NATURE AND CLIMATE SOLUTIONS FOR MINNESOTA

2021

The Nature Conservancy

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ACKNOWLEDGMENTS
The authors would like to thank the Cox Family Fund for Science and Research for their generous financial contribution to this work.

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Improved forest management has significant climate mitigation potential in Minnesota. © John Gregor

EXECUTIVE SUMMARY

Minnesota's climate is changing and will continue to do so long into the future. Minnesotans are already witnessing rising temperatures, warming water, and fewer days of ice. Warming temperatures pose threats in a range of ways, from health to economic productivity to crime rates. It is imperative that we act now to preserve our Minnesota; our land, our communities, and our ways of life are all at risk. Nature is one of the keys to climate action.

Minnesota is poised to take the lead when it comes to fighting climate change in the U.S.—one of the world's top three emitters of greenhouse gases. Minnesota is leading the Midwest through state emissions reductions targets, which include the reduction of greenhouse gas emissions by 80% by 2050 compared to 2005 levels. The state has already reduced emissions by more than 10%—but it's not enough. We failed to meet our 2015 target, and we're not on track for 2025 either.

Natural climate solutions can help to meet these state climate targets. They offer an estimated mitigation potential of 26 million metric tonnes per year—as much as taking seven coal plants offline. Practical opportunities like reforestation and cover cropping can affordably help Minnesota reduce the severity of climate change (see **Figure ES-1**). And, implementing just 25% of our NCS in Minnesota could yield $97 million annual revenue through a carbon market.

In addition to mitigating a significant portion of Minnesota's greenhouse gas emissions, nature can make us more resilient to climate change. A range of nature-based adaptation opportunities are available in

Minnesota—practices that can help our communities cope with the changing climate. Nature-based adaptation strategies can protect our land against flooding, maintain our soil, and protect our cities against the urban heat island effect.

For natural climate solutions and nature-based adaptation to reach their full potential, protecting our communities and reducing the impact of climate change, we must choose to act now. These opportunities require funding and capacity to implement. State policy, agency action, private sector climate responses, philanthropic support, and individual action will all play a significant in achieving our natural climate potential. Planning today will enable Minnesotans to protect our communities and our wild places like they deserve.

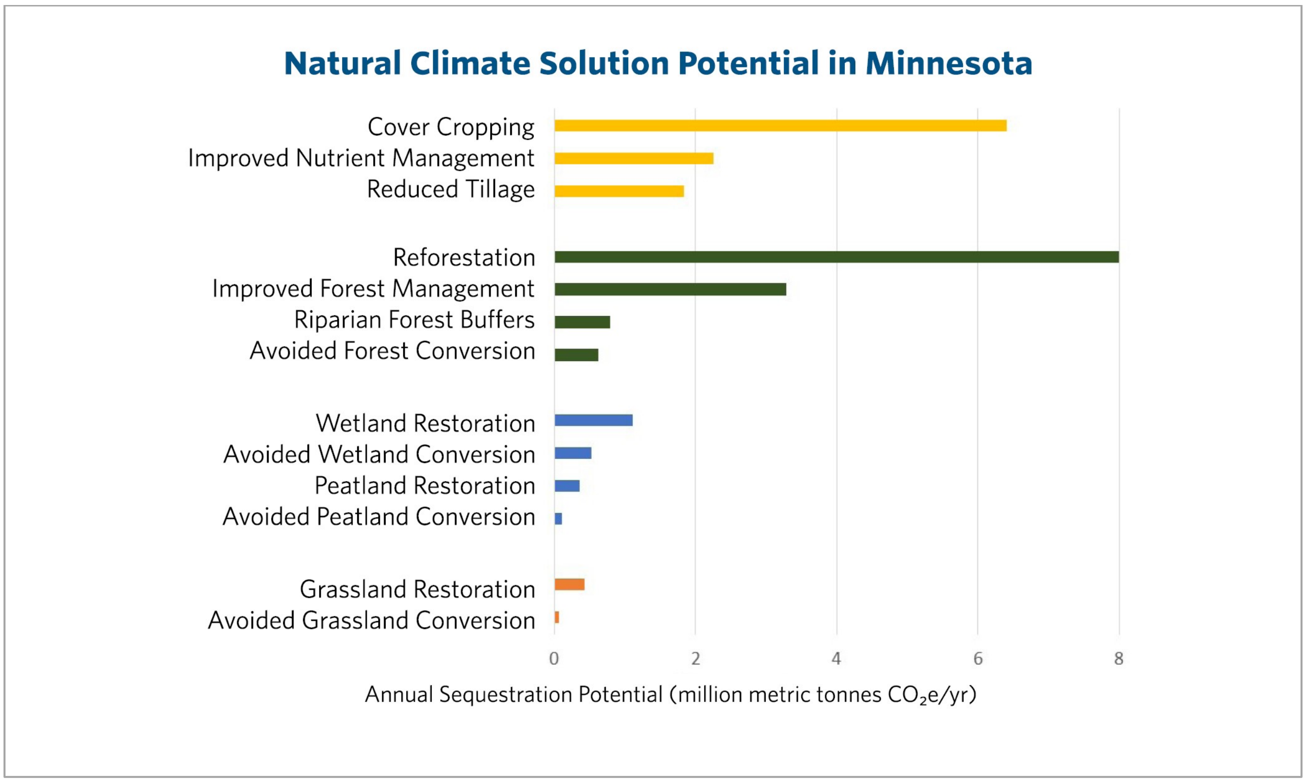


Figure ES-1. Natural climate solutions offer 26 million metric tonnes CO_2e/year mitigation potential in Minnesota, with the largest opportunities within the forestry and agriculture sectors.

This report is intended to share a high-level understanding of the natural climate solutions practices available in the state of Minnesota. The authors emphasize that the numbers are not final but represent our best current estimate of the opportunity. Research in the coming years will certainly refine our estimates and will need to be considered as they are available.

Widespread use of conservation practices in agriculture could help producers and store more carbon. © Bruce Leventhal

CLIMATE CHANGE AND MINNESOTA

Climate change[i,1] is one of the greatest challenges facing Minnesota. The effects of climate change are already evident in many of our landscapes and communities. For instance, streams in the Twin Cities metro area demonstrate increasing water temperatures. Ice-in is delayed, while ice-out occurs earlier.[2] By 2018, Minnesota rivers saw about 10 fewer days of ice than in 1930, and this dampened experiences ranging from skating season to fishing rules.[3]

BOX 1.

MINNESOTA'S CHANGING CLIMATE, BY THE NUMBERS

2.9: Average temperature increase, degrees Fahrenheit, over the last century

3.4: Average increase in inches of annual precipitation over the last century

4.8: Average increase in Northern Minnesota winter lows in degrees Fahrenheit since 1895[4]

[i] Climate change is caused by the accumulation of greenhouse gases in the atmosphere, which lead to changing environmental conditions around the world. Although atmospheric conditions are global, many of the causes and solutions to climate change are local. And, although climate change has become a politically polarizing issue in the last several decades, the Intergovernmental Panel on Climate Change says scientific evidence for warming of the climate system is unequivocal.

Projections for climate change in Minnesota indicate significant impacts to our local ecosystems. Northern conifers like tamarack, spruces, fir and pines are already seeing insect damage; and climate amplified insect populations will hasten the decline of boreal forest tree species (additional forest impacts are further documented in a recent Minnesota Forest Resources Council report).[5] Loons will likely move north out of Minnesota due to warming temperatures by the end of the century—while other species, like the lynx and the moose, have already started to move on.[6]

Minnesota temperatures are rising faster than the global average, and both summer and winter temperatures will likely rise more than six degrees Fahrenheit over pre-industrial levels in the next 50 years.

