2015 NATIONAL COOPERATIVE
SOIL SURVEY CONFERENCE

Guidebook to Field Tours
June 7-11, 2015
Duluth, Minnesota
Acknowledgements and Appreciation

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Thank you to Kathryn Desforge for providing the cover page photograph.

I also wish to thank all the last minute volunteers!

Very sincerely,

[Signature]

John F. Beck
Minnesota State Soil Scientist
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**Cover: Photograph by Kathryn DesForge**

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MLRA-DUL, REGION 10
UNITED STATES DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVICE, SOIL SCIENCE DIVISION

DULUTH MLRA SOIL SURVEY OFFICE IN R10

June 2015
Figure K-1: Location of Land Resource Region K

K—Northern Lake States Forest and Forage Region

This region (shown in fig. K-1) is in Wisconsin (37 percent), Minnesota (37 percent), Michigan (24 percent), and Illinois (2 percent). It makes up 118,775 square miles (307,795 square kilometers).

This region is in the Central Lowland areas south and west of the western Great Lakes. It is a glaciated region with numerous lakes and wetlands. Slopes are nearly level to gently undulating in areas of glacial lake deposits, gently undulating to rolling on till plains and ground moraines, and steep on end moraines, on valley sidewalls, and on escarpments along the margins of lakes.

Winters are cold in this region, and significant amounts of snow can accumulate. The average annual precipitation ranges from 26 to 34 inches (660 to 865 millimeters). Most of the precipitation falls in spring and summer. The average annual temperature ranges from 39 to 44 degrees F (4 to 7 degrees C). The freeze-free period ranges from 120 to 175 days, increasing in length from north to south.
The total withdrawals of freshwater in this region average about 5,650 million gallons per day (21,385 million liters per day). About 82 percent is from surface water sources, and 18 percent is from ground water sources. Most of the region is used for farming or timber production, but the region is heavily populated from the center of the west shore of Lake Michigan to its southern end. About 75 percent of the water in the region is used for municipal and industrial supply, and 18 percent is used for public supply. Wood pulp, paper, mining, and food-processing industries use significant amounts of the water.

The soils in this region are dominantly Histosols, Alfisols, Spodosols, and Entisols. Some areas also have a significant acreage of Mollisols or Inceptisols. Almost all of the soils in the region have a frigid soil temperature regime, and all have an aquic or udic soil moisture regime. Soils with a mesic soil temperature regime are in many areas in the southern part of the region. Mineralogy is dominantly mixed, but it is isotic in some areas.

About 90 percent of the land in this region is privately owned. Most of the Federal land is in national forests. The native vegetation consists of forest species in about 58 percent of the region (fig. K-2). The rest of the region is mainly cropland or grassland. Important crops include corn, wheat, alfalfa, oats, barley, and soybeans. Much of the forage and feed grain grown in the region is used by onsite dairy and beef cattle industries. Other locally important crops include sunflowers, potatoes, edible beans, sweet corn, peas, berries, and fruit. Water erosion, especially on cropland, is a major resource concern. Wind erosion is a hazard in areas of silty and sandy soils. Soil wetness, fertility, and tilth and protection of water quality are additional resource concerns.

NCSS Preconference Field Tour to the Marcell Experimental Forest (MEF)

Hosted by Randy Kolka, Research Soil Scientist
USDA Forest Service Northern Research Station, Grand Rapids, MN

Sunday, June 7th, 2015

Agenda
8:00-10:15 – Drive from Duluth to the Marcell Research Center
10:15-10:45 – Introduction to MEF and the SPRUCE Experiment
10:45-11:45 – Visit SPRUCE
11:45-12:15 – Lunch -Provided
12:15-1:00 – Visit Peatland Soil Site, conduct some peat sampling, Greenwood Series
1:00-1:45 – Roadcut to see/sample St. Louis Sublobe till, Warba Series
1:45-2:30 – Roadcut to see/sample Rainy Lobe Outwash, Menahga Series
2:30-5:00 – Return to Duluth

Included in Background Information
SPRUCE Brief
Description of Greenwood Series
Description of Warba Series
Description of Menahga Series

Book Chapter: Geology, Vegetation, and Hydrology of the S2 Bog at the MEF: 12,000 Years in Northern Minnesota – Overview of the glacial and vegetation history of the MEF in general and specifically the development of one of the most studied bogs (S2) on the planet.

Background
Although they cover only 3 percent of Earth’s land surface, peatlands store about 30 percent of the total carbon stored in soil. Because they store so much carbon, peatlands may be one of the most important ecosystems in terms of gaining insight into global climate change. Despite the importance of these ecosystems and the uncertainty about their response to climate change, large scale experimental manipulations to simulate climatic warming and predicted atmospheric carbon dioxide levels have not been conducted until SPRUCE.

The SPRUCE Experiment
Spruce and Peatland Responses Under Climatic and Environmental Change, or SPRUCE, is an ambitious ecosystem-level experiment that will test the response of high-carbon northern peatland ecosystems to increased temperatures and elevated carbon dioxide. Located at the Northern Research Station’s Marcell Experimental Forest near Grand Rapids, MN, the experiment is a collaboration between the U.S. Forest Service and the Department of Energy’s Oak Ridge National Laboratory.

Scientists at the U.S. Department of Energy’s Oak Ridge National Laboratory conceived the SPRUCE concept and design and have been developing the technology to produce large-scale whole-ecosystem warming conditions for the target black spruce peatland ecosystem. Scientists from the U.S. Forest Service’s Northern Research Station, Oak Ridge National Lab and numerous researchers from across the globe are working in collaboration to understand the water, soil, and plant responses to elevated temperature and carbon dioxide.

Support
Funding for SPRUCE comes from the U.S. Department of Energy through support of the Oak Ridge National Laboratory’s Terrestrial Ecosystem Science and Climate Change Research efforts. The infrastructure (construction, instrumentation, power supply) will cost about $11 million. Estimated operational cost will be about $5 million per year for the 10-year life of the experiment.

Status
To date, electrical power has been brought in, boardwalks have been built, center climate towers have been erected, measurement instrumentation is deployed, belowground heaters have been installed, belowground and aboveground chambers have been constructed and current work is establishing the above ground heating system and carbon dioxide exchangers. Full operation of the experiment is anticipated to begin in June of 2015.

For more information, visit http://www.nrs.fs.fed.us/disturbance/climate_change/spruce/ and the Oak Ridge National Lab’s website: http://mnspruce.ornl.gov/

For more information, contact: Randy Kolka, Principal Investigator, Northern Research Station. rkolka@fs.fed.us
GREENWOOD SERIES

The Greenwood series consists of very deep, very poorly drained soils formed in organic deposits more than 51 inches thick on outwash plains, till floored lake plains, or lake plains. These soils have moderate or moderately rapid permeability. Slopes range from 0 to 2 percent. Mean annual precipitation is about 29 inches, and mean annual temperature is about 43 degrees F.

TAXONOMIC CLASS: Dysic, frigid Typic Haplohemists

TYPICAL PEDON: Greenwood mucky peat - on a 1 percent slope in a forested area. (Colors are for moist soil unless otherwise stated.)

Oi--0 to 6 inches; brown (7.5YR 4/4) peat (fibric material); about 95 percent fiber, about 90 percent rubbed; massive; friable; primarily live roots and sphagnum moss; extremely acid; clear smooth boundary.

Oe1--6 to 10 inches; very dark brown (10YR 2/2) broken face and rubbed mucky peat (hemic material); about 80 percent fiber, about 20 percent rubbed; massive; friable; primarily herbaceous fibers; extremely acid; gradual smooth boundary.

Oe2--10 to 35 inches; dark brown (7.5YR 3/2) broken face and rubbed mucky peat (hemic material); about 80 percent fibers, about 20 percent rubbed; massive; friable; primarily herbaceous fibers; extremely acid; gradual smooth boundary.

Oe3--35 to 60 inches; dark brown (7.5YR 3/2) broken face and rubbed mucky peat (hemic material); about 90 percent fibers, about 35 percent rubbed; massive; friable; primarily herbaceous fibers; very strongly acid.

TYPE LOCATION: Clare County, Michigan; about 5 miles south and 1 mile west of Temple; 300 feet east and 825 feet south of the northwest corner, sec. 16, T. 18 N., R. 6 W.

RANGE IN CHARACTERISTICS: The organic layers are more than 51 inches thick. The surface tier is commonly peat (fibric material) derived from sphagnum moss. In some places, these layers are largely undecomposed sphagnum moss and in others they are stratified muck, mucky peat, and peat derived from both herbaceous plants and sphagnum moss. Muck, mucky peat, and peat types have been recognized. The O layers have hue of 10YR to 5YR, value of 2 to 6, and chroma of 1 to 4; colors become darker upon brief exposure to air. Oi layers have the highest values and chromas. In some pedons, colors after rubbing change from 0.5 to 1 unit in
value or chroma or both. The layers in the subsurface and bottom tiers are dominantly mucky peat (hemic material) derived from herbaceous plants. In some pedons, layers of peat or muck have a combined thickness of less than 10 inches in the lower two tiers. These layers have pH of 4.5 or less in 0.01M calcium chloride and commonly range from pH 3.5 to 4.5. Fragments of woody material ranging from about 1 to 8 inches in diameter are throughout the control section. Woody fibers comprise less than 50 percent of the organic volume after rubbing. There is no mineral soil material recognized in the profile.

COMPETING SERIES: There are none. The Burnt Vly, Citypoint, Dawson, Loxley and Pleasant Lake soils are in closely related families. All of these soils are dominantly composed of sapric materials. In addition, the Citypoint series has a lithic or paralithic contact within 60 inches and the Burnt Vly and Dawson soils have sandy mineral soil within 51 inches of the surface.

GEOGRAPHIC SETTING: Greenwood soils are in depressions that range in size from small enclosed bogs in moraines to areas of about 1,000 acres in size. The larger areas commonly are on outwash plains, till floored lake plains, or lake plains. The mineral soils in the surrounding upland are generally derived from acid parent materials. Slopes range from 0 to 2 percent. Then mean annual precipitation ranges from about 22 to 35 inches, and the mean annual temperature is about 36 to 45 degrees F. Frost free days range from 88 to 150. Elevation above sea level ranges from 600 to 1,600 feet.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Dawson, Deford, Kinross, and Roscommon soils. Dawson soils are shallow organic soils in similar landscape positions underlain by sand at a depth of 16 to 50 inches. The Deford, Kinross and Roscommon soils are poorly or very poorly drained sandy mineral soils in slightly higher landscape positions.

DRAINAGE AND PERMEABILITY: Very poorly drained. The representative depth to wet soil moisture status is at the surface to 1 foot below the surface at some time throughout the year. The representative depth of ponding is from 0 to 1.0 foot at some time throughout the year. Surface runoff is negligible. Permeability is moderate or moderately rapid.

USE AND VEGETATION: Very little use is made of these soils because of the extreme acidity and high water table. Few trees except some black spruce and tamarack grow on these soils. Ground cover is blueberries, bog rosemary, laurel, leatherleaf, and sphagnum mosses.


MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Ogemaw County, Michigan, 1923.
WARBA SERIES

The Warba series consists of very deep, moderately well and well drained soils formed in loamy calcareous glacial till on moraines. Permeability is moderate to moderately rapid in the upper part and moderately slow in the lower part. Slopes range from 1 to 25 percent. Mean annual precipitation is about 25 inches. Mean annual air temperature is about 39 degrees F.

TAXONOMIC CLASS: Fine-loamy, mixed, superactive, frigid Haplic Glossudalfs

TYPICAL PEDON: Warba very fine sandy loam, on a northeast-facing, convex slope of 4 percent, about 50 feet below the crest of a knoll, on a till plain, under northern hardwoods forest. This pedon represents the moderately well drained phase. (Colors are for moist soils unless otherwise noted.)

O--0 to 2 inches; dark reddish brown (5YR 2/2) forest litter derived from leaves, twigs and roots. (0 to 3 inches thick)

A--2 to 3 inches; very dark gray (10YR 3/1) very fine sandy loam, gray (10YR 5/1) dry; weak very fine granular structure; very friable; many fine and very fine roots; about 4 percent gravel; moderately acid; abrupt smooth boundary. (0 to 2 inches thick)

E1--3 to 8 inches; grayish brown (10YR 5/2) very fine sandy loam; light gray (10YR 7/2) dry; weak thin platy structure; very friable; many very fine and fine roots; few vesicular pores; about 5 percent gravel; strongly acid; clear wavy boundary.

E2--8 to 13 inches; light brownish gray (10YR 6/2) very fine sandy loam; light gray (10YR 7/1) dry; moderate thin platy structure; friable; many fine and very fine roots; common vesicular pores; about 3 percent gravel; moderately acid; abrupt wavy boundary. (Combined thickness of the E horizon is 5 to 13 inches.)

E/B--13 to 17 inches; 70 percent light brownish gray (10YR 6/2) very fine sandy loam (E); massive; friable; tongued into and surrounding 30 percent brown (10YR 4/3) clay loam (Bt); weak coarse subangular blocky structure; firm; many fine and very fine roots; few pores; about 3 percent gravel; moderately acid; clear wavy boundary.

B/E--17 to 20 inches; 75 percent brown (10YR 4/3) clay loam (Bt); moderate medium and coarse subangular blocky structure; firm; with 25 percent tongues of light brownish gray (10YR 6/2) loamy very fine sand (E); massive; friable; few fine and very fine roots; few pores; about 3
percent gravel; moderately acid; clear wavy boundary. (Combined thickness of the glossic horizon is 3 to 14 inches.)

Bt1--20 to 26 inches; light olive brown (2.5Y 5/4) clay loam; strong medium prismatic structure that parts to moderate medium angular blocky structure; firm; few very fine and fine roots; few pores; many distinct brown (10YR 4/3) clay films on faces of peds and in pores; few faint ped coats of E material; about 3 percent gravel; moderately acid; clear wavy boundary.

Bt2--26 to 31 inches; light olive brown (2.5Y 5/4) clay loam; moderate coarse prismatic structure parting to moderate medium angular blocky structure; firm; few very fine roots; few pores; many distinct thin brown (10YR 4/3) clay films on faces of peds and in pores; few clean sand grains on some of the vertical faces of peds; about 4 percent gravel; moderately acid; clear wavy boundary.

Bt3--31 to 39 inches; light olive brown (2.5Y 5/4) clay loam; weak very coarse prismatic structure; friable; few very fine roots; few pores; common distinct brown (10YR 4/3) clay films on faces of peds; very few fine soft manganese nodules; about 4 percent gravel; moderately acid; clear wavy boundary. (Combined thickness of the Bt horizon is 12 to 36 inches.)

C1--39 to 44 inches; light olive brown (2.5Y 5/4) loam; massive; friable; few very fine roots; few pores; few fine prominent yellowish red (5YR 5/6) Fe concentrations; about 5 percent gravel; neutral; clear wavy boundary.

C2--44 to 60 inches; light olive brown (2.5Y 5/4) loam; massive; friable; few very fine roots; few pores; few fine prominent yellowish red (5YR 5/6) Fe concentrations; about 6 percent gravel; slightly effervescent; slightly alkaline.

TYPE LOCATION: Cass County, Minnesota; in the Pike Bay Experimental Forest, about 3.5 miles east and 3.7 miles south of the community of Cass Lake; located about 990 feet north and 1,270 feet west of the southeast corner of sec. 31, T. 145 N., R. 30 W.; USGS Pike Bay topographic quadrangle; lat. 47 degrees 19 minutes 34 seconds N. and long. 94 degrees 31 minutes 42 seconds W., NAD 83.

RANGE IN CHARACTERISTICS: Depth to carbonates ranges from 35 and 70 inches. The till has 2 to 12 percent by volume of rock fragments of mixed lithology, but typically high in gray, extremely hard, flat shale. Most pedons have a few cobblestones throughout the soil. The soil moisture control section is not dry in any part for as long as 90 cumulative days in most years. Many pedons have a mantle with a high content of coarse silt and very fine sand. It is as much as 20 inches thick. It has 0 to 5 percent by volume of rock fragments.

The O horizons have hue of 10YR to 5YR, value of 2 to 4, and chroma of 1 to 3. It is Oa, Oe or Oi. It is comprised of accumulated forest litter of deciduous tree leaves, coniferous tree needles and remains of forest floor flora.

The A horizon has value of 2 or 3 and chroma of 1 or 2. The E horizon has value of 4 to 6 and chroma of 2 or value of 6 and chroma of 3. The A and E horizons are very fine sandy loam, silt
loam, fine sandy loam or loam. They are strongly acid to slightly acid. Some pedons have an Ap horizon with dry value of 5 or higher.

The glossic horizon consists of an E/B or B/E or both. The E and Bt material each occupy 15 percent or more of the horizon. Colors and textures are similar to E and Bt horizons respectively.

The Bt horizon has matrix hue of 10YR or 2.5Y, value of 4 to 6, and a typical chroma of 3 or 4. Some pedons have a minor amount of chroma of 2 beginning 10 inches or more below the upper boundary of the Bt horizon. It is clay loam, loam or sandy clay loam having 20 to 35 percent of clay. It typically has 30 to 40 percent of fine sand and coarser sand. It averages less than 45 percent sand. It commonly is moderately acid to neutral but may be strongly acid in the upper part. It has manganese oxide nodules in the lower part in some pedons. Some pedons have a Bk horizon.

The C horizon has hue of 2.5Y or 10YR, value of 4 to 6, and chroma of 3 or 4. Most pedons have high chroma Fe concentrations. It is loam, sandy clay loam, or clay loam. It is neutral to moderately alkaline. Below the upper few inches it has calcium carbonate equivalent in the range of about 5 to 15 percent.

**COMPETING SERIES:** These are the Bamfield, Cushing, Duluth, Lozeau, and Sol series. The Cushing soils average less than 25 percent clay and greater than 45 percent total sand in the Bt and C horizon. The Bamfield and Duluth soils have hue of 7.5YR or redder in the middle and lower third of the series control section. Lozeau soils have a paralithic contact above a depth of 40 inches. The Sol soils have less than 18 percent clay in the lower one-third of the series control section and have more than 45 percent sand in the argillic horizon and below.

**GEOGRAPHIC SETTING:** The Warba soils have convex and plane slopes on moraines. Slope ranges from 1 to 25 percent, mainly 1 to 6 percent. They formed in calcareous loamy till in the late Wisconsinan glaciation. Mean annual air temperature ranges from 36 to 42 degrees F. Mean annual precipitation ranges from 22 to 28 inches. Frost-free period ranges from 88 to 135 days. Elevation ranges from 1,000 to 1,600 feet above sea level.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are Stuntz and Talmoon soils, members of a hydrosequence with Warba soils. The somewhat poorly drained Stuntz soils are less sloping with slightly concave slopes and the very poorly drained Talmoon soils are in shallow depressions. Cathro, Greenwood, Lupton, Mooselake, and Seelyeville are organic soils in adjacent depressions.

**DRAINAGE AND PERMEABILITY:** Moderately well and well drained. Permeability is moderate to moderately rapid in the upper part and moderately slow in the lower part. Runoff is moderately low to high depending upon slope. The moderately well drained phase has an apparent water table at 3.5 to 6.0 feet at some time during April to May in normal years.

**USE AND VEGETATION:** Most of this soil is forested. Main trees are basswood, quaking aspen, red oak, sugar maple, and white spruce. A minor amount is cleared for the production of hay, pasture, and small grains.

MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: St. Paul, Minnesota


REMARKS: Diagnostic horizons and features recognized in this pedon are: ochric epipedon - the zone from the mineral soil surface to 15 inches (A, E1, E2, E/B horizons); albic horizons - the zones from 1 to 15 inches (E1, E2, and E/B horizons); glossic horizon - the zone from 6 to 15 inches (E/B and B/E horizons); argillic horizon - the zone from 15 to 37 inches (B/E, Bt1, Bt2 and Bt3 horizons); Base saturation above 60 percent in all parts of argillic horizon.

The moderately wet phase needs field study to determine if it does or does not qualify as an Oxyaquic subgroup of Glossudalfs.

ADDITIONAL DATA: Refer to MAES Central File Code No. 879 for results of some laboratory analyses of the typifying pedon and to Nos. 733 and 796 for data on two other pedons. Soil Interpretation Record numbers are MN0140 and MN0708, moderate wet phase.

_____________________________________
National Cooperative Soil Survey
U.S.A.
MENAHGA SERIES

The Menahga series consists of very deep, excessively drained to well drained soils that formed in sandy glacial outwash sediments on outwash plains, valley trains, and some moraines and drumlins. These soils have rapid permeability. Their slopes range from 0 to 55 percent. Mean annual precipitation is about 26 inches. Mean annual air temperature is about 42 degrees F.

**TAXONOMIC CLASS:** Mixed, frigid Typic Udipsamments

**TYPICAL PEDON:** Menahga loamy sand with a 1 percent nearly level slope on an outwash plain in a jack pine forest. (Colors are for moist soil unless otherwise noted.)

A--0 to 3 inches; very dark brown (10YR 2/2) loamy sand, grayish brown (10YR 5/2) dry; weak fine granular structure; very friable; many fine roots; 1 percent gravel; strongly acid; clear smooth boundary. (0 to 4 inches thick)

Bw--3 to 17 inches; dark yellowish brown (10YR 4/4) loamy sand; weak fine subangular blocky structure parting to single grain; very friable; common fine roots; 1 percent gravel; strongly acid; clear smooth boundary. (5 to 45 inches thick)

C1--17 to 37 inches; brownish yellow (10YR 6/6) sand; single grain; loose; few coarse roots; 1 percent gravel; moderately acid; gradual smooth boundary.

C2--37 to 64 inches; light yellowish brown (10YR 6/4) sand; single grain; loose; few coarse roots; 1 percent gravel; moderately acid; gradual smooth boundary.

C3--64 to 80 inches; light yellowish brown (10YR 6/4) sand; single grain; loose; few coarse roots; 5 percent gravel; slightly acid.

**TYPE LOCATION:** Hubbard County, Minnesota; about 1/2 mile northeast of Lake George; about 200 feet north and 400 feet west of the southeast corner, sec. 9, T.143N., R.34W.; USGS Lake George quadrangle; lat. 47 degrees 12 minutes 39.5 seconds N. and long. 94 degrees 59 minutes 5.5 seconds W., NAD 27.

**RANGE IN CHARACTERISTICS:** Depth to free carbonates is 40 inches or more. Typically, these soils do not have gravel, but in some pedons gravel of mixed lithology and mostly less than 1 cm in size comprises as much as 10 percent of the volume of the solum and C horizon, either as distinct strata or dispersed throughout part to all of the sandy matrix. The average texture in the 10- to 40- inch zone is coarse sand, sand, loamy coarse sand or loamy sand. Fine sand is less
than 40 percent, medium sand is greater than 25 percent, and coarse sand and very coarse sand from 20 to 35 percent. Reaction in the solum typically is strongly acid to neutral. Some pedons have an O horizon as much as 2 inches in thickness. The soil moisture control section in 6 out of 10 years is dry for 20 to 35 consecutive days at some time during the 120 days following the summer solstice in most years.

The A horizon typically has hue of 10YR, value of 2 to 4, and chroma of 1 to 2. Some pedons have an E horizon as much as 6 inches thick with hue of 10YR, value of 4 or 5, and chroma of 1 or 2. The A and E horizons are coarse sand, sand, loamy coarse sand, or loamy sand. In cultivated areas the Ap horizon has moist value of 3 or 4 and/or dry value of 5 or 6.

Some pedons have an AB horizon.

The Bw horizon has hue of 10YR or 7.5YR, value of 3 to 5, and chroma of 3 to 6. The lower value and chroma are only in the upper part of the B horizon. Texture is coarse sand, sand, loamy coarse sand or loamy sand.

Some pedons have a BC horizon.

The C horizon has hue of 10YR or 7.5YR, value of 4 to 6, and chroma of 3 to 6. Texture is coarse sand, sand, loamy coarse sand or loamy sand and in some pedons it is stratified with those textures. It is moderately acid to slightly acid in the upper part and slightly acid to slightly alkaline in the lower part. Some areas have a loamy 2C horizon below 40 inches. A (friable) loamy substratum phase and a (dense) till substratum phase are recognized.

COMPETING SERIES: These are the Abbeylake, Cantlin, Champlain, Claire, Corliss, Feldtmann (T), Friendship, Grayling, Mahtomedi, Nymore, Plainbo, Sartell, Serden, Shawano, and Sunday series. Abbeylake soils have carbonates above 40 inches. Cantlin and Friendship soils have redoximorphic features and a water table in the lower part of the series control section. Champlain soils have less than 30 percent medium sand or coarser in the series control section. Claire soils do not have a B horizon and are dry in the soil moisture control section for 35 to 45 consecutive days during the 120 days following the summer solstice in most years. Corliss soils have carbonates within 40 inches. Feldtmann (T) soils have hue of 2.5YR or redder throughout the series control section. Grayling and Nymore soils have less than 20 percent coarse and very coarse sand in the series control section. Mahtomedi soils have more than 10 percent gravel in the series control section. Plainbo soils have bedrock beginning at depths ranging from 20 to 40 inches. Sartell, Serden and Shawano soils have more than 40 percent fine sand in the series control section. Sunday soils do not have a B horizon and the soil moisture control section is not dry for 20 or more consecutive days in the 4 months following the summer solstice.

GEOGRAPHIC SETTING: These soils have plane to slightly convex slopes with gradients of 0 to 55 percent. They primarily are on outwash plains and valley trains, but some are on moraines or sand mantled drumlins. They formed in thick glacial outwash deposits that are mostly coarse sand or sands. The deposits are late Wisconsinan in age. Mean annual air temperature ranges from 36 to 45 degrees F. Mean annual precipitation ranges from 22 to 33
inches. Frost-free days range from 88 to 150. Elevation above sea level ranges from 670 to 1600 feet.

**GEOGRAPHICALLY ASSOCIATED SOILS:** They commonly are the dominant soil in their area of occurrence. In some places they are associated with the somewhat poorly drained Meehan soils and the poorly and very poorly drained Newson soils, which are members of a hydrosequence with the Menahga soils. These soils are on nearby lower lying terrain. They are the end member of a biosequence that includes the Mollisol, Hubbard and the Typic Udipsamment, Nymore, which has an A horizon that is intermediate in thickness between that of the Hubbard and that of the Menahga.

**DRAINAGE AND PERMEABILITY:** Excessively drained. Surface runoff is moderately low to moderately high. Permeability is rapid.

**USE AND VEGETATION:** Mostly forested with jack pine being the major tree. A few areas are cropped or pastured. Native vegetation is coniferous forest with jack pine being the dominant tree.

**DISTRIBUTION AND EXTENT:** Central and northern Minnesota and northwestern Wisconsin. Extensive.

**MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE:** St. Paul, Minnesota

**SERIES ESTABLISHED:** Wadena County, Minnesota, 1926.

**REMARKS:** Diagnostic horizons and features recognized in this pedon are: ochric epipedon - zone from the surface of soil to a depth of 4 inches (A and AB horizons). The soil moisture control section may be dry for 20 to 35 consecutive days following the summer solstice.

Type location moved to Hubbard County to better reflect the series as it occurs in MLRA 57.

4

Geology, Vegetation, and Hydrology of the S2 Bog at the MEF: 12,000 Years in Northern Minnesota

Elon S. Verry and Joannes Janssens

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Introduction

A clear understanding of geology and landscape setting is fundamental to the interpretation of water and solute movement among landscape forms. This understanding allows us to assess how land use affects water, soils, and vegetation as well as assess the fate of acids, nutrients, trace metals, and organic compounds deposited from the atmosphere. Pleistocene Glaciation and the Holocene accumulation of peat in ice-block depressions are two primary determinants of the landscape in the recessional moraine area of north-central Minnesota, which is the setting of the Marcell Experimental Forest (MEF). We examine these two processes using studies of lacustrine and peat sediment accumulation, ice-block paleobotany, mineral-soil development, and a review of Wisconsin Glaciation at the MEF.

An understanding of geology and soil development illuminates the physical link between water in “pothole” bogs and recharge of water in the lagg at their perimeter to groundwater aquifers. Regional paleobotany patterns reveal broad climate change as a third driver of landscape development, imposing its control on water levels, plant migration, interspecies competition, and the vegetation community—in short, a 12,000 year interpretation of Earth processes since a great ice sheet.

This chapter is an account of geologic, hydrologic, paleobotanical, and current botanical development in and around a single ice-block depression now occupied by a black spruce (*Picea mariana*)-Sphagnum bog on deep peat (Figure 4.1). Included with interpretations of the published literature are previously unpublished soil, water chemistry, piezometer and well records, topographic surveys, rigorous peat-core dating and pollen analysis, and a critical, regionally specific application of recent interpretations of Wisconsin Glaciation and climate change. The insights into environmental change over 26 millennia place our current evaluations of anthropogenic environmental change in perspective. In particular, the last 20,000 years, including Late-Wisconsin Glaciation and the Holocene (the last 12,000 years at this site), encompass fundamental geologic events that drive today’s ecosystems and our interpretation of their function.
Geology, Vegetation, and Hydrology of the S2 Bog at the MEF

FIGURE 4.1
Oblique view of S2 bog on June 11, 1964 (photo by Bluford Muir, USDA Forest Service). The central peatland filling an ice block depression is forested with black spruce and the uplands with aspen and birch. The view is looking NNE. Numbers locate instrumentation: weir (1), weather station (2), bog well (3), upland wells (4–5), upland runoff plots (7, 9), soil pit A (9), soil pit B (10), piezometer nest (11–16), soil temperature stack (17), and neutron soil moisture tubes (18, 19). The arrow identifies the exit stream and the dashed line shows a picture-truncated watershed boundary.

General Setting and Contemporary Climate

The MEF is located in north central Itasca County, Minnesota (Lat. 47°31'52"N, Long. 93°28'07"W) at about 430 m above sea level (NAVD 1929). The Marcell Hills are in the Humid Temperate Domain (200), Warm Continental Division (210), Laurentian Mixed Forest Province (212), Northern Minnesota Drift and Lake Plains Section (212), and St. Louis Moraines Subsection (212Nb) of terrestrial ecoregions in North America (Keys and Carpenter, 1995).

In the North American aquatic classification (Maxwell et al., 1995), it is in the Nearctic Zone (North America), the Arctic-Atlantic Subzone (A), the Mississippi Region (A2), and at the very northern tip of the Upper Mississippi Subregion (A2a), several kilometers west of the tricontinental divide point for the Upper Mississippi, St. Lawrence, and Hudson Bay watersheds.

