invasions continue to increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Woody-Invaded Prairie start state to Utility Prairie end state is $1504 per acre (Figure 36). This cost estimate assumes vegetation removal includes cutting trees and shrubs, piling and burning the slash, and one controlled burn (whole site); the site is seeded with a no-till drill; post-seeding management includes a total of ten mowing treatments, one selective herbicide treatment of invading exotic perennials and/or woody resprouts that are not effectively controlled by fire, and a controlled burn on each of two management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

10. Woody-Invaded Prairie to Conservation Prairie

a. Vegetation Removal

Woody-invaded prairies typically require a combination of mechanical removal, selective herbicide treatments, and prescribed fire to control invasive trees and shrubs and prepare the site for interseeding native prairie species (Pauly 1997, Solecki 1997, Smith 2010a, b, Williams 2010e). Tree seedlings and smaller saplings (diameter < ½ in.) can often be managed by reintroducing controlled burns, but larger trees require mechanical removal and, in most cases, chemical stump treatment to prevent resprouting. Equipment options include brush hogs, slashers, brush cutters and chain saws; the most efficient and effective methods of tree and shrub removal will depend on the species, size, density and spatial pattern of the targeted species. Degraded prairies that are invaded by trees and shrubs will often also have some herbaceous invasive perennials and other weed problems as well; if invasion is minimal (as we will assume for this restoration plan), they may also be controlled effectively with reintroduced fire. However, if invasive perennials are vigorous and spreading, they may require selective herbicide treatments (see Mixed Native-Invasive to Conservation Prairie restoration plan for details.) Native remnants should be divided into multiple management units in order to preserve local habitat refugia for resident wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002); ideally, not more than 1/3 of the site will be burn in a given season. For a given management unit, woody removal and site preparation can be carried out in a single season prior to interseeding Conservation Prairie.

Recommended Protocol:

- Cut dense brush thickets (e.g. with brush cutter) that are unlikely to be controlled by fire alone
- Cut trees > 5cm diameter (e.g. with chainsaws or slashers)
- Treat stumps with appropriate herbicide, e.g. Triclopyr (Garlon 4), Picloram (Tordon), and glyphosate (Roundup)
    - Exception: red cedar (*Juniperus virginiana*) does not resprout; stump treatment is not needed.
- Haul and pile woody slash using tractor-mounted skid steers or grapple attachments
- If woody invasion is more extensive, slash should be piled and burned, or chipped in a woodchipper and removed
    - If woody cover is relatively low (<10%), slash may be distributed and left to rot or burn during a prescribed fire
- Burn or mow/hay (4 in. height) site to kill woody seedlings and remove thatch (fall or spring prior to seeding).
- Invading stands of clonal species, such as aspen, may be controlled more gradually by girdling.
- Cropping and disking should not occur on remnants.

b. Seedbed Preparations

When interseeding remnants, seedbed preparations are minimized to avoid disturbing native soil communities and established natives, and to prevent bringing additional weed seeds and rhizomes to the soil surface. Native remnants should never be tilled or disked; instead, seeds should be broadcast directly into established vegetation following a burn (Smith 2010b, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Seeding prairie remnants should be undertaken with caution to avoid negatively impacting remnant vegetation, soil communities, and wildlife (Smith 2010b, MN BWSR 2012a). Seed mixes should be tailored specifically to the site to avoid introducing aggressive species that may outcompete existing vegetation; in general, species already present on site should not be planted unless the seed is harvested on site. Whenever possible, locally-harvested seed should be used, and species selection should be based on historical records and/or reference sites. We have provided example conservation prairie seed mixes with this restoration plan (Table 63–Table 66) with the expectation that species already present on a given site (or not appropriate for a given site) will be eliminated from the list; relative rates of conservative to common species will be increased; and locally-harvested seeds will be prioritized over commercially-produced seed.

Upland prairie remnants may be interseeded either by no-till drill or broadcasting with a spreader mounted to a tractor or ATV, or by hand (Rowe 2010, Smith 2010b, Williams 2010d, MN BWSR 2012a). However, broadcasting is the preferred seeding method for remnant prairies because it minimizes soil disturbance, produces a more natural appearance, allows for selectively seeding and favors forb species, which contribute much of the diversity and cost in a conservation mix. Broadcasting also allows access into difficult site conditions (e.g. rocky or uneven soils) and is more conducive to selectively seeding targeted areas and mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. Additionally, broadcast seeding allows for the use of raw, uncleaned seeds, which can be helpful when using wild-harvested seed. The use of no-till drills on remnants should be limited to large, extremely low-diversity sites with few remaining native species (Smith 2010b).

Recommended Protocol:

- Broadcast seeds into recently-burned soils using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV (or by hand if selectively seeding small patches)
- Incorporate the seeds into the soil with a drag harrow or piece of chain link fence pulled behind the tractor/ATV while broadcasting

    - Note: if frost seeding (late fall/early winter), snow seeding (late winter/early spring) or ash seeding (sowing into ash immediately following a burn), mechanical incorporation may not be needed; freeze-thaw, snowmelt- and rainfall action may naturally incorporate seeds into the soil.
- When to seed: any season except summer
    - Fall/dormant seeding (i.e. frost or snow seeding) promotes cool season grasses and forbs and is therefore the preferred option for interseeding to increase diversity
    - Spring seeding promotes warm season grasses
- Design: use mosaic seeding design to tailor seed mixes to their most suitable site conditions to prevent costly seed losses, e.g. sow dry conservation prairie mix (Table 63 or Table 65) onto dry ridge tops and a mesic mix (Table 64 orTable 66) into mesic soil conditions.
    - Note: if the site is relatively homogeneous (e.g. either dry or mesic soils throughout), a single seed mix can be sown evenly across the site.
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in “nodes” located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
    - Low cost/conservative interseeding option: selectively broadcast into bare patches resulting from invasive species removal and/or specific areas of low cover/diversity
- Seed rate: minimum 40-60 seeds/sq. foot (10-12 lbs/acre); as high as 100 seeds/sq. foot
    - Minimum 60 seeds/sq. foot on steep slopes (3:1 grade)
- Cover/nurse crops are not recommended for interseeding.
- Conservative option: seed remnants in two phases:
    1) Sow only seeds collected on site; in conjunction with management to encourage recovery of existing vegetation (e.g. prescribed fire); monitor vegetation response to determine additional seeding needs
    2) Add new species using local-ecotype seed, collected from a nearby reference site (or, locally-sourced nursery seed)

d. Post-Seeding Management

Establishment of interseeded prairie species, particularly conservative forbs, may take at least 5 – 7 years, though this will vary depending on competitive pressure, soil moisture and climate conditions. During the establishment phase, management efforts should focus on reducing competition from existing vegetation and preventing reinvasion of woody species that degrade prairie vegetation and reduce habitat over time. Management strategies include frequent mowing or haying to reduce competition (Williams et al. 2007), selective mechanical or chemical control of resprouting woody species (Solecki 1997, Smith 2010a, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion (Pauly 1997, Smith 2010a, b). The restoration site should continue to be burned on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002). Monitoring vegetation is also critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Selectively mow vegetation to a height of 4-6 inches weekly to bimonthly to reduce competition from established natives and minimize thatch build-up
  - Mow in strips or nodes representing 25-50% of site (Grygiel et al. 2009); if existing vegetation is sparse, focus mowing on dense patches only
  - Note: if conservative species are present on site, protect from mowing or forgo mowing treatments entirely and expect lower and slower establishment of interseeded species;
- Spot-control resprouting woody species with brush cutters or cut-stump treatments

Year 2:

- Locate and spot-control woody species as needed

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- To promote rapid establishment of prairie species, may burn at an interval of 1-2 years from years 3-5; thereafter burn at an interval of 3-5 years.
- Spot-control woody species as needed
- Conduct stand evaluation to assess seedling establishment outcomes
  - If native plant density is < 1 plant per square foot, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 3-5 years to stimulate productivity of native prairie plants and prevent invasion of herbaceous perennial weeds and woody trees and shrubs
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining

- Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
- Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
- Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

e. Cost Estimate

The estimated cost to transition from the Woody-Invaded Prairie start state to Conservation Prairie end state is $2205 per acre (Figure 36). This cost estimate assumes vegetation removal includes cutting trees and shrubs, piling and burning the slash, and conducting one controlled burn on each of two management units; the site is broadcast-seeded and cultipacked; post-seeding management includes a total of ten mowing treatments, one selective herbicide treatment (spot-spray) of invading exotic perennials and/or woody resprouts that are not effectively controlled by fire, and a controlled burn on each of three management units. Costs assume services and seed are purchased from restoration contractors and native seed nurseries.

B. Wet Prairie and Wet Meadow Transitions

1. Crop to Utility Meadow

a. Vegetation Removal

Vegetation removal is not necessary on annual crop fields, provided restoration is initiated immediately following harvest. If the crop field is left fallow for one or more growing seasons and has become dominated by annual weeds, see the Annual Dominated Field to Utility Meadow restoration plan.

b. Seedbed Preparations

Crop fields require little seedbed preparation, unless heavy crop residue is present that might interfere with seeding. Soybean fields are the preferred crop "start state" for restoration, because they are essentially ready to seed (Rowe 2010), however wet sites tend to be less suitable for soybean cultivation. The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Jacobson 2006, Williams 2010e). Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Utility Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- If light crop residue is present (e.g. soybean field):
  - Lightly harrow (e.g. with spike tooth harrow)
  - (No site preparation needed if frost seeding or no-till drilling)
- If heavy crop residue is present (e.g. corn field):
  - Mow stalks
  - Disk site multiple times (3+) to incorporate residue into soil
  - Cultipack if possible
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance may bring weed seeds to the soil surface; herbicide applications may be required prior to native seed establishment (see Annual-Dominated to Utility Meadow restoration plan for more details).

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
  - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: use mosaic seeding design to tailor seed mixes to their most appropriate hydrologic zone (i.e. wet prairie and wet meadow; Table 61 and Table 62) to prevent costly seed losses
  - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
  - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
  - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 160 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie and wet meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of wet meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions

- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Wet prairie/meadow establishment typically requires a minimum of 3-5 years but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Annual weeds can also pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the site. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zone to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.

  - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zone to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage.

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses and sedges have achieved dominance.
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
  - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 4-7 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat

- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
    - Spot-treat reed canary grass and other weeds as needed; reed canary grass may continue to emerge from the seed bank for 10 years following seeding!
    - Temporarily increase burn frequency if woody invasions become problematic (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Crop start state to Utility Meadow end state is $1096 per acre plus a $700 flat rate, for a minimum total of $1796 (Figure 36). This cost estimate assumes the site is harrowed, broadcast seeded and cultipacked; post-seeding management activities include five mowing treatments (wet prairie); a single herbicide application (spot-spray) of invading exotic perennials; and two controlled burns (one on each management unit). The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost estimate assumes services and seed are purchased from restoration contractors and native seed nurseries.

2. Crop to Conservation Meadow

a. Vegetation Removal

Vegetation removal is not necessary on annual crop fields, provided restoration is initiated immediately following harvest. If the crop field is left fallow for one or more growing seasons and has become dominated by annual weeds, see Annual Dominated Field to Conservation Meadow restoration plan.

b. Seedbed Preparations

Crop fields require little seedbed preparation, unless heavy crop residue is present that might interfere with seeding. Soybean fields are the preferred crop "start state" for restoration, because they are essentially ready to seed (Rowe 2010), however wet sites tend to be less suitable for soybean cultivation. The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Jacobson 2006, Williams 2010e). Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Conservation Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- If light crop residue is present (e.g. soybean field):
  - Lightly harrow (e.g. with spike tooth harrow)
  - (No site preparation needed if frost seeding or no-till drilling)
- If heavy crop residue is present (e.g. corn field):
  - Mow stalks
  - Disk site multiple (3+) times to incorporate residue into soil
  - Cultipack if possible
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance may bring weed seeds to the soil surface; herbicide applications may be required prior to native seed establishment (see Annual-Dominated to Conservation Meadow restoration plan for more details).

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). Additionally, broadcasting is preferred for conservation sites, because it produces a more natural appearance and is better-suited to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded. If drills are used to seed conservation meadows, the persistence of unnatural-appearing drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d). In some cases, the wettest areas may need to be hand-seeded or planted with transplants or plugs.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
  - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination.
- Design: "mosaic seeding" –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 67) and wet meadow (Table 68)) to prevent costly seed losses.
  - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
  - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible.
  - If some forb seed quantities are insufficient to seed entire site, cluster these species in "nodes" located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
- Seed rate: 160-210 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in Western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Establishment of a diverse conservation meadow with typically requires 5-7 years but will vary depending but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Annual weeds can also pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the site. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a).

Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002).

Recommended Management Protocol:

Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zone to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
    - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zone to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage.

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining

- Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
- Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
- Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Crop start state to Conservation Meadow end state is $1890 per acre plus a $700 flat rate, for a minimum total of $2590 (Figure 36). This cost estimate assumes the site is harrowed, broadcast seeded and cultipacked; post-seeding management activities include six mowing treatments (wet prairie); a single herbicide application (spot-spray) of invading exotic perennials; and a controlled burn on each of three management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

3. Exotic Annual-Dominated Field to Utility Meadow

a. Vegetation Removal

Annual weeds are not typically a serious post-seeding management problem in meadow systems, particularly in areas that will be flooded following hydrologic restoration. If sites are to be restored primarily to wet meadow and/or marsh, then controlling annual weeds prior to seeding is likely unnecessary. Annual weeds may, however, persist in the wet prairie zone, and if densities are high, they can suppress native seedlings, reducing their survival and growth (Williams et al. 2007). Controlling annual weeds and reducing their seed bank prior to seeding and in the early establishment phase will typically result in faster and more complete establishment of planted natives. Annual weeds are commonly controlled with mowing or burning (Williams 2010e). Herbicide applications are not typically necessary to control annual weeds on a wet site; however, if herbicides are used, select an aquatic-approved herbicide (e.g. Rodeo) if standing water is present.

Recommended Protocol:

- If heavy thatch is present, burn or mow site (particularly wet prairie and upland zones) to remove thatch in the fall prior to seeding and hydrologic restoration (site may be inaccessible to mowing equipment after flooding)
- Optional: for additional weed control, mow annual weeds 1-3 times throughout the summer prior to a final fall mowing to reduce seed inputs
- If patches of reed canary grass are intermixed with annual vegetation, see Invasive Perennial-Dominated Field to Utility Meadow restoration plan for management recommendations, as mowing and burning may hinder reed canary grass control efforts (Adams and Galatowitsch 2004, Jacobson 2006).

b. Seedbed Preparations

The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Jacobson 2006, Williams 2010e). Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Utility Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Lightly harrow site (e.g. with a spike-tooth harrow) to loosen the soil and remove thatch
- If site was burned (thatch removed) and if planning to frost-seed, no site preparation is necessary
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance will likely result in a flush of annual weeds, as seeds are brought to the soil surface; additional herbicide applications may be required prior to native seed establishment.

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet meadows, because wet soils often cannot support heavy machinery such as seed drills, and many wet meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: “mosaic seeding” –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 61) and wet meadow (Table 62)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and sedge meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 160 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil

Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Meadow establishment typically a minimum of 3-5 years but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Reinvading annual weeds can pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the site. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zone to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
  - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zone to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage.

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses and sedges have achieved dominance.
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
  - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)

- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 4-7 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
    - Spot-treat reed canary grass and other weeds as needed; reed canary grass may continue to emerge from the seed bank for 10 years following seeding!
    - Temporarily increase burn frequency if woody invasions become problematic (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Annual-Dominated Field start state to Utility Meadow end state is $1132 per acre plus a $700 flat rate, for a minimum total of $1832 (Figure 36). This cost estimate assumes the site is mowed once prior to seeding, harrowed, broadcast seeded and cultipacked; post-seeding management activities include five mowing treatments (wet prairie); a single herbicide application (spot-spray) of invading exotic perennials; and two controlled burns (one on each management unit). The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

4. Exotic Annual-Dominated Field to Conservation Meadow

a. Vegetation Removal

Annual weeds are not typically a serious post-seeding management problem in meadow systems, particularly in areas that will be flooded following hydrologic restoration. If sites are to be restored primarily to wet meadow and/or marsh, then controlling annual weeds prior to seeding is likely unnecessary. Annual weeds may, however, persist in the wet prairie zone, and if densities are high, they can suppress native seedlings, reducing their survival and growth (Williams et al. 2007). Controlling annual weeds and reducing their seed bank prior to seeding and in the early establishment phase will typically result in faster and more complete establishment of planted natives. Annual weeds are commonly controlled with mowing or burning (Williams 2010e). Herbicide applications are not typically necessary to control annual weeds on a wet site; however, if herbicides are used, select an aquatic-approved herbicide (e.g. Rodeo) if standing water is present.

Recommended Protocol:

- If heavy thatch is present, burn or mow site (particularly wet prairie and upland zones) to remove thatch in the fall prior to seeding and hydrologic restoration (site may be inaccessible to mowing equipment after flooding)
- For maximum annual weed control, mow 1-3 times throughout the summer prior to a final fall mowing to reduce seed inputs
- If patches of reed canary grass are intermixed with annual vegetation, see Invasive Perennial-Dominated Grassland to Conservation Meadow restoration plan for management recommendations, as mowing and burning may hinder reed canary grass control efforts (Adams and Galatowitsch 2004, Jacobson 2006).

b. Seedbed Preparations

The appropriate method of seedbed preparation is influenced by the intended seeding method, as well as site conditions (Jacobson 2006, Williams 2010e). Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Conservation Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Lightly harrow site (e.g. with a spike-tooth harrow) to loosen the soil and remove thatch
- If site was burned (thatch removed) and if planning to frost-seed, no site preparation is necessary
- If soils are severely compacted, till to 4-inch depth and harrow (e.g. with drag harrow or chain link fence) to break up soil clods; Note: soil disturbance will likely result in a flush of annual weeds, as seeds are brought to the soil surface; additional herbicide applications may be required prior to native seed establishment.

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). Additionally, broadcasting is preferred for conservation sites, because it produces a more natural appearance and is better-suited to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded. If drills are used to seed conservation meadows, the persistence of unnatural-appearing drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d). In some cases, the wettest areas may need to be hand-seeded or planted with transplants or plugs.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: "mosaic seeding" –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 67) and wet meadow (Table 68)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in "nodes" located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
- Seed rate: 160-210 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Establishment of a diverse conservation meadow typically requires 5-7 years but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Annual weeds can also pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the site. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a).

Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of native seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002).

Recommended Management Protocol:
Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zones to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
    - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zones to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage.

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes

- If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application)
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Annual-Dominated Field start state to Conservation Meadow end state is $2054 per acre plus a $700 flat rate, for a minimum total of $2754 (Figure 36). This cost estimate assumes the site is mowed and burned once prior to seeding to control annuals; harrowed, broadcast seeded and cultipacked; post-seeding management activities include six mowing treatments (wet prairie); a single herbicide application (spot-spray) of invading exotic perennials; and a controlled burn on each of three management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

5. Invasive Perennial-Dominated Grassland to Utility Meadow

a. Vegetation Removal

Unmanaged invasive perennials can out-compete even otherwise dominant native wet prairie/meadow species. Reed canary grass (*Phalaris arundinaceae*) is one of the most problematic invasive perennials in prairie wetlands, and restoration of wet prairie and wet meadow communities inevitably involves control and prevention of reed canary grass invasion. Producing a robust seed and rhizome bank, reed canary grass can continue germinating from the seed bank for 10 years or more, at densities that can rapidly overwhelm planted native vegetation (Green and Galatowitsch 2002, Adams and Galatowitsch 2006). Thorough site preparation is critical to minimizing reinvasion, because control options after seeding and hydrologic restoration are limited by the presence of standing water and saturated soils, and by the need to avoid harming native plants.

A carefully timed "spray-burn-spray" approach using glyphosate (Roundup if the site is dry; or aquatic-approved Rodeo if standing water is present) is an effective strategy for controlling reed canary grass (Adams and Galatowitsch 2004, Jacobson 2006, MN BWSR 2012c). Timing is critical—herbicide should be applied in the fall (September) reed canary grass is still physiologically active in order to affect mature plants and regrowth from rhizomes, and because burning and mowing increase light availability and stimulate reed canary grass germination (Lindig-Cisneros and Zedler 2002), they should be followed with an late spring/summer herbicide application to kill emerging seedlings. Meadow restoration requires a certain amount of flexibility, as wet site conditions may preclude necessary management actions in any given year; if at all possible, it is preferable to delay seeding to allow for the full sequence of reed canary grass control rather than seed with incomplete management. The significant control effort and costs required to produce a successful restoration outcome may be unfeasible for some project areas.

While the acceptable threshold for invasive perennial cover in Utility Meadow may vary by land owner and project goals, it is important to remember that any amount of reed canary grass remaining on site at the time of seeding has the potential to eventually out-compete native species; long-term viability of a wet meadow restoration thus depends on the achieving the highest level of control possible, given the available resources. The better the pre-seeding control achieved, the less long-term management will be required in the post-establishment phase and beyond. We recommend a minimum of one full year (fall through fall) of invasion control prior to seeding Utility Meadow.

Recommended Protocol:
Year 1:

- Apply glyphosate to reed canary grass in the fall – September is optimal

    - Use broadcast application, i.e. with tractor-mounted boom sprayer
    - If standing water is present, use aquatic-approved formula, such as Rodeo

Year 2:

- Spring burn to stimulate reed canary grass seed germination
    - Note: if site is likely to be too wet for a spring burn, burn in fall of year 1 instead
- Apply second glyphosate application to kill emerging seedling - late spring/early summer
- Fall: assess re-emergence of reed canary grass from rhizomes:
    - If site is fairly clean (<15% cover), spot-spray remaining vegetation in September; mow or burn to remove thatch; prepare to seed.
    - If >15% cover, repeat the spray-burn-spray sequence and delay seeding until fall of year 3.
- Wait at least 2 weeks following last herbicide application to seed

Additional Notes:

- If invasive woody species are present, see "Woody-invaded Meadow to Utility Meadow restoration plan; saplings < ½ in. diameter can be herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- Alternate option 1: If site conditions allow, crop field for 1-4 years prior to restoration to deplete reed canary grass seed and rhizome bank and convert the site to the relatively easy cropland start state (Rowe 2010); then refer to Crop to Utility Meadow Restoration Plan.
    - Many wet invasive perennial-dominated sites are too wet to farm; this option has limited applicability to wet meadow restoration
- Alternate option 2: late spring/early summer applications of grass-specific herbicides, such as sethoxydim (Poast, Vantage) may be useful when controlling reed canary grass mixed with native sedges and forbs; they can only be used in dry sites (no standing water), and should be used cautiously if native grasses are present.
- Alternate option 3: After spring mowing/burn, and herbicide application, disk the site repeatedly (every 3-4 weeks) throughout the growing season to maximize control of invasive perennial rhizomes; follow with additional herbicide applications as needed
    - This risks bringing additional invasive seeds and rhizomes to the soil surface and should be done in conjunction with multiple herbicide treatments to control regrowth
    - Not recommended for highly erodible sites
    - Method requires dry, firm soils throughout the summer

b. Seedbed Preparations

The appropriate method of seedbed preparation in an invasive perennial-dominated site is influenced by the site conditions, the amount of resources available for continued vegetation management, and the intended seeding method (Jacobson 2006, Williams 2010e). If the soil surface is uneven or severely compacted, harrowing or disking may be required to prepare the site, which often results in a flush of new invasive perennial growth, as seeds and rhizomes are brought to the soil surface. If such soil cultivation is required, invasive perennial regrowth should be treated with repeated herbicide applications prior to native seedling establishment. Alternatively, several rounds of deep tillage may be used intentionally to break up rhizomes and bring them to the surface for winter kill (Morgan 1997). Whenever possible, however, most practitioners prefer to avoid soil disturbance to prevent bringing seeds and rhizomes to the soil surface and minimize both reinvasion and the need for continued intensive management. Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Utility Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Forgo seedbed preparation to minimize soil disturbance and subsequent reinvasion (frost-seeding, snow seeding or ash seeding may help incorporate seeds into soil). Exceptions:
    - If soil surface is very uneven (e.g. numerous soil clods), lightly harrow to create a smoother surface; if possible: treat invasive regrowth with repeated herbicide applications prior to native seedling establishment
    - If soils are severely compacted, multiple rounds of tilling and disking (4-inch depth) may be used to loose soil and break up invasive rhizomes; finish soils by harrowing to break up soil clods; if possible: treat invasive regrowth with repeated herbicide applications prior to native seedling establishment.

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination

- Design: "mosaic seeding" –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 61) and wet meadow (Table 62)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009) or rest paddocks (Jackson 1999)
- Seed rate: minimum 160 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Wet prairie/meadow establishment typically requires a minimum of 3-5 years but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reinvading reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the establishment phase and beyond; seedlings may continue to emerge from the seed bank for 10 years! Additionally, reinvading annual weeds can pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of native seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zone to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
    - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) and methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zone to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage to native seedlings

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses and sedges have achieved dominance.
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 4 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 4-7 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing

- Spot-treat reed canary grass and other weeds as needed
- Temporarily increase burn frequency if woody invasions become problematic (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Invasive Perennial-Dominated Grassland start state to Utility Meadow end state is $1547 per acre plus a $700 flat rate, for a minimum total of $2247 (Figure 36). This cost estimate assumes that vegetation removal includes one mowing treatment, two broadcast herbicide applications and one follow-up spot-spray application, and one prescribed burn (whole site); the site is broadcast-seeded and cultipacked; post-seeding management activities include five mowing treatments (wet prairie); three herbicide applications (spot-spray) of invasive perennial regrowth; and a controlled burn on each of two management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

6. Invasive Perennial-Dominated Grassland to Conservation Meadow

a. Vegetation Removal

Unmanaged invasive perennials can outcompete even otherwise dominant native wet prairie/meadow species. Reed canary grass (*Phalaris arundinaceae*) is one of the most problematic invasive perennials in prairie wetlands, and restoration of wet prairie and wet meadow communities inevitably involves control and prevention of reed canary grass invasion. Producing a robust seed and rhizome bank, reed canary grass can continue germinating from the seed bank for 10 years or more, at densities that can rapidly overwhelm planted native vegetation (Green and Galatowitsch 2002, Adams and Galatowitsch 2006). Thorough site preparation is critical to minimizing reinvasion, because control options after seeding and hydrologic restoration are limited by the presence of standing water and saturated soils, and by the need to avoid harming native plants.

A carefully timed “spray-burn-spray” approach using glyphosate (Roundup if the site is dry; or aquatic-approved Rodeo if standing water is present) is an effective strategy for controlling reed canary grass (Adams and Galatowitsch 2004, Jacobson 2006, MN BWSR 2012c). Timing is critical—herbicide should be applied in the fall (September) reed canary grass is still physiologically active in order to affect mature plants and regrowth from rhizomes, and because burning and mowing increase light availability and stimulate reed canary grass germination (Lindig-Cisneros and Zedler 2002), they should be followed with an late spring/summer herbicide application to kill emerging seedlings. Meadow restoration requires a certain amount of flexibility, as wet site conditions may preclude necessary management actions in any given year; if at all possible, it is preferable to delay seeding to allow for the full sequence of reed canary grass control rather than seed with incomplete management. The significant control effort and costs required to produce a successful restoration outcome may be unfeasible for some project areas.

While the acceptable threshold for invasive perennial cover in Conservation Meadow may vary by land owner and project goals, it is important to remember that any amount of reed canary grass remaining on site at the time of seeding has the potential to eventually out-compete native species; long-term viability of a wet meadow restoration thus depends on the achieving the highest level of control possible, given the available resources. The better the pre-seeding control achieved, the less long-term management will be required in the post-establishment phase and beyond. This is especially important for conservation end states; seeding diverse and costly seed mixes is not advised if there are insufficient funds for thorough and complete invasion control. When planning a restoration from the invasive perennial-dominated grassland start state, the level of vegetation management anticipated should be proportional to the quality, diversity and cost of the seed mix to be planted. We recommend a minimum of two complete sequences of the spray-burn-spray approach, i.e. two full calendar years of invasion control, prior to seeding Conservation Meadow.

Recommended Protocol:

Year 1:

- Apply glyphosate to reed canary grass in the fall – September is optimal
    - Use broadcast application, i.e. with tractor-mounted boom sprayer
    - If standing water is present, use aquatic-approved formula, such as Rodeo

Year 2:

- Spring burn to stimulate reed canary grass seed germination
    - Note: if site is likely to be too wet for a spring burn, burn in fall of year 1 instead
- Apply second glyphosate application to kill emerging seedling - late spring/early summer
- Fall: assess re-emergence of reed canary grass from rhizomes:
    - If site is fairly clean (< 5% cover), spot-spray remaining vegetation in September; mow or burn to remove thatch; prepare to seed.
    - If > 5% cover, repeat herbicide applications in September (broadcast or spot-spray) and continue spray-burn-spray sequence in year 3.
        - Optional: plant site with cover crop or temporary mix to prevent erosion and suppress reinvasion (Jacobson 2006)

Year 3:

- Spring burn to stimulate reed canary grass seed germination
- Apply second glyphosate application to kill emerging seedling - late spring/early summer (broadcast or spot-spray)
- Fall: assess re-emergence of reed canary grass from rhizomes:
    - If site is fairly clean (< 5% cover), spot-spray remaining vegetation in September and prepare to seed.
    - If > 5% cover, decide whether to proceed with planting or continue invasion control for another year.
- Wait at least 2 weeks following last herbicide application to seed

Additional Notes:

- If invasive woody species are present, see the "Woody-invaded Meadow to Utility Meadow restoration plan; saplings < ½ in. diameter can be herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- Alternate option 1: If site conditions allow, crop field for 1-4 years prior to restoration to deplete reed canary grass seed and rhizome bank and convert the site to the relatively easy cropland start state (Rowe 2010); then refer to the Crop to Utility Meadow Restoration Plan.

    - Many wet invasive perennial-dominated sites are too wet to farm; this option has limited applicability to meadow restoration
- Alternate option 2: late spring/early summer applications of grass-specific herbicides, such as sethoxydim (Poast, Vantage) may be useful when controlling reed canary grass mixed with native sedges and forbs; they can only be used in dry sites (no standing water), and should be used cautiously if native grasses are present.
- Alternate option 3: After spring mowing/burn, and herbicide application, disk the site repeatedly (every 3-4 weeks) throughout the growing season to maximize control of invasive perennial rhizomes; follow with additional herbicide applications as needed
    - This risks bringing additional invasive seeds and rhizomes to the soil surface and should be done in conjunction with multiple herbicide treatments to control regrowth
    - Not recommended for highly erodible sites
    - Method requires dry, firm soils throughout the summer

b. Seedbed Preparations

The appropriate method of seedbed preparation in an invasive perennial-dominated site is influenced by the site conditions, the amount of resources available for continued vegetation management, and the intended seeding method (Jacobson 2006, Williams 2010e). If the soil surface is uneven or severely compacted, harrowing or disking may be required to prepare the site, which often results in a flush of new invasive perennial growth, as seeds and rhizomes are brought to the soil surface. If such soil cultivation is required, invasive perennial regrowth should be treated with repeated herbicide applications prior to native seedling establishment. Alternatively, several rounds of deep tillage may be used intentionally to break up rhizomes and bring them to the surface for winter kill (Morgan 1997). Whenever possible, however, most practitioners prefer to avoid soil disturbance to prevent bringing seeds and rhizomes to the soil surface and minimize both reinvasion and the need for continued intensive management. Late summer/fall is the best time for seedbed preparations in wet sites, as the soils are more likely to be firm and dry. This Conservation Meadow restoration plan assumes seeds will be broadcast (vs. drilled).

