A Comparison of Soil Infiltration Rates across Silvopasture, Open Pasture and Traditional Forest Management in Central Minnesota

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Abstract

Growing populations and increasing demands for meat production have resulted in an exponential increase in livestock farming. Minnesota has over 527,000 acres of grazed woodlands and has been ranked in the top ten states in the United States for red meat production, milk cows, cattle/calves, poultry and hog production (MDA, 2016). However, the majority of the woodland grazing has little to no management. As negative effects can arise with unmanaged woodland grazing, silvopastoral implementation has been proposed as an environmentally and economically beneficial practice for the livestock farmers in Central Minnesota.

To assess the adoptability and merits of silvopastoral systems, three five-acre paddocks: conventional open pasture, unmanaged traditional woodlands, and silvopasture where established at three locations in Crow Wing and Cass County in Central Minnesota. Water infiltration was used as a metric for water quality assessment and was measured in situ and in the lab. Soil infiltration tests were conducted for five test locations per paddock in Fall 2013, Spring 2014, Fall 2014, Fall 2015 and Spring 2016 utilizing Modified Philip-Dunne falling head infiltrometers. The locations were selected randomly, but subjectively, to encompass a representation of the landscape. Additionally, data collection for soil moisture content, saturated hydraulic conductivity, and soil properties (bulk density, porosity, soil texture) were conducted at each soil infiltration test location. Subsurface nutrient transport and laboratory experiment components were also added to the study.

The soil infiltration results identified an increase in overall infiltration from the beginning to the end of the project at 47 percent of the test locations, with 11 in the silvopasture, six in the open pasture and four in the traditional forest paddocks. However, there were no consistent trends that emerged across all sites for soil infiltration. Statistical analysis was used to further explore changes and identify any significant differences and correlations between infiltration and variables K_{sat}, soil texture, bulk density, landscape position, initial soil moisture, season and treatment type. Although there were significant results between infiltration and some of the variables, there was no consistency across research sites. With no resounding trends or statistically significant results, it is implied that there are many complex factors that influence soil infiltration in this project, not just vegetation and animal management.

Subsurface nutrient transport was measured through bromide tracers in situ via vadose zone access tubes and in a controlled environment via soil columns. The results determined that although there was initial movement of bromide from undeveloped secondary porosity in the soil profile, there was no evidence that the volume or concentration of nutrient transport would cause groundwater pollution in these types of soils with the implementation of silvopastoral practice.

Factors that were identified most likely to contribute to changes in soil infiltration were bulk density, initial soil moisture content, vegetative growth (above and belowground), secondary porosity and resiliency to disturbances. These factors are most likely driven by vegetation and animal management, geology and soils, climate change and prior land use.

Although results are preliminary, it can be assumed that farmers that practice unmanaged woodland grazing can improve soil infiltration without increasing the risk of associated water pollution through the implementation of silvopasture systems. A longer trial period would be necessary to determine if there are any consistent and significant changes in soil infiltration rates and help identify key indicators of those changes associated with the adoption of silvopastoral practices in Central Minnesota.

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Chapter 1. Introduction

1.1. Purpose

The demand for global meat production has increased with a growing population by tripling in the last four decades and 20 percent in the last 10 years (Worldwatch Institute, 2011). This has prompted an increase in livestock production and land use conversion. Throughout the United States, the primary management types for livestock grazing include conventional open pastures and woodland grazing. Conventional open pasture systems are comprised of grassland with minimal trees and shrubs present in the landscape. Woodland grazing is a forested system with minimal silvicultural or forb management, where livestock are allowed to graze freely. According to Clason and Sharrow (2000), approximately 34 percent of all forests are being grazed throughout the United States (as cited in Sharrow, 2007). However, there is another option for livestock management known as silvopasture (Garrett et al., 2004). Silvopasture is a form of agroforestry that intentionally combines trees, forage and livestock in an integrated, intensively managed, single system (Figure 1) (Association for Temperate Agroforestry, N.D.). Researchers at the Center for Agroforestry indicated that the environmental benefits associated with management of silvopastoral systems will increase the amount of forested land while mediating for the land degradation issues that are associated with grazing of livestock (Garrett et al., 2004).