The climate is strongly continental (Chapter 2). The mean annual precipitation from 1961 to 2000 was 78 cm, and the annual temperature 3.3°C. Monthly precipitation ranges from 4 cm in February to 33 cm in August (Figure 4.2) and annual precipitation ranges from 412 to 946 mm. Monthly average temperatures are 16°C, 19°C, and 15°C in June, July, and August, and −12°C, −16°C, and −11°C in December, January, and February (Figure 4.3).
FIGURE 4.2
Monthly maximum, average, and minimum precipitation for the S2 meteorological station.

FIGURE 4.3
Monthly maximum, average, and minimum temperature for the S2 meteorological station.

Bedrock Setting
The MEF site is underlain by the Giants Range Batholith, a large complex of intrusions formed about 2.7 Ga before present (BP) (Figure 4.4). The bedrock lies some 40–50m under late Wisconsin glacial drift (Oakes and Bidwell, 1968). The MEF and S2 bog lie in a recessional moraine complex (the Marcell
Geology, Vegetation, and Hydrology of the S2 Bog at the MEF

FIGURE 4.4
The MEF lies within the Bigfork USGS quadrangle (black rectangle) above the Giants Ridge, granitoid, batholith composed of tonalite to granodiorite, part of the Wawa subprovince of the Superior bedrock province (from Jirsa and Chandler, 2007). Black lines are major faults or NW trending dikes. ILB is Island Lake batholith, DLB is Dora Lake batholith, and BB is Bemidji batholith.

Hills) formed by Late-Wisconsin glaciation (26–12 ka BP), with elevation ranges of 10–30 m, mineral soil side slopes of 5%–40%, flat-topped hills, and peat- or lake-filled, ice-block depressions (Figure 4.5). Because this location is within 3 km of the Hudson Bay-Mississippi Continental Divide, we speculate that the bedrock surface may also be a topographic high.

Methods
Mapping
In 1966, Mark Hurd Aerial Surveys (Minneapolis, Minnesota) produced topographic maps with 4 ft contours for the MEF. We interpolated contour lines by hand at 1 m intervals. In 1982, we recorded a hollow and a hummock
Surface contours of the uplands (1 m interval) and peatland (3 cm interval) in the S2 watershed. A surface stream drains from the southwest tip of the bog.

Surface elevation near each point on a 30.5 m grid over the S2 peatland (Verry, 1984). In 1988, we sounded the same grid for depth to the Koochiching till the surface lying below the peat deposit and mapped 1 m contours of the ice-block depression. We mapped only the hollow elevation of the peat surface and interpolated a series of 3 cm contour intervals. Detailed metric maps for watershed S2 were drawn and digitized in December 1994.

Peat Coring

On November 20, 1983, Herb Wright Jr. (emeritus professor, University of Minnesota) extracted a 782 cm-long peat core (MR2-8307) using a 10 cm-diameter piston corer at a site near the middle of bog S2 located 80° east of north and 33 m from the recording well. On April 20, 1994 at the same location, Janssens, Paul H. Glaser (senior research associate, University of Minnesota), Howard D. Mooers (professor, University of Minnesota), and Verry collected a 106 cm-long core (MR2-9401) using a Waadenaar corer. In addition, Janssens collected several short cores in S2 bog in July 1986. Data composites from the short cores were useful in documenting the post settlement peat horizon developing after about 1865.
Weather, Water, Soil, and Geologic Studies

Weather records were summarized for 1961–2000 at a weather station on the upland, 20 m north of bog S2. At the MEF technicians measured streamflow, bog and regional water table elevations continuously, and took soil moisture and water-chemistry samples periodically from 1966 to 2001 (Chapter 2). We derived the elevation, referenced to U.S. Geological Survey quad map elevations and benchmarks, of soil and peat horizons from logs for wells, piezometers, soil pits, and surface topography.

Soil descriptions are detailed in Paulson (1968) and Nyberg (1987). Detailed mineral- and organic-soil physical properties (including bulk density, carbonate content, hydraulic conductivity, color, texture, and degree of decomposition) were determined in two large, soil pits (about 3 m deep) in contiguous mineral and peat soils at two locations on the edge of the S2 bog (Brooks and Kreft, 1991; Tracy, 1997). Hydraulic conductivity was measured in the peat (Boelter, 1965; Gafni and Brooks, 1986, 1990) and in the A/E and Bt upland soil horizons of S2 (Tracy, 1997).

Sander (1971) carried out a local groundwater geology study from 1967 to 1969, which included a fully penetrating well for an aquifer pumping test (water transmissivity) and descriptions of geologic material, seismic refraction, resistivity, and residual Bouger gravity anomalies. Samples of surface and deep sand were collected in late September 2004 at 11 locations surrounding the S2 watershed to help differentiate between Rainy and Des Moines drift; both wet and dry soil color chips and hand textures were used.

Late Wisconsin Glaciation

Glacial Advances, Stable Margins, and Meltout over Stagnant Ice

Rainy/Itasca Lobe ice (from the north and northeast) stagnated north of the Itasca Moraine (lying along an east-west band near the southern shore of Leech Lake in north-central Minnesota; 100 km SW of MEF) after 18,000 calibrated years (cal y) BP. However, the Rainy/Itasca ice established stable margins northeast of Leech Lake about 3 km east of S2 bog (a north-south-oriented margin of the Rainy Lobe), and about 15 km to the north (an east-west-oriented margin of the Itasca Lobe). The ice sheet terminated at this stable margin for several thousand years. Meltwater and sediment released from the ice accumulated on the stagnant ice surface north and east of S2 bog, forming a large outwash fan.

Stagnant ice to the west and south of S2 bog melted over several thousand years, forming a topographic low. About 14,000 cal y BP, ice of the Des Moines Lobe advanced through this low from east to west along an axis extending through Grand Rapids, Minnesota and the large Lake Winnibigoshish
WSW of MEF. The northern margin of this advance, the St. Louis Sublobe, abutted against the Rainy/Itasca Lobe outwash fan about 15 km southwest of the S2 bog.

Meltwater and sediment then poured onto stagnant ice in the triangle-shaped, topographically low area bounded by the Itasca Lobe to the north, the Rainy Lobe to the east, and the St. Louis sublobe to the southwest. Meltwater escaped from the low area by means of a subglacial drainage channel passing through the Giant’s Range near present-day Taconite, Minnesota. While the advance of the St. Louis Sublobe was short-lived, and its ice rapidly stagnated and melted, its advance allowed about 15 m of glaciofluvial and glaciolacustrine sediment to accumulate over stagnant ice at the S2 bog site.

After 13,000 cal y BP, the Rainy and Itasca Lobes retreated further to the north. Glaciofluvial sediment no longer accumulated at the S2 site but stagnant ice cored the topography (lay buried in the sediment) for thousands of years (to as late as about 11,000 cal y BP). As the buried ice melted gradually the overlying sediment slowly collapsed. Sediment slumped from high areas, accumulating in low areas. As the last ice melted, the sediment-filled areas remained as hills, while the relatively sediment-poor formerly high areas had collapsed to form depressions (kettles), one of which was the precursor to S2.

Concurrent with meltout of the last buried ice, large glacial lakes formed to the west and north of S2, most notably Lake Agassiz and its precursor Lake Koochiching. As the levels of these lakes fluctuated and finally drained, large areas of unvegetated lake bottom were exposed to wind erosion. Silt and very fine sand sediment eroded from the lake bottom and entrained by the prevailing westerly winds was deposited as a blanket of loess on the landscape to the south and east, including S2.

Sander (1971) describes sands beneath the till cap at S2 as brown. In addition, Rainy (reddish brown) and St. Louis Sublobe (yellowish brown) drifts are in the MEF area. The younger St. Louis Sublobe drift overlies the older Rainy drift in much of north-central Minnesota. Although the S2 watershed is overlain by a till cap of Koochiching drift origin, 11 samples of sand drift around the S2 watershed show a tongue of Rainy drift with no St. Louis drift. Sample sites with Rainy drift extend from at least 2.4 km north-northeast of the S2 watershed to 0.6 km south-southwest in a tongue about 0.6 km wide. The Rainy drift is overlain by St. Louis Sublobe drift in areas to the north, west, and south. The Rainy drift samples have a soil color description of 5YR 6/6 (dry) and 5YR 5/8 (wet) while the St. Louis Sublobe drift samples have a soil color description of 10YR 7/2 (dry and wet). The Rainy drift color is described as orange to bright reddish brown, while the St. Louis Sublobe drift is described as dull yellow orange. The Rainy sands are coarse, medium, and fine textured with few small-gravel pebbles while the Des Moines sands are coarse, medium to fine with a wide range of gravel and small cobble.

Table 4.1 lists the geologic materials documented at the MEF (Sander, 1971) and two possible interpretations of their drift origin (Meyer, 1986; Mooers,
<table>
<thead>
<tr>
<th>Geologic Material at the MEF or Near the S2 Bog</th>
<th>Elevation (m)</th>
<th>Mooers et al. Interpretation of Source Area</th>
<th>Mooers et al. Interpretation of Dates BP (ka)</th>
<th>Meyer et al. Interpretation of Source Area</th>
<th>Meyer et al. Interpretation of Dates BP (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Vermillion Phase drift at MEF</td>
<td></td>
<td>Rainy Lobe</td>
<td>12.3</td>
<td>Koochiching Lobe</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vermillion Phase</td>
<td></td>
<td>Riding Mtn. Prov.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
<td>Keewatin Center</td>
<td></td>
</tr>
<tr>
<td></td>
<td>429</td>
<td>Red R-Kooch. Lobe</td>
<td>11.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Riding Mtn. Prov.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>424</td>
<td>Keewatin Center</td>
<td>12.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Keewatin Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown Sand, fine to medium sands, with slight streaks of clay near the top, and some coarse sand with up to 13-mm pebbles near the bottom; noncalcareous</td>
<td>424</td>
<td>Rainy Lobe</td>
<td>13.2</td>
<td>Rainy Lobe</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bemis Phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>North-central Ontario</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>395</td>
<td></td>
<td>14</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brown sand, medium to coarse sand with few pebbles up to 13-mm in top 1.0 m and bottom 1.2 m; noncalcareous</td>
<td>395</td>
<td>Rainy Lobe</td>
<td>15</td>
<td>Rainy Lobe</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>St. Croix Phase</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West of James Bay</td>
<td>17.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>391</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inasa Lobe Outwash</td>
<td>18</td>
<td>Rainy Lobe</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hudson Provenance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West Hudson Bay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>387</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(continued)
TABLE 4.1 (continued)
Geologic Materials Documented at the MEF (Shaded), Others in the Region, and Alternative Interpretations of Wisconsin Glaciation using Information from Mooers and Lehr (1997) or Meyer et al. (1986)

<table>
<thead>
<tr>
<th>Geologic Material at the MEF or Near the S2 Bog</th>
<th>Elevation (m)</th>
<th>Mooers et al. Interpretation of Source Area</th>
<th>Mooers et al. Interpretation of Dates BP (ka)</th>
<th>Meyer et al. Interpretation of Source Area</th>
<th>Meyer et al. Interpretation of Dates BP (ka)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray till, compacted clay, sand, silt, pebbles and limestone fragments up to 13 mm in diameter</td>
<td>387</td>
<td>Itasca Lobe</td>
<td>20</td>
<td>Winnipeg Lobe</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hudson Provenance</td>
<td></td>
<td>Browerville Phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
<td>Keeawatin Center</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>West Hudson Bay</td>
<td></td>
<td>from the NNW</td>
<td></td>
</tr>
<tr>
<td></td>
<td>380</td>
<td></td>
<td>(Pre-Late Wisc.)</td>
<td>30?</td>
<td></td>
</tr>
<tr>
<td>Greenstone and granite bedrock</td>
<td>380</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other early Late-Wisconsin and pre Late-Wisconsin glacial drifts were not documented at the MEF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbonate (&lt;25%) and graywacke clasts called “Omars” (Mooers and Lehr, 1997)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainy Lobe</td>
<td></td>
<td></td>
<td></td>
<td>Rainy Lobe</td>
<td></td>
</tr>
<tr>
<td>Hewitt Phase</td>
<td></td>
<td></td>
<td></td>
<td>Hewitt Phase</td>
<td></td>
</tr>
<tr>
<td>Labrador Center</td>
<td></td>
<td></td>
<td></td>
<td>Labrador Center</td>
<td></td>
</tr>
<tr>
<td>East Hudson Bay</td>
<td></td>
<td></td>
<td></td>
<td>Wagner Lobe</td>
<td></td>
</tr>
<tr>
<td>Winnipeg Lobe</td>
<td></td>
<td></td>
<td></td>
<td>Browerville Phase</td>
<td></td>
</tr>
<tr>
<td>Browerville Phase</td>
<td></td>
<td></td>
<td></td>
<td>Keeawatin Center</td>
<td></td>
</tr>
<tr>
<td>Keeawatin Center</td>
<td></td>
<td></td>
<td></td>
<td>from the NNW</td>
<td></td>
</tr>
<tr>
<td>Silty clay, silty fine sand, coarse sand at base; gravel, cobbles and boulders, greenish gray, clay noncalcareous to moderately calcareous; rocky, hard, and compact. Alternates with Winnipeg Lobe (Meyer et al., 1986)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Elevations and dates are listed for the top and bottom of each major material described.
FIGURE 4.6
Longitudinal cross section of the S2 watershed (WNW to ESE) showing age and depth of major geologic and soil materials and the position of the bog and regional water tables during contemporary times. Note the slightly domed peat surface and parallel peatland water table. Vertical arrows are deep well locations.

1990; Mooers and Dobbs, 1993; Meyer, 1997; Mooers and Lehr, 1997; Mooers and Norton, 1997; Meyer et al., 1998). Figure 4.6 is a descriptive cross section drawn longitudinally through S2 bog and the entire S2 watershed using our interpretations based on various works of Mooers. It includes a surface deposit of loess and glacial flour at the bottom of the ice-block depression.

Beneath S2 Bog

The limestone fragments in the Itasca Lobe drift are the source of high calcium concentrations in groundwater (>20 mg L⁻¹) discharging from aquifers in the overlying Rainy Lobe sand into area streams and lakes. Rainy Lobe sands are brown and lack calcium carbonate except near the upper boundary where more recent slightly calcareous till overlies it.

Koochiching till caps the deep sandy drift of the Rainy Lobe, covering more than 75% of the MEF and ranging in thickness from 3 to 5 m; it was not covered with glacial meltwater or ice. An additional 20–30 cm of eolian loess was deposited over both the till cap and sandy drift. The loess is fine sandy loam in texture. It blew from the dry hills exposed after meltback of the ice (Nyberg, 1987). Beneath the bog peat the Koochiching till surface is mostly glacial flour formed directly beneath the grinding ice sheet, or washed into the tundra pond, beginning about 11,900 years ago.
Ice-Block Depression

The surface below the S2 bog is a muted contour of the original ice-block depression and hides much of the detail needed to explain the sequence of events resulting in the basin's current shape (Figure 4.7). The bottom contour is not the original ice-block depression, but the contour of the Koochiching till collapsed into an ice-block cavity in the underlying Rainy outwash. Nevertheless, it reveals the track of the original ice block (from the Rainy ice sheet) being dragged, pushed, and finally over-ridden by its mother sheet into the Rainy sands below.

It began when a wedge of ice broke from the leading edge of the Rainy Lobe glacier and rested near the outlet of S2, where the stream is today. It was perhaps 50 m wide at its base, 100 m wide at its top, and at least 20 m tall. We estimated its size from the width of the depression in the Rainy Lobe drift (Figure 4.6). It was a small block of ice compared to the enormous Laurentide ice sheet that rose 2,200 m into the air at maximum development some 18,000 years ago near its eastern Hudson Bay maximum. However, when the block broke away, perhaps 13,000 years ago, the ice was much thinner. There were tens of thousands of these ice-block depressions across the Lake States, New England, and the Canadian Provinces, giving rise to kettle (pothole) topography throughout.

![Contour Map of S2 Bog and周边地区](image)  
**FIGURE 4.7**  
Contours at 1 m intervals of the uplands surface and the Koochiching drift that lies below the peatland in the S2 watershed.
Revealing Sequence of Soil Horizons at Lagg Edge

A physical basis for chemical, hydrologic, and plant-biodiversity characteristics in the lagg is revealed when we interpret the story of horizons in a large soil pit near the east (or right) side of bog S2 (Figure 4.8). A deeper section showing the entire bog (see Figure 4.10) also uses our local climate interpretations to explain the accumulations of peat types within the S2 peatland.

Holocene Vegetation

Gross Composition of Core Segments

Figure 4.9 shows the gross composition of the long core from the S2 bog and indicates the slices examined for pollen and macrofossils. Relatively high bulk densities at the bottom reflect mineral entrainment in the algal gyttja on the now-filled lake bottom; low bulk densities at the top reflect the uncompacted Sphagnum, Ericaceae shrubs stems, and Carex roots in the acrotelm (active surface layer).
Dating of Core Segments and Peat Accumulation Rates

Eight 5 cm segments of the long core (MR28307) and one segment of the short core (MR29401) were radiocarbon dated and calibrated (Table 4.2). Calibrated year dates BP are plotted in Figure 4.10. The charcoal layer signifying post-fire establishment of the existing black spruce stand is dated at 1865 calendar year using tree rings.

Calendar years 1864 and 1810 are shown at a depth of 75 cm at the strong charcoal layer located there. The divergence between the long and short core also may reflect the loss of peat in fires (Figure 4.10). Prescribed fire in other peatlands at MEF have consumed 6–10 cm of peat; it is likely that hot fires during droughts can consume at least 15 cm of peat. The years 1863 and 1864 were two of the driest on record at St. Paul, MN; only 400 mm of annual precipitation fell in each year (Meyer, 1944). Fire likely burned the surface of the
### TABLE 4.2
Calibrated Dates for Long-Core and Short-Core-Samples at the S2 Bog

<table>
<thead>
<tr>
<th>Sample</th>
<th>Depth of Top (cm)</th>
<th>Depth of Bottom (cm)</th>
<th>Radiocarbon Date (y BP)</th>
<th>Radiocarbon Error (y BP)</th>
<th>Calibrated Date, Initial Intercep (y BP)</th>
<th>Calibrated Date, -28 (y BP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MR28507A</td>
<td>-100</td>
<td>-3</td>
<td>1,860</td>
<td>60</td>
<td>1,567</td>
<td>1,567</td>
</tr>
<tr>
<td>MR28507B</td>
<td>-200</td>
<td>-205</td>
<td>1,870</td>
<td>70</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507C</td>
<td>-300</td>
<td>-305</td>
<td>1,870</td>
<td>69</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507D</td>
<td>-400</td>
<td>-305</td>
<td>1,870</td>
<td>70</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507E</td>
<td>-500</td>
<td>-305</td>
<td>1,870</td>
<td>65</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507F</td>
<td>-600</td>
<td>-305</td>
<td>1,870</td>
<td>70</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507G</td>
<td>-700</td>
<td>-305</td>
<td>1,870</td>
<td>70</td>
<td>1,554</td>
<td>1,554</td>
</tr>
<tr>
<td>MR28507H</td>
<td>-800</td>
<td>-305</td>
<td>1,870</td>
<td>70</td>
<td>1,554</td>
<td>1,554</td>
</tr>
</tbody>
</table>

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S2 bog in the autumn of 1864. Seed within the surface peat or from surrounding unburned or standing burned black spruce on the peatland germinated in 1865. Tree cores on S2 show a 20 year range in dominant tree ages, suggesting a fully stocked stand by 1885.

The mass of peat accumulated (above the algal gyttja at a date of 9245 cal y BP) to the surface is 56.2 g m\(^{-2}\) y\(^{-1}\) (29.2 g C m\(^{-2}\) y\(^{-1}\)) is close to the overall rate for northern peatlands of 29 g C m\(^{-2}\) y\(^{-1}\) as calculated by Gorham (1991) (Figure 4.11). Accumulation rates from 18 cores in northern North America range from 16 to 80 g m\(^{-2}\) y\(^{-1}\) (8–41 g C cm\(^{-2}\) y\(^{-1}\)), and 12 sites within the Red Lake Peatland located 160 km northwest of the MEF are relatively high at 50–100 g m\(^{-2}\) y\(^{-1}\) (26–52 g C cm\(^{-2}\) y\(^{-1}\)). The Red Lake peatland sites developed over upwelling groundwater (Siegel and Glasser, 1987). Accumulation rates at the S2 bog are similar for all of the periods between dating ages except for the period 6000–7300 cal y BP, which accumulated carbon at the rate of 67 g C m\(^{-2}\) y\(^{-1}\).

**Major Changes in Upland Trees**

Figure 4.12 shows pollen occurrence for upland trees and shrubs, upland herbs and ferns, wetland trees and shrubs, and aquatic plants. Four major
Vegetation associations are shown based on upland trees. The first association, 11,000–9,500 cal y BP, is dominated by *Picea*, which makes up 75%–30% of the segment volume. At the same time, *Pinus resinosa/Pinus banksiana* (red and jack pine) increases from 15% to 35% of the segment volume. A similar tree mixture at Steel Lake 106 km southwest of the MEF began its decline of *Picea* in favor of *Pinus resinosa/Pinus banksiana* at 11,200 and made the transition to *P. resinosa/P. banksiana* by 11,000 cal y BP as the climate became too warm and dry for *Picea* (Wright et al., 2004). At the MEF, the beginning of this decline is beyond the core depth, but the transition to the period dominated by *P. resinosa/P. banksiana* did not occur until 9500 cal y BP, some 1500 years later. Between 9500 and 6500 cal y BP, *P. resinosa/P. banksiana* dominates the segment volumes (~40%) for 3000 years. Beginning at 6500 cal y BP, *Pinus sylvestris* (white pine) rises and dominates the pollen volume at 40% while *P. resinosa/P. banksiana* recedes to about 20% of the segment volume.

**Major Changes in Wetland Vegetation**

An examination of macrofossils with depth in the peat-core segments suggests seven vegetation phases in the S2 wetland (Figures 4.13 and 4.14). Changes in wetland vegetation occur more frequently and do not coincide with changes in upland vegetation (Figure 4.12).
Peatland Biogeochemistry and Watershed Hydrology

FIGURE 4.12

Pollen occurrence (percent of sample volume) in the long core from the S2 bog. Location of radiocarbon-dated (calibrated) core slices are shown on the x-axis.
**Geology, Vegetation, and Hydrology of the S2 Bog at the MEF**

![Graph showing geology, vegetation, and hydrology of the S2 Bog at the MEF]

**FIGURE 4.13**
*Sphagnum* and other mosses in the peat core of the S2 bog.

---

**Discussion of Findings**

**11,900–11,800 Years BP**

During the initial formation of a shallow pond, the Koochiching drift sank into the water-filled ice-block depression that eventually would become a small lake at the S2 bog site. The water level in the small lake began this period at an elevation of 422 m (near the top of the Koochiching till on the upland) and then dropped as the till sank to 420.2 m (see Figure 4.8 at the extent of the eolian deposit). Above the till, sediment of glacial flour and algal remains were slowly deposited. Algae are the only plant residues represented in both the bottom gyttja of the long core (MR2-8307) and in the
FIGURE 4.14
Major vegetation phases in the ice-block depression of S2 that filled with water and peat.

TABLE 4.3
Texture at the Organic-Mineral Interface at the Deepest Location in the S2 Depression

<table>
<thead>
<tr>
<th>Elevation in (m)</th>
<th>Material Description</th>
<th>OM (%)</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>416.7-416.5</td>
<td>Sapropeat and coprogenous gyttja</td>
<td>38</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>416.5-425.8</td>
<td>Silty clay loam</td>
<td>18</td>
<td>4</td>
<td>60</td>
<td>26</td>
</tr>
<tr>
<td>415.8-415.5</td>
<td>Silt loam</td>
<td>3</td>
<td>17</td>
<td>59</td>
<td>25</td>
</tr>
<tr>
<td>415.5-414.7</td>
<td>Loam</td>
<td>3</td>
<td>45</td>
<td>35</td>
<td>20</td>
</tr>
<tr>
<td>414.7-414.4</td>
<td>Loam</td>
<td>2</td>
<td>42</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>414.4-414.3</td>
<td>Clay loam</td>
<td>2</td>
<td>33</td>
<td>37</td>
<td>30</td>
</tr>
</tbody>
</table>


Note: This bucket auger hole is deeper than the length of the long core shown in Figure 4.10.

The auger hole sampled in the deepest part of the depression (Brooks and Kreft, 1991). Below the gyttja, the first 2.2 m into the Koochiching till, at the deepest part of the depression, averages 2% organic matter, 34% sand, 42% silt, and 23% clay (Table 4.3). Diameters in the sand fraction are fine to very fine (0.12-0.06 mm in diameter) and sand-particle edges under magnification are rounded indicating an eolian origin.
Geology, Vegetation, and Hydrology of the S2 Bog at the MEF

11,800–9,200 Years BP

The sedimentary profiles illustrate this period as a major zone of brown moss (Warnstorfia fluitans) near the base of the peat core, corresponding to Lacustrine Period II (10,900–9,200 cal y BP; Figures 4.13 and 4.14). The water level in the small lake dropped during this period as successively lower outlets to Lake Superior developed (Teller and Leverington, 2004). Perhaps the drop was slow at first as Figure 4.8 shows a possible wave-cut shelf in the Kociching till at an elevation of 420 m. At 9200 y BP, the water level in the S2 depression had dropped a total of 6 m to the 414 m elevation. The southeast shore of glacial Lake Agassiz was 135 km north of S2 at 10,000 cal y BP, and 4,500 km north of S2 at 9,000 cal y BP (Viau et al., 2006).

Schwalb and Dean (2002) showed a drop in water levels at Williams and Shingobee Lakes 120 km SE of the MEF near the prairie boundary beginning at 9800 and extending to 7700 y BP (further lowering of lake levels occurred up to 5000 y BP). Donovan et al. (2002) showed that even in the droughts of the twentieth century, groundwater levels could drop by as much as 5 m in west-central Minnesota. Digerfeldt et al. (1992) reconstructed a drop in lake levels of 3–6 m at the Parkers Prairie sandplain in west-central Minnesota and Filip et al. (2002) reconstructed a drop in water level of 3.5 m in Williams Lake. The S2 bog is located only 3 km from the subcontinental divide (Hudson Bay, Mississippi Basins), so a drop in water level of 6 m from 11,000 to 9,200 cal y BP was possible (Figure 4.14).

The aquatic moss W. fluitans flourished during the end of this period (several centuries) when the water level was near 416 m. This species is the most acidophilous among its congeners (Hedenäs, 2003; Hedenäs and Kooijman, 1996) and among most of the “brown mosses” typically found in more minerotrophic peatland mesohabitats. The water chemistry of the lake likely was more akin to today’s upland subsurface or surface runoff than to the groundwater chemistry (Table 4.4) during this early period when the elevation of regional water tables ranged from 420 to 416 m.