Minnesota temperatures are rising faster than the global average, and both summer and winter temperatures will likely rise more than six degrees Fahrenheit over pre-industrial levels in the next 50 years. By that time, Minnesota summers will feel more like Kansas today.[7] Southern Minnesota may face 15–20 more 90 degree days than in the past. Rising temperatures will be most extreme in the center of Minneapolis, where the urban heat island effect will cause the city to feel four degrees warmer than the rest of the state.[8] More than 110,000 Minnesotans are already vulnerable to extreme heat, and this number will rise in tandem with temperatures.[9]

Precipitation across the state is also likely to increase with climate change.[10] Extreme rain events and floods will be nearly 50% more common by 2050. These floods will augment the deleterious effects of pests like the emerald ash borer, and 1.7 billion gallons of additional water will run off of unprotected landscapes—stimulating algal blooms and other ecological challenges.[11] In addition to affecting native wildlife, changing conditions on lakes and rivers will impact coastal property values and trade. As flooding and erosion increase, transportation on (and near) the Mississippi River could experience stress due to extreme heat and flooding.[12]

As Minnesota experiences these climatic changes, statewide economic activity and growth potential will shift. Warmer winters could extend growing seasons, and soybean yields could increase by up to 17% by 2050 due to warmer temperatures and greater carbon dioxide concentrations. However, the production of other crops, like corn, will likely decrease; and livestock production may dip as animals' body temperatures increase.[13] Labor productivity is expected to decline, especially in sectors with high-risk work, such as construction, transportation, and agriculture.[14] Residents of the greater Twin Cities region will spend less on heating in the winter but more on cooling in the summer, which will cause a total increase in electricity demand.[15] And, rising temperatures are linked with greater crime. Minnesota may see up to a 6% increase in crime by 2100 due to climate change.[16]

Climate change is caused by greenhouse gases; and in 2016, the state of Minnesota emitted 140 million metric tonnes (MMT) of carbon dioxide equivalents (CO_2e).[17] This puts Minnesota close to the national median of per capita emissions.[18] As a state, Minnesota has already reduced emissions by 12%;[ii] but we have more work to do. Minnesota has set ambitious goals of 30% emissions reduction by 2025 and 80% by 2050, compared to 2005 levels.[19] This means we must reduce annual emissions by an additional 30 MMT CO_2e by 2025.[20] In addition to reducing our emissions—*mitigation*—we must also *adapt* to enable society to cope with the already-present impacts of climate change (see Box 2 for more on adaptation, mitigation, and natural solutions to both).

As the impacts of climate change become more extreme, Minnesotans will experience greater threats to our livelihoods, communities, and ways of life. Solutions to combat climate change exist, and now it is up to us to find the strategies that will work best for Minnesota.

[ii] Compared to 2005 levels

BOX 2.

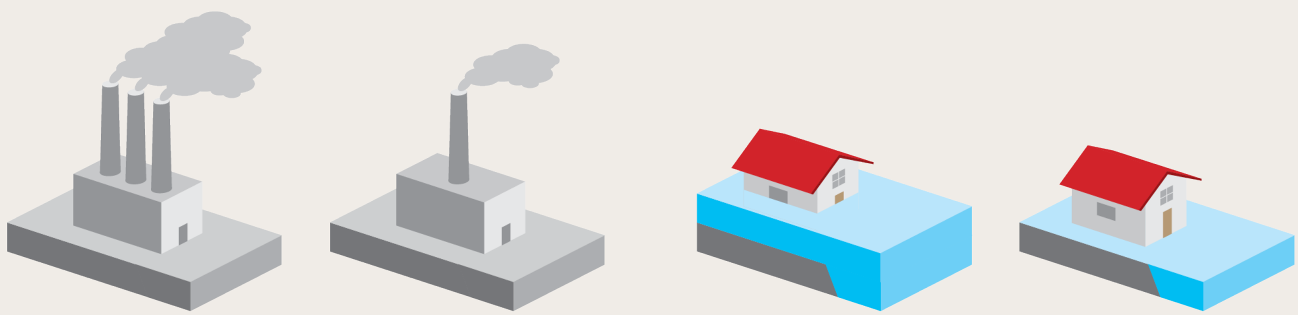
ADAPTATION AND MITIGATION

Now is the time for us to act. Minnesota has vast opportunities to mitigate and adapt to climate change immediately.

Mitigation refers to actions that reduce the severity of climate change by decreasing our greenhouse gas emissions. This can be done through transitions away from fossil-based energy (coal, gasoline) or by storing more carbon (for example, in biomass).

Adaptation refers to actions that improve the ability of people and nature to cope with climate change. We can adapt through natural or technological means—for instance, by restoring floodplains to decrease the impact of floods on our local communities, or by building stronger more storm-resistant buildings. Nature also needs to adapt to climate change, because as many ecosystems warm and weather patterns change, plant and animal species may no longer find favorable conditions in places they once thrived.

Many solutions contribute both to mitigation and adaptation efforts. For instance, reforestation can store carbon in trees (reducing net carbon emissions) while also creating a more resilient natural system that can handle greater precipitation and temperature variability. A transition to renewable energy can reduce carbon emissions from fossil fuel combustion while also making our communities more resilient through decreased dependence on international supply chains that can be interrupted by storms.



Mitigation – reducing emissions

- Natural Climate Solutions can mitigate 30% of current emissions globally
- Land use practices are "the most cost-effective carbon sequestration method available[21]
- Implementing 25% of our NCS in Minnesota would yield $97 million annual revenue in a carbon market[iii]

Adaptation – reducing damage

- Natural systems can address climate hazards like flooding and erosion
- 96% of the U.S. population lives in counties where weather-related disasters were federally declared in the last decade[22]
- Improved management and greater plant diversity can ensure future environmental, health, economic, and societal resilience while ensuring our natural climate solutions are sustainable over the long-term

[iii] Assuming $15/metric tonne CO_2e/yr offset.

Reforestation is the natural climate solution with the greatest overall potential in Minnesota. © Jason Whalen/Fauna

NATURAL CLIMATE SOLUTIONS

***Natural Climate Solutions (NCS)* are conservation, restoration, and improved land management practices that increase carbon storage or avoid greenhouse gas emissions in landscapes and wetlands across the globe.** NCS take advantage of natural mechanisms through which earth systems already process carbon and other harmful gases. For instance, through photosynthesis, trees absorb carbon dioxide and turn it into solid biomass. Chemical and microscopic processes convert carbon dioxide from the air into solids that are stored as soil carbon. And peatlands—one of Minnesota's most unique ecological systems—store carbon from ancient plants and animals, preventing it from being released into the atmosphere.

Minnesota offers the eighth largest NCS opportunity of any U.S. state.[iv][23]

Natural climate solutions offer a 26 million metric tonne CO_2e annual mitigation potential in Minnesota. This is equal to taking seven coal plants offline and represents an annual value of $390 million.

NCS offer a 26 million metric tonne (MMT) CO_2e annual mitigation potential in Minnesota—meaning that if implemented to their full scale, they could offset emissions equal to 26 MMT each year. This is equal to the reductions we would see by taking seven coal power plants offline,[24] representing an annual value of about

[iv] The carbon stored by many products emerging from natural and working land industries, including wood products, can contribute significantly to climate impacts but is beyond the scope of this report.

$390 million.[v] Further, 26 MMT represents 16% of Minnesota's total 2005 emissions, and more than half of our commitment to reach 30% reduction by 2025. NCS offer a crucial opportunity to supplement the ambitious energy and transportation transitions already underway to further mitigate climate change.

This report summarizes 13 natural climate solutions practices available in Minnesota, which unlike many proposed technological approaches to carbon capture, are ready to implement today. The relevant potential of these practices is illustrated in **Figure 1**, while **Appendices A, B, and C** contain more detailed data.

The NCS practices with the highest opportunity for carbon storage in Minnesota include reforestation, cover cropping, improved forest management, improved nutrient management, and no-till/low-till (reduced tillage). These practices are defined below, and detail for all 13 practices is provided in **Appendix A**.