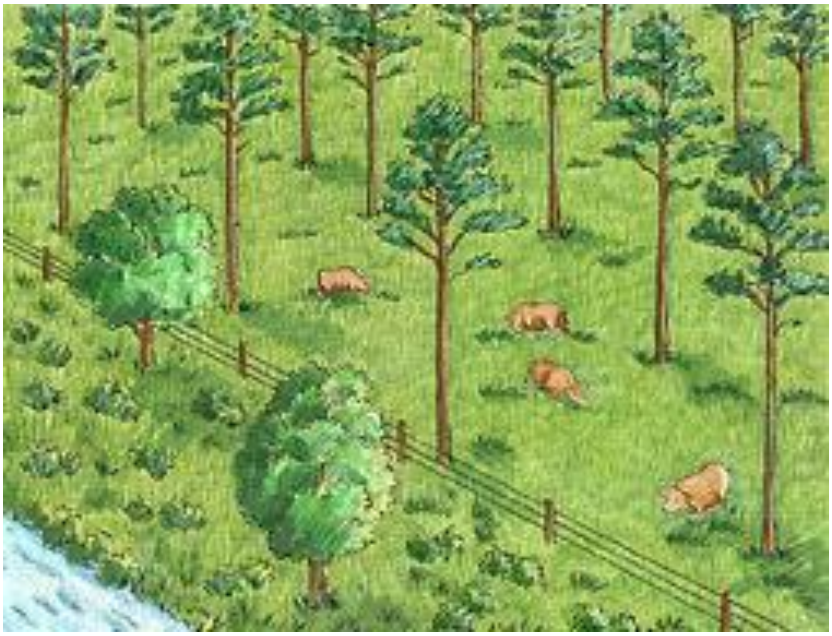

Figure 1. Schematic of Silvopastoral System (Image Source: Versaland, 2013)

Soil and water quality are directly related to land management; thus vegetative cover, geology and landscape, disturbances can offer insight on impacts to stream and water body health. Some disturbances, such as land use changes, can alter the landscape in a manner that changes and reduces the connectivity and productivity of the land. Disturbances can result in degraded soils, minimized wildlife habitat, alterations in nutrient cycling and reduced water quality. Introduction of livestock into the landscape without proper management can lead to soil compaction associated with hoof impact and loss of soil health from overgrazing, as well as contribute as a non-point source pollution of water resources.

In order to monitor the effects of these systems, a metric to gauge the merits and adoptability of a silvopastoral system as an alternative for other livestock grazing practices is needed. Due to its negative correlation with overland flow and thereby, the transport of excess nutrients and sediment to nearby surface water bodies, soil infiltration can be used as a representation of overall soil, water and landscape health. This study examined the relationship between infiltration rates and nutrient transport with differing types of livestock grazing management in Central Minnesota.

1.2. Literature Review

1.2.1. Silvopasture

Most of the benefits associated with silvopasture management can be attributed to the integration of trees into perennial grasses and forb landscapes. Trees and forage create an extensive, varying root system that increases soil porosity, which increases infiltration rates and soil moisture storage (Neary et al., 2009). In addition, the accumulation of forest litter and organic matter acts as a nutrient sink and a filtering system for excess nutrients (Neary et al., 2009; Gundersen et al., 2010). These extensive rooting zones tend to have a greater nutrient uptake (Nair et al., 2006), which aids in retaining nutrients, such as phosphorus (P) and nitrogen (N), and the potential to decrease runoff from the landscape. Therefore, research has determined that silvopasture systems can benefit the environment through soil conservation and improved soil quality, improved water quality, increased nutrient storage and carbon sequestration, as well as increased wildlife habitat protection and aesthetics (Garrett et al., 2004; Shrestha and Alavalapati, 2004; Nyakatawa et al., 2011).

1.2.2. Factors Affecting Infiltration

Soil infiltration can control “water availability for vegetation, groundwater recharge, overland flow and solute transport” (Stewart, et al., 2013). It is inferred that soil infiltration can serve as an index of water and soil quality and biological health (Radke and Berry, 1993). Infiltration is instrumental to the volume and transport route of overland flow and therefore, movement of potentially harmful contaminants to nearby surface water; thus, soil infiltration can infer surface water quality (Li et al., 1995; Bharati, et. al, 2002; Sauer, et. al, 2005). Water moving into and through the soil profile determines the amount of water available for root uptake and plant growth (USDA NRCS, 2008a). In areas of low infiltration, soil water capacity is reached and then surface runoff occurs. Surface runoff can lead to erosion, which can transport sediment and nutrients to the nearest surface water body. Therefore, the greater the infiltration, the less Hortonian overland flow (i.e. horizontal flow of water on the land surface when soil has reached saturation) and transport of potentially harmful contaminants (N, P) to nearby surface water sources.

Factors such as catchment landscape [i.e. landscape position and topography (Dunne et al., 1991; Li et al., 1995; Fox et al., 1997; Sauer et al, 2005; Huang et al., 2013)] and soil properties [i.e. soil texture, clay mineralogy, bulk density and antecedent moisture content (Bharati, et al, 2002; USDA NRCS, 2008; Thompson, et. al, 2010)], influence infiltration rates and determine the threshold value at which runoff occurs. Vegetative cover (i.e. density and type) and grazing practices (i.e. over grazing, hoof compaction) also influence the rate at which water can enter the soil profile. Livestock also contribute nutrient loading and have an effect on nutrient cycling, such as increasing or decreasing the presence and retention of nitrogen, phosphorus and carbon.