Recommended Protocol:

- Forgo seedbed preparation to minimize soil disturbance and subsequent reinvasion (frost-seeding, snow seeding or ash seeding may help incorporate seeds into soil). Exceptions:
    - If soil surface is very uneven (e.g. numerous soil clods), lightly harrow to create a smoother surface; if possible: treat invasive regrowth with repeated herbicide applications prior to native seedling establishment
    - If soils are severely compacted, multiple rounds of tilling and disking (4-inch depth) may be used to loose soil and break up invasive rhizomes; finish soils by

harrowing to break up soil clods; if possible: treat invasive regrowth with repeated herbicide applications prior to native seedling establishment.

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for seeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, MN BWSR 2012c). Additionally, broadcasting is preferred for conservation sites, because it produces a more natural appearance and is better-suited to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded. If drills are used to seed conservation meadows, the persistence of unnatural-appearing drill rows can be minimized by drilling the site in two passes at right angles to each other, resulting in a grid that will fill in more quickly than rows (Williams 2010d). In some cases, the wettest areas may need to be hand-seeded or planted with transplants or plugs.

Recommended Protocol:

- Broadcast seeds into prepared seedbed using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: “mosaic seeding” –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 67) and wet meadow (Table 68)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and sedge meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in “nodes” located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
- Seed rate: 160-210 seeds/sq. foot
- Cover/nurse crops are optional, but should be included with the seed mix when seeding highly erodible sites, e.g. slopes (MN BWSR 2011). Oats (*Avena sativa*) are typically

recommended, but winter wheat (*Triticum aestivum*) may have better overwintering survival for seedings done between Aug. 1 and Oct. 15.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Establishment of a diverse conservation meadow typically requires 5-7 years but will vary depending on soil moisture and climate conditions. Post-seeding management goals include discouraging weeds and encouraging rapid and robust establishment of native species that can sustain grazing, haying and other uses. Early management is critical to preventing reinvading reed canary grass, other invasive perennials, and woody species from out-competing, and displacing establishing natives. Maintaining control of reed canary grass emerging from the seed and rhizome bank will be important throughout the establishment phase and beyond; seedlings may continue to emerge from the seed bank for 10 years! Additionally, reinvading annual weeds can pose problems in wet prairie zones, forming a dense canopy that can shade prairie seedlings, decreasing their growth and survival. Saturated conditions will often limit management options, preventing access by heavy equipment. Management strategies include mowing annual weeds

(Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a).

Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie/meadow seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b). The restoration site should be divided into management units for burning on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002).

Recommended Management Protocol:

Year 1:

- When site is dry and firm enough (early to mid-summer) spot-mow exotic annual weeds and cover crops in wet prairie zone to a height of 4-6 inches every 4 weeks, or when canopy reaches a height of 12-18 inches; most prairie plants will not reach this height in first year and will not be damaged by mower.
    - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
- Spot-spray re--invading canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) and methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).

Year 2:

- Mow annual weeds in wet prairie zone to a height of 12 inches 1-2 times to reduce cover and seed set
- Spot-spray reed canary grass in September using methods that will minimize damage to native seedlings

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- Spot-treat reed canary grass (annually in September) and other invasive perennials as necessary with aquatic-approved herbicide

- Mowing should no longer be needed; spot-treat weeds as necessary using dormant season applications and/or back-pack sprayer/wick applicator to minimize damage to native species
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
    - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application); assume annual to biennial reed canary grass treatments through at least year 10
    - Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Invasive Perennial-Dominated Grassland start state to Conservation Meadow end state is $2638 per acre plus a $700 flat rate, for a minimum total of $3338 (Figure 36). This cost estimate assumes that vegetation removal includes four broadcast herbicide applications and one follow-up spot-spray applications, and two prescribed burn (whole site); site is broadcast-seeded and cultipacked; post-seeding management activities include six mowing treatments (wet prairie); three selective herbicide applications (spot-spray) of invasive perennial regrowth; and a controlled burn on each of three management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

7. Mixed Native & Invasive Grassland to Utility Meadow

a. Vegetation Removal

Unmanaged invasive perennials can outcompete even otherwise dominant native wet prairie/meadow species. Reed canary grass (*Phalaris arundinaceae*) is one of the most problematic invasive perennials in prairie wetlands, and restoration of wet prairie and wet meadow communities inevitably involves control and prevention of reed canary grass invasion. Producing a robust seed and rhizome bank, reed canary grass can continue germinating from the seed bank for 10 years or more, at densities that can rapidly overwhelm planted native vegetation (Green and Galatowitsch 2002, Adams and Galatowitsch 2006). For the Mixed Native-Invasive Grassland start state, the primary challenge of vegetation removal is to control aggressive invasive perennials with minimal harm to the existing native vegetation. If the native vegetation includes only a few very competitive native species, it may also be important to reduce their cover of these species to allow for the addition of new species and increase the site's diversity. Vegetation management will free existing sub-dominant natives from competition and open microsites for native seed establishment.

A carefully timed "spray-burn-spray" approach using selective applications of glyphosate (Roundup if the site is dry; or aquatic-approved Rodeo if standing water is present) is an effective strategy for controlling reed canary grass (Adams and Galatowitsch 2004, Jacobson 2006, MN BWSR 2012c) and opening microsites to allow interseeded natives to establish (Williams 2010e, MN BWSR 2012a). Timing is critical—herbicide should be applied in the fall (September) reed canary grass is still physiologically active in order to affect mature plants and regrowth from rhizomes (Adams and Galatowitsch 2006), and because burning and mowing increase light availability and stimulate reed canary grass germination (Lindig-Cisneros and Zedler 2002), they should be followed with an late spring/summer herbicide application to kill emerging seedlings. Wet meadow restoration requires a certain amount of flexibility, as wet site conditions may preclude necessary management actions in any given year; if at all possible, it is preferable to delay seeding to allow for the full sequence of reed canary grass control rather than seed with incomplete management. Thorough site preparation is critical to minimizing reinvasion, because control options after seeding and hydrologic restoration are limited by the presence of standing water and saturated soils, and by the need to avoid harming native plants. We recommend a minimum of one full year (fall through fall) of invasion control prior to interseeding Utility Meadow.

Recommended Protocol:
Year 1:

- Selectively apply glyphosate to reed canary grass in fall - September is optimal

- To minimize damage to natives, herbicide can be "spot-sprayed" into larger patches using ATV-mounted sprayers; applied to smaller patches with backpack sprayers; or applied with a wicking device to individual plants.
- If standing water is present, use aquatic-approved formula, such as Rodeo

- Mark reed canary grass patches for easy relocation during post-seeding management.

Year 2:

- Spring burn to stimulate reed canary grass seed germination.
- Repeat selective glyphosate application to kill emerging seedlings - late spring/early summer
- Fall: assess re-emergence of reed canary grass from rhizomes; if control is adequate, mow or burn to remove thatch and prepare to seed; otherwise repeat spray-burn-spray sequence and seed in Year 3.
- Wait at least 2 weeks following last herbicide application to seed

Additional notes:

- If invasive woody species are present, see the Woody-invaded Meadow to Utility Meadow restoration plan; saplings < ½ in. diameter can be burned or herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- Selective disking to reduce competition from invasive and native vegetation prior to interseeding (Grygiel et al. 2009, Williams 2010e) is not recommended for invaded wet meadow sites, as the soil disturbance is likely to bring additional reed canary grass seeds to the soil surface, resulting in an even greater invasion management problem
- Cropping is not recommended for Mixed Native-Invasive Grassland start states

b. Seedbed Preparation

When interseeding into existing vegetation, seedbed preparations are often minimized to avoid disturbing established natives and bringing additional weed seeds and rhizomes to the soil surface. If invasive species are minimal, selective disking or tilling (i.e. in nodes or strips covering 25-50% of the site) is sometimes used to reduce competition from established natives (Grygiel et al. 2009, Williams 2010e). However, in an invaded site with mixed natives and invasive species present, we recommend avoiding soil disturbance and instead broadcasting seeds into newly burned ground after a fall burn (Jacobson 2006, Williams 2010e, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for interseeding wet meadows, because wet soils often cannot support heavy machinery such as seed drills, and many wet meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, Williams 2010d, MN BWSR 2012c, a). However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded.

Recommended Protocol:

- Broadcast seeds using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV following a burn or mow to remove thatch
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: “mosaic seeding” –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 61) and wet meadow (Table 62)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009), rest paddocks (Jackson 1999), or bare patches remaining from invasive species control
- Seed rate: minimum 160 seeds/sq. foot
- Cover/nurse crops are not recommended for interseeding.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Interseeded meadow species will require a minimum of 3-5 years to establish, depending on competitive pressure, soil moisture and climate conditions. During this time, the primary management objective is to maintaining control of invasive perennials, and to encouraging rapid and robust establishment of native species that can compete with reed canary grass. When possible, existing native vegetation should also be carefully managed to promote rapid establishment of planted natives, however vegetation management options are limited by wet soils. Management strategies include selective mowing to reduce competition (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Mowing and fire must be used conservatively, because both can promote reed canary grass seed germination and negatively impact sedges. Reed canary grass seedlings may continue to emerge from the seed bank for 10 years; continual management will be required for many years. Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of native seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) and methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).
    - Flag or map any new patches for future control
- Spot-mow to reduce native competition ONLY if possible to avoid (marked) reed canary grass patches, and as site conditions allow. When site is dry and firm enough (early to mid-summer) mow weekly to bimonthly to reduce competition and prevent thatch OR hay monthly (expect low yields);
    - Avoid mowing reed canary grass except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
    - Note: if mowing is not possible, establishment of planted seedlings may be slower

Year 2:

- Spot-spray reed canary grass in September using methods that will minimize damage to native seedlings

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses and sedges have achieved dominance.
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity
    - Note: if mowing was not done in year 1, establishment rates may be slower; after stand evaluation, postpone burning, haying and grazing until year 5 if necessary

Year 4 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)

- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 4-7 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
    - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
    - Interseed as needed to increase native cover and diversity if native species are declining
    - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
    - Spot-treat reed canary grass and other weeds as needed (likely up to 10 years)

  Temporarily increase burn frequency if woody invasions become problematic (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Mixed Native-Invasive Grassland start state to Utility Meadow end state is $1517 per acre plus a $700 flat rate, for a minimum total of $2217 (Figure 36). This cost estimate assumes that vegetation removal includes one mowing treatment, two selective herbicide applications (spot-treatments), and one prescribed burn (whole-site); the site is broadcast-seeded and cultipacked; post-seeding management activities include four mowing treatments; three selective herbicide treatments of invasive perennial regrowth; and a controlled burn on each of two management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

8. Mixed Native & Invasive Grassland to Conservation Meadow

a. Vegetation Removal

Unmanaged invasive perennials can outcompete even otherwise dominant native wet prairie/meadow species. Reed canary grass (*Phalaris arundinaceae*) is one of the most problematic invasive perennials in prairie wetlands, and restoration of wet prairie and wet meadow communities inevitably involves control and prevention of reed canary grass invasion. Producing a robust seed and rhizome bank, reed canary grass can continue germinating from the seed bank for 10 years or more, at densities that can rapidly overwhelm planted native vegetation (Green and Galatowitsch 2002, Adams and Galatowitsch 2006). When restoring invaded wetland remnants, the primary challenge of vegetation removal is to control aggressive invasive perennials with minimal harm to the existing native vegetation. If the native vegetation includes only a few very competitive native species, it may also be important to reduce their cover of these species to allow for the addition of new species and increase the site's diversity. Vegetation management will free existing sub-dominant natives from competition and open microsites for native seed establishment. When invasive species are minimal, it is possible to dormant-seed directly into recently-burned soils without disrupting existing vegetation; this approach is easy and cheap, but seedling establishment may be delayed and reduced due to competition from dominant vegetation, and invasive species may persist for many years (Williams 2010e). Sowing native hemiparasites (e.g. *Castilleja* spp.; *Commandra* spp.) may also reduce the cover of dominant native grasses and create gaps for forb establishment (R. Campbell, pers. comm.). Although not feasible at large scales due to limited seed availability, this approach could be considered in sensitive locations where herbicide poses too great a risk to species of high conservation value. When invasive species such as reed canary grass are present on site, we recommend chemically controlling these species prior to seeding to prevent their further spread and minimize impacts to planted native species.

A carefully timed "spray-burn-spray" approach using selective applications of glyphosate (Roundup if the site is dry; or aquatic-approved Rodeo if standing water is present) is an effective strategy for controlling reed canary grass (Adams and Galatowitsch 2004, Jacobson 2006, MN BWSR 2012c) and opening microsites to allow interseeded natives to establish (Williams 2010e, MN BWSR 2012a). Timing is critical—herbicide should be applied in the fall (September) reed canary grass is still physiologically active in order to affect mature plants and regrowth from rhizomes (Adams and Galatowitsch 2006), and because burning and mowing increase light availability and stimulate reed canary grass germination (Lindig-Cisneros and Zedler 2002), they should be followed with an late spring/summer herbicide application to kill emerging seedlings. Meadow restoration requires a certain amount of flexibility, as wet site conditions may preclude necessary management actions in any given year; if at all possible, it is preferable to delay seeding to allow for the full sequence of reed canary grass control rather than seed with incomplete management. Thorough site preparation is critical to minimizing reinvasion, because control options after seeding and hydrologic restoration are limited by the presence of standing water and saturated soils, and by the need to avoid harming native plants. We recommend a two full years (fall through fall) of invasion control prior to interseeding Conservation Meadow.

Recommended Protocol:

- Divide remnant into multiple burn units in order to preserve local habitat refugia for resident wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002); avoid burning more than ½ of the site in any one season.
- On each management unit, conduct the following sequence:

Year 1:

- Selectively apply glyphosate to reed canary grass in fall-September is optimal
    - To minimize damage to natives, herbicide can be applied to smaller patches with backpack sprayers; or applied with a wicking device to individual plants.
    - If standing water is present, use aquatic-approved formula, such as Rodeo
    - Avoid using herbicide near sensitive species; if species of high conservation value are intermixed with reed canary grass, hand-pull reed canary grass to minimize risk
- Mark reed canary grass patches for easy relocation during post-seeding management.

Year 2:

- Spring burn to stimulate reed canary grass seed germination.
- Repeat selective glyphosate application or hand-pulling to kill emerging seedlings - late spring/early summer
- Fall: assess re-emergence of reed canary grass from rhizomes; if control is adequate, prepare to seed; otherwise repeat spot-applications and seed in fall of Year 3.

Year 3:

- Hand pull or selectively apply glyphosate to reed canary grass in fall (September)
- Mow or burn to remove thatch
- Wait at least 2 weeks following last herbicide application to seed

Additional notes:

- If invasive woody species are present, see the Woody-invaded Meadow to Conservation Meadow restoration plan; saplings < ½ in. diameter can be burned or herbicide- treated along with invasive perennials, but larger trees will require mechanical removal.
- Selective disking to reduce competition from invasive and native vegetation prior to interseeding (Grygiel et al. 2009, Williams 2010e) is not recommended for invaded wet meadow sites, as the soil disturbance is likely to bring additional reed canary grass seeds to the soil surface, resulting in an even greater invasion management problem

- Cropping is not recommended for Mixed Native-Invasive Grassland start states

b. Seedbed Preparations

When interseeding remnants, seedbed preparation is minimized to avoid disturbing native soil communities and established natives, and to prevent bringing additional weed seeds and rhizomes to the soil surface. Native remnants should never be tilled or disked; instead, seeds should be broadcast directly into established vegetation following a fall burn (Jacobson 2006, Smith 2010b, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Seeding wet prairie/meadow remnants should be undertaken with caution to avoid negatively impacting remnant vegetation, soil communities, and wildlife (Smith 2010b, MN BWSR 2012a). Seed mixes should be tailored specifically to the site to avoid introducing aggressive species that may outcompete existing vegetation; in general, species already present on site should not be planted unless the seed is harvested on site. Whenever possible, locally-harvested seed should be used, and species selection should be based on historical records and/or reference sites. We have provided example conservation wet prairie and conservation wet meadow seed mixes with this restoration plan (Table 67 and Table 68) with the expectation that species already present on a given site (or not appropriate for a given site) will be eliminated from the list; relative rates of conservative to common species will be increased; and locally-harvested seeds will be prioritized over commercially-produced seed.

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for interseeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, Williams 2010d, MN BWSR 2012a). Additionally, broadcasting is preferred for remnant sites, because it minimizes soil disturbance, produces a more natural appearance and is better-suited to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. Broadcast seeding also allows for the use of raw, uncleaned seeds, which can be helpful when using wild-harvested seed. The use of no-till drills on remnant meadows should be limited to large, low-diversity sites with few remaining native species (Smith 2010b). If the seedbed is dry and firm, grasses may be drilled in a grid pattern (2 passes at right angles) to minimize the persistence of unnatural-appearing drill rows (Williams 2010d), followed by broadcasting sedges and forbs. In some cases, the wettest areas may need to be hand-seeded or planted with transplants or plugs.

Recommended Protocol:

- Broadcast seeds using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV following a burn or mow to remove thatch
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: “mosaic seeding” –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 67) and wet meadow (Table 68)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - If some forb seed quantities are insufficient to seed entire site, cluster these species in “nodes” located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
    - Low cost/conservative interseeding option: selectively broadcast into bare patches resulting from invasive species removal and/or specific areas of low cover/diversity
- Seed rate: 160-210 seeds/sq. foot
- Cover/nurse crops are not recommended for interseeding
- Conservative option: seed remnants in two phases:
    1) Sow only seeds collected on site; in conjunction with management to encourage recovery of existing vegetation (e.g. prescribed fire); monitor vegetation response to determine additional seeding needs
    2) Add new species using local-ecotype seed, collected from a nearby reference site (or, locally-sourced nursery seed)

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Establishment of interseeded wet prairie/meadow species, particularly sedges and conservative forbs, may take at least 5-7 years, depending on competitive pressure, soil moisture and climate conditions. During this time, the primary management objectives are to maintain control of invasive perennials, and to encouraging rapid and robust establishment of native species that can compete with reed canary grass. When possible, existing native vegetation should also be carefully managed to promote rapid establishment of planted natives, however vegetation management options are limited by wet soils. Management strategies include selective mowing to reduce competition (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Mowing and fire must be used conservatively, because both can promote reed canary grass seed germination and negatively impact sedges. Reed canary grass seedlings may continue to emerge from the seed bank for 10 years; continual management will be required for many years. Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b). The restoration site should continue to be burned on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002).

Recommended Management Protocol:

Year 1:

- Spot-spray re-establishing reed canary grass in September using aquatic-approved glyphosate (e.g. Rodeo) and methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize drift).
  - Flag or map any new patches for future control
- Selectively mow vegetation (to a height of 4-6 inches weekly to bimonthly to reduce competition from established natives and minimize thatch build-up
  - Mow in strips or nodes representing 25-50% of site (Grygiel et al. 2009)
  - Avoid mowing reed canary grass patches except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
  - Note: if conservative species are present on site, protect from mowing or forgo mowing treatments entirely and expect lower and slower establishment of interseeded species

Year 2:

- Spot-spray reed canary grass in September using methods that will minimize damage to native seedlings

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- Spot-treat reed canary grass (annually in September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
  - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 6 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Continue to burn in rotations (up to 1/3 of site per burn)
- Adjust seasonality and intensity of burning to maximize diversity
- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining

- Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
- Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application); assume annual to biennial reed canary grass treatments through at least year 10
- Temporarily increase burn frequency (e.g. annual burns for 2 years) if invasive perennials and woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Mixed Native-Invasive Grassland start state to Conservation Meadow end state is $2713 per acre plus a $700 flat rate, for a minimum total of $3413 (Figure 36). This cost estimate assumes that vegetation removal includes four selective herbicide applications (spot-treatment) and two prescribed burns on each of two management units (four burns total); the site is broadcast seeded and cultipacked; post-seeding management activities include six mowing treatments (wet prairie); three selective herbicide applications to control regrowth of invasive perennials, and a controlled burn on each of three management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

9. Woody-Invaded Meadow to Utility Meadow

a. Vegetation Removal

Woody-invaded meadows typically require a combination of mechanical removal, selective herbicide treatments, and prescribed fire to control invasive trees and shrubs and prepare the site for interseeding native wet prairie and wet meadow species (Pauly 1997, Solecki 1997, Smith 2010a, b, Williams 2010e). Tree seedlings and smaller saplings (diameter < ½ in.) can often be managed by reintroducing controlled burns, but larger trees require mechanical removal and, in most cases, chemical stump treatment to prevent resprouting. Equipment options include brush hogs, slashers, brush cutters and chain saws; the most efficient and effective methods of tree and shrub removal will depend on the species, size, density and spatial pattern of the targeted species, as well as the soil moisture conditions (saturated soils will not support heavy machinery). Degraded meadows that are invaded by trees and shrubs will often also have other weed problems; if reed canary grass is present, carefully-timed selective herbicide treatments will be required in addition to the tree removal methods described herein (see Mixed Native-Invasive to Utility Meadow restoration plan for details.) In most cases, tree and shrub removal can be carried out in a single season prior to interseeding Utility Meadow.

Recommended Protocol:

- Cut dense brush thickets (e.g. with brush cutter) that are unlikely to be controlled by fire alone
- Cut trees > 5cm diameter (e.g. with chainsaws or slashers)
- Treat stumps with appropriate herbicide, e.g. Triclopyr (Garlon 4), Picloram (Tordon), and glyphosate (Roundup)
- Haul and pile woody slash using tractor-mounted skid steers or grapple attachments
- If woody invasion is more extensive, slash should be piled and burned, or chipped in a woodchipper and removed
    - If woody cover is relatively low (<10%), slash may be distributed and left to rot or burn during a prescribed fire
- Burn or mow/hay (4 in. height) site to kill woody seedlings and remove thatch (fall or spring prior to seeding).
- Invading stands of clonal species, such as aspen, may be controlled more gradually by girdling.
- Cropping and disking are not recommended for woody-invaded meadows

b. Seedbed Preparations

When interseeding into existing vegetation, seedbed preparations are often minimized to avoid disturbing established natives and bringing additional weed seeds and rhizomes to the soil surface. If invasive species are minimal, selective disking or tilling (i.e. in nodes or strips covering 25-50% of the site) is sometimes used to reduce competition from established natives

(Grygiel et al. 2009, Williams 2010e). However, a more conservative approach is to avoid soil disturbance and instead broadcasting seeds into newly burned ground after a fall burn (Jacobson 2006, Williams 2010e, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

C. Seeding

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for interseeding wet meadows, because wet soils often cannot support heavy machinery such as seed drills, and many wet meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, Williams 2010d, MN BWSR 2012a). However, if the seedbed is dry and firm, grasses may be seeded with a no-till drill, followed by broadcasting forbs and sedges. In some cases, the wettest areas may need to be hand-seeded.

Recommended Protocol:

- Broadcast seeds using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV following a burn or mow to remove thatch
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
    - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: "mosaic seeding" –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 61) and wet meadow (Table 62)) to prevent costly seed losses.
    - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
    - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
    - Limited budget option: seed entire site with grass mix and cluster expensive forb seeds in nodes (Grygiel et al. 2009), rest paddocks (Jackson 1999), or bare patches remaining from woody species removal
- Seed rate: minimum 160 seeds/sq. foot
- Cover/nurse crops are not recommended for interseeding.

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Interseeded wet prairie/meadow species will require a minimum of 3-5 years to establish, depending on competitive pressure, soil moisture and climate conditions. During the establishment phase, management efforts should focus on preventing invasion of reed canary grass and maintaining control of woody species. When possible, existing native vegetation should also be carefully managed to promote rapid establishment of planted natives, however vegetation management options are limited by wet soils. Management strategies include selective mowing to reduce competition (Jacobson 2006, Williams et al. 2007), selective mechanical or chemical control of resprouting woody species (Solecki 1997, Smith 2010a, Williams 2010c), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Mowing and fire must be used conservatively, because both can promote reed canary grass seed germination and negatively impact sedges. Reed canary grass seedlings may continue to emerge from the seed bank for 10 years; continual management will be required for many years. Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b).

Recommended Management Protocol:

Year 1:

- Spot-mow to reduce native competition when site is dry and firm (early to mid-summer); mow weekly to bimonthly to reduce competition and prevent thatch OR hay monthly (expect low yields);
    - If reed canary grass is present on site, avoid mowing except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
    - Note: if mowing is not possible, establishment of planted seedlings may be slower
- If resprouting woody trees and brush are too dense to control via mowing, spot-control with brush cutters or cut-stump treatments
- Scout for invading reed canary grass; if detected, spot-treat with aquatic-approved glyphosate (e.g. Rodeo) in September using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize herbicide drift).

Year 2:

- Spot-control resprouting woody species as necessary
- Scout for invading reed canary grass; if detected, spot-treat with aquatic-approved glyphosate (e.g. Rodeo) in September using methods that will minimize damage to native seedlings

Year 3:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Begin grazing or haying after three growing seasons (Fall - year 3 or Spring - year 4), or when native grasses and sedges have achieved dominance.
- Spot-treat reed canary grass (September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

- Note: if mowing was not done in year 1, establishment rates may be slower; after stand evaluation, postpone burning, haying and grazing until year 5 if necessary

Year 4 & Beyond:

- Burn at a frequency of every 4-7 years to stimulate productivity of native prairie plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
- Burn and hay in rotations in order to maintain diversity and local refugia for wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002): burn/hay no more than ½ of field at a given time (suggested: burn 1/3 of field annually; so that each patch has effectively a 3 –year rotation)
- Graze at low to moderate intensities; maintain vegetation height of 10 inches on 50% of fields to provide habitat for grassland birds (Sample and Mossman 1997)
- Time burning, haying and grazing to allow sufficient biomass accumulation for each activity; e.g. an alternating biennial rotation of grazing and haying within a 4-7 year burn rotation (Smith 2010a).
- Hay mid-to late summer (late July – August) to promote diversity and avoid grassland bird nesting season; leave 6-8 inch stubble and regrowth for winter cover/spring nesting habitat
- Adjust seasonality and intensity of burning, grazing and haying to maximize diversity and adjust species composition (e.g. maintaining sufficient coverage of both warm and cool season grasses)
  - Grazing in late spring/early summer will favor warm season grasses; mid-late summer grazing will favor cool season grasses
- Periodically (every 1-3 years) monitor vegetation composition and diversity
  - Interseed as needed to increase native cover and diversity if native species are declining
  - Adjust management plan (e.g. frequency and intensity of burning, haying, grazing) accordingly if native species are declining, desired composition is not being maintained, or if invasive species are increasing
  - Spot-treat reed canary grass and other weeds as needed (likely up to 10 years)
  - Temporarily increase burn frequency if woody invasions become problematic (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Woody-Invaded Meadow start state to Utility Meadow end state is $1568 per acre plus a $700 flat rate, for a minimum total of $2268 (Figure 36). This cost estimate assumes that vegetation removal includes cutting trees and shrubs, piling and burning the slash, as well as a full-site burn; site is broadcast-seeded and cultipacked; post-seeding management activities include four mowing treatments; one selective herbicide treatment of invading exotic perennials (i.e. reed canary grass) or woody resprouts that are not effectively controlled by fire; and a controlled burn on each of two management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

10. Woody-Invaded Meadow to Conservation Meadow

a. Vegetation Removal

Woody-invaded meadows typically require a combination of mechanical removal, selective herbicide treatments, and prescribed fire to control invasive trees and shrubs and prepare the site for interseeding native wet prairie and wet meadow species (Pauly 1997, Solecki 1997, Smith 2010a, b, Williams 2010e). Tree seedlings and smaller saplings (diameter < ½ in.) can often be managed by reintroducing controlled burns, but larger trees require mechanical removal and, in most cases, chemical stump treatment to prevent resprouting. Equipment options include brush hogs, slashers, brush cutters and chain saws; the most efficient and effective methods of tree and shrub removal will depend on the species, size, density and spatial pattern of the targeted species, as well as the soil moisture conditions (saturated soils will not support heavy machinery). Degraded meadows that are invaded by trees and shrubs will often also have other weed problems; if reed canary grass is present, carefully-timed selective herbicide treatments will be required in addition to the tree removal methods described herein (see Mixed Native-Invasive to Conservation Meadow restoration plan for details). Native remnants should be divided into multiple management units in order to preserve local habitat refugia for resident wildlife (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002); ideally, not more than 1/3 of the site will be burn in a given season. For a given management unit, woody removal and site preparation can be carried out in a single season prior to interseeding Conservation Meadow.

Recommended Protocol:

- Cut dense brush thickets (e.g. with brush cutter) that are unlikely to be controlled by fire alone
- Cut trees > 5cm diameter (e.g. with chainsaws or slashers)
- Treat stumps with appropriate herbicide, e.g. Triclopyr (Garlon 4), Picloram (Tordon), and glyphosate (Roundup)
    - Note: if standing water is present, an aquatic-approved herbicide (e.g. Rodeo) must be used
- Haul and pile woody slash using tractor-mounted skid steers or grapple attachments
- If woody invasion is more extensive, slash should be piled and burned, or chipped in a woodchipper and removed
    - If woody cover is relatively low (<10%), slash may be distributed and left to rot or burn during a prescribed fire
- Burn or mow/hay (4 in. height) site to kill woody seedlings and remove thatch (fall or spring prior to seeding).
- Invading stands of clonal species, such as aspen, may be controlled more gradually by girdling.
- Cropping and disking should not occur on remnants.

b. Seedbed Preparations

When interseeding remnants, seedbed preparation is minimized to avoid disturbing native soil communities and established natives, and to prevent bringing additional weed seeds and rhizomes to the soil surface. Native remnants should never be tilled or disked; instead, seeds should be broadcast directly into established vegetation following a fall burn (Jacobson 2006, Smith 2010b, MN BWSR 2012a).

Recommended Protocol:

- Forgo seedbed preparations to minimize soil disturbance and reinvasion
- Burn prior to seeding to remove thatch (see Vegetation Removal)

c. Seeding

Seeding wet prairie/meadow remnants should be undertaken with caution to avoid negatively impacting remnant vegetation, soil communities, and wildlife (Smith 2010b, MN BWSR 2012a). Seed mixes should be tailored specifically to the site to avoid introducing aggressive species that may outcompete existing vegetation; in general, species already present on site should not be planted unless the seed is harvested on site. Whenever possible, locally-harvested seed should be used, and species selection should be based on historical records and/or reference sites. We have provided example conservation wet prairie and conservation wet meadow seed mixes with this restoration plan (Table 67 and Table 68) with the expectation that species already present on a given site (or not appropriate for a given site) will be eliminated from the list; relative rates of conservative to common species will be increased; and locally-harvested seeds will be prioritized over commercially-produced seed.

Broadcast seeding with a spreader mounted to a tractor or ATV is the recommended method for interseeding wet prairie/meadow, because wet soils often cannot support heavy machinery such as seed drills, and many meadow species have very small, light-sensitive seeds that can be buried too deeply by a seed drill (Jacobson 2006, Williams 2010d, MN BWSR 2012c, a). Additionally, broadcasting is preferred for remnant sites, because it minimizes soil disturbance, produces a more natural appearance and is better-suited to mosaic seeding—sowing multiple mixes separately into different seed zones that reflect variable site conditions. Broadcast seeding also allows for the use of raw, uncleaned seeds, which can be helpful when using wild-harvested seed. The use of no-till drills on remnant meadows should be limited to large, low-diversity sites with few remaining native species (Smith 2010b). If the seedbed is dry and firm, grasses may be drilled in a grid pattern (2 passes at right angles) to minimize the persistence of unnatural-appearing drill rows (Williams 2010d), followed by broadcasting sedges and forbs. In some cases, the wettest areas may need to be hand-seeded or planted with transplants or plugs.