- **Reforestation** (7.99 MMT CO_2e/yr potential). Reforestation stores carbon in biomass above and below the ground, and targets historically forested areas.[25] Reforestation includes the replanting of trees on degraded, converted, agricultural, and urban landscapes. In Minnesota, the primary reforestation practice is to restore northern or mixed woods on over 3 million acres. Tree-planting on agricultural lands (i.e. alley cropping) may be feasible on over 2 million acres; and urban reforestation is likely possible on only 0.1 million acres.
- **Cover cropping** (6.41 MMT CO_2e/yr potential). Cover cropping provides "additional soil carbon sequestration gained by growing a cover crop in the fallow season between main crops" and is mainly considered where it can supplement major row crops like corn and soybeans.[26]
- **Improved forest management** (IFM) (3.29 MMT CO_2e/yr potential). Acknowledging the importance of active forest management, IFM includes practices such

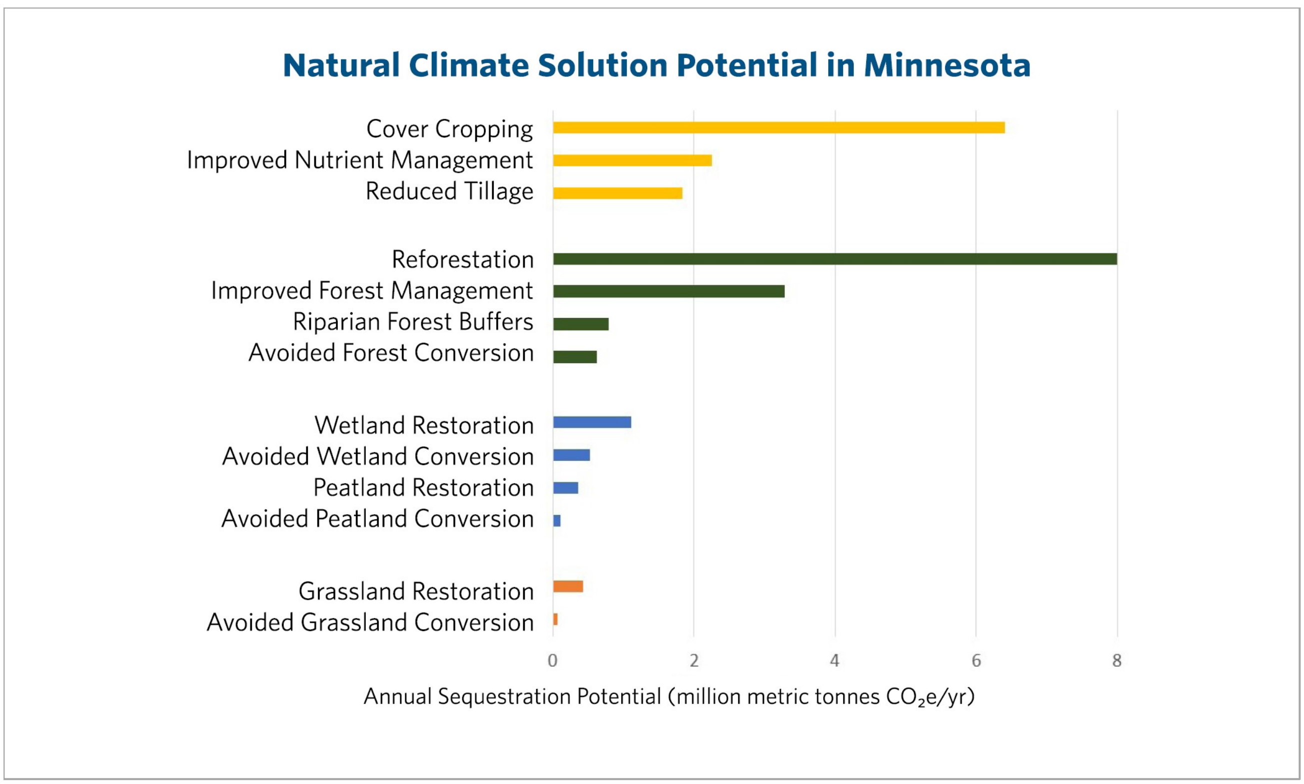


Figure 1. Natural climate solutions offer 26 million metric tonnes CO_2e/year mitigation potential in Minnesota, with great opportunity in the agriculture and forestry sectors.

[v] Assuming a conservative $15/metric tonne value of carbon. The value to society would be much higher.

as extended rotation, increased stocking, thinning, and multi-age management. In general, these practices increase the amount of biomass in a forest by enabling longer growth, greater diversity, and/or greater resilience. They also help increase the amount of carbon stored in harvested forest products.

- **Improved nutrient management** (2.25 MMT CO_2e/yr potential). Improved nutrient management reduces nitrous oxide (N_2O) emissions that result from the reaction of nitrogen-based fertilizers. Reduced nutrient application rates, the transition from anhydrous ammonia to urea, improved timing of fertilizer application, or variable fertilizer application within the field can all reduce the total base of nitrogen available for potential release to the atmosphere.[27]
- **Low-till/no-till** (1.83 MMT CO_2e/yr potential). Reduced tillage practices, including low-till and no-till, reduce aeration of the soil. Since aeration of upper levels of the soil ordinarily accounts for greater decomposition rates and the release of greenhouse gases, reduced aeration can result in slower decomposition and thus greater stocks of carbon and other nutrients throughout the soil. Reduced tillage practices are noted to vary significantly across different soil types and measurement practices.[28]

It is important to note that although these five practices offer the greatest total magnitude of opportunity, they may not be the most efficient mechanisms for carbon storage. For instance, avoided forest conversion and avoided peatland conversion offer faster sequestration rates (tonnes CO_2e/acre/year) than any other practice—by nearly a factor of ten. This illustrates the fact that, while the area available for these practices is relatively small, the protection of at-risk ecosystems may be an important first step.

Leadership within the land use sector is especially critical for driving systemic climate action among all sectors. While land use is the third leading source of emissions in Minnesota today, it also offers the greatest potential for carbon storage.[29] There is great opportunity for direction from agricultural and forestry leaders. One such leader, the Field to Market Alliance, has indicated that more than half of its members have already established public climate commitments and measurable targets for greenhouse gas emissions reduction.[30]

To reach scale, NCS require the support from a wide range of stakeholders. Individual efforts are required to build awareness, acceptance, and demonstration of new practices so that they can become more widely implemented. Nonprofit and philanthropic efforts will likely need to help bridge the gap to scalable, financially viable implementation—which will be implemented by corporate and private-sector businesses. Finally, policy support is needed to incentivize and scale solutions to achieve our full NCS potential.

Cover crops, reduced tillage, and improved nutrient management have enormous potential in Minnesota. © Jason Whalen/Fauna Creative

Ensuring our lands are adapted to climate change will benefit both nature and people. © Richard Hamilton Smith

NATURE-BASED ADAPTATION

***Nature-Based Adaptation (NBA)* refers to the use of nature-based strategies to facilitate adaptation in natural systems for both biodiversity and for the people who rely on those systems.** Although the focus of this report is Natural Climate Solutions for mitigation, NBA is equally important when it comes to Minnesota's response to climate change and for making sure Natural Climate Solutions can persist. NBA reflects many of the practices required for community and ecosystems to continue thriving in the face of increasingly severe climate impacts. In Minnesota, some of the most critical NBA practices are solutions to address flooding. These practices mimic or restore nature's potential to reduce flooding and erosion through planning, zoning, regulations, and built projects.[31] Globally, wetlands provide adaptation and ecosystem services valued at $15 trillion.[32] Floodplains, flood bypasses, waterfront parks, resettlement, and the preservation of open space can all increase the capacity of landscapes to absorb extreme precipitation events, reducing damage to communities and ecosystems near rivers and streams. Urban tree planting, rain gardens, green roofs, and floodwater retention are just some of the solutions available to reduce urban stormwater flooding and improve quality of life for city-dwellers.[33] Notably, many of these solutions will also enhance carbon sequestration potential to provide mitigation, as well as adaptation, benefits.

Other NBA solutions will protect our communities in other ways. Urban tree-planting will reduce the urban heat island effect to decrease the negative health impacts of rising temperatures. Increasing resilience and adaptability in our natural and working lands in Minnesota will improve livelihoods for farmers and ranchers across much of the state, as well as outdoor recreation opportunities and experiences for all Minnesotans.