The Lacustrine Period (11,900–9,200 y BP) included the aquatic mosses (Figure 4.13) but also floating-leaved and emergent aquatic plants: Nuphar, Potamogeton, Brasenia, Sagittaria, Sparganium, and Typha (Figure 4.12). Black ash (Fraxinus nigra) in shallow depressions and swales were at their Holocene climax during this initial tundra setting; their pollen accounted for 14% of the pollen sum. Salix (willow) also reached its Holocene maximum (6%) in this early lake period, as did Larix (eastern larch), but it accounted for less than 2% of the pollen sum. Two members of the Cupressaceae family, Thuja and Juniperus, represent less than 1% of the pollen but they too were at their Holocene maximum. Thuja likely is Thuja occidentalis (northern white cedar), which is well suited to wet and calcareous habitats. Juniperus probably is the shrubby, circumpolar Juniperus communis (common juniper) now common in northeastern and northwestern United States and Canada, and/or Juniperus virginiana (eastern redcedar) growing on cold dry ridge tops.
### Peatland Biogeochemistry and Watershed Hydrology

#### TABLE 4.4
Water Chemistry at Major Locations in the S2 Watershed on the MEF

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Deep Groundwater, Number of Samples</th>
<th>Deep Groundwater, Mean</th>
<th>Deep Groundwater, Standard Deviation</th>
<th>Upland Subsurface Runoff, Number of Samples</th>
<th>Upland Subsurface Runoff, Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td></td>
<td>76</td>
<td>7.43</td>
<td>0.29</td>
<td>496</td>
<td>6.28</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>ppm/L</td>
<td>73</td>
<td>3144</td>
<td>314</td>
<td>484</td>
<td>62</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/L</td>
<td>74</td>
<td>41.60</td>
<td>2.65</td>
<td>486</td>
<td>3.44</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/L</td>
<td>74</td>
<td>7.62</td>
<td>0.70</td>
<td>486</td>
<td>1.04</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/L</td>
<td>74</td>
<td>3.62</td>
<td>0.75</td>
<td>485</td>
<td>1.15</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/L</td>
<td>74</td>
<td>1.31</td>
<td>0.21</td>
<td>486</td>
<td>0.89</td>
</tr>
<tr>
<td>Ammonium-N</td>
<td>mg/L</td>
<td>69</td>
<td>0.08</td>
<td>0.07</td>
<td>418</td>
<td>0.05</td>
</tr>
<tr>
<td>Nitrate-N</td>
<td>mg/L</td>
<td>44</td>
<td>0.06</td>
<td>0.04</td>
<td>351</td>
<td>0.12</td>
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<tr>
<td>Sulfate</td>
<td>mg/L</td>
<td>73</td>
<td>3.13</td>
<td>1.03</td>
<td>485</td>
<td>2.56</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/L</td>
<td>73</td>
<td>1.03</td>
<td>0.47</td>
<td>467</td>
<td>0.49</td>
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<tr>
<td>Total phosphorus</td>
<td>mg/L</td>
<td>45</td>
<td>0.04</td>
<td>0.01</td>
<td>355</td>
<td>0.06</td>
</tr>
<tr>
<td>Phosphate-P</td>
<td>mg/L</td>
<td>54</td>
<td>0.017</td>
<td>0.006</td>
<td>395</td>
<td>0.042</td>
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<tr>
<td>Total organic carbon</td>
<td>mg/L</td>
<td>36</td>
<td>6.20</td>
<td>3.38</td>
<td>416</td>
<td>22.45</td>
</tr>
<tr>
<td>Total Kjeldahl nitrogen</td>
<td>mg/L</td>
<td>56</td>
<td>0.27</td>
<td>0.11</td>
<td>393</td>
<td>0.58</td>
</tr>
<tr>
<td>Carbon:nitrogen</td>
<td>Ratio</td>
<td>Ave.</td>
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<td>—</td>
<td>—</td>
<td>38.7</td>
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<tr>
<td>Aluminum</td>
<td>mg/L</td>
<td>28</td>
<td>0.18</td>
<td>0.01</td>
<td>245</td>
<td>0.77</td>
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<tr>
<td>Iron</td>
<td>mg/L</td>
<td>61</td>
<td>3.12</td>
<td>4.77</td>
<td>412</td>
<td>0.60</td>
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<tr>
<td>Manganese</td>
<td>mg/L</td>
<td>25</td>
<td>1.38</td>
<td>0.01</td>
<td>254</td>
<td>0.03</td>
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<tr>
<td>Copper</td>
<td>mg/L</td>
<td>1</td>
<td>0.03</td>
<td>—</td>
<td>17</td>
<td>0.06</td>
</tr>
<tr>
<td>Zinc</td>
<td>mg/L</td>
<td>25</td>
<td>13.24</td>
<td>2.87</td>
<td>234</td>
<td>0.29</td>
</tr>
</tbody>
</table>

*Note:*

- b. Zinc levels are elevated by galvanized plot borders or galvanized well pipe.
<table>
<thead>
<tr>
<th>Upland Subsurface Runoff, Standard Deviation</th>
<th>Upland Subsurface Runoff, Number of Samples</th>
<th>Upland Subsurface Runoff, Mean</th>
<th>Upland Subsurface Runoff, Standard Deviation</th>
<th>Streamflow, Number of Samples</th>
<th>Streamflow, Mean</th>
<th>Streamflow, Standard Deviation</th>
<th>Mean Precipitation</th>
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<td>0.45</td>
<td>376</td>
<td>6.64</td>
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<td>118</td>
<td>4.07</td>
<td>0.22</td>
<td>5.06</td>
</tr>
<tr>
<td>70</td>
<td>376</td>
<td>222</td>
<td>191</td>
<td>14</td>
<td>-73</td>
<td>54</td>
<td>—</td>
</tr>
<tr>
<td>1.00</td>
<td>366</td>
<td>5.56</td>
<td>2.24</td>
<td>116</td>
<td>2.32</td>
<td>0.87</td>
<td>0.20</td>
</tr>
<tr>
<td>0.29</td>
<td>366</td>
<td>1.27</td>
<td>0.54</td>
<td>116</td>
<td>0.83</td>
<td>0.31</td>
<td>0.03</td>
</tr>
<tr>
<td>0.52</td>
<td>365</td>
<td>0.38</td>
<td>0.29</td>
<td>115</td>
<td>0.53</td>
<td>0.21</td>
<td>0.07</td>
</tr>
<tr>
<td>0.74</td>
<td>366</td>
<td>4.92</td>
<td>3.61</td>
<td>116</td>
<td>0.92</td>
<td>0.64</td>
<td>0.04</td>
</tr>
<tr>
<td>0.10</td>
<td>349</td>
<td>0.30</td>
<td>0.58</td>
<td>109</td>
<td>0.14</td>
<td>0.21</td>
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<tr>
<td>0.21</td>
<td>364</td>
<td>1.14</td>
<td>2.47</td>
<td>96</td>
<td>0.13</td>
<td>0.28</td>
<td>1.05</td>
</tr>
<tr>
<td>2.43</td>
<td>367</td>
<td>2.04</td>
<td>2.03</td>
<td>114</td>
<td>1.22</td>
<td>2.41</td>
<td>1.03</td>
</tr>
<tr>
<td>4.07</td>
<td>361</td>
<td>0.93</td>
<td>1.43</td>
<td>111</td>
<td>0.41</td>
<td>0.26</td>
<td>0.08</td>
</tr>
<tr>
<td>0.14</td>
<td>285</td>
<td>0.41</td>
<td>0.85</td>
<td>85</td>
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<tr>
<td>0.12</td>
<td>308</td>
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<td>13.35</td>
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<td>43.3</td>
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<tr>
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<td>137</td>
<td>0.3</td>
<td>0.19</td>
<td>50</td>
<td>0.64</td>
<td>0.31</td>
<td>—</td>
</tr>
<tr>
<td>0.42</td>
<td>296</td>
<td>0.21</td>
<td>0.25</td>
<td>98</td>
<td>1.14</td>
<td>0.71</td>
<td>—</td>
</tr>
<tr>
<td>0.78</td>
<td>127</td>
<td>0.03</td>
<td>0.07</td>
<td>46</td>
<td>0.05</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>0.05</td>
<td>7</td>
<td>0.09</td>
<td>0.13</td>
<td>11</td>
<td>0.05</td>
<td>0.05</td>
<td>—</td>
</tr>
<tr>
<td>1.08</td>
<td>127</td>
<td>4.89p</td>
<td>3.46</td>
<td>46</td>
<td>0.13</td>
<td>0.66</td>
<td>—</td>
</tr>
</tbody>
</table>
Betula (birch) and undifferentiated Populus then, as now, were early invaders of disturbed landscapes (about 15% of the pollen sum). Oak (Quercus) and elm (Ulmus) were earlier invaders in smaller numbers (5% of the pollen sum). These may be associated with broad glacial river corridors assuming that the Quercus had a greater representation of white oaks (Quercus alba and Quercus macrocarpa) typical today on bottomlands and deep, well-drained, moist sites (Harlow and Harrar, 1958). The more abundant northern red oak (Quercus rubra), found today in association with sugar maple and white pine (and moister red pine sites), is typical of temperate forests on sandy loams and silty clay loams. The common upland trees were red and jack pine (P. resinosa/P. banksiana) beginning with pollen in 15% of the core volume and expanding rapidly to 42% of core volume by 9200 y BP.

Immediately after ice melt spruce (Picea), presumably both black (P. mariana) and white (Picea glauca), dominated the area with pollen in 75% of the pollen sum. This was reduced to 10% at the end of Lacustrine Period I (9200 BP) and remained below 2% until an intense fire in 1864 burned the peatland and, following harvest of white pine, P. mariana once again exceeded over 50%.

Balsam fir (Abies balsamea) was a minor component of the upland forest during the early lake period and remained under 5% of the pollen sum until immigrant harvest of the white pine in the late 1800s. The upland hazel shrubs (Corylus americana and Corylus rostrata) were early and persistent forest components, always occurring at 1%-2%. At the wet edges of the lake and shallow depressions within the upland, speckled alder (Alnus rugosa) was the only wetland shrub.

The upland was not a continuous forest as evidenced by the grass (Poaceae) and horsetail (Equisetum) pollen, which accounted for more than 10% of the core volume. Other upland herbs invading the glacial melt exposures included goosefoot (Chenopodiaceae), aster (Asteraceae), ragweed (Ambrosia), amaranth (Amaranthaceae), and wormwood (Artemisia).

The entire Lacustrine Phase shown in the pollen record (Figure 4.14) suggests a widespread, large, and presumably gradual decline in the regional water table from 11,000 to 9,200 y BP. This is evidenced by decreases in tree pollen characteristic of wetter sites: Picea, Thuja, Fraxinus, and Abies, and increases in drier-site pines: P. resinosa/P. banksiana in particular but also small increases in the temperate and mesic P. strobus. Concomitant decreases in Betula and Populus may record early colonization by species adapted to a wide range of moisture regimes followed by declines owing to competition from the invading pines. Reductions in upland herb and fern pollen are strong and may reflect large forest areas nearing crown closure.

9200–8400 5Years BP

Water levels during this period remained at a pond-surface elevation of about 416m. Calliergon trifarium, another aquatic brown moss, joined and succeeded by W. fluitans in what now were two small ponds, perhaps thinly
joined, and then smothered by an emergent bryophyte mat at the water surface (see 416 and 417 contours in Figures 4.13 and 4.14). Pollen of submerged aquatics declined (Brasenia 4.9%–0%, Nuphar 4.9%–0.2%, Potamogeton 2.4%–0%), as did that of emergent aquatics (Cyperaceae 12.2%–0.6%, Sagittaria 2.4%–0%, Sparganium/Typha angustifolium 2.4%–0%).

The Rich-Fen Bryophyte Mat period is the shortest, only 800 years, C. trifarium peaked about 300 years into the period and appeared late in the Rich-Fen Phase. Sedges flourished in the next 500 years, poking through the bryophyte mat reaching their Holocene maximum. They persisted at 5%–10% of the pollen count for millennia until the latter part of the poor-fen period.

Wetlands with trees have sufficient drainage to a surface outlet to provide both air and water for growth in the near surface pore space. Wetlands without surface outlets collect water and retain it, giving rise to higher water levels and either sedge or shrub habitats (Verry, 2000). In the landlocked ponds at the bottom of S2, the floating plants Brasenia (water-shield) and Potamogeton (pondweed), increased. Most characteristically for the pond gyttja, C. trifarium smothered the surfce and formed peat (Figure 4.13).

The bryophyte mat period reveals a landscape with dry uplands, aquatic moss, and sedge wetlands (mildly calcareous) with little drainage, and minor increases in treed wetlands with sufficient surface drainage to a small stream. The next major pollen reconstruction period (rich-fen sedge 8400–5500 cal y BP) reveals a drier period with longer summers when the local region reached its climatic optimum.

8400–5500 Years BP

A rich-fen sedge peat characterized this period. The peatland had a water pH of about 8 and associated calcium and magnesium values were near the high end of the groundwater chemistry dataset in Table 4.4 as inferred from plant species (Vitt et al., 1995). Early in the Rich-Fen period, the first identifiable Sphagnum species, the aquatic Sphagnum papyphyllum (an alkaline species), appeared (Figure 4.13). Sometimes known as Sphagnum subsecundum var. papyphyllum it grows in mineral-rich, open habitats in sedge mats marginal to eutrophic lakes and in the hollows of sedge fens (Crum, 1988). Also consistent with a calcium-rich environment is the first appearance of Warnstorfia exannulata and additional mats of C. trifarium late in the period (Figure 4.13). Toward and beyond the end of the rich-fen period, the pollen of Ambrosia, Artemisia, and Chenopodiaceae/Amaranthaceae peaked between 7000 and 6000 y BP.

The MEF pollen record reveals an apparent warming and drying period during this transition from the Pleistocene to the Holocene. Over this early Aquatic Moss Phase there is a major reduction in the Picea pollen count representing cool/wet sites from 11,000 to 9,300 y BP (75%–5%, Figure 4.13). By contrast, P. resinosa/P. banksiana pollen count representative of warm/dry sites rises from 15% to 40% (Figure 4.14). Upland herbs and ferns also
significantly decrease during this period (35%–15%) suggesting a forest succession explanation as well as an increasing amount of *P. resinosa/P. banksiana* invading the eolian and outwash sands on uplands.

The *P. resinosa/banksiana* pollen data at the MEF suggest that a warm/dry period achieved by 9200 cal y BP lasted until 6500 cal y BP. The next 500 years saw a transition to a cooler/wetter climate favoring *P. strobus* with pollen counts rising from 2% to 30% over the warmer/drier climate that favors *P. resinosa/P. banksiana* when pollen counts fell from 40% to 12% (Figure 4.12).

There is an “acid anomaly” during this high pH period: *Sphagnum* section *Cuspidata* sp. occurs in 1.5% of the core pollen/spore count at a depth of 400 cm (Figure 4.13) and an elevation of 418.5 m. *Sphagnum* section *Cuspidata* sp. is rare in the Great Lakes Region, where it occurs as a submerged moss growing at the margins of acid lakes (Crum, 1988). The occurrence of this acidophilous, aquatic *Sphagnum* with the alkaliophilous aquatic moss *C. trifarium* is curious. The 400 cm depth corresponds to 6000 cal y BP. The occurrence of *Sphagnum* section *Cuspidata* sp. is sandwiched in a bulk core description showing ligneous peat below it and aquatic mosses above it (Figure 4.13). Though relatively rare, thin acid bands of peat (pH 2.7–3.5) have been reported within alkaline peat profiles in Minnesota (Alvaris, 1920), Michigan (Davis and Lucas, 1959), and Poland (Okruszkko, 1960). Acidity in organic soils is accounted for by the presence of organic compounds, exchangeable H, iron sulfide, and silicic acid. It is believed that these thin acid layers are formed under conditions similar to “cat clays” (cation clays) found in brackish coastal waters (Davis and Lucas, 1959). In these instances, the roots of reeds may contain as much as 3% sulfur in the form of bisulfides. When oxidized sulfuric acid is formed along with scattered crystals of calcium sulfate. The acid layer at the S2 peatland occurs at an elevation of 418.5 m, just about half meter above two deep pools in the bottom of S2 (Figure 4.14). It may be that the high lignin sedges accumulated on the shelf between the two pools (roughly the area between the 418 and 419 m contour lines in Figure 4.7). They also may be high in sulfur and during a period of high summer temperatures, relatively low rainfall, and low lake levels in the northern hemisphere oxidized to produce a thin acid layer in the otherwise alkaline peat.

How did calcium-rich groundwater rise into the S2 depression during the rich-fen, sedge-dominated period? First, the hydraulic conductivity of the Koochiching till, though extremely low (5 × 10⁻⁷ cm s⁻¹), is sufficient to allow regional groundwater to enter and exit the peat depression slowly over long periods. The hydraulic conductivity of the unweathered, silty clay layer (glacial flour) is even lower (1 × 10⁻⁸ cm s⁻¹), but over centuries can pass small amounts of water. Second, the hydraulic head on the regional water table at the S2 depression derives from the subcontinental divide 3 km north, where the contemporary water table elevation peaks near 418 m and fluctuates down to 417 m. The same regional water table range at the S2 depression is 414.8–413.8 m. In other words, the 4 m head drop over 3 km allows groundwater in the depression to rise to an elevation approaching 418 m. This elevation
Geology, Vegetation, and Hydrology of the S2 Bog at the MEF

is just shy of the upper boundary of the Rich-Fen, Sedge-Dominated Peat Sediment Phase. Perhaps in the long Holocene after 9000 y BP water table elevations fluctuated through a range of 1.5 m as opposed to the contemporary 50 year record of 1 m.

Cyperaceae dominate the aquatic and wetland species in the peat sediment record. There also is one calciphile Sphagnum (Sphagnum platyphyllum) and two calciphile aquatic mosses (C. trifarium and W. fluviatilis). Salix spp., A. rugosa, and Alnus crispa (its first occurrence) dominate the tall wetland shrubs. Short ericaceous shrubs also are strong in the peat record. Wetland trees strong in the record are Fraxinus and Larix with a notable near absence of Picea. This is not a pond or lake environment, but a wet sedge meadow with ericaceous shrubs underlain by aquatic mosses and a calciphile Sphagnum. The sedge-shrub meadow is surrounded by alder and willow shrubs with sparse ash and tamarack trees, sitting in a landscape first dominated by dry site red and jack pine and then mixed with the temperate, moister, and dominant-crowned white pine.

Paludification is the process allowing the wet sedge meadow to accumulate peat. It occurs when there is a hydrostatic head (pressure field) above the meadow surface. Centuries of peat accumulation fill this energy field with pore space (about 8 cm per century), allowing groundwater under pressure to fill the pores at progressively higher elevations. The growth of sedge, Ericaceae, and moss continues upward. Hence, the peatland is a feature of the landscape that grows upward (and outward where the hills allow) on the death of its own vegetation and the pore structure that it creates in the organic soil.

5600–3000 Years BP

The overall picture of sediment during the Transitional-Fen Phase is nearly identical with that during the Rich-Fen Phase. The difference is the occurrence of circumneutral Sphagnum mosses, both Sphagnum centrale and S. subsecundum. S. centrale is typical of Thuja swamps (treed fens) where it occurs frequently today. It has been observed in a contemporary ice-block depression in outwash sands only 0.5 km distant and 7.5 m lower at an elevation of 414.5 m (Bay, 1967). The 414.5 m elevation at the S3 fen is coincident with the algal gyttja at the deepest part of S2 bog (Lacustrine, Calcareous Lake Phase) and also coincides with the contemporary upper limit of regional water table fluctuation beneath the S2 bog.

Groundwater in the S3 fen has a contemporary pH of 6.9–7.4, calcium of 17–20 mg L⁻¹, and magnesium of 3–4 mg L⁻¹. Groundwater beneath S2 bog has a contemporary pH of 6.8–8.0, calcium ranges from 37 to 47 mg L⁻¹, and magnesium ranges from 6 to 9 mg L⁻¹ (Table 4.4). S. subsecundum grows in mineral-rich mats in open habitats, and in the hollows of poor-sedge fens (Crum, 1988). Thus, the Transitional-Fen Phase marks a subtle change in water chemistry from alkaline pH values near 8 to circumneutral values slipping below 7 (Vitt et al., 1995).
The hydraulic head arising at the subcontinental divide enables strong groundwater control on peatland water chemistry and water table elevation. Downward flowing groundwater flow lines begin at the divide and then flow deep through the Rainy sands into the Itasca Lobe ground moraine above the bedrock. There it dissolves the limestone fragments, pushed 20,000 years ago from south-central Hudson Bay. The flow lines then curve upward and fill the aquifer sands with water rich in calcium bicarbonate. This is the water flowing under S2 bog and discharging in large amounts to the surface at S3 fen. The groundwater control weakened when the peat surface in the S2 sedge meadow rose above the water table at the subcontinental divide (417.5 m) about 5500 cal y BP.

The paludification process continues upward and the surface water draining to the depression from the upland increases in importance relative to the slow lateral and upward seep of deep groundwater. The paludification process (about 6 cm per century during the Transitional-Fen Phase) accumulates an additional 1.6 m of peat, such that the peat surface rises above the subcontinental water table but retains (by chemical diffusion) a chemical groundwater memory during the process.

Annual peatland water table fluctuations (0.5 m) and severe drought fluctuations (1.2 m) (Verry, 1980) repeatedly mix the water in the undecomposed to moderately decomposed active peat layer (acrotelm) with water in the well-decomposed catotelm (Verry, 1984). During the Transitional-Fen Phase, groundwater still controlled the peat development through the power of a constant hydraulic head. This power gradually gave way to periodic processes including water table fluctuation, biologic mixing (vegetation growth, decay, and gas exchange), and deep frost penetration (0.1–0.5 m) that preferentially drives fine organic matter and elements to the bottom of freezing ice. Thus, frost formation fosters the transfer of material from the acrotelm to the catotelm (Verry, 1991).

At the end of the Transitional Fen Phase there is a clearer break with groundwater chronicled by new Sphagna such as Sphagna magellanicum, Sphagna angustifolium, and Sphagna fuscum, changes in water chemistry, and transition to a warmer continental climate.

### 2900–390 Years BP

There was a severe fire (a distinct charcoal layer) at the upper boundary in 1864, 130 years BP, but the layer may contain charcoal from an earlier fire documented north of Grand Marais, MN, in 1610 AD (384 y BP). An analysis of peat accumulation rates suggests how many years and how many centimeters of peat accumulation were consumed by the 1864 fire.

The amount of catotelm peat consumed by the 1864 fire are estimated by subtracting the years to reach the projected open poor-fen surface (413) from the middle of the last dated core slice (782). This yields a 369 y BP. A more reliable date estimated from St. Paul, MN, weather records and tree-ring
cores from 1994 in the spruce at S2 bog is 1864 or 130 y BP. Thus, 369–130 suggests that the fire burned 239 years of catotelm peat. The lost years multiplied by the accumulation rate suggests the fire consumed 14 cm of catotelm peat. Because another severe fire occurred in 1610, the charcoal layer may represent two fires.

We derived our open poor-fen upper date of 390 y BP from peat accumulation rates extrapolated above the fire horizon depth of 75 cm (421.25 m elevation). The peat accumulation rate averaged over the last three dating slices is 0.55 mm y⁻¹. This rate applied to 22.5 cm of projected peat accumulation (decomposed and relatively dense catotelm peat) suggests that peat accumulated up to the pre-fire surface of the Open Poor-Fen Phase over a 413 year period beyond the center of the previous dating slice (782 y BP). This accumulation of catotelm peat extends from the middle of the last dating slice (421.07 m elevation, 97.5 cm depth) to just below the elevation of the contemporary stream outlet (421.29 m elevation, 75 cm depth). A less dense acrotelm peat of about 20 cm occurs above the catotelm boundary (Verry, 1984). Accordingly, we project the actual peat hollow surface at the end of the Open Poor-Fen Phase at virtually the stream-outlet elevation (421.5 m). This is deduced from the continued occurrence of S. magellanicum throughout the Open Poor-Fen Phase, the frequent occurrence of S. angustifolium above the 75 cm depth (Figure 4.12), and the peat humification values of 8 and 9 (on the von Post scale of 1:10; see Malterer et al., 1992) immediately below the charcoal horizon.

Characteristic of this Open Poor-Fen Phase is the occurrence (dominance) of acid Sphagnum species, particularly S. magellanicum, which first appeared about 2900 cal y BP and heralded the initiation of the Open Poor-Fen period. It was accompanied by Sphagnum recurvum agg., identifiable as S. angustifolium at the top of the peat core (Figure 4.13) along with some transitional S. fuscum.

130/390–0 Years BP

Pinus pollen rose sharply, from 2% to 60% of the upland pollen sum, as a forest of black spruce developed on the bog. Pollen of Betula also increased from 7% to 24%, presumably owing to the logging of pine and subsequent slash fires. White-pine pollen declined from 35% to 5%. The pollen of woody invaders of open spaces, Ambrosia sp., Artemisia sp., and Chenopodiaceae/Amaranthaceae sp. increased by 5%–15% for the same reason. Fire history documents initiation of the aspen forest (Populus tremuloides) in 1917 and 1918 in the MEF.

The intense fire in 1864 probably burned peat accumulated in the narrow surface outlet on the southwest side of the S2 bog, and effectively lowered the water table at least 5 cm. This was sufficient to establish and grow a poor- to medium-site stand of black spruce (Verry, 1982, 2000). Bog development began immediately after the fire, fostered by unobstructed streamflow drainage, colonization by acidiphile Sphagnum species, decomposition of acid-producing Sphagnum moss (Gorham et al., 1985), minimal availability of
bicarbonates from the deep peat (and little from the upland), and continuation of a wetter climate.

Since 1865, the S2 peatland has developed an S. angustifolium/S. magellanicum dome rising 18 cm from its edge to a high near the existing recording well (Figure 4.5). A small dome may have existed before the 1864 fire as well. This dome, built by Sphagnum accumulation above the elevation of the outlet stream, developed a localized groundwater flow net above the much deeper regional groundwater flow net (Ingram, 1978). Even before the acid, ombrotrophic peat in the Forested-Bog Phase rose an additional meter above the stream elevation, paludification had reversed the flow of water deep in the depression from vertically upward to vertically downward. Today the water table of the bog (422.2m) is 4–5 m higher than that at the subcontinental divide (417.5 m).

Contemporary Water Chemistry in S2 Peatland

Extensive data on water chemistry for regional groundwater, upland, bog, streamflow, and precipitation show strong site differences (Table 4.4). Precipitation at the MEF is moderately impacted by industrial emissions. Sulfate concentration is slightly elevated (1.03 mg L⁻¹) and nitrate (1.05 mg L⁻¹) and ammonium (0.33 mg L⁻¹) more so. However, alkaline dust from the prairies yields high calcium (0.20 mg L⁻¹) and magnesium (0.03 mg/L) concentrations. Thus, pH is within the normal range for precipitation (5.06) as is chloride (0.08 mg L⁻¹) for midcontinental sites.

Although S2 streamflow pH reflects a mixing of the interior bog dome and the poor-fen lagg, it is acid (4.07) while calcium (2.3 mg L⁻¹) and magnesium (0.8 mg L⁻¹) are slightly elevated above bog waters in other cool and humid areas with no influence from windborne dust. Organic matter dissolved and suspended in the bog water yields high total phosphorus (TP) values (0.08 mg L⁻¹) and high total organic carbon (49.8 mg L⁻¹). Total Kjeldahl nitrogen (TKN) also is high (1.15 mg L⁻¹), but the carbon to nitrogen ratio (C/N) of 43 is still very high compared with many natural systems.

The two components of upland water are surface and subsurface flow (Chapter 7). Upland surface water flows through the forest floor, whereas the subsurface component is water collected from the saturated A horizon of the mineral soil. Verry and Timmons (1982) described the chemical analyses and physical collection methods. Concentrations of calcium, magnesium, and alkalinity are higher in the surface flow than in the subsurface flow (Table 4.4). Uptake of these elements from the mineral-soil horizons by trees (P. tremuloides) and their subsequent release from decaying leaves is the source of elevated calcium and magnesium in the upland surface flow. Similarly, potassium, TKN, ammonium, TP, and phosphate-phosphorus (phosphate-P) are high in leaves and higher in upland surface flow than
subsurface flow (Table 4.4). By contrast, sodium is higher in the subsurface flow, reflecting the quick release and leaching from leaves to the saturated A horizon. Total organic carbon and pH concentrations are similar between subsurface and surface flows. However, the C/N for subsurface flow is more than three times that in the surface flow. Aluminum is high in the subsurface flow and the peatland streamflow, reflecting acid leaching in both locations.

Regional groundwater (drawn from 3.2 cm diameter galvanized pipe, screened for 1 m, 15 m beneath the surface) is high in pH, alkalinity, calcium, magnesium, sodium, potassium, iron, and manganese relative to all other sites (Table 4.4) and provides the alkaline environment for the early lake and rich fen environments deep in the S2 depression. These same concentrations are typical of the S3 fen 2 km north of the S2 bog. Phosphorous and nitrogen values are low as is TOC (6 mg L⁻¹), but the C/N of 23 is midway among all sites.

Contemporary Vegetation in the S2 Peatland

Tables 4.5 and 4.6 show the species present in single relevés (10 x 10 m²) from both the bog dome and the marginal fen lagg. The bog relevé contains 19 species while the relevé from the lagg contains 35 species. Nomenclature follows Ownbey and Morley (1991) for vascular plants, Anderson (1990) for Sphagnum, Anderson et al. (1990) for other mosses, and Stotler and Crandall-Stotler (1977) for liverworts.

The overstory vegetation of the bog was almost entirely black spruce with some birches (Betula papyrifera) and tamarack (Larix laricina). Ledum groenlandicum was the dominant broad-leaved, evergreen woody shrub with five other Ericaceous heaths present. Carex trisperma dominated the graminoids and Smilacina trifolia is the only common forb. Among the bryophytes, S. magellanicum and S. angustifolium—characteristic of low hummocks and cushions—had high cover values with another 14 species present (Table 4.6). Also common was Pleurozium schreberi, a feather moss usually found on taller, drier hummocks. The shrubby overstory of the lagg was dominated by Alnus incana with five other deciduous, broadleaf woody species. C. trisperma and Carex d. disperma were most common of the six graminoids, whereas Calla palustris was the chief forb among the 13 species present. S. centrale and S. russoi were the most common bryophytes in the relevé. When bryophyte species were enumerated during quantitative collections from the lagg, Callitriche halensis was the most frequent of the species collected followed by Tetraphis pellucida, S. magellanicum, S. angustifolium, and S. centrale. The bog plant list comprised 17 taxa on 2.8 ha while the lagg list comprised 55 taxa on just 0.4 ha (Table 4.6). The relative area-weighted species ratio (lagg:bog) is 23:1 and plant diversity in the lagg is three times greater than that in the bog.
### TABLE 4.5
Vegetation of the S2 Bog and Lagg

<table>
<thead>
<tr>
<th>Life Form</th>
<th>Species</th>
<th>Cover Scales S Bog</th>
<th>Cover Scales S Lagg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Needleleaf evergreen</td>
<td>Abies balsamea (&lt;2 m)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinus maritima (10–35 m)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pinus maritima (&lt;2 m)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Broadleaf deciduous</td>
<td>Acer rubrum (&lt;2 m)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alnus incana (&lt;2 m)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alnus incana (2–10 m)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Amelanchier intermedia</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Betula papyrifera (2–10 m)</td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Cornus stolonifera</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ribes glandulosum</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Broadleaf evergreen</td>
<td>Chamaedaphne calyculata</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gaultheria hispida</td>
<td>1</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Kalmia polifolia</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ledum groenlandicum</td>
<td>3</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Vaccinium angustifolium</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Vaccinium oxyccocoides</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Forbs</td>
<td>Asper pratiense</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Calla palustris</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clintonia borealis</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cornus canadensis</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Drosera rotundifolia</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dryopteris carthusiana</td>
<td>+</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Equisetum sylvaticum</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lyceopus uniflorus</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lysimachia thyrsiflora</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Osmunda cinnamomea</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ruabis pubescens</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sarracenia purpurea</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smilacina trifolia</td>
<td>2</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Trisetalis borealis</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Viola incognita</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Graminoids</td>
<td>Calamagrostis canadensis</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex brunnescens</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex disperma</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex trinervis</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex elatius</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex pascenfolia</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex princeps</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carex trisperma</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Erigeron spissian</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 4.5 (continued)

**Vegetation of the S2 Bog and Lagg**

<table>
<thead>
<tr>
<th>Life Form</th>
<th>Species</th>
<th>Cover Scales(^a) Bog</th>
<th>Cover Scales(^a) Lagg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bryophytes</td>
<td>Calliergon giganteum</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pleurozium schreberi</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polytrichum commune</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sphagnum angustifolium</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sphagnum centrale</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sphagnum magellanicum</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sphagnum russowii</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

*Note: The cover scores are those of the Braun-Blanquet scale.*

\(^a\) \(+5\%\); several individuals; \(1=5\%\); many individuals; \(2=5\%–25\%\); \(3=25\%–50\%\).