Recommended Protocol:

- Broadcast seeds using an agitating spreader (e.g. Vicon) mounted to a tractor or ATV following a burn or mow to remove thatch
- Incorporate the seeds into the soil with a drag (e.g. piece of chain link fence) or packer pulled behind the tractor/ATV while broadcasting
  - Note: if frost or snow seeding, mechanical incorporation may not be needed; freeze-thaw action may naturally incorporate seeds into the soil.
- When to seed: Fall/winter, when seedbed is more likely to be dry and firm; overwintering is necessary to prime many wetland sedges and forbs for germination
- Design: "mosaic seeding" –sow seed mixes into their appropriate hydrologic zone (i.e. wet prairie (Table 67) and wet meadow (Table 68)) to prevent costly seed losses.
  - Note: if the site is relatively homogeneous a single seed mix can be sown evenly across the site.
  - Wet prairie and wet meadow mixes can also be combined and seeded across the entire site if seed zones are closely intermixed and seeding individual zones is not feasible
  - If some forb seed quantities are insufficient to seed entire site, cluster these species in "nodes" located in suitable soil conditions as opposed to seeding at low densities across the site (Grygiel et al. 2009); this will encourage pollination and reproduction, as well as having greater visual impact.
  - Low cost/conservative interseeding option: selectively broadcast into bare patches resulting from invasive species removal and/or specific areas of low cover/diversity
- Seed rate: 160-210 seeds/sq. foot
- Cover/nurse crops are not recommended for interseeding
- Conservative option: seed remnants in two phases:
  1) Sow only seeds collected on site; in conjunction with management to encourage recovery of existing vegetation (e.g. prescribed fire); monitor vegetation response to determine additional seeding needs
  2) Add new species using local-ecotype seed, collected from a nearby reference site (or, locally-sourced nursery seed)

d. Hydrologic Restoration

Nearly all wet prairie/meadow sites in western Minnesota have been impacted by altered hydrology. Restoring hydrology by removing drainage features is a critical component of meadow restoration. Although the focus of these restoration plans is on vegetation management and addition, we encourage wet prairie/meadow restoration planners to take note of the following recommendations and refer to Restoring Prairie Wetlands: an ecological approach (Galatowitsch and van der Valk 1994) and the Minnesota Wetland Restoration Guide (Board of Water and Soil Resources, in review: http://www.bwsr.state.mn.us/publications/WRG/) for more information on evaluating and implementing the engineering aspects of hydrologic restoration.

Recommended Protocol:

- Use a backhoe to break drainage tiles and/or plug drainage ditches
- Break tile in strategic locations (e.g. at the wetland's outlet); it is usually not necessary to remove the entire length of tile to restore hydrology of wetland depressions
- Hydrologic restoration should be implanted after vegetation removal; after the site is flooded, access will be limited and herbicide options are restricted to aquatic-approved formulas (e.g. Rodeo)
- Time hydrologic restoration to occur in the fall/early winter in close conjunction with seeding, preferably 1-2 weeks following seeding (after flooding, site access will be limited)
- Reserve a small amount of seed to hand-broadcast over areas disturbed by backhoe operations
- If transplanting live plant material or plugs, this can be done in the late spring following hydrologic restoration

e. Post-Seeding Management

Establishment of interseeded wet prairie/meadow species, particularly sedges and conservative forbs, may take at least 5-7 years, depending on competitive pressure, soil moisture and climate conditions. During the establishment phase, management efforts should focus on reducing competition from existing vegetation and preventing reinvasion of woody species that degrade prairie vegetation and reduce habitat over time. Additionally, it is important to prevent invasion of reed canary grass and encourage rapid and robust establishment of native species that can compete with reed canary grass. Management strategies include selective mowing to reduce competition (Jacobson 2006, Williams et al. 2007), selective use of appropriately-timed aquatic-approved herbicide to control reed canary grass and other invasive perennials (Solecki 1997, Adams and Galatowitsch 2004, Adams and Galatowitsch 2006, Williams 2010c), and prescribed fire to promote native prairie species and discourage further invasion, particularly in the wet prairie zone (Pauly 1997, Smith 2010a). Vegetation management options are limited by wet soils, and mowing and fire must be used conservatively, because both can promote reed canary grass seed germination and negatively impact sedges. Because wet site conditions may prevent management in some years, monitoring vegetation is especially critical to evaluate establishment of prairie seedlings and re-seed if necessary; detect and respond to invasions while still at manageable densities; and adjust management plans as necessary to achieve the desired species composition and diversity (Masters 1997, Elzinga et al. 1998, Bockenstedt and Thunshelle 2006, Jacobson 2006, Williams 2010b). The restoration site should continue to be burned on a rotational basis to maintain diversity and wildlife refugia (Sample and Mossman 1997, Panzer and Schwartz 2000, Panzer 2002).

Recommended Management Protocol:

Year 1:

- Spot-mow to reduce native competition when site is dry and firm (early to mid-summer); mow weekly to bimonthly to reduce competition and prevent thatch OR hay monthly (expect low yields);

    - If reed canary grass is present on site, avoid mowing except to prevent going to seed; mowing may reduce effectiveness of herbicide and stimulate seed germination
    - Note: if mowing is not possible, establishment of planted seedlings may be slower
- If resprouting woody trees and brush are too dense to control via mowing, spot-control with brush cutters or cut-stump treatments
- Scout for invading reed canary grass; if detected, spot-treat with aquatic-approved glyphosate (e.g. Rodeo) in September using methods that will minimize damage to native seedlings (e.g. backpack sprayer or wick applicator; avoid windy days to minimize herbicide drift).

Year 2:

- Spot-control resprouting woody species as necessary
- Scout for invading reed canary grass; if detected, spot-treat with aquatic-approved glyphosate (e.g. Rodeo) in September using methods that will minimize damage to native seedlings

Years 3-5:

- Begin prescribed burns after three growing seasons (Fall - year 3 or Spring - year 4) or as soon as biomass accumulation is sufficient to carry a burn.
- Rotate burns in management units, burning no more than 1/3 of site (1/2 for small sites) at a time
- Continue to scout, map and spot-treat reed canary grass (annually in September) and other invasive perennials as necessary with aquatic-approved herbicide
- Conduct stand evaluation to assess seedling establishment outcomes
    - If native plant density is < 1 plant per square foot, or if site has < 70% native cover or <50% of planted species present, interseed to increase cover and diversity

Year 6 & Beyond:

    - Burn at a frequency of every 4-7 years to stimulate productivity of native plants (particularly in the wet prairie zone) and prevent invasion of herbaceous perennial weeds and woody trees and shrubs. (Note: burning more frequently may negatively impact sedges).
    - Continue to burn in rotations (up to 1/3 of site per burn)
    - Adjust seasonality and intensity of burning to maximize diversity
    - Periodically (every 1-3 years) monitor vegetation composition and diversity
        - Interseed as needed to increase native cover and diversity if native species are declining
        - Adjust management plan accordingly if native diversity is declining or if invasive species are increasing
        - Spot-treat weeds as needed (hand-pulling, back-pack sprayer, wick-applicator or dormant-season application); continue to scout, map and treat reed canary grass

- Temporarily increase burn frequency (e.g. annual burns for 2 years) if woody species increase in cover (note, however: sustained burn intervals of < 3 years will negatively impact cool-season natives and wildlife).

f. Cost Estimate

The estimated cost to transition from the Woody-Invaded Meadow start state to Conservation Meadow end state is $2437 per acre plus a $700 flat rate, for a minimum total of $3137 (Figure 36). This cost estimate assumes that vegetation removal includes cutting trees and shrubs, piling and burning the slash, and a controlled burn on each of two management units (two burns total); the site is broadcast seeded and cultipacked; post-seeding management activities include six mowing treatments (wet prairie); two selective herbicide treatments of invading exotic perennials (i.e. reed canary grass) or woody resprouts that are not effectively controlled by fire; and a controlled burn on each of three management units. The $700 flat rate is a low-end estimate of hydrologic restoration (e.g. tile removal) that assumes a modest mobilization fee and includes the costs to excavate, remove tile, seal the ends, and backfill and compact the trench (see Cost Estimation, Chapter 7 for details). This cost assumes services and seed are purchased from restoration contractors and native seed nurseries.

Appendix 4: Seed Mixes

In this Appendix, we provide example seed mixes for the Utility and Conservation Prairie and Meadow end states. More detailed descriptions of these end states, seed mixes, and recommendations for their use can be found in Chapter 7.

A. Seed Mixes for Utility Prairie and Meadow

Tables 60 – 62 are example seed mixes for the Utility Prairie and Utility Meadow end states. The Utility Prairie mix (Table 60) is appropriate for mesic to dry soil conditions (although note that Elymus virginicus, Virginia wild rye, is a mesic to wet-mesic species and should be excluded from the mix or substituted with another species if planting on dry to dry-mesic sites). Two examples mixes are provided for the Utility Meadow end state: the Utility Wet Prairie mix (Table 61) is suitable for sites with 3-4 weeks of soil saturation per year, and the Utility Wet Meadow mix (Table 62) is suitable for sites with soil saturation for 6-8 weeks per hear and some ponding. All Utility Meadow seed mixes are suitable for both the Agassiz Beach Ridges and Ordway-Glacial Lakes landscape areas.

B. Seed Mixes for Conservation Prairie and Meadow

Tables 63 – 68 are example seed mixes for the Conservation Prairie and Conservation Meadow end states. There are four Conservation Prairie mixes, specific to either dry or mesic soil conditions, and to either northwest Minnesota (including the Agassiz Beach Ridges landscape), or southwest Minnesota (including the Ordway-Glacial Lakes landscape). Specifically, the Conservation Prairie mixes are: Dry Conservation Prairie – Northwest (Table 63); Mesic Conservation Prairie – Northwest (Table 64); Dry Conservation Prairie – Southwest (Table 65); and Mesic Conservation Prairie – Southwest (Table 66).

Two Conservation Meadow mixes are provided: the Conservation Wet Prairie mix (Table 67) is suitable for sites with 3-4 weeks of soil saturation per year, and the Conservation Wet Meadow mix (Table 68) is suitable for sites with soil saturation for 6-8 weeks per hear and some ponding. All Conservation Meadow seed mixes are suitable for both the Agassiz Beach Ridges and Ordway-Glacial Lakes landscape areas.

Utility Prairie Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sq ft	Height (in.)	Succes-sional Stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes - Forage & Wildlife Value, Regional Suitability	Forage Value and Plant Info Links
CP25	G	*Andropogon gerardii*	big bluestem	3	11.00	36-96	L	M, MZ, D	Nests	8,9	high quality forage species	http://plants.usda.gov/plantguide/pdf/pg_ange.pdf http://extension.missouri.edu/p/M181-15
CP25	G	*Bouteloua curtipendula*	side-oats grama	0.5	1.1	12-36	M	MZ,D	Nests	7,8,9	high quality forage	http://plants.usda.gov/plantguide/pdf/pg_bocu.pdf
CP25	G	*Bouteloua gracilis*	blue grama	0.1	1.5	6-20	L	D	Nests		highly palatable to livestock (possibly low productivity)	http://plants.usda.gov/plantguide/pdf/pg_bogr2.pdf http://animalrangeextension.montana.edu/articles/forage/species/grasses/Blue-grama.htm
CP25	G	*Elymus canadensis*	nodding/Canada wild rye	0.5	1	36-60	E	MZ,D	None	7,8	good forage value early in season; less so after it matures	http://plants.usda.gov/factsheet/pdf/fs_elca4.pdf http://www.fs.fed.us/database/feis/plants/graminoid/elycan/all.html
CP25	G	*Elymus trachycaulus*	slender wheatgrass	0.5	1.3	24	M	MZ,D			palatable; grazed by wildlife & livestock	http://plants.usda.gov/plantguide/pdf/pg_eltr7.pdf http://www.fs.fed.us/database/feis/plants/graminoid/elytra/all.html
CP25	G	*Elymus virginicus**	Virginia wild rye	0.5	0.8	48	M	S-MZ	None		*Appropriate for wet-mesic to mesic sites; if site is dry, substitute or remove; increase percentages of other spp. Palatable, productive and nutritious forage for livestock	http://plant-materials.nrcs.usda.gov/pubs/stpmcfs0758.pdf
CP25	G	*Panicum virgatum*	switchgrass	0.1	0.5	24-84	M	M,MZ	None	7,8,9	productive, high quality hay; biofuels; value to wildlife as well	http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf http://www.uwex.edu/ces/forage/pubs/switchgrass.pdf http://extension.missouri.edu/p/M181-23
CP25	G	*Schizachyrium scoparium*	little bluestem	0.3	1.7	12-30	L	MZ,D	None	8,9	fair forage species; palatable by wildlife	http://plants.usda.gov/factsheet/pdf/fs_scsc.pdf
CP25	G	*Sorghastrum nutans*	Indian grass	1.5	6.6	36-96	L	M	Nests	8,9,	high to fair forage value; wildlife value	http://plants.usda.gov/factsheet/pdf/fs_sonu2.pdf
Pick	G	*Koeleria macrantha*	junegrass			12-24	L	D	None		Good forage value	http://plants.usda.gov/plantguide/pdf/pg_koma.pdf
Pick	G	*Sporobolus cryptandrus*	sand dropseed			12-36	L	MZ,D	None	7,8	Sand specialist; good forage value. Possible substitute for *E. virginicus* on very dry, sandy sites.	http://plants.usda.gov/factsheet/pdf/fs_spcr.pdf
Graminoids subtotal: 9												
CP25	A	*Achillea millefolium*	common yarrow	0.03	2	12-30	E	MZ,D	Low	4,5,6,7,8,9	low palatability to livestock (tend to avoid)	http://www.fs.fed.us/database/feis/plants/forb/achmil/all.html http://plants.usda.gov/plantguide/pdf/pg_acmio.pdf
CP25	L	*Astragalus canadensis*	Canada milk vetch	0.19	1.2	12-48	M	MZ, D	Low	7,8	palatable; quality forage	http://www.plant-materials.nrcs.usda.gov/pubs/ndpmcfs7521.pdf http://plant-materials.nrcs.usda.gov/pubs/ndpmcpgcamlk.pdf
CP25	L	*Dalea candida*	white prairie clover	0.19	1.3	12-30	M	MZ,D	Medium	6,7,8	good forage quality, but low yield; palatable and nutritious forage; wildlife value; can be overgrazed	http://npj.uwpress.org/content/5/2/152.full.pdf http://www.plant-materials.nrcs.usda.gov/pubs/kspmcpg7797.pdf
CP25	L	*Dalea purpurea*	purple prairie clover	0.31	1.7	12-30	M	MZ,D	Very High	7,8	good forage quality, but low yield; excellent forage but can be overgrazed	http://npj.uwpress.org/content/5/2/152.full.pdf http://www.plant-materials.nrcs.usda.gov/pubs/kspmcpg7796.pdf
CP25	A	*Helianthus maximilianii*	Maximilian's sunflower	0.08	0.4	48-60	E	M, MZ	High	9,10	protein; can be grazed into fall. May increase under grazing pressure.	http://plants.usda.gov/plantguide/pdf/pg_hema2.pdf
CP25	F	*Monarda fistulosa*	wild bergamot	0.01	0.2	24-48	M	MZ,D	Very High	7,8	little info, but appears to have medium palatability	http://plants.usda.gov/java/charProfile?symbol=MOFI
CP25	F	*Potentilla arguta*	tall/prairie cinquefoil	0.03	2.4	24	L	MZ,D	Medium	6,7,8,9		http://plants.usda.gov/java/charProfile?symbol=POAR7
CP25	A	*Ratibida pinnata**	gray-headed/yellow coneflower	0.09	1	36-72	M	MZ	Medium	7,8,9	*Substitute *Ratibida columnifera* in ABR; young plants offer good forage	plants.usda.gov/factsheet/doc/fs_rapi.docx
CP25	A	*Rudbeckia hirta*	black-eyed susan	0.07	2.3	12-36	E	MZ	Very Low	7,8,9,10	moderately grazed by cattle	http://www.fs.fed.us/database/feis/plants/forb/rudhir/all.html
Pick	L	*Amorpha canescens*	lead plant			18-48	L	MZ,D	Very High	6,7,8	thought to be grazing-tolerant; palatable to livestock and wildlife	http://plants.usda.gov/plantguide/pdf/pg_amca6.pdf http://www.fs.fed.us/database/feis/plants/shrub/amocan/all.html#ImportanceToWildlifeAndLivestock
Exp.	L	*Desmanthus illinoensis*	Illinois bundle flower			60		MZ, D		7,8	recommended for forage value; can improve forage quality of native grasses; relatively high forage yield	http://plants.usda.gov/plantguide/pdf/pg_deil.pdf http://npj.uwpress.org/content/5/2/152.full.pdf
Pick	L	*Desmodium canadense*	Canada tick trefoil			24-48	M	MZ	Low	7,8	historically rare in Eco Section 4. Can improve forage quality of native grasses; relatively high yield	http://npj.uwpress.org/content/5/2/152.full.pdf
Pick	A	*Echinacea pallida/angustifolia*	narrow-leaved purple coneflower			12-48	L	MZ,D	High	6,7	nutritious and palatable; may decrease under grazing pressure (reseed if necessary); wildlife value	http://plants.usda.gov/plantguide/pdf/pg_ecpa.pdf
Pick	A	*Helianthus pauciflorus*	stiff sunflower			12-48	M	MZ,D	High	7,8	quality forage	http://plants.usda.gov/factsheet/pdf/fs_hepa19.pdf
Pick	L	*Lespedeza capitata*	round-headed bush clover			12-24	M	MZ,D	Low	7,8	cattle prefer, and possibly grazing tolerant; relatively high yield	http://npj.uwpress.org/content/5/2/152.full.pdf
Pick	A	*Liatris aspera*	rough blazing star			24-36	L	MZ,D	High	7,8,9	*Liatris* spp. have fair to good forage value & wildlife benefit.	http://plants.usda.gov/factsheet/pdf/fs_lipu.pdf
Forbs subtotal: 9												
Total Species Richness: 18			**Total Seeding Rate:**	**8 lbs/acre**	**37.9 Seeds/sq**							
Total Cost/Acre: $188.50			(Opt.) Cover Crop - Oats/Winter Wheat	25 lbs/acre	11 Seeds/sq							

Table 60. Utility Prairie Seed Mix, suitable for mesic to dry soil conditions in the Agassiz Beach Ridges and Glacial Lakes landscapes.

Utility Wet Prairie Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sqft	Height (in.)	Succes-sional Stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes - Forage & Wildlife Value, Regional Suitability	Forage Value and Plant Info Links
33-262	G	*Andropogon gerardii*	big bluestem	1.5	5.50	36-96	L	M, MZ, D	Nests	8,9	high quality forage species	http://plants.usda.gov/plantguide/pdf/pg_ange.pdf http://extension.missouri.edu/p/M181-15
33-262	G	*Beckmannia syzigachne*	American slough grass	1.5	27.6	24	E	S	None		and hayed; seeds provide food for wildlife; serves as nurse crop	http://plants.usda.gov/factsheet/pdf/fs_besy.pdf Jacobson 2005
33-262	G	*Bromus ciliatus*	fringed brome	1.5	6.05	24-48	M	S	None	7,8	Rare or not native across much of southern MN; palatable to wildlife and livestock	http://www.fs.fed.us/database/feis/plants/graminoid/brocil/all.html
33-262	G	*Elymus canadensis*	nodding/Canada wild rye	4	7.64	36-60	E	MZ,D	None	7,8	good forage value early in season; less so after it matures	http://plants.usda.gov/factsheet/pdf/fs_elca4.pdf http://www.fs.fed.us/database/feis/plants/graminoid/elycan/all.html
33-262	G	*Elymus trachycaulus*	slender wheatgrass	4	10.15	24	M	MZ,D			palatable; grazed by wildlife & livestock	http://www.fs.fed.us/database/feis/plants/graminoid/elytra/all.html
33-262	G	*Elymus virginicus*	Virginia wild rye	4	6.17	48	M	S-MZ	None		Palatable, productive and nutritious forage for livestock and wildlife	http://plant-materials.nrcs.usda.gov/pubs/stpmcfs0758.pdf
33-262	G	*Panicum virgatum*	switchgrass	0.4	2.05	24-84	M	M,MZ	None	7,8,9	productive, high quality hay; biofuels; value to wildlife as well	http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf http://www.uwex.edu/ces/forage/pubs/switchgrass.pdf http://extension.missouri.edu/p/M181-23
33-262	G	*Poa palustris*	fowl bluegrass	1.6	76.4	24	M	S,M	None		serves as nurse crop; low palatibility; may substitute equivalent amount of seeds with more palatible species as budget allows	http://plants.usda.gov/java/charProfile?symbol=POPA2 Jacobson 2005
33-262	G	*Sorghastrum nutans*	Indian grass	1.5	6.6	36-96	L	M	Nests	8,9,	high to fair forage value; wildlife value	http://plants.usda.gov/factsheet/pdf/fs_sonu2.pdf
Graminoids subtotal: 9												
33-262	F	*Asclepias incarnata*	swamp milkweed	0.06	0.1	21-48	L	S	High	6,7	low palatability but high wildlife/pollinator value	http://plants.usda.gov/java/charProfile?symbol=ASIN
33-262	L	*Dalea purpurea*	purple prairie clover	0.09	0.5	12-30	M	MZ,D	Very High	7,8	good forage quality, but low yield; excellent forage but can be overgrazed	http://npj.uwpress.org/content/5/2/152.full.pdf http://www.plant-materials.nrcs.usda.gov/pubs/kspmcpg7796.pdf
33-262	L	*Desmodium canadense*	Canada tick trefoil	0.09	0.19	24-48	M	MZ	Low	7,8	forage quality of native grasses; relatively high yield	http://npj.uwpress.org/content/5/2/152.full.pdf
33-262	A	*Heliopsis helianthoides*	ox-eye	0.09	0.2	24-60	M	MZ, D	Very Low	6,7,8	forage quality ranges from poor to good	http://plants.usda.gov/plantguide/pdf/pg_hehe5.pdf
Pick	A	*Liatris pycnostachya*	great blazing star	0.02	0.1	24-48	L	M,MZ	High	7,8	*Liatris* spp. have fair to good forage value & wildlife benefit.	http://plants.usda.gov/factsheet/pdf/fs_lipu.pdf
33-262	A	*Rudbeckia hirta*	black-eyed susan	0.07	2.49	12-36	E	MZ	Very Low	7,8,9,10	moderately grazed by cattle	http://www.fs.fed.us/database/feis/plants/forb/rudhir/all.html
33-262	F	*Verbena hastata*	blue vervain	0.1	3.5	24-72	M	S,M,MZ	Medium	7,8,9		
Forbs subtotal: 7												
Total Species Richness: 16			**Total Seeding Rate:**	**20.5 lbs/acre**	**155.2 Seeds/sqft**							
Total Cost/Acre: $323			(Opt.) Cover Crop - Oats/Winter Wheat	25 lbs/acre	11.14 Seeds/sqft							

Table 61. Utility Wet Prairie Seed Mix, suitable for sites with 3-4 weeks saturated soil annually in the Agassiz Beach Ridges and Glacial Lakes landscapes.

Utility Wet Meadow Seed Mix												
Source	**Guild**	**Scientific Name**	**Common Name**	**Rate: PLS lb/acre**	**Rate: Seeds/sqft**	**Height (in.)**	**Succes-sional Stage**	**Hydro-logic Zone**	**Pollinator Value**	**Bloom Time**	**Notes - Forage & Wildlife Value, Regional Suitability**	**Forage Value and Plant Info Links**
33-261	G	*Andropogon gerardii*	big bluestem	2	7.35	36-96	L	M, MZ, D	Nests	8,9	high quality forage species	http://plants.usda.gov/plantguide/pdf/pg_ange.pdf http://extension.missouri.edu/p/M181-15
33-261	G	*Bromus ciliatus*	fringed brome	2	8.1	24-48	M	S	None	7,8	Rare or not native across much of southern MN; palatable to wildlife and livestock	http://www.fs.fed.us/database/feis/plants/graminoid/brocil/all.html
33-261	G	*Calamagrostis canadensis**	bluejoint	0.06	6.4	24-60	L	S	None	6,7,8	**C. canadensis* not appropriate for ABR region; ideally replace with *C. stricta* (limited commercial availability but can likely be obtained via combine-harvest sources); or remove and increase seed rates of other grasses Provides forage for wildlife; forage value for cattle ranges from poor to good; fair palatability	http://plants.usda.gov/factsheet/pdf/fs_caca4.pdf http://www.fs.fed.us/database/feis/plants/graminoid/calcan/all.html J. Meissen, pers. comm.
33-261	G	*Carex stipata*	awl-fruited sedge	0.25	3.1	36	L	S	None	6,7	low forage value for livestock; medium for wildlife;	http://plants.usda.gov/java/charProfile?symbol=CAST5
33-261	G	*Elymus trachycaulus*	slender wheatgrass	1	2.53	24	M	MZ,D			palatable; grazed by wildlife & livestock	http://plants.usda.gov/plantguide/pdf/pg_eltr7.pdf http://www.fs.fed.us/database/feis/plants/graminoid/elytra/all.html
33-261	G	*Elymus virginicus*	Virginia wild rye	1.5	2.31	48	M	S-MZ	None		Palatable, productive and nutritious forage for livestock and wildlife	http://plant-materials.nrcs.usda.gov/pubs/stpmcfs0758.pdf
33-261	G	*Panicum virgatum*	switchgrass	0.38	1.93	24-84	M	M,MZ	None	7,8,9	productive, high quality hay; biofuels; value to wildlife as well	http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf http://www.uwex.edu/ces/forage/pubs/switchgrass.pdf http://extension.missouri.edu/p/M181-23
33-261	G	*Poa palustris*	fowl bluegrass	1.06	50.7	24	M	S,M	None		serves as nurse crop; low palatibility; may substitute equivalent amount of seeds with more palatible species as budget allows	http://plants.usda.gov/java/charProfile?symbol=POPA2 Jacobson 2005
33-261	G	*Scirpus atrovirens*	dark green bulrush	0.19	31.7	60	E	S	None		serves as nurse crop	Jacobson 2005
33-261	G	*Scirpus cyperinus*	woolgrass	0.06	39	60	E	S	Nests		Historically rare in most Eco Sections 9 and 4; medium palatability for livestock	http://plants.usda.gov/java/charProfile?symbol=SCCY
33-261	G	*Sorghastrum nutans*	Indian grass	0.12	0.55	36-96	L	M	Nests	8,9,	high to fair forage value; wildlife value	http://plants.usda.gov/factsheet/pdf/fs_sonu2.pdf
33-261	G	*Spartina pectinata*	prairie cordgrass	0.38	0.91	48-120	L	S	None	7,8,9	forage quality variable; most palatable in spring; prevents erosion (soil stabilization); mowing and haying an option when soil moisture conditions allow; provides wildlife cover	http://www.fs.fed.us/database/feis/plants/graminoid/spapec/all.html
Graminoids subtotal: 12												
33-261	F	*Anemone canadensis*	Canada anemone	0.07	0.2	12-24	L	S	Low	5,6,7		
33-261	F	*Asclepias incarnata*	swamp milkweed	0.11	0.2	21-48	L	S	High	6,7	low palatability but high wildlife/pollinator value	http://plants.usda.gov/java/charProfile?symbol=ASIN
33-261	A	*Bidens frondosa*	leafy beggarticks	0.11	0.2	36	E	M	Medium	8,9,10	low palatability	http://plants.usda.gov/java/charProfile?symbol=BIFR
33-261	A	*Aster umbellatus (Doellingeria umbellata)*	flat-topped aster	0.06	1.5	40-72	L	S,M	Medium	8,9	Rare in 9, associated with groundwater seepage	
33-261	A	*Eutrochium maculatum (Eupatorium)*	spotted Joe pye weed	0.06	2.19	20-78	L	S	High	7,8,9	Food/nectar source for butterflies and birds; livestock may eat leaves, but not a prefered forage species	http://www.plant-materials.nrcs.usda.gov/pubs/mdpmcfs8331.pdf
33-261	A	*Helenium autumnale**	autumn sneezeweed	0.13	5.97	24-36	M	S	High	8,9,10	*may be poisnous to livestock; consider replacing with *Symphyotrichum puniceum* or removing and increasing seeding rates of other forbs	http://www.npwrc.usgs.gov/resource/plants/floramw/species/heleautu.htm
33-261	F	*Physostegia virginiana*	obedient plant	0.07	0.3	48	M	M	High	8,9		
33-261	A	*Rudbeckia laciniata*	tall coneflower	0.07	0.37	48-72	M	M	High	8,9	high palatability for livestock and wildlife; note: may be toxic to sheep	http://plants.usda.gov/java/charProfile?symbol=RULA3 http://aces.nmsu.edu/pubs/_circulars/CR-636.pdf
33-261	A	*Aster novae-angliae (Symphyotrichum)*	New England aster	0.07	1.56	36-54	L	S	Very High	9,10		http://plants.usda.gov/factsheet/pdf/fs_syno2.pdf
33-261	F	*Verbena hastata*	blue vervain	0.05	1.85	24-72	M	S,M,MZ	Medium	7,8,9		
33-261	F	*Zizia aurea*	golden alexanders	0.2	0.79	12-36	M	M,MZ	Low	4,5,6		http://plants.usda.gov/factsheet/pdf/fs_ziau.pdf
Forbs subtotal: 11												
Total Species Richness: 16			**Total Seeding Rate:**	**10 lbs/acre**	**169.7 Seeds/sqft**							
Total Cost/Acre: $569			(Opt.) Cover Crop - Oats/Winter Wheat	25 lbs/acre	11.14 Seeds/sqft							

Table 62. Utility Wet Meadow Seed Mix, suitable for sites with 6-8 weeks/year of saturated soil in the Agassiz Beach Ridges and Glacial Lakes landscapes.