Leading institutions are beginning to consider NBA as a climate response at every level of governance. The Army Corps of Engineers is implementing an Engineering with Nature initiative that focuses on the community co-benefits realized through green infrastructure around water systems.[34] The Resiliency and Adaptation Team recommendations to Minnesota's climate change subcabinet include a focus on incentivizing ecosystem-based green infrastructure. And the City of Minneapolis Climate Action Plan highlights the need for Green Zones including green infrastructure as well as transportation systems that "promote and strengthen green infrastructure and natural systems that can build resilience, sequester or reduce emissions, and improve neighborhoods."[35]

As climate risks grow, Minnesotans are increasingly aware of the need for better resiliency and adaptation efforts. Planning and implementation of adaptation at the state, county, and municipal levels must include NBA as part of a holistic, economy-wide, equitable package to support all people and ecosystems as the climate changes.


Protecting and restoring nature will help protect Minnesota's quality of life and economy. © Paula Champagne

Policy will play a critical role in advancing natural climate solutions in Minnesota. © iStock

CLIMATE POLICY IN MINNESOTA

The scale of action required to address climate change is staggering (see **Box 3**). **Minnesota is poised to take the lead when it comes to climate action, but our current efforts aren't enough**. Ongoing advances towards emissions reduction must be paired with greater carbon sequestration—fueled by natural climate solutions.

Minnesota is a leader in climate policy, as one of only thirteen states and the only Midwest state with a statutory greenhouse gas reduction requirement.[vi,36] A state climate change subcabinet was tasked in 2019 to "tackle climate change, create good-paying jobs, and pioneer the clean energy economy."[37] Numerous pieces of legislation have been developed to advance clean energy progress and access, but much more must still be done to identify and implement the right climate solutions for Minnesota. And, among a host of mitigation policy options, we know that nature will play a role.

Global society has already hit the point at which "carbon drawdown is now essential and must be expanded rapidly."[38] Minnesota missed the first intermediate goal of the Next Generation Energy Act, which required 15% emissions reduction from 2005 levels by 2015. The state is currently not on track to meet the next intermediate target of 30% reduction by 2025.[39]

[vi] Michigan has an executive greenhouse gas emissions reduction target, but not a statutory one.

There are numerous opportunities for reducing net greenhouse gas emissions in Minnesota. *Net emissions* refers to the total impact of actual emissions compared to any negative emissions realized through carbon storage and sequestration.

Four key opportunities exist to significantly reduce emissions in Minnesota:

- **Reduce electricity emissions.** Minnesota has already made significant progress reducing emissions associated with energy generation. The emissions of electricity generated in-state have declined by 6 million tonnes, and overall electricity-associated emissions decreased by 29% between 2005-2016.[40] Additional coal plant closures and renewable energy build-out suggest that electricity-related emissions will continue to fall over the coming decades.
- **Reduce transportation emissions.** Transportation-related emissions have decreased by 8% since 2005, but they are now the leading source of greenhouses gases in the state. Advances in vehicle electrification and the proposed Clean Cars Minnesota effort may enable significant reduction in the future.[41]
- **Reduce land-based emissions.** Minnesota's emissions from the agriculture, forestry, and land use sector have stayed approximately constant since 2005.[42] Slight fluctuations have increased and decreased emissions, but there is no clear trend.
- **Reduce industrial emissions.** Industrial, residential, and commercial emissions have all increased in the state of Minnesota since 2005.[43] Reductions in these sectors through electrification (fuel-switching) and energy efficiency measures will be critical in the future.

Box 3.

THE SCALE OF CHANGE

Total emissions in 2016: 139.9 million metric tonnes are equivalent to:

30 million passenger cars[44]

36 coal-fired plants[45]

15 million trees (or more)[46]

To meet our state targets as indicated in the Next Generation Energy Act, we must do more than gradually reduce emissions. Natural climate solutions can help us meet our goals by "drawing down" carbon from the atmosphere to increase carbon storage and sequestration. This drawdown can complement emissions reduction through a transition to clean electricity, clean transportation, and clean buildings.

To meet our state targets as indicated in the Next Generation Energy Act,[47] we must do more than gradually reduce emissions. **Natural climate solutions can help us meet our goals** by "drawing down" carbon from the atmosphere to increase carbon storage and sequestration. This drawdown can complement emissions reduction through a transition to clean electricity, clean transportation, and clean buildings. Since our environment requires more drastic changes than our economy will allow, carbon storage and sequestration will be critical to sufficiently decreasing net emissions while we maintain a robust state economy. To offset emissions:

- **Natural Climate Solutions** enable carbon capture through natural means—most commonly through photosynthesis. Natural and working lands, including ranches, farms, and working forests, can capture and store carbon in plant biomass and in the soil in a manner that is compatible with economic production. Natural climate solutions can offset 18% of Minnesota's 2016 emissions.
- **Carbon capture and storage** represents a few technical solutions that can be deployed to capture carbon at the source and store it, avoiding release into the atmosphere. Most carbon capture and storage (CCS) technologies are still being developed and have not been widely deployed to date. Generally, CCS technologies are also significantly more expensive than their natural counterparts, which can be a barrier to near-term implementation.[48]

Now that we understand the severity of climate change, we need to slow it down. Natural climate solutions offer one of our best opportunities for storing vast quantities of carbon. They are more affordable and more practical to implement immediately than other sequestration techniques, since they rely on natural mechanisms that are already well-understood. But **nature needs our help.** A combination of state and private efforts must accelerate the widespread adoption of natural climate solutions in Minnesota. In particular, state agencies can lead the way by, for instance, expanding forestry programs, implementing improved forest management on state lands, and protecting additional grasslands. State agencies can also support private implementation as well, such as by ensuring financing mechanisms are available for agricultural best management practices and incentivizing soil health practices.

As we work toward climate mitigation, we also need to help Minnesotan communities adapt to climate change. Nature has a role to play when it comes to adaptation, as well as mitigation. Nature-based adaptation includes proven strategies for helping communities become more resilient to changing weather patterns and enhanced risk. They offer relatively well-understood solutions rooted in the land that can complement other infrastructure needs. And, nature-based approaches to both mitigation and adaptation are more cost-effective than other solutions, while offering numerous co-benefits.[49]

Farmers can play a leading role in helping Minnesota achieve its climate goals © John Gregor

Ensuring Minnesota's Northwoods remain diverse and healthy is a key climate strategy © John Gregor

NEXT STEPS

The findings of this report demonstrate the size of the opportunity for nature to help Minnesota address climate change. By offering the potential to mitigate nearly 20% of state emissions while enhancing our adaptive capacity, nature-based solutions simply cannot be ignored. To enable our natural systems and the protection they offer against climate change, action is required from key sectors:

Policy action will be required to enable nature-based adaptation and mitigation activities to reach scale. Policy can be a tool to set state targets for natural climate solutions, direct research and implementation, enable new practices on public land, and provide funding and financing opportunities for new equipment or other investments required to scale NCS practices. Policy and planning mechanisms could also drive local action, such as city adaptation planning that accounts for nature-based adaptation needs. To complement NCS, decision-makers should also consider the carbon stored in durable products from natural and working lands—such as wood products—as well as the practices discussed in this report.[50]

Corporate and philanthropic leadership can drive the implementation of new practices. Funding and investment, for instance, may be essential to achieve significant reforestation on private lands. Corporate leaders may also benefit, both by enhanced perception as environmental and climate leaders and through the use of NCS to mitigate Scope 3 emissions.

Individual action offers a final opportunity to scale nature-based climate solutions. Individual landowners, for example, may be early adopters, demonstrating the concept of new NCS practices before they reach the mainstream. Individual advocacy will also be critical in driving local, county, and state governments to prioritize and plan for the implementation of NCS and NBA.

Academic and industry research is required to continue refining our understanding of the NCS opportunity, highest-value intervention points, and to guide on-the-ground practices. The authors of this report have noted that many NCS numbers are still evolving. Scientists from The Nature Conservancy, the University of Minnesota Institute on the Environment and Forest Resources Department, the Natural Resources Research Institute, Dovetail Partners, Inc., Resource Assessment at the Minnesota Department of Natural Resources, and other institutions are working to understand nature's true capacity. We will update this report and other documentation to ensure that we provide the best and most accurate information about the impact of natural climate solutions in Minnesota.