### TABLE 4.6

**Additional Bryophyte Species Found in the Bog and Poor-Fen Lagg Habitats in the S2 Peatland, in Order of Frequency**

<table>
<thead>
<tr>
<th>Bog</th>
<th>Lagg</th>
<th>Lagg</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Sphagnum magellanicum</em></td>
<td><em>C. haldarii</em></td>
<td><em>Camptothecium hispidulum</em></td>
</tr>
<tr>
<td><em>Sphagnum angustifolium</em></td>
<td><em>Tetraphis pellucida</em></td>
<td><em>Cladonia dendroidea</em></td>
</tr>
<tr>
<td><em>Pleurozium schreberi</em></td>
<td><em>Sphagnum magellanicum</em></td>
<td><em>Dicranum polysetum</em></td>
</tr>
<tr>
<td><em>Ptilium palustrinum</em></td>
<td><em>Sphagnum angustifolium</em></td>
<td><em>Orthotrichum saxatile</em></td>
</tr>
<tr>
<td><em>C. haldarii</em></td>
<td><em>Sphagnum centrale</em></td>
<td><em>Plagiomnium cuspidatum</em></td>
</tr>
<tr>
<td><em>Dicranum polysetum</em></td>
<td><em>Pleurozium schreberi</em></td>
<td><em>Plagiomnium ellipticum</em></td>
</tr>
<tr>
<td><em>Dicranum undulatum</em></td>
<td><em>Ptilium cristae-tenus</em></td>
<td><em>Pseudobryum circulare</em></td>
</tr>
<tr>
<td><em>Ptilium cristae-tenus</em></td>
<td><em>Dicranum flagellare</em></td>
<td><em>Amblystegium serpens</em></td>
</tr>
<tr>
<td><em>Aylocrenia palustris</em></td>
<td><em>Brachythecium oedipodium</em></td>
<td><em>A. serpens var. foresti</em></td>
</tr>
<tr>
<td><em>Brotherella recurvans</em></td>
<td><em>Thuidium recognitum</em></td>
<td><em>Anastrophyllum hellerianum</em></td>
</tr>
<tr>
<td><em>Dicranum ontariense</em></td>
<td><em>Plagiomnium ciliare</em></td>
<td><em>Brachythecium rivulare</em></td>
</tr>
<tr>
<td><em>Leproleuca heterophylla</em></td>
<td><em>Brachythecium salicifolium</em></td>
<td><em>Brachythecium velutinum</em></td>
</tr>
<tr>
<td><em>Sphagnum fuscum</em></td>
<td><em>Calliergon fruticulosum</em></td>
<td><em>Brotherella recurvans</em></td>
</tr>
<tr>
<td><em>Pohlia splagmica</em></td>
<td><em>Plagiomnium medius</em></td>
<td><em>Calliergon giganteum</em></td>
</tr>
<tr>
<td><em>Cephaloziella multiceps subsp. spinulosum</em></td>
<td><em>Polytrichum commune</em></td>
<td><em>Dicranum undulatum</em></td>
</tr>
<tr>
<td><em>Polytrichum strictum</em></td>
<td><em>Sphagnum uliginosum</em></td>
<td><em>Hypnum pallescens</em></td>
</tr>
<tr>
<td><em>Dicranum fuscescens</em></td>
<td><em>Aylocrenia palustris</em></td>
<td><em>Hypnum pallescens</em></td>
</tr>
<tr>
<td></td>
<td><em>Jamesoniella autumnalis</em></td>
<td><em>Orthotrichum spectabile</em></td>
</tr>
<tr>
<td></td>
<td><em>Leproleuca heterophylla</em></td>
<td><em>Plagiomnium ciliare</em></td>
</tr>
<tr>
<td></td>
<td><em>Plagiomnium dextrodatum</em></td>
<td><em>Polytrichum longisetum</em></td>
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<td></td>
<td><em>Pohlia nitens</em></td>
<td><em>Pyhulocystis selvatici</em></td>
</tr>
<tr>
<td><em>Ptilium pulcherrimum</em></td>
<td><em>Rhytidolepidothrix triquetra</em></td>
<td><em>Sauria umbilicata</em></td>
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<tr>
<td><em>Brachythecium erythrochilum</em></td>
<td><em>Sphagnum russowii</em></td>
<td><em>Sphagnum subulatum</em></td>
</tr>
<tr>
<td><em>Bryum localium microphyllum</em></td>
<td><em>Pleurosclerium laetum</em></td>
<td><em>Sphagnum warneckii</em></td>
</tr>
<tr>
<td><em>Pleurosclerium repens</em></td>
<td><em>Sphagnum warneckii</em></td>
<td><em>Warneckia flabellata</em></td>
</tr>
<tr>
<td><em>Sphagnum teres</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Brachythecium reflexum</em></td>
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</tbody>
</table>

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The greater plant diversity in the lagg is driven by the chemistry of water upwelling from the underlying A horizon of eolian loess beneath the peatland (Figure 4.8). At the time the relevés were established, pH was 4.03 in the bog and 5.28 in the marginal poor-fen lagg (compare to upland runoff pH of 6.5, Table 4.4). Specific conductivity ($K_{\text{SP-Cart}}$) reduced by the conductivity attributable to H$^+$ ions indicated that both waters were dilute, the bog 17 and the lagg 23μS cm$^{-1}$. The bog water is tea colored with an absorbance value (Abs$_{350nm \text{ cm}}$) of 0.77; the lagg water less so with a value of 0.31, reflecting the admixture of bog water and less colored water from the surrounding upland. Both the floristic and the water-chemistry data characterize the central peatland as a bog and the lagg as a poor fen according to the widely accepted classification of DuRietz (1949); see also Vitt et al. (1995).

**Summary and Discussion**

**Accumulation of Peat Sediment**

Dates in a long peat core ($^{14}$C dates) stretched over 610 cm and ranged from 783 y BP to 10,900 cal y BP. Simple division yielded an annual peat accumulation rate of 0.06 m century$^{-1}$. Overall, this was 56 g m$^{-2}$ y$^{-1}$ equivalent to 29 g C m$^{-2}$ y$^{-1}$ and similar to the North America average (Gorham, 1991).

Dates and pollen identification in the long core from the S2 bog identified seven peat sediment phases. The first was Lake Phase I (11,900–10,900 cal y BP), characterized by algal gyttja in the first 900 years. Lake Phase II (10,900–9,200 cal y BP) accumulated the remains of aquatic mosses (Amblystegiaceae, principally $W.$ $fluitans$). Also prevalent were emergent lake aquatics (e.g., $Nuphar$, Potamogeton, Baeosia, Sagittaria, Sparganium, and Typha). During Lake Phase II, the water level in the ice-block dropped from an elevation of 420–416 m.

The Rich-Fen/Emergent-Bryophyte Mat Phase spanned only 800 years (9200–8400 cal y BP). A bryophyte mat smothered two small ponds near the bottom of the ice-block depression. The aquatic mosses $W.$ $fluitans$ and $C.$ $trifarium$ formed the mat. The water had high concentrations of calcium and magnesium and pH values around 8 (in both the Lake and Rich-Fen/Bryophyte Mat Phases). It occurred when the ice front was 390–470 km north fronted by the large glacial Lake Agassiz (Via et al., 2006).

The Rich-Fen/Sedge Phase encompassed 2900 years (8400–5500 cal y BP). $S.$ $platyphyllum$ (an alkaline Sphagnum species), $C.$ $trifarium$, the appearance of $W.$ $exannulatus$, and abundant Cyperaceae characterize this long period of peat accumulation. Between 6300 and 5700 y BP there was a single 5–10 cm slice representing about a 75–150 year period containing Sphagnum section Cuspidata sp., an acid anomaly in a long period of alkaline water conditions caused by the oxidation of reed roots containing high concentrations of sulfide when water levels dropped to the level of the central flat in the
bottom of S2 bog. Peat accumulation during this phase (2.4 m) responded to a piezometric water elevation set by a water table high at the subcontinental divide 3 km north of the S2 peatland. Limestone fragments in the mixed-texture Itasca ground moraine derived from the west side of Hudson Bay. Regional groundwater flowing in the deep sands above this layer dissolved the limestone and brought water into the S2 depression at pH values near 8.

The Transitional-Fen Phase encompassed 2600 years (5500–2900 cal y BP). Pollen of peatland origin during the Transitional-Fen Phase was virtually identical with that of the Rich-Fen/Sedge Phase, marked only by additions of the circumneutral Sphagna—S. cernale and S. subsecundum. At the beginning of the Transitional-Fen Phase, the peatland was still under the influence of groundwater, but as further paludification occurred (accumulations of another 1.6 m), the groundwater influence waned and water pH values shifted from above 8 to just below 7. At the end of the phase, peat had risen to an elevation of 420.39 m and the depression began to drain to a stream. In the beginning of the phase, the pressure of constant, upwelling groundwater was a dominant force for peat accumulation. During this period, when the peat rose above the subcontinental divide water table at 418 m, the flow of water within the peat mass reversed from upward to downward. Flow reversals and the concurrent existence of local and regional groundwater flow systems are common in peatlands and paramount in understanding hydrology and biogeochemistry in peatlands (Devito et al., 1997). At the end of the Phase, the constant influence of regional, circumneutral, groundwater gave way to periodic processes controlling the chemistry of peat formation. These included water table fluctuation, biologic mixing (vegetation growth, decay, and gas exchange between soils and the atmosphere), and deep frost penetration. Frost penetration preferentially moves colloidal organic matter to the bottom of the frost layers, reaching as much a 45 cm below the surface hollows. At the end of the Transition-Fen Phase, there was a clear break with high calcium, regional groundwater.

The Open Poor-Fen Phase (2900-130/360 y BP) is marked by the arrival of acid Sphagna species—S. magellanicum, S. angustifolium, and S. fuscum. This period accumulated peat (about 1.1 m), but intense fire during 1864 (based on St. Paul, MN weather records) burned 14 cm of peat. Heinselman (1973, 1996) also documented nearly a half million acres of fire-origin pine dating from 1863 and 1864 in the Boundary Waters Canoe Area Wilderness. He documented an earlier fire in 1610 north of Grand Marais, MN. Surface drainage to the stream was well established with no groundwater upwelling.

The Forested-Bog Phase (1864–2001) accumulated 70 cm of peat, including the construction of an 18 cm-high dome near the recording well toward the east end of bog S2. Built by Sphagna mosses and Ericaceae roots, the dome rises above the stream elevation. Bog water acid derives from H-ion generation during organic-matter decomposition in the absence of significant bicarbonate ions (Gorham et al., 1985). The bog dome also contains its own shallow groundwater flow system on top of the 77 m of fen and algal gyttja once influenced by the flow strength and alkaline chemistry of the regional
groundwater system. The additional 70 cm of hydraulic head induces minute amounts of vertically downward seepage through the bog bottom. However, much larger amounts of water leave the bog above the von Post H9 peat layer in the lagg as unsaturated flow through the thin Koochiching till and the Rainy River sands to the regional water table that is 7 m below.

Climate Change

The occurrence of upland pollen in the long peat core allowed us to interpret major changes in the regional climate at the MEF over the last 12,000 years. First is a transition-climate period (12,000–9300 y BP). Its definition is hampered by the inability to slice algal gyttja, but change from the bottom of the core to the top of the Aquatic Moss Sediment Phase suggests an average annual temperature rising from -1°C to +5°C, and 1000 mm of annual precipitation at 12,000 y BP dropping to 700 mm at 9300 y BP.

A dry and warm phase persisted for 2700 years (9300–7400 y BP). During this period, P. resinosa/P. banksiana from the uplands dominated the long core with pollen counts that were 40% of the total pollen sum, the highest of any species in the Holocene. The local pollen record, other pollen work (Kutzbach et al., 1993), and CCM modeling suggest annual temperatures at 4°C–5°C and annual precipitation at 700 mm.

A transition climate from 7400 to 6100 y BP cooled from 4°C to 2°C and became wetter with 700–800 mm of annual precipitation. There was a major shift in upland tree pollen. The P. resinosa/P. banksiana component decreased from 40% to 15% and the P. strobus component increased from 8% to 35%. Then, the relative distribution of pines persisted through a stable period of nearly 3000 years from 6100 to 3200 y BP. A slight cooling period for 800 years from 3200 to 2400 y BP followed, with a subsequent shift to a short (200 year) warmer and drier period from 2000 to 1800 y BP. Changes in P. resinosa/P. banksiana and P. strobus pollen of 10%–20% followed suit.

The Little Ice Age from 600 to 150 y BP or about 1370–1840 saw the maximum amount of P. strobus pollen (40%). Average annual temperature cooled to 1°C and precipitation increased to 800 mm. For a brief period of 75–150 years, the acidophilous aquatic Sphagnum section Cupulata sp. occurred in the S2 bog pond-waters. In, 6000 y BP, significant remnants of the Keewatin and Labrador Ice Centers remained (Hamblin, 1989) but large expanses of ice in western and eastern Canada had melted, releasing enormous stress on the crust of North America and initiating rebound of the Earth’s surface.

Peatland Ecology Perspective

Moore and Bellamy (1974) reviewed the evolution of mire ecology; treatises by Weber (1908) and Potonie (1908) conceptualize how peatlands develop from
groundwater-fed basins that accumulate peat until the elevation exceeds the height of a surface outlet. Then the peat mass in the center is fed only by rainwater. Weber (1909) developed the hypothesis of terrestrialization based on a natural history of developing peat masses (ontogeny) near Hanover, Germany. The terms used to describe the three stages of mire development were: niedermoore or flachmoore (rich fen), übergangsmoore or zwischenmoore (poor fen), and hochmoore (moss or bog) for both Weber and Potonie. These terms simply mean low, medium, and high moors, referring to their elevation as they develop low to high. Mellin (1917) used a similar division for Swedish mires as riekarr, karr, and moss.

Kivinen (1935) summarized all the early chemistry of lake and moorwässer that laid a phytosociological foundation for the work of Witting (1947, 1949) to explain the occurrence of mire vegetation. It was accepted by DuRietz (1949) that water in the peat mass was distinctly different among the three mire types. Early work in Sweden by Sjörs (1948) followed, but he used the terms rich fen, poor fen, and moss. Later Sjörs (1950) made a direct correlation between water chemistry and vegetation in Swedish mires, but considered the change in mires and their vegetation as they built from low to high elevations as gradual rather than three distinct types.

Kulczynski (1949) also used three divisions for Polish mires—rehophilous or niedermoore, transition or übergangsmoore, and ombrophilous or hochmoore. This was the first use of the term “transition.” Earlier work was autecological in nature, while Kulczynski’s work, which linked the terminology and classification of mires using the ontogenic, phytosociologic, and chemical approaches, was synecological in nature. Thunmark (1942) classified mire types in Sweden by pH and calcium concentrations, which Vitt et al. (1995) in Canada and Bridgham et al. (1996) in the United States further defined. In Europe, subsequent correlations between water chemistry and mire vegetation were made for England (Pearsall and Lind, 1941; Gorham, 1956a,b), Poland (Tolpa et al., 1967) and Ireland (Bellamy and Bellamy, 1967).

The work reported here for the S2 bog supports the three class divisions (i.e., rich fen, poor fen, and bog). However, it extends previous investigations to show how ice-block, watershed, and regional hydrology influence the amount and chemistry of water and eventually yield a peat mass based on peat phase development. It also considers not only the waning influence of groundwater under constant piezometric pressure but also the importance of a variety of periodic processes that weaken dependence of the developing peat mass from alkaline groundwater to rainwater at the top of the bog clone. Although the water-flow and water-chemistry drivers of peat development gradually change as peat develops (Sjörs, 1950), the phytosociological character of rich fen, poor fen, and bog yield distinct phases of peat development interpreted in the study of paleobotany in peat cores.

In Pennoscandia mire terminology, lagg refers to the plant-rich peatland edge (Cajander, 1913; Sjörs, 1948; Kulczynski, 1949). Lagg always is described in terms of plant diversity. However, the detail of geologic and soil lithology
at the edge of the S2 bog functionally defines a lagg that results from the movement of upland water through mineral soil horizons beneath the peat and upwelling to the lagg surface. It also shows and quantifies water movement at the lagg in three directions (Chapter 7). Water upwells to the lagg when upslope mineral soil horizons are saturated. Water seeps downward beneath the lagg to the regional water table daily. And, water forms surface flow (water tracks) originating from both the bog dome and the upland and sends it around the lagg to form first order streams leaving the peatland (Figures 4.7 and 4.8).

Lessons Learned

1. **Pleistocene, Wisconsin glaciation.** Matching glacial drift lithology to dates and regions of origin is a continuing process improved with new chemistry, cores, and insight. It includes details of contemporary soil surveys (e.g., shale fragments in the Koochiching till) and accounts for both regional (western Great Lakes) and distant geology.

2. **Topography.** Detailed maps of surface topography, soil horizons, ice-block bathymetry, and water table elevations that are tied to the same elevation datum greatly improve our ability to interpret Pleistocene and Holocene materials, dating, and climate.

3. **Core dating.** The precision of peat or lake sediment cores is derived from the thickness and clearness of the slice, in our case 5–10 cm representing about 75–150 years; however, accuracy is a function of carbon dating with a variety of adjustments (± 250 years), tree rings (± 5 years), and climate or historic records (± 1 year).

4. Interpreting sediment cores. Records of moss and aquatic pollen preserved in the peat sediment core provide an insight to plant environmental conditions in the ice-block depression, suggesting identification of major peat sediment phases. Tree, shrub, and herbaceous pollen from the uplands provide an insight into major climate periods of transition or stability.

5. **Landscape hydrology.** Water table position, whether within the ice block depression or in the region, helps differentiate between environmental conditions within the depression giving rise to peat phases and climate periods within the region.

6. Hemisphere or regional? Local pollen records representing the regional climate temper our application of climate based on CCM models or interpreted between century and millennial periods in regional cores not subjected to inferences related to watershed hydrology.
7. Linkages. Linkages among the upland, lagg, bog, stream, and the regional water table define how a given watershed ecosystem functions. Topography, soil and glacial lithology, climate periods, peat phases, water chemistry, vegetation autecology and synecology, and hydrology refine our deductions of watershed and ecosystem function.

References


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Peatland Biogeochemistry and Watershed Hydrology


Geology, Vegetation, and Hydrology of the S2 Bog at the MEF


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Peatland Biogeochemistry and Watershed Hydrology


NCSS Conference -Wednesday North Shore Tour  
Duluth, Minnesota  
June 10th, 2015

7:30AM – 7:30PM: The North Shore Tour will depart from the Holiday Inn and Suites, downtown Duluth at 7:30 AM and will return to the Holiday Inn and Suites at 7:30 PM.

Content: The tour will be focused on soils formed from the Superior Lobe of the Laurentian Ice Sheet. The tour will depart from the Holiday Inn and Suites in downtown Duluth at 7:30 a.m. and will visit sites along the North Shore of Lake Superior. Sites will include a) soil topohydrosequences of Superior Dense Loamy Tills; b) dysic and euic transitions in hemic organic deposits; c) ecological site description of the Till Upland Mesic Hardwood Forests; and d) soils formed in Superior Very Fine Red Tills. The tour will conclude with a dinner in Two Harbors, Minnesota. Buses will return to the Holiday Inn and Suites in downtown Duluth at 7:30 p.m.

Three buses will be visiting Sites: A, B, C, and D in a round-robin fashion. Each bus will have a team leader and its own schedule. All buses will meet at Lester Park for lunch. All buses will also meet at Castle Danger Brewery in Two Harbors, MN for dinner. Dinner hosted by MAPSS (Minnesota Association of Professional Soil Scientists).

Lunch, dinner, and breaks are included.

Site A: Ahmeek & Normanna soils
Topics: Topohydrosequences of Superior Dense Loamy Till; Perching Water

Site B: Organics
Topics: Dysic and Euic Transitions in Hemic Organic Deposits; Fluctuating Fibric Cap

Site C: Ecological Site Description - Till Upland Mesic Hardwood Forests
Topics: Sugar Maple Stands Productivity; Microclimate of Lake Superior

Site D: Cuttre soils
Topics: Superior Very Fine Red Tills; Hydric Indicators in Red Parent Material
Wednesday North Shore Field Tour

Site A
Site B
Site C
Site D

Convention Center

Dinner

Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community.
Hazards:

**Deer Ticks:** Deer ticks, also known as blacklegged ticks, are just one of thirteen known tick species in Minnesota. They are most common in the east and central areas of the state and are found in hardwood forests and wooded and brushy areas. Deer ticks are potential carriers of Lyme disease, human anaplasmosis and babesiosis. Risk Timeframe: Primarily risks are from mid-May through mid-July when the smaller nymph stage of the deer tick is feeding. Risk is present, but lower, in early spring and again in the fall (late September-October) when the adult stage of the deer tick is active.

Preventions: Check and re-check for ticks when you are in tick-infested areas.

1. When in deer tick habitat, walk in the center of the trail to avoid picking up ticks from grass and brush.
2. Wear light colored clothing so ticks will be more visible.
3. Create a barrier to ticks by tucking pants into socks or boots and tuck long sleeved shirt into pants.
4. Use a repellent containing DEET or permethrin, and carefully follow the directions on the container.
5. After being outdoors in tick habitat, get out of your clothes immediately, do a complete body check, shower and vigorously towel dry. Wash your clothes immediately as to not spread any ticks around your living area.

Tick Removal: The risk of getting a tick-borne disease is small if the tick is removed soon after it becomes attached. Deer ticks must remain attached one to two days to transmit Lyme disease, and about one day for the other diseases.

1. Take precautions when in tick habitat, but don't panic if you find a deer tick on you. Not all ticks are infected, and prompt tick removal can prevent illness
2. Use tweezers to grasp the tick close to its mouth.
4. To avoid contact with the bacteria, if present, do not squeeze the ticks' body.
5. Wash the area and apply an antiseptic to the bite.
6. Watch for early signs and symptoms of Lyme disease

Lyme Disease sign, symptoms, and treatment: Please visit the Minnesota Department of Health for more information on this topic.  [http://www.health.state.mn.us/divs/idepc/diseases/lyme/index.html](http://www.health.state.mn.us/divs/idepc/diseases/lyme/index.html)

**Poison Ivy:** Usually has three broad, spoon-shaped leaves or leaflets, but it can have more. The phrase, "Leaves of three? Let it be." may help you remember what poison ivy looks like. Grows as a climbing vine or a low, spreading vine that sprawls through grass (more common in eastern states) or as a shrub (more common in northern states, Canada, and the Great Lakes region).
SITE A: TOPOHYDROSEQUENCES OF SUPERIOR DENSE LOAMY TILLS
AHMEEK & NORMANNA SOILS
NCSS Wednesday Field Tour
MLRA 93A – Superior Stony and Rocky Loamy Plains and Hills, Western Part

Figure 93A-1: Location of MLRA 93A in Land Resource Region K

Introduction

This area is entirely in northeast Minnesota (fig. 93A-1). It makes up about 8,570 square miles (22,205 square kilometers). The towns of Ely, Finland, Grand Marais, Two Harbors, and Cloquet are in this MLRA. The main highways through the area are U.S. Highway 53 and Minnesota Highways 1 and 61. Most of the area is in the Superior National Forest, and the Boundary Waters Canoe Area Wilderness is in this MLRA. Because of its shape, this area is called the “Arrowhead region” of Minnesota. The Grand Portage Indian Reservation is at the tip of the “arrowhead.” Part of the Fond du Lac Indian Reservation is in the southeast tip of the area, and the Vermilion Lake Indian Reservation is in the central part of the area.

Physiography

This area is in the Superior Upland Province of the Laurentian Upland. It was glaciated by numerous advances of the Superior, Rainy, and Des Moines glacial lobes during the Wisconsin and pre-Wisconsin glacial periods. Most of the surface of this area is young, dominated by drumlin fields, moraines, small glacial lake plains, outwash plains, and bedrock-controlled uplands. Elevation generally ranges from about 600 to 2,100 feet (185 to 640 meters). Eagle Mountain, at an elevation of 2,301 feet (701 meters), is the highest point in Minnesota. Closed depressions, lakes, ponds, and bogs are throughout the area. The several thousand lakes within the Boundary Waters Canoe Area Wilderness were formed by the scouring of the bedrock landscape by glacial ice. Local relief ranges from 10 to more than 100 feet (3 to 30 meters). It can be 600 feet (185 meters) or more in some areas adjacent to Lake Superior.
The extent of the major Hydrologic Unit Areas (identified by four digit numbers) that make up the MLRA is as follows: Rainy (0903), 53 percent; Western Lake Superior (0401), 45 percent; Mississippi Headwaters (0701), 1 percent; and St.Croix (0703), 1 percent. The surface drainage network in this area is immature. It is made up primarily of remnants of glacial meltwater channels. The major channels are occupied by the Vermilion, Whiteface, and St. Louis Rivers. Many small tributaries drain into Lake Superior from the uplands to the west, including the Lester, Baptism, and Temperance Rivers.

Geology

This area is covered by glacial till, drift, and outwash and by lake sediments, alluvium, and thin layers of loess. These deposits range from only a few inches to several hundred feet in thickness. Bedrock is on the surface or at a shallow depth in many areas. The bedrock formations in this area include Middle Precambrian graywacke and mudstone and their metamorphic equivalents, Upper Precambrian basalts, gabbroic rocks, including the Duluth complex, and Lower Precambrian granitics, metabasalt, and graywacke. Iron ore is mined in this area.

Climate

The average annual precipitation in almost all of this area is 25 to 30 inches (635 to 760 millimeters). It is as much as 33 inches (840 millimeters) at the tip of the “arrowhead.” About 65 percent of the precipitation falls as rain during the growing season (May through September), and about 21 percent falls as snow. The average annual temperature is 36 to 40 degrees F (2 to 4 degrees C). The freeze-free period averages about 150 days and ranges from 120 to 175 days.

Water

Following are the estimated withdrawals of freshwater by use in this MLRA:

- Public supply—surface water, 8.4%; ground water, 0.0%
- Livestock—surface water, 4.2%; ground water, 9.1%
- Irrigation—surface water, 0.0%; ground water, 0.0%
- Other—surface water, 78.3%; ground water, 0.0%

The total withdrawals average 19 million gallons per day (72 million liters per day). About 9 percent is from ground water sources, and 91 percent is from surface water sources. The numerous lakes and streams are sources of water. The timber and mining industries use most of the surface water that is used in this area. This water is of very good quality and is suitable for most uses.

Ground water occurs in joints, fractures, and bedding planes in the Precambrian crystalline rocks underlying most of this area. This water typically has more than 500 parts per million (milligrams per liter) total dissolved solids and is hard. The median level of iron exceeds the national secondary standard for drinking water of 300 parts per billion (micrograms per liter). This aquifer may be the only source of ground water for domestic use and livestock in most of this area. Volcanic rocks along the
shore of Lake Superior also contain ground water. The water in these basalt flows generally has a median level of total dissolved solids of about 200 parts per million (milligrams per liter) and is moderately hard. This aquifer provides water mostly for domestic use and livestock. Naturally occurring areas with very saline water are not used.

Soils

This MLRA is dominated by Entisols, Inceptisols, and Histosols. The soils have a frigid soil temperature regime, a udic soil moisture regime, and isotic or mixed mineralogy. The parent material is dominantly dense loamy till, coarse glacial drift and outwash, silty glaciolacustrine sediment, local loess, alluvium, and organic material. The soils are dominantly shallow or moderately deep in the northern part of the area and very deep in the southern part. They are very poorly drained to excessively drained and are level to very steep. Eutrudepts (Ahmeek, Brimson, Eveleth, Hermantown, Normanna, and Toimi series) formed in till. Dystrudepts (Conic, Insula, and Mesaba series) formed in till over bedrock. Udorthents (Quetico series) formed in loamy and very shallow loamy material over bedrock. Udipsamments (Grayling and Mahtomedi series) formed in sandy outwash. Haplohemists (Rifle and Greenwood series) formed in thick layers of organic material.

Biological Resources

This MLRA makes up the true forested region of Minnesota. Prior to settlement, the vegetation consisted almost entirely of forest communities. The forest types included white pine-red pine forest, aspen-birch forest, mixed hardwood-pine forest with sugar maple on ridges, and jack pine barrens in the uplands. Conifer swamps or bogs occupied the depressions and areas of outwash. Fire dependence characterizes all of these forest types. This MLRA is still dominantly forested. Much of the land is in public ownership and managed for wood products and recreation. Many areas on uplands support quaking aspen and paper birch. Some scattered areas have old-growth pine stands.

Some of the major wildlife species in this area are white-tailed deer, moose, and ruffed grouse. Because of its relatively unaltered landscape, this MLRA supports a high percentage of the rare plants and animals that occur in Minnesota. Such species include the bald eagle, the Canada lynx, and the eastern timber wolf. The thousands of kettle and bog lakes in this area support populations of common game fish, such as walleye, northern pike, and smallmouth bass. Numerous short, high-gradient streams lead directly from the highlands to the shores of Lake Superior. These cold-water streams support native, sustaining populations of brook trout and rainbow trout and also serve as breeding waters for several species of anadromous fish common to Lake Superior, including steelhead trout and lake trout.

Land Use

Following are the various kinds of land use in this MLRA: Cropland—private, 1%
  Forest—private, 44%; Federal, 31%
  Urban development—private, 2%
  Water—private, 10%; Federal, 8%
Other—private, 2%; Federal, 2%

About 75 percent of this MLRA is forested, and nearly all of the forestland consists of county, State, or national forests. Lumbering, iron mining, and recreation are important. The many bodies of surface water in the area provide opportunities for recreation.

The major resource concerns include the water erosion and reduced water quality caused by timber harvesting. They also include management of wildlife habitat and riparian areas. Conservation practices on forestland generally include forest stand improvement and forest trails and landings. These practices reduce the impacts of timber management activities on water quality. Riparian forest buffers help to protect streams and rivers from timber harvesting activities, improve wildlife habitat, and protect water quality.

AHMEEK SERIES

The Ahmeek series consists of very deep, well drained soils that formed in a friable loamy mantle and the underlying dense loamy till. These soils are on till plains, moraines, and drumlins. Slope ranges from 0 to 45 percent. Mean annual air temperature is about 4 degrees C. Mean annual precipitation is about 750 millimeters.

TAXONOMIC CLASS: Coarse-loamy, isotic, frigid Dystric Eutrudepts

TYPICAL PEDON: Ahmeek fine sandy loam with a convex slope of 8 percent on a moraine in a clear cut planted to red pine. Elevation of about 430 meters. (Colors are for moist soil unless otherwise stated.)

A--0 to 10 centimeters; very dark grayish brown (10YR 3/2) fine sandy loam, dark grayish brown (10YR 4/2) dry; moderate fine and medium granular structure; friable; many very fine and fine roots and common medium and coarse; about 8 percent gravel; strongly acid; clear smooth boundary. (5 to 15 centimeters thick)

Bw1--10 to 23 centimeters; reddish brown (5YR 4/4) gravelly sandy loam; weak fine subangular blocky structure parting to weak fine granular; friable; many very fine and fine roots and common medium and coarse; about 15 percent gravel and 2 percent cobbles; strongly acid; gradual wavy boundary.

Bw2--23 to 38 centimeters; reddish brown (5YR 4/3) gravelly sandy loam; weak fine and medium subangular blocky structure; friable; common very fine and fine roots and few medium and coarse; about 15 percent gravel and 2 percent cobbles; strongly acid; gradual wavy boundary. (Combined Bw horizon thickness is 10 to 147 centimeters)

2BC--38 to 89 centimeters; reddish brown (5YR 4/4) gravelly sandy loam; moderate thick platy structure parting to moderate fine subangular blocky; friable; common very fine and fine roots and few medium; about 15 percent gravel, 2 percent cobbles and 3 percent stones; moderately acid; diffuse wavy boundary. (0 to 51 centimeters thick)

2BCd1--89 to 140 centimeters; dark reddish brown (5YR 3/4) gravelly sandy loam; few fine distinct yellowish red (5YR 5/6) Fe accumulations around stones; moderate very coarse and extremely coarse prismatic structure parting to moderate fine and medium platy, few 2 to 3 millimeter oblique fractures 15 centimeters to 1 meter apart; very firm; few very fine and fine roots; about 17 percent gravel, 4 percent cobbles and 3 percent stones; slightly acid; diffuse wavy boundary.

