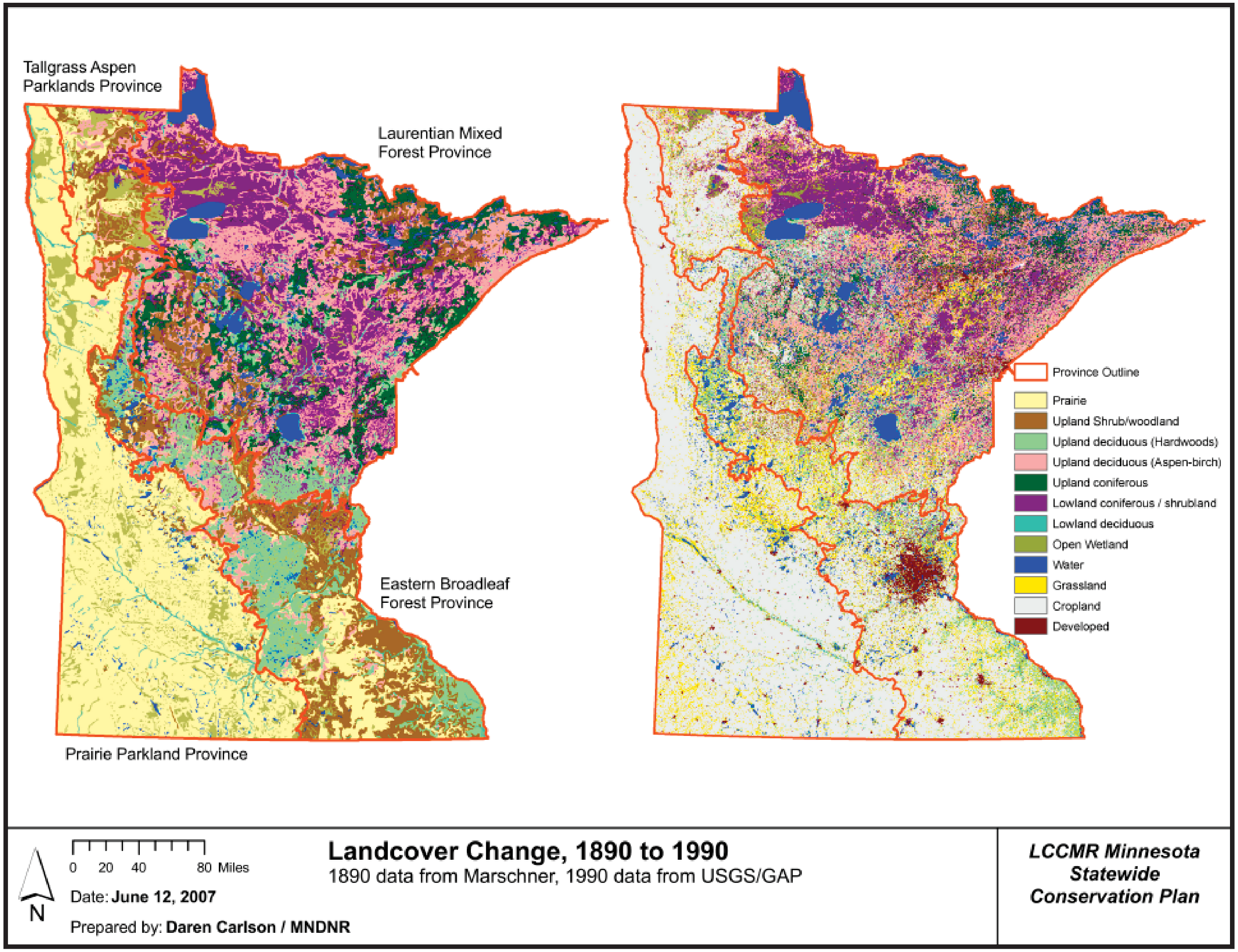

Figure 1: Marschner's Map of vegetation around the time of European settlement and contemporary landcover based on 1990 GAP data.
Credit: Daren Carlson, Minnesota DNR

"Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends to do otherwise."

—Aldo Leopold, *Sand County Almanac*

History

For purposes of this report, the land resource is defined as soils, land cover, with a particular emphasis on the four dominant vegetation associations as well as developed land uses, and the underlying geology across the entire state of Minnesota. Land also shows evidence of change induced by 'drivers' including both natural and constructed or engineered processes. The land resource:

- Provides food, fiber, shelter and energy.
- Is the source of diverse biological and physical key resources for human use and appreciation, including outdoor recreation.
- Is the source of biological and physical resources for other animals.
- Provides industrial raw materials, including timber and mineral resources which are the basis for major industries.
- Is a key component of the state's hydrology and water resources, including water storage (on the land with surficial lakes, or within the soils and geologic resource as groundwater, and bedrock aquifers) and transport (rivers and streams).

The land provides habitat for diverse plants and animals valued by humans for their use, beauty and increasingly the ecosystem processes and environmental services (e.g., clean water, productive soils, biodiversity, etc.) we have come to depend upon. The primary focus here is on the conservation of habitat values, productivity, processes and services of the Land resource.

Broadly speaking, there are five major categories of land cover/land use types in Minnesota:

- Agricultural
- Forest
- Grassland and Prairie
- Mining
- Developed - Residential/commercial/industrial/roadways

At the time the first European settlers arrived, Minnesota offered a rich and diverse landscape. Early settlers in southern Minnesota found the tall-grass prairie stretching across the southwest half of the state. Arid bluffs supported species adapted to the scorching summer heat, drying winds, and thin gravelly soil, while depressions on the rolling land below supported pockets of wetland. Fire was a regular visitor to the prairie, maintaining the open grasslands.

Further north, the landscape was more rolling, the climate more moist, and fires less frequent. Because of reduced fire frequency, trees dominated the landscape. Oak woodlands marked the transition between prairie to the southwest and the oak, elm, and sugar maple forests of central Minnesota. Mixed conifer-hardwood forests dominatws in north-central and northeastern Minnesota.

The state was a mosaic of prairie, mesic hardwood forest, and mixed conifer-hardwood forest stretching in bands trending roughly from the southeast to the northwest across the state. The particular plant community present at a given location was the result of a complex interaction of many factors, including soils, topography, slope, aspect (the direction a site faces), local weather patterns and regional climate, hydrology, and the history of major and minor disturbance —including fire, windthrow, and the presence or absence of large grazers such as elk and bison. The vegetation at the time of European settlement is shown in Figure 1, page 26.