Appendix A. Natural Climate Solutions Practices Data Summary

Thirteen natural climate solutions (NCS) practices are relevant to Minnesota. An overview of the opportunity for these is provided in **Table A1**, while they are further defined below.

Table A1. Summary of Minnesota's 13 NCS practices and the magnitude of their respective sequestration rates, area of relevance, and total carbon storage potential.

Practice	Sequestration Rate (Mt/acre/year)*	Potential Scale (million acres)	Total Annual Sequestration Potential (MMT/year)*
Avoided Forest Conversion	12.49	0.05	0.62
Avoided Grassland Conversion	1.21	0.06	0.07
Avoided Peatland Conversion	10.25	0.01	0.10
Avoided Wetland Conversion	2.10	0.25	0.53
Cover Cropping	0.47	13.63	6.41
Grassland Restoration	2.53	0.17	0.43
Improved Forest Management	0.75	4.39	3.29
Improved Nutrient Management	0.17	13.63	2.25
No-Till / Low-Till	0.33	5.63	1.83
Peatland Restoration	0.70	0.50	0.35
Reforestation	1.06**	5.58	7.99
Riparian Forest Buffers	4.00	0.20	0.79
Wetland Restoration	3.70	0.30	1.11
Total			25.77

*Mt = Metric tonnes CO_2 equivalents ; MMT = Million metric tonnes CO_2 equivalents
**for 2.38 million acres of reforestation available on agricultural land, the sequestration rate is somewhat higher (see Appendix B).

Practice Descriptions

Avoided Forest Conversion refers to the reduction of persistent forest clearing, through which forest land is converted to another land use that stores less carbon in biomass and in the soil.[51]

Avoided Grassland Conversion maintains the significant carbon stocks available in native grasslands. Carbon is stored above- and below-ground in grassland ecosystems.

Avoided Peatland Conversion retains existing carbon stocks and prevents their release into the atmosphere. Peatlands store large quantities of carbon due to the slow decomposition of organic matter. The conversion of peatland, via draining or other harvest, can result in the release of significant CO_2 stores.[52]

Avoided Wetland Conversion reduces the loss of carbon naturally stored in plant biomass, soil organic matter, and other sediment buildup.[53]

Cover Cropping provides "additional soil carbon sequestration gained by growing a cover crop in the fallow season between main crops" and is mainly considered where it can supplement major row crops like corn and soy.[54]

Grassland Restoration enables additional carbon storage in soil and plant biomass when land formerly converted for other uses is returned to its original grassland state.[55]

Improved Forest Management acknowledges the importance of active forest management and includes practices such as extended rotation, increased stocking, thinning, and multi-age management. These practices increase the amount of biomass in a forest by enabling longer growth, greater diversity, and/or greater resilience—in addition to helping increase the amount of carbon stored in harvested forest products. In particular, older trees and the inclusion of multiple age cohorts within a single stand can store more carbon per acre. By introducing greater age and species diversity, forests develop greater resilience and reduced susceptibility to disturbances. This resiliency enables better carbon management due to improved overall health—as well as by enabling greater tree density due to differential tree size.[56]

Improved Nutrient Management reduces N_2O emissions—a greenhouse gas—that result from the reaction of nitrogen-based fertilizers. Reduced nutrient application rates, the transition from anhydrous ammonia to urea, improved timing of fertilizer application, or variable fertilizer application within the field can all reduce the total base of nitrogen available for potential release to the atmosphere.[57]

No-Till/Low-Till practices, also referred to as reduced tillage, reduce aeration of the soil. Since aeration of upper levels of the soil ordinarily accounts for greater decomposition rates and the release of greenhouse gases, reduced aeration can result in slower decomposition and thus greater carbon (and other nutrient) stocks throughout the soil. Reduced tillage practices are noted to vary significantly across different soil types and measurement practices.[58]

Peatland Restoration refers to the rewetting and restoration of former peatlands that have been drained for agriculture or other purposes. The rewetting process slows continued emissions from organic matter decomposition in the peat, returning the land to its slow rate of decomposition.

Reforestation offers "carbon sequestration in above- and belowground biomass and soils by converting non-forest to forest in areas where forests are the native cover type."[59] Here, it includes the potential for carbon sequestration through tree-planting in all historically forested areas, including degraded, converted, agricultural, and urban lands. In particular, some studies refer to urban reforestation—additional carbon stored in above- and below-ground biomass in urban settings—or alley cropping, which stores carbon "by planting wide rows of trees with a companion crop grown in the alley-ways between the rows" and is assumed to be feasible on no more than 10% of row cropland.[60]

Riparian Forest Buffers protect land adjacent to streams, lakes, or other bodies of water by filtering runoff, reducing erosion, and creating habitat through the restoration of tree coverage. They offer climate adaptation benefits by protecting nearby land from floods, and climate mitigation benefits by increasing carbon storage in plant biomass and soil carbon through increased vegetation and vegetative diversity.[61]

Wetland Restoration enables carbon lost from biomass, soil carbon, and sediment to be rebuilt. It is most common where wetlands have been drained or altered for agricultural activity and the soil degraded. Wetland restoration offers a host of other benefits as well, including community and reduced flood risk, water retention, and biodiversity enhancement.[62]

Appendix B. Sequestration Potential of Natural Climate Solution Practices

The sequestration potential of natural climate solution (NCS) practices calculated here result from an upper Great Plains analysis across Minnesota, North Dakota, and South Dakota. They are used to represent Minnesota values in this report because this regional analysis is more specific to Minnesota's ecoregional NCS potential than other studies to date. High, medium, and low sequestration rates are calculated to demonstrate the potential range of rates that may occur across the landscape; however, unless noted otherwise, medium sequestration rate values were assumed for NCS potential calculations throughout this report.

The sequestration rates noted throughout **Appendix B** reflect the best available understanding of Minnesotan NCS practices. These rates will likely be refined as climate science is improved.

Avoided Conversion

Avoided Conversion practices are separated from the others, because the emissions avoided by preventing land conversion are a one-time benefit sustained over a period of time (as opposed to a measurable annual benefit). That timeframe differs by habitat type, as indicated in the gray box summarizing each practice. The sequestration rate associated with each practice is assumed to be the average annual release of carbon upon conversion, assuming the total carbon stored by the landcover type is released (i.e., the total storage capacity divided by the timeframe).

Avoided Forest Conversion

Storage Capacity: 124.88 metric tonnes (Mt) carbon dioxide equivalents (CO_2e) per acre

Timeframe: 10 years

Sequestration Rate: 12.49 Mt CO_2e/acre/year

Methods: Values were derived from the Forest Inventory and Analysis (FIA) Program plot database for forests between 50-100 years old, accessed through the Evalidator tool[63] and GTR343.[64] GTR343 provides regional carbon estimates for forest type group for the continental United States. Data were accessed directly through Evalidator. Minnesota has a large area of forest and double the sampling density compared with requirements. Therefore, there are sufficient plots to calculate estimates for individual cover types.

For Minnesota's Northern Temperate-Southern Boreal Forests, the avoided conversion estimates for high, medium, and low, respectively are as follows: Red pine-white pine, oak-hickory, and spruce-fir. Aspen-birch also fits in the medium category.

Consistent with Fargione et al. (2018), avoided conversion estimates for forests exclude the soil carbon pool given inconsistencies in the literature regarding soil carbon loss following forest conversion.[65] However, estimates do include above- and below-ground biomass (live and dead trees, coarse woody debris, leaf litter and detritus, understory vegetation).

Avoided Grassland Conversion

Storage Capacity: 60.54 metric tonnes (Mt) carbon dioxide equivalents (CO_2e) per acre

Timeframe: 50 years

Sequestration Rate: 1.21 Mt CO_2e/acre/year

Methods: The Climate Action Reserve Tool was used to calculate the total emissions per acre over a 50 year period and down to a soil depth of 20 cm.[66] Following standard practice and including the baseline emissions from soil carbon (including belowground biomass), baseline N_2O, and project methane emissions from enteric fermentation from beef cattle grazing yielded an average storage rate of 55.55 CO_2e. The baseline scenario refers to the case where the site would have been converted to row crop agriculture, while the project scenario reflects a site protected from conversion.