1.2.3. Catchment Landscape

Infiltration rates can vary with landscape position. Factors such as catena position and slope can influence the ability of water to infiltrate the surface. According to the literature, there is no consensus of the effect that surface slope has on soil infiltration (Huang et al., 2013). Sauer et al. (2005) determined that infiltration rates were consistently lower in upland and side slopes and higher in the valley bottom. Researchers also determined that there was very little difference in infiltration rates between steep (22-36%) slopes in forested landscapes compared to pasture plots with 4.4 to 15.4 percent slopes (Sauer et al., 2005). Li et al. (1995) observed highest infiltration rates at the hilltop, decreasing along the hillslope with lowest infiltration at a steep gully wall. The differences between these findings may be attributed to differences in vegetation density and soil properties, not surface slope alone. Nonetheless, slope can affect the amount of soil loss. Mwendera and Saleem (1997) observed greater amounts of soil loss on steeper slopes with vegetation remaining constant and determined that the greater the slope, the less resilient to grazing pressure.

Dunne and others (1991) argue that infiltration increases with hillslope length due to the increase of overland flow discharge and depth, as well as the presence of macropores at greater densities. Fox and others (1997) studied the relationship between slope angle and infiltration in inter-rill areas with the presence of a surface crust. When observing infiltration from plots with slope angles ranging from 1.5 to 21.5 degrees, they determined that as slope angle increased, infiltration rates decreased. They attribute this to decreases in overland flow depth and surface storage with increased slope angles. Similarly, significant differences in soil water storage were determined between gradual (8.8-17.6%) and steep (26.8-36.4%) slopes (Huang et al., 2013); as the slope increased, overall water storage decreased.

1.2.4. Soil Properties: Texture, Hydraulic Conductivity, and Bulk Density

Soil properties, with an emphasis on texture, clay content, bulk density and presence of preferential flow patterns, have a prominent impact on the volume and path that water may enter into the soil profile. Soil texture affects infiltration and subsurface flow due to the porosity: the presence of micro and macropores throughout the soil profile. In mesic-hydric areas, soil texture is the greatest indicator of soil infiltration, when compared to arid sites, where biomass is the primary indicator of soil infiltration (Thompson, et al., 2010). The presence of clay particles especially has an influence on soil infiltration, where the greater the percentage of clay content, the lower the infiltration rate (Stern et al.3, 1991; Knuehl and Boeteng, 2009; Thompson, et al., 2010). Due to the small soil grain size, clay particles have a high porosity, but can also swell with increased moisture and reduce the soil pore space even more, minimizing the amount of space available for water infiltration (Lui, et al., 2011). On average, steady infiltration rates per soil texture are less than 3.0 cm/hour for gravel and coarse sands, 2.0 to 3.0 cm/hour for sandy loams, 1.0 to 2.0 cm/hour for loams, 0.5 to 1.0 cm/hour for clay loams, and 0.1 to

0.5 cm/hour for clay soils (exception for clay soils with extensive fractures and macropores) (Brouwer et al., 1988).

Hydraulic conductivity *K* of a soil is defined by Darcy's law as the coefficient of proportionality, also referred to as the soil's permeability, and is the ratio of Darcy's velocity to the applied hydraulic gradient. The *K* value can fluctuate within and between soil layers and per soil moisture content, thus the saturated hydraulic conductivity (K_{sat}) value is identified as the average *K* value. The K_{sat} value is a function of the size, shape and distribution of the pores within a soil, as well as the soil temperature, and viscosity and density of the water (Oosterbaan and Nijland, 1994) and is used to measure the soil's ability to transmit water when submitted to a hydraulic gradient (USDA NRCS, 2004). A higher K_{sat} value will yield a higher infiltration rate, while a lower K_{sat} value will yield a lower infiltration rate.

Bulk density is dependent on soil texture and is calculated as the dry weight of a soil per its volume of soil, which includes the soil and pore space (USDA NRCS, 2008b). Sandy soils tend to have a higher bulk density than silt or clay soils, where sandy soils range from 1.3 to 1.7 g/cm^3 and fine silts and clays range from 1.1 to 1.6 g/cm^3 (Brown and Wherrett, 2016). However, in Minnesota, compaction from multiple glacial lobes that advanced and retreated over the landscape caused instances of greater levels of bulk density for glacial tills, ranging from 1.6 to 2.0 g/cm^3 at the soil surface (MPCA, 2015).

As soil compaction increases bulk density, infiltration rates then decrease. The Ocean County Soil Conservation District (OCSCD) (2001) studied and determined that as soil bulk density increased to 1.65 g/cm^3, infiltration rates decreased rapidly, whereas when the bulk density increased past 1.65 g/cm^3, infiltration decreased slowly until reaching zero. The interaction between bulk density of the uppermost topsoil layer (0-10 cm) and macroporosity of the lower soil is the controlling factor for macropore flow (Alaoui, 2015). If the topsoil layer is compacted, water is inhibited from infiltrating to the lower soil layers until the threshold matric potential has been reached, then causing infiltration in the lower soil layers to become slow and uniform (Alaoui, 2015).