Cover Type	Acres (1890)	Acres (1990)
Cropland	0	23,981,079
Grassland	0	5,109,924
Developed	0	599,675
Open Wetland	4,163,031	2,074,773
Lowland Conifer/shrubland	6,639,649	5,350,747
Prairie	15,677,426	27,632
Upland Shrub/Woodland	6,383,580	1,031,659
Upland Deciduous (Aspen-birch)	8,362,227	7,053,315
Upland Deciduous (Hardwoods)	4,388,564	2,179,753
Total Acres*	**48,774,203**	**49,073,973**

Table 1: Change in cover type between the dates of the General Land Office Survey (circa 1848-1907, depending on the region of the state) and 1990 GAP landcover. Source: Daren Carlson, Minnesota DNR. Note: Total Acreage amounts differ primarily to increased mapping accuracy and/or change in the amount of open water area; open water acreages are not included in the cover type data.

With the advent of European settlement, existing plant communities and patterns of interaction on the landscape (both human and natural) were disrupted, and the patterns of disturbance permanently altered. The land resource became the foundation of the Minnesota economy. Logging, land clearing, settlement, agriculture, mining and urban development became part of our history and changed the landscape forever. It should be noted that the pre-European settlement was not devoid of human impact, notably by Native Americans. Today we continue to seek a broader understanding of these historic landscapes and the factors that shaped them.

At the time of settlement, the entire state was, with the exception of Native American villages, a matrix of native plant communities. Today, satellite land-cover analysis has identified approximately 19 million acres of native and semi-native habitat remaining in the state, less than half of the original landcover. Of this acreage, only a small percent (e.g., 5% of the area surveyed to date) meet the high standards necessary to be included in the Minnesota County Biological Survey maps of native plant communities. The remaining sites in the survey areas are of lower quality, or represent non-native plant communities that have developed since European settlement in response to new and altered disturbance regimes.

There are slightly over 2,000 plant species documented as occurring in the state; almost 20% are introduced, either from other countries or from outside the Midwest. Of the native species, 256 are state listed as Special Concern, Threatened, or Endangered. Two, the Minnesota dwarf trout lily (see "Trout Lily", facing page) and Frenchman's bluff moonwort, are known to occur only in select locations in Minnesota and nowhere else on earth. These endemic species are especially vulnerable to extinction.

The land resource today provides recreational and economic opportunities for many. However, the land resource is impacted to a very broad degree by many of the drivers of change to the state's other natural resources. Moreover, it is perhaps one of the slowest to recover from various stressors. This is because the time needed to restore all aspects of a complex ecological system such as a prairie is far greater than the time needed to regenerate a specific resource such as a tree. Still other resources are not renewable on a practical timescale; this includes mineral resources and some soil resources.

The key factors that are driving change in the land resources are discussed in the following sections. Recommendations to address long-term conservation of the resources are provided in a separate section of this report and at the end of each section.

Drivers of Change

- Habitat Degradation
  - Fragmentation
  - Altered Natural Disturbance Regimes
  - Invasive Species
- Soil Erosion
- Consumptive Use
- Contaminants
- Changes in Soil Structure
- Soil Nutrient Loading
- Increased Carbon Dioxide

Habitat Degradation

The land uses noted previously imply different types, frequencies, and degrees of disturbance, both natural and human in origin. For example, disturbance on reserved forest is primarily natural in origin and infrequent. For example, forests managed for economic purposes have regular, designed disturbances and shorter periods between disturbance compared to the natural frequency. Disturbance in protected forest is primarily natural in origin and typically occurs less frequently than in managed systems.

The subject of habitat degradation is treated broadly here, and includes a variety of factors that contribute to the deterioration of habitat quality. Permanent loss of habitat due to an irreversible land cover conversion is also discussed under Consumptive Use.

Degradation of habitat, defined here as a decline in its quality, can occur when any specific land cover type is altered. Cause of habitat degradation may include: invasion by noxious exotic or native species, extreme climate events, and temporary or permanent changes of use. Sometimes the change may be temporary and by degree, e.g., forest thinning, with regrowth following. In this example, the area remains forest, but habitat values shift to those of a less dense or younger forest. In other cases, the change may be permanent. Note that alterations of ecosystems, such as restoration, can improve habitat quality—thus modification is not by default negative. Additionally, habitat quality is context dependent- the "appropriate" habitat in any given area depends on societal priorities.

Below are additional factors that are sometimes associated with Habitat Degradation.

Trout Lily
Like all native species, the Minnesota dwarf trout lily has its own specific niche in the ecosystem and relationships to other plants and animals with which it lives. As such, it is a part of the whole, a part whose unknown utility is best expressed in the words of Wisconsin conservationist Aldo Leopold: "The first rule of intelligent tinkering is to save all the parts. The unique genetic information in each species is potentially valuable to all of us. Alkaloids from many wild plants are active ingredients in medicines and other useful products. Loss of the dwarf trout lily would eliminate forever the potential for such benefits. [The dwarf trout lily possesses a genetic and chemical makeup unlike that of any other plant. The dwarf trout lily is found in 3 counties in south central Minnesota and nowhere else in the world.] —from US Fish and Wildlife Service Website. Credit: Welby Smith, Minnesota DNR

Habitat Degradation - Fragmentation

"Fragmentation" describes the degree to which natural land cover types are broken into smaller patches interspersed with non-natural land cover types. Sources of fragmentation can be natural or human-induced; a few examples include the breakup of landscapes by natural disturbance (e.g., windstorm, fire), and human induced processes such as road building and development.

Research has shown that forest areas bordering non-forest vegetation are often warmer and drier, more likely to be affected by wind, and more likely to be invaded by non-native species. This is termed the "edge effect." Similarly, as the amount of fragmentation increases, habitat is created for species adapted to edge conditions, while plant and animal species that require the cooler, more moist conditions in the forest interior experience habitat reductions.

As fragmentation increases and the non-native areas between forest areas increase, these non-native areas can become barriers to animal movement, and can also serve to isolate native plant populations. These isolated populations can be more vulnerable to local extinction, and may suffer from genetic isolation if populations are too far apart to facilitate movement or cross pollination. This can be of significant concern on prairie remnants in Minnesota, which are often very isolated from each other. Corridor plans, such as the one undertaken in the Blue Earth Watershed, are an attempt to overcome some of the effects of fragmentation by identifying areas most suited to habitat restoration (see Figure 2).