Conservation Prairie - Dry NW Seed Mix											
Source	**Guild**	**Scientific Name**	**Common Name**	**Rate: PLS lb/acre**	**Rate: Seeds/sqft**	**Height (in.)**	**Succes-sional Stage**	**Hydro-logic Zone**	**Pollinator Value**	**Bloom Time**	**Notes**
Pick	G	*Andropogon gerardii*	big bluestem	1.5	5.51	36-96	L	M, MZ, D	Nests	8,9	
35-421	G	*Bouteloua curtipendula*	side-oats grama	1.4	3.09	12-36	M	MZ,D	Nests	7,8,9	
35-421	G	*Bouteloua gracilis*	blue grama	0.5	7.35	6-20	L	D	Nests		
35-421	G	*Bromus kalmii*	kalm's brome	0.9	2.64	18-36	M	MZ,D	None	8,9	
35-421	G	*Elymus canadensis*	nodding wild rye	1	1.91	36-60	E	MZ,D	None	7,8	
35-421	G	*Elymus trachycaulus*	slender wheatgrass	1	2.53	24	M	MZ,D			
35-421	G	*Hesperostipa spartea (Stipa)*	porcupine grass	0.45	0.11	48	L	D	None		
35-421	G	*Koeleria macrantha (pyramidata)*	junegrass	0.15	11.02	12-24	L	D	None		
35-421	G	*Schizachyrium scoparium*	little bluestem	2.3	12.67	12-30	L	MZ,D	None	8,9	
Pick	G	*Sorghastrum nutans*	Indian grass	1	4.41	36-96	L	M	Nests	8,9,	
35-421	G	*Sporobolus cryptandrus*	sand dropseed	0.08	5.88	12-36	L	MZ,D	None	7,8	Sand specialist
MNPC	G	*Sporobolus heterolepis*	prairie dropseed	0.25	1.47	18-48	L	MZ	Nests	8,9	
Graminoids subtotal: 12											
Pick	F	*Agastache foeniculum*	blue giant hyssop	0.05	1.65	24-48	M	MZ,D	Very High	7,8,9,10	Rare/not appropriate in E.S. 9 south/west of Minnesota River valley
35-421	F	*Allium stellatum*	Prairie Wild Onion	0.03	0.12	6-12	M	MZ,D	Medium	6,7	
Pick	L	*Amorpha canescens*	lead plant	0.1	0.59	18-48	L	MZ,D	Very High	6,7,8	
Pick	F	*Anemone patens*	pasque flower	0.01	0.07	6	L	D	Low	4,5	
Pick	A	*Antennaria plantaginifolia*	plantain-leaved pussytoes	0.01	1.01	12	L	D	None	4,5,6	
Pick	F	*Asclepias verticillata*	whorled milkweed	0.05	0.20	10-20	L	MZ,D	Very High	6,7,8,9	Rare in E.S. 4 north of Polk Co.
35-421	L	*Astragalus canadensis*	Canada milk vetch	0.08	0.42	12-48	M	MZ, D	Low	7,8	
Pick	L	*Astragalus crassicarpus*	ground plum	0.0625	0.12	4-12	M	D	High	5,6	
MNPC		*Castillegia sessiiflora*	downy paintbrush	0.01	0.73	12		MZ,D		5,6	
35-421	L	*Dalea candida*	white prairie clover	0.07	0.42	12-30	M	MZ,D	Medium	6,7,8	
35-421	L	*Dalea purpurea*	purple prairie clover	0.12	0.60	12-30	M	MZ,D	Very High	7,8	
35-421	L	*Desmodium canadense*	Canada tick trefoil	0.06	0.10	24-48	M	MZ	Low	7,8	Historically rare in E.S. 4
Pick	A	*Echinacea pallida var. angustifolia*	narrow-leaved purple coneflower	0.05	0.10	12-48	L	MZ,D	High	6,7	Not native in E.S. 4 north of Polk Co.
35-421	A	*Helianthus pauciflorus*	stiff sunflower	0.03	0.05	12-48	M	MZ,D	High	7,8	
35-421	A	*Heliopsis helianthoides*	ox-eye	0.07	0.14	24-60	M	MZ, D	Very Low	6,7,8	
35-421	A	*Liatris aspera*	rough blazing star	0.03	0.15	24-36	L	MZ,D	High	7,8,9	
35-421	A	*Liatris punctata*	dotted blazing star	0.02	0.05	12-24	L	D	Very High	7,8,9	
35-421	F	*Monarda fistulosa*	wild bergamot	0.03	0.77	24-48	M	MZ,D	Very High	7,8	
35-421	A	*Oligoneuron rigidum (Solidago rigida)*	stiff goldenrod	0.03	0.45	12-60	M	MZ, D	Very High	8,9	
Pick	F	*Penstemon grandiflorus*	large-flowered beard tongue	0.02	0.10	24-40	L	D	Very High	6,7	Native only to naturally sand-gravel areas within this range
35-421	A	*Ratibida columnifera*	prairie coneflower	0.07	0.93	24-36	M	MZ,D	Medium	7,8	Rare north of Polk Co. in E.S. 4
Pick	F	*Rosa arkansana*	prairie rose	0.2	0.18	24	L	MZ,D	High	6,7,8	
35-421	A	*Rudbeckia hirta*	black-eyed susan	0.07	2.03	12-36	E	MZ	Very Low	7,8,9,10	
Pick	F	*Sisyrinchium campestre*	field blue-eyed grass	0.01	0.17	6	L	D	Low	5,6	
35-421	A	*Solidago nemoralis*	gray goldenrod	0.02	2.00	6-36	L	D	High	7,8	
Pick	A	*Solidago speciosa*	showy goldenrod	0.01	0.35	12-50	M	MZ	Very High	8,9	rare in E.S. 9 south/west of MN River valley
Pick	A	*Symphyotrichum sericeum (Aster sericeus)*	silky aster	0.02	0.19	12-30	L	D	Very High	8,9,10	
35-421	A	*Symphyotricum ericoides (Aster)*	heath aster	0.01	1.10	12-36	M	MZ,D	High	8,9,10	
35-421	A	*Symphyotricum laeve (Aster)*	smooth aster	0.03	0.61	31-54	L	MZ,D	High	8,9,10	
Pick	F	*Tradescantia bracteata*	bracted spiderwort	0.05	0.18	12	M	MZ,D	High	5,6,7	In E.S. 4, not north of Polk Co.
Pick	F	*Verbena stricta*	hoary vervain	0.1	1.03	18-36	M	D	Medium	7,8,9	
Pick	F	*Viola pedatifida*	bearded birdfoot violet	0.05	0.51	6	L	MZ,D	Low	4,5,6	Preferred food of regal fritillaries
35-421	F	*Zizia aptera*	heart-leaved alexanders	0.06	0.24	24	L	MZ	Low	4,5	
Forbs subtotal: 33											
Total Species Richness: 45			**Total Seeding Rate:**	**12 lbs/acre**	**76 Seeds/sqft**						
Total Cost/Acre: $788			(Opt.) Cover Crop - Oats/Winter Wheat	3 lbs/acre	1.34 Seeds/sqft						

Table 63. Seed mix for dry conservation prairies in northwest Minnesota, including the Agassiz Beach Ridges landscape area.

Conservation Prairie - Mesic NW Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sqft	Height (in.)	Succes-sional Stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes
35-441	G	*Andropogon gerardii*	big bluestem	1	3.67	36-96	L	M-D	Nests	8,9	
35-441	G	*Bouteloua curtipendula*	side-oats grama	1.2	2.64	12-36	M	MZ,D	Nests	7,8,9	
Pick	G	*Bromus kalmii*	kalm's brome	0.4	1.18	18-36	M	MZ,D	None	8,9	
Pick	G	*Carex bicknellii*	Bicknell's sedge	0.02	0.12	36	L	MZ	None		
Pick	G	*Carex brevior*	short sedge	0.2	2.13	12	L	MZ,D	None		
35-441	G	*Elymus canadensis*	nodding wild rye	1	1.91	36-60	E	MZ,D	None	7,8	
35-441	G	*Elymus trachycaulus*	slender wheatgrass	1	2.54	24	M	MZ,D			
35-441	G	*Hesperostipa spartea*	porcupine grass	0.42	0.11	48	L	D	None		
Pick	G	*Koeleria macrantha (pyramidata)*	junegrass	0.03	2.20	12-24	L	D	None		
35-441	G	*Panicum virgatum*	switchgrass	0.18	0.90	24-84	M	M,MZ	None	7,8,9	
35-441	G	*Schizachyrium scoparium*	little bluestem	1.5	8.28	12-30	L	MZ,D	None	8,9	
35-441	G	*Sorghastrum nutans*	Indian grass	1.2	5.29	36-96	L	M	Nests	8,9,	
MNPC	G	*Sporobolus heterolepis*	prairie dropseed	0.25	1.47	18-48	L	MZ	Nests	8,9	
Graminoids subtotal: 13											
Pick	F	*Agastache foeniculum*	blue giant hyssop	0.05	1.65	24-48	M	MZ,D	Very High	7,8,9,10	
35-441	F	*Allium stellatum*	Prairie Wild Onion	0.03	0.12	6-12	M	MZ,D	Medium	6,7	
Pick	L	*Amorpha canescens*	lead plant	0.05	0.29	18-48	L	MZ,D	Very High	6,7,8	
MNPC	L	*Amorpha nana*	fragrant false indigo	0.04	0.15						
Pick	F	*Anemone cylindrica*	long-headed thimbleweed	0.03	0.29	18-24	L	MZ,D	Low	6,7	
Pick	F	*Asclepias verticillata*	whorled milkweed	0.04	0.16	10-20	L	MZ,D	Very High	6,7,8,9	
35-441	L	*Astragalus canadensis*	Canada milk vetch	0.06	0.37	12-48	M	MZ, D	Low	7,8	
35-441	L	*Dalea candida*	white prairie clover	0.06	0.42	12-30	M	MZ,D	Medium	6,7,8	
35-441	L	*Dalea purpurea*	purple prairie clover	0.09	0.50	12-30	M	MZ,D	Very High	7,8	
35-441	L	*Desmodium canadense*	Canada tick trefoil	0.08	0.17	24-48	M	MZ	Low	7,8	Historically rare in EcoSection 4
Pick	A	*Echinacea pallida var. angustifolia*	narrow-leaved purple coneflower	0.08	0.15	12-48	L	MZ,D	High	6,7	
Pick	F	*Gentiana andrewsii*	bottle gentian	0.01	1.03	6-24	L	M,MZ	High	8,9	
Pick	F	*Geum triflorum*	prairie smoke	0.01	0.10	6-18	L	MZ,D	None	5,6	
Pick	L	*Glycyrrhiza lepidota*	wild licorice	0.07	0.10	12-36	M	MZ	Medium	6,7	
Pick	A	*Helianthus maximilianii*	Maximilian's sunflower	0.04	0.19	48-60	E	M, MZ	High	9,10	
35-441	A	*Heliopsis helianthoides*	ox-eye	0.06	0.14	24-60	M	MZ, D	Very Low	6,7,8	
35-441	A	*Liatris aspera*	rough blazing star	0.03	0.18	24-36	L	MZ,D	High	7,8,9	
Pick	A	*Liatris ligulistylis*	northern plains blazing star	0.03	0.11	18-36	L	S-MZ	High	8,9	
35-441	A	*Liatris pycnostachya*	great blazing star	0.06	0.24	24-48	L	M,MZ	High	7,8	
35-441	F	*Monarda fistulosa*	wild bergamot	0.03	0.77	24-48	M	MZ,D	Very High	7,8	
35-441	A	*Oligoneuron rigidum (Solidago)*	stiff goldenrod	0.03	0.45	12-60	M	MZ, D	Very High	8,9	
MNPC	F	*Pedicularis canadensis*	wood betony	0.01	0.12						
Pick	F	*Potentilla arguta*	tall cinquefoil	0.03	2.53	24	L	MZ,D	Medium	6,7,8,9	
Pick	A	*Prenanthes racemosa*	smooth rattlesnakeroot	0.02	0.15	36	M	M,MZ	Medium	7,8,9,10	
35-441	F	*Pycnanthemum*	Virginia mountain mint	0.04	3.00	12-36	L	S-MZ	High	6,7,8,9	
35-441	A	*Ratibida columnifera*	prairie coneflower	0.06	0.93	24-36	M	MZ,D	Medium	7,8	
Pick	F	*Rosa arkansana*	prairie rose	0.2	0.18	24	L	MZ,D	High	6,7,8	
35-441	A	*Rudbeckia hirta*	black-eyed susan	0.07	2.20	12-36	E	MZ	Very Low	7,8,9,10	
Pick	A	*Solidago speciosa*	showy goldenrod	0.01	0.35	12-50	M	MZ	Very High	8,9	
Pick	A	*Symphyotrichum novae-angliae (Aster)*	New England aster	0.01	0.24	36-54	L	S	Very High	9,10	
35-441	A	*Symphyotricum ericoides (Aster)*	heath aster	0.01	1.10	12-36	M	MZ,D	High	8,9,10	
35-441	A	*Symphyotricum laeve (Aster laevis)*	smooth aster	0.03	0.61	31-54	L	MZ,D	High	8,9,10	
MNPC	F	*Thalictrum dasycarpum*	tall meadow-rue	0.12	0.48	20-60	L	S	None	5,6,7	
Pick	F	*Tradescantia bracteata*	bracted spiderwort	0.05	0.18	12	M	MZ,D	High	5,6,7	
35-441	F	*Verbena hastata*	blue vervain	0.09	2.91	24-72	M	S,M,MZ	Medium	7,8,9	
Pick	F	*Veronicastrum virginicum*	Culver's root	0.01	2.94	36-72	L	S-MZ	Very High	7,8	
Pick	F	*Viola pedatifida*	bearded birdfoot violet	0.04	0.41	6	L	MZ,D	Low	4,5,6	Preferred food of regal fritillaries
35-441	F	*Zizia aurea*	golden alexanders	0.17	0.70	12-36	M	M,MZ	Low	4,5,6	
Forbs subtotal: 32											
Total Species Richness: 45			**Total Seeding Rate:**	**10.4 lbs/acre**	**59 Seeds/sqft**						
Total Cost/Acre: $836			(Opt.) Cover Crop - Oats/Winter Wheat	2.5 lbs/acre	1.12 Seeds/sqft						

Table 64. Seed mix for mesic conservation prairies in northwest Minnesota, including the Agassiz Beach Ridges landscapes.

Conservation Prairie - Dry SW Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sqft	Height (in.)	Successional Stage	Hydrologic Zone	Pollinator Value	Bloom Time	Notes
Pick	G	*Andropogon gerardii*	big bluestem	1.5	5.51	36-96	L	M, MZ, D	Nests	M	
35-521	G	*Bouteloua curtipendula*	side-oats grama	1.75	3.86	12-36	M	MZ,D	Nests	7,8,9	
35-521	G	*Bouteloua gracilis*	blue grama	0.4	5.88	6-20	L	D	Nests		
35-521	G	*Elymus canadensis*	nodding wild rye	1.2	2.29	36-60	E	MZ,D	None	7,8	
35-521	G	*Elymus trachycaulus*	slender wheatgrass	1	2.53	24	M	MZ,D			
35-521	G	*(Stipa)*	porcupine grass	0.8	0.20	48	L	D	None		
35-521	G	*Koeleria macrantha (pyramidata)*	junegrass	0.2	14.69	12-24	L	D	None		
Pick	G	*Panicum oligosanthes*	Scribner's panic grass	0.01	0.03	12	M	MZ,D			
35-521	G	*Schizachyrium scoparium*	little bluestem	1.75	9.64	12-30	L	MZ,D	None	8,9	
Pick	G	*Sorghastrum nutans*	Indian grass	0.8	3.53	36-96	L	M	Nests	8,9,	
35-521	G	*Sporobolus cryptandrus*	sand dropseed	0.1	7.35	12-36	L	MZ,D	None	7,8	Sand specialist
Pick	G	*Sporobolus heterolepis*	prairie dropseed	0.2	1.18	18-48	L	MZ	Nests	8,9	
Graminoids subtotal: 12											
Pick	F	*Allium stellatum*	Prairie Wild Onion	0.04	0.16	6-12	M	MZ,D	Medium	6,7	
Pick	L	*Amorpha canescens*	lead plant	0.1	0.59	18-48	L	MZ,D	Very High	6,7,8	
Pick	F	*Anemone cylindrica*	long-headed thimbleweed	0.02	0.19	18-24	L	MZ,D	Low	6,7	
Pick	A	*Antennaria plantaginifolia*	plantain-leaved pussytoes	0.01	1.01	12	L	D	None	4,5,6	
Pick	F	*Asclepias tuberosa*	butterfly milkweed	0.02	0.03	24-36	L	MZ,D	Very High	6,7,8	Not native in west part of E.S. 9
35-521	F	*Asclepias verticillata*	whorled milkweed	0.01	0.05	10-20	L	MZ,D	Very High	6,7,8,9	Rare in E.S. 4 north of Polk Co.
35-521	L	*Astragalus canadensis*	Canada milk vetch	0.06	0.40	12-48	M	MZ, D	Low	7,8	
Pick	A	*Coreopsis palmata*	bird's foot coreopsis	0.5	1.84	12-30	L	MZ, D	Medium	7,8	
35-521	L	*Dalea candida*	white prairie clover	0.06	0.40	12-30	M	MZ,D	Medium	6,7,8	
35-521	L	*Dalea purpurea*	purple prairie clover	0.1	0.55	12-30	M	MZ,D	Very High	7,8	
35-521	L	*Desmodium canadense*	Canada tick trefoil	0.04	0.09	24-48	M	MZ	Low	7,8	Historically rare in E.S. 4
35-521	A	*Echinacea pallida var. angustifolia*	narrow-leaved purple coneflower	0.08	0.20	12-48	L	MZ,D	High	6,7	Not native in E.S. 4 north of Polk Co.
35-521	A	*Heliopsis helianthoides*	ox-eye	0.04	0.10	24-60	M	MZ, D	Very Low	6,7,8	
35-521	L	*Lespedeza capitata*	round-headed bush clover	0.03	0.10	12-24	M	MZ,D	Low	7,8	
35-521	A	*Liatris aspera*	rough blazing star	0.02	0.13	24-36	L	MZ,D	High	7,8,9	
35-521	A	*Liatris punctata*	dotted blazing star	0.02	0.05	12-24	L	D	Very High	7,8,9	
MNPC	F	*Linum sulcatum*	grooved yellow flax	0.08	0.12						
35-521	F	*Monarda fistulosa*	wild bergamot	0.03	0.76	24-48	M	MZ,D	Very High	7,8	
Pick	F	*Oenothera biennis*	common evening primrose	0.01	0.33	72	E	MZ,D	Medium	6,7,8,9	biennial
35-521	A	*Oligoneuron rigidum (Solidago rigida)*	stiff goldenrod	0.07	1.00	12-60	M	MZ, D	Very High	8,9	
Pick	F	*Penstemon grandiflorus*	large-flowered beard tongue	0.02	0.10	24-40	L	D	Very High	6,7	Native only to naturally sand-gravel areas within this range
Pick	F	*Potentilla arguta*	tall cinquefoil	0.02	1.69	24	L	MZ,D	Medium	6,7,8,9	
Pick	A	*Ratibida pinnata*	gray-headed	0.2	2.20	36-72	M	MZ	Medium	7,8,9	
Pick	F	*Rosa arkansana*	prairie rose	0.2	0.18	24	L	MZ,D	High	6,7,8	
35-521	A	*Rudbeckia hirta*	black-eyed susan	0.07	2.20	12-36	E	MZ	Very Low	7,8,9,10	
Pick	F	*Sisyrinchium campestre*	field blue-eyed grass	0.01	0.17	6	L	D	Low	5,6	
Pick	A	*Solidago nemoralis*	gray goldenrod	0.01	1.10	6-36	L	D	High	7,8	
35-521	A	*Symphyotrichum ericoides (Aster)*	heath aster	0.01	0.90	12-36	M	MZ,D	High	8,9,10	
35-521	A	*Symphyotrichum laeve (Aster)*	smooth aster	0.03	0.60	31-54	L	MZ,D	High	8,9,10	
MNPC	A	*Symphyotrichum oolentangiense var. oolentangiense (Aster)*	skyblue aster	0.02	0.59						
Pick	A	*Symphyotrichum sericeum (Aster sericeus)*	silky aster	0.04	0.38	12-30	L	D	Very High	8,9,10	
35-521	F	*Tradescantia bracteata*	bracted spiderwort	0.02	0.06	12	M	MZ,D	High	5,6,7	In E.S. 4, not north of Polk
35-521	F	*Verbena stricta*	hoary vervain	0.1	1.00	18-36	M	D	Medium	7,8,9	
Pick	F	*Viola pedatifida*	bearded birdfoot violet	0.03	0.31	6	L	MZ,D	Low	4,5,6	Preferred food of regal fritillaries
35-521	F	*Zizia aurea*	golden alexanders	0.21	0.85	12-36	M	M,MZ	Low	4,5,6	
Forbs subtotal: 35											
Total Species Richness: 47			**Total Seeding Rate:**	**12 lbs/acre**	**77 Seeds/sqft**						
Total Cost/Acre: $872			(Opt.) Cover Crop - Oats/Winter Wheat	4.25 lbs/acre	1.9 Seeds/sqf						

Table 65. Seed mix for dry conservation prairies in southwest Minnesota, including the Glacial Lakes landscape area.

Conservation Prairie - Mesic SW Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sqft	Height	Succes-sional stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes
35-541	G	*Andropogon gerardii*	big bluestem	1.5	5.51	36-96	L	M-D	Nests	8,9	
35-541	G	*Bouteloua curtipendula*	side-oats grama	0.9	1.98	12-36	M	MZ,D	Nests	7,8,9	
Pick	G	*Carex bicknellii*	Bicknell's sedge	0.08	0.50	36	L	MZ	None		
Pick	G	*Carex brevior*	short sedge	0.05	0.53	12	L	MZ,D	None		
35-541	G	*Elymus canadensis*	nodding wild rye	0.9	1.71	36-60	E	MZ,D	None	7,8	
35-541	G	*Elymus trachycaulus*	slender wheatgrass	0.9	2.27	24	M	MZ,D			
Pick	G	*Muhlenbergia racemosa*	marsh muhly grass	0.05	1.47	24	L	M,MZ	None		
35-541	G	Nassella viridula	green needle grass	0.44	1.70						
35-541	G	*Panicum virgatum*	switchgrass	0.16	0.80	24-84	M	M,MZ	None	7,8,9	
35-541	G	Pascopyrum smithii	western wheatgrass	0.5	1.30	12-36	M	MZ,D	None	7	
35-541	G	*Schizachyrium scoparium*	little bluestem	1.5	8.27	12-30	L	MZ,D	None	8,9	
35-541	G	*Sorghastrum nutans*	Indian grass	2	8.82	36-96	L	M	Nests	8,9,	
MNPC	G	*Spartina pectinata*	prairie cordgrass	0.1	0.24	48-120	L	S	None	7,8,9	
Pick	G	*Sporobolus heterolepis*	prairie dropseed	0.25	1.47	18-48	L	MZ	Nests	8,9	
Graminoids subtotal: 14											
Pick	F	*Allium stellatum*	prairie wild onion	0.05	0.20	6-12	M	MZ,D	Medium	6,7	
Pick	L	*Amorpha canescens*	lead plant	0.06	0.35	18-48	L	MZ,D	Very High	6,7,8	
Pick	F	*Anemone cylindrica*	thimbleweed	0.03	0.29	18-24	L	MZ,D	Low	6,7	
Pick	F	*Asclepias tuberosa*	butterfly milkweed	0.05	0.08	24-36	L	MZ,D	Very High	6,7,8	Not native in west part of E.S. 9
Pick	F	*Asclepias verticillata*	whorled milkweed	0.04	0.16	10-20	L	MZ,D	Very High	6,7,8,9	Rare in E.S. 4 north of Polk Co.
35-541	L	*Astragalus canadensis*	Canada milk vetch	0.06	0.40	12-48	M	MZ, D	Low	7,8	
35-541	L	*Chamaecrista fasciculata*	partridge pea	0.1	0.10	6-24	E	MZ,D	Very High	7,8,9	Restricted to sandy sites along MN River in E.S. 9
Pick	A	*Coreopsis palmata*	bird's foot coreopsis	0.5	1.84	12-30	L	MZ, D	Medium	7,8	
35-541	L	*Dalea candida*	white prairie clover	0.03	0.20	12-30	M	MZ,D	Medium	6,7,8	
35-541	L	*Dalea purpurea*	purple prairie clover	0.07	0.40	12-30	M	MZ,D	Very High	7,8	
35-541	L	*Desmodium canadense*	Canada tick trefoil	0.05	0.11	24-48	M	MZ	Low	7,8	Historically rare in E.S. 4
35-541	A	*Echinacea pallida var. angustifolia*	narrow-leaved purple coneflower	0.08	0.20	12-48	L	MZ,D	High	6,7	Not native north of Polk Co. in E.S. 4
Pick	F	*Gentiana andrewsii*	bottle gentian	0.01	1.03	6-24	L	M,MZ	High	8,9	
Pick	A	*Helianthus maximilianii*	sunflower	0.04	0.19	48-60	E	M, MZ	High	9,10	
35-541	A	*Heliopsis helianthoides*	ox-eye	0.06	0.14	24-60	M	MZ, D	Very Low	6,7,8	
Pick	L	*Lespedeza capitata*	clover	0.06	0.18	12-24	M	MZ,D	Low	7,8	
35-541	A	*Liatris aspera*	rough blazing star	0.03	0.20	24-36	L	MZ,D	High	7,8,9	
35-541	A	*Liatris pycnostachya*	great blazing star	0.02	0.10	24-48	L	M,MZ	High	7,8	Not native north of Polk Co in E.S. 4
35-541	F	*Monarda fistulosa*	wild bergamot	0.04	0.90	24-48	M	MZ,D	Very High	7,8	
35-541	A	*Oligoneuron rigidum (Solidago)*	stiff goldenrod	0.03	0.50	12-60	M	MZ, D	Very High	8,9	
MNPC	F	*Pedicularis canadensis*	wood betony	0.01	0.12						
Pick	A	*Prenanthes racemosa*	smooth rattlesnakeroot	0.02	0.15	36	M	M,MZ	Medium	7,8,9,10	
35-541	A	*Ratibida pinnata*	gray-headed coneflower	0.07	0.80	36-72	M	MZ	Medium	7,8,9	
Pick	F	*Rosa arkansana*	prairie rose	0.1	0.09	24	L	MZ,D	High	6,7,8	
35-541	A	*Rudbeckia hirta*	black-eyed susan	0.06	2.00	12-36	E	MZ	Very Low	7,8,9,10	
Pick	A	*Solidago speciosa*	showy goldenrod	0.01	0.35	12-50	M	MZ	Very High	8,9	Rare in E.S. 9 south/west of MN River valley
MNPC	A	*Symphyotrichum oolentangiense var. oolentangiense (Aster)*	skyblue aster	0.02	0.59						
Pick	A	*Symphyotricum ericoides (Aster)*	heath aster	0.01	0.73	12-36	M	MZ,D	High	8,9,10	
35-541	A	*Symphyotricum laeve (Aster)*	smooth aster	0.03	0.60	31-54	L	MZ,D	High	8,9,10	
MNPC	F	*Thalictrum dasycarpum*	tall meadow-rue	0.08	0.32						
Pick	F	*Tradescantia bracteata*	bracted spiderwort	0.03	0.11	12	M	MZ,D	High	5,6,7	In E.S. 4, not north of Polk Co.
35-541	F	*Verbena hastata*	blue vervain	0.07	2.50	24-72	M	S,M,MZ	Medium	7,8,9	
35-541	F	*Verbena stricta*	hoary vervain	0.05	0.50	18-36	M	D	Medium	7,8,9	
Pick	F	*Veronicastrum virginicum*	Culver's root	0.01	2.94	36-72	L	S-MZ	Very High	7,8	
Pick	F	*Viola pedatifida (V. palmata)*	bearded birdfoot violet	0.03	0.31	6	L	MZ,D	Low	4,5,6	Preferred food of regal fritillaries
35-541	F	*Zizia aurea*	golden alexanders	0.25	1.00	12-36	M	M,MZ	Low	4,5,6	
Forbs subtotal: 36											
Total Species Richness: 50			**Total Seeding Rate:**	**11.6 lbs/acre**	**57 Seeds/sqft**						
Total Cost/Acre: $646			(Opt.) Cover Crop - Oats/Winter Wheat	3.2 lbs/acre	1.42 Seeds/sqft						

Table 66. Seed mix for mesic conservation prairies in southwest Minnesota, including the Glacial Lakes landscape area.

Conservation Wet Prairie Seed Mix											
Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sq ft	Height	Succes-sional stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes
34-262	G	*Andropogon gerardii*	big bluestem	1.25	4.59	36-96	L	M-D	Nests	8,9	
34-262	G	*Bromus ciliatus*	fringed brome	1.6	5.88	24-48	M	S	None	7,8	Rare or not native across much of southern MN
34-262	G	*Calamagrostis canadensis**	bluejoint	0.04	4.00	24-60	L	S	None	6,7,8	*Not appropriate for ABR; replace with *C. stricta* (limited availability; obtain via combine-harvest
Pick	G	*Carex hystericina*	porcupine sedge	0.18	1.98	36	M	E	None	6,7	
Pick	G	*Carex interior*	interior sedge	0.01	0.14	24	L	S,M	None		
Pick	G	*Carex scoparia*	pointed broom sedge	0.1	3.09	24	L	S	None		Substitute for *C. pellita* (state seed mix); lower mortality
Pick	G	*Carex stipata*	awl-fruited sedge	0.2	2.50	36	L	S	None	6,7	Substitute for *C. stricta* (state seed mix); higher germination
34-262	G	*Carex vulpinoidea*	fox sedge	0.1	3.50	36	E	S	None	8,9	
34-262	G	*Elymus virginicus*	Virginia wild rye	1.75	2.70	48	M	S-MZ	None		
34-262	G	*Glyceria grandis*	tall manna grass	0.15	3.80	48-60	L	E	None	7	
34-262	G	*Glyceria striata*	fowl manna grass	0.13	4.30	36	M	S	None		
Pick	G	*Juncus dudleyi*	Dudley's rush	0.01	11.75	24	E	M	None		
34-262	G	*Panicum virgatum*	switchgrass	0.75	3.85	24-84	M	M,MZ	None	7,8,9	
34-262	G	*Poa palustris*	fowl bluegrass	0.2	9.60	24	M	S,M	None		
34-262	G	*Scirpus atrovirens*	dark green bulrush	0.1	17.74	60	E	S	None		
34-262	G	*Scirpus cyperinus*	woolgrass	0.03	16.00	60	E	S	Nests		Historically rare in most of E.S. 4 and 9
34-262	G	*Sorghastrum nutans*	Indian grass	0.5	2.20	36-96	L	M	Nests	8,9,	
34-262	G	*Spartina pectinata*	prairie cordgrass	0.5	1.21	48-120	L	S	None	7,8,9	
MNPC	G	*Sporobolus heterolepis*	prairie dropseed	0.25	1.47	18-48	L	MZ	Nests	8,9	
Graminoids subtotal: 19											
34-262	F	*Anemone canadensis*	Canada anemone	0.03	0.09	12-24	L	S	Low	5,6,7	
34-262	F	*Asclepias incarnata*	swamp milkweed	0.08	0.14	21-48	L	S	High	6,7	
34-262	L	*Desmodium canadense*	Canada tick trefoil	0.5	1.00	24-48	M	MZ	Low	7,8	Historically rare in E.S. 4
34-262	A	*Doellingeria umbellata (Aster umbellatus)*	flat-topped aster	0.05	1.20	40-72	L	S,M	Medium	8,9	Rare in E.S. 9, associated with groundwater seepage
34-262	A	*Eupatorium perfoliatum*	common boneset	0.03	2.00	36-60	L	S	High	8,9	
34-262	A	*Euthamia graminifolia*	grass-leaved goldenrod	0.02	2.00	24	M	M,MZ	Low	7,8,9	
34-262	A	*Eutrochium maculatum (Eupatorium maculatum)*	spotted Joe pye weed	0.04	1.50	20-78	L	S	High	7,8,9	
Pick	F	*Gentiana andrewsii*	bottle gentian	0.02	2.06	6-24	L	M,MZ	High	8,9	
34-262	A	*Helenium autumnale*	autumn sneezeweed	0.05	2.39	24-36	M	S	High	8,9,10	
Pick	A	*Helianthus maximilianii*	Maximilian's sunflower	0.02	0.10	48-60	E	M, MZ	High	9,10	
Pick	F	*Iris versicolor*	northern blue flag	0.3	0.14	24-36	L	S,M	Low	5,6,7	Do not use in western half of E.S. 9
Pick	A	*Liatris ligulistylis*	northern plains blazing star	0.05	0.18	18-36	L	S-MZ	High	8,9	
34-262	A	*Liatris pycnostachya*	great blazing star	0.02	0.10	24-48	L	M,MZ	High	7,8	Not native north of Polk Co in E.S. 4
34-262	F	*Lobelia siphilitica*	great lobelia	0.01	1.40	12-48	M	M	Very High	7,8,9	Not native north of Polk Co in E.S. 4
Pick	F	*Lobelia spicata*	rough-spiked lobelia	0.01	0.33	12-24	M	M,MZ	High	8,9	
MNPC	F	*Lycopus americanus*	cut-leaved bugleweed	0.03	1.43	24		S,M		7,8,9	
34-262	F	*Mimulus ringens*	blue monkey flower	0.01	6.40	24	M	S	Low	6,7,8,9	
Pick	F	*Pedicularis lanceolata*	swamp lousewort	0.04	0.65	6-18	M	M	Medium	8,9	
34-262	F	*Pycnanthemum virginianum*	Virginia mountain mint	0.08	6.50	12-36	L	S-MZ	High	6,7,8,9	Do not use in E.S. 4 north of Pennington Co
Pick	A	*Rudbeckia laciniata*	tall coneflower	0.02	0.10	48-72	M	M	High	8,9	
Pick	A	*Solidago riddellii*	Riddell's goldenrod	0.05	1.71	36	L	M	Very High	8,9,10	
Pick	A	*Symphyotrichum lanceolatum (Aster*	eastern panicled aster	0.03	1.72	24-48	L	S	Medium	9,10	
Pick	A	*Symphyotrichum novae-angliae (Aster)*	New England aster	0.05	1.21	36-54	L	S	Very High	9,10	
34-262	A	*Symphyotrichum puniceum (Aster puniceus)*	red-stemmed aster	0.08	2.40	60	L	S	High	8,9,10	
Pick	F	*Thalictrum dasycarpum*	tall meadow-rue	0.12	0.48	20-60	L	S	None	5,6,7	
34-262	F	*Verbena hastata*	blue vervain	0.15	5.25	24-72	M	S,M,MZ	Medium	7,8,9	
34-262	A	*Vernonia fasciculata*	bunched ironweed	0.03	0.30	30-51	L	S	High	8,9	
34-262	F	*Veronicastrum virginicum*	Culver's root	0.02	6.00	36-72	L	S-MZ	Very High	7,8	
34-262	F	*Zizia aurea*	golden alexanders	0.25	1.03	12-36	M	M,MZ	Low	4,5,6	
Forbs subtotal: 29											
Total Species Richness: 48			**Total Seeding Rate:**	**11.5**	**150**						
Total Cost/Acre: $1210			(Opt.) Cover Crop - Oats/Winter Wheat	6.2	2.76						

Table 67. Seed mix for conservation wet prairies, suitable for sites with 3-4 weeks saturated soil annually in the Agassiz Beach Ridges and Glacial Lakes landscape areas.