2BCd2--140 to 203 centimeters; dark reddish brown (5YR 3/4) gravelly sandy loam; few fine distinct yellowish red (5YR 5/6) Fe accumulations around stones; moderate very coarse and extremely coarse prismatic structure parting to moderate fine and medium platy, few 2 to 3 millimeter oblique fractures 15 centimeters to 1 meter apart; very firm; about 18 percent gravel, 4 percent cobbles and 3 percent stones; slightly acid.

TYPE LOCATION: Major Land Resource Area (MLRA) 93A - Superior Stony and Rocky Loamy Plains and Hills, Western Part; St. Louis County, Minnesota subset; about 18.5 miles northeast of Duluth; 900 feet east and 2,250 feet south of the northwest corner, section 10, T. 52 N., R. 13 W., USGS Barrs Lake
quadrangle, lat. 47 degrees 0 minutes 14.6 seconds N., Lon. 91 degrees 58 minutes 50.3 seconds W., NAD27.

**RANGE IN CHARACTERISTICS:**
Depth to the 2BCd horizon (densic contact)--46 to 152 centimeters
Depth to free carbonates--more than 203 centimeters

Some pedons have a thin O horizon (duff layer).

A horizon:
Hue--10YR
Value--2 or 3
Chroma--1 or 2
Texture--fine sandy loam, very fine sandy loam, loam or silt loam
Clay content--5 to 15 percent
Sand content--30 to 55 percent
Rock fragment content--total 0 to 14 percent; with 0 to 12 percent gravel, 0 to 5 percent cobbles and 0 to 3 percent stones and boulders
Reaction--very strongly acid to moderately acid

Some pedons have a thin E horizon.

Bw horizon:
Hue--5YR or 7.5YR
Value--3 to 5
Chroma--3 or 4
Texture--sandy loam, silt loam, loam, fine sandy loam, very fine sandy loam or their gravelly analogues
Clay content--5 to 15 percent
Sand content--35 to 60 percent
Rock fragment content--total 0 to 20 percent; with 0 to 18 percent gravel, 0 to 7 percent cobbles and 0 to 3 percent stones and boulders. It averages between 35 to 60 percent sand with 5 to 15 percent clay
Reaction--very strongly acid or moderately acid

Some pedons have a 2Bt horizon.
Some pedons have a 2Bw horizon.

2BC horizon (when present):
Hue--5YR
Value--3 or 4
Chroma of 3 or 4
Texture--sandy loam, fine sandy loam, loam or their gravelly analogues
Clay content--5 to 15 percent
Sand content--50 to 70 percent
Rock fragment content--total 8 to 25 percent; with 8 to 25 percent gravel, 0 to 10 percent cobbles and 0 to 5 percent stones and boulders
Reaction--moderately acid to neutral
2BCd horizons:
Hue--2.5YR or 5YR
Value--3 or 4
Chroma--3 or 4
Texture--sandy loam, fine sandy loam, loam or their gravelly analogues
Rock fragment content--total 8 to 25 percent; with 8 to 25 percent gravel, 0 to 10 percent cobbles and 0 to 5 percent stones and boulders
Reaction--moderately acid to neutral
It typically has 1 to 3 millimeter oblique fractures 10 centimeters to 3 meters apart.

COMPETING SERIES: These are the Aldenlake, Linneus, and Mesaba series.
Aldenlake--have sandy textures dominant in the lower third of the series control section
Linneus--have sola terminated by bedrock within the series control section
Mesaba--have sola terminated by bedrock within the series control section

GEOGRAPHIC SETTING: These soils have linear to convex slopes that range from 0 to 45 percent. They typically are on till plains, moraines or drumlins. They formed in a friable loamy mantle and the underlying dense, firm and very firm, loamy Superior lobe till of the Late Wisconsinan glaciation. Mean annual air temperature ranges from 2 to 6 degrees C. and mean annual precipitation ranges from 710 to 790 mm. Annual frost free days range from 80 to 140. The elevation above sea level ranges from 200 to 600 meters.

GEOGRAPHICALLY ASSOCIATED SOILS: These are the Normanna, Hermantown, Canosia, Giese, Cathro and Twig soils. The moderately well drained Normanna and somewhat poorly drained Hermantown soils are on lower lying or less sloping positions on the landscape. The poorly drained Canosia soils are in drainageways, and on flats and toeslopes. The very poorly drained Giese and Twig soils are in depressions or drainageways. The very poorly drained Cathro soils are in depressions.

DRAINAGE AND SATURATED HYDRAULIC CONDUCTIVITY:
Drainage class--well drained--frequent saturation does not occur within a depth of 2.0 meters during the wettest periods of normal years
Saturated hydraulic conductivity--4.23 to 42.34 micrometers per second (0.6 to 6.0 inches per hour) in the loamy mantle and 0.01 to 0.42 micrometers per second (0.0015 to 0.06 inches per hour) in the underlying dense till

USE AND VEGETATION: Most of this soil is forested. A small portion is cropped to small grains and hay or is in pasture. Native vegetation was mixed deciduous-coniferous forest. Major species of trees are quaking aspen, paper birch, balsam fir, northern red oak, and eastern white pine.

DISTRIBUTION AND EXTENT:
Physiographic Divisions--Laurentian Upland or Interior Plains
Physiographic Provinces--Superior Upland or Central Lowland
Physiographic sections--undefined(if in the Superior Upland Province) or Western lake section(if in the Central Lowland Province)
MLRAs--Superior Stony and Rocky Loamy Plains and Hills, Western Part(93A) and Wisconsin and Minnesota Thin Loess and Till, Northern Part(90A)
LRR K; Northeastern Minnesota and possibly northwestern Wisconsin.
Extent--large
MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: St. Paul, Minnesota

SERIES ESTABLISHED: Houghton County, Michigan in 1943.

REMARKS:
Particle-size control section--the zone from a depth of 25 to 100 centimeters
series control section--the zone from the surface to a depth of 150 centimeters.

Diagnostic horizons and features recognized in this pedon include:
ochric epipedon--the zone from the surface to a depth of 10 centimeters (A horizon);
cambic horizon--the zone from a depth of 10 to 89 centimeters (Bw1, Bw2 and 2BC horizons);
dystric subgroup--no carbonates within a depth of 1 meter;
densic contact--at a depth of 89 centimeters;
Isotic mineralogy--based on a 15 kPa water to measured clay ratio equal to or greater than 0.6

The designation of the 2BCd horizon is based on fractures and platy structure in the densic material. Evidence of clay and silt translocation can be seen on faces of peds.

NORMANNA SERIES

The Normanna series consists of very deep, moderately well drained soils that formed in a friable, loamy or silty mantle and the underlying dense loamy till on moraines, till plains and drumlins. Slopes range from 0 to 8 percent. Mean annual air temperature is about 4.0 degrees C., and the mean annual precipitation is about 750 mm.

TAXONOMIC CLASS: Coarse-loamy, isotic, frigid Oxyaquic Eutrudepts

TYPICAL PEDON: Normanna loam with a slope of 5 percent on a convex shoulder on a moraine under a stand of quaking aspen, balsam fir and paper birch. Elevation is 427 meters. (Colors are for moist soil unless otherwise stated.)

A--0 to 10 cm; very dark grayish brown (10YR 3/2) loam, grayish brown (10YR 5/2) dry; weak fine and medium granular structure; friable; many fine, medium and coarse roots; about 5 percent gravel and 1 percent cobbles; very strongly acid; clear wavy boundary. (5 to 15 cm thick)

E--10 to 15 cm; brown (10YR 5/3) sandy loam, very pale brown (10YR 7/3) dry; weak fine subangular blocky structure; friable; many fine, medium and coarse roots; few fine brown (7.5YR 4/4) worm casts; about 5 percent gravel and 1 percent cobbles; very strongly acid; clear wavy boundary. (0 to 8 cm thick)

Bw1--15 to 46 cm; brown (7.5YR 4/4) sandy loam; weak fine and medium subangular blocky structure; friable; many fine, medium and coarse roots; about 10 percent gravel and 3 percent cobbles; strongly acid; gradual wavy boundary.
**Bw2**—46 to 79 cm; brown (7.5YR 4/4) sandy loam; weak fine and medium subangular blocky structure; friable; common fine and medium roots; about 10 percent gravel and 3 percent cobbles; strongly acid; gradual wavy boundary.

**Bw3**—79 to 114 cm; brown (7.5YR 4/3) sandy loam; weak medium subangular blocky structure; friable; few fine and very fine roots; common fine distinct strong brown (7.5YR 4/6) Fe concentrations and few fine distinct brown (7.5YR 5/2) Fe depletions; about 10 percent gravel and 3 percent cobbles; moderately acid; clear wavy boundary. (Combined thickness of the Bw horizons is 36 to 102 cm)

**BC**—114 to 122 cm; brown (7.5YR 4/3) fine sandy loam; weak thick platy structure parting to weak medium subangular blocky; friable; few fine and very fine roots; common fine distinct strong brown (7.5YR 5/6) Fe concentrations and common fine distinct brown (7.5YR 5/2) Fe depletions; about 5 percent gravel, 1 percent cobbles and 1 percent stones; moderately acid; clear wavy boundary. (0 to 36 cm thick)

**2BCd1**—122 to 163 cm; reddish brown (5YR 4/4) gravelly sandy loam; moderate very coarse and extremely coarse prismatic structure parting to moderate fine and medium platy, few 2 to 3 millimeter oblique fractures 15 cm to 1 meter apart; very firm; common fine distinct yellowish red (5YR 4/6) Fe concentrations and few fine prominent brown (7.5YR 5/2) Fe depletions; about 18 percent gravel, 3 percent cobbles and 2 percent stones; slightly acid; gradual wavy boundary.

**2BCd2**—163 to 203 cm; dark reddish brown (5YR 3/4) gravelly sandy loam; moderate very coarse and extremely coarse prismatic structure parting to moderate fine and medium platy, few 2 to 3 millimeter oblique fractures 15 cm to 1 meter apart; firm; few fine distinct yellowish red (5YR 4/6) Fe concentrations; about 20 percent gravel, 2 percent cobbles and 2 percent stones; slightly acid.

**TYPE LOCATION:** St. Louis, Minnesota; about 7 miles north of Hermantown; 600 feet north and 1,200 feet west of the southeast corner, section 3, T. 51 N., R. 15 W.; Fredenberg Quadrangle, latitude 46 degrees 55 minutes 31.22 seconds N. and longitude 92 degrees 13 minutes 18.49 seconds W., NAD 27.(GPS)

**RANGE IN CHARACTERISTICS:** Depth to the 2BCd horizon (densic contact) ranges from 76 to 152 cm. The depth to free carbonates is more than 203 cm.

Some pedons have a thin O horizon (duff layer).

The A horizon has hue of 10YR, value of 2 or 3, and chroma of 1 or 2. It is loam, fine sandy loam, and very fine sandy loam or silt loam. Rock fragment content ranges from 0 to 14 percent with 0 to 12 percent gravel, 0 to 5 percent cobbles and 0 to 3 percent stones and boulders. It is very strongly acid to moderately acid.

The E horizon has hue of 7.5YR or 10YR, value of 4 or 5, and chroma of 1 to 3. It is silt loam, loam, sandy loam, fine sandy loam or very fine sandy loam. Rock fragment content ranges from 0 to 15 percent with 0 to 12 percent gravel, 0 to 5 percent cobbles and 0 to 3 percent stones and boulders. It is very strongly acid to moderately acid.
The Bw horizon has hue of 5YR or 7.5YR, value of 3 to 5 and chroma of 3 or 4. It is sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam or their gravelly analogues. Rock fragment content ranges from 0 to 20 percent with 0 to 18 percent gravel, 0 to 7 percent cobbles and 0 to 3 percent stones and boulders. It is very strongly acid to moderately acid.

The BC horizon has hue of 5YR or 7.5YR, value of 3 to 5 and chroma of 3 or 4. It is fine sandy loam, sandy loam, loam, or their gravelly analogues. Rock fragment content ranges from 8 to 25 percent with 8 to 25 percent gravel, 0 to 10 percent cobbles and 0 to 5 percent stones and boulders. It is moderately acid to neutral. Some pedons have a 2Bw horizon.

The 2BCd horizon has hue of 2.5YR or 5YR and value and chroma of 3 or 4. It is sandy loam or fine sandy loam or their gravelly analogues. Rock fragment content ranges from 8 to 25 percent with 8 to 25 percent gravel, 0 to 10 percent cobbles and 0 to 5 percent stones and boulders. It is moderately acid to neutral. It typically has 1 to 3 mm oblique fractures 10 cm to 3 meters apart.

**COMPETING SERIES:** These are the Greysolon, Soudan, Wahlsten and Toimi series. Soudan soils formed in dense glacial till that has colors of 2.5Y or 10YR. Greysolon and Wahlsten soils have a lithic contact at depths of 51 to 102 cm. Toimi soils are underlain by very firm dense Rainy Lobe till with colors of 10YR.

**GEOGRAPHIC SETTING:** These soils have convex slopes with gradients of 0 to 8 percent. They typically are on undulating, moraines or till plains. They formed in a friable loamy and silty mantle and the underlying dense, firm or very firm, loamy Superior Lobe till of the Late Wisconsin Age. Mean annual air temperature ranges from 2 to 6 degrees C., mean annual precipitation ranges from 710 to 790 mm. Annual frost free days range from 80 to 140. The elevation above sea level ranges from 200 to 600 meters.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are the Ahmeek, Hermantown, Canosia, Giese, and Twig soils. The well drained Ahmeek soils are usually on more sloping areas. The somewhat poorly drained Hermantown soils are on lower lying or less sloping positions on the landscape. The poorly drained Canosia soils are in low lying positions. The very poorly drained Giese soils are in drainageways and depressions. The Twig soils are in depressions.

**DRAINAGE AND SATURATED HYDRAULIC CONDUCTIVITY:** Moderately well drained. Surface runoff is medium to rapid. Saturated hydraulic conductivity is 4.23 to 42.34 micrometers per second (.6 to 6.0 inches per hour) in the upper mantle and .01 to 0.42 micrometers per second (.0015 to .06 inches per hour) in the densic horizons. Normanna soils have a perched seasonal saturation as high as 46 cm below the surface during spring in normal years.

**USE AND VEGETATION:** These soils are used mainly for timber production, some areas are in pasture. Native vegetation was mixed deciduous-coniferous forest. Major species of trees are quaking aspen, paper birch, balsam fir, red pine and eastern white pine. Some areas are cropped to small grains and hay or is in pasture.

**DISTRIBUTION AND EXTENT:** MLRA-90 and 93. Northeastern Minnesota. Moderately extensive.

**MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE:** St. Paul, Minnesota
SERIES ESTABLISHED: St. Louis County, Minnesota, 2007

REMARKS: Diagnostic horizons and features recognized are: ochric epipedon - the zone from the surface to a depth of 15 cm (A and E horizons); cambic horizon - the zone from 15 to 114 cm (Bw horizons); Oxyaquic subgroup - based on soil saturation above 102 cm; densic contact at 122 cm. The soils do not have an increase in organic carbon materials in the subsoil and are not believed to be Spodosols.

The designation of the 2BCd horizon is based on fractures and platy structure in the densic material. Clay and silt translocation can be seen between the horizontal plates when broken apart.
**AHMEEK – PEDON DESCRIPTION**

**Description Date:** 8/7/2014  
**Describers:** Roger Risley, Larissa Schmitt  
**Site ID:** S2014MN137026  
**Soil Name as Sampled:** Ahmeek  

**Soil Name as Correlated:** Normanna  

**Classification:** Coarse-loamy, isotic, frigid Oxyaquic Eutrudepts  

**Geomorphic Setting:** on summit of moraine  

**Particle Size Control Section:**  

**Diagnostic Features:**  
- ochric epipedon 0 to 16 cm.  
- cambic horizon 16 to 104 cm.  
- denseic materials 104 to 200 cm.  

**State:** Minnesota  
**County:** St. Louis  
**MLRA:** 93A – Superior Stony and Rocky Loamy Plains and Hills, Western Part  
**Datum:** WGS83  
**UTM Zone:** 15  
**Latitude:** 46 degrees 55 minutes 55.30 seconds North  
**Longitude:** 92 degrees 11 minutes 46.00 seconds West  
**Upslope shape:** convex  
**Cross slope shape:** linear  

**Restriction:** Denseic material  
**Drainage:** Moderately Well  
**Slope:** 3 percent  
**Aspect:** 90

A--0 to 16 centimeters; very dark grayish brown (10YR 3/2) silt loam; moderate fine granular structure; very friable; 7 percent 2- to 76-millimeter unspecified fragments; ; abrupt smooth boundary.

Bw1--16 to 29 centimeters; brown (7.5YR 4/3) silt loam; weak fine subangular blocky structure; very friable; 10 percent 2- to 76-millimeter unspecified fragments; ; clear wavy boundary.

Bw2--29 to 55 centimeters; brown (7.5YR 4/4) very fine sandy loam; moderate medium subangular blocky structure; friable; 30 percent distinct pinkish gray (7.5YR 6/2), moist, silt coats on all faces of peds; 10 percent 2- to 76-millimeter unspecified fragments; ; clear wavy boundary.

Bw3--55 to 104 centimeters; brown (7.5YR 4/3) fine sandy loam; moderate thin platy structure; friable; 20 percent fine distinct strong brown (7.5YR 5/6), moist, masses of oxidized iron in matrix; 10 percent 2- to 76-millimeter unspecified fragments; ; clear wavy boundary.

2Cd--104 to 200 centimeters; brown (7.5YR 4/3) gravelly fine sandy loam; structureless massive structure; very firm; 2 percent 76- to 250-millimeter unspecified fragments and 25 percent 2- to 76-millimeter unspecified fragments; platy dense parent material fabric.
### Primary Characterization Data

**St. Louis, Minnesota**

Sampled as on Jul 06, 2014: Normanna; Coarse-loamy, isoxic, frigid Oxyaquic Eutrudult

**Pedon ID:** S2014MN137026

**Project:** C2014USMN079 2015 National Work Planning Conference

**Site ID:** S2014MN137026 Lat: 46° 55' 55.30" north Long: 92° 11' 46.00" west WGS84 MLRA: 93A

**Pedon No.:** 14N0995

**General Methods:** 1B1A, 2A1, 2B

United States Department of Agriculture
Natural Resource Conservation Service
National Soil Survey Center
Soil Survey Laboratory
Lincoln, Nebraska 68508-3886

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- Weighted Particles, 0.1-75mm, 75 mm Base
- Volume, >2mm, Weighted Average
- Clay, total, Weighted Average
- Clay, carbonate free, Weighted Average
- CEC Activity, CEC/Clay, Weighted Average, CECd, Sot 4
- LE, Whole Soil, Summed to 1m

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### Primary Characterization Data

**Pedon ID:** S2014MN137026  
**Sampled As:** Normanna  
**USDA-NRCS-NSSC-National Soil Survey Laboratory:**

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<th>Prop</th>
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### Primary Characterization Data

**Pedon ID:** S2014MN137026  
**Sampled As:** Normanna  
**USDA-NRCS-NSSC-National Soil Survey Laboratory**

#### CEC & Bases

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Extractable Ca may contain Ca from calcium carbonate or gypsum. CEC7 base saturation set to 100.

#### Salt

| Layer | Horz | Prep | Depth (cm) | Ca | Mg | Na | K | CO3 | HCO3 | F | Cl  | PO4 | Br  | OAC | SO4 | NO3 | NO2 | H2O | Salts | Cond | Cond | Na | SAR |
|-------|------|------|------------|----|----|----|----|-----|------|---|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|----|-----|
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| 14N04835 | Bw2 | S | 29-55      | -- | -- | -- | -- | --  | --   | -- | --  | --  | --  | --  | --  | --  | --  | --  | --   | --  | --  | -- | --  |
| 14N04836 | Bw3 | S | 55-104     | -- | -- | -- | -- | --  | --   | -- | --  | --  | --  | --  | --  | --  | --  | --  | --   | --  | --  | -- | --  |
| 14N04837 | 2Cd | S | 104-200    | -- | -- | -- | -- | --  | --   | -- | --  | --  | --  | --  | --  | --  | --  | --  | --   | --  | --  | -- | --  |

**pH & Carbonates**

|     |     |     |     |     |     |     |     |
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### Primary Characterization Data

**Pedon ID:** S2014MN137026  
**Sampled As:** Normanna  
**USDA-NRCS-NSSC-National Soil Survey Laboratory:**  
**Coarse-loamy, Isolic, Frigid Oxyaquic Eutrochrept**  
**Pedon No.:** 14N0895

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### Primary Characterization Data

Pedon ID: S2014MN137026  
St Louis County, Minnesota  
USDA-NRCS-NSSC-National Soil Survey Laboratory  
Pedon No. 14N0995

**Depth** | **Fract** | **7A1b1** | **X-Ray** | **Thermal** | **Elemental** | **EGME** | **Interpretation**
---|---|---|---|---|---|---|---
14N04834 15.0-29.0 | Bar | tcy | VR 2 | KK 2 | CL 2 | VERM
14N04835 29.0-55.0 | Bar | tcy | VR 2 | KK 2 | FP 1 | CL 1 | MI 1 | VERM

**Fraction Interpretation:**  
tcy = Total Clay, <0.002 mm

**Mineral Interpretation:**  
CL = Chlorite  
FP = Plagioclase Feldspar  
KK = Kaolinite  
MI = Mica  
VR = Vermiculite

**Relative Peak Size:**  
5 Very Large  
4 Large  
3 Medium  
2 Small  
1 Very Small  
0 No Peaks

**Interpretation (by horizon):**  
VERM = Vermiculite
### Primary Characterization Data

**St. Louis County, Minnesota**
Coarse-loamy, isolic, frigid Oxyaquic Eutrudept

**Pedon No.: 14N0966**

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<td>csl</td>
<td>74</td>
<td>QZ 70</td>
<td>FK 16</td>
<td>HN 3</td>
<td>PR 3</td>
<td>BT 2</td>
<td>FE 2</td>
<td>SMIX</td>
<td></td>
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<td>29.0-55.0</td>
<td>Bw2</td>
<td>csl</td>
<td>75</td>
<td>QZ 69</td>
<td>FK 14</td>
<td>BT 5</td>
<td>PR 4</td>
<td>FE 3</td>
<td>HN 3</td>
<td>SMIX</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**FRACTION INTERPRETATION:**
csl - Coarse Silt, 0.02-0.05 mm

**MINERAL INTERPRETATION:**

<table>
<thead>
<tr>
<th>BT - Biotite</th>
<th>BY - Beryl</th>
<th>CD - Chert (Chalcedony)</th>
<th>FE - Iron Oxides (Goethite)</th>
<th>FK - Potassium Feldspar</th>
</tr>
</thead>
<tbody>
<tr>
<td>FP - Plagioclase Feldspar</td>
<td>GS - Glass</td>
<td>HN - Hornblende</td>
<td>MS - Muscovite</td>
<td>OP - Opales</td>
</tr>
<tr>
<td>PO - Plant Opal</td>
<td>PR - Pyroxene</td>
<td>QZ - Quartz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**RELATIVE PEAK SIZE:**

5 Very Large 4 Large 3 Medium 2 Small 1 Very Small 6 No Peaks

**INTERPRETATION (BY HORIZON):**

SMIX - Mixed Sand
SITE B: DYSIC & EUIC TRANSITIONS IN HEMIC ORGANIC DEPOSITS
GREENWOOD and MERWIN SOILS
NCSS Wednesday Field Tour
GREENWOOD SERIES

The Greenwood series consists of very deep, very poorly drained soils formed in organic deposits more than 51 inches thick on outwash plains, till floored lake plains, or lake plains. These soils have moderate or moderately rapid permeability. Slopes range from 0 to 2 percent. Mean annual precipitation is about 29 inches, and mean annual temperature is about 43 degrees F.

TAXONOMIC CLASS: Dysic, frigid Typic Haplohemists

TYPICAL PEDON: Greenwood mucky peat - on a 1 percent slope in a forested area. (Colors are for moist soil unless otherwise stated.)

Oi--0 to 6 inches; brown (7.5YR 4/4) peat (fibric material); about 95 percent fiber, about 90 percent rubbed; massive; friable; primarily live roots and sphagnum moss; extremely acid; clear smooth boundary.

Oe1--6 to 10 inches; very dark brown (10YR 2/2) broken face and rubbed mucky peat (hemic material); about 80 percent fiber, about 20 percent rubbed; massive; friable; primarily herbaceous fibers; extremely acid; gradual smooth boundary.

Oe2--10 to 35 inches; dark brown (7.5YR 3/2) broken face and rubbed mucky peat (hemic material); about 80 percent fibers, about 20 percent rubbed; massive; friable; primarily herbaceous fibers; extremely acid; gradual smooth boundary.

Oe3--35 to 60 inches; dark brown (7.5YR 3/2) broken face and rubbed mucky peat (hemic material); about 90 percent fibers, about 35 percent rubbed; massive; friable; primarily herbaceous fibers; very strongly acid.

TYPE LOCATION: Clare County, Michigan; about 5 miles south and 1 mile west of Temple; 300 feet east and 825 feet south of the northwest corner, sec. 16, T. 18 N., R. 6 W.

RANGE IN CHARACTERISTICS: The organic layers are more than 51 inches thick. The surface tier is commonly peat (fibric material) derived from sphagnum moss. In some places, these layers are largely undecomposed sphagnum moss and in others they are stratified muck, mucky peat, and peat derived from both herbaceous plants and sphagnum moss. Muck, mucky peat, and peat types have been recognized. The O layers have hue of 10YR to 5YR, value of 2 to 6, and chroma of 1 to 4; colors become darker upon brief exposure to air. Oi layers have the highest values and chromas. In some pedons, colors after rubbing change from 0.5 to 1 unit in value or chroma or both. The layers in the subsurface and bottom tiers are dominantly mucky peat (hemic material) derived from herbaceous plants. In some pedons, layers of peat or muck have a combined thickness of less than 10 inches in the lower two tiers. These layers have pH of 4.5 or less in 0.01M calcium chloride and commonly range from pH 3.5 to 4.5. Fragments of woody material ranging from about 1 to 8 inches in diameter are throughout the control section. Woody fibers comprise less than 50 percent of the organic volume after rubbing. There is no mineral soil material recognized in the profile.

COMPETING SERIES: There are none. The Burnt Vly, Citypoint, Dawson, Loxley and Pleasant Lake soils are in closely related families. All of these soils are dominantly composed of sapric materials. In
addition, the Citypoint series has a lithic or paralithic contact within 60 inches, and the Burnt Vly and Dawson soils have sandy mineral soil within 51 inches of the surface.

**GEOGRAPHIC SETTING:** Greenwood soils are in depressions that range in size from small enclosed bogs in moraines to areas of about 1,000 acres in size. The larger areas commonly are on outwash plains, till floored lake plains, or lake plains. The mineral soils in the surrounding upland are generally derived from acid parent materials. Slopes range from 0 to 2 percent. Then mean annual precipitation ranges from about 22 to 35 inches, and the mean annual temperature is about 36 to 45 degrees F. Frost free days range from 88 to 150. Elevation above sea level ranges from 600 to 1,600 feet.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are the Dawson, Deford, Kinross, and Roscommon soils. Dawson soils are shallow organic soils in similar landscape positions underlain by sand at a depth of 16 to 50 inches. The Deford, Kinross and Roscommon soils are poorly or very poorly drained sandy mineral soils in slightly higher landscape positions.

**DRAINAGE AND PERMEABILITY:** Very poorly drained. The representative depth to wet soil moisture status is at the surface to 1 foot below the surface at some time throughout the year. The representative depth of ponding is from 0 to 1.0 foot at some time throughout the year. Surface runoff is negligible. Permeability is moderate or moderately rapid.

**USE AND VEGETATION:** Very little use is made of these soils because of the extreme acidity and high water table. Few trees except some black spruce and tamarack grow on these soils. Ground cover is blueberries, bog rosemary, laurel, leatherleaf, and sphagnum mosses.

**DISTRIBUTION AND EXTENT:** Minnesota, Wisconsin, New Hampshire, New York, and the northern Lower Peninsula and Upper Peninsula of Michigan. The soil is of large extent.

**MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE:** St. Paul, Minnesota

**SERIES ESTABLISHED:** Ogemaw County, Michigan, 1923.

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**MERWIN SERIES**

The Merwin series consists of deep very poorly drained organic soils that formed in 16 to 51 inches of organic soil material consisting mostly of hemic material overlying a loamy mineral soil in glacial sediments. These soils are on glacial moraines and lacustrine and outwash plains. The saturated hydraulic conductivity is rapid in the upper part and slow and moderately slow in the underlying material. They have slopes of 0 to 1 percent. Mean annual air temperature is about 42 degrees F, and mean annual precipitation is about 28 inches.

**TAXONOMIC CLASS:** Loamy, mixed, dysic, frigid Terric Haplohemists
**TYPICAL PEDON:** Merwin peat with a level slope in a bog of about 300 acres on a ground moraine in an open forest of black spruce with an understory of heaths and sphagnum moss. (Colors are for moist soil unless otherwise stated.)

**Oi**—0 to 6 inches; dark yellowish brown (10YR 4/4) broken face fibric material, dark yellowish brown (10YR 3/4) rubbed, light yellowish brown (10YR 6/4) pressed; about 95 percent fiber, about 90 percent rubbed; massive; nonsticky; about 15 percent woody fragments mostly about 0.5 cm in diameter and 25 cm long; sphagnum moss fiber; few 1 cm thick layers of sapric material in lower part; about 15 percent mineral matter; layer ranges from 4 to 12 inches thick within dimensions of pedon; extremely acid; gradual wavy boundary.

**Oe**—6 to 40 inches; dark brown (7.5YR 3/3) broken face hemic material, dark brown (7.5YR 3/2) rubbed and pressed; about 50 percent fiber, about 20 percent rubbed; massive; nonsticky; mostly herbaceous fiber; about 10 percent mineral material; few charcoal fragments; very strongly acid; gradual smooth boundary.

**Oa**—40 to 42 inches; very dark gray (10YR 3/1) broken face, rubbed and pressed, sapric material; about 15 percent fiber, about 5 percent rubbed; massive, slightly sticky; herbaceous fiber; about 25 percent mineral material; very strongly acid; abrupt smooth boundary.

**Ab**—42 to 45 inches; very dark gray (10YR 3/1) loam; massive; friable; sticky; about 2 percent coarse fragments; very strongly acid; clear smooth boundary. (0 to 6 inches thick)

**Cg**—45 to 60 inches; dark gray (5Y 4/1) fine sandy loam; massive; firm; slightly sticky; very strongly acid.

**TYPE LOCATION:** Carlton County, Minnesota; about 4 miles west of Moose Lake; 2123 feet west and 2085 feet north of the southeast corner of sec. 20, T. 46 N., R. 20 W.