Agriculture has historically been the leading source of fragmentation in Minnesota, especially in the agricultural southwest, but also in the forested northeast. Roads development has overtaken agriculture as the leading cause of forest fragmentation in the state. Forest parcelization is also increasing, and may lead to fragmentation. From 1989 to 2003 there was an 18% decrease in the size of forested parcels sold with more than half of the

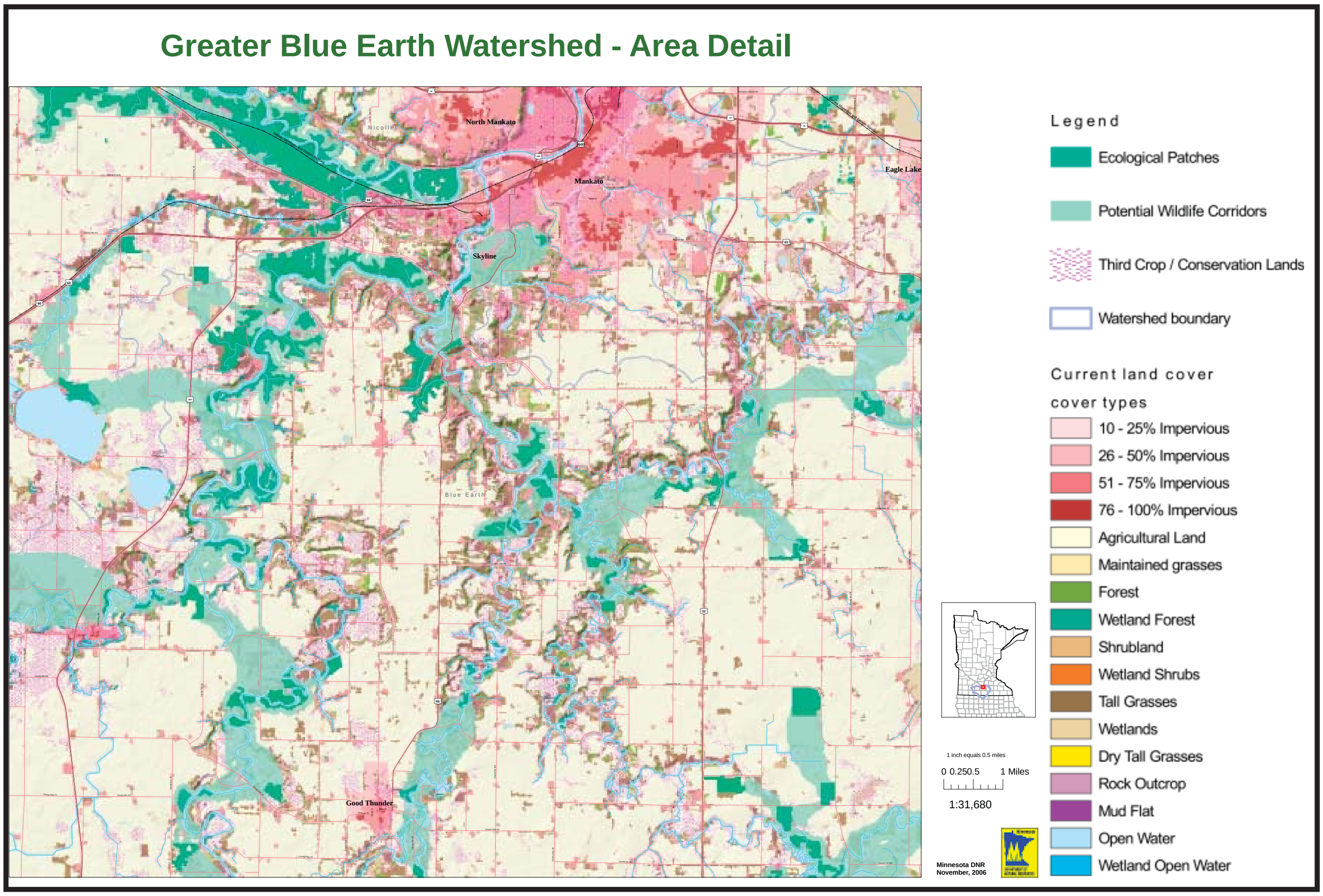

Figure 2: Existing natural areas and open space in the Mankato area. GIS modeling was used to identify potential connections between habitat areas and to reduce fragmentation. Credit: Terry Brown, University of Minnesota

parcels sold being smaller than 40 acres. During that same time period, "individuals accounted for 94% of all acreage purchased and 89% of all acreage sold, indicating a slight but gradual shift in forestland ownership out of [corporations] and to individuals" (Kilgore and MacKay). Forest parcelization does not, however, invariably lead to fragmentation; parcelization and associated fragmentation studies are currently underway.

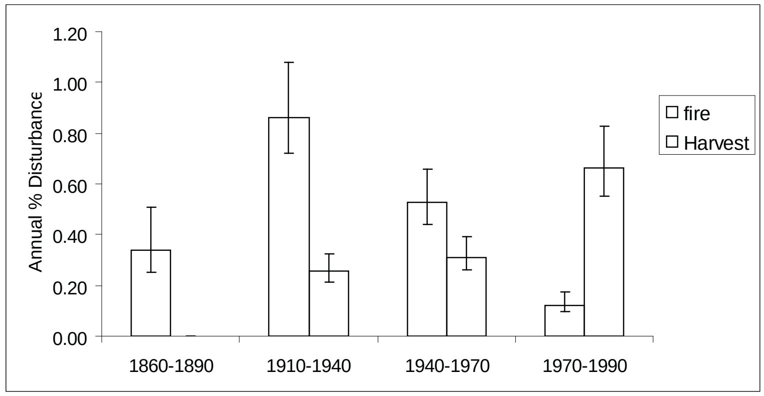

Figure 3: Fire versus logging as disturbance factor in northern Minnesota forests. Credit: Mark A. White and George E. Host University of Minnesota

Some but not all of the concern for forest fragmentation is captured in the dynamics of forest area described in Table 1, page 28. It is also important to understand the forest cover type areas and age class structures for further understanding.

Habitat Degradation - Altered Natural Disturbance Regimes

As used here, natural disturbance regime refers to natural or aboriginal activities common to the land prior to Euro-American settlement. Examples of natural disturbances that have been altered since settlement include natural fires and the influence of grazers such as bison and locusts. However, some natural disturbances such as windthrow damage still influence forested landscapes, sometimes over large areas. Still other disturbances, such as logging, are occurring on a larger scale and more frequently than natural disturbances, and can produce significant changes in landscape composition and structure. For instance, during the early to mid-20th century timber harvest replaced fire as the dominant disturbance factor in managed northern Minnesota forests (see Figure 3). This resulted in more uniform disturbance intervals within these forests and created a more homogeneous and aspen-dominated pattern of forest vegetation in the landscape (see Figure 4).