Conservation Wet Meadow Seed Mix

Source	Guild	Scientific Name	Common Name	Rate: PLS lb/acre	Rate: Seeds/sq ft	Height (in.)	Succes-sional Stage	Hydro-logic Zone	Pollinator Value	Bloom Time	Notes
34-271	G	*Bromus ciliatus*	fringed brome	1.5	5.51	24-48	M	S	None	7,8	Rare or not native across much of southern MN
34-271	G	*Calamagrostis canadensis**	bluejoint	0.05	5.00	24-60	L	S	None	6,7,8	*Not appropriate for ABR; replace with *C. stricta* (limited availability; obtain via combine-harvest sources)
34-271	G	*Carex comosa*	bristly sedge	0.4	4.41	20-50	M	E	None	7,8	
Pick	G	*Carex hystericina*	porcupine sedge	0.4	4.41	36	M	E	None	6,7	
Pick	G	*Carex interior*	interior sedge	0.01	0.14	24	L	S,M	None		
Pick	G	*Carex lacustris*	lake sedge	0.03	0.12	20-50	L	E,S	None	6,7,8	
MNPC	G	*Carex prairea*	prairie sedge	0.06	1.85						
34-271	G	*Carex scoparia*	pointed broom sedge	0.05	1.60	24	L	S	None		If *C. rostrata* is available; substitute for *C. scoparia*
34-271	G	*Carex stipata*	awl-fruited sedge	0.17	2.10	36	L	S	None	6,7	
34-271	G	*Carex vulpinoidea*	fox sedge	0.14	5.00	36	E	S	None	8,9	
Pick	G	*Eleocharis palustris*	marsh spikerush	0.05	0.15	15	M	S	None		
34-271	G	*Elymus virginicus*	Virginia wild rye	2	3.09	48	M	S-MZ	None		
34-271	G	*Glyceria grandis*	tall manna grass	0.15	3.90	48-60	L	E	None	7	
34-271	G	*Glyceria striata*	fowl manna grass	0.1	3.30	36	M	S	None		
Pick	G	*Juncus nodosus*	knotted rush	0.02	7.35	24	E	S	None		
34-271	G	*Juncus tenuis*	path rush	0.04	15.00	6-12	L	S-MZ	None	7	
34-271	G	*Leersia oryzoides*	rice cut grass	0.25	3.10	48	E	S	None		
34-271	G	*Poa palustris*	fowl bluegrass	0.25	11.94	24	M	S,M	None		
34-271	G	*Scirpus atrovirens (or S. pallidus, per MNPC)*	dark green bulrush	0.12	20.28	60	E	S	None		
34-271	G	*Scirpus cyperinus*	woolgrass	0.05	31.22	60	E	S	Nests		Historically rare in most of E.S. 4 and 9
Pick	G	*Spartina pectinata*	prairie cordgrass	0.1	0.24	48-120	L	S	None	7,8,9	
Graminoids subtotal: 21											
Pick	F	*Anemone canadensis*	Canada anemone	0.03	0.09	12-24	L	S	Low	5,6,7	
34-271	F	*Asclepias incarnata*	swamp milkweed	0.24	0.43	21-48	L	S	High	6,7	
Pick	F	*Caltha palustris*	marigold	0.02	0.19	8-16	M	E	Medium	4,5	
Pick	A	*Doellingeria umbellata (Aster umbellatus)*	flat-topped aster	0.01	0.25	40-72	L	S,M	Medium	8,9	Rare in E.S. 9, associated with groundwater seepage
34-271	A	*Eupatorium perfoliatum*	common boneset	0.02	1.30	36-60	L	S	High	8,9	
34-271	A	*Euthamia graminifolia*	grass-leaved goldenrod	0.01	1.00	24	M	M,MZ	Low	7,8,9	
34-271	A	*Eutrochium maculatum (Eupatorium maculatum)*	spotted Joe pye weed	0.02	0.75	20-78	L	S	High	7,8,9	
34-271	A	*Helenium autumnale*	autumn sneezeweed	0.03	1.30	24-36	M	S	High	8,9,10	
Pick	F	*Iris versicolor*	northern blue flag	0.1	0.05	24-36	L	S,M	Low	5,6,7	Do not use in west half of E.S. 9
Pick	L	*Lathyrus palustris*	marsh vetchling			24	M	S,M	Medium	6,7,8	
Pick	A	*Liatris ligulistylis*	star	0.05	0.18	18-36	L	S-MZ	High	8,9	
34-271	F	*Lobelia siphilitica*	great lobelia	0.02	2.90	12-48	M	M	Very High	7,8,9	Not native north of Polk Co in E.S.
MNPC	F	*Lycopus asper*	rough bugleweed	0.05	0.28						
34-271	F	*Mimulus ringens*	blue monkey flower	0.01	6.80	24	M	S	Low	6,7,8,9	
MNPC	F	*Pedicularis lanceolata*	swamp lousewort	0.04	0.65	6-18	M	M	Medium	8,9	
34-271	F	*Pycnanthemum virginianum*	Virginia mountain mint	0.06	5.10	12-36	L	S-MZ	High	6,7,8,9	Do not use in E.S. 4 north of Pennington Co
34-271	A	*Solidago gigantea*	giant goldenrod	0.02	1.50	72	L	S	High	8,9	
Pick	A	*Solidago riddellii*	Riddell's goldenrod	0.05	1.71	36	L	M	Very High	8,9,10	calcareous (alkaline soils ph 7-8)
34-271	A	*Symphyotrichum lanceolatum (Aster*	eastern panicled aster	0.03	1.50	24-48	L	S	Medium	9,10	
Pick	A	*Symphyotrichum novae-angliae (Aster)*	New England aster	0.06	1.45	36-54	L	S	Very High	9,10	
34-271	A	*Symphyotrichum puniceum (Aster puniceus)*	red-stemmed aster	0.17	5.00	60	L	S	High	8,9,10	
34-271	F	*Thalictrum dasycarpum*	tall meadow-rue	0.01	0.11	20-60	L	S	None	5,6,7	
34-271	F	*Verbena hastata*	blue vervain	0.13	4.61	24-72	M	S,M,MZ	Medium	7,8,9	
34-271	A	*Vernonia fasciculata*	bunched ironweed	0.03	0.30	30-51	L	S	High	8,9	
34-271	F	*Veronicastrum virginicum*	Culver's root	0.01	4.20	36-72	L	S-MZ	Very High	7,8	
34-271	F	*Zizia aurea*	golden alexanders	0.25	1.00	12-36	M	M,MZ	Low	4,5,6	
Forbs subtotal: 26											
Total Species Richness: 47			**Total Seeding Rate:**	**7.45**	**173**						
Total Cost/Acre: $1110			(Opt.) Cover Crop - Oats/Winter Wheat	7	3.12						

Table 68. Seed mix for conservation wet meadows, suitable for sites with 6-8 weeks/year of saturated soil in the Agassiz Beach Ridges and Glacial Lakes landscape areas**.**

Appendix 5. Detailed Yield and Budget Tables

Yield and budget data tables are presented in this appendix at a finer spatial resolution than the data presented in summary format in Chapter 8. Data here are presented by land capability class and subclass, and in several cases, for each of these classes within individual counties. Data presented in Chapter 8 are averaged across counties and frequently presented by land capability class group.

A. Yield Data

Detailed information on the extent of each land capability class and subclass in each county that falls within either the two landscapes or the major watershed boundaries are shown in Table 69–Table 72. Acres presented reflect only the fraction of each county falling within either the landscape or watershed boundaries, not the acres/LCCS within the entire county.

1. Cropland Yield Data

The weighted averages of SSURGO non-irrigated crop yield estimates for each soil component were aggregated to generate yield estimates for each crop by map unit. Crop yield data in are summarized by land capability class and subclass using a weighted average based on the subclass area (ABR: Table 78–Table 83; GL: Table 84–Table 89).
For map units in the SSURGO database that represent permanent water features and which lacked an LCC classification (W, water; M-W, water-miscellaneous; 1356, water-miscellaneous; and INT, intermittent water), a value of 10 was assigned. Other soils in these landscapes that lacked LCC data tended to be gravel pits, fill soils, marshes, or lake beaches; these remaining map units with no LCC data are indicated with a "." in tables and figures within this report. Where yield data was missing for a map unit within a county, county level average yields for the assigned LCCS were utilized. Where there was no county level yield data for a given LCCS, the average yield for that LCCS class across the region was utilized (region is used here to mean either the focal landscape area or the watershed area). Any remaining yield values of zero were changed to "Null" such that averages were not skewed by missing data.

2. Grassland Yield Data

Grassland yield data based on the Forage Suitability Group dataset (cite) is shown by LCCS in Table 73–Table 76 for both landscape and within the corresponding major watershed boundaries.

	1	2			3			4			5	6			7			8		10	.	
County	.	e	s	w	e	s	w	e	s	w	w	e	s	w	e	s	w	s	w	.	.	Total
MN027	3,359	3,352	13,136	7,122	1,038	15,465	12,857	4,957	16,1118	3,176	613	.	5,242	5,820	.	5	.	.	1,069	101	3,685	97,115
MN107	850	1,618	7,371	4,316	.	1,499	3,875	413	1,187	2,482	34	.	3,625	2,101	.	.	.	.	.	3	287	29,659
Total	4,209	4,969	20,506	11,437	1,038	16,964	16,731	5,370	17,305	5,659	647	.	8,867	7,921	.	5	.	.	1,069	104	3,972	126,774
% Total	3	4	16	9	1	13	13	4	14	4	1	.	7	6	.	<1	.	.	1	1	3	100

Table 69. Acres per land capability class and subclass within the ABR landscape boundary by county. Acreage only includes the portion of each county falling within the landscape boundaries.

	1	2				3			4			5	6			7			8		10	.	
County	.	c	e	s	w	e	s	w	e	s	w	w	e	s	w	e	s	w	s	w	.	.	Total
MN027	21,840	.	69,259	169,777	88,364	39,021	26,687	28,675	17,330	24,408	4,334	2,074	3,889	10,431	16,386	402	1,033	.	.	10,764	5,649	8,901	549,222
MN107	9,518	.	35,423	83,526	76,306	3,298	14,233	18,695	2,826	20,360	5,990	3,585	211	8,762	6,852	284	.	.	.	.	1,052	4,952	295,873
MN005	4,676	.	60,472	49,989	55,226	47,724	4,622	9,845	13,613	3,328	396	.	10,224	723	24,864	753	.	1,917	415	9,890	23,527	157	322,361
MN029	8,469	.	39,862	4,228	6,406	12,468	6,275	60	1,639	4,062	957	.	6,415	6,962	11,309	476	1,042	11,326	.	3,084	5,797	24	130,861
MN087	2,371	1,865	83,802	64,827	51,670	42,185	13,663	2,725	6,133	2,311	2,293	5,910	7,374	1,186	13,784	.	.	359	.	23,541	14,218	190	340,407
MN111	1,769	.	10,355	520	3,142	11,780	330	1,428	4,053	607	.	.	259	679	385	653	3	.	.	1,632	2,282	30	39,906
MN119	152	.	703	.	1,085	114	.	45	.	5	.	.	.	.	190	.	.	.	.	47			2,341
MN167	8,352	.	16,911	22,466	11,929	5,910	7,439	4,940	3,045	2,129	625	.	.	379	3,711	.	.	.	.	722	24	1,612	90,194
Total	57,147	1,865	316,787	395,333	294,127	162,500	73,249	66,414	48,639	57,210	14,595	11,570	28,372	29,122	77,481	2,568	2,078	13,602	415	49,680	52,548	15,865	1,771,166
% Total	3	<1	18	22	17	9	4	4	3	3	1	1	2	2	4	<1	<1	1	<1	3	3	1	100

Table 70. Acres per land capability class and subclass within the ABR major watershed boundary by county. Acreage only includes the portion of each county falling within the watershed boundaries. For the first four counties which overlap the landscape boundary, acreage includes the area within the landscape boundary as well as the area outside the landscape boundary but still falling within the watershed boundary.

	1	2			3			4			5	6			7			8		10	.	
County	.	e	s	w	e	s	w	e	s	w	w	e	s	w	e	s	w	s	w	.	.	Total
MN067	350	4,782	425	3,767	10,623	17,980	10,649	5,034	5,115	.	.	1,200	2,458	1,503	1,146	1,156	.	.	7,181	7,625	787	81,782
MN121	636	8,839	743	1,673	10,071	2,846	4,571	6,769	1,881	.	231	1,841	3,467	5,542	933	4,215	252	.	974	4,136	18	59,639
MN145	.	.	5	29	7	943	1,136	.	4	202	131	.	3	12	.	.	.	.	109	21	.	2,602
MN151	69	385	4,318	3,280	4,871	945	374	3,239	211	27	.	.	555	3,315	531	.	.	.	2,562	266	89	25,039
Total	1,055	14,006	5,491	8,749	25,573	22,714	16,730	15,043	7,212	229	362	3,041	6,483	10,372	2,610	5,371	252		10,826	12,048	894	169,061
% Total	1	8	3	5	15	13	10	9	4	<1	<1	2	4	6	2	3	<1	.	6	7	1	100

Table 71. Acres per land capability class and subclass within the GL landscape boundary by county. Acreage only includes the portion of each county falling within the landscape boundaries.

	1	2			3			4			5	6			7			8		10	.	
County	.	e	s	w	e	s	w	e	s	w	w	e	s	w	e	s	w	s	w	.	.	Total
MN067	16,193	80,214	9,394	100,760	38,288	37,869	43,853	12,124	8,221			2,139	4,430	2,754	1,713	1,391			17,702	31,221	5,065	413,331
MN121	20,584	93,455	17,800	32,773	49,381	51,081	42,863	19,572	9,590		2,371	4,292	13,097	22,268	1,896	8,056	701		5,622	31,067	444	426,911
MN145	14,817	18,623	523	29,628	4,294	35,888	19,051	1,490	1,859	1,207	1,928	1,080	378	11,169		1,054			2,370	6,632	244	152,235
MN151	12,122	22,313	109,428	107,824	36,697	12,521	32,352	10,958	8,655	2,221			1,109	4,411	1,030				10,111	3,376	640	375,768
MN019	357	1		409	4		126	7						10								914
MN023	50,765	62,671	116,565	56,077	12,476	2,134	32,865	2,321	352		2,596	2,612	558		60				1,697	1,476	3,694	348,919
MN041	3,886	50,267	655	21,479	43,966	5,884	11,706	9,634	849	118	502	1,214	1,264	4,929	1,319	531				29,142	42	187,387
MN051	2,471	6,773	1,453	3,161	289	260	952	3,764	1,235				299	492	159	69			1,123	1,648	117	24,263
MN053	1,876	4,994	439	6,281	3,830	828	1,044	2,087	1,460	44	113	680	850	1,161	244	115	96		554	1,280	178	28,154
MN073	2,159	8,681	1,706	10,297	1,448	313	1,240	141	36				668	24	435	219			304	209	70	27,951
MN081	11,583	68,336	3,741	35,317	22,503	178	8,415	4,799			3,612	1,264	695	546	3,413				1,942	3,143	164	169,653
MN083	13,180	32,441	6,926	31,931	5,479	556	8,379	1,167	210		1,887	434	79	1,650	808				564	998	156	106,844
MN085	94	2,974		2,408	1,585	111	258	224	11						51				778	977		9,472
MN093	16,476	43,899	3,699	72,228	23,744	24,977	9,207	6,386	5,489	1,618	4,365	2,724	1,035	4,022	967	2,211		620	25,943	15,860	3,240	268,710
MN111	958	3,574	63	1,527	5,079	213	258	1,780	7			397	0	1,661	776				1,686	1,551	2	19,532
MN127	4,322	9,541	2,107	16,596	2,199	1,346	4,426	599	61		584	212	422	84	1,423	9	475			464	2,785	47,654
MN129	37,344	56,666	15,163	127,612	10,456	3,822	24,163	896	212		3,970	1,296		183	4,120	1,535		795	1,522	203	583	290,542
MN149	8,922	10,987	10,643	4,684	2,482	4,651	5,426	789	890	238	57		83	341	92				251	3,166	44	53,747
MN171	7,875	88,586	1,520	51,120	40,668	8,929	24,349	14,214	6,541	1,043	6,527	6,861	337	4,834	2,203	304			10,972	22,437	1,442	300,763
MN173	15,250	118,559	15,864	137,159	12,030	3,206	29,043	3,412	1,289		671	3,521	231	5,939	2,847				1,794	3,241	982	355,036
Total	241,233	783,553	317,689	849,270	316,897	194,768	299,975	96,365	46,965	6,489	29,184	28,727	25,537	66,479	23,558	15,496	1,273	1,415	84,934	158,090	19,892	3,607,788
% Total	7	22	9	24	9	5	8	3	1	<1	1	1	1	2	1	<1	<1	<1	2	4	1	100

Table 72. Acres per land capability class and subclass within the GL major watershed boundary by county. Acreage only includes the portion of each county falling within the watershed boundaries. For the first four counties which overlap the landscape boundary, acreage includes the area within the landscape boundary as well as the area outside the landscape boundary but still falling within the watershed boundary.

Grass Type	LCC	LCCS	Grassland Productivity, Grazing lb DM/ac high	lb DM/ac medium	lb DM/ac low	Potential AUM/ac high	Potential AUM/ac medium	Potential AUM/ac low	Stocking Rate CCpr/ac high	Stocking Rate CCpr/ac medium	Stocking Rate CCpr/ac low
	1	.	7,400	5,400	2,800	6.1	3.1	1.1	1.1	0.6	0.2
		e	7,327	5,302	2,776	6.0	3.0	1.1	1.1	0.6	0.2
	2	s	7,113	5,017	2,704	5.9	2.9	1.0	1.1	0.5	0.2
		w	.	.	.	.	.	.	1.1	0.6	0.2
		e	5,822	4,145	2,057	4.8	2.4	0.8	1.1	0.5	0.2
	3	s	4,680	3,350	1,729	3.9	1.9	0.7	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
		e	6,888	5,018	2,600	5.7	2.9	1.0	1.0	0.5	0.2
Warm Season Grass	4	s	4,900	3,500	1,600	4.0	2.0	0.6	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	5	w	.	.	.	.	.	.	.	.	.
	6	e	.	.	.	.	.	.	0.8	0.4	0.1
		s	.	.	.	.	.	.	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	7	e	.	.	.	.	.	.	0.8	0.4	0.1
		s	3,000	2,000	1,000	2.5	1.1	0.4	0.5	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.
	1	.	9,733	9,733	9,733	8.0	4.0	1.1	1.4	0.7	0.2
		e	9,732	9,617	9,701	8.0	4.0	1.1	1.4	0.7	0.2
	2	s	9,600	9,526	9,565	7.9	3.9	1.0	1.3	0.6	0.2
		w	9,375	9,355	9,367	7.7	3.8	1.2	1.3	0.6	0.2
		e	7,599	.	7,599	6.3	3.1	0.8	1.3	0.7	0.2
	3	s	6,189	7,082	6,346	5.2	2.6	0.7	0.6	0.3	0.1
		w	9,400	9,400	9,400	7.7	3.8	1.1	0.7	0.4	0.1
		e	3,678	9,733	4,561	3.8	1.9	0.4	1.2	0.6	0.2
Cool Season Grass Mix	4	s	5,516	6,200	5,578	4.6	2.3	0.5	0.5	0.3	0.1
		w	6,800	6,519	6,686	5.5	2.8	0.8	1.1	0.5	0.2
	5	w	7,800	.	7,800	6.4	3.2	0.9	.	.	.
	6	e	.	.	.	.	.	.	1.1	0.6	0.2
		s	3,600	3,600	3,600	3.0	1.5	0.3	0.6	0.3	0.1
		w	.	4,800	4,800	3.9	1.9	0.7	.	.	.
	7	e	.	.	.	.	.	.	1.0	0.5	0.1
		s	4,000	.	4,000	3.3	1.6	0.5	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.

Table 73. Landscape grassland productivity estimates by LCCS for ABR. Warm season grass data were used as yield estimates for native dominated grassland communities. The cool season mix data were used as yield estimates for non-native dominated grassland communities. A 5 month grazing season was assumed for stocking rate calculation.

Grass Type	LCC	LCCS	lb DM/ac			Grassland Productivity, Grazing Potential AUM/ac			Stocking Rate CCpr/ac		
			high	medium	low	high	medium	low	high	medium	low
Warm Season Grass	1	.	8,400	6,000	3,000	6.9	3.4	1.1	1.1	0.6	0.2
	2	e	8,370	5,985	2,985	6.9	3.4	1.1	1.1	0.6	0.2
		s	8,084	5,809	2,936	6.7	3.3	1.1	1.1	0.6	0.2
		w	8,400	6,000	3,000	6.9	3.4	1.1	1.1	0.6	0.2
	3	e	8,074	5,782	2,874	6.6	3.3	1.1	1.1	0.5	0.2
		s	5,271	3,775	1,758	4.3	2.2	0.7	0.9	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	4	e	7,361	5,304	2,647	6.1	3.0	1.0	1.0	0.5	0.2
		s	5,200	3,800	1,800	4.3	2.2	0.7	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	5	w	.	.	.	.	.	.	.	.	.
	6	e	6,260	4,448	2,224	5.2	2.5	0.8	0.8	0.4	0.1
		s	5,465	3,900	1,923	4.5	2.2	0.7	0.8	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	7	e	5,692	4,062	2,031	4.7	2.3	0.8	0.8	0.4	0.1
		s	4,000	2,800	1,400	3.3	1.6	0.5	0.5	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.
Cool Season Grass Mix	1	.	10,333	7,400	3,200	8.5	4.2	1.2	1.4	0.7	0.2
	2	e	10,248	7,337	3,172	8.4	4.2	1.2	1.4	0.7	0.2
		s	9,506	6,829	2,839	7.8	3.9	1.1	1.4	0.7	0.2
		w	9,651	6,871	3,179	7.9	3.9	1.2	1.3	0.6	0.2
	3	e	9,974	7,142	3,022	8.2	4.1	1.1	1.4	0.7	0.2
		s	4,706	3,377	1,171	3.9	1.9	0.4	0.8	0.4	0.1
		w	5,528	3,930	1,977	4.5	2.2	0.8	1.2	0.6	0.2
	4	e	8,888	6,337	2,762	7.3	3.6	1.0	1.2	0.6	0.2
		s	3,882	2,809	930	3.2	1.6	0.4	0.6	0.3	0.1
		w	8,100	5,800	2,600	6.7	3.3	1.0	1.1	0.6	0.2
	5	w	.	.	.	.	.	.	1.2	0.6	0.2
	6	e	8,436	6,024	2,803	6.9	3.4	1.1	1.1	0.5	0.2
		s	4,753	3,426	1,294	3.9	2.0	0.5	0.6	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	7	e	7,141	5,110	2,336	5.9	2.9	0.9	1.0	0.5	0.1
		s	5,400	3,800	1,800	4.4	2.2	0.7	0.7	0.3	0.1
			.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.

Table 74. Landscape grassland productivity estimates by LCCS for GL. Warm season grass data were used as yield estimates for native dominated grassland communities. The cool season mix data were used as yield estimates for non-native dominated grassland communities. A 5 month grazing season was assumed for stocking rate calculation.

Grass Type	LCC	LCCS	Grassland Productivity, Grazing								
			lb DM/ac			Potential AUM/ac			Stocking Rate CCpr/ac		
			high	medium	low	high	medium	low	high	medium	low
Warm Season Grasses	1	.	7,258	5,293	2,757	6.0	3.0	1.0	1.0	0.5	0.2
	2	c	7,400	5,400	2,800	6.1	3.1	1.1	1.0	0.5	0.2
		e	7,170	5,208	2,727	5.9	3.0	1.0	1.0	0.5	0.2
		s	7,124	5,037	2,708	5.9	2.9	1.0	1.0	0.5	0.2
		w	7,400	5,400	2,800	6.1	3.1	1.1	1.0	0.5	0.2
	3	e	6,882	4,976	2,612	5.7	2.8	1.0	0.9	0.5	0.2
		s	4,945	3,539	1,817	4.1	2.0	0.7	0.7	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	4	e	4,796	3,456	1,837	3.9	2.0	0.7	0.6	0.3	0.1
		s	4,900	3,500	1,607	4.0	2.0	0.6	0.7	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	5	w	7,100	5,000	2,700	5.8	2.8	1.0	1.0	0.5	0.2
	6	e	2,847	2,071	1,179	2.3	1.2	0.4	0.4	0.2	0.1
		s	3,394	2,295	1,098	2.8	1.3	0.4	0.5	0.2	0.1
		w	.	.	.	.	.	.	.	.	.
	7	e	2,762	1,994	1,113	2.3	1.1	0.4	0.4	0.2	0.1
		s	3,017	2,013	1,004	2.5	1.1	0.4	0.4	0.2	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.
Cool Season Mix	1	.	9,532	6,916	2,772	7.8	3.9	1.1	1.3	0.6	0.2
	2	c	9,733	7,067	2,800	8.0	4.0	1.1	1.3	0.7	0.2
		e	9,438	6,838	2,746	7.8	3.9	1.0	1.3	0.6	0.2
		s	9,591	6,892	2,725	7.9	3.9	1.0	1.3	0.6	0.2
		w	9,189	6,498	3,177	7.6	3.7	1.2	1.2	0.6	0.2
	3	e	9,057	6,547	2,641	7.5	3.7	1.0	1.2	0.6	0.2
		s	6,673	4,747	1,822	5.5	2.7	0.7	0.9	0.4	0.1
		w	9,399	6,600	3,001	7.7	3.8	1.1	1.3	0.6	0.2
	4	e	6,062	4,345	1,869	5.0	2.5	0.7	0.8	0.4	0.1
		s	5,357	3,815	1,365	4.4	2.2	0.5	0.7	0.4	0.1
		w	5,953	4,316	2,041	4.9	2.5	0.8	0.8	0.4	0.1
	5	w	8,400	6,033	2,500	6.9	3.4	0.9	1.1	0.6	0.2
	6	e	3,999	2,774	1,385	3.3	1.6	0.5	0.5	0.3	0.1
		s	3,794	2,717	917	3.1	1.5	0.3	0.5	0.3	0.1
		w	4,828	3,420	1,807	4.0	1.9	0.7	0.7	0.3	0.1
	7	e	3,989	2,735	1,427	3.3	1.6	0.5	0.5	0.3	0.1
		s	4,026	2,817	1,209	3.3	1.6	0.5	0.5	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	3,600	2,600	800	3.0	1.5	0.3	0.5	0.2	0.0
		w	.	.	.	.	.	.	.	.	.

Table 75. Watershed grassland productivity estimates by LCCS for ABR. Warm season grass data were used as yield estimates for native dominated grassland communities. The cool season mix data were used as yield estimates for non-native dominated grassland communities. A 5 month grazing season was assumed for stocking rate calculation.

Grass Type	LCC	LCCS	Grassland Productivity, Grazing: lb DM/ac high	lb DM/ac medium	lb DM/ac low	Potential AUM/ac high	Potential AUM/ac medium	Potential AUM/ac low	Stocking Rate CCpr/ac high	Stocking Rate CCpr/ac medium	Stocking Rate CCpr/ac low
Warm Season Grasses	1	.	8,323	5,955	2,976	6.8	3.4	1.1	1.1	0.6	0.2
	2	e	8,325	5,959	2,970	6.8	3.4	1.1	1.1	0.6	0.2
		s	8,357	5,972	2,989	6.9	3.4	1.1	1.1	0.6	0.2
		w	8,400	6,000	3,000	6.9	3.4	1.1	1.1	0.6	0.2
	3	e	8,148	5,844	2,899	6.7	3.3	1.1	1.1	0.5	0.2
		s	6,322	4,546	2,195	5.2	2.6	0.8	0.9	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	4	e	7,258	5,235	2,616	6.0	3.0	1.0	1.0	0.5	0.2
		s	5,185	3,785	1,799	4.3	2.2	0.7	0.7	0.4	0.1
		w	.	.	.	.	.	.	.	.	.
	5	w	.	.	.	.	.	.	.	.	.
	6	e	6,029	4,295	2,149	5.0	2.4	0.8	0.8	0.4	0.1
		s	5,577	4,004	1,975	4.6	2.3	0.8	0.8	0.4	0.1
			.	.	.	.	.	.	.	.	.
	7	e	5,743	4,089	2,054	4.7	2.3	0.8	0.8	0.4	0.1
		s	3,977	2,781	1,382	3.3	1.6	0.5	0.5	0.3	0.1
			.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.
Cool Season Mix	1	.	10,293	7,373	3,179	8.5	4.2	1.2	1.4	0.7	0.2
	2	e	10,264	7,350	3,176	8.4	4.2	1.2	1.4	0.7	0.2
		s	10,523	7,531	3,194	8.7	4.3	1.2	1.4	0.7	0.2
		w	9,703	6,910	3,146	8.0	3.9	1.2	1.3	0.6	0.2
	3	e	10,038	7,186	3,071	8.3	4.1	1.2	1.4	0.7	0.2
		s	5,681	4,084	1,559	4.7	2.3	0.6	0.8	0.4	0.1
		w	8,612	6,112	2,880	7.1	3.5	1.1	1.2	0.6	0.2
	4	e	8,794	6,265	2,746	7.2	3.6	1.0	1.2	0.6	0.2
		s	4,509	3,263	1,188	3.7	1.9	0.5	0.6	0.3	0.1
		w	8,461	6,042	2,752	7.0	3.4	1.0	1.1	0.6	0.2
	5	w	9,182	6,539	2,985	7.6	3.7	1.1	1.2	0.6	0.2
	6	e	7,922	5,658	2,609	6.5	3.2	1.0	1.1	0.5	0.2
		s	4,664	3,377	1,279	3.8	1.9	0.5	0.6	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	7	e	7,168	5,125	2,347	5.9	2.9	0.9	1.0	0.5	0.1
		s	5,073	3,599	1,601	4.2	2.0	0.6	0.7	0.3	0.1
		w	.	.	.	.	.	.	.	.	.
	8	s	.	.	.	.	.	.	.	.	.
		w	.	.	.	.	.	.	.	.	.