**RANGE IN CHARACTERISTICS:** The thickness of the organic soil material and the depth to the mineral soil substratum range from 16 to 51 inches. The content of woody fragments ranges from 0 to 25 percent, but the higher contents are only in the upper part of the control section. The fiber is dominantly of herbaceous origin except for some pedons that have fiber of sphagnum moss dominant in part to all of the surface tier. Reaction (in 0.01 M calcium chloride) typically is less than 4.5 in all parts of the organic soil material; however, in some pedons part to all of the organic soil material in the bottom tier has reaction of slightly more than 4.5.

The surface tier consists of either fibric, hemic, or sapric material or any combination of two or more of these materials. However, hemic material is dominant in the organic soil portion of the control section in pedons that have a mineral substratum beginning above a depth of 35 inches.

The subsurface tier is dominantly hemic material, and sapric material totals less than 10 inches in thickness in the subsurface and bottom tier in pedons that have the mineral substratum below a depth of 35 inches. A layer of sapric material commonly is immediately above the mineral substratum. Fibric material is not present in the subsurface or bottom tiers.

The hemic material has on the broken face hue of 5YR through 10YR with value and chroma of 2 through 4. Color of material with the higher value and chroma commonly darkens about one unit in value or
chroma or both after exposure to the air. Color upon rubbing commonly is up to one unit lower in value or chroma or both than the broken face. The hemic material has 6 to 15 percent of mineral material.

The mineral substratum ranges from 5YR to 5Y hue, with the redder hues commonly becoming dominant with depth. It has value of 2 through 5 and chroma of 0 to 4. It typically is glacial till and commonly is fine sandy loam, sandy loam, or loam, but the full range includes other kinds of glacial sediments and all other texture classes within the limits of the loamy particle-size class. The upper few inches of the mineral substratum is sandy in some pedons. The mineral substratum ranges from extremely acid to neutral.

COMPETING SERIES: This is the Ossipee series. Ossipee soils lack a buried soil at the upper part of the mineral layer and are in a wetter climate.

GEOGRAPHIC SETTING: Merwin soils are in bogs primarily in rather shallow depressions chiefly on ground moraines, but they also are in bogs in lacustrine and outwash plains. They generally have slope gradients of less than 5 feet per mile. They formed in 16 to 51 inches of organic soil material that is derived primarily from herbaceous plants over loamy, noncalcareous glacial sediments of Late Wisconsin Age. These sediments primarily are glacial till. Mean annual precipitation ranges from 24 to 32 inches, and mean annual air temperature ranges from 35 to 45 degrees F.

GEOGRAPHICALLY ASSOCIATED SOILS: The main ones are the very poorly drained Greenwood soils which are in parts of bogs where the organic soil material is thicker. Associated mineral soils primarily include soils formed in reddish, noncalcareous, loamy glacial till.

DRAINAGE AND SATURATED HYDRAULIC CONDUCTIVITY: Very poorly drained; surface runoff is very low or ponded. Saturated hydraulic conductivity is rapid in the upper part and slow and moderately slow in the underlying material. Merwin soils have an apparent seasonal high saturation at the surface for some time from October to June in normal years.

USE AND VEGETATION: Almost all of this soil is in native vegetation. Native vegetation consists primarily of sedges and grasses, but sphagnum mosses are common in some areas. An overstory of scattered black spruce, tamarack, or alder also is in some areas.


MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE: St. Paul, Minnesota


REMARKS: Diagnostic horizons and properties recognized in this pedon are: Organic material - the zone from 9 to 42 inches (O1, Oe, Oa horizons); terric subgroup based on mineral soil material starting at 2 inches; dysic based on one or more layer within the control section having a pH less than 4.5.
SITE C: ECOLOGICAL SITE DESCRIPTION OF TILL UPLANDS MESIC HARDWOOD FOREST

- Minnesota Maple Sugar Production
- ESD is on Ahmeek and Normanna soils, the same as SITE A

Site C: Till Uplands Mesic Hardwood Forests ESD
Ecological Site Description

Major Land Resource Area 93a
Superior Stony and Rocky Loamy Plains and Hills, Western Part

Till Upland Mesic Hardwood Forests
Sugar Maple – Yellow Birch / Mountain Maple – Thimbleberry / Spinulose Woodfern – Western Oakfern
United States Department of Agriculture

Contact for Lead Authors: Kyle Steele (Kyle.Steele@usda.gov), Ecological Site Specialist, United States Department of Agriculture (USDA) - Natural Resources Conservation Service (NRCS), Albert Lea, MN; and Roger Risely (Roger.Risely@usda.gov), USDA-NRCS Soil Survey Office Leader, Duluth, MN.

Front cover: Top photo is of a Till Upland Mesic Hardwoods reference state taken at Tetepague State Park, Lake County, Minnesota (by Kyle Steele, USDA-NRCS). Bottom left photo is of a black-throated blue warbler (Setophaga caerulescens), taken in southern St. Louis County (by Mike Furtman, ©michaelfurtman.com). Bottom right photo is of an eastern red-backed salamander (Plethodon cinereus), taken in southern Lake County, Minnesota (by Carol Hall, MN DNR). Both species are reliant upon these forest types found in northeastern Minnesota.
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General Information

Ecological Site Description

Ecological Site Name

Abiotic: Till Upland Mesic Hardwood Forests

Biotic: Sugar Maple – Yellow Birch / Mountain Maple – Thimbleberry / Spinulose Woodfern – Western Oakfern

Acer saccharum – Betula alleghaniensis / Acer spicatum – Rubus parviflorus / Dryopteris carthusiana – Gymnocarpium dryopteris

Ecological Site ID: 093AY001

Hierarchical Framework Relationships

Major Land Resource Area (MLRA): Superior Stony and Rocky Loamy Plains and Hills, Western Part (93A)

USFS Subregions: Northern Superior Uplands Section (2121); North Shore Highlands Subsection (2121b)

Ecological Site Concept

The Superior Stony and Rocky Loamy Plains and Hills, Western Part is located and completely contained in northeastern Minnesota (Figure 1). This area has both the highest and lowest elevations in the state, as well as some of the state’s most rugged topography (Ojakangas and Matsch, 1982). The MLRA was glaciated by numerous advances of the Superior, Rainy, and Des Moines glacial lobes during the Wisconsin glaciation as well as pre-Wisconsin glacial periods. The geomorphic surfaces in this MLRA are geologically very young (i.e., 10,000 to 20,000 years) and dominated by drumlin fields, moraines, small lake plains, outwash plains, and bedrock-controlled uplands (USDA-NRCS, 2006). There are thousands of lakes scattered throughout the region that
were created by these glacial events. Most of these lakes are bedrock-controlled in comparison to adjacent glaciated regions where glacial drift deposits are much thicker and the lakes occur in depressions atop the glacial drift (Ojakangas and Matsch, 1982). In contrast to adjacent MLRAs, the depth to the predominantly crystalline or sandstone bedrock in MLRA 93A is relatively thin because the most recent glacial events were more erosional than depositional (Ojakangas and Matsch, 1982).

Till Upland Mesic Hardwood Forest ecological sites are associated with the Automba phase of the Superior glaciation, the first of several main advances of the Superior Lobe along the north shore of Lake Superior (Wright and Watts, 1969). This advance deposited gravelly, coarse-loamy material in the form of till plains, end moraines, and ground moraines. These sites also occur in bedrock-controlled, till mantled landscapes, but still contain soils that are very deep, and thus the bedrock does not affect site conditions for forest communities. They can be located on multiple hillslope positions, including backslopes, summits, and shoulders. Soils are very deep (>60 inches to bedrock), coarse-loamy (<18 percent clay), have <35 percent subsurface coarse fragments, are well or moderately well drained, and often have dense properties in the substratum that can percolate water seasonally.

Spring flowering, sub-boreal ground flora within a northern hardwoods forest type characterizes the vegetation of this site. Sub-boreal species are those that have an affinity to the boreal forest biome along with the associated sub-arctic climate. Examples include: thimbleberry (Rubus parviflorus), mountain maple (Acer spicatum), American fly honeysuckle (Lonicera canadensis), bigleaf aster (Eurybia macrophylla), bluebeard (Clematis borealis), Canada mayflower (Maianthemum canadense), wild sarsaparilla (Aralia nudicaulis), twistedstalk (Spartucus lanceolatus), bunchberry dogwood (Cornus canadensis), and small enchanter’s nightshade (Circaeoa alpina) (Jim Drake, NatureServe ecologist, personal communication). It is well-established that northern hardwoods are nutrient-demanding ecosystems requiring a relatively narrow set of growing conditions: always having consistent moisture, high nutrient availability, and lack of fire disturbance (Landfire, 2007; MN Div. of Forestry, 2008; and Nyland, 1999). Shade-tolerant and fire-intolerant species like sugar maple (Acer saccharum), yellow birch (Betula alleghaniensis), and American basswood (Tilia americana) are the iconic tree species of this ecosystem. Sugar maple in particular is a dominant species and tends to accumulate in all layers of the overstory and understory, similar to other northern hardwood types (Nyland, 1999). Later successional, shade-tolerant conifers like northern white
Ecological Site Description

cedar (*Thuja occidentalis*), white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*) also are present, which in part distinguishes this site from similar northern hardwoods-dominated ecological sites in the Great Lakes region (Flaccus and Ohmann, 1964; MN DNR, 2005). This is especially true within the northern populations where conifers gradually become more prevalent. Eastern white pine (*Pinus strobus*) may also have been historically important as scattered super canopy trees (MN DNR, 2005). In MLRA 93A, northern hardwoods are on the northwestern extent of their range. Lake Superior has a significant effect on the climate and thus growing conditions of this ecological site; including a moderation of both summer and winter high and low daily temperatures, increased insolation of the soil surface due to frequent lake effect snowfall, and a longer frost-free period (Albert, 1994; Anderson in review; Butters and Abbe, 1953; Rosendahl and Butters, 1928). Although soils and environmental conditions are suitable for this forest type, this ecological site produces comparatively low quality timber. Average site index at base age 50 of sugar maple was 51 feet (averaged from twelve trees at three Type Locations and using site index curves developed by Carmean (1989; 1978). In comparison, sugar maple site indices can be as high as 80 in the northeastern U.S., while indices between 50 and 65 are generally thought to be good quality sites in other parts of the Midwest (Godman et al., 1990).

Minor variation in composition, structure and response to disturbance likely occurs from southern to northern populations within the MLRA. Northern populations tend to have more of the aforementioned sub-boreal species in the understory along with more coniferous species such as white spruce and balsam fir in the overstory. In comparison, southern populations are more likely to have understory species such as blue cohosh (*Caulophyllum thalictroides*) and a pure stand of hardwoods in the overstory, including American basswood and ironwood (*Ostrya virginiana*; Flaccus and Ohmann, 1964; NatureServe, 2013a). Both are indicative of a somewhat richer and more temperate environment. This gradient is at least partially due to the combination of gradual climate transition as well as possible changes in soil-nutrient status from south to north (Flaccus and Ohmann, 1964).

It is important to note the distribution map included (Figure 1) is the maximum possible extent of this ecological site. It is likely that an additional ecological site will be correlated to map unit delineations outside of the Lake Superior climate effect (which was not considered during the time of soil mapping). We believe interior populations transition from a northern hardwoods type to a mixed mesic conifer-hardwood
type. Future soil survey update projects are needed and it is likely a separate climate zone will be described for the distant delineations of these map units.

**Physiographic Features**

These sites are located on end moraines, ground moraines, and drumlin-like landforms associated with the Automba phase of the Superior Lobe glacial advance (Table 1). Elevation is mainly above 1,300 feet and below 1,800 feet. These sites are most common in morainal areas with thick glacial deposits, but also occur in bedrock-controlled landscapes closer to Lake Superior (e.g., the Sawtooth Mountains Landtype Association). Hillslope positions are summits, shoulders, and backslopes ranging from 0 to 18 percent slope and include all aspect classes. Slopes often are complex and occur in a stair-stepping pattern, making it difficult to clearly distinguish one summit position from another. Vertical and horizontal slope shape is variable, but mostly linear and/or convex. These sites generate runoff and lateral subsurface flow to adjacent, downslope ecological sites. These sites do not flood or pond.

**Table 1. Physiographic features.**

(Data and information presented here were obtained from the National Soil Information System (NASIS), NRCS integrated plot data, and high resolution digital elevation models.)

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elevation (ft.)</td>
<td>1,300</td>
<td>1,800</td>
</tr>
<tr>
<td>Slope (percent)</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>Aspect (degrees)</td>
<td>0</td>
<td>360</td>
</tr>
<tr>
<td>Water Table Depth (in.)</td>
<td>18</td>
<td>80</td>
</tr>
<tr>
<td>Flooding</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Ponding</td>
<td>None</td>
<td>None</td>
</tr>
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</table>

**Landforms:** end moraines, ground moraines, and drumlins

**Climatic Features**

The average freeze-free period of this ecological site is about 140 days, and ranges from 131 to 149 days (Table 2). Average annual precipitation is 32 inches, which includes rainfall plus the water equivalent from snowfall. About 65 percent of the precipitation falls as rain during the growing season (from May through September), and about 21 percent falls as snow (Table 3). Most of the spring snowmelt runs off the steeply sloping or high relief surfaces into high gradient drainageways and then into wetlands, streams or lakes.

Most of the rainfall during the growing season is transpired by plants, which leaves a small proportion of
the total precipitation for deep aquifer recharge. The high ridges above Lake Superior which support this ecological site receive the most snowfall in Minnesota, averaging over 70 inches annually (Flaccus and Ohmann, 1964; MN DNR, 2013a). This "lake effect" snow is the result of warm, moist air rising and moving inland from the lake, ultimately cooling to produce localized snowfall (Anderson in review; MN DNR, 2013a). The average annual low and high temperatures are 28 and 48 degrees Fahrenheit, respectively (Table 3). These data are derived from 30-year averages gathered from four National Oceanic and Atmospheric Administration (NOAA) weather stations contained within the range of this ecological site and located on correlated map units (Table 4).

Table 2. Frost-free and freeze-free days.
(Data were obtained from NOAA weather stations within the range of this ecological site, using 30-year averages.)

<table>
<thead>
<tr>
<th></th>
<th>Minimum days</th>
<th>Maximum days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frost-free period (32.5°F or greater, 90% probability)</td>
<td>97</td>
<td>124</td>
</tr>
<tr>
<td>Freeze-free period (less than 28.5 °F, 90% probability)</td>
<td>131</td>
<td>149</td>
</tr>
</tbody>
</table>

Table 3. Monthly and annual precipitation and Temperature.
(Data were obtained from NOAA weather stations within the range of this ecological site, using 30-year averages.)

<table>
<thead>
<tr>
<th></th>
<th>Average Precipitation</th>
<th>Average Low</th>
<th>Average High</th>
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<tbody>
<tr>
<td>January</td>
<td>1.21</td>
<td>-0.3</td>
<td>19.0</td>
</tr>
<tr>
<td>February</td>
<td>0.86</td>
<td>3.5</td>
<td>24.3</td>
</tr>
<tr>
<td>March</td>
<td>1.59</td>
<td>14.8</td>
<td>34.5</td>
</tr>
<tr>
<td>April</td>
<td>2.63</td>
<td>28.2</td>
<td>48.6</td>
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<tr>
<td>May</td>
<td>3.25</td>
<td>39.0</td>
<td>61.4</td>
</tr>
<tr>
<td>June</td>
<td>4.03</td>
<td>48.6</td>
<td>70.2</td>
</tr>
<tr>
<td>July</td>
<td>3.64</td>
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<td>75.6</td>
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<tr>
<td>August</td>
<td>3.70</td>
<td>53.1</td>
<td>73.5</td>
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<tr>
<td>September</td>
<td>3.78</td>
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<td>October</td>
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<td>2.50</td>
<td>20.7</td>
<td>35.2</td>
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<tr>
<td>December</td>
<td>1.56</td>
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<td>Annual</td>
<td>32.10</td>
<td>28.8</td>
<td>48.3</td>
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</table>
Ecological Site Description

On a multi-regional scale, northern hardwoods forest types are transitional between the oak-hickory types to the south and the boreal forest types to the north (Johnson et al., 2009; Tubbs, 1997). The distribution of this ecological site abuts the southern edge of the boreal forest biome. The climate-moderating effect of Lake Superior allows this forest type to persist at this latitude (Albert, 1994; Anderson in review). In addition to Lake Superior’s overall temperature moderation, the insulating effect of the elevated snowfall on the rooting zone and the near absence of late spring frosts likely provide the opportunity for this forest type to exist in an otherwise inhospitable climate (Albert, 1994; Anderson in review; Houston, 1999). Even so, this forest type is on the limit of its botanic range and faces a myriad of disturbance factors such as frost cracking, ice damage, and fungal pathogens, as well as herbivory from insects and mammals, and as a result produces poor quality timber.

Table 4. NOAA climate stations used for data analysis, located within the range of this ecological site.

<table>
<thead>
<tr>
<th>Station ID</th>
<th>Location</th>
<th>From</th>
<th>To</th>
</tr>
</thead>
<tbody>
<tr>
<td>MN4918</td>
<td>LUTSEN 3NNE</td>
<td>1981</td>
<td>2010</td>
</tr>
<tr>
<td>MN8421</td>
<td>TWO HARBORS 7NW</td>
<td>1981</td>
<td>2010</td>
</tr>
<tr>
<td>MN9134</td>
<td>WOLF RIDGE ELC</td>
<td>1981</td>
<td>2010</td>
</tr>
<tr>
<td>MN4913</td>
<td>DULUTH INTL AP</td>
<td>1981</td>
<td>2010</td>
</tr>
</tbody>
</table>

Influencing Water Features

This ecological site is not influenced by wetland or riparian water features.

Representative Soil Features

These soils were formed in glacial till deposited during the first and most extensive advance of the Superior Lobe of the Wisconsin Glaciation. They are very deep (>60 inches to bedrock; Table 5) and have contact with compacted densic horizons between 20 and 60 inches deep. Drainage class is moderately well to well drained. These soils are affected by seasonal wetness in the spring months from a water table perched on subsurface dense horizons, which likely promotes the potential for rich, mesophytic vegetation. Soil family is characterized as coarse-loamy, having less than 18 percent clay within the majority of the rooting zone. Soil textural classes include mostly loam or fine sandy loam to a depth of about 5 inches, with weakly developed subsurface horizons of sandy loam or gravelly sandy loam above the dense layer. Coarse fragments mostly are between 5 and 25 percent, becoming more abundant with depth. Soil pH ranges from slightly acidic to nearly neutral (4.5 to 6.8). Since small-scale tree throw was the historically dominant
regenerating disturbance, characteristic pits and mounds (also known as cradle-knolls) are scattered throughout this site and can provide microenvironments for certain plants and wildlife. For example, the mounds produce microsites for tree recruitment (Kabrick et al., 1997) and the pits can temporarily hold water, thus allowing species characteristic of wetter environments to persist. Buildup of downed woody debris is an important characteristic of properly functioning natural communities within this ecological site. Downed woody debris can help the soil retain moisture, provides refuge and habitat for wildlife (particularly amphibians), and act as nurse-longs that are essential for some species such as yellow birch and northern white cedar to regenerate (Table 6; Erdmann, 1990; Great Lakes Worm Watch, 2013; Johnston 1990). Soil series associated with this site are in the Inceptisol order, and include Ahmeek and Normanna.

Table 5. Representative soil features.
(Data and Information presented here were obtained from the National Soil Information System (NIASIS) and NRCS Integrated plot data.)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Fragments less than 3” (percent cover)</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Surface Fragments greater than 3” (percent cover)</td>
<td>0</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Subsurface Fragments less than 3” (percent volume)</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Subsurface Fragments greater than 3” (percent volume)</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Drainage Class</td>
<td>well</td>
<td>moderately well</td>
</tr>
<tr>
<td>Permeability Class (most limiting layer)</td>
<td>very slow</td>
<td>very slow</td>
</tr>
<tr>
<td>Soil Depth (in)</td>
<td>60</td>
<td>80+</td>
</tr>
<tr>
<td>Available Water Capacity (in)</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Soil Reaction/pH (1:1 water)</td>
<td>4.5</td>
<td>6.8</td>
</tr>
</tbody>
</table>

Parent Material – Kind: loamy drift, basalt till, and lodgment till
Parent Material – Origin: various igneous and sedimentary bedrock types
Surface Texture: loam, silt loam, or fine sandy loam
Surface Texture Modifier: none
Subsurface Group: loamy
States and Community Phases

Ecological Dynamics

Till Upland Mesic Hardwood Forests were historically uneven-aged, well developed forests with overstories dominated by shade-tolerant, fire-intolerant species, such as sugar maple, yellow birch, northern white cedar, and sometimes American basswood (Tables 7 and 8). Paper birch (*Betula papyrifera*) was an important component in mid- to early stand development stages (Figure 2). Similarly, the shrub and herbaceous layers contained a high percentage of shade-tolerant and fire-intolerant species such as mountain maple and baneberry (*Actaea spp.*), as well as many generalist species (i.e., those having little indicator value because they occur on a variety of sites) such as beaked hazelnut (*Corylus cornuta*) and bigleaf aster (Table 9). In contrast to other ecological sites within the MLRA, deep soils in combination with reliable moisture and nutrients allowed these communities to support many rich-site species and to have higher forest site productivity. Nutrient cycling was high, producing enrichment of the soil and resulting in comparatively little accumulation of leaf litter in organic surface horizons (Nyland, 1999). Altogether, these attributes provided little opportunity for fires to spread. Most communities were steady-state and self-renewing, and tree replacement occurred by means of advance reproduction following individual tree throws. Broad-scale fire and wind disturbance return intervals were in excess of 1,000 years. Low-intensity surface fires were essentially absent except in extremely dry periods. Fires entering mature forest stands from adjacent fire-dependent natural communities would quickly lose vigor and ultimately burn out, rarely injuring overstory trees (SNF unpublished report (a); Landfire, 2007). Only in extreme cases would high-intensity fires occur, often following stand-leveling blowdowns with subsequent dry conditions, thereby setting succession back to earlier stages. These storm events are estimated to have occurred only once in every 1,000+ years, and once in every 2,000+ years a severe fire would ensue (Landfire, 2007; MN DNR, 2005; MN DNR, 2013). In contrast to more stress-inducing environments, insects, disease, and herbivory were of lesser importance within these sites (Landfire, 2007). Variability in soil or landform characteristics likely produced minor differences in vegetation composition, structure, and response to disturbances.

Due to the dominance of sugar maple, these forests were not clearcut like other forests in the Great Lakes states during settlement times. Instead, they were selectively logged (i.e., high-grafted) in multiple pulses during the early part of the Twentieth Century, leaving behind mostly stands of inferior quality and composition (Johnson et al., 2009). Very few old-growth stands exist today. As a result of these selective
logging practices, some overstory species may have been essentially extirpated. For example, there is some suggestion that eastern white pine was historically a component of these systems, possibly in the form of a super canopy (MN DNR, 2005). However, post-settlement land clearing and subsequent problems with pine regeneration limit this species potential in the future forest. Yellow birch was also a preferred species for loggers, which may be part of the reason we see limited yellow birch regeneration today. Most areas are second- or third-growth. As a result, the majority of land area of this ecological site is in a comparatively earlier successional state or in mixed stands of early-, mid-, and late-successional species, which is a distortion of historical patterns (Figure 2). Remaining old growth or remnant natural communities have been significantly affected by exotic earthworms and high white-tailed deer (Odocoileus virginianus) densities. Earthworms, which were introduced post-settlement, significantly alter soil surface horizons and disrupt nutrient cycling dynamics, and thus directly affect habitat conditions for native flora (Great Lakes Worm Watch, 2013). Selective browse resulting from unnaturally high deer densities has caused decline in many genera and an overall loss of species diversity. Although this site (and northern hardwood forests in general) requires a relatively narrow range of environmental conditions in terms of moisture and nutrients to persist (MN Div. of Forestry, 2008), when those conditions are met they are resilient and offer many opportunities for restoration (Hale et al., 1999).

STATE 1 – REFERENCE STATE

Community phases within the Reference State follow classic successional trajectories. Although we document this historical range of variability, late-successional closed canopy, multistoried forests were the dominant condition during pre-settlement (Tables 7 and 9; Landfire, 2007; MN DNR, 2013 and 2005). Sugar maple is the most influential species and can even be co-dominant in the early-successional community phase following intense blowdown events due to its ability to accumulate in all layers of the forest understory as advance regeneration. However, if such blowdown events are followed by a combination of drought and fire, quaking aspen (Populus tremuloides) and paper birch will be favored (Frelich, 1999; NatureServe, 2007). Although these events did happen and are possible today, due to the historically infrequent nature of such events we do not describe a separate early-successional community phase. By the mid-successional community phase the canopy is closed, and sugar maple and yellow birch begin to take over. The early stages of the late-successional community phase continue to be dominated by sugar maple and yellow birch, but with shade-tolerant conifers beginning to take hold (such as northern white
Ecological Site Description

Table 6. Reference State community phase 1.1 ground surface cover, downed wood, and tree snags.
(Data presented are based on ground cover transects at three NRCS type locations.)

<table>
<thead>
<tr>
<th>Type</th>
<th>Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ground Surface Cover</strong></td>
<td></td>
</tr>
<tr>
<td>Grass/Grasslike</td>
<td>1</td>
</tr>
<tr>
<td>Forb</td>
<td>5</td>
</tr>
<tr>
<td>Shrub/Vine</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Tree</td>
<td>5</td>
</tr>
<tr>
<td>Non-Vascular Plants</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Biological Crust</td>
<td>0</td>
</tr>
<tr>
<td>Litter</td>
<td>55</td>
</tr>
<tr>
<td>Surface Fragments (.25-.3&quot;)</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Surface Fragments (&gt;3&quot;)</td>
<td>1</td>
</tr>
<tr>
<td>Bedrock</td>
<td>0</td>
</tr>
<tr>
<td>Water</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Bare Ground</td>
<td>&lt;1</td>
</tr>
<tr>
<td><strong>Downed Wood</strong></td>
<td></td>
</tr>
<tr>
<td>Fine/Small (1-hour)</td>
<td>10</td>
</tr>
<tr>
<td>Fine/Medium (10-hour)</td>
<td>7</td>
</tr>
<tr>
<td>Fine/Large (100-hour)</td>
<td>5</td>
</tr>
<tr>
<td>Coarse/Small (1,000-hour)</td>
<td>4</td>
</tr>
<tr>
<td>Coarse/Large (10,000-hour)</td>
<td>7</td>
</tr>
<tr>
<td><strong>Tree Snags (No./acre)</strong></td>
<td></td>
</tr>
<tr>
<td>Hard Snags</td>
<td>20</td>
</tr>
<tr>
<td>Soft Snags</td>
<td>5</td>
</tr>
</tbody>
</table>
Today, good examples of the Reference State are rare. However, some do exist in a few state parks or natural areas, largely limited to northern populations within large intact landscapes having high biological significance. Post-settlement logging and contemporary forest management in part mimic early- and mid-successional dynamics, and are much more common today.

Table 7. Reference State community phase 1.1 canopy cover by height class. (Data presented are based on type location from Tettegouche State Park.)

<table>
<thead>
<tr>
<th>Height Above Ground (ft)</th>
<th>Grass/Grasslike</th>
<th>Forb</th>
<th>Shrub/Vine</th>
<th>Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1-5</td>
<td>1-5</td>
<td>0-1</td>
<td>0-1</td>
</tr>
<tr>
<td>0.5-1</td>
<td>1-5</td>
<td>5-15</td>
<td>1-5</td>
<td>1-5</td>
</tr>
<tr>
<td>1-2</td>
<td>-</td>
<td>25-50</td>
<td>1-5</td>
<td>1-5</td>
</tr>
<tr>
<td>2-4.5</td>
<td>-</td>
<td>-</td>
<td>5-25</td>
<td>25-50</td>
</tr>
<tr>
<td>4.5-13</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50-75</td>
</tr>
<tr>
<td>13-40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50-75</td>
</tr>
<tr>
<td>40-80</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50-75</td>
</tr>
<tr>
<td>80-120</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0-20</td>
</tr>
</tbody>
</table>

Table 8. Reference State community phase 1.1 overstory diameter, volume, and density. (Stand totals are based on Hale et al. (1999), species totals are based on Importance values listed in Flacou and Ohman, 1964.)