Eliminating natural disturbances that historically sustained natural systems can and has resulted in a loss of plant and animal biodiversity at species, community and ecosystem levels. For instance,

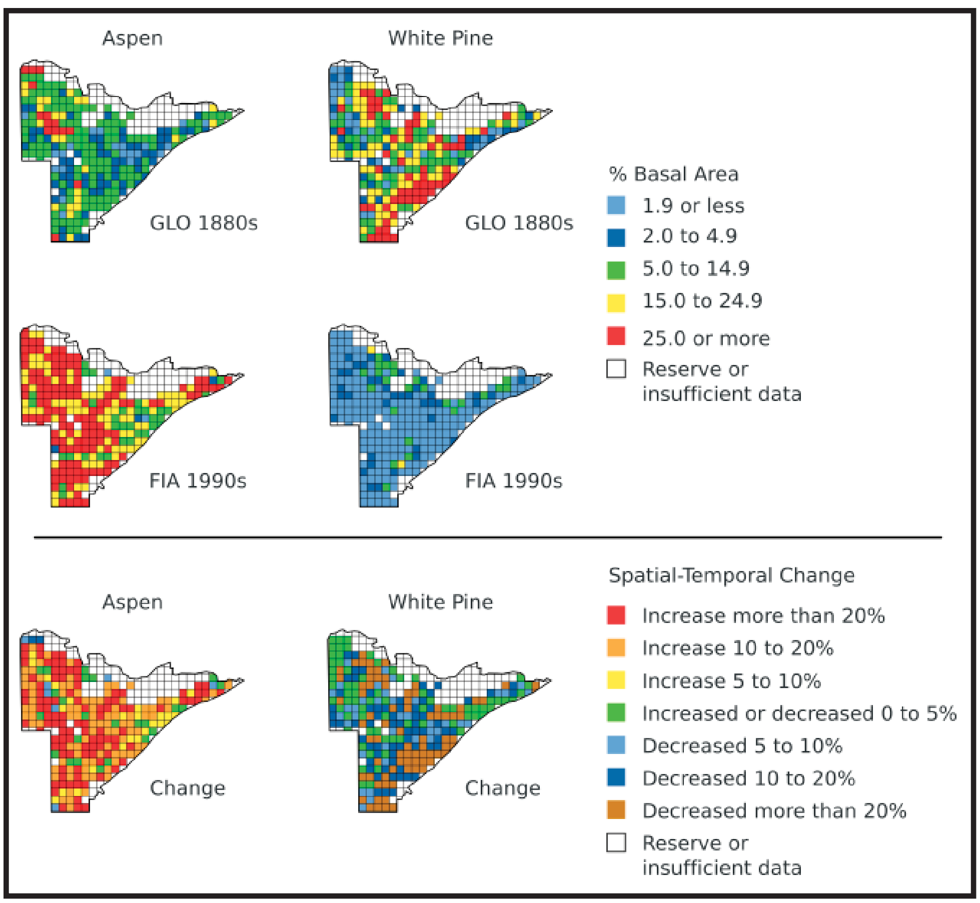

Figure 4: Changes in Aspen and White Pine distribution from pre-settlement to 1990. Credit: S. K. Friedman and P.B. Reich, University of Minnesota

lack of wildfire has contributed, along with timber harvest, to the enormous reduction in natural pine stands throughout northern Minnesota (see Figure 4). Habitat degradation and loss and altered natural disturbance regimes can also amplify each another and have a profound impact on natural areas. As an example, lack of wildfire, along with agricultural land conversion, has led to the near extirpation of oak savanna.

Primary drivers such as climate change and proximal drivers such as nutrient loading may also serve to increase the negative influence of altered natural disturbance regimes. For instance, climate warming is likely to make it even more difficult to retain cold-climate requiring boreal species in our northern forests. Altered natural disturbance patterns influence nearly all the ecosystems found in Minnesota, from prairie to hardwoods, to the mixed coniferous-deciduous forest.

Habitat Degradation - -Invasive Species

Invasive species primarily refers to plant and animal species not native to Minnesota that have escaped cultivation or have been inadvertently transported into new habitats. Species that are native to the region, but overpopulate communities where they would not normally occur are also considered invasive species. Invasive plants have a demonstrated ability to readily colonize in natural areas. They usually displace native species of plants, and in some instances, contribute to declines in native wildlife species. Invasive animal species can also degrade native ecosystems. European earthworms, for example, are non-native species that have a significant effect on species diversity in certain forest types. The Minnesota DNR currently lists 36 terrestrial plant species as invasive (see Table 2).

Amur Maple	*Amur Silver grass*
Birdsfoot trefoil	*Black Locust*
Butter and Eggs	*Canada Thistle*
Common Tansy	*Cow vetch and hairy vetch*
Creeping Charlie	*Crown Vetch/Axseed*
European and Glossy Buckthorns	*Bull Thistle*
Perennial Sow Thistle	*Japanese Knotweed*
Purple Loosestrife	*Hoary Alyssum*
Queen Ann's Lace	*Musk or nodding thistle*
Reed Canary Grass	*Japanese Barberry*
Russian Olive	*Leafy Spurge*
Siberian peashrub	*Norway Maple*
Siberian Elm	*Grecian foxglove*
Smooth brome grass	*Flowering Rush*
Spotted knapweed	*Oxeye daisy*
While and yellow sweet clover	*Exotic honeysuckles*
Wild Parsnip	*Orange Hawkweed*
Yellow iris	*Garlic mustard*

Table 2: Terrestrial plants listed as invasive by the Minnesota DNR

Introduction and expansion of invasive species is in turn driven by a number of other drivers, including population, land use, policy choices and the transportation network. State and Federal agencies and institutions have begun tracking the occurrence and expansion of invasive plants and animals in the upper Midwest more closely in the last decade. Recent efforts in Minnesota and at the Federal level seek to increase research into methods for control of invasive, nonnative species. However, current information lags behind the number and geographic extent of invasive species in Minnesota.

Habitat Degradation - Conclusion

Habitat degradation and loss is affected by nearly all of the primary drivers. Clearly, demographic and land use trends lead to habitat loss, fragmentation and degradation across the state, and contribute to the conversion of native lands to agriculture as well as the conversion of agricultural lands to housing or other development.

Expanding transportation corridors increases fragmentation and improves access to formerly isolated areas, facilitating development and the introduction of exotic species.

Farm and land use policies influence crop choices. Developing trends in energy policy, especially the interest in corn-based ethanol, may potentially have negative effects on the land resource if areas currently in perennial plant cover are plowed and converted to corn. Natural resource based industries have a strong effect on the land resource because these activities shift the composition of forest stands (in the case of logging) or eliminate the resource completely (as in extractive mining practices). Finally, these all interact with changing climate patterns, which could have major ecosystem effects, particularly at the transitional regions between prairie, broadleaf, and coniferous-deciduous forests.

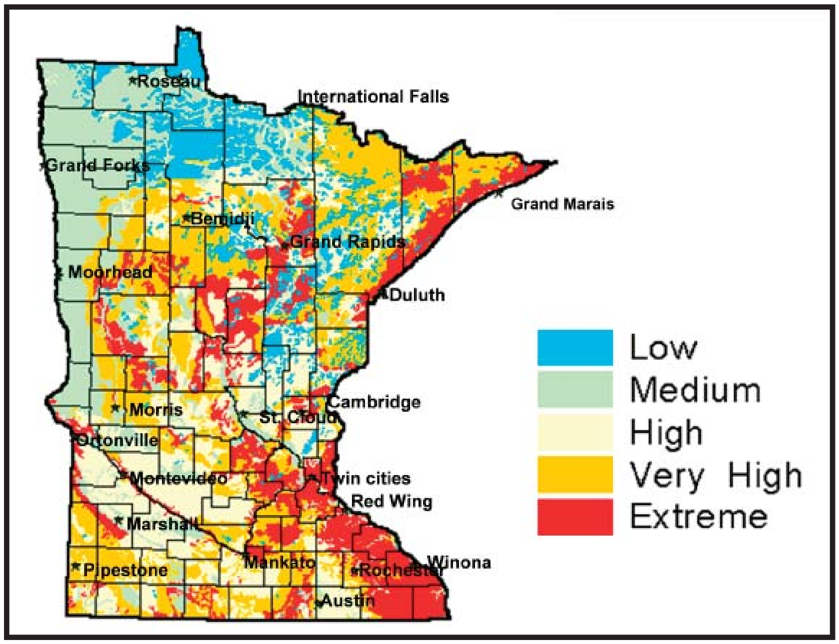

Figure 5: Maps showing erosion potential for three regions in Minnesota. Credit: David Mulla, University of Minnesota

Particularly important are concerns about the effects of drivers in terms of degradation of the habitat values of the land resource through:

- Changes in landscape structure that lead to loss of plant species diversity
- Increased opportunities for invasive species to move into native plant communities
- Loss of large, natural patches necessary for reproduction of area-sensitive species, such as forest interior and prairie bird species
- Genetic erosion/loss of genetic diversity for native species
- Deterioration in water quality through loss or degradation of buffers for aquatic systems

The full potential and importance of some of these effects is understood for only a few species and situations; impacts are anticipated to vary widely according to species and land cover/land use type.

For effective planning to occur, county biological inventories should be completed for all counties in MN, including those areas in southern Minnesota that have been previously omitted. It will also be important to survey the "average" ecosystem, not just the highest quality ones; thus the county biological inventories should be expanded to simultaneously represent a unbiased census of the state as well as an inventory or our richest remaining communities. GIS analysis of land cover on a statewide basis is needed to identify high priority sites, natural resource corridors, and at-risk ecosystems for protection and focused conservation efforts.

Finally, an effort to create a statewide ecotype project to develop a seed bank and increase native seed stocks representing the genetic diversity of Minnesota plant species is essential for ensuring that species and genotypes persist. These steps are key for preserving both the diversity within the state, and for developing an "ecological infrastructure" that will maximize the ability of the land resource to adapt to new, as yet unknown, conditions resulting from global climate change.

Soil Erosion

Soil erosion refers to the detachment and transport of soil particles by water and wind. Soil erosion by water is a major concern in some areas of Minnesota, including the southeast, the Prairie Coteau, and wherever there are bluffs or other steep slopes. Wind erosion is significant in western Minnesota, especially the Red River Valley. Soil erosion is of moderate concern in other parts of the state with flatter topography and lower wind speeds (see Figure 5).

Erosion is accelerated by soil disturbance such as tillage, grading and construction, removal of protective vegetation and plant residue, reduction in soil organic matter with attendant loss in soil cohesion, and loss of soil structure resulting in reduced water infiltration and increased surface water flow. Changes in land cover also affect erosion. Reduction in perennial plant cover leads to increased surface water runoff and drainage tile flows due to less evapotranspiration from annual crops. Increases in impervious surface area increase concentrated flows and with it, gully and streambank erosion. In addition, the climate in Minnesota has become increasingly wet; this is increasing the amount of runoff and related erosion from rain events.

Erosion results from the interactions between changes in land cover and changing weather patterns has a significant effect on both land and water quality. Streambank erosion, which is a major source of sediment in streams and lakes, is accelerated by these factors. In the Blue Earth River basin 40-50% of the sediment delivered to the mouth of the watershed arises from streambank erosion.

Erosion has a variety of impacts. Soil erosion results in a loss of productive topsoil, frequently leaving surface soil with higher clay and lower organic matter content, lower water infiltration capacity, and poor physical properties for seedling emergence and root growth. In some cases the concentration of sand and rock at the surface is increased due to differential transport of fine materials. Gulley erosion leads to loss and dissection of land. This impacts agriculture, recreation, development opportunities and other uses, as well as loss of native plant cover. The sediment from erosion fills drainage ditches and degrades aquatic habitat.

Changing land use, especially as relates to agriculture, as well as policy choices and industry (both natural resource based and non-natural resource based) directly and indirectly affect erosion.

The number of acres planted to annual row crops have increased dramatically over the last 100 years (see Figure 6) and continues to increase, while the acres in perennial systems such as pasture have decreased. The annual row crop system leads to increased erosion because it creates vast stretches of unprotected bare soil in the spring before before crop canopy closure. Unfortunately, rainfall is highest in the spring when annual row crop soils are most vulnerable to erosion. Rain drops strike the bare ground, dislodging lose particles of soil. Then,

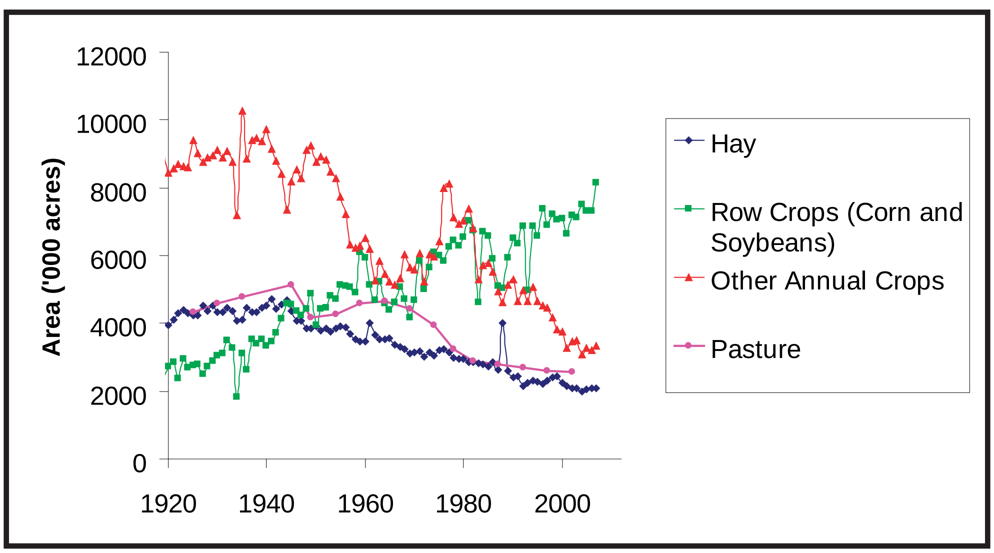

Figure 6: Acreages planted to hay, row crops, pasture and other annual crops. Credit: Laura Schmitt, University of Minnesota..

because there are no established plants to slow down or soak up the rainwater, the raindrops becomes run-off carrying sediment along with them. This run-off quickly enters streams, contributing to streambank erosion. Perenniel systems tend to protect soil from erosion better than annual systems because they provide soil cover all year long.

Policy choices have a strong influence on agricultural practices affecting erosion, especially the:

- relative size of production incentives versus conservation incentives;
- choice of crops for which production incentives are provided; and
- absence of conservation compliance standards on most cropland.

Policy choices also affect the allocation of land among various uses, all of which affect rates of soil erosion. This includes natural resource based industries such as agriculture and forestry, as well as non-natural resource based industry –specifically, construction and construction practices.

There are significant data gaps in determining rates and causes of soil erosion. It is not easily measured by remote sensing, so must be estimated by models for which some data is often not current or available.

- Accurate slope information for erosion estimation is not available in the absence of statewide high resolution elevation data. LiDAR-acquired high resolution elevation data is available for only ten counties at this time. This data is urgently needed to identify critical landscape areas, for modeling to determine sediment delivery and effects of alternative management practices and for estimation of streambank erosion rates.
- Crop and soil cover on agricultural land changes over time and over seasons. Annual surveys of crop residue cover after planting are necessary since remote sensing has not yet evolved sufficiently for its accurate measurement.
- Paired watershed studies on effectiveness of BMPs are needed to estimate how much area needs to be treated to obtain different levels of reduction in erosion.

Consumptive Use

Consumptive use is the non-renewable use of resources such as development of open space via a variety of means, including conversion of native communities to agricultural use, housing developments, unsustainable logging practices, mineral extraction/mining, and similar activities. It is related to the conversion of land use from a sustainable (see definition, text box below) practice to a non-sustainable practice, or the permanent removal of the resource. Examples include:

- Conversion of diverse native plant communities to agriculture.
- Soil loss and degradation from agricultural practices.
- Non-renewable consumption of resources, such as non-sustainable logging practices, non-sustainable cropping practices, and mineral extraction/mining.
- Conversion of land through land development and associated infrastructure.

> The 1987 Brundtland Commission definition: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Consumptive use in previously natural areas results in the permanent loss of habitat. The loss of native plant cover is significantly higher in the southern areas of the state than in the north. Throughout Minnesota areas of native habitat have been converted to other cover types (see Figure 7, next page), including agriculture, mining, development, and other uses. Also, in the north, logging and land clearing in the period 1865-1930 dramatically altered the tree species composition and age class structure of the northern forests.

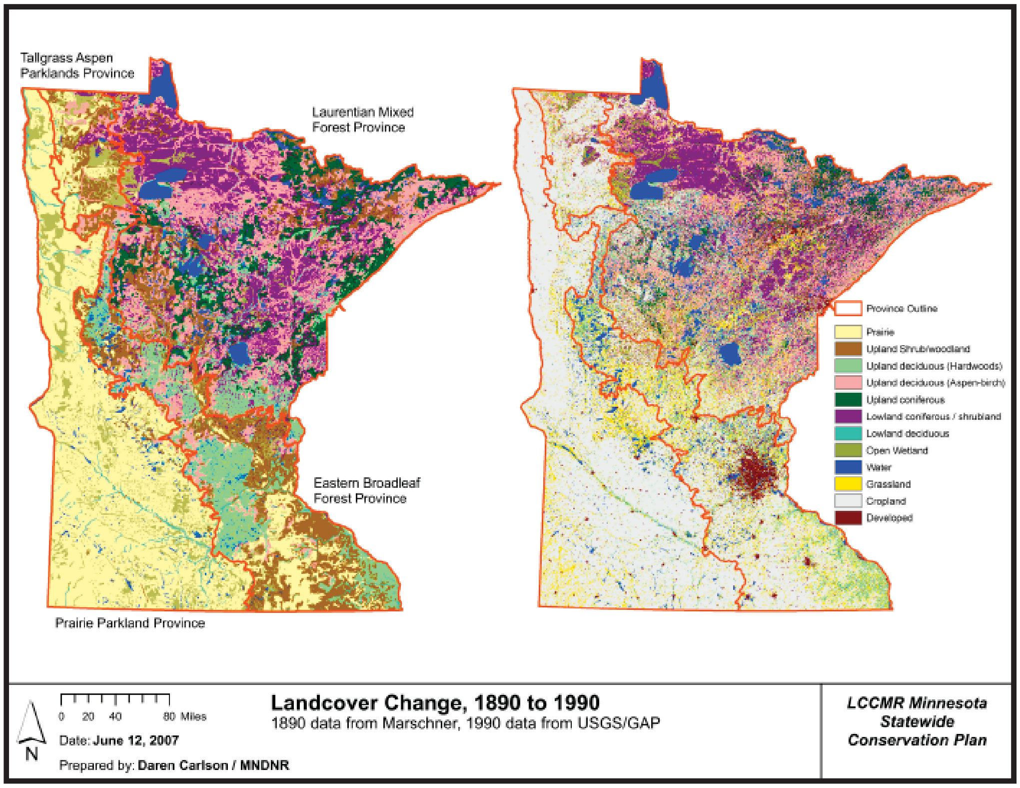

Figure 7: Changes in native land cover in the different ecoregions of Minnesota between 1890 and 1990. Credit: Daren Carlson, Minnesota DNR

While restoration and re-creation efforts for some habitat types have increased, the rate of loss exceeds the rate of reconstructon and restoration. The final cost of restoring or reconstructing a lost habitat is often quite high, and despite significant expenditures even the best habitat reconstruction efforts cannot achieve the high levels of diversity and ecological function found in even a low or moderate quality remnant natural community. Important research questions are the full extent of potential changes and whether it is feasible to restore some habitat types in the face of climate change, cost and other priorities.

Mining inevitably causes changes in the landscape, and directly impacts the land cover as well as the mineral resource itself through consumptive use. As a practical matter, mines have a life cycle that might range from 10 years or less for a small gravel deposit, to more than a hundred years for a large iron-ore deposit. At some point, the cost of mining at a particular location exceeds the cost of obtaining the same commodity elsewhere and the mine closes. There may still be mineral content, and it may, if conditions change, become economically feasible to extract it at a later time. Recycling of mineral-derived products (glass, steel, aluminum, copper, and aggregate) can extend the life of an extracted mineral.

More philosophically, the benefits of mining can be sustainable, even as the supply of the mineral resource is finite. If comprehensive planning recognizes that mining will not go on indefinitely, and the community uses the economic benefits of mining to prepare for or develop an alternative industry or other land use in the wake of mine closure, the community can be sustainable. Mining is, or can be, a temporary use of land. However, the degree to which the land is changed varies greatly depending on the size and depth of the mining operation. Some mineland can be easily converted to other uses (gravel pits to shopping centers or parks and lakes, for example, as in the large commercial area in the city of Maple Grove or Cascade Lake in Rochester). Other mineland is changed greatly and probably for all time (iron mines hundreds of feet deep filling with water).