Table 76. Watershed grassland productivity estimates by LCCS for GL. Warm season grass data were used as yield estimates for native dominated grassland communities. The cool season mix data were used as yield estimates for non-native dominated grassland communities. A 5 month grazing season was assumed for stocking rate calculation.

3. Cropland and Grassland Yield Maps

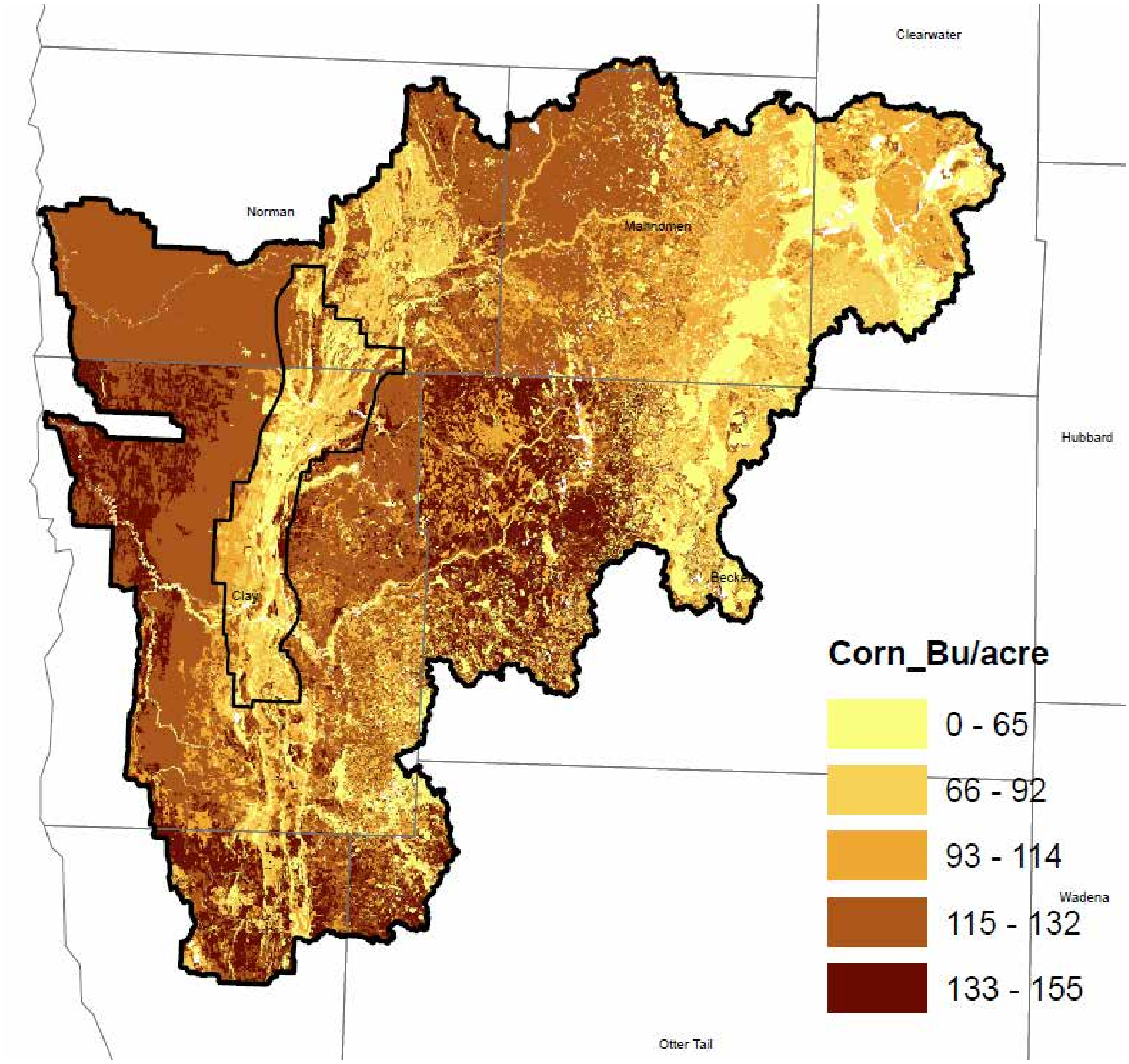

Figure 48. Corn yields, Agassiz Beach Ridges. Yields are reported in bu/acre.

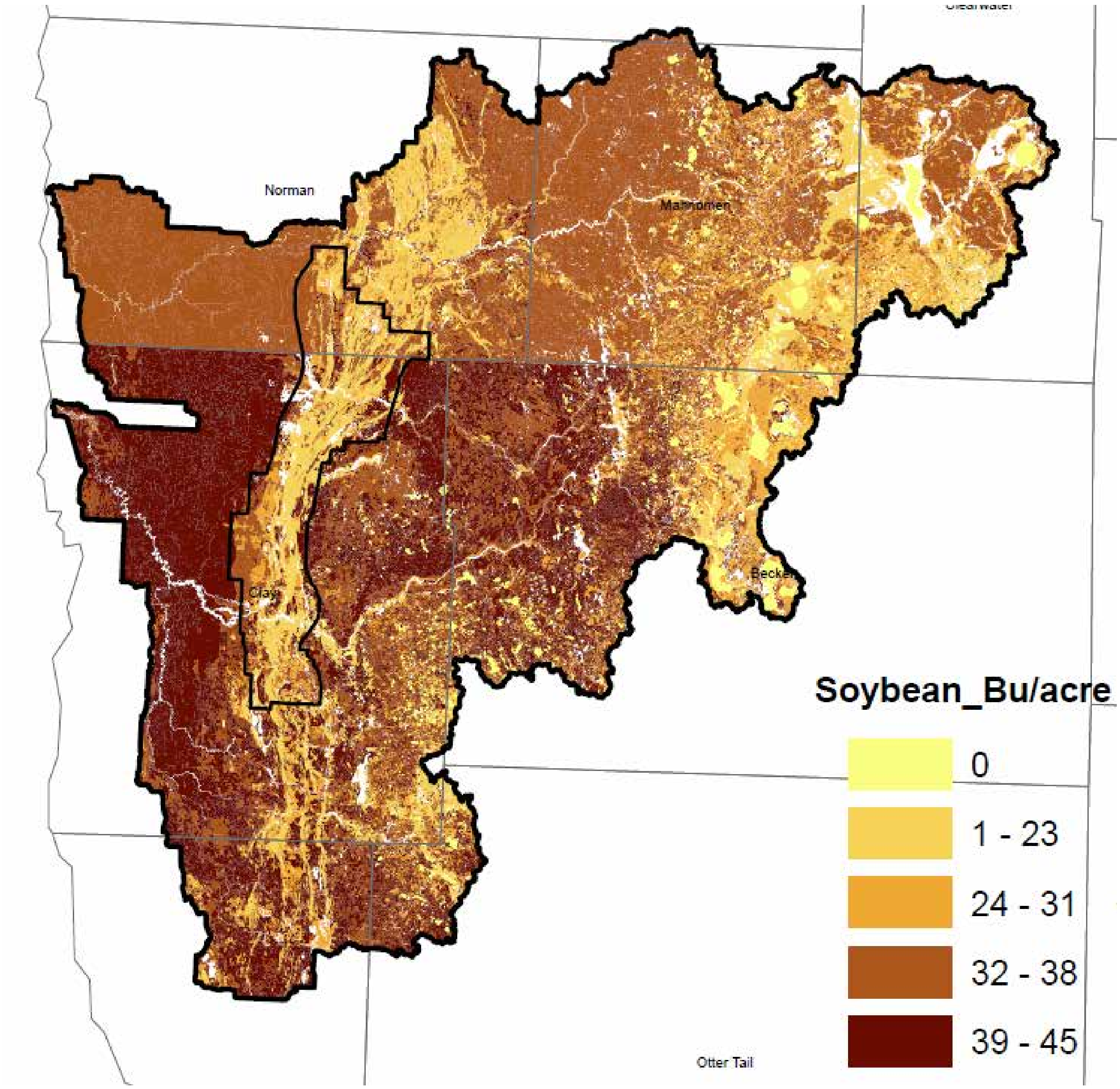

Figure 49. Soybean yields, Agassiz Beach Ridges. Yields are reported in bu/acre.

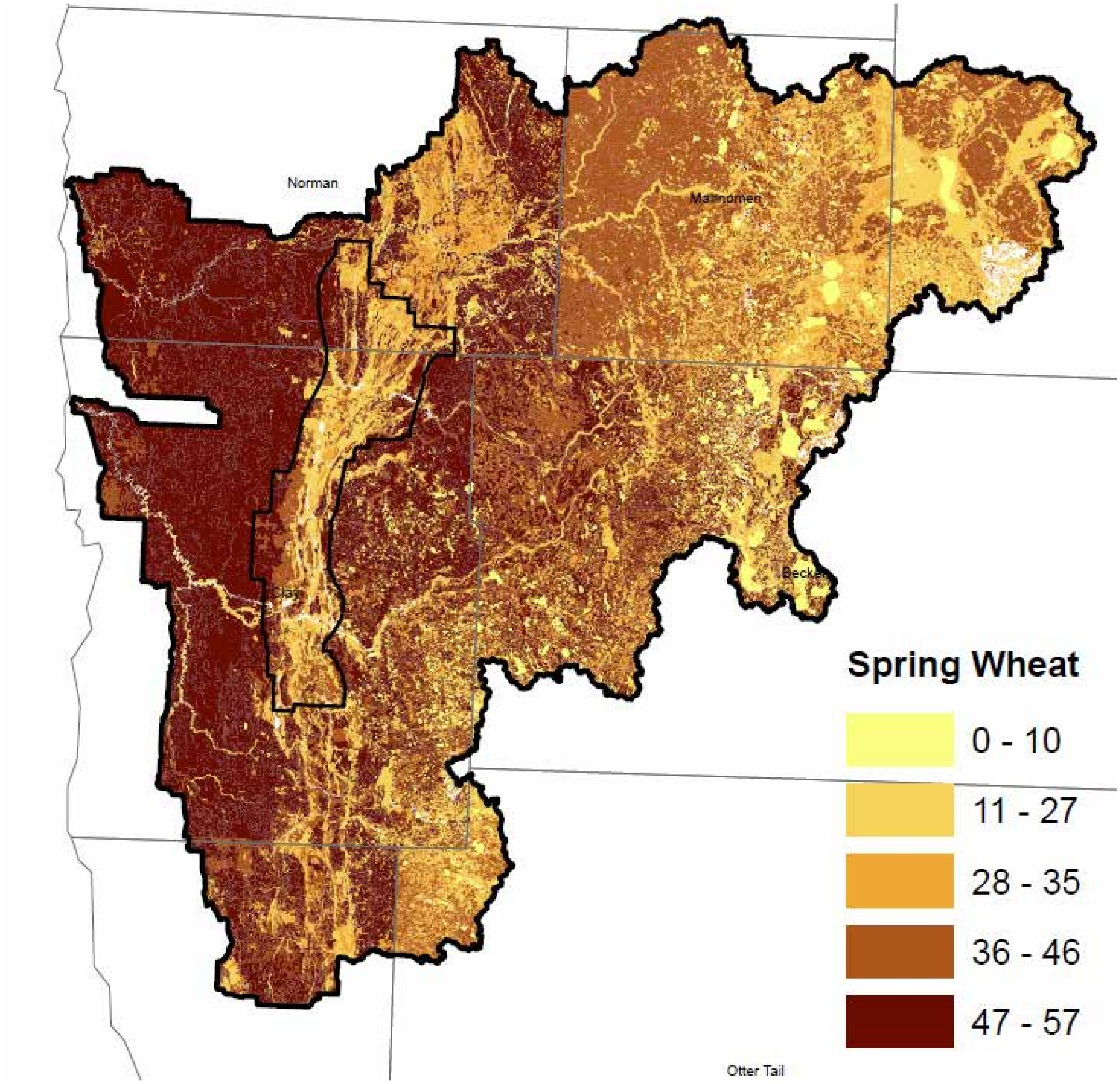

Figure 50. Spring wheat yields, Agassiz Beach Ridges. Yields are reported in bu/acre.

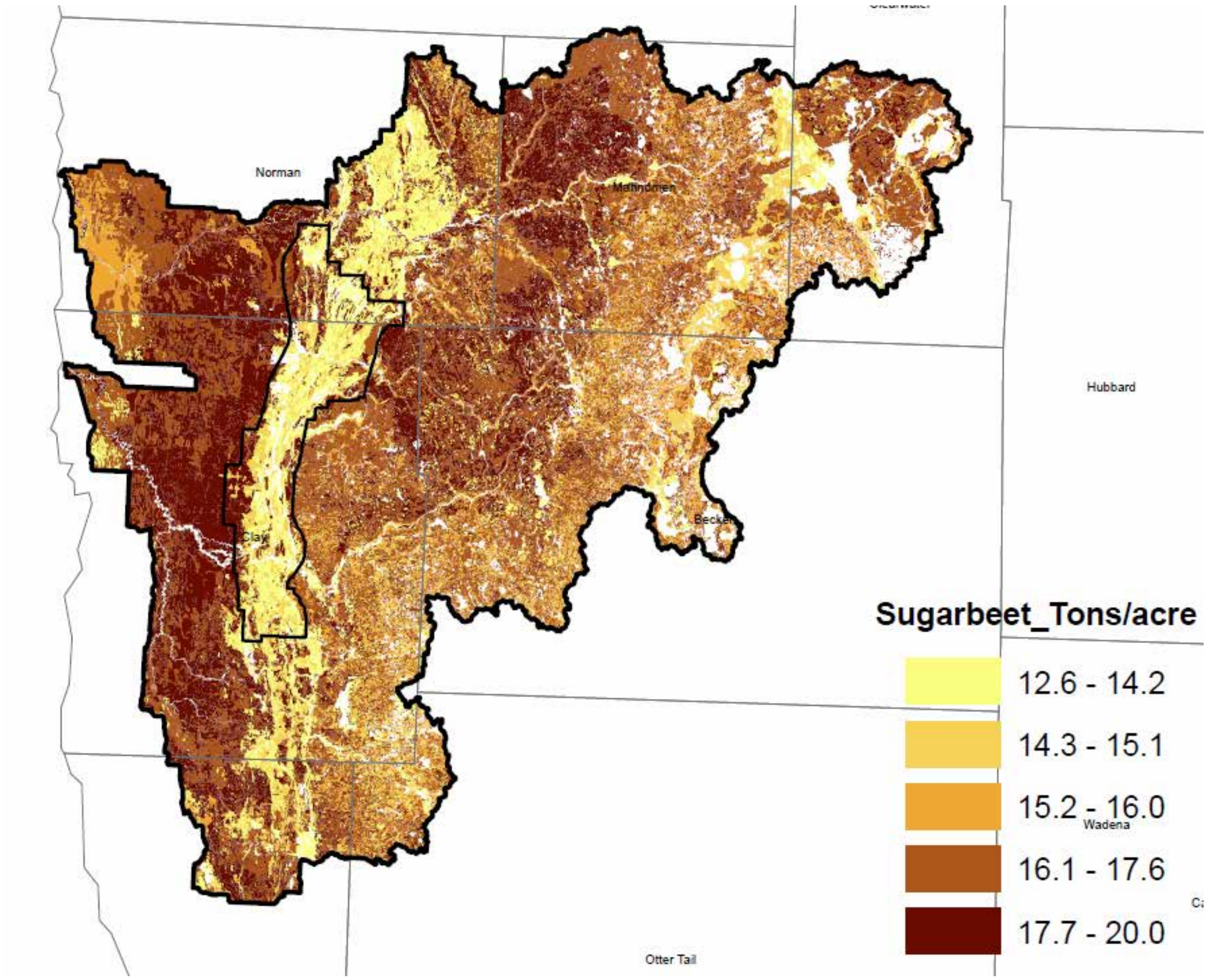

Figure 51. Sugar beet yields, Agassiz Beach Ridges. Yields are reported in tons/acre.

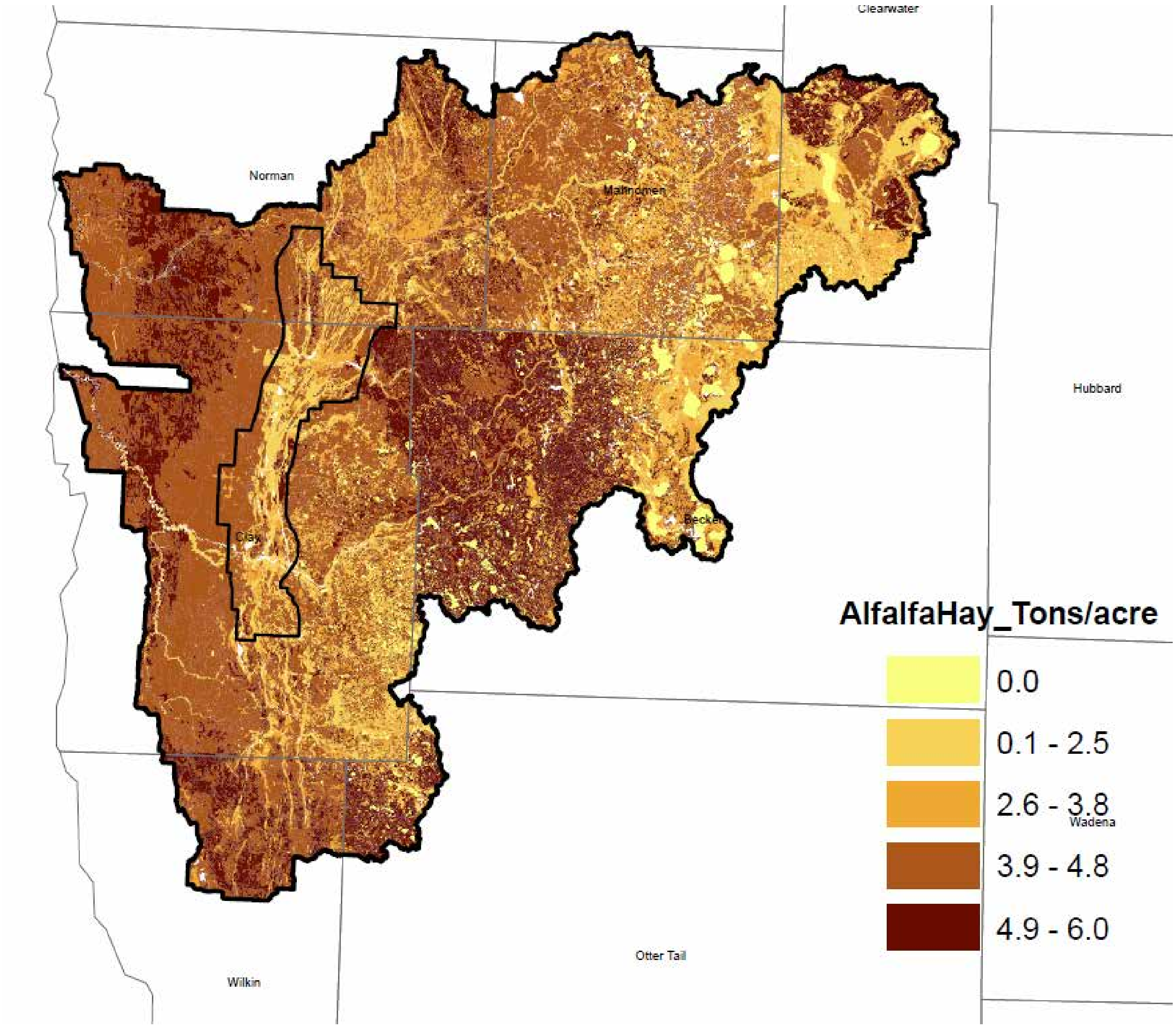

Figure 52. Alfalfa hay yields, Agassiz Beach Ridges. Yields are reported in tons/acre.

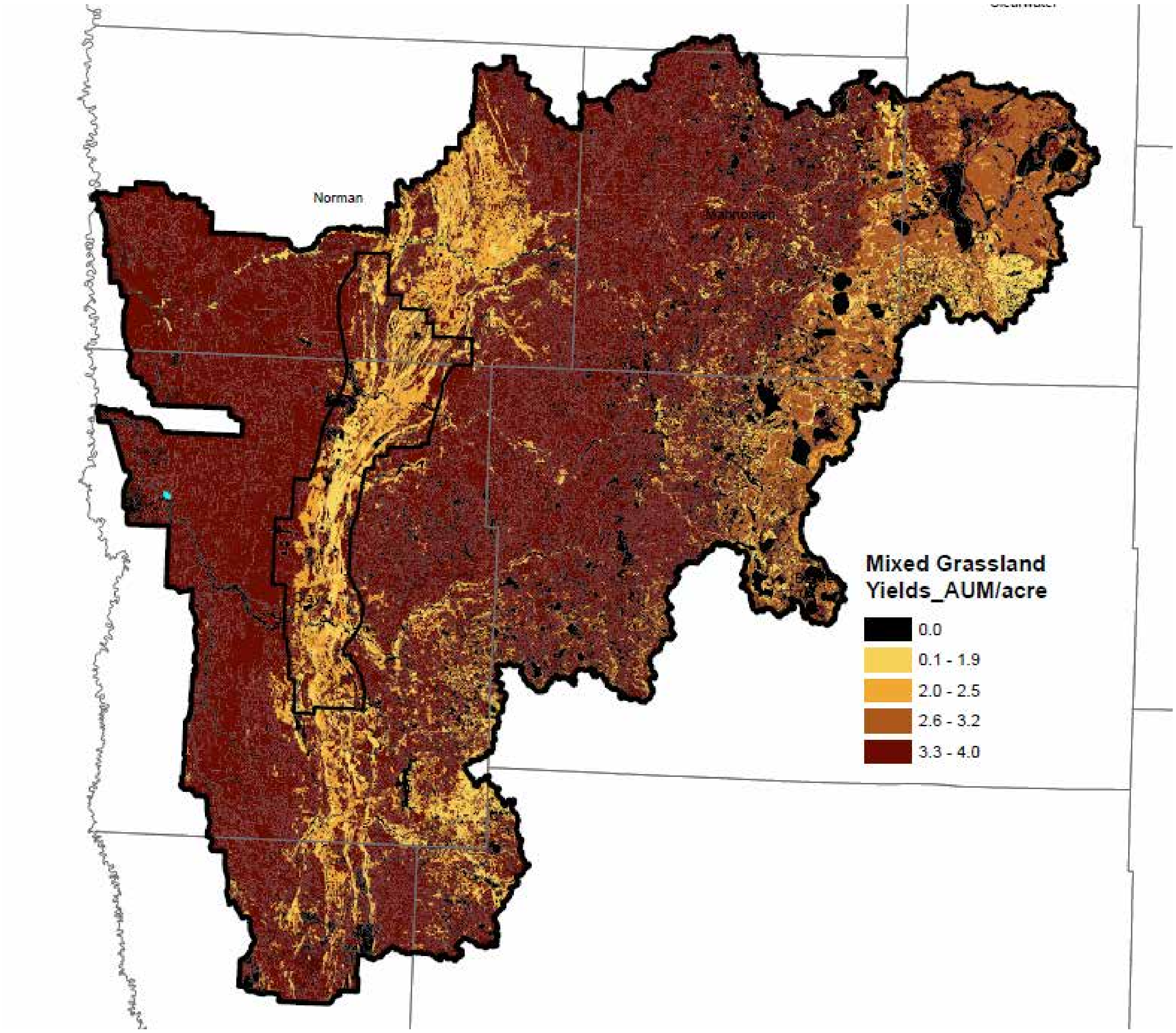

Figure 53. Medium productivity mixed cool season grasslands, Agassiz Beach Ridges. Yields shown are potential AUM/acre. High and low productivity mixed grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

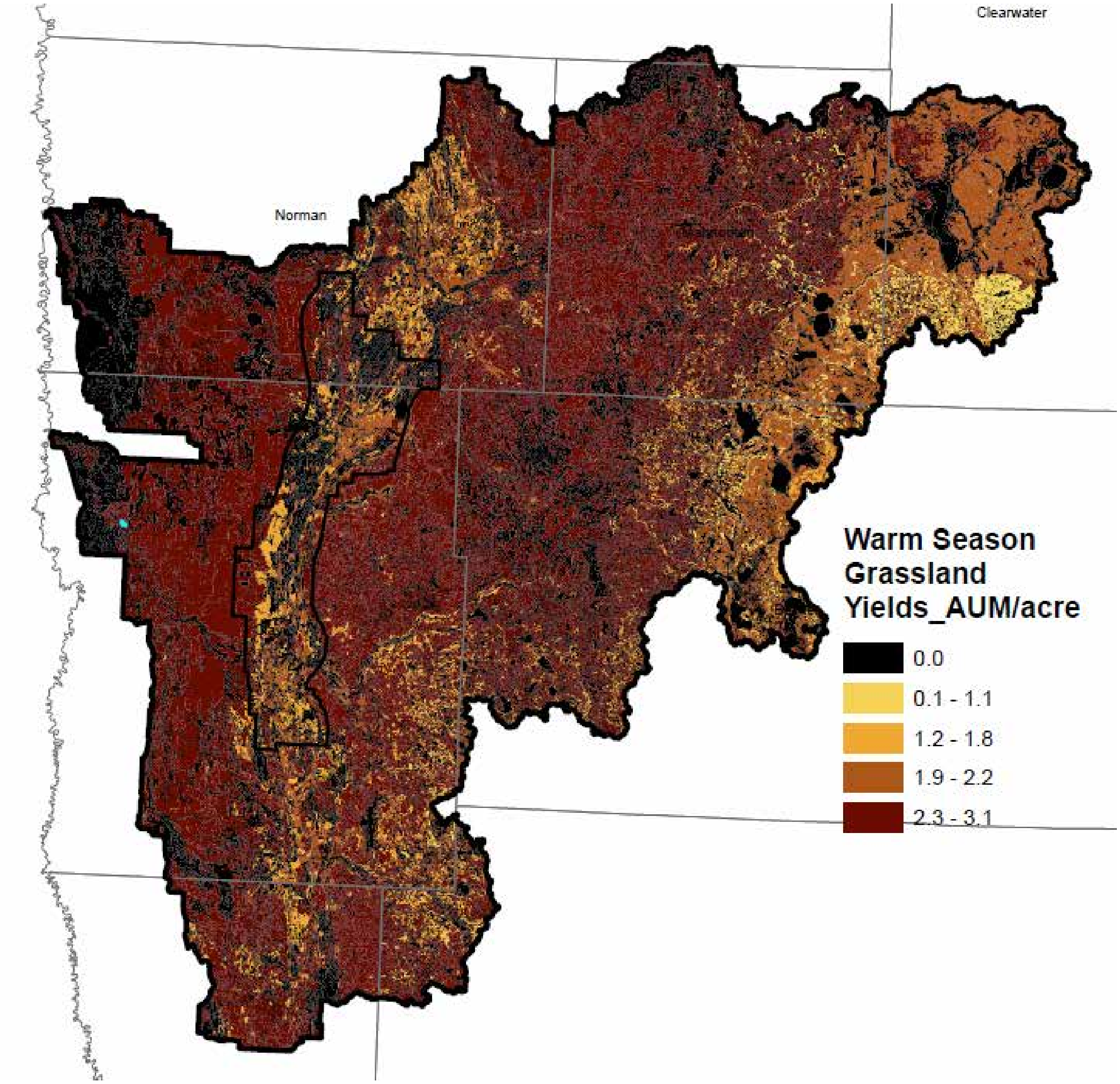

Figure 54. Watershed map of medium productivity warm season grasslands, Agassiz Beach Ridges. Yields shown are potential AUM/acre. High and low productivity warm season grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

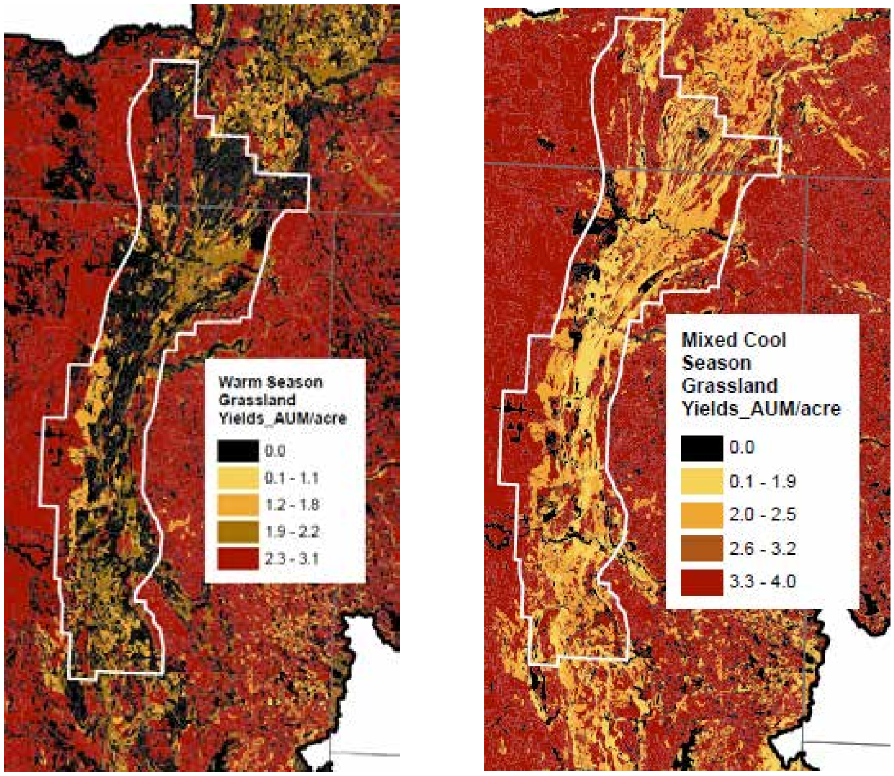

Figure 55. Landscape map of warm season and mixed cool season grassland yields, ABR. Yields shown are potential AUM/acre. High and low productivity warm season grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