<table>
<thead>
<tr>
<th>Species</th>
<th>USDA Symbol</th>
<th>DBH (in)</th>
<th>Basal Area (ft²/ac)</th>
<th>Trees Per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>SUGAR MAPLE (Acer saccharum)</td>
<td>ACSA3</td>
<td>2-30</td>
<td>70-90</td>
<td>70-90</td>
</tr>
<tr>
<td>YELLOW BIRCH (Betula alleghaniensis)</td>
<td>BEAL2</td>
<td>2-30</td>
<td>20-40</td>
<td>20-40</td>
</tr>
<tr>
<td>AMERICAN BASSWOOD (Tilia americana)</td>
<td>TIAM</td>
<td>2-30</td>
<td>0-40</td>
<td>0-40</td>
</tr>
<tr>
<td>BALSAM FIR (Abies balsamea)</td>
<td>ABBA</td>
<td>2-30</td>
<td>10-20</td>
<td>10-20</td>
</tr>
<tr>
<td>WHITE SPRUCE (Picea glauca)</td>
<td>PGL</td>
<td>2-30</td>
<td>5-15</td>
<td>5-15</td>
</tr>
<tr>
<td>NORTHERN WHITE CEDAR (Thuja occidentalis)</td>
<td>THOC2</td>
<td>2-30</td>
<td>5-15</td>
<td>5-15</td>
</tr>
<tr>
<td>STAND TOTAL</td>
<td>-</td>
<td>2-30</td>
<td>130-140</td>
<td>130-140</td>
</tr>
</tbody>
</table>
Table 9. Reference State community phase 1.1 composition.  
(Adapted from Flaccus and Ohman, 1984 and MN DNR, 2005, and USDA NRCS integrated plot data. Not all species are assumed to be present in one location.)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Common Name</th>
<th>Scientific Name</th>
<th>USDA Symbol</th>
<th>Type</th>
<th>Cover (%)</th>
<th>Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canopy</td>
<td>Sugar Maple</td>
<td>Acer saccharum</td>
<td>ACFA3</td>
<td>tree</td>
<td>50-100</td>
<td>50-80</td>
</tr>
<tr>
<td></td>
<td>Yellow Birch</td>
<td>Betula alleghaniensis</td>
<td>BEAL2</td>
<td>tree</td>
<td>25-75</td>
<td>50-80</td>
</tr>
<tr>
<td></td>
<td>American Basswood</td>
<td>Tilia americana</td>
<td>TIAM</td>
<td>tree</td>
<td>0-50</td>
<td>50-80</td>
</tr>
<tr>
<td></td>
<td>Balsam Fir</td>
<td>Abies balsamea</td>
<td>ABBA</td>
<td>tree</td>
<td>10-25</td>
<td>50-80</td>
</tr>
<tr>
<td></td>
<td>White Spruce</td>
<td>Picea glauca</td>
<td>PIGL</td>
<td>tree</td>
<td>10-25</td>
<td>50-80</td>
</tr>
<tr>
<td></td>
<td>Northern White Cedar</td>
<td>Thuja occidentalis</td>
<td>THOC2</td>
<td>tree</td>
<td>10-25</td>
<td>50-80</td>
</tr>
<tr>
<td>Sub Canopy</td>
<td>Sugar Maple</td>
<td>Acer saccharum</td>
<td>ACFA3</td>
<td>tree</td>
<td>25-50</td>
<td>16-40</td>
</tr>
<tr>
<td></td>
<td>Yellow Birch</td>
<td>Betula alleghaniensis</td>
<td>BEAL2</td>
<td>tree</td>
<td>25-50</td>
<td>16-40</td>
</tr>
<tr>
<td></td>
<td>American Basswood</td>
<td>Tilia americana</td>
<td>TIAM</td>
<td>tree</td>
<td>0-50</td>
<td>16-40</td>
</tr>
<tr>
<td></td>
<td>White Spruce</td>
<td>Picea glauca</td>
<td>PIGL</td>
<td>tree</td>
<td>5-25</td>
<td>16-40</td>
</tr>
<tr>
<td></td>
<td>Balsam Fir</td>
<td>Abies balsamea</td>
<td>ABBA</td>
<td>tree</td>
<td>5-25</td>
<td>16-40</td>
</tr>
<tr>
<td>Shrub/Seedling</td>
<td>Sugar Maple</td>
<td>Acer saccharum</td>
<td>ACFA3</td>
<td>tree</td>
<td>25-75</td>
<td>1-10</td>
</tr>
<tr>
<td></td>
<td>White Spruce</td>
<td>Picea glauca</td>
<td>PIGL</td>
<td>tree</td>
<td>5-25</td>
<td>1-10</td>
</tr>
<tr>
<td></td>
<td>Mountain Maple</td>
<td>Acer spicatum</td>
<td>ACSP2</td>
<td>shrub</td>
<td>25-75</td>
<td>1-10</td>
</tr>
<tr>
<td></td>
<td>Beech Hazelnut</td>
<td>Corylus cornutus</td>
<td>COCO6</td>
<td>shrub</td>
<td>25-75</td>
<td>1-10</td>
</tr>
<tr>
<td></td>
<td>Chokecherry</td>
<td>Prunus virginiana</td>
<td>PRVI</td>
<td>shrub</td>
<td>5-25</td>
<td>1-10</td>
</tr>
<tr>
<td></td>
<td>American Fly Honeysuckle</td>
<td>Lonicera canadensis</td>
<td>LOCA7</td>
<td>shrub</td>
<td>5-25</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Thimbleberry</td>
<td>Rubus parviflorus</td>
<td>RUPA</td>
<td>shrub</td>
<td>0-25</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Red Elderberry</td>
<td>Sambucus racemosa</td>
<td>SARA2</td>
<td>shrub</td>
<td>0-25</td>
<td>1-5</td>
</tr>
<tr>
<td>Herbaceous</td>
<td>Bigleaf Aster</td>
<td>Eurybia macrophylla</td>
<td>EUMA27</td>
<td>forb</td>
<td>10-50</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Common Lady Fern</td>
<td>Athyrium flexifolium</td>
<td>ATFI</td>
<td>fern</td>
<td>5-25</td>
<td>0.1-2</td>
</tr>
<tr>
<td></td>
<td>Wild Sarsaparilla</td>
<td>Aralia nudicaulis</td>
<td>ARNU2</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-2</td>
</tr>
<tr>
<td></td>
<td>Spinulose Woodfern</td>
<td>Dryopteris carthusiana</td>
<td>DRA11</td>
<td>fern</td>
<td>5-25</td>
<td>0.1-2</td>
</tr>
<tr>
<td></td>
<td>Bluebead</td>
<td>Chloris borealis</td>
<td>CLBO3</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Twisted Stalk</td>
<td>Streptopus lanceolatus</td>
<td>STL13</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Starflower</td>
<td>Trientalis borealis</td>
<td>TRBO2</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Canada Mayflower</td>
<td>Mammanthemum canadense</td>
<td>MACA4</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Longstalk Sedge</td>
<td>Carex pedunculata</td>
<td>CAPE4</td>
<td>graminoid</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Fragrant Bedstraw</td>
<td>Galium triflorum</td>
<td>GATK3</td>
<td>forb</td>
<td>5-25</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Baneberries</td>
<td>Actaea rubra / A. pachypodi</td>
<td>ACRU2/ACP</td>
<td>forb</td>
<td>0.15</td>
<td>0.1-2</td>
</tr>
<tr>
<td></td>
<td>Hairy Solomon's Seal</td>
<td>Polygonatum pubescens</td>
<td>POPU4</td>
<td>forb</td>
<td>0.15</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Groundpines</td>
<td>Lycopodium dendroides / L. hickey</td>
<td>LYDE/LYHI2</td>
<td>forb</td>
<td>0.15</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Dwarf Red Blackberry</td>
<td>Rubus pubescens</td>
<td>RUPU</td>
<td>forb</td>
<td>0.15</td>
<td>0.1-1</td>
</tr>
<tr>
<td></td>
<td>Whipt-Poor-Will Flower</td>
<td>Trillium cernuum</td>
<td>TRCE</td>
<td>forb</td>
<td>0.15</td>
<td>0.1-1</td>
</tr>
</tbody>
</table>
### Ecological Site Description

#### Species List continued

<table>
<thead>
<tr>
<th>Layer</th>
<th>Common Name</th>
<th>Scientific Name</th>
<th>USDA Symbol</th>
<th>Type</th>
<th>Cover (%)</th>
<th>Height (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENCHANTER’S NIGHTSHADE</td>
<td>Circaea alpina</td>
<td>CIAL</td>
<td>forb</td>
<td>0-15</td>
<td>0.3-1</td>
<td></td>
</tr>
<tr>
<td>WESTERN OAKFERN</td>
<td>Gymnocarpium dryopteris</td>
<td>GYDR</td>
<td>fern</td>
<td>0-15</td>
<td>0.1-1</td>
<td></td>
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<tr>
<td>ROUGHLEAF RICEGRASS</td>
<td>Oryzopsis asperifolia</td>
<td>ORAS</td>
<td>graminoid</td>
<td>0-15</td>
<td>0.1-1</td>
<td></td>
</tr>
<tr>
<td>DOWNY YELLOW VIOLET</td>
<td>Viola pubescens</td>
<td>VIFU3</td>
<td>forb</td>
<td>0-15</td>
<td>0.1-1</td>
<td></td>
</tr>
<tr>
<td>SHINING CLUBMOSS</td>
<td>Huperzia lucidula</td>
<td>HULUZ</td>
<td>forb</td>
<td>0-15</td>
<td>0.1-1</td>
<td></td>
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<tr>
<td>LONG BEECH FERN</td>
<td>Phegopteris connectilis</td>
<td>PHCO24</td>
<td>fern</td>
<td>0-15</td>
<td>0.1-1</td>
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<td>WOOD ANEMONE</td>
<td>Anemone quinquefolia</td>
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<td>forb</td>
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<td>0.1-1</td>
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<tr>
<td>CAROLINA SPRINGBEAUTY</td>
<td>Claytonia caroliniana</td>
<td>CLCA</td>
<td>forb</td>
<td>0-15</td>
<td>0.1-1</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3.** Potential Reference State (community phase 1.1) for Till Upland Mesic Forest ecological site; Ahmeek soils. Photo by Kyle Steele at Tettegouche State Park, Lake County, Minnesota, in September of 2013.
Community Phase 1.1 By stand age 120, quaking aspen, paper birch and early-successional shrubs and ground flora have completely subsided. Forest interior, shade-tolerant ground flora take over, particularly spring-flowering species. The dominance of sugar maple and yellow birch may begin to subside while the extremely shade-tolerant white spruce and northern white cedar become more prominent in the overstory (MN DNR, 2013). At this stage the forest is essentially self-sustaining, with fine-scale treefall events providing opportunities for small-scale gap regeneration (Kabrick et al., 1997). The resulting “pit and mound” topography adds to habitat and structural complexity, resulting in unique niches for certain plant and wildlife species. Beyond age 120, the stand continues to develop structural complexity through structural layering as well as extensive build-up of coarse woody debris (Hale et al., 1999). Old stumps, downed logs, and the mounds created from fallen trees provide regeneration potential species like northern white cedar, yellow birch, and occasionally even the sun-loving paper birch (Erdman 1990; Johnston 1990; and Safford 1990). These structural dynamics result in habitat diversity essential to support various species of birds, amphibians, and other forest interior species. Historically, this was the most dominant community phase on the landscape.

Pathway 1.1A - Stand-leveling disturbance from wind. Fire may have worked interactively with drought to intensify disturbance, setting succession back even further. Such disturbances were historically uncommon.

Community Phase 1.2 The initiation of the stand development process begins following major blowdown events favoring the establishment of early-successional trees and shrubs, such as quaking aspen, paper birch, beaked hazelnut, and Rubus species. In addition at this time, dominance can be shared with sugar maple and yellow birch advance regeneration in place. It has been estimated that about 40 percent of these may have burned in the years following the blowdown due to extreme fuel buildup and dry conditions (Landfire, 2007). In these cases, the fire-intolerant suite of overstory dominants would have been further set back, favoring complete dominance of quaking aspen and paper birch. Historically, a small portion of the landscape was in this phase.

Pathway 1.2A - Succession (40 – 120 years without disturbance).
**Ecological Site Description**

**Community Phase 1.3** Shade-tolerant species (particularly sugar maple) begin to accumulate in all structural layers of vegetation. Quaking aspen and paper birch begin to die out while sugar maple and yellow birch begin to dominate the young forest. Similar transitions are occurring in the herbaceous layer, with shade tolerant mesophytes becoming more prevalent. After about age 75, a more complex canopy structure develops, and dominant and co-dominant trees become more susceptible to windthrow, providing the first opportunities for gap regeneration. During this phase, shade-tolerant coniferous species like northern white cedar and white spruce begin to accumulate in the understory and midstory. Historically, this community phase was more common than phase 1.2, but it still was a comparatively small portion of the landscape.

Pathway 1.3A - Succession (>120 years without disturbance).

Pathway 1.3B - Stand-leveling disturbance from wind. Fire may have worked interactively with drought to intensify disturbance, setting succession back even further. Such disturbances historically were uncommon.

*Transition 1A* - Selective/intensive logging (high-grading) of healthy, large-diameter conifers and yellow birch.

*Transition 1B* - Clearcut: mechanical removal of all or nearly all trees.

**STATE 2 - SIMPLIFIED MAPLE STATE**

The simplified maple state was the most common state that followed the pre-settlement forests, and may be the most common today. In general, forests on this ecological site were not completely cleared like other forests in the Great Lakes states (as in many coniferous forest types). This was largely due to the abundance of sugar maple which was not a sought after species, and partially because maple (and other hardwoods) could not be easily transported along waterways (Johnson et al., 2009). Instead, destruction of reference communities came in the way of selective logging of sought after species of adequate size (i.e., high-grading). This occurred in numerous pulses, with large eastern white pine and yellow birch removed initially, which likely accounts for the limited occurrence and/or decline of these species today. In many cases, overstory vegetation turned into monotypic sugar maple stands; however, in other cases some level of diversity in the overstory was secured, although probably less than before. These two situations
represent each of the community phases within this state. Like the reference state, these forests tend to be uneven-aged and, with natural succession or thoughtful silviculture (e.g., retention of snags, poor quality trees, etc.), it may be possible to restore some sites to reference conditions (Hale et al., 1999).

Communities in this state are a common occurrence on the modern landscape, particularly in private landholdings which tend to be unmanaged. Today, depending upon the specific location, there may be early stages of earthworm invasion (e.g., Dendrobaena octaedra) as well as some elevated deer browse, but not enough to push it into the Invaded State (which is described later in this Ecological Site Description).

Community Phase 2.1 This may be the most common community phase we see today throughout the distribution of this ecological site. In this phase, sugar maple accumulates to an extreme extent, producing many structural layers in the overstory, subcanopy, and understory. Presumably all or nearly all other overstory species have been selectively cut, leaving sugar maple to dominate. This is essentially a “high-graded” condition. By removal of the sub-dominants (e.g., yellow birch and scattered conifers), there is a high potential for near-extirpation of these species from the site, partly because a legacy seed source no longer is present and partly because of the overwhelming competitive nature of sugar maple. Small sugar maple seedlings also carpet the forest floor, outcompeting forb species and further simplifying the diversity of the ecosystem. Due to the lack of high quality browse and mast, these monotypic stands produce limited habitat for most wildlife species (MN Division of Forestry, 2008), but are often an important local source for maple syrup and probably are under-utilized in this regard.

Given time and appropriate silvicultural prescription to improve diversity and structural development, this community phase could move to 2.2 or possibly even be restored a reference condition. To promote future diversity in the overstory these stands need to be managed. A common technique is to “thin from below”, removing approximately a third of the basal area in the 5-9” and 9-15” diameter classes (Paul Moran, MN DNR Forester, personal communication; Tubbs, 1977). Larger trees (>15” diameter) are often of very poor quality and take up significant growing space, likely inhibiting regeneration. Unfortunately, it is difficult and economically impracticable to remove these trees because they have little timber value. These trees can either be left as residual wildlife trees or cut to promote buildup of coarse woody debris and/or nurse logs for yellow birch regeneration. Foresters often prescribe thinning to be conducted in the summer months in
hopes of scarifying the soil surface to produce a suitable seedbed for yellow birch (Paul Moran, MN DNR Forester, personal communication; Tubbs 1977) which cannot germinate in thick maple thatch (Erdmann, 1990). Artificial regeneration also can be undertaken during this time by planting bare-root seedlings of white spruce and eastern white pine.

**Figure 4.** Photo of Sugar Maple Dominant community within the Simplified Maple State (community phase 2.1) of Till Upland Mesic Hardwood Forests. Photo by Kyle Steele at Finland State Forest, Lake County, Minnesota in September 2012.

Pathway 2.1A - Light disturbance providing fine-scale canopy openings, possibly coupled with underplanting of appropriate tree species, such as yellow birch, white spruce, and northern white cedar. The size of the gap will affect light levels, and thus affect the tree seedlings ability to compete.
Community Phase 2.2. This community phase is very similar to 2.1 but has higher species diversity in the overstory and understory. It is not well-understood why some sites retain more diversity than others. It is likely these communities may have benefited from legacy trees not removed during post-settlement logging activities. In some cases paper birch, beaked hazelnut, and other sun-loving species are more common, possibly resulting from light to moderate disturbances. This could also be related to inherent site factors affecting drainage and available water capacity. While still within the range of correlated soils, these communities are sometimes found on uncharacteristically coarser-textured soils containing higher amounts of sand and rock fragments than is typical. In addition, sites lacking a dense subsurface layer may affect this. One or both of these factors could be enough to allow a greater diversity of vegetation to compete with the sugar maple. It is presumed that the higher diversity in composition and structure characterized by this community produces better wildlife habitat; however, more investigation is needed to understand these dynamics. Similar management recommendations as described in 2.1 should be considered here. Given time and appropriate silvicultural prescription to improve diversity and structural development, this community phase could be restored to a reference condition.

Pathway 2.2A - Selective/intensive logging (high-grading) of conifers and yellow birch, leaving sugar maple to dominate. This community may succeed to 2.1 without management in locations where sugar maple is particularly competitive.

Transition 2A - Clearcut, mechanical removal of all or nearly all trees.
Transition 2B - Introduction of exotic earthworms (particularly Aporrectodea spp. and Lumbricus spp.) or heavy deer browse.

Restoration Pathway 2A - Long term succession (>120 years without disturbance), including a diversity of canopy species (e.g., yellow birch, American basswood, white spruce, eastern white pine, etc.) from natural or artificial regeneration, along with recovery of relevant herbaceous species indicative of the reference state.
STATE 3 - CLEARCUT STATE

Clearcutting in state 1, or more typically in state 2, will convert the community to an even-aged stand which produces an uncharacteristic, age structure for this ecological site. However, community phases within this state can be similar to community phases 1.2 and 1.3 from the reference state, particularly in terms of stand structure. Communities in this state are most common in managed forest settings where forest managers often have goals of improving the sugar maple quality as well as providing better wildlife habitat for various game species, such as white-tailed deer and ruffed grouse (Bonasa umbellus; Tubbs, 1977). Besides the occasional paper birch or localized thicket of quaking aspen, the result is generally a dense monotypic stand of sugar maple (Paul Moran, MN DNR Forester, personal communication). As the stand matures, opportunities develop for management and restoration to states 1 or 2.

There may be early stages of earthworm invasion (e.g., Dendrobaena octaedra) as well as some elevated deer browse in this state, but not enough to significantly alter vegetation or dynamic soil properties. This state is a common occurrence on the modern landscape, particularly in managed, publicly-owned forestland.

Community Phase 3.1 Clearcut management produces the potential for more tree diversity in the future canopy. Due to heavy seedling accumulation and advance regeneration, sugar maple will continue to be a dominant woody species, even in the early years following overstory removal. Sun loving species such as quaking aspen and paper birch will be co-dominant, along with other early-successional species. Yellow birch may be common in this community, depending upon biological legacies from the former stand or on adjacent sites. Without fuel management, these areas will be prone to wildfire, particularly if a period of drought follows the clearcut.

Pathway 3.1A - Succession (>40 years without disturbance).

Community Phase 3.2 Similar to community phase 1.3 in the reference state, shade-tolerant species (particularly sugar maple) will begin to accumulate in all structural layers of vegetation. Quaking aspen and paper birch begin to die out, while sugar maple and possibly yellow birch begin to dominate the young forest. Similar transitions are occurring in the herbaceous layer, with shade-tolerant mesophytes becoming
more prevalent. After about age 75, a more complex canopy structure develops and dominant and co-dominant trees become more susceptible to windthrow, providing the first opportunities for gap regeneration. During this phase, shade-tolerant coniferous species also begin to accumulate in the understory and midstory.

Figure 5. Photo of Mid-Successional community within the Clearcut State (community phase 3.2) of Till Upland Mesic Hardwood Forests. Photo by Kyle Steele at Grand Portage State Forest, Cook County, Minnesota in July 2012.

Pathway 3.2A - 40 – Clearcut, mechanical removal of all or nearly all trees.

Transition 3A - Succession (>75 years without disturbance), monotypic maple stands.
Ecological Site Description

Transition 3B - Introduction of exotic earthworms (particularly *Aporrectodea* spp. and *Lumbricus* spp.) or heavy deer browse.

Restoration Pathway 3A - Succession (>75 years without disturbance), diversity of canopy species (e.g., yellow birch, American basswood, white spruce, eastern white pine, etc.) from natural or artificial regeneration, along with recovery of relevant herbaceous species indicative of the reference state.

STATE 4 – INVADED STATE

The Invaded State is the furthest removed from the Reference State and can transition here from either state 2 or state 3 following long-term heavy deer browse or advanced stage earthworm invasion from *Aporrectodea* spp. and/or *Lumbricus* spp. This state is more common throughout the southwestern part of this ecological site’s distribution, where habitat fragmentation and human development are prevalent.

Stands in this state can be either even-aged following clearcutting, or uneven-aged following selective logging.

Herbivory by deer affects both woody and herbaceous vegetation by direct consumption of plant material. In areas of high deer densities sugar maple may become even more favored due to preferential browsing of other woody species, such as yellow birch and northern white cedar (Rooney and Waller, 2003). Deer herbivory by itself has the potential to cause extirpation of the most preferred, palatable species, such as those in the lily family (Augustine and Frelich, 1998). In extreme cases, vegetation can become so sparse it is possible that changes in soil moisture, soil temperature, and dynamic soil properties may occur; for example, a reduction in soil organic carbon, which may result in a decline in soil moisture or an increase in soil temperature. Overall, elevated herbivory can result in distorted vegetation composition and structure in the forest understory (Alverson et al., 1988; Augustine and Frelich, 1998) and indirectly alter the trajectory of the entire forest ecosystem, thus creating novel, deer-induced natural communities affecting vegetation as well as wildlife patterns (Rooney and Waller, 2003; White, 2012).

Due to the rich soils and lush vegetation, this ecological site (and mesic hardwood forests in general) is particularly susceptible to earthworm degradation (Frelich et al., 2006). The type of leaf litter (e.g., sugar
maple, American basswood, etc.) these forests produce has high nutritional value in comparison to the drier and less nutrient-rich pine, oak, and spruce-fir forests (Frelch et al., 2006; Godman et al., 1990). In previous states, the organic surface horizons may or may not have been affected by the epigeic (i.e., above the soil surface) Dendrobaena octaedra species of earthworm. This species does not by itself cause transition to the invaded state because it only affects the organic surface horizons, which happens by mixing the Oa (i.e., well decomposed) and Oe (i.e., partly decomposed) horizons, but leaving the Oi (i.e., recent litter) intact (Frelch et al., 2006). The advanced stages of earthworm invasion include the presence of D. octaedra as well as the deeper burrowing endogeic (i.e., beneath the soil surface) species in the Aporrectodea and Lumbricus genera, which cause the most significant dynamic soil property changes (Hale et al., 2006; Loss et al., 2013). Aporrectodea and Lumbricus species completely consume the organic surface horizons and incorporate that material into the upper mineral soil horizons (Frelch et al., 2006), producing an uncharacteristic bloated A horizon, along with mixing of any existing E horizons (Figure 6).

In earthworm-free forest soils, there tends to be a net increase in organic material on the soil surface (Great Lakes Worm Watch, 2013). By comparison, in the advanced stages of earthworm invasion, all of this organic material can be completely removed within 3-5 years, making the only input of organic material from new leaf litter each fall, which is quickly consumed, leaving bare soil at the surface by the next fall (Great Lakes Worm Watch, 2013). This process completely alters the nitrogen cycle (which is ultimately depleted from leaching) and produces an unnaturally dense, pan-like layer similar to what happens in plowed agricultural soils (Frelch et al., 2006). Changes in dynamic soil properties, such as loss of the organic surface along with higher bulk densities in the subsoil, could produce drier growing conditions for plants, affecting the ability for characteristic native species to persist. The loss of the organic surface also can expose tree roots, potentially causing long-term effects on the life and/or health of trees. However, immature trees (i.e., saplings and seedlings) are likely to be the most at risk to root exposure. Sugar maple seedlings in particular decrease dramatically as a result of earthworm invasion (Hale et al., 2006). Plant seeds also are affected, as the duff layer provides insulation from hot and cold weather extremes and protection from predation by small mammals and birds (Great Lakes Worm Watch, 2013). Another negative consequence of advanced earthworm invasion is the effect on important soil bacterial and fungal networks, including symbiotic mycorrhizae, which facilitate essential water and nutrient uptake to many native plant species (Great Lakes Worm Watch, 2013).
Advanced earthworm invasion results in a dramatically altered plant rooting environment, both physically and chemically. Some species are able to handle these changes, while others are not. Pennsylvania sedge (Carex pensylvanica), one of the few non-mycorrhizal species, along with wild leeks (Allium tricoccum) and jack in the pulp (Anisocoma triphyllum), which produce toxic secondary chemicals hazardous to herbivores (and may also be avoided by earthworms), have been shown to increase in these situations (Table 10: Frelch et al., 2008; Holdsworth et al., 2007). In comparison, other species like bigleaf aster and wild sarsaparilla tend to decrease (Table 10: Holdsworth et al., 2007; Great Lakes Worm Watch, 2013). Although earthworms do not kill canopy trees, it is expected that long-term recruitment will be affected, particularly in the sapling stage. This may cause elevated sunlight to the forest floor, increasing the likelihood for dry-mesic, mid-tolerant species to establish (Frelch et al., 2008).

Ultimately, the interaction of both heavy deer browse and advanced stage earthworm invasion results in extremely degraded conditions, potentially paving the way for other invasive, exotic species such as common buckthorn (Rhamnus cathartica), honeysuckle (Lonicera tatarica, L. morrowii, L. x bella spp.), and garlic mustard (Alliaria petiolata, as represented in community phases 4.3 and 4.4: Figure 2). Overall,
combined effects of invasion by deer, earthworms, and exotic plants can initiate an ecosystem decline syndrome that can negatively affect all parts of the ecosystem, from overstory structure, to forb diversity, soil properties, bacteria, fungi, insects, birds, reptiles, amphibians, and mammals. Sites near larger cities, heavily-used lakes, or other developed areas are particularly susceptible to the combination of deer, earthworm, and invasive vegetation problems. Currently, we do not believe any community phases with advanced earthworm invasion can be restored. More research on this topic is needed.

Community Phase 4.1. This community phase can be variable depending on the type, amount, and timing of deer browse. If browse occurs in both summer and winter, all vegetation types are affected. If browse is more common in the winter months, woody vegetation will be affected. In these cases no species are spared, however, balsam fir and white spruce seem to be the less preferred (Anderson et al., 2002; White, 2012). If browse occurs in the summer, mostly forb species are affected, often increasing the importance of grasses, sedges (Carex spp.), and less palatable forb species, such as jack in the pulpit and wild leeks (Frellich et al., 2006; Rooney and Waller, 2003).

Table 10. List of common plant species documented to increase or decrease following earthworm invasion. Reproduced with approval by Great Lakes Worm Watch (www.mlwr.umn.edu/worms).

<table>
<thead>
<tr>
<th>Life Form</th>
<th>Scientific Name</th>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Common Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forbs and Sedges</td>
<td>Acorus calamus</td>
<td>Wild sarsaparilla</td>
<td>Arisaema triphyllum</td>
<td>Jack in the pulpit</td>
</tr>
<tr>
<td></td>
<td>Polygonatum pubescens</td>
<td>Hairy Solomon's seal</td>
<td>Molanthemum racemosum subsp. racemosum</td>
<td>False Solomon's seal</td>
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<td></td>
<td>Uvularia grandiflora</td>
<td>Largeflower bellwort</td>
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<tr>
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<td>Uvularia sessilifolia</td>
<td>Sessileleaf bellwort</td>
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<td>Streptopus roseus</td>
<td>Twistedstalk</td>
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<td></td>
<td>Aster macrophyllus</td>
<td>Bigleaf aster</td>
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<td>Hepatica nobilis var. obtusa</td>
<td>Roundlobe hepatica</td>
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<tr>
<td></td>
<td>Trifolium borealis</td>
<td>Starflower</td>
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<tr>
<td>Ferms</td>
<td>Dryopteris spp.</td>
<td>Woodferns</td>
<td>None</td>
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<td>Tree Seedlings</td>
<td>Acer saccharum</td>
<td>Sugar maple</td>
<td>Fraxinus spp.</td>
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</tr>
<tr>
<td></td>
<td>Acer rubrum</td>
<td>Red maple</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tilia americana</td>
<td>American basswood</td>
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<tr>
<td></td>
<td>Amelanchier spp.</td>
<td>Serviceberry</td>
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</tbody>
</table>
Ecological Site Description

Significant deer browse is most common near developed areas, especially around the City of Duluth. Deer browse is not common in more natural, undeveloped landscapes common in the northeastern extent of this ecological site. In a more natural landscape setting, this ecological site does not provide great deer habitat. In the summer months, deer use these areas as corridors and sporadically browse individual plants. During the winter months, these sites often experience heavy lake effect snow that can accumulate to several feet in depth and as a result, deer tend to migrate closer to the shore of Lake Superior where temperatures are warmer and there is less snowfall (Chel Anderson, MN DNR Ecologist, personal observation). In addition, the open nature of a hardwood-dominated canopy does not shelter snow well, as one would expect beneath a coniferous forest.

Figure 7. Photo of Invaded State (community phase 4.2) of Till Upland Mesic Hardwood Forests showing effect of earthworm invasion, including thin seedling layer, loss of organic surface horizons, and Pennsylvania Sedge in the forb layer. Photo by Kyle Steele at Magney-Snively Natural Area, St. Louis County, Minnesota in September, 2011.
Ecological Site Description

Pathway 4.1A - Advanced stage earthworm invasion by species in the *Aporrectodea* and/or *Lumbricus* genera.

**Community Phase 4.2** Advanced stage earthworm invasion from *Aporrectodea* spp. and/or *Lumbricus* spp. This community phase results in removal of organic duff layers incorporated into the mineral surface horizons, affecting rooting and nutrient availability. Pennsylvania sedge and jack in the pulpit increase while others decrease or become extirpated (Table 10). Downed woody debris decays at an accelerated rate, affecting various wildlife species such as salamanders.

Pathway 4.2A - Heavy deer browse.

**Community Phase 4.3** Following the initial pulse of plant mortality by advanced stage earthworm invasion or deer herbivory, the combined effect of both of these unnatural disturbances puts plants at even greater risk of extirpation and produces a severely degraded community. Species already affected in 4.1 and 4.2 are now dangerously susceptible to elimination from the site, due in large part to a higher deer-to-plant ratio.

Pathway 4.3A - Deer management.
Pathway 4.3B - Introduction of invasive vegetation (buckthorn, honeysuckle, and/or garlic mustard).

**Community Phase 4.4** Following the interaction of heavy deer browse and advanced earthworm invasion the ecosystem changes significantly, potentially paving the way for better-adapted exotic plant species like common buckthorn, honeysuckle, and garlic mustard. Lack of competition from native plants combined with a warmer, drier, and sunnier understory is a benefit to these species (Great Lakes Worm Watch, 2013).

Pathway 4.4A - Invasive vegetation management.
Pathway 4.4B - Invasive vegetation + deer management.

**Restoration Pathway 4A** - Currently we only have community phase 4.1 as a potentially restorable community, following the management of deer herbivory. At this time there is no evidence showing it is possible to remove earthworms from a forest soil.