1.2.5. Antecedent Moisture

Antecedent soil moisture can vary greatly, and has a significant effect on soil infiltration rates (Hawlery et al., 1983; Hardie et al., 2011). Hardie and others (2011) determined that antecedent soil moisture had a greater influence on the rate and depth of infiltration than soil morphology. They suggest that soil morphology and chemistry have little effect on soil infiltration and determined that dry treatment had greater depth and rate of infiltration than wet treatments. Similarly, Liu et al. (2011) summarized that in general, infiltration was greater in dry soil initially but decreased rapidly until it reached a constant rate equal to the saturated hydraulic conductivity of the soil. This is primarily due to a lower hydraulic gradient at the wetting front (Liu et al., 2011). Wei and others (2007) studied runoff and soil erosion in alley cropping systems (incorporating rows of trees into agricultural landscape) and found that the “runoff coefficient was exponentially correlated to the inverse of antecedent soil water potential in the wet season and negatively and linearly correlated to antecedent soil water potential in the dry season”.

Therefore, the wetter the soil profile, the greater the runoff potential due to the maximum water holding capacity when rainfall exceeds infiltration.

1.2.6. Vegetation

Vegetation affects infiltration twofold: 1) by altering the hydrological process of rainfall-infiltration, and 2) by modifying the structure of pore spaces with incorporation of root systems (Huang et al., 2013). When comparing vegetation to bare soil plots with the same soil types and rainfall intensity, a vegetated plot was found to have a greater wetting front depth, two times greater soil moisture content, and a reduced amount of surface runoff (Huang et al., 2013). These researchers also indicated that the presence of vegetation, including a cover canopy, could reduce raindrop impact on a bare soil surface and the potential of surface soil sealing.

Trees and forage create an extensive and varying root system that increases soil porosity, which increases infiltration rates and soil moisture storage (Neary et al., 2009). Greater rooting systems can cause preferential flow, allowing greater infiltration of precipitation into the soil matrix. When studying the influence of vegetation in three vegetation types, (grass field, a pine plantation and an 80 to100-year old hardwood forest) researchers determined from infiltration tests that there was approximately 20 percent greater infiltration in the hardwood forest site than the grass field (Thompson, et al., 2010). This indicates the importance of differing root depths and types for increased infiltration capacity.

In addition to vegetation presence and varieties, density of vegetation also influences the rate of soil infiltration. Different regions of the world have varying critical threshold values for runoff from vegetation density. Eastern Kenya reported 40 percent ground cover, while Australia determined 70-75 percent ground cover to be the critical level for surface runoff (Owens, Edwards, and Van Keuren, 1996). Other research has identified vegetative cover of 65 percent to significantly increase infiltration, and therefore decrease surface runoff (Marston, 1952 as cited in Huang et al., 2013). In plots with differing vegetation densities, Dunne and others (1991) found that the maximum infiltration with 5 to 10 percent cover was 3.5 cm $hour^{-1}$, while plots with 35 percent cover had at least 6 cm $hour^{-1}$ infiltration rate. They also determined that the vegetative cover with 75 percent density had a consistent rise in infiltration, but when the vegetation was removed by clipping to 35 percent, the infiltration dropped (Dunne et al., 1991). They attributed this to a reduction in hydraulic roughness and inundation of the permeable micro-topography.

1.2.7. Livestock Grazing

The effects of livestock grazing can be summarized into three categories: alteration of species composition of plant communities, disruption of ecosystem functioning, and alteration of ecosystem structure (Fleischner, 1994). These negative effects from livestock can be associated with overgrazing (decreased vegetation), hoof compaction, and a potential point source of concentrated nutrients.

Livestock grazing, especially if unmanaged, decreases overall plant cover. Species composition, to include native plant species, animal, bird and possibly insect populations, can be altered by the loss of biodiversity and lowering of taxa population densities from overgrazing (Fleischner, 1994). Milchunas and Lauenroth (1993) determined that grazing by large herbivores causes a loss of tissue of the individual plants, which alters the canopy structure and affects the entire community. Selective grazing by large herbivores causes loss of individual plants while leaving undesired plants, which decreases overall biodiversity (Milchunas and Lauenroth, 1993; Semmartin et. al, 2004). A reduction in vegetation and biodiversity changes the ecosystem structure and can have negative effects on terrestrial and aquatic habitats (Fleischner, 1994; Jones, 2000; Hoorman and McCutcheon, 2005) possibly forcing certain species to become threatened or endangered. In addition, grazing can cause a reduction in nutrients. Hiernaux et al. (1998) observed reduced pH, and reduced organic carbon, nitrogen and phosphorus concentration after four years of grazing. Phosphorus and pH had even greater reduction after nine years.

Loss of biomass and soil compaction can occur from grazing and trampling of hooved animals, which create higher proportions of bare ground and decreased plant litter. Greenwood and McKenzie (2001) compared grazing animals to heavy equipment used for agricultural management due to the downward pressures exerted on the soil surface as a function of the animal's mass, foot size and kinetic energy. The pressure of grazing animals causes compaction of the soils resulting in the majority of soils being compacted to a certain extent, usually confined to the upper 5 to 15 cm of the soil profile

(Greenwood and McKenzie, 2001). It is estimated that cattle apply a force of 190 kPa to 300kPa, whereas a logging skidder exerts 30 to 85 kPa (Willatt and Pullar, 1983 as cited in Sharrow, 2007; Scholefield et al., 1985 as cited in Greenwood and McKenzie, 2001). In addition, greater stocking rates can decrease the hydraulic conductivity or the soil (Willatt and Pullar, 1984). Therefore, soil compaction and loss of forest litter decreases soil moisture content and porosity, which leads to lessened infiltration rates (hydraulic conductivity), poorer quality soils and higher rates of runoff and soil erosion (Willatt and Pullar, 1984; Fleischner, 1994; Greenwood and McKenzie, 2001).