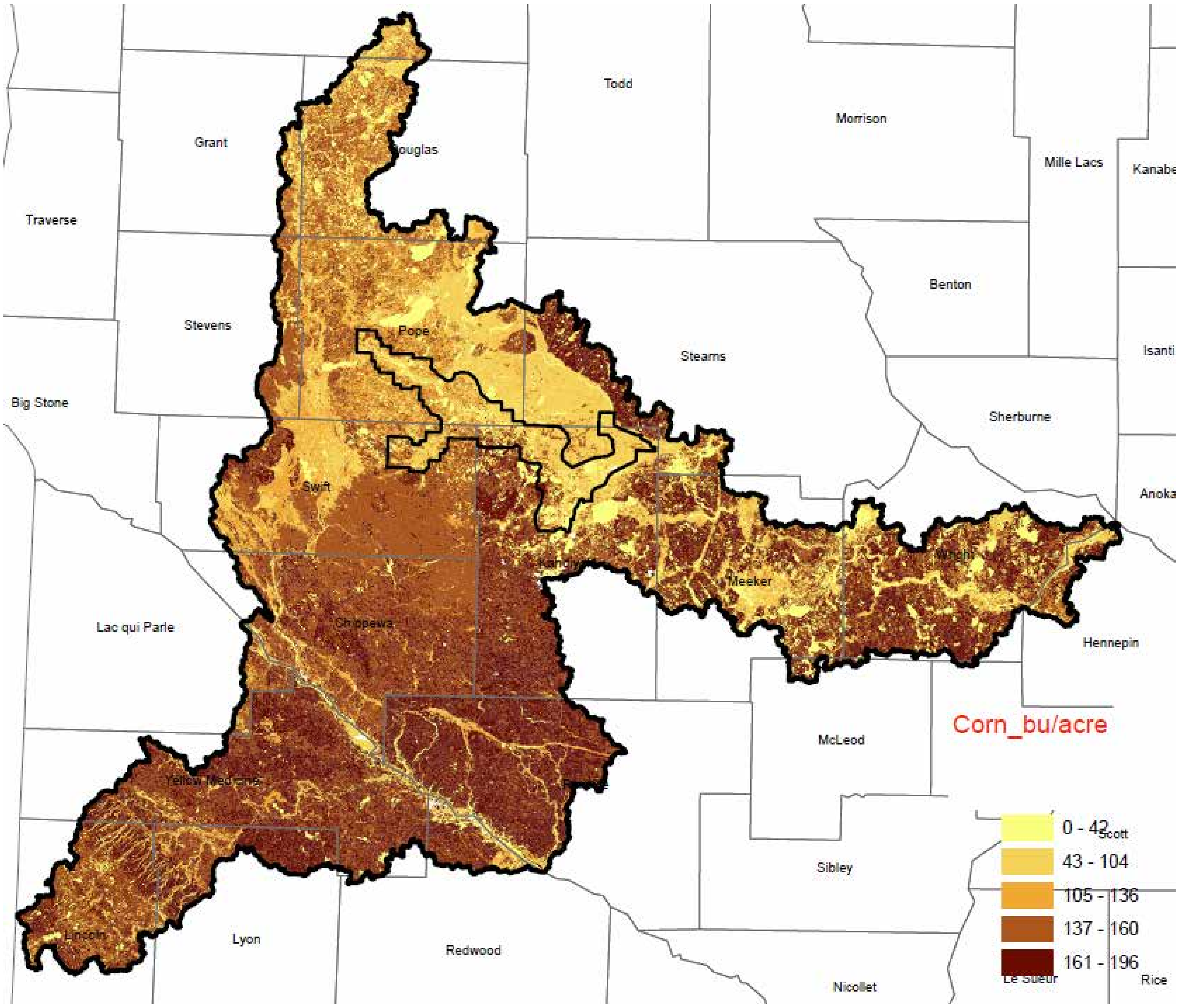

Figure 56. Corn yield, Glacial Lakes. Areas in black represent locations with no yields, these are primarily waterbodies**.**

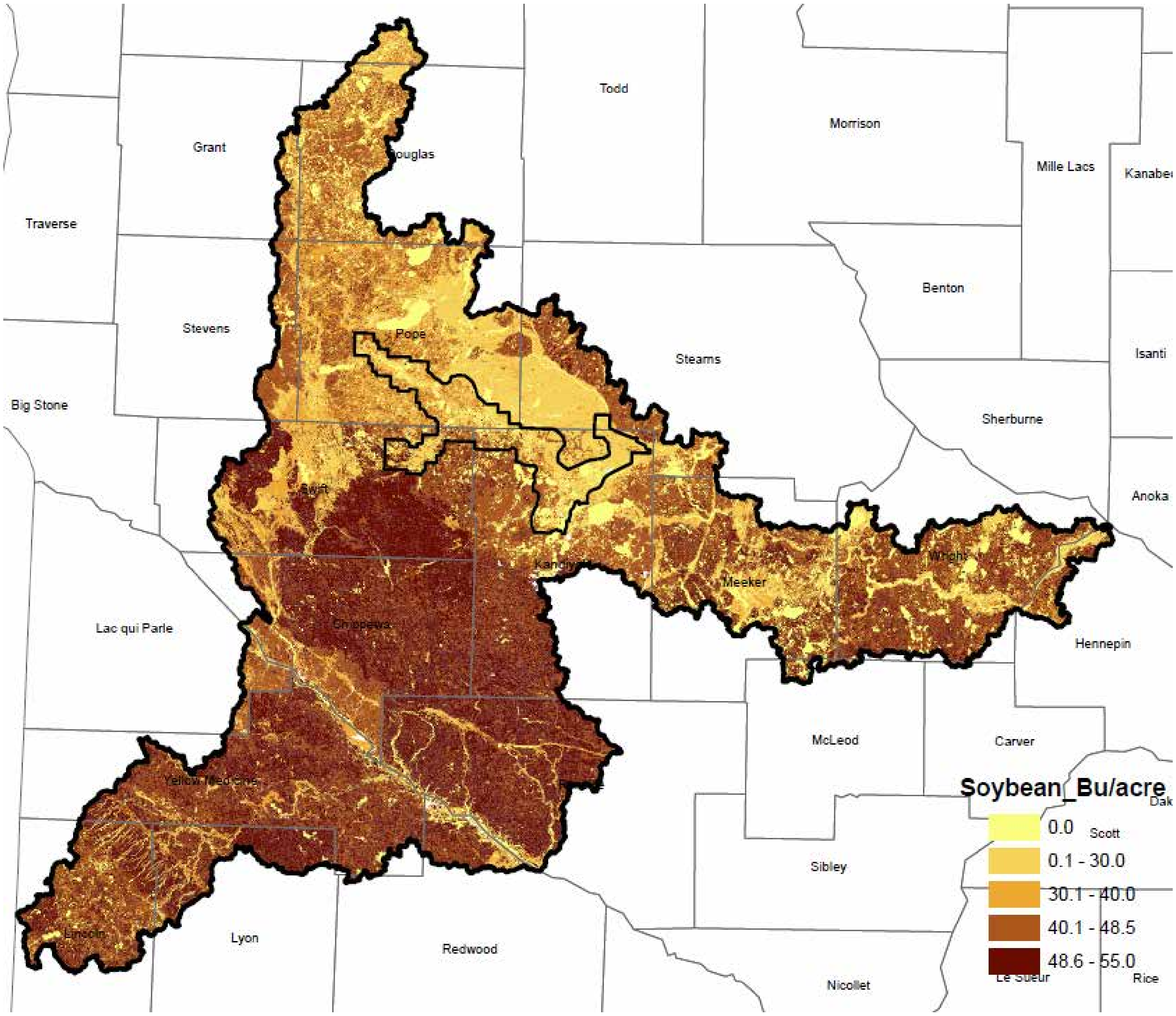

Figure 57. Soybean yields, Glacial Lakes. Areas in black represent locations with no yields, these are primarily waterbodies**.**

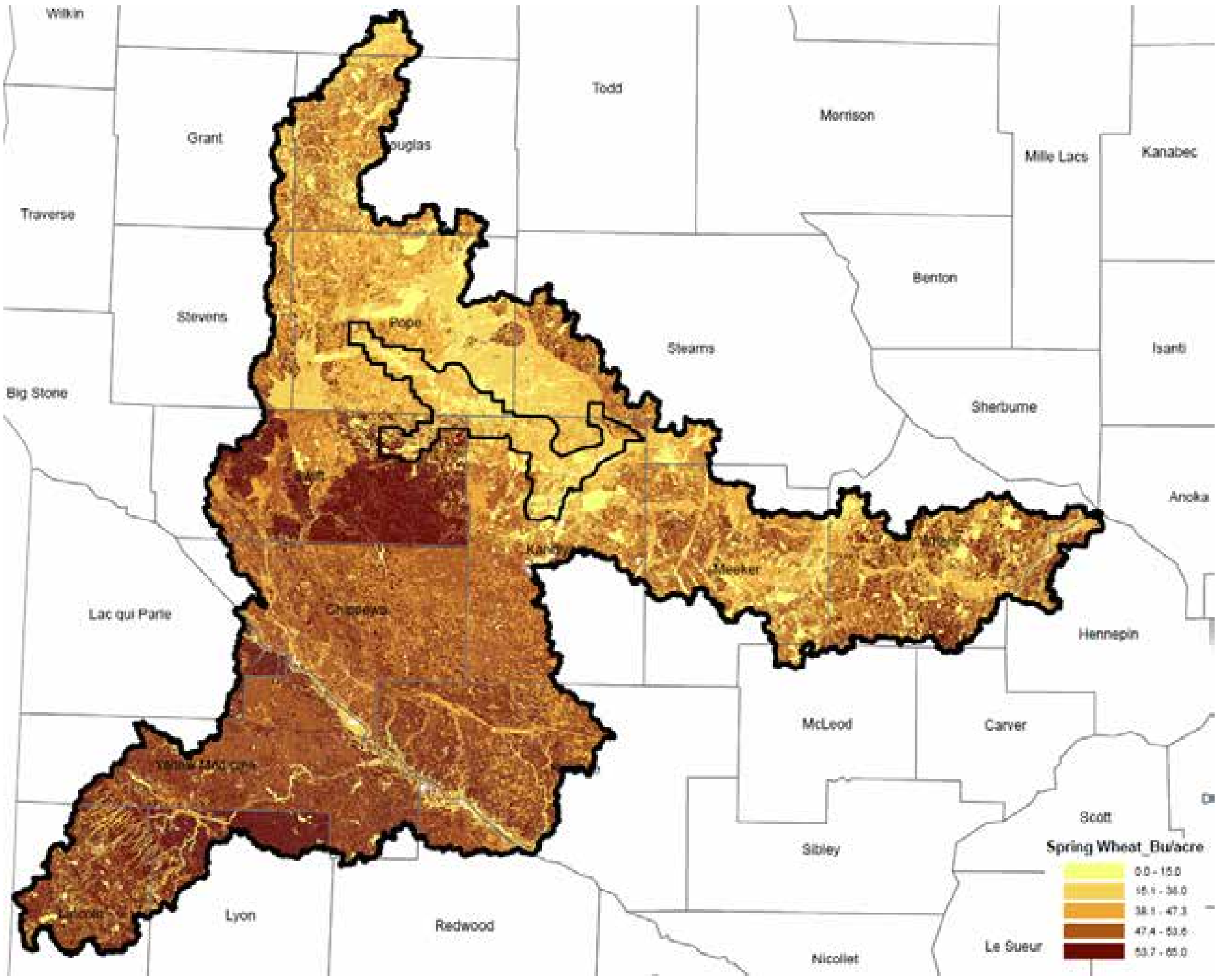

Figure 58. Spring wheat yields, Glacial Lakes. Areas in black represent locations with no yields, these are primarily waterbodies**.**

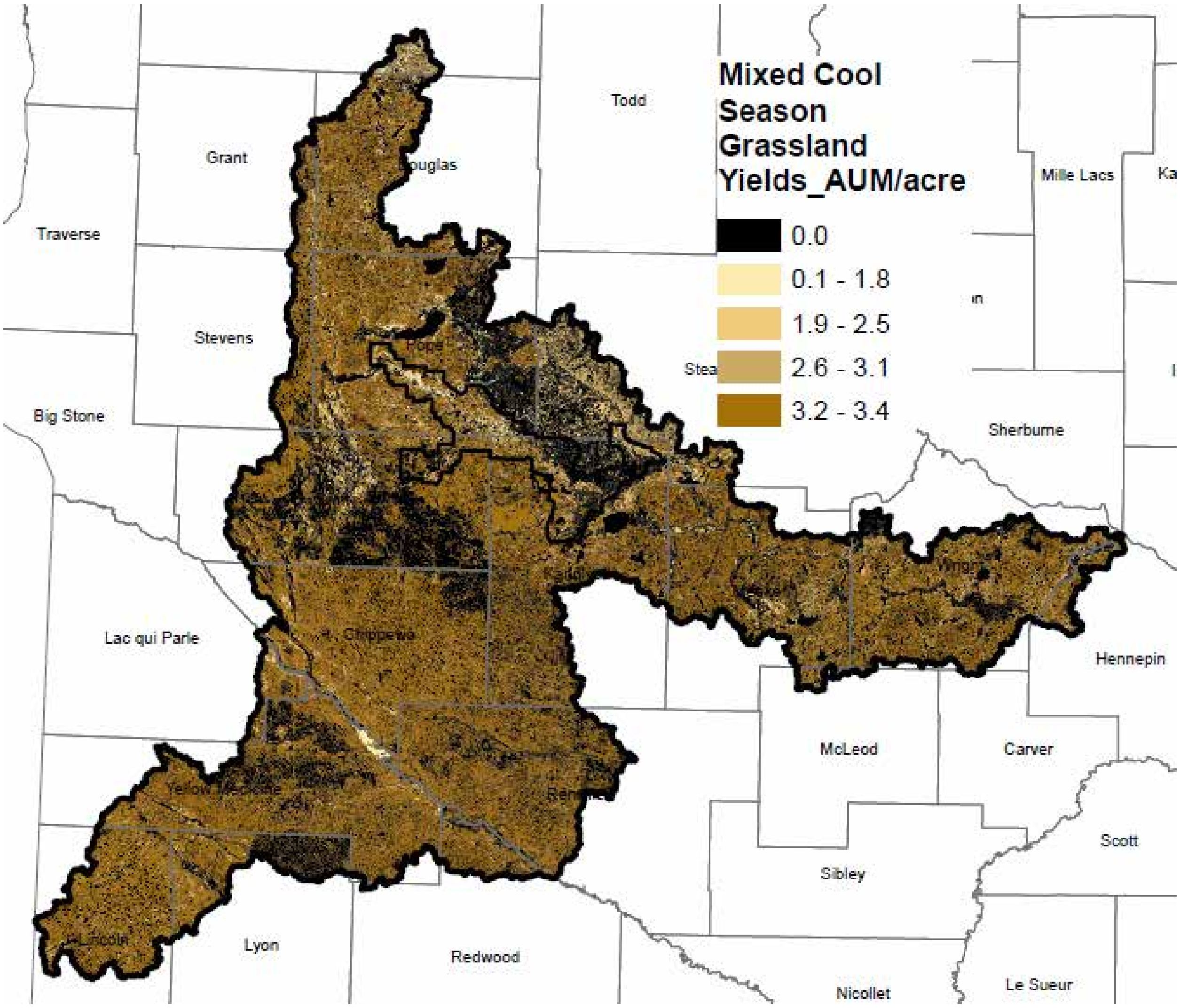

Figure 59. Medium productivity mixed cool season grasslands, Glacial Lakes. Yields shown are potential AUM/acre. High and low productivity mixed cool season grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

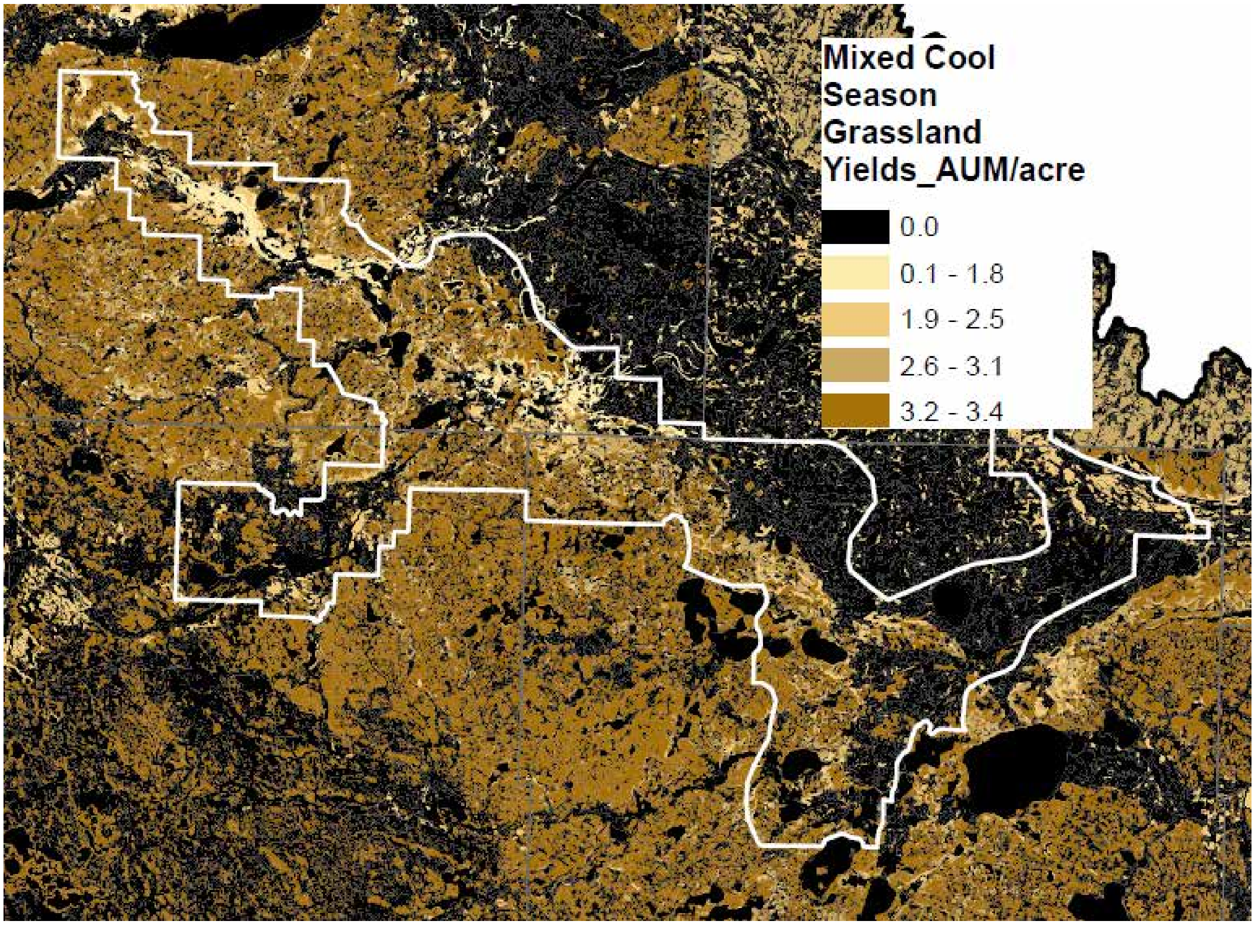

Figure 60. Landscape map of medium productivity mixed cool season grasslands, GL. Yields shown are potential AUM/acre. High and low productivity mixed cool season grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

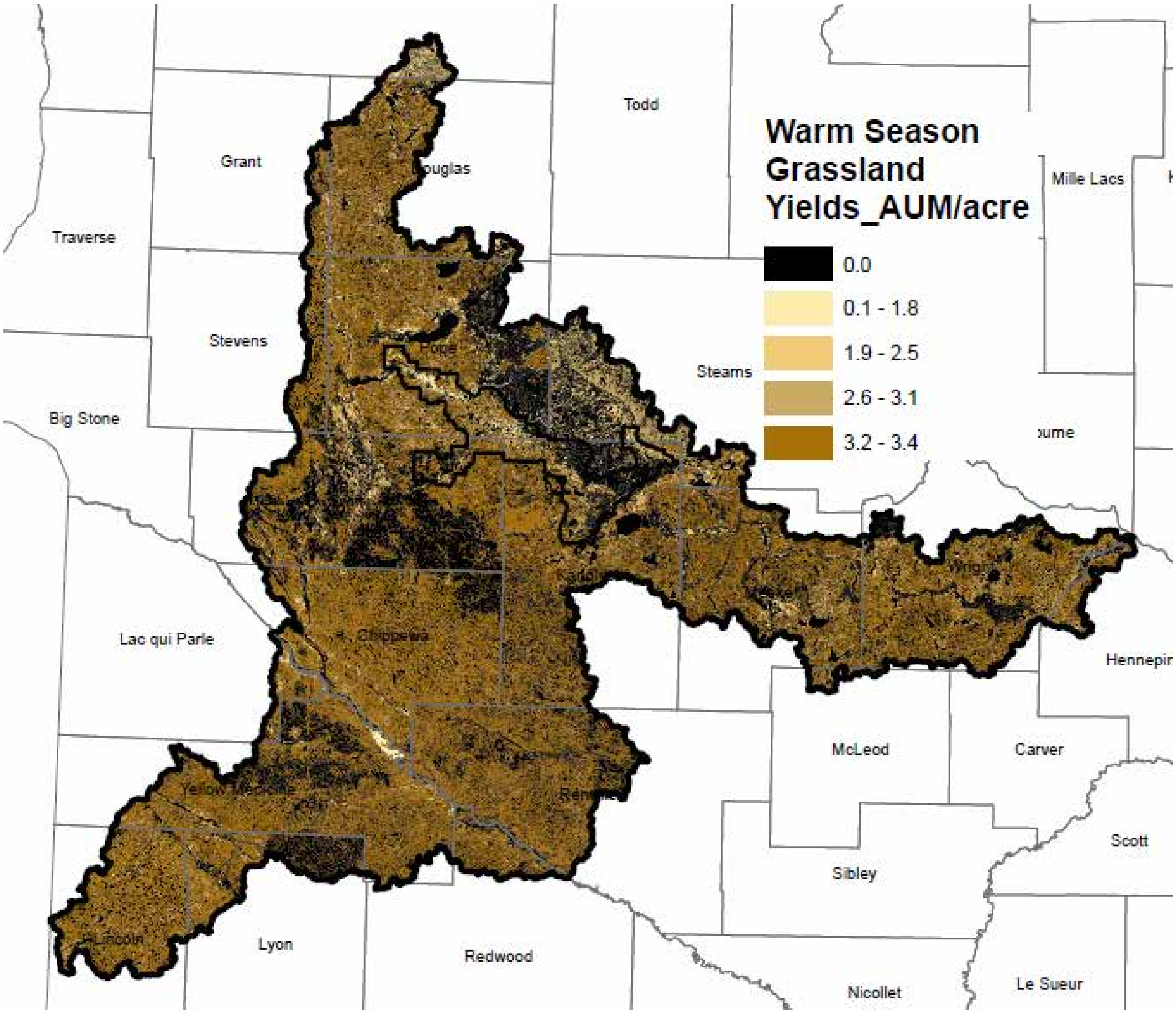

Figure 61. Medium productivity warm season grasslands, Glacial Lakes. Yields shown are potential AUM/acre. High and low productivity warm season grasslands exhibit similar regional patterns and are not shown. Areas shown in black represent locations with no yield data including water.

B. Budget Data Tables

Methods of compiling budget data for both cropland and grassland budgets from FINBIN (FINBIN 2013b) were outlined in Chapter 8. Tables in this appendix include additional detail on cropland budgets and variability in those budgets over time to reflect the impact of changing prices and production costs for cropland operations. Grazing system returns have fluctuated less in recent years and are only presented for 2007-2011. These returns are summarized in Chapter 8.

Table 77 includes price, other crop return, and production cost data. All values shown here reflect returns to the operator on owned land unless otherwise noted. Data are shown for 2011, 2007-2011, and 2002-2006. Table 78–Table 89 present yield and net returns to the land and to the operator for each of the cropland classes as well as alfalfa hay.

Crop	Location	2011			2007-2011			2002-2006		
		Price	OthRtn	Cost	Price	OthRtn	Cost	Price	OthRtn	Cost
corn	ABR_LS	5.72	19.99	522.72	4.09	13.68	432.69	1.91	27.55	240.43
	ABR_WS	5.70	17.00	511.05	4.34	13.13	439.19	1.97	31.35	238.04
	GL_LS	5.59	31.34	627.13	4.09	32.98	529.81	1.89	36.91	304.83
	GL_WS	5.65	33.95	599.02	4.33	27.51	513.48	1.89	36.52	280.57
soybean	ABR_LS	11.47	19.34	269.18	9.67	18.92	230.82	5.02	21.86	143.34
	ABR_WS	11.43	16.29	268.64	9.91	15.70	234.38	4.98	28.34	141.80
	GL_LS	11.21	25.17	356.69	9.60	20.48	320.34	4.92	22.13	197.94
	GL_WS	11.31	24.00	334.73	9.90	20.00	297.39	4.90	25.46	181.43
spring wheat	ABR_LS	8.28	35.86	330.95	6.23	14.64	275.63	3.25	11.81	153.46
	ABR_WS	8.07	23.42	326.90	6.39	13.42	276.48	3.21	18.43	149.86
	GL_LS	7.70	74.76	349.94	6.45	48.93	300.33	3.12	45.56	166.70
	GL_WS	7.77	68.99	352.05	6.34	39.73	298.51	3.18	43.11	154.14
sugar beets	ABR_LS	55.61	60.56	1091.28	43.06	25.45	902.39	32.57	23.38	623.83
	ABR_WS	58.32	48.99	1092.56	46.59	29.38	931.15	32.67	13.11	581.03
	GL_LS	61.26	122.08	1164.13	43.14	54.44	956.42	30.30	53.66	647.96
	GL_WS	62.73	107.79	1125.38	46.03	53.99	951.69	30.70	87.32	624.04
hay-alfalfa	ABR_LS	85.48	8.13	303.70	77.97	6.92	244.76	59.33	11.22	167.35
	ABR_WS	81.29	7.82	279.80	75.08	6.90	238.40	56.59	12.98	153.02
	GL_LS	134.80	14.60	450.83	121.19	12.40	378.59	81.70	11.93	247.80
	GL_WS	128.91	13.27	423.45	117.87	10.53	358.50	76.35	11.96	207.62
oats	ABR_LS	3.30	15.32	212.28	2.68	15.37	169.00	1.41	20.59	100.56
	ABR_WS	3.30	15.73	213.25	2.69	15.75	170.51	1.41	21.35	100.98
	GL_LS	3.11	59.36	225.05	2.57	65.92	203.14	1.32	56.37	123.14
	GL_WS	3.12	49.77	248.12	2.48	74.49	214.96	1.30	67.47	137.21

Table 77. Crop price and cost data. Crop price, other crop returns (OthRtn), and production costs shown for 2011, 2007-2011, and 2002-2006. Data are averages across counties and land capability classes and are shown for the landscapes (LS) and for the watersheds (WS).

Corn		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	122	173.33	161.62	145	170.91	149.98	130	49.30	38.69
	2c	.	.	.	.	.	.	.	.	.
	2e	110	106.56	94.85	131	113.88	92.95	117	24.85	14.23
	2s	111	109.05	97.34	132	116.10	95.17	118	25.63	15.02
	2w	111	111.67	99.96	132	118.21	97.28	118	26.78	16.16
	3e	89	(10.41)	(22.12)	106	14.16	(6.77)	95	(18.21)	(28.83)
	3s	70	(116.89)	(128.60)	83	(77.07)	(98.00)	75	(56.81)	(67.42)
	3w	101	52.58	40.87	119	67.71	46.78	107	5.20	(5.42)
	4e	70	(115.14)	(126.85)	84	(74.90)	(95.83)	75	(57.11)	(67.73)
	4s	58	(182.48)	(194.19)	69	(132.79)	(153.72)	62	(81.24)	(91.86)
	4w	54	(203.98)	(215.69)	65	(151.38)	(172.31)	58	(88.79)	(99.41)
	5w	62	(164.34)	(176.05)	73	(117.37)	(138.30)	65	(74.49)	(85.11)
	6e	58	(183.20)	(194.91)	70	(131.75)	(152.68)	61	(83.82)	(94.44)
	6s	46	(249.39)	(261.10)	55	(190.06)	(210.99)	49	(105.56)	(116.17)
	6w	54	(206.96)	(218.67)	64	(153.80)	(174.73)	57	(90.06)	(100.68)
	7-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	131	250.27	230.38	143	192.91	171.17	126	44.49	43.58
	2c	126	231.70	209.08	133	164.05	142.04	117	28.40	30.72
	2e	118	176.96	157.07	128	132.31	110.57	113	19.83	18.92
	2s	119	178.54	159.03	129	135.52	113.82	114	21.67	20.30
	2w	120	188.49	168.60	131	141.79	120.04	115	23.67	22.76
	3e	99	67.94	48.04	107	42.09	20.35	95	(17.07)	(17.98)
	3s	71	(91.06)	(110.57)	77	(87.49)	(109.19)	68	(69.05)	(70.42)
	3w	102	88.28	68.38	111	59.23	37.49	98	(9.71)	(10.63)
	4e	73	(79.40)	(98.90)	79	(77.73)	(99.43)	70	(65.48)	(66.85)
	4s	53	(186.46)	(206.36)	58	(167.65)	(189.39)	51	(102.07)	(102.98)
	4w	57	(170.17)	(189.16)	62	(151.14)	(172.79)	55	(94.73)	(96.72)
	5w	64	(138.67)	(154.02)	73	(110.60)	(131.89)	65	(75.03)	(81.33)
	6e	75	(65.71)	(84.70)	82	(64.77)	(86.42)	72	(61.13)	(63.12)
	6s	50	(208.36)	(227.86)	54	(184.78)	(206.48)	48	(109.00)	(110.37)
	6w	59	(153.80)	(173.70)	64	(141.16)	(162.90)	57	(91.57)	(92.48)
	7-.	.	.	.	.	.	.	.	.	.

Table 78. Yield and net returns from corn, ABR. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Soybeans		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	40	215.59	203.12	42	194.47	189.67	42	92.79	82.77
	2c	.	.	.	.	.	.	.	.	.
	2e	36	171.90	159.43	38	155.57	150.78	38	72.45	62.43
	2s	36	172.63	160.16	38	156.22	151.42	38	72.75	62.73
	2w	37	176.13	163.66	38	159.35	154.55	39	74.49	64.47
	3e	29	91.86	79.38	31	84.32	79.52	31	35.13	25.11
	3s	23	19.92	7.44	24	20.30	15.50	24	2.02	(8.00)
	3w	33	133.67	121.20	35	121.56	116.76	35	54.82	44.80
	4e	23	20.65	8.18	24	20.92	16.12	24	1.85	(8.17)
	4s	19	(22.80)	(35.27)	20	(17.74)	(22.54)	20	(18.06)	(28.09)
	4w	18	(30.23)	(42.70)	19	(24.35)	(29.15)	19	(21.51)	(31.53)
	5w	.	.	.	.	.	.	.	.	.
	6e	25	40.82	24.88	26	38.32	32.08	27	10.17	(0.90)
	6s	.	.	.	.	.	.	.	.	.
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	42	230.23	214.83	43	207.03	196.90	40	81.03	82.70
	2c	39	203.44	187.07	40	183.00	171.09	36	64.39	69.95
	2e	38	184.05	168.66	38	165.89	155.76	36	61.79	63.45
	2s	38	187.86	172.61	39	169.31	159.44	36	64.06	65.17
	2w	38	189.46	174.06	39	170.71	160.58	36	64.04	65.71
	3e	31	112.82	97.42	32	102.44	92.31	30	31.88	33.55
	3s	22	12.28	(2.98)	23	12.90	3.02	22	(9.15)	(8.04)
	3w	35	156.10	140.70	36	141.00	130.86	33	49.99	51.66
	4e	23	18.50	3.24	24	18.43	8.56	22	(6.78)	(5.68)
	4s	17	(46.41)	(61.80)	18	(39.41)	(49.54)	17	(33.86)	(32.19)
	4w	18	(35.17)	(49.98)	19	(29.27)	(38.34)	18	(28.26)	(28.94)
	5w	.	.	.	.	.	.	.	.	.
	6e	25	40.82	24.88	26	38.32	32.08	27	10.17	(0.90)
	6s	16	(68.52)	(84.89)	16	(59.33)	(71.24)	14	(44.84)	(39.28)
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.