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March 13, 2014
Supporting Information

Relationship to Other Established Classifications

Superior National Forest Terrestrial Ecological Unit Inventory (SNF unpublished report a, b); mapping concepts are most similar to:
- Landtype: 14 Upland Deep Medium Loamy
- Landtype Phase: 55 Unnamed (Superior moraines, well/mod well drained, >40°, <18 percent clay)

MN DNR Native Plant Community Classification (MN DNR, 2005); the reference community of this ecological site is most similar to:
- Primary: MHN45a,c Northern Mesic Hardwood (Cedar) Forest
- Secondary: MHN47a Northern Rich Mesic Hardwood Forest

Vegetation Associations (National Vegetation Classification System, NatureServe, 2013a); the reference community of this ecological site is most similar to:
- Primary: Sugar Maple – Yellow Birch – (American Basswood) – Forest

Ecological Systems (National Vegetation Classification System, NatureServe, 2013); the reference community of this ecological site is most similar to:
- Laurentian-Acadian Northern Hardwood Forest

Associated Ecological Sites

Spatial distribution of the associated map units for this ecological site currently do not reflect the lake-moderated climate effect. As a result, there likely is at least one additional ecological site within the distribution of the components correlated to Till Upland Mesic Hardwood Forests that is not described here. More work is needed and map unit separation likely will be necessary.

Similar Ecological Sites

The northern hardwood forest type is uncommon in this MLRA. However, there may be a similar ecological site of small extent on the deep, loamy soils derived from Rainy Lobe materials in west-central St. Louis County. There currently is no ecological site developed for this unit. Further investigation is needed.
Inventory Data References

A total of 27 integrated plots, ranging from Tier 2 to Tier 3 intensity, were used as a basis for this ecological site (Figure 8). Three of these were Type Locations representing the data-supported community phase 1.1 in the state-and-transition model (Figure 2), and included all necessary data elements for a Tier 3 dataset (Table 11). No other community phases were supported with quantitative data analysis, and were composed mostly of community phases closely resembling 1.1, 1.3, 2.1, and 4.2. All 27 plots had soil pedon and site data collected by a professional soil scientist using a form equivalent to SF-232. Most pits were hand-dug using spade shovels, sharpshooters, and/or bucket augers. A few were collected using a backhoe. Of the 27 plots, 20 were located at established MN DNR relevé points, obtained and used with permission from the MN DNR County Biological Survey (see list below). Three additional relevés were completed by NRCS ecological site staff. Nine locations also had Tier 2 level vegetation data collected, which included species lists and qualitative structure and cover estimates.

List of MN DNR relevé plots used with verified soils data: 100, 106, 117, 891, 983, 984, 4694, 5639, 8268, 8275, 8276, 8279, 8282, 8293, 8294, 8413, 8845, 8846, 8852, and 8855.

Figure 8. Tier 2 and 3 plot locations used as a basis for this ecological site, and NOAA climate stations used for climate analysis.
### Table 11. Location of Tier 3 data used for Type Locations.

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<td>T49 R15 S22</td>
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Other References


Acknowledgements

Ethan Perry and Chel Anderson (Ecologists, MN DNR - County Biological Survey) provided invaluable guidance throughout the development of this ecological site concept, and participated in development of the state and transition model. Jeff Kroll (Ecologist, BARR Engineering – formerly NRCS) was instrumental in the initiation of the ecological site concept. Myles Elsen and Larissa Schmitt (Soil Scientists, NRCS) collected soils point data. Stacey Clark (Regional Ecological Site Specialist, NRCS), Ginger Kopp (MN State Forester, NRCS), and Will Bomier (Area Resource Conservationist, NRCS) collected type location data. Peter Weikle (Soil Data Quality Specialist, NRCS) provided database support. Mark Krupinski (Ecological Site Specialist, NRCS) conducted the quality control review. Stacey Clark conducted the quality assurance review and provided guidance throughout the development of this ecological site description.

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Finally, we thank the MN DNR for the use of their relevé plot database and associated Native Plant Community Classification. This unparalleled work paved the way for our understanding of this ecosystem.
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Maple syrup makers see early start across Northland
By John Myers
March 23, 2015
Reprinted with permission from the Duluth News Tribune

The warm March days of late have awakened sugar maple trees from their winter naps, starting a process that has yielded sweet sensations for centuries.

Across the region, the warm-up has spurred sap to start flowing in maple woods, called sugarbushes, where maple syrup lovers have hammered in taps. In buckets, bags or through plastic tubes, that sap is being collected now to be boiled down to make pure maple syrup.

“Forty degrees during the day is good, and about 25 to 30 at night ... you need the up and down to keep it going good,” said Mark Spinler, who, with Melinda Spinler, runs Maple Hill Sugarbush just off the Gunflint Trail outside Grand Marais.

Spinler said this season’s early warm-up was just what their maples needed. But only if temperatures keep going up and down past the freezing mark.

The sap run “can last until the trees start to bud out, as long as you get that temperature range,” Spinler said. “Six weeks is about what we get out of a good season.”

“This was a really early start,” said Dave Rogotzke, whose family taps sugar maples just north of Duluth.

The string of unusually warm days “kickstarts the trees” to produce sap. “But it can also shut things down if it gets warm and stays warm,” Rogotzke said. “So far, it’s been just perfect. It hasn’t been so warm that it caused problems.”

In 2012, Northland temperatures rose too soon and never cooled off, drastically cutting into sap production. In 2013 and 2014, spring came late but the sap flowed into May, and Rogotzke had two good seasons.

On average it takes about 40 gallons of sap to make one gallon of syrup.

The Spinlers tap 650 trees and will end up with about 150 gallons of pure, sweet maple syrup to sell each spring — most of it by word of mouth or at the family’s Superior North bicycle shop in town.

“We get a lot of school groups and people up here to watch how it’s done,” said Spinler, who has been tapping trees and boiling sap down to syrup for 30 years, the last 15 of those commercially.

The Spinlers have an average-size sugarbush in northern Minnesota where operations range from a few hundred taps to more than 24,000 at Sawtooth Mountain Maple Syrup north of Lutsen — Minnesota’s largest sugarbush.

Rogotzke finished with 900 gallons of syrup bottled last year off his 200 acres where 50 miles of plastic tubing connects 5,000 trees in his sugarbush to his sugar shack, a high-tech processing center filled with gleaming stainless steel tanks and cookers.
A vacuum pump sucks the sap out of the trees, through the tubes and into a pair of 3,000-gallon stainless steel tanks designed for dairy farms. From there the sap runs through a reverse osmosis filter system that pulls out 70 percent of the water, saving time and energy in the cooking process.

The thicker sap is then cooked at 220 degrees to boil off even more water until sticky sweet perfection is reached. The family’s bottled syrup is sold to local restaurants, grocery stores, over the Internet and out of their sugar shack in Lakewood Township.

On a sunny afternoon last week, Rogotzke battled through wafts of steam from the boilers to check the temperature and sugar content before declaring that batch perfect enough to bottle. “There’s a lot of chemistry going on here,” he said.

“The weather has a lot to do with it. We had a little moisture this morning and a change in the barometric pressure and the trees were really going,” Rogotzke said before checking another valve and tightening a filter.

He’s busier a little earlier than normal this year, but with many gallons of syrup already bottled, boxed and ready to deliver, Rogotzke wasn’t complaining.

“I think today is the best day we’ve had so far this season,” Rogotzke said. “It’s looking good.”

To learn more

To buy syrup or take a tour of a maple syruping operation, call the Spinlers at (218) 387-2186 at Maple Hill Sugarbush near Grand Marais or the Rogotzkes at Simple Gifts Syrup and Salmon near Duluth at (218) 525-5474 or at www.simplegiftssyrupandsalmon.com.
SITE D: SUPERIOR VERY FINE TILLS
MLRA 9A - CUTTRE SOILS
NCSS Wednesday Tour
MLRA 92 – Superior Lake Plain

Figure 92-1: Location of MLRA 92 in Land Resource Region K

Introduction

This area (shown in fig. 92-1) is in Wisconsin (48 percent), Michigan (39 percent), and Minnesota (13 percent). It makes up about 2,920 square miles (7,570 square kilometers). The cities of Duluth, Minnesota, Superior, and Ashland, Wisconsin, and Ontonagon, Michigan, are in this MLRA. Interstate 35 ends in Duluth. A large part of the Ottawa National Forest is in the eastern half of this area. The Ontonagon, Bad River, and Red Cliff Indian Reservations are in the area. Numerous State parks and State forests are throughout the area. The Apostle Islands National Lakeshore is in this MLRA.

Physiography

All of this area is in the Superior Upland Province of the Laurentian Upland. The area is characterized by a till plain mixed with lake plains, lake terraces, beaches, flood plains, swamps, and marshes. Some rocky knobs, hills, and low mountains make up part of this nearly level lake plain. Elevation ranges from 600 to 1,400 feet (185 to 425 meters), increasing gradually from the lakeshore inland. Local relief on the lake plain is only 3 to 6 feet (1 to 2 meters), but the adjoining hills and low mountains rise sharply from 85 feet (25 meters) to more than 330 feet (100 meters) above the plains.

The extent of the major Hydrologic Unit Areas (identified by four-digit numbers) that make up this MLRA is as follows: Western Lake Superior (0401), 60 percent, and Southern Lake Superior-Lake Superior (0402), 40 percent. Some of the streams crossing this area and emptying into Lake Superior are the Bois Brule, Nemadji, Whittlesey, Montreal, Black, Presque Isle, and Ontonagon Rivers in Wisconsin and Michigan and numerous steep-gradient streams along the north shore of Minnesota.

Geology

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This area has been glaciated, and most of the surface deposits are fine textured till derived from glacial lake sediments. The bedrock in the area is a mixture of late Precambrian and Cambrian sandstones and shales and mafic igneous rocks. It is known as the Keweenawan Group in Wisconsin and Minnesota. The bedrock units in Michigan are known as the Freda and Jacobsville sandstones, Nonesuch shale, the Portage Lake volcanics, and the Copper Harbor conglomerate.

Climate

The average annual precipitation in this area is 27 to 37 inches (685 to 940 millimeters). It is lowest along the lakeshore and highest in inland areas. The maximum precipitation occurs as high-intensity, convective thunderstorms in summer, and the lowest precipitation occurs in midwinter. Precipitation in winter occurs as snow. The average annual temperature is 38 to 42 degrees F (4 to 6 degrees C). The freeze-free period averages about 155 days and ranges from 125 to 190 days.

Water

Following are the estimated withdrawals of freshwater by use in this MLRA:

- Public supply—surface water, 3.4%; ground water, 0.0%
- Livestock—surface water, 0.7%; ground water, 0.4%
- Irrigation—surface water, 0.0%; ground water, 0.0%
- Other—surface water, 95.5%; ground water, 0.0%

The total withdrawals average 155 million gallons per day (585 million liters per day). Almost 100 percent is from surface water sources. Precipitation is adequate for crops and pasture. Drainage of level areas of wet soils is needed for good growth of crops. The area has few inland lakes, but much of the area has access to Lake Superior for water supply and recreation. Most of the “other” water use in this area is for the wood and paper products industries. Iron ore, limestone, and dolomite are shipped from the Great Lakes harbors at Duluth, Minnesota, and Superior, Wisconsin, and some surface water is used in handling those materials. The surface water is of good quality. It is hard but is suitable for most uses with little or no treatment.

Two sources of ground water occur in this area. One is the isolated pockets of unconsolidated sand and gravel in the glacial drift. The other is the Lake Superior Sandstone and Precambrian Lava Flows aquifer. Water from both of these aquifers is moderately hard to very hard and is typically very low in total dissolved solids, having less than 300 parts per million (milligrams per liter). About 30 percent of all the wells tested in these aquifers had iron and manganese concentrations that exceeded the national secondary standards for drinking water. These standards are for esthetics and do not affect human health. Staining and scale-buildup in pipes and on appliances occur when high amounts of iron and manganese occur in water.

Soils

The dominant soils in this MLRA are Alfisols, Spodosols, Inceptisols, and Entisols. The soils in the area have a frigid soil temperature regime, an udic or aquic soil moisture regime, and mixed or isotic
mineralogy. The major soils formed in clayey to loamy till in some areas with a sandy mantle. Some soils, primarily along the edges of the MLRA, have stratified silty and clayey lacustrine deposits. The soils in some areas along the shore of Lake Superior formed in organic material or in sandy beach deposits.

Glossudalfs on till plains formed in very deep clayey or loamy till (Miskoaki, Amnicon, Cuttre, Odanah, Sanborg, Badriver, Watton, Flintsteel, and Big Iron series) or in clayey till that is deep to loamy or sandy lacustrine deposits (Anton, Borea, Cornucopia, Portwing, and Herbster series). Haplorthods formed in clayey till mantled with loamy material (Superior, Ubly, and Belding series), in clayey till mantled with sandy material (Manistee, Kellogg, and Ashwabay series), and in loamy till mantled with sandy material (Menominee and Morganlake series) on till plains and remnant beaches; in silty lacustrine deposits (Sporley and Fence series) on lake plains and remnant beaches; in sandy beach, dune, or lacustrine deposits (Rousseau, Neconish, Vilas, Croswell, Sultz, and Cublake series) on remnant beaches and dunes; in clayey, loamy, and sandy deposits over sandstone bedrock (Lapoin, Abbaye, Brownstone, and Redrim series) in bedrock-controlled areas along Lake Superior. Epiaquepts formed in very deep clayey or loamy till (Bergland, Pickford, and Munuscong series); in clayey till that is deep to loamy and sandy lacustrine material (Lerch and Happyhollow series); or in clayey till mantled with sandy material (Wakeley series) in depressions on till plains. Haplohemists (Rifle series) formed in organic deposits in marshes along Lake Superior, and Haplosaprists (Seeleyville, Cathro, Lupton, Dorval, and Tawas series) formed in organic deposits in inland swamps and in side-hill seep areas. Udipsamments (Grayling, Wurtsmith, and Meehan series) formed in sandy beach and dune deposits on active beaches. Udifluvents formed in silty alluvium (Moquah series) or sandy alluvium (Pelkie and Dechamps series) on flood plains.

**Biological Resources**

This area supports deciduous and evergreen trees. Boreal forests (aspen, white birch, balsam fir, white spruce, white pine, red pine, white cedar, and tamarack) and mixed deciduous and coniferous forests (hemlock, sugar maple, yellow birch, red pine, and white pine) are dominant. Swamp conifers and lowland brush commonly grow on the wetter soils.

Some of the major wildlife species in this area include black bear, white-tailed deer, coyote, snowshoe hare, timber wolf, ruffed grouse, tree squirrel, bald eagle, and Canada goose. The species of fish in the area include northern pike, perch, walleye, largemouth bass, smallmouth bass, brook trout, steelhead trout, and panfish.

**Land Use**

Following are the various kinds of land use in this MLRA: Cropland—private, 10%
- Grassland—private, 4%
- Forest—private, 68%; Federal, 12%
- Urban development—private, 3%
- Water—private, 1%
- Other—private, 2%
More than three-fourths of this area is forested, and about two-thirds is privately owned forestland used for timber production and recreation. About one-tenth of the MLRA is cropland used mainly for small grains and hay for dairy cattle and other livestock. Apples, blueberries, trefoil seed, and other specialty crops are important cash crops in some areas. Only a small part of the land is used for pasture.

The major soil resource management concerns are water erosion, wetness, soil fertility, and soil tilth. Conservation practices on cropland generally include crop rotations, conservation tillage systems, and grassed waterways. Surface drainage systems are needed to remove surface water from wet areas.

CUTTRE SERIES

The Cuttre series consists of very deep, somewhat poorly drained soils formed in clayey till on till plains. Permeability is extremely slow or very slow. Slopes typically are 0 to 3 percent but range to 8 percent. Mean annual precipitation is about 31 inches. Mean annual air temperature is about 40 degrees F.

TAXONOMIC CLASS: Very-fine, mixed, active, frigid Aeric Glossaqualfs

TYPICAL PEDON: Cuttre clay, on a concave, southeast facing, 1 percent slope in an area of mixed conifer and northern hardwoods at an elevation of about 860 feet. (Colors are for moist soil unless otherwise noted.)

A--0 to 3 inches; dark reddish brown (5YR 2.5/2) clay, dark reddish gray (5YR 4/2) dry; weak medium granular structure; friable; many fine and medium and few coarse roots; about 1 percent gravel; strongly acid; abrupt smooth boundary. (2 to 4 inches thick)

E/B--3 to 6 inches; 70 percent brown (7.5YR 5/2) clay loam (E), pinkish gray (7.5YR 7/2) dry; weak medium subangular blocky structure; friable; few faint reddish brown (5YR 4/3) clay films on faces of peds; many medium distinct brown (7.5YR 5/4) and few medium distinct strong brown (7.5YR 4/6) masses of iron accumulation; extends as tongue into and surrounds remnants of reddish brown (5YR 5/3) clay (Bt); weak medium subangular blocky structure; firm; many fine and medium and few coarse roots; about 1 percent gravel; strongly acid; clear wavy boundary.

B/E--6 to 12 inches; 70 percent reddish brown (2.5YR 4/4) clay (Bt); moderate medium angular blocky structure; firm; common distinct reddish brown (5YR 5/3) clay films on faces of peds; common brown (7.5YR 5/2) coatings of E material on faces of some Bt peds; penetrated by tongues of brown (7.5YR 5/2) clay loam (E), pinkish gray (7.5YR 7/2) dry; moderate medium subangular blocky structure; firm; common fine and medium roots; common medium prominent yellowish red (5YR 5/6) masses of iron accumulation; about 1 percent gravel; moderately acid; clear wavy boundary. (Glossic horizon - 2 to 15 inches thick)

Btk1--25 to 31 inches; dark reddish brown (2.5YR 3/4) clay; moderate fine angular blocky structure; firm; common fine and few medium roots; common faint reddish brown (2.5YR 4/4) clay films on faces of peds; few brown (7.5YR 5/2) coatings of E material on faces of peds; few fine faint reddish brown (2.5YR 5/4) masses of iron accumulation; about 1 percent gravel; slightly alkaline; clear wavy boundary (5 to 19 inches thick)

Btk2--25 to 31 inches; dark reddish brown (2.5YR 3/4) clay; moderate fine angular blocky structure; firm; few fine and medium roots between peds; common faint reddish brown (2.5YR 4/4) clay films on faces of peds; common fine and medium irregular distinct light reddish brown (2.5YR 6/4) soft masses of calcium carbonate; strongly effervescent (11 percent calcium carbonate); about 1 percent gravel; moderately alkaline; clear wavy boundary.

Btk2--31 to 41 inches; reddish brown (2.5YR 4/4) clay; weak coarse angular blocky structure; firm; few fine roots between peds; few faint dark reddish brown (2.5YR 3/4) clay films on faces of peds; common medium and coarse irregular faint light reddish brown (2.5YR 6/4) soft masses of calcium carbonate; many very fine and fine irregular prominent black (N 2.5/0) soft masses of iron-manganese oxides;
violently effervescent (14 percent calcium carbonate); about 2 percent gravel; moderately alkaline; gradual wavy boundary. (Combined thickness of the Btk horizon ranges from 15 to 45 inches)

**BC**—41 to 80 inches; reddish brown (2.5YR 4/4) clay; weak coarse prismatic structure; firm; few fine roots between peds; common medium irregular faint light reddish brown (2.5YR 6/4) soft masses of calcium carbonate and few medium irregular prominent greenish gray (5GY 6/1) carbonate coats on vertical faces of peds; many very fine and fine irregular prominent black (N 2.5/0) soft masses of iron-manganese oxides; violently effervescent (13 percent calcium carbonate); about 2 percent gravel; moderately alkaline. (0 to 50 inches thick)

**TYPE LOCATION:** Douglas County, Wisconsin; about 1/2 mile east and 2 1/2 miles north of Poplar; 50 feet south and 920 feet west of the northeast corner of section 30, T. 48 N., R. 11 W.; USGS Poplar, WI quad.; lat. 46 degrees, 37', 08" N. and long. 91 degrees, 47', 14" W.

**RANGE IN CHARACTERISTICS:** Depth to the base of the argillic horizon ranges from 40 to 60 inches. Depth to free carbonates ranges from 20 to 40 inches. The weighted average clay content of the particle-size control section ranges from 60 to 85 percent. These soils have linear extensibility of 6 cm or more in the upper 40 inches. Volume of gravel ranges from 0 to 6 percent throughout. Volume of cobbles ranges from 0 to 2 percent throughout. Mudflow lenses or remnant discontinuous disoriented varves occur in individual horizons in some pedons. Redox features occur in all layers between either the lower boundary of an Ap horizon or a depth of 10 inches below the mineral soil surface (whichever is deeper) and a depth of 16 inches. Aquic conditions occur within 20 inches for some time in most years. Cuttre soils react positively to alpha, alpha-dipyridyl at some time when the soil is saturated.

The A horizon has hue of 5YR, or 7.5YR, value of 2 or 3, and chroma of 1 to 3. Cultivated pedons have an Ap horizon with hue of 5YR or 7.5YR, value of 3 or 4, and chroma of 2 or 3. Reaction naturally ranges from very strongly acid to moderately acid but ranges to neutral, where the soil is limed.

Some pedons have an E horizon with hue of 2.5YR, 5YR or 7.5YR; value of 4 or 5, and chroma of 2 or 3. Colors of 4/3 or 5/3 have value dry of 7 or more. The E horizon is loam, silt loam, silty clay loam, clay loam, silty clay or clay.

Cuttre soils have a gossic horizon (E/B or B/E horizon or both). The E part has color like the E horizon described above. Typically it is clay loam, silty clay loam, silty clay or clay but in some pedons, it is silt loam or loam in the upper part. The Bt part has hue of 2.5YR or 5YR, value of 3 to 5, and chroma of 3 to 6. It is silty clay loam, silty clay, or clay. Reaction is strongly acid or moderately acid.

The Bt horizon has hue of 2.5YR or 5YR, value of 3 or 4, and chroma of 4 to 6. Reaction is neutral or slightly alkaline. Typically it is clay but subhorizons of silty clay are in some pedons.

The Btk horizon has hue of 2.5YR or 5YR; value of 3 to 5; and chroma of 4 to 6. Reaction is slightly alkaline or moderately alkaline.

The BC horizon has hue of 2.5YR or 5YR and value of 3 to 5. It is moderately alkaline or strongly alkaline.

Some pedons have a C horizon with color, texture, and reaction like the BC horizon described above.
**COMPETING SERIES:** This is the Borea series. Borea soils have stratified loamy and sandy lacustrine deposits in the lower part of the series control section at a depth of 40 to 60 inches.

**GEOGRAPHIC SETTING:** Cuttre soils are on flats, drainageways, depressions and long backslopes on till plains. Slopes typically are 0 to 3 percent but range to 8 percent on backslopes and footslopes. They formed in clayey till derived from clayey lacustrine deposits. Mean annual precipitation ranges from 28 to 33 inches. Mean annual air temperature ranges from 36 to 43 degrees F. The frost free period ranges from about 90 to 120 days. Elevation ranges from 600 to 1000 feet.

**GEOGRAPHICALLY ASSOCIATED SOILS:** These are the Amnicon(T), Anton(T), Bergland, Borea(T), Miskoaki(T), and Sedgwick soils. The moderately well drained Amnicon soils, the well drained Miskoaki soils, and the poorly drained Bergland soils form a drainage sequence with Cuttre soils. The moderately well drained Anton soils and the somewhat poorly drained Borea soils form a drainage sequence in areas adjacent to some Cuttre soils where there is stratified loamy and sandy lacustrine deposits at 40 to 60 inches. The somewhat poorly drained Sedgwick soils are nearby where there is a loamy outwash mantle 10 to 24 inches thick over the clayey till.

**DRAINAGE AND PERMEABILITY:** Somewhat poorly drained. Runoff is low to high. Permeability is extremely slow or very slow. Cuttre soils have a perched seasonal high water table at a depth of 0.5 to 2.0 feet for much of the time from September to June in most years. On the steeper slopes the duration is about a month following snowmelt and/or periods of heavy rainfall.

**USE AND VEGETATION:** Most area are used for woodland. Some areas are used for cropland or pastureland. Oats, timothy, bromegrass, bluegrass, alfalfa, and trefoil are the principal crops. Many areas which were formally cropland are now idle and are reverting to natural vegetation. Native vegetation is mixed deciduous and coniferous forest. Common trees are red maple, balsam fir, balsam poplar, quaking aspen, paper birch, bur oak, and willow. Common understory plants are speckled alder, redosier dogwood, black snakeroot, wild sarsaparilla, and bracken fern.

**DISTRIBUTION AND EXTENT:** Northern Wisconsin along Lake Superior (MLRA K92). This series is extensive.

**MLRA SOIL SURVEY REGIONAL OFFICE (MO) RESPONSIBLE:** St. Paul, Minnesota

**SERIES ESTABLISHED:** Douglas County, Wisconsin, 1994. The name is coined.

**REMARKS:** An Aeric Vertic subgroup should be proposed to recognize the vertic feature. Diagnostic horizons and features recognized in this pedon: ochric epipedon - 0 to 3 inches (A); glossic horizon - 3 to 12 inches (E/B, B/E); argillic horizon - 6 to 41 inches (B/E, Bt, Btk1, Btk2); vertic feature - linear extensibility is 6 cm or more in the upper 40 inches; aquic feature - redox features in all layers between a depth of 10 inches below the mineral soil surface and a depth of 16 inches and aquic conditions within 20 inches for some time in most years.
CUTTRE – PEDON DESCRIPTION

Description Date: 7/29/2014
Describers: Roger Risley, Larissa Schmitt
Site ID: S2014MN137025
Soil Name as Sampled: Cuttre
Soil Name as Correlated: Cuttre
State: Minnesota
County: St. Louis
MLRA: 92 – Superior Lake Plain
Datum: WGS83
UTM Zone: 15
Latitude: 46 degrees 56 minutes 12.17 seconds North
Longitude: 91 degrees 52 minutes 51.16 seconds West

Classification: Very-fine, active, frigid Aeric Glossaqualfs
Geomorphic Setting: on summit of till plain
Particle Size Control Section: 38 to 78 cm

Diagnostic Features:
- albic horizon 13 to 22 cm.
- aquic conditions 13 to 38 cm.
- glossic horizon 22 to 38 cm.
- argillic horizon 38 to 78 cm.

A--0 to 13 centimeters; very dark gray (10YR 3/1) silt loam, dark brown (10YR 3/3), dry; strong medium granular structure; very friable; ; very abrupt wavy boundary.

E--13 to 22 centimeters; brown (7.5YR 6/2), dry; strong very thick platy structure parts to strong thick angular blocky structure; friable; 2 percent fine distinct strong brown (7.5YR 5/6), moist, iron-manganese masses; 5 percent very fine prominent spherical black (10YR 2/1) ferromagnesian minerals; ; gradual wavy boundary.

2B/Et--22 to 38 centimeters; 60 percent reddish brown (5YR 4/4) and 40 percent brown (7.5YR 5/2) silty clay, loam; strong medium angular blocky structure; firm; 5 percent fine distinct strong brown (7.5YR 5/6), moist, masses of oxidized iron and 5 percent medium distinct strong brown (7.5YR 4/6) iron-manganese concretions; 5 percent very fine prominent black (10YR 2/1) ferromagnesian minerals; ; diffuse irregular boundary.

2Bt--38 to 78 centimeters; reddish brown (5YR 4/4) clay; strong medium angular blocky structure; firm; faint reddish brown (5YR 4/4) clay films on all faces of peds and distinct pressure faces on vertical faces of peds; 1 percent 2- to 20-millimeter mixed rock fragments; ; clear wavy boundary.

2Bk--78 to 103 centimeters; reddish brown (5YR 5/4) clay; moderate medium angular blocky structure; firm; pressure faces; 5 percent fine distinct light gray (5YR 7/1) carbonate masses; 2 percent 2- to 20-millimeter mixed rock fragments; strong effervescence, by HCl, unspecified; ; clear wavy boundary.
Guidebooks for Field Trips

*** Primary Characterization Data ***

(St. Louis, Minnesota)

Sampled as on Jul 29, 2014.
Cutline: Very fine, mixed, active, frigid Aeric Gleysol aqua

United States Department of Agriculture
Natural Resources Conservation Service
Soil Survey Laboratory
Lincoln, Nebraska 68508-3666

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Pedon Calculations

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Aggregated results based on whole profile - cm

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**Sample As:** Cutterr  
**USDA NRCS-NSSC National Soil Survey Laboratory**

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### Primary Characterization Data

*St. Louis County, Minnesota*

Very fine, mixed, active, frigid Aeric Glossaqualf

_Pedon No. 14N0994_

### CEC & Bases

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*Extractable Ca may contain Ca from calcium carbonate or gypsum. CEC7 base saturation set to 100.*

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**NCSS Wednesday North Shore Tour**

**LUNCH: LESTER PARK**

Lester Park is one of many city parks in Duluth within a woods setting. The local Ojibwa call the river, Busabikazibi, which means, “Rocky Canyon River, or the river where the water flows through a worn place in the rocks.” The name Lester came from the George V. Leicester who settled the banks of the river in the mid-1850’s.

The park was been a picnicking and fishing spot for Duluthians since the 1880. The neighborhood of Lester Park and the park itself were annexed into Duluth in 1893. Over the years there have been many land additions to the park and today the park is over 400 acres. Activities in the park include cross-country ski trails, hiking trails, fishing, a golf course, and whitewater class IV-V kayak race in the spring.

The trout stream, Amity Creek joins Lester River at the south part of the park. Lester River is still a main fishing spot in spring and fall with salmon, steelhead and kamloops rainbow. Plus, the smelt run in spring.


**DINNER IN TWO HARBORS:**

**Two Harbors’ Ore Docks**

Charlemagne Tower’s Duluth & Iron Range Railroad built an ore dock at Agate Bay (now Two Harbors) in 1883; a year later the dock accepted its first load of Vermilion Iron Range ore, ten cars full pulled from Soudan, Minnesota, by the steam locomotive Three Spot. The railroad became the property of Illinois Steel in 1887, and in 1901 part of U.S. Steel; it was officially merged with U.S. Steel’s Duluth, Missabe & Iron Range Railway in 1938. The railroads would eventually build six docks at Two Harbors.

Ore demand increased dramatically during World War II, and in 1944 the DM&IR docks in Duluth and Two Harbors broke loading records three times. The docks set a forty-eight hour loading record by filling sixty ships with 649,275 tons of ore between Sunday, May 28, and Tuesday, May 30. And they didn’t stop. The following day they broke the seventy-two-hour record when the loading total reached 859,959 tons. And from that Wednesday morning at 7 a.m. until the same time Thursday morning, crews loaded 406,484 tons, setting the single-day record in the process. (The previous twenty-four-hour record was set in 1942 with 337,180 tons.)

They reached an all-time high of 49 million tons in 1953. As the iron-rich ore was mined out, the docks slowed down. The Two Harbors docks actually closed from 1963 to 1966, when the mining industry picked up again with the development of taconite. Three docks remain, two of them still in operation.

Sources: [www.zenithcity.com/zenith-city-history-archives](http://www.zenithcity.com/zenith-city-history-archives)
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