Overgrazing and trampling can increase soil bulk density while decreasing aggregate stability (Mwendera and Saleem, 1997; Bharati et. al, 2002). Hoof impact collapses larger soil pores, creating small pores, which then increases soil surface bulk density and reduces soil infiltration (Sharrow, 2007). This process also increases soil water holding capacity, which can infer increased antecedent soil moisture, also contributing to lower infiltration and reduced availability of water for root uptake. Meek et al. (1992) found a decrease in infiltration rates with compacted soils from a bulk density of 1.7 to 1.89 g/cm^3 (as cited in Bharati et al., 2002). Tate et al. (2004) conducted a study comparing soil surface bulk density between research sites not grazed by cattle (for greater than 26 years and 6 years) versus sites grazed by cattle over a 15-year period in light, moderate and heavy grazing regimes. They compared bulk density factors in different grazing exclusion sites and found that canopy cover and grazing management significantly affected bulk density. They discovered a 16 to 22 percent lower soil bulk density in oak savanna rangelands when compared to open grasslands. They also consistently found greater soil surface bulk densities in grazed sites versus non-grazed sites (Tate et al., 2004). Therefore, it can be inferred that even with the presence of vegetation and canopy cover, livestock stocking rates have a significant influence on bulk density, and thereby, soil infiltration rates.

In addition, if a soil texture is fine (clay and silt), then there can be an exaggerated amount of compaction from grazing (Mwendera and Saleem, 1997). In comparing livestock stocking rates in two research sites, trampling from livestock significantly reduced infiltration rates in both sites with both stocking rates. However, heavy grazing resulted in significantly lower infiltration rates compared to light to moderate grazing with clay loam soil texture, while there was little difference in infiltration reduction under different stocking rates in with sandy clay loam soil texture (Mwendera and Saleem, 1997). The researchers attributed this to the nature of the fine textured topsoil, which would compact more readily than soils with coarse sand components, even with comparative livestock grazing rates.

1.2.8. Potential Negative Impacts of Increased Infiltration

Although the majority of the above discussion indicated that increased infiltration can protect soil and surface water quality by decreasing runoff, there is a potential for groundwater contamination associated with greater infiltration rates. Groundwater contamination is influenced by pollutant concentration, the underlying soil's ability to remove the pollutant, and the rate of water movement through the soil profile (Clark and Pitt, 2007). Organic content, presence of microorganisms in the vadose zone, and pore space between grains are all contributors to how well a soil is able to break down contaminants while infiltrating through the soil (Clark and Pitt, 2007). The Groundwater Recharge Committee of the National Academy of Science determined that general causes of concern for potential groundwater contamination include 1) high mobility in the vadose zone, 2) high abundance (high concentration and high detection frequencies) of a contaminant, and 3) high contaminant solubility (Clark and Pitt, 2007).

Water movement from moderate and small pore sizes can be disrupted with the presence of large pores referred to as macropores (Bharati et al., 2002). These disruptions, such as deep rooting systems, earthworm burrows, fractures, or cracks, can provide alternate flow patterns, which moves water rapidly through the soil profile and influences the directional path of the water through preferential flow (nonmatrix flow). These flow paths allow the water to bypass segments of the soil matrix, penetrating deeper regions of the soil profile at a greater rate (Hardie, et al., 2011). Preferential flow reaching a shallow groundwater table can cause potential contamination from pesticides, fertilizers or other excess nutrients.

In a study identifying the effects of earthworms on infiltration and nutrient transport, Lachnight et al. (1997) determined that macropores ranging from 1 to 16 mm^2 contributed to solute transport up to depths of 30 cm. Deep rooting plants, such as switchgrass (*Panicum virgatum*) or big bluestem (*Andropogon gerardii)*, could also pose a potential groundwater contamination. Inorganic N has been identified as having significant retention rates in soil, as well as leaching deeper within the soil profile, in areas with deep rooting plant systems (Thorup-Kistensen, 2006). Greater movement of nutrients into the soil profile via deep rooting systems or increased infiltration could pose a risk to the shallow groundwater table.

1.3. Research Objectives

The research conducted for this thesis is a small part of a larger study designed to assess the viability of silvopasture adoption in Minnesota by assessing water quality, livestock performance, plant species diversity (forage and grasses), and economic profitability. This research focused specifically on infiltration rates and subsurface nutrient transport relationships in silvopasture, open pasture and traditional forest paddocks throughout three research sites in Central Minnesota. The primary objective of this study was to evaluate how soil conditions, vegetation and livestock management affect infiltration rates and subsurface nutrient transport in Central Minnesota.