The Climate Action Reserve Tool's Baseline Emission Factor tables, modeled for each Major Land Resource Area (MLRA)[67] across the US using the DAYCENT mechanistic model, were used to identify the MLRAs for Minnesota, North Dakota, and South Dakota. Soil carbon emissions were then averaged across the three modeled soil textures (fine, medium, coarse) for each MLRA. The model results were used for grasslands that have existed as grasslands for at least 30 years, assuming many of the sites we will be interested in working on are remnants. The same process was conducted for the N_2O emissions for each MLRA in the region. Finally, soil carbon and N_2O emissions were summed together to provide the total baseline emissions.

For the project scenario, it was assumed that all sites would be grazed with beef cattle. Emissions related to enteric fermentation were subtracted from baseline emissions. The Climate Action Reserve's table for grazing values yielded 0.2521 kg CH_4/head/day as the enteric fermentation emission factor for cattle. A stocking rate of 0.607 beef cattle/acre/month was assumed--rounded up from stocking recommendations from South Dakota and North Dakota.[68] A season-long grazing practice of 2.56 months (May 15 – Sept 15) every year was also assumed. These inputs resulted in 1.558 beef cattle/acre for the 2.56 months and 0.3938 kgCH_4/acre/yr or 19.64 kgCH_4/acre/50yrs.

The Climate Action Reserve's Global Warming Potential values of 25 for methane and 298 for N_2O were assumed. Final average CO_2e storage rates were calculated of 65.53, 55.55, and 43.31 Mt/acre for high, medium, and low sequestration based on MLRAs represented across the three states.

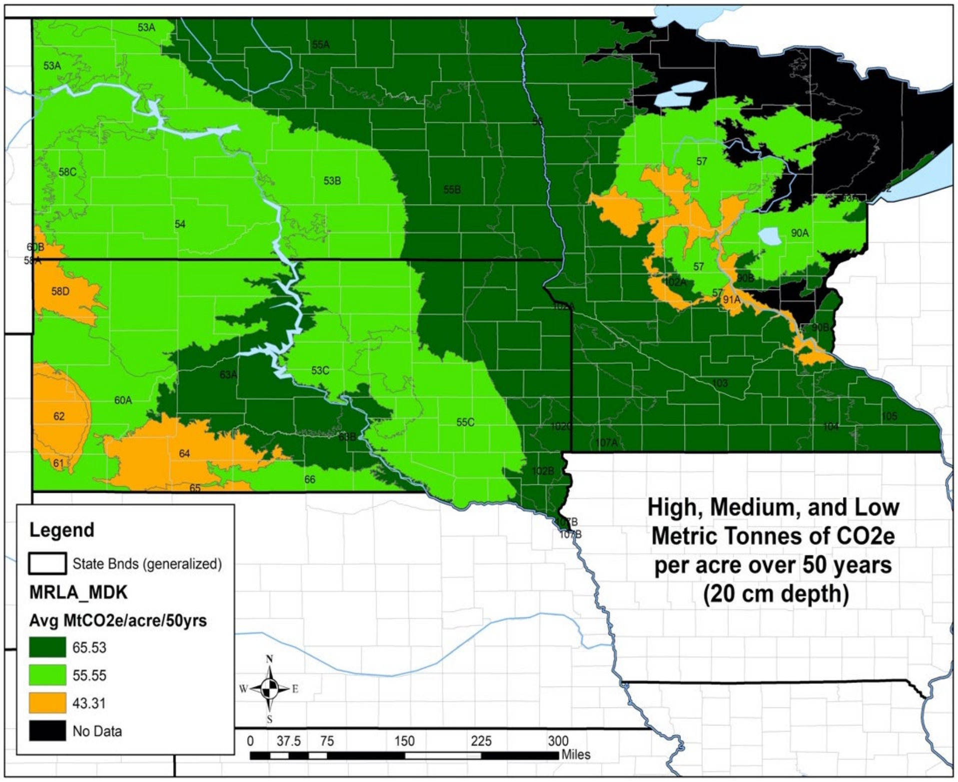


Figure A1. High, medium, and low grassland carbon dioxide equivalent storage rates per acre over 50 years

Avoided Peatland Conversion

Storage Capacity: 1024.5 metric tonnes (Mt) carbon dioxide equivalents (CO_2e) per acre

Timeframe: 100 years

Sequestration Rate: 10.25 Mt CO_2e/acre/year

Methods: Avoided peatland conversion mitigation benefits were estimated using values from published reports and unpublished data. Minnesota peatlands store an estimated of 2,703 Mg CO_2e per acre.[69] Conversion in peatlands usually occurs when they are ditched and drained. The drying of the peat layers exposes the organic material to oxygen, and the slow process of decomposition and generation of CO_2 emissions ensues.

This study assumed that 50% of peat would be lost over a 100-year period because the depth of drainage ditches (six to eight feet) is less than half the depth of the peat (often 10–20 feet). If the peat loss from conversion were spread out over 100 years, the loss rate would be 27.3 Mg CO_2e/year. A better estimate would halve the peat loss to 13.65 Mg CO_2e/acre/year at the high end and use 50% of that at the lower end (6.8 Mg CO_2e/acre/year).

For peatlands, avoided conversion makes up most of the overall benefit—or more—for a restoration project. This is because the rate of organic matter accumulation is so low and the existing stock is so large.[70] (from Scott Bridgham unpublished data, some of which was used in Fargione et al. 2018).

Avoided Wetland Conversion

Storage Capacity: 105 metric tonnes (Mt) carbon dioxide equivalents (CO_2e) per acre

Timeframe: 50 years

Sequestration Rate: 2.10 Mt CO_2e/acre/year

Methods: Avoided conversion mitigation benefits for non-peat wetlands were estimated using values from the literature. The midpoint of the estimated carbon stock was taken to be 227–258 Mt carbon/acre for wetlands (or 242.5 Mt C/acre).[71][72] In the Midwest, carbon stocks for wetlands are reported as ranging from 75–200 Mg/ha. Mg/ha were converted to Mt/acre by multiplying by 2.47 (acres per hectare) and 3.67 (CO_2e/C), respectively.

A high storage value was derived by multiplying 242.5 Mt C/acre * 30–50% loss of soil carbon, the amount of organic matter that wetland soils in the Midwest are assumed to have lost following drainage and agriculture. This quantity was then multiplied by 3.67 to convert carbon to CO_2e.

A medium storage value was estimated by multiplying the wetlands carbon sequestration rate (2.1 Mt CO_2e/acre/year)[73] * 50 years of lost sequestration.

A low storage value was estimated by taking a low-end estimate for wetland carbon sequestration (0.7 Mt CO_2e/acre/year) * 50 years. This approach yielded the same result as starting with a lower-end estimate for wetland C stocks of 81 Mg C / ha * 30% loss of soil carbon[74] * 3.67 CO_2e/C * 1 ha/2.47 acres.

All Other Natural Climate Solutions Practices

Thirteen additional NCS practices are explored here. These practices represent practices available on the land, which offer annual carbon sequestration benefits once implemented. Some of these are combined in the summary provided in Table A1 and throughout this report.

Cover Cropping

Sequestration Rate: 0.47 Mt CO_2e/acre/year

Methods: A range of values for carbon sequestration through cover cropping were obtained from agency reports, online tools and published literature.