Table 79. Yield and net returns from soybeans, ABR. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Spring Wheat		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	38	15.76	42.94	59	101.47	88.92	55	39.95	31.09
	2c	.	.	.	.	.	.	.	.	.
	2e	35	(10.05)	17.13	54	72.57	60.02	50	25.76	16.90
	2s	35	(6.84)	20.34	55	76.14	63.59	51	27.08	18.22
	2w	34	(19.30)	7.88	53	62.20	49.65	49	20.46	11.60
	3e	30	(51.49)	(24.31)	47	26.12	13.57	43	2.04	(6.82)
	3s	27	(74.76)	(47.58)	42	0.08	(12.47)	39	(10.62)	(19.48)
	3w	24	(101.36)	(74.18)	37	(29.70)	(42.26)	35	(25.36)	(34.22)
	4e	22	(115.14)	(87.96)	35	(45.15)	(57.70)	32	(33.33)	(42.19)
	4s	19	(147.34)	(120.16)	29	(81.25)	(93.80)	26	(51.90)	(60.76)
	4w	20	(133.55)	(106.37)	31	(65.76)	(78.31)	29	(43.40)	(52.26)
	5w	18	(155.14)	(127.96)	27	(89.96)	(102.51)	25	(55.86)	(64.72)
	6e	17	(160.21)	(133.03)	26	(95.62)	(108.18)	24	(58.44)	(67.30)
	6s	13	(193.71)	(166.53)	20	(133.16)	(145.71)	19	(77.43)	(86.30)
	6w	15	(173.28)	(146.10)	24	(110.28)	(122.83)	22	(66.02)	(74.88)
	7e	15	(173.49)	(146.31)	24	(110.52)	(123.07)	22	(66.14)	(75.00)
	7s	11	(198.37)	(165.10)	17	(147.04)	(161.22)	17	(84.56)	(95.26)
	7w	.	.	.	.	.	.	.	.	.
	8s	.	.	.	.	.	.	.	.	.
	8w	12	(195.15)	(161.88)	18	(143.44)	(157.61)	18	(82.62)	(93.32)
	10-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	44	51.57	51.76	54	81.60	68.13	48	21.00	24.20
	2c	46	70.50	61.70	53	81.37	67.59	46	17.49	24.71
	2e	40	24.67	24.86	50	55.70	42.22	44	9.25	12.45
	2s	40	21.67	23.15	50	55.46	42.03	44	9.51	12.13
	2w	37	(4.71)	(4.52)	45	28.38	14.91	40	(2.93)	0.27
	3e	33	(33.38)	(33.18)	41	0.53	(12.94)	36	(15.80)	(12.60)
	3s	28	(76.88)	(75.40)	35	(38.57)	(52.00)	31	(33.00)	(30.38)
	3w	28	(73.07)	(72.87)	35	(38.29)	(51.76)	31	(33.57)	(30.37)
	4e	24	(109.16)	(107.68)	30	(70.44)	(83.87)	26	(47.81)	(45.19)
	4s	20	(139.70)	(139.51)	25	(101.55)	(115.02)	22	(62.32)	(59.12)
	4w	25	(95.53)	(92.33)	32	(57.20)	(70.57)	28	(42.11)	(40.26)
	5w	20	(138.26)	(123.07)	27	(86.13)	(99.10)	25	(54.80)	(58.31)
	6e	17	(166.20)	(163.01)	21	(123.60)	(136.96)	19	(71.91)	(70.05)
	6s	15	(174.86)	(173.38)	19	(135.09)	(148.52)	17	(77.76)	(75.13)
	6w	20	(139.85)	(139.65)	24	(103.01)	(116.48)	22	(63.30)	(60.11)
	7e	19	(146.79)	(141.20)	24	(104.72)	(118.01)	22	(63.97)	(63.18)
	7s	14	(180.28)	(175.05)	18	(141.97)	(155.88)	16	(81.16)	(79.91)
	7w	19	(149.16)	(157.96)	22	(119.27)	(133.05)	19	(70.60)	(63.39)
	8s	13	(191.79)	(200.59)	15	(158.22)	(171.99)	13	(87.70)	(80.48)
	8w	16	(170.92)	(173.71)	19	(136.60)	(150.43)	17	(78.41)	(73.75)
	10-.	.	.	.	.	.	.	.	.	.

Table 80. Yield and net returns from spring wheat, ABR. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Sugar beets		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	15	(226.68)	(160.15)	19	(55.27)	(55.07)	17	(15.14)	(32.02)
	2c	.	.	.	.	.	.	.	.	.
	2e	14	(268.13)	(201.60)	18	(96.47)	(96.27)	16	(43.99)	(60.87)
	2s	15	(207.53)	(141.00)	19	(36.24)	(36.04)	18	(1.82)	(18.70)
	2w	14	(254.74)	(188.21)	18	(83.16)	(82.96)	17	(34.67)	(51.55)
	3e	13	(315.23)	(248.70)	17	(143.27)	(143.08)	15	(76.76)	(93.64)
	3s	12	(358.32)	(291.79)	16	(186.09)	(185.90)	14	(106.74)	(123.62)
	3w	11	(401.41)	(334.88)	15	(228.92)	(228.72)	13	(136.73)	(153.60)
	4e	12	(360.93)	(294.40)	16	(188.69)	(188.49)	14	(108.56)	(125.44)
	4s	12	(395.81)	(329.28)	15	(223.36)	(223.16)	14	(132.83)	(149.71)
	4w	10	(469.00)	(402.47)	13	(296.10)	(295.90)	12	(183.76)	(200.64)
	5-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	17	(67.03)	(52.54)	18	(19.34)	(18.86)	18	24.09	(4.84)
	2c	17	(35.04)	(37.90)	18	(25.73)	(25.16)	17	25.13	(7.82)
	2e	16	(116.71)	(102.22)	17	(63.65)	(63.17)	17	(5.41)	(34.35)
	2s	17	(51.87)	(34.90)	19	(0.65)	(0.18)	18	35.83	7.47
	2w	16	(100.66)	(86.17)	18	(49.34)	(48.86)	17	4.12	(24.81)
	3e	15	(173.15)	(158.66)	16	(114.00)	(113.52)	16	(38.93)	(67.86)
	3s	14	(231.15)	(214.18)	15	(161.30)	(160.83)	15	(71.36)	(99.72)
	3w	13	(276.43)	(261.94)	14	(206.12)	(205.64)	14	(100.25)	(129.19)
	4e	14	(234.25)	(217.28)	15	(164.08)	(163.61)	15	(73.21)	(101.57)
	4s	13	(269.72)	(255.23)	15	(200.14)	(199.66)	14	(96.27)	(125.21)
	4w	11	(369.84)	(349.56)	13	(280.35)	(279.91)	12	(152.29)	(179.89)
	5-.	.	.	.	.	.	.	.	.	.

Table 81. Yield and net returns from sugar beets, ABR. Yield (Yld, tons/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Oats		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	100	114.90	110.59	118	142.71	138.96	104	62.54	61.84
	2c	.	.	.	.	.	.	.	.	.
	2e	97	104.28	99.97	114	132.95	129.20	100	57.93	57.23
	2s	101	116.12	111.81	119	143.83	140.08	104	63.07	62.37
	2w	95	96.44	92.13	112	125.75	122.00	98	54.52	53.82
	3e	85	65.67	61.36	100	97.48	93.73	88	41.17	40.46
	3s	83	61.05	56.74	98	93.24	89.49	86	39.16	38.46
	3w	83	60.79	56.48	98	93.00	89.25	86	39.05	38.34
	4e	70	18.13	13.82	83	53.82	50.07	73	20.53	19.83
	4s	74	30.23	25.92	87	64.94	61.18	76	25.78	25.08
	4w	73	28.88	24.57	87	63.69	59.94	76	25.19	24.49
	5w	.	.	.	.	.	.	.	.	.
	6e	19	(145.49)	(149.80)	22	(96.49)	(100.24)	20	(50.51)	(51.22)
	6s	29	(114.05)	(118.36)	34	(67.60)	(71.35)	30	(36.86)	(37.56)
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	88	75.87	71.57	104	107.57	103.80	91	45.42	46.23
	2c	99	108.84	104.56	116	138.45	134.67	102	59.68	60.99
	2e	81	51.89	47.60	95	85.39	81.62	84	35.01	35.81
	2s	90	79.90	75.60	106	111.25	107.48	93	47.18	47.91
	2w	80	48.24	43.94	94	82.02	78.25	82	33.43	34.23
	3e	72	22.61	18.32	85	58.35	54.58	74	22.30	23.10
	3s	70	18.14	13.85	83	54.18	50.41	73	20.37	21.10
	3w	68	12.22	7.93	81	48.73	44.96	71	17.79	18.59
	4e	53	(37.96)	(42.25)	62	2.32	(1.45)	55	(3.99)	(3.26)
	4s	55	(32.02)	(36.31)	64	7.83	4.06	56	(1.42)	(0.61)
	4w	67	8.88	4.58	79	45.64	41.87	70	16.36	16.99
	5w	.	.	.	.	.	.	.	.	.
	6e	19	(146.00)	(150.30)	22	(97.36)	(101.12)	20	(50.89)	(50.25)
	6s	25	(126.03)	(130.32)	30	(78.95)	(82.72)	26	(42.23)	(41.49)
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.

Table 82. Yield and net returns from oats, ABR. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Alfalfa Hay		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
ABR_LS	1	4.0	18.28	3.62	4.4	87.02	75.81	5.1	141.68	138.29
	2c	.	.	.	.	.	.	.	.	.
	2e	3.8	1.54	(13.12)	4.2	70.49	59.28	4.8	124.96	121.57
	2s	3.9	6.70	(7.96)	4.2	75.58	64.37	4.9	130.11	126.72
	2w	3.9	8.45	(6.21)	4.3	77.31	66.10	5.0	131.86	128.47
	3e	2.7	(78.93)	(93.59)	3.0	(9.02)	(20.22)	3.5	44.53	41.14
	3s	3.1	(48.94)	(63.60)	3.4	20.61	9.40	4.0	74.50	71.11
	3w	3.4	(28.25)	(42.91)	3.7	41.05	29.84	4.3	95.18	91.79
	4e	2.3	(112.07)	(126.73)	2.5	(41.76)	(52.97)	2.9	11.40	8.01
	4s	2.2	(119.36)	(134.02)	2.4	(48.96)	(60.17)	2.8	4.12	0.73
	4w	3.3	(39.07)	(53.73)	3.6	30.36	19.16	4.2	84.37	80.98
	5w	2.2	(119.30)	(133.96)	2.4	(48.90)	(60.10)	2.8	4.19	0.79
	6e	2.4	(101.54)	(116.20)	2.7	(31.35)	(42.56)	3.1	21.93	18.54
	6s	1.5	(175.67)	(190.33)	1.6	(104.59)	(115.80)	1.9	(52.16)	(55.55)
	6w	1.7	(159.49)	(174.15)	1.8	(88.60)	(99.81)	2.1	(35.98)	(39.38)
	7e	1.5	(172.53)	(187.19)	1.6	(101.49)	(112.69)	1.9	(49.02)	(52.41)
	7s	1.7	(155.50)	(170.16)	1.9	(84.66)	(95.87)	2.2	(32.00)	(35.39)
	7w	.	.	.	.	.	.	.	.	.
	8s	.	.	.	.	.	.	.	.	.
	8w	1.7	(160.49)	(175.15)	1.8	(89.60)	(100.80)	2.1	(36.99)	(40.38)
	10-.	.	.	.	.	.	.	.	.	.
ABR_WS	1	4.9	147.07	135.56	5.0	143.18	134.86	4.8	128.29	126.68
	2c	5.1	178.83	168.37	5.1	151.77	144.42	4.6	117.03	116.02
	2e	4.7	132.10	120.59	4.8	129.27	120.95	4.6	117.55	115.94
	2s	4.8	135.32	123.66	4.9	135.15	126.69	4.7	124.22	122.53
	2w	4.2	85.70	74.19	4.3	87.35	79.04	4.1	90.02	88.41
	3e	3.7	49.26	37.75	3.8	52.54	44.22	3.6	59.31	57.71
	3s	3.5	30.85	19.19	3.6	39.15	30.70	3.5	54.49	52.79
	3w	3.5	28.14	16.63	3.5	34.43	26.11	3.4	51.44	49.83
	4e	2.8	(27.21)	(38.87)	2.9	(14.95)	(23.41)	2.8	12.12	10.43
	4s	2.6	(40.06)	(51.57)	2.7	(29.25)	(37.57)	2.6	1.06	(0.55)
	4w	3.3	8.96	(2.90)	3.4	23.16	14.52	3.4	47.03	45.23
	5w	2.2	(98.19)	(111.45)	2.4	(52.96)	(62.88)	2.5	(5.78)	(8.38)
	6e	2.1	(87.72)	(99.58)	2.2	(66.17)	(74.81)	2.2	(19.89)	(21.70)
	6s	1.9	(101.33)	(112.99)	1.9	(83.62)	(92.07)	1.9	(40.05)	(41.74)
	6w	2.2	(75.67)	(87.18)	2.2	(62.35)	(70.66)	2.1	(24.52)	(26.13)
	7e	2.1	(86.02)	(98.16)	2.2	(62.20)	(71.10)	2.2	(24.95)	(26.92)
	7s	2.0	(95.91)	(107.77)	2.0	(75.06)	(83.70)	2.0	(31.91)	(33.72)
	7w	2.0	(74.14)	(84.60)	2.0	(77.53)	(84.89)	1.8	(36.75)	(37.76)
	8s	2.9	(3.28)	(13.74)	2.9	(13.30)	(20.65)	2.6	6.33	5.32
	8w	1.9	(113.31)	(125.87)	2.0	(79.93)	(89.21)	2.0	(34.43)	(36.63)
	10-.	.	.	.	.	.	.	.	.	.

Table 83. Yield and net returns from alfalfa hay, ABR. Yield (Yld, tons/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the ABR landscape (LS) and the broader watershed area (WS).

Corn		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	162	345.08	268.17	174	244.01	179.27	174	71.46	47.10
	2e	147	262.41	185.50	158	178.34	113.60	158	41.68	17.33
	2s	134	191.89	114.98	144	123.93	59.19	145	17.47	(6.89)
	2w	141	230.17	153.26	152	153.95	89.21	152	29.93	5.57
	3e	121	118.77	41.86	130	66.35	1.61	131	(10.80)	(35.16)
	3s	81	(102.16)	(179.07)	87	(108.45)	(173.19)	88	(90.26)	(114.61)
	3w	127	148.04	71.13	136	89.91	25.17	136	0.34	(24.01)
	4e	101	7.97	(68.94)	109	(21.68)	(86.42)	109	(50.29)	(74.64)
	4s	71	(159.93)	(236.84)	77	(152.91)	(217.65)	77	(111.25)	(135.61)
	4w	74	(117.73)	(192.39)	78	(122.87)	(182.74)	79	(103.57)	(126.84)
	5w	.	.	.	.	.	.	.	.	.
	6e	92	(53.66)	(129.86)	99	(61.21)	(125.80)	98	(71.70)	(96.21)
	6s	80	(110.60)	(187.51)	86	(114.05)	(178.79)	86	(93.82)	(118.18)
	6w	77	(126.21)	(203.12)	83	(126.32)	(191.06)	83	(99.48)	(123.83)
	7-.	.	.	.	.	.	.	.	.	.
GL_WS	1	160	344.48	332.08	172	265.85	247.10	174	75.42	93.89
	2e	147	269.93	257.53	158	204.48	185.74	159	48.35	66.82
	2s	137	218.26	204.07	148	161.91	141.89	150	29.76	47.04
	2w	145	261.84	249.44	156	198.24	179.49	158	45.40	63.87
	3e	121	126.83	114.43	131	87.00	68.25	132	(3.77)	14.70
	3s	82	(93.76)	(107.01)	88	(94.72)	(114.06)	89	(83.90)	(65.99)
	3w	135	207.37	194.97	146	153.80	135.06	147	25.64	44.11
	4e	99	(1.02)	(13.42)	106	(18.48)	(37.22)	107	(50.13)	(31.66)
	4s	64	(194.43)	(208.62)	69	(177.71)	(197.73)	70	(120.58)	(103.30)
	4w	88	(55.37)	(74.04)	94	(63.86)	(86.14)	95	(72.43)	(58.24)
	5w	.	.	.	.	.	.	.	.	.
	6e	95	(23.94)	(37.34)	102	(35.22)	(54.75)	103	(58.32)	(40.64)
	6s	79	(109.86)	(125.11)	85	(107.98)	(128.75)	86	(89.98)	(73.40)
	6w	77	(125.50)	(139.69)	82	(120.73)	(140.75)	83	(95.61)	(78.32)
	7-.	.	.	.	.	.	.	.	.	.

Table 84. Yield and net returns from corn, GL. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).

Soybeans		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	48	239.03	166.44	53	238.54	179.38	51	84.30	60.59
	2e	43	189.29	116.70	48	190.74	131.58	46	61.54	37.84
	2s	39	147.63	75.04	44	150.97	91.81	42	42.79	19.08
	2w	41	168.94	96.35	46	172.05	112.89	44	51.73	28.02
	3e	36	105.38	32.80	40	111.67	52.51	38	21.89	(1.82)
	3s	24	(24.80)	(97.39)	27	(14.21)	(73.37)	26	(37.44)	(61.15)
	3w	37	120.17	47.58	41	124.78	65.62	40	29.37	5.66
	4e	30	42.94	(29.64)	34	50.92	(8.24)	32	(6.30)	(30.01)
	4s	21	(61.42)	(134.01)	23	(49.03)	(108.19)	22	(54.63)	(78.34)
	4w	22	(55.86)	(130.55)	24	(31.48)	(85.41)	24	(46.74)	(69.78)
	5w	.	.	.	.	.	.	.	.	.
	6e	28	10.60	(58.39)	31	21.64	(40.30)	29	(28.26)	(51.84)
	6s	24	(27.97)	(100.55)	27	(15.85)	(75.01)	25	(39.92)	(63.63)
	6w	23	(38.24)	(110.82)	26	(25.64)	(84.80)	24	(44.69)	(68.39)
	7-.	.	.	.	.	.	.	.	.	.
GL_WS	1	48	246.75	227.90	52	244.07	227.47	52	91.01	101.86
	2e	45	205.18	186.33	48	205.03	188.43	48	71.94	82.78
	2s	42	177.86	157.53	45	179.38	161.59	45	59.40	69.28
	2w	44	198.30	179.45	47	198.67	182.07	47	68.69	79.53
	3e	37	115.71	96.86	39	121.45	104.85	39	30.63	41.48
	3s	25	(17.82)	(37.38)	27	(4.00)	(21.16)	27	(30.64)	(20.25)
	3w	41	164.66	145.81	44	166.95	150.35	44	53.25	64.09
	4e	30	38.68	19.83	32	49.12	32.52	32	(4.64)	6.20
	4s	20	(78.89)	(99.23)	21	(61.14)	(78.92)	21	(58.82)	(48.93)
	4w	27	0.83	(24.38)	29	16.38	(3.29)	29	(21.00)	(13.67)
	5w	.	.	.	.	.	.	.	.	.
	6e	29	28.70	9.67	31	39.97	22.01	31	(10.81)	(0.56)
	6s	24	(24.68)	(45.90)	26	(10.20)	(28.68)	26	(34.14)	(24.82)
	6w	23	(35.25)	(55.58)	25	(20.05)	(37.84)	25	(38.93)	(29.05)
	7-.	.	.	.	.	.	.	.	.	.

Table 85. Yield and net returns from soybeans, GL. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).

Spring Wheat		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	39	37.51	19.84	58	131.15	90.96	60	69.94	57.31
	2e	35	4.86	(12.80)	51	91.76	51.57	53	49.08	36.45
	2s	33	(10.25)	(27.91)	48	73.55	33.36	50	39.22	26.58
	2w	33	(10.56)	(28.23)	48	73.04	32.85	50	39.49	26.85
	3e	31	(25.79)	(43.45)	46	54.89	14.69	47	30.27	17.63
	3s	28	(46.56)	(64.22)	42	29.83	(10.37)	43	17.22	4.59
	3w	31	(26.11)	(43.77)	46	54.59	14.40	47	30.11	17.47
	4e	25	(67.66)	(85.33)	38	4.54	(35.65)	39	4.68	(7.96)
	4s	24	(80.73)	(98.39)	35	(11.29)	(51.48)	36	(3.97)	(16.61)
	4w	32	(6.31)	(9.89)	47	82.78	45.98	49	39.64	27.91
	5w	29	(67.22)	(97.49)	41	24.51	(14.50)	46	29.29	17.59
	6e	19	(131.14)	(157.21)	28	(57.94)	(97.46)	31	(19.53)	(31.48)
	6s	16	(143.63)	(161.29)	23	(86.75)	(126.94)	24	(41.21)	(53.84)
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.
GL_WS	1	38	(8.40)	33.10	56	90.35	88.96	59	58.87	92.01
	2e	35	(31.13)	10.38	52	63.43	62.04	54	44.39	77.53
	2s	33	(41.93)	(2.07)	50	50.23	47.76	52	36.95	68.81
	2w	33	(44.88)	(3.37)	49	47.14	45.75	51	35.68	68.81
	3e	30	(71.77)	(30.26)	44	15.47	14.08	46	18.66	51.79
	3s	27	(96.77)	(56.04)	39	(14.26)	(16.16)	41	2.55	35.08
	3w	31	(62.69)	(21.18)	46	26.16	24.77	48	24.45	57.58
	4e	23	(120.83)	(79.33)	35	(42.45)	(43.84)	36	(12.36)	20.77
	4s	22	(129.18)	(89.32)	33	(52.80)	(55.27)	34	(18.22)	13.64
	4w	29	(68.30)	(29.11)	43	19.40	14.82	45	18.11	46.60
	5w	28	(92.77)	(49.79)	41	(5.56)	(4.53)	43	10.22	46.13
	6e	19	(156.44)	(117.79)	28	(82.00)	(83.94)	30	(31.86)	0.60
	6s	16	(179.72)	(140.82)	23	(112.85)	(115.95)	24	(50.01)	(18.90)
	6w	.	.	.	.	.	.	.	.	.
	7-.	.	.	.	.	.	.	.	.	.

Table 86. Yield and net returns from spring wheat, GL. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).

Sugar Beets		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	14	(188.25)	(156.07)	23	99.94	25.24	22	91.82	46.30
	2e	14	(217.03)	(184.85)	22	68.03	(6.67)	21	69.87	24.35
	2s	12	(295.31)	(263.13)	20	(18.77)	(93.47)	19	10.18	(35.34)
	2w	12	(318.33)	(286.16)	20	(44.30)	(119.00)	19	(7.38)	(52.90)
	3e	.	.	.	.	.	.	.	.	.
	3s	.	.	.	.	.	.	.	.	.
	3w	11	(367.45)	(335.27)	18	(98.76)	(173.46)	17	(44.84)	(90.36)
	4-.	.	.	.	.	.	.	.	.	.
GL_WS	1	16	(62.00)	17.73	23	129.49	117.72	23	123.88	186.52
	2e	15	(94.93)	(15.19)	22	95.70	83.94	22	100.99	163.64
	2s	14	(187.57)	(109.16)	20	3.17	(10.34)	20	37.96	97.60
	2w	13	(210.84)	(131.11)	19	(23.23)	(35.00)	19	20.45	83.10
	3e	.	.	.	.	.	.	.	.	.
	3s	.	.	.	.	.	.	.	.	.
	3w	13	(267.03)	(187.30)	18	(80.90)	(92.66)	18	(18.60)	44.05
	4-.	.	.	.	.	.	.	.	.	.

Table 87. Yield and net returns from sugar beets, GL. Yield (Yld, tons/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).

Oats		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	60	10.19	(34.16)	89	89.35	59.49	89	50.14	38.34
	2e	56	(2.99)	(47.34)	82	74.15	44.29	83	42.08	30.28
	2s	51	(16.44)	(60.79)	76	58.65	28.79	76	33.86	22.06
	2w	52	(15.19)	(59.53)	76	60.09	30.23	77	34.62	22.82
	3e	46	(33.07)	(77.41)	68	39.48	9.62	69	23.69	11.89
	3s	40	(51.36)	(95.70)	59	18.39	(11.47)	60	12.50	0.70
	3w	48	(26.30)	(70.64)	71	47.28	17.43	72	27.83	16.03
	4e	38	(57.48)	(101.83)	56	11.33	(18.53)	57	8.76	(3.04)
	4s	35	(66.56)	(110.91)	52	0.86	(29.00)	52	3.20	(8.60)
	4w	48	(25.99)	(70.34)	71	47.63	17.77	72	28.01	16.21
	5w	48	(26.63)	(70.98)	71	46.89	17.04	72	27.62	15.82
	6e	28	(89.73)	(134.08)	41	(25.86)	(55.71)	41	(10.97)	(22.77)
	6s	23	(103.01)	(147.36)	35	(41.17)	(71.03)	35	(19.09)	(30.89)
	6w	45	(34.75)	(79.10)	67	37.53	7.68	68	22.66	10.86
	7e	.	.	.	.	.	.	.	.	.
	7s	26	(94.57)	(138.92)	39	(31.44)	(61.30)	39	(13.93)	(25.73)
	7w	.	.	.	.	.	.	.	.	.
	8-.	.	.	.	.	.	.	.	.	.
GL_WS	1	66	47.18	35.32	86	84.76	75.49	91	50.23	56.72
	2e	64	39.21	27.35	82	76.23	66.96	88	45.54	52.04
	2s	60	26.26	13.49	77	63.66	53.82	82	38.56	44.55
	2w	61	30.79	18.93	79	67.25	57.98	84	40.61	47.10
	3e	54	7.94	(3.92)	69	43.27	34.00	74	27.32	33.82
	3s	46	(16.22)	(28.51)	59	18.41	8.87	63	13.53	19.79
	3w	57	17.55	5.69	73	53.33	44.07	78	32.90	39.40
	4e	42	(29.61)	(41.47)	54	3.98	(5.29)	57	5.52	12.02
	4s	38	(41.34)	(54.11)	49	(7.36)	(17.20)	53	(0.77)	5.22
	4w	57	16.74	1.40	74	56.71	45.23	79	34.60	39.14
	5w	54	10.04	0.06	69.17	43.34	35.26	74	27.42	34.97
	6e	32	(59.72)	(72.16)	41.39	(27.25)	(36.88)	44	(11.71)	(5.54)
	6s	26	(78.43)	(91.73)	34	(46.05)	(56.22)	36	(22.12)	(16.43)
	6w	51	(1.98)	(14.74)	66	34.07	24.23	70	22.15	28.14
	7e	.	.	.	.	.	.	.	.	.
	7s	29	(70.40)	(85.21)	38	(36.01)	(47.15)	40	(16.57)	(11.73)
	7w	.	.	.	.	.	.	.	.	.
	8-.	.	.	.	.	.	.	.	.	.

Table 88. Yield and net returns from oats, GL. Yield (Yld, bu/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).

Alfalfa Hay		2011			2007-2011			2002-2006		
		Yld	NR_land	NR_op	Yld	NR_land	NR_op	Yld	NR_land	NR_op
GL_LS	1	4.4	197.69	121.73	4.5	219.86	152.86	4.5	155.30	106.64
	2e	4.3	184.53	108.57	4.4	207.67	140.66	4.4	147.20	98.54
	2s	4.3	176.45	100.49	4.4	200.17	133.17	4.3	142.23	93.56
	2w	3.8	109.11	33.14	3.9	137.73	70.73	3.8	100.77	52.10
	3e	3.6	82.07	6.11	3.7	112.66	45.66	3.6	84.12	35.46
	3s	2.8	(21.19)	(97.15)	2.9	16.92	(50.08)	2.8	20.55	(28.11)
	3w	3.3	40.93	(35.04)	3.3	74.51	7.51	3.3	58.79	10.13
	4e	3.2	32.62	(43.34)	3.3	66.81	(0.19)	3.3	53.68	5.01
	4s	2.1	(111.87)	(187.83)	2.2	(67.16)	(134.17)	2.2	(35.28)	(83.94)
	4w	2.8	(24.61)	(97.32)	2.8	14.04	(56.92)	2.8	19.12	(39.05)
	5w	.	.	.	.	.	.	.	.	.
	6e	2.7	(39.61)	(114.49)	2.7	(0.27)	(65.51)	2.7	8.98	(36.51)
	6s	1.2	(239.09)	(315.06)	1.2	(185.12)	(252.13)	1.2	(113.60)	(162.27)
	6w	2.1	(118.53)	(194.49)	2.1	(73.34)	(140.34)	2.1	(39.38)	(88.04)
	7e	2.5	(56.36)	(135.58)	2.6	(15.80)	(81.91)	2.6	(1.33)	(46.82)
	7s	1.2	(233.10)	(307.97)	1.3	(179.66)	(244.91)	1.2	(110.14)	(155.63)
	7w									
	8s									
	8w									
	10-.									
GL_WS	1	4.6	200.57	172.14	4.7	214.19	191.08	4.5	151.84	148.62
	2e	4.5	183.97	155.55	4.5	198.87	175.76	4.4	142.25	139.04
	2s	4.4	167.94	138.19	4.4	184.31	159.97	4.3	133.16	128.68
	2w	4.0	117.83	89.40	4.0	137.80	114.68	3.9	103.85	100.64
	3e	3.7	83.59	55.16	3.8	106.20	83.09	3.6	84.09	80.88
	3s	2.6	(64.44)	(93.49)	2.6	(30.31)	(54.01)	2.5	(1.29)	(5.10)
	3w	3.4	42.17	13.74	3.4	67.96	44.85	3.3	60.10	56.89
	4e	3.2	17.99	(10.43)	3.2	45.66	22.54	3.1	46.24	43.03
	4s	2.0	(132.70)	(162.45)	2.1	(93.25)	(117.59)	2.0	(41.17)	(45.64)
	4w	2.7	(41.29)	(73.87)	2.8	(8.18)	(37.13)	2.7	11.79	0.99
	5w	.	.	.	.	.	.	.	.	.
	6e	2.9	(24.52)	(53.56)	2.9	6.49	(17.03)	2.8	21.23	17.88
	6s	1.3	(230.17)	(260.69)	1.3	(183.17)	(208.22)	1.3	(98.20)	(103.42)
	6w	2.1	(125.15)	(154.90)	2.1	(86.30)	(110.63)	2.1	(36.93)	(41.40)
	7e	2.7	(48.65)	(75.63)	2.7	(16.20)	(37.34)	2.6	7.57	6.78
	7s	1.2	(235.79)	(268.24)	1.3	(188.07)	(214.69)	1.2	(101.90)	(108.38)
	7w									
	8s									
	8w									
	10-.									

Table 89. Yield and net returns from alfalfa hay, GL. Yield (Yld, tons DM/acre) and average annual returns to land (NR_land) and to the operator (NR_op) are shown for owned land within the GL landscape (LS) and the broader watershed area (WS).