The first objective of this study was to quantify the soil infiltration rate and soil moisture content in situ and assess change over time with alterations in management, (i.e. before seeding, after seeding and before livestock grazing, after one season of livestock grazing and after two seasons of livestock grazing). The second objective was to quantify the hydraulic conductivity within a laboratory setting, utilizing a soil core collected from the field site in order to estimate solute transport to groundwater. This included replicating the in situ infiltration tests to determine infiltration rates, nutrient transport and any preferential flow patterns. This started from a one-year room temperature dried soil core and progressed to a saturated state. The third objective of this study was to evaluate the relationship between infiltration, hydraulic conductivity, soil conditions and geology of this region of Minnesota. The final objective was to examine transferability of field results and determine if increasing infiltration rates, given varying soil and management types, would also increase the potential of groundwater contamination using silvopastoral practices.

Chapter 2. Materials and Methods

2.1. Project Description

This paper examines the relationship between infiltration rates and nutrient transport with differing vegetative and livestock grazing management types by utilizing the assumption that water quality is directly correlated with land management. Soil infiltration was used to represent overall soil, water and landscape health, due to its negative correlation with overland flow and the transport of excess nutrients and sediment to nearby surface water bodies.

The greater purpose of this project was to assess the adoptability and merits of silvopasture systems and identify if they are a feasible option for grazing management within Minnesota's hardwood transition zones where livestock production is practiced. In order to accomplish this, three project sites were established in Cass County and Crow Wing County in Central Minnesota. The project started July 2013 and ended June 2016. The three research sites were located on three different farms, referred to as: Booth, Caughey, and Moe. Within these research sites, three five-acre paddocks were established in the summer of 2013, representing one of each type of grazing management regime per site: conventional open pasture, unmanaged traditional forest, and silvopasture paddock.

Conventional open pasture paddocks were identified as pastures void of trees, traditional forest paddocks were areas of unmanaged woodland grazing, while silvopasture paddocks were intensively managed for trees, forage and livestock in a single system. The open pasture and silvopasture paddocks were seeded with grasses and forbes, while the traditional forest was left as it was.

A seed mixture of red clover (*Trifolium pratense*) and timothy grass (*Phleum pratense*) was applied via broadcast in late November and early December 2013 to the open pasture and silvopasture paddocks. Additionally, Virginia wild rye (*Elymus virginicus*), slender wheatgrass (*Elymus trachycaulus*), and fringed brome (*Bromus ciliates*) was added with fertilizer and applied as a winter frost seeding in April 2014. Furthermore, a tree inventory was completed for all silvopasture paddocks and trees were removed to achieve a basal area of 3.7 to 4.2 m^2/acre during the summer of 2013 (July to August).

Four cow-calf pairs were introduced and allowed to graze intermittently in the summer of 2014 and 2015. They were removed to allow a fallow period twice per field season (June to September), where the paddocks were not grazed to allow for regrowth of vegetation. Complete tables of grazing and fallowing periods are included in each research site’s description.

Water infiltration was measured in situ during Fall 2013, Spring 2014, Fall 2014, Fall 2015 and Spring 2016 using a Modified Philip-Dunne (MPD) falling head infiltrometer. Tests were conducted at five locations across each paddock, per research site, equaling a total of 45 infiltration tests per data collection period. The locations were chosen randomly, but subjectively, to encompass a representation of the soil catena by choosing different positions across the landscape, including variations in slope and elevation. Lab measurements were conducted during the Winter 2015, with the purpose of emulating how soil infiltration is affected by drought versus saturated state, to identify the presence of preferential flow, and to determine the rate at which nutrients may potentially move through the soil.

2.1.1. Glacial Geology of Central Minnesota

Minnesota can attribute its span of landscapes to the varying geologic processes over time. Due to influences from volcanism to glaciation, Minnesota displays a vast difference in geology and soils across the state. The research area was formed by the advance and retreat of the Rainy Glacial and Superior Lobes from the northeast. While the Rainy Lobe has brown sandy soil texture, the Superior Lobe has been identified to have red-brown silty to loamy soil texture (Knaeble et al., 2004). There are also till deposits from the St. Croix moraine in this area. The NRCS soil surveys list the primary landforms associated with this area to include hillslopes, swales or drainage-ways on moraines (Booth), and glacial drainage channels, drumlins or interdrumlins (Caughey and Moe), and flood plains (Moe) (NRCS, 2016a; NRCS, 2016b; NRCS 2016c).

The Farms are located in Cass (Booth) and Crow Wing (Caughey and Moe) Counties. Geologic Atlases are being produced by county by the Minnesota Geologic Survey (MGS). Cass County does not have a complete geologic atlas at this time, but Crow Wing County does (Figure 2). The surficial materials of Crow Wing County can be itemized into three types: till, sand and gravel and lacustrine sand (Knaeble et al., 2004). Specifically, the area around Caughey and Moe's Farms is primarily South Long Lake drumlinized till deposits, a component of the Brainerd assemblage, which includes glacial, fluvial and lacustrine sediment deposited by the Rainy lobe and its meltwater (Knaeble, et al., 2004). The glacial deposits are categorized by relatively thin (less than 3 meters) sandy loam unsorted sediment with pebbles, cobbles and boulders and is commonly overlain by one meter of fluvial, eolian or lacustrine sand near outwash and lake deposits (Knaeble et al., 2004). Moe's Farm also has areas of mixed outwash and floodplain alluvium, both fluvial units. The mixed outwash was primarily deposited by meltwater that consists of sand, gravelly sand and gravel; also included are fine-grained sediment that was ponded near former ice margins (Knaeble et al., 2004). The floodplain alluvium is associated with the Mississippi river, is typically less than two meters deep consisting of silt loam to loamy sand, including remains of wood or shells overlying sand, gravelly sand or gravel, as well as depressions with thick silty or clayey sediment (Knaeble et al., 2004).

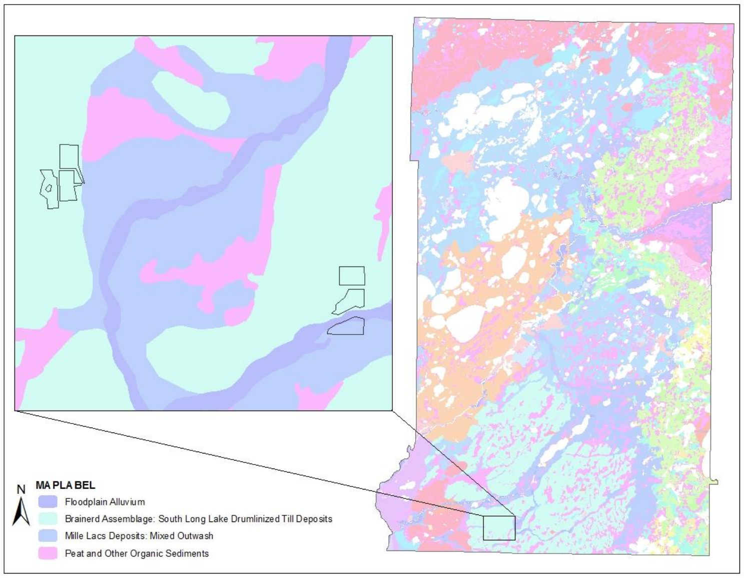

Figure 2. Crow Wing County Geologic Atlas (Source: MGS, 2004)

2.1.2. Greg Booth Site Description

Booth's farm is located approximately seven miles west of Baxter, Minnesota in Cass County (Figure 3). The farm has been part of the family since the early 1970s, where it was utilized as pasture for dairy cattle. The research area was continuously grazed until 2009, when it was divided and rotational grazing was implemented. Besides removal of dead and diseased trees, minimal land management was implemented for this area prior to the research project. The dominant tree species for the silvopasture paddock was paper birch (*Betula papyrifera*) and red oak (*Quercus rubra*), with some American elm (*Ulmus Americana*), green ash (*Fraxinus pennsylvanica*), black cherry (*Prunus serotina*) and red maple (*Acer rubrum*) present as well.

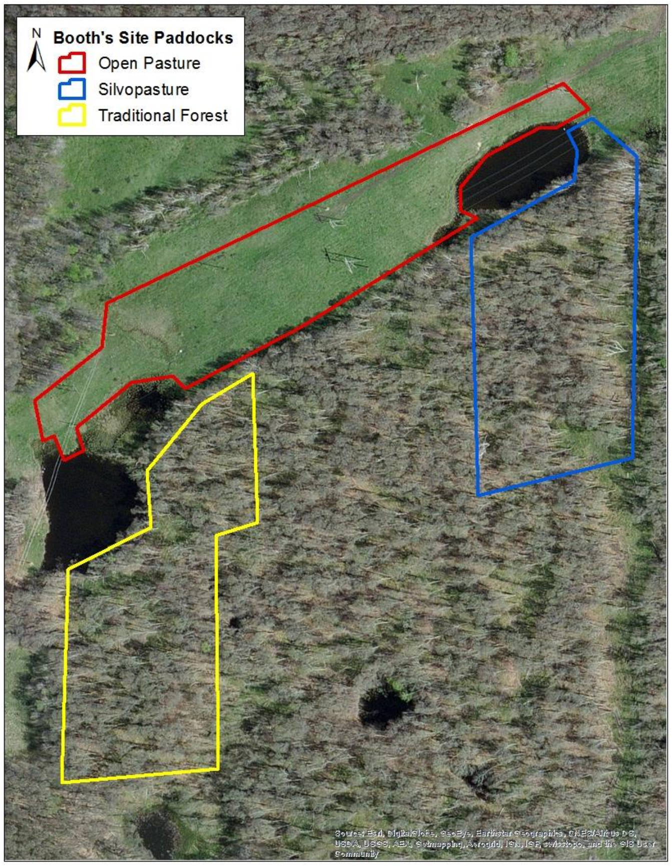

Figure 3. Booth Research Site

Three main types of soil were identified for the Booth farm via the USDA NRCS Web Soil Survey (2016a): DeMontreville-Mahtomedi-Cushing complex, Sandwick loamy sand and Warba very fine sandy loam. The DeMontreville-Mahtomedi-Cushing complex is the dominant soil series for this area (51.6%), followed by the Warba very fine sandy loam (40.5%), and the Sandwick loamy sand (7.6%) (Figure 4). The remaining area is covered by water. The DeMontreville-Mahtomedi-Cushing complex is a well-drained soil, often associated with moraines and hillslopes (backslope and shoulder) with a loamy glacial till parent material. The textural class as a complex is identified as a sandy loam. The DeMontreville component is an alfisol with a loamy fine sand texture, the Mahtomedi component is an entisol with a loamy sand texture, and the Cushing component is an alfisol with a fine sandy loam texture. When the complex was compared to in field soil profile analysis, the complex appeared to be primarily consistent with the Cushing soil series versus the other two soil series. The Sandwick loamy sand soil series is a very deep loamy fine sand and poorly drained soil, formed by sandy glacial outwash or eolian material (USDA, 2006a). The Warba very fine sandy loam is also a very deep soil, but is a moderated-well to well-drained soil formed in loamy calcareous glacial till on hillslopes on moraines (USDA, 2006b). In accordance to the respective drainage classes, DeMontreville-Mahtomedi-Cushing complex and the Sandwick loamy sand soil series are not considered prime farmland, while the Warba very fine sandy loam soil series is considered prime farmland.

Bulk density in the upper 5 to 10 cm ranged from 1.25 to 1.59 g/cm3, according to the NRCS Web Soil Survey. Bulk density was also measured at each soil infiltration test location, discussed further in later chapters. All soil types were considered in the C Hydrologic Soil Group, which indicated that the soils had a slow infiltration rate when thoroughly wet. Table 1 summarizes the soil properties for the Booth farm location in accordance to the web soil survey. A complete NRCS soil survey can be found in Appendix A.

Figure 4. Booth Soil Map (Source: USDA NRCS, 2015a left; USDA NRCS, 2016a, right)

Table 1. Booth Soil Series Summary (Source: USDA NRCS, 2016a)

Map Unit Symbol	Soil Series	Percent AOI	Bulk Density (1/3 bar) (g/cm^3)	Texture Class	Clay (%)	Sand (%)	Silt (%)	Drainage Class	Hydrologic Soil Group	Parent Material
240B	Warba very fine sandy loam	40.5	1.25	Very fine sandy loam	10.0	63.8	26.2	Well drained	C	Loamy glacial till
625	Sandwick loamy sand	7.6	1.50	Loamy fine sand	4.0	79.2	16.8	Poorly drained	C/D	Sandy outwash over loamy glacial till
928E	DeMontreville-Mahtomedi-Cushing complex	51.6	1.59	Sandy loam	4.0	79.2	16.8	Well drained	C	Sandy outwash over loamy glacial till

In order to quantify the landscape position on the soil catena, elevation was extrapolated from a LiDAR contour geodatabase from the MNDNR MnTOPO website (2015). At Booth's Farm, elevation ranged from 376 to 401 meters (1236 to 1316 feet).

The annual mean summer (June to August) temperature for this site is 18.3 degrees Celsius, while the mean winter (December to February) temperature is -12.2 degrees Celsius, and on average, this area receives 68.6 cm of precipitation annually (MNDNR, 2013). Based on temperature and precipitation data collected at the Brainerd-Crow Wing County Regional Airport, this area received 49.4 cm of precipitation with an average annual temperature of 4.5 degrees Celsius in 2014, while in 2015, it received 45.3 cm of precipitation with an average annual temperature of 6.3 degrees Celsius (Weather Underground, 2016a).

There were two grazing periods and one fallow period per field season. In 2014, four cow-calf pairs were allowed to graze for 19 days and 21 days, with a fallow period of 9 days. In 2015, the same amount of cow-calf pairs were grazed for 19 days and 12 days, with a 29 day fallow period (Table 2).

Table 2. Booth Cow-Calf Grazing Rotation for 2014 and 2015

Year	Treatment	Number of Cow-Calf Pairs	Introduction	Removal	Total Days Grazed: First Period	Total Days Fallow	Introduction	Removal	Total Days Grazed: Second Period	Total Days Grazed: Season
2014	OP	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
	SV	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
	TF	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
2015	OP	4	6/13/2015	7/2/2015	19	29	7/31/2015	8/12/2015	12	31
	SV	4	6/13/2015	7/2/2015	19	29	7/31/2015	8/12/2015	12	31
	TF	4	6/13/2015	7/2/2015	19	29	7/31/2015	8/12/2015	12	31

2.1.3. Dan Caughey Site Description

The Caughey farm location is approximately ten miles east of Fort Ripley, Minnesota in Crow Wing County (Figure 5). The pasture area was bought in 1980 and the silvopasture area in 1990, both being used for pasture and continuously grazed since they were purchased. It is speculated by the Caughey family that the area was used for pasture before they acquired the land. The dominant tree species for the silvopasture paddock was quaking aspen (*Betula papyrifera*) and bur oak (*Quercus macrocarpa*), with some American elm (*Ulmus Americana*), red maple (*Acer rubrum*), red oak (*Quercus rubra)*, and balsam poplar (*Populus balsamifera*) as well.