High sequestration rate: A sequestration rate was adopted from the Minnesota Board of Water and Soil Resources, as derived from Anderson et al.[75,76] (0.6 Mt CO_2e/acre/year)

Medium sequestration rate: The US State Carbon Mapper tool on Nature4Climate was used to calculate annual sequestration rates for the Cover Cropping practice (based on Fargione et al. 2018).[77] This straight-forward calculation involved dividing the millions of Mt CO_2e per year benefit by millions of acres available for the practice. This was calculated at the state level with equivalent results for Minnesota, North Dakota, and South Dakota. (0.47 Mt CO_2e/acre/year)

Low sequestration rate: The sequestration rate from Biardeau et al. (2016) was adopted as a low-end estimate.78 (0.4 Mt CO_2e /acre/year)

Grassland Restoration

Sequestration Rate: 2.53 Mt CO_2e/acre/year

Methods: The US State Carbon Mapper tool on the Nature4Climatewebsite—based on Fargione et al. 2018—was used to calculate annual sequestration rates for the Grassland Restoration practice in Minnesota, North Dakota, and South Dakota.[79] This straight-forward calculation involved dividing the millions of Mt CO_2e per year benefit by millions of acres available for the practice. The sequestration rate is highest for Minnesota (2.53 Mt/acre/year) and lowest for South Dakota. (2.06 Mt/acre/year)

Improved Forest Management (IFM)

Sequestration Rate: 0.75 Mt CO_2e/acre/year

Methods: Forest Vegetation Simulator results for temperate-southern boreal, extended rotation were used projecting 50–70 years beyond economic rotation age.[80] The same were assessed for multi-aged mixed-wood management based on results from White and Manolis (2011).[81]

For aspen forests, extended rotation is ~20 years beyond a normal rotation (usually 40 years). Multi-age values represent the difference in CO_2e uptake rates for the first 100 years of simulation. Additional CO_2e uptake was calculated based on the increase in carbon gained using multi-aged management above baseline values in business as usual forest management. Because extended rotation yielded an approximate sequestration rate of 0.75 Mt CO_2e/acre/year and multi-age management a rate of 0.81 Mt CO_2e/acre/year, the conservative rate of 0.75 Mt CO_2e/acre/year is assumed for all IFM implemented.

To determine total carbon stored for a given number of years above baseline sequestration rate, additional storage capacity is added to the baseline value. For example, a calculation for extended rotation is provided below.

ER = extended rotation rate

$$ER = \frac{C_{y,t1} - C_{y,t2}}{total\ years}\ where\ C_{y,t1} = Carbon\ at\ year\ 120\ and\ C_{y,t2=Carbon\ at\ year\ 61}$$

ER = (195-120)/50 = 1.51 MtCO_2e/acre/yr

*Extended rotation of 40 years: Total C at age 110 = 120(C age 60) + (1.51 *40 years) = 180.4 Additional C = 40 MtCO2e/acre*

Improved (Precision) Nutrient Management

Sequestration Rate: 0.17 Mt CO_2e/acre/year

Methods: A range of values were obtained from published literature and online tools.

High sequestration rate: Rate was adopted from Biardeau et al.[82] (0.2 Mt CO_2e/acre/year)

Low sequestration rate: Figures from the US State Carbon Mapper tool on Nature4Climate (based on Fargione et al. 2018) were used to calculate annual sequestration rates for the Improved Nutrient Management practice.[83] This assumes climate impacts accrue from avoided N_2O emissions achieved through more efficient use of nitrogen fertilizers and avoided upstream emissions from fertilizer manufacture. Nature4Climate considered four improved management practices: 1) Reduced whole-field application rate; 2) switching from anhydrous ammonia to urea; 3) improved timing of fertilizer application; 4) variable application rate within field.

The low sequestration rate figure was calculated using numbers for South Dakota, dividing millions of Mt CO_2e per year benefit by (2.41 Million Mt CO_2e total) by millions of acres of cropland (19 million acres according to the USDA for SD). (0.13 Mt CO_2e/acre/year)

Medium sequestration rate: The medium value was taken as the midpoint between the high and low values identified from the literature. (0.17 Mt CO_2e/acre/year)

No-Till / Low-Till (Reduced Till)

Sequestration Rate: 0.33 Mt CO_2e/acre/year

Methods: Numbers were adopted from Biardeau et al. (2016) for high and low levels and a value for medium levels was calculated between the two endpoints.[84]

High sequestration rate: Numbers for no-till were used, which considers additional carbon stored as compared to conventional agriculture practices. (0.45 Mt CO_2e/acre/year)

Low sequestration rate: Numbers for reduced tillage were used, which considers additional carbon stored as compared to conventional agriculture practices. (0.2 Mt CO_2e/acre/year)

Medium sequestration rate: The medium value was taken as the midpoint between the high and low values identified from the literature. (0.33 Mt CO_2e/acre/year)

Peatland Restoration (Rewetting)

Sequestration Rate: 0.70 Mt CO_2e/acre/year

Methods: Very few data are available on peatland restoration and carbon storage change in the U.S., though there has been some assessment in Canada and northern Europe (Scotland and Ireland). Although some wetlands may be net sources of carbon from past drainage and recent climate change, restoration through re-wetting will have a positive benefit on the carbon balance, reducing the rate of loss to CO_2 emissions.

High sequestration rate: The high number was derived from Bridgham et al. used to develop averages for Fargione et al. (2018).[85] (1.4 Mt CO_2e/acre/year)

Medium sequestration rate: This figure was obtained from Anderson et al., which provide a more conservative estimate than Bridgham.[86] (0.7 Mt CO_2e/acre/year)

Low sequestration rate: The low number is 0 and assumes a failed restoration.

Reforestation

Sequestration Rate: 1.06 Mt CO_2e/acre/year for general reforestation; 1.93 Mt Co_2e/acre/year for reforestation on agricultural lands

Methods: Values were derived from the FIA plot database for forests between 50-100 years old for MN, ND and SD accessed through the Evalidator tool[87] and GTR343.[88] GTR343 provides regional carbon estimates for forest type group for the continental United States. Data were accessed directly through Evalidator as the regional estimates indicated significantly higher rates for North and South Dakota than individual state data. The main issue with the North Dakota, and South Dakota is the low sample size, with many cover types poorly represented. In contrast, Minnesota has a large area of forest and double the sampling density compared with requirements. Therefore, there are sufficient plots to calculate estimates for individual cover types.

For **Minnesota**'s Northern Temperate-Southern Boreal Forests, the Reforestation estimates for high, medium, and low, respectively are as follows: Red pine-white pine, oak-hickory, and spruce-fir. Aspen-birch also fits in the medium category.

Within **North and South Dakota**, the estimates for high, medium, and low, respectively are as follows: oak-hickory (SD) forest on timberland (ND) and ponderosa pine (SD).

The sequestration values represent the rate of carbon accumulated over a specified time period. For example, the rate for red pine-white pine is calculated as follows:

$$\text{Rate: } R = \frac{C_{y,t2} - C_{y,t2}}{total\ years}\text{, where } C_{y,t1} = \text{ Carbon at year 120 and } C_{y,t2} = \text{ Carbon at year 10}$$

$$C_{y,t1} = 228.2\ MtCO2e - \ C_{y,t2} = \frac{55.27 * (228.2 - 55.27)\ MtCO2e}{(120 - 10)years} = 1.57\ MtCO2e/yr$$

$$R = 1.57\ MtCO2e/yr$$

E.g., To estimate total Carbon at year 41: = 55.27 + (1.57 *40) = 118.6 MtCO2e/acre/year.

Alley Cropping Methods: For the purposes of NCS in Minnesota, North Dakota and South Dakota, we consider alley cropping to be a subset of reforestation defined as carbon sequestration gained by planting wide rows of trees with a companion crop grown in the alleys between the rows.

> **High sequestration rate:** The US State Carbon Mapper tool on Nature4Climate (based on Fargione et al. 2018) was used to calculate annual sequestration rates for the Alley Cropping practice.[89] This straight-forward calculation involved dividing the millions of Mt CO_2e per year benefit by millions of acres identified in Fargione et al. (2018) as available for the practice. This was calculated at the state level with equivalent results for Minnesota, North Dakota, and South Dakota when rounded to the second decimal. (2.15 Mt CO_2e/acre/year)
>
> **Low sequestration rate:** We adopted the sequestration rate from Biardeau et al. (2016).[90] (1.7 Mt CO_2e /acre/year)
>
> **Medium sequestration rate:** The medium value was taken as the midpoint between the high and low values identified from the literature. (1.93 Mt CO_2e /acre/year)

Riparian Forest Buffers

Sequestration Rate: 4.00 Mt CO_2e/acre/year

Methods: A range of values for riparian forest buffers was obtained from agency reports, online tools and published literature.