Some 2004 Minnesota mining industry facts:

- Valued at $1.89 billion; 7th of the 50 states in non-fuel mineral production value
- Number 1 ranked state in iron ore production
- Iron ore is the highest value mineral in Minnesota followed by construction sand and gravel (5th of 50 states), industrial sand and gravel, dimension stone, and lime.

Other impacts of consumptive use include significant impacts on the soil resource, including the loss of soil through erosion, change in soil structure, and altered soil fertility. These are discussed in greater detail in sections on soil erosion, changes in soil structure, and soil nutrient loading.

Consumptive use is driven by nearly all of the primary order drivers. Higher order drivers that are especially significant include:

- Economy
- Policy choice
- Land use
- Transportation
- Climate change
- Natural resource based industry

Contaminants

Agricultural contaminants affecting the land resource include chemical compounds that accumulate in soils of agricultural lands and emissions of these compounds to terrestrial ecosystems. Nitrogen(N) emissions are among the most significant sources of contamination to the land resource; these result from volatilization of reduced forms of N (NHx) from intensive animal agriculture and from fertilization of intensive annual crop production systems. Agricultural contaminants are a significant concern in some areas of Minnesota, including regions where intensive animal agriculture and intensive annual crop production occupy a large portion of the landscape. Pesticide emissions via spray drift and emissions from soil accumulations of pesticides are also a concern in relatively localized areas where conditions cause significant spray drift or where significant soil accumulations of pesticides exist. For example, atrazine leaching risks are shown in Figure 8.

Agricultural contamination affects the resource by:

- Nitrogen(N) deposition causes eutrophication in terrestrial ecosystems and changes in plant communities, frequently increasing the abundance of invasive species and reducing native biodiversity.
- N deposition also causes acidification of soils, as well as changes in soil nutrient and carbon cycling.
- Accumulation of N in agricultural soils makes conversion of land to less-intensive forms of agriculture more difficult by promoting the growth of weeds and invasive plant species.
- Deposition of pesticides by spray drift and other mechanisms affects adjacent land use and ecological communities. Field-margin areas, which are often contaminated by pesticides in this way, are of great significance for biodiversity conservation, water quality protection and other aspects of environmental quality protection in agriculture-dominated landscapes.

Agricultural contamination is driven by several primary order drivers. Higher order drivers that are especially significant include:

- Land use, especially in allocation to intensive animal production systems.
- Policy choices, such as regulatory standards affecting emissions from intensive animal production systems, and other policy measures that encourage intensive animal and annual

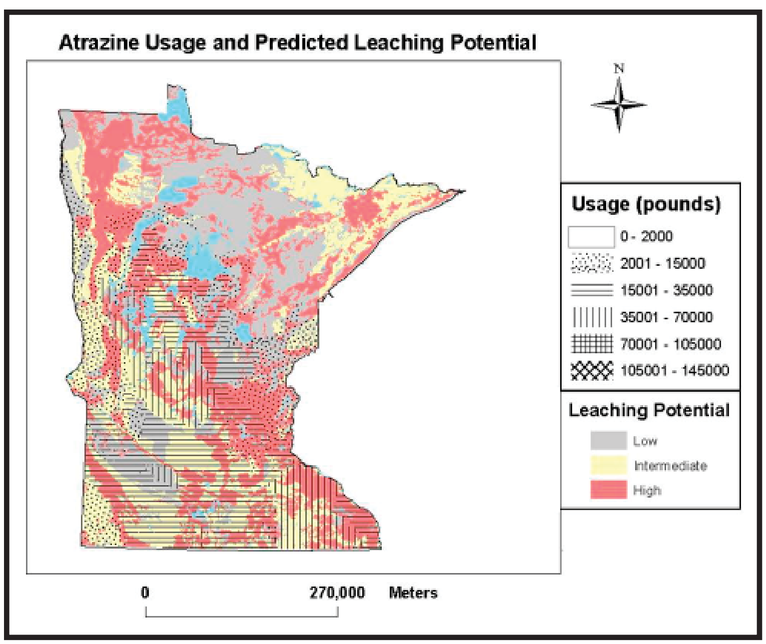

Figure 8: Atrazine usage and predicted leaching potential. Credit: David Mulla, University of Minnesota.

crop production, such as subsidies to major commodity crops used for animal feed.

Urban and industrial uses are also contamination sources for the land resource. "Brownfields" is a term used to describe land resources that have been degraded or destroyed through the contamination of land cover ecosystems, soil, or hydrogeological systems. Brownfields include abandoned, idled, or underused industrial and commercial properties where expansion or redevelopment is complicated by actual or suspected environmental contamination. Brownfields also include historic land-based disposal sites such as landfills and industrial dumps, railroad corridors and related uses such as grain elevators, smaller contaminated sites such as gasoline stations or drycleaners, and abandoned mines and airports.

There are also some significant long-term contaminant issues of national scale, such as superfund sites in Silver Bay & Striker Bay associated with mining. The St. Louis River estuary is the only EPA-designated Area of Concern (AOC) in the State of Minnesota (shared with Wisconsin) of the 28 AOCs in the Great Lakes basin. Most of the drainage to the St. Louis AOC originates in Minnesota.

Information on the location of brownfield sites and the types of contamination is collected by the MPCA and available at http://www.pca.state.mn.us/backyard/neighborhood.html

Changes in Soil Structure

Soil structure refers to the arrangement and degree of aggregation of sands, silts and clays that make up natural soils. Soil structure is diminished as aggregate size and strength decrease, and as the spaces and continuity of spaces between aggregates decrease. Soils with poor structure may be relatively impermeable, have increased runoff, and poor aeration. Poor soil structure may arise from: heavy machinery traffic at times when the soil is relatively wet; by repeated tillage operations that bury crop residue and lead to oxidation of soil organic matter; by management practices that rely on inorganic fertilizer rather than animal or green manures; by management practices that decrease soil biological activity (especially earthworms); or by cropping systems that have shallow rooting plants. Decreased soil structure leads to poor soil aeration that can reduce biomass accumulation and crop productivity. Decreased soil structure can also lead to increased runoff and erosion which decreases topsoil depth and causes sediment deposition at lower slope positions. Decreased soil structure also leads to reduced water storage in soil and reduced soil biological activity. Changes in soil structure in forested ecosystems can result in decreased forest productivity and increases in weedy or invasive species. The predominant driver for increased soil compaction in forests is heavy logging equipment in inappropriate seasons or under the wrong soil moisture conditions.

Soil Nutrient Loading

Nutrient loading refers to an unnaturally high and typically excessive increase in nutrients to natural systems. Nutrient loading to the Land Resource in Minnesota occurs from a variety of conditions.

The largest source of nutrient loading in Minnesota is excessive application of fertilizer and manure to agricultural fields. Other notable examples include excessive application of fertilizers (particularly Phosphorus(P)-containing fertilizers) to residential lawns and atmospheric redeposition throughout the state of primarily fall-applied ammonia fertilizer to crop ground. Nutrient loading occurs largely as a result of human activity through land use decisions, often at the local and property owner level.

For groundwater and Gulf of Mexico effects, nitrogen(N) is the primary nutrient pollutant. For lakes and streams, phosphorus is the primary nutrient pollutant. Phosphorus(P) is a bigger concern in Minnesota than nitrogen. Phosphorus is building up in Minnesota soils as a result of agricultural or horticultural applications of fertilizer and manure in excess of crop removal rates. Atmospheric redeposition of nitrogen on natural plant systems, and sediment transport of phosphorus into lakes can also have significant effects.

Nutrient loading influences a number of other proximal drivers on the Land Resource, particularly invasive species, habitat degradation and loss, altered natural disturbance regime.

There are significant data gaps in determining rates of nutrient loss across the landscape. These rates are controlled by climate, landscape features, and management practices. Further study is needed to:

- Evaluate the impact of changing climate on nutrient losses in runoff, erosion, and drainage.
- Evaluate the impact of alternative cropping and animal production systems on the nutrient losses.
- Develop tools to identify critical landscape areas where the largest losses of nutrients are occurring.
- Conduct paired watershed studies to evaluate the effectiveness of BMPs for nutrient reductions.

Increased Carbon Dioxide

Emissions of carbon dioxide (CO_2), one of several greenhouse gasses, have increased by about 80% between 1970 and 2004. CO_2 is the largest contributor to greenhouse gasses, constituting 77% of total greenhouse gasses emitted in 2004 (IPCC 4th assessment report). In order of magnitude, electricity generation, transportation and industry are the major contributors to increased CO_2. They account for 80% of CO_2 emissions. The increase in atmospheric CO_2 is occurring at a global scale, and this increase does not show strong geographic variation across Minnesota: most ecosystems are exposed to similar CO_2 environments. The ecological and economic implications of increased CO_2, however, vary between the agricultural regions to the south and the forested regions of the north.

It is also important to note that increased CO_2 has both direct effects, including changes in plant productivity and response to insects and diseases, and indirect effects due to climatic change resulting from increased CO_2 and other greenhouse gasses. A 50-year assessment needs to include both these direct effects and the potentially more important response of forest and agricultural landscapes to changes in temperature and precipitation patterns (see Figure 9). It is also important to note that the effects of elevated CO_2 do not occur in isolation, other greenhouse gasses, such as ozone, are also showing steady increases.The response of ecosystems to a changing trace gas environment is complex and not entirely predictable.

CO_2 has both direct and indirect effects on the land resource, with the indirect effects being stronger drivers of change.

Direct effects include:

- Short term (and perhaps persistent) increases in plant productivity due to the CO_2 fertilization effect. However, these increases are smaller in infertile than fertile conditions

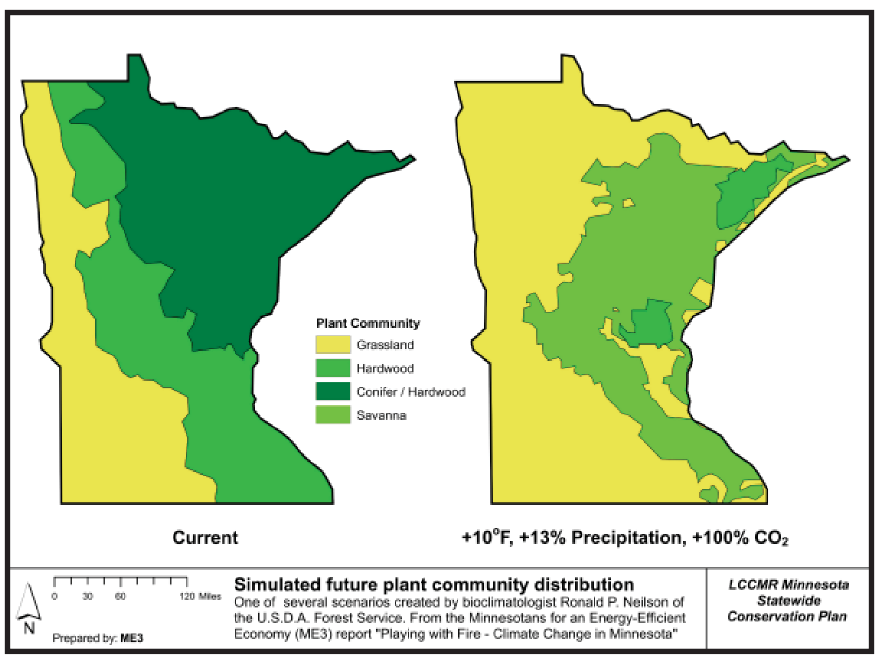

Figure 9: Projection of future plant community distribution based on one climate change scenario. Credit: Minnesotans for an Energy Efficient Economy (now Fresh Energy).

- Potential adverse effects on nutrient availability- a kind of "reverse" eutrophication due to excess carbon
- Decreased nutritional value of crop plants due to reduced levels of nitrogen (N) in seeds
- Changes in plant defense mechanisms resulting from changes in leaf chemistry

Indirect effects include:

- Changes to species composition of native communities in response to changes in the mean and variation in seasonal and annual temperature and precipitation regimes. These include both direct climate effects and indirect effects of climate change on invasive species, native insects and diseases, and on major climate and disturbance events such as droughts, windstorms, and fires.

Collectively, such changes are likely to be enormous by the end of the century and should represent a major area for long-range policy consideration.

CO_2 increases result from several primary order drivers; among the most significant drivers are:

- Energy, particularly generation of energy from fossil fuels
- Transportation, use of hydrocarbon fuels
- Industry via energy consumption and emissions

There is considerable data on documenting the increase on CO_2 and other greenhouse gasses, and the fact that, under current mitigation policies, these emissions will continue to grow over the next few decades (Intergovernmental Panel on Climate Change). There are also numerous studies documenting the immediate response of agricultural crops and forest species to altered trace gas composition. The primary gaps in knowledge are understanding the long-term effects of multiple interacting stresses on ecosystems. Specifically, research should address how changes in trace gasses, temperature and precipitation will influence pest/ pathogen relationships, food webs, the spread of invasive species, ecosystem nutrient dynamics, and other ecosystem-scale processes.

Figure 10: William O'Brien State Park.
Credit: Michael Kelberer, University of Minnesota

"We need a no-net-loss-of-public-lands ethic."

—Minnesota 2050 Project participant