High sequestration rate: A sequestration rate was adopted from the Minnesota Board of Water and Soil Resources as derived from Anderson et al. (2008).[91] (5.5 Mt CO_2e/acre/year)

Low sequestration rate: The sequestration rate from Biardeau et al. (2016) was adopted.[92] (2.50 Mt CO_2e /acre/year)

Medium sequestration rate: The medium value was taken as the midpoint between the high and low values identified from the literature. (4.00 Mt CO_2e /acre/year)

Wetland Restoration (non-peat)

Sequestration Rate: 3.70 Mt CO_2e/acre/year

Methods: Restoration is assumed to be implemented on land now in a drained, farmed condition. Values were derived from the scientific literature, agency reports, and tools, converting to standard units of Mt CO_2e/acre as required.

High sequestration rate: The high value was obtained directly from BWSR (2009) (as derived from Anderson et al. 2008), which is consistent with Euliss et al. 2006 (originally presented as 305 g C/m^2).[93,94,95] (4.5 Mt CO_2e/acre/year)

Low sequestration rate: The low value was adopted from Lennon (2008) (originally presented as 195 g/m^2).[96] (2.9 Mt CO_2e/acre/year)

Medium sequestration rate: The medium value was taken as the midpoint between the high and low values identified from the literature. (3.70 Mt CO_2e/acre/year)

Appendix C. Area Available for Natural Climate Solutions Implementation in Minnesota

This report assesses the total NCS potential on all available land for the implementation of the 13 identified practices. It does not consider the practicality nor cost of implementing NCS on these lands, but the applicability of the practice to the land itself. For example, the cost of cover cropping on all farmland is not considered; this analysis simply considers the relevant acreage of cultivated cropland to which cover cropping could be applied.

The areas noted throughout Appendix C reflect the best available understanding of Minnesotan NCS practices and their relevance to current and historic land cover. These areas will likely be refined as climate science is improved.

Avoided Grassland Conversion

Area available for avoided grassland conversion was based on the area of grassland available today; these were identified through the Fargione et al. (2018) study and Nature4Climate resource.[97,98]

Avoided Forest Conversion

Area available for avoided forest conversion was pulled directly from the Fargione et al. study and Nature4Climate resource.[99,100]

Avoided Peatland Conversion

Peatland conversion is limited by the Minnesota Wetland Conservation Act.[101] However, over 8,000 acres of peat lands are currently under lease by the state for mining operations.[102] This analysis assumes that about 10,000 acres are at risk given the potential change in peat leases.

Avoided Wetland Conversion

Any of Minnesota's 9.5 million acres of wetlands that are converted must be offset by equal restoration activities, according to the no net loss provision in the state's Wetland Conservation Act.[103] However, Lark et al. (2015) confirm that 25,000 acres of wetland were lost between 2008–2012 in Minnesota (approximately 5,000 acres per year).[104] Converted wetlands lose their carbon stocks over about a 50 year time period. Thus, this study assumes that 5,000 acres lost per year, and impacting carbon stocks for 50 years each, equates to 5,000 * 50 = 250,000 acres of total wetland conversion potential that can be avoided.

Cover Cropping

We follow the methodology of Fargione et al. to assume cover cropping is applicable on land used to grow five major field crops—13.63 million acres.[105] Because the best available data indicates cover cropping has been introduced on very little land in Minnesota, this report assumes all acres are still available to the practice.

Grassland Restoration

Area available for grassland restoration was based on the assumptions identified through the Fargione et al. (2018) study and Nature4Climate resource.[106,107]

Improved Forest Management

This analysis follows the assessment of White et al., who find that "31% of Minnesota forest land is classified in poor condition and in need of significant restoration."[108] This estimate is believed to be conservative and is consistent with MFRC's findings that "about 40% of Minnesota's forests are considered to contain only poor or medium stocking levels."[109]

Improved Nutrient Management

We follow the methodology of Fargione et al. to assume that agricultural practices are applicable on the land area used to grow five major field crops—or on 13.63 million acres.[110]

No-Till / Low-Till (Reduced Tillage)

We follow the methodology of Fargione et al. to assume that agricultural practices are applicable on the land area used to grow five major field crops—or on 13.63 million acres.[111] However, roughly 8 million acres are already under conservation tillage practices.[112] Thus, this report assumes 5.63 million acres are available for improvement via this practice.

Peatland Restoration

There are 500,000–750,000 acres of drainage-impacted peatlands that could be hydrologically restored in Minnesota in the northern half of the state not including southern organic-soil wetlands.[vii] This report assumes the lower bound of 500,000 acres of peatland can be restored in Minnesota.[113]

This estimate can be confirmed by overlaying a 150m buffer applied to ditches identified by an altered watercourse layer on the Native Plant Communities peatland systems data,[114] which demonstrates that about 400,000 acres of peat have likely been impacted in the northern 60% of the state. However, this estimate clearly omits restoration opportunities in the western and southern portions of the state, which were not included in the Native Plant Communities data for forested peat, open peat, and/or acid peatlands. In particular, DNR peat inventories from 1979 visually demonstrate significant concentrations of peat in southwest Stearns, Pope, northern Kandiyohi, and Le Sueur counties, as well as other small plots elsewhere in the state.[115] Thus, we feel comfortable rounding to a statewide opportunity of about 500,000 acres.

Reforestation

Area available for reforestation was based on the assumptions identified through the Fargione et al. (2018) study and Nature4Climate resource—including both reforestation, urban reforestation, and alley elements.[116,117] 200,000 acres identified for riparian forest buffers were subtracted from the overall reforestation land availability to avoid double-counting.

Riparian Forest Buffers

Susan Cook Patton (2020) estimates 197,000 acres of riparian buffer potential in Minnesota.[118] This study uses that conservative figure excluding additional floodplain restoration potential.

Wetland Restoration

About half of Minnesota's original wetlands have been lost.[119] However, much of this land cannot practically be restored today given conversion to highly productive cropland, the introduction of subsurface drainage (tiling), and approximately 27,000 miles of drainage ditches.[120]

This study estimates approximately 300,000 acres of wetland restoration potential in Minnesota. This area would comprise about 100,000 acres of potential floodplain reclamation (from agricultural or urban lands to perennial forest or wetland) and about another 200,000 acres of upland wetland restoration potential that would most likely be implemented primarily to provide downstream source water, Nutrient Reduction Strategy water quality, or flood storage benefits.

The identified 300,000 acres of restorable wetland can be understood in the context of the following state targets and wetlands inventory:

- Minnesota's Nutrient Reduction Strategy targets 440,000 acres of perennial restoration and 620,000 acres of drainage water retention and manage by 2025.[121] Conservatively assuming 5–10% of these goals represent wetland restoration, the 2025 target would include 44,000–62,000 acres of wetland restoration.
- Minnesota's 2020 State Water Plan targets the protection of 400,000 acres within Drinking Water Supply Management Areas (DWSMAs) vulnerable to contamination. Currently, 30% of DWSMA areas are in perennials, of which roughly 9,000 DWSMA acres are permanently protected through easements.[122] Up to 280,000 additional acres thus require protection via land retirement, restoration or cover crop/perennial crop. Conservatively assuming 10% could be restored as wetland (a reasonable assumption, given pre-settlement land use and the Restorable Wetland Inventory as a fraction of the state), 28,000 acres of wetland restoration are needed.
- The Restorable Wetlands Inventory identifies a total statewide acreage of 4.2 million acres of restorable wetlands, of which 2.9 million acres are not in perennial vegetation.[123,124] Of this territory, 444,000 acres are located within wetland floodplains.[125]

[vii] Internal TNC estimate.

Assuming a 10% threshold for remaining wetland required to protect watershed health and resilience (a standard assumption), and limiting our area to hydrologic unit code 8 watersheds with greater than 50% historic wetland loss, total statewide wetland restoration required is at least 296,000 acres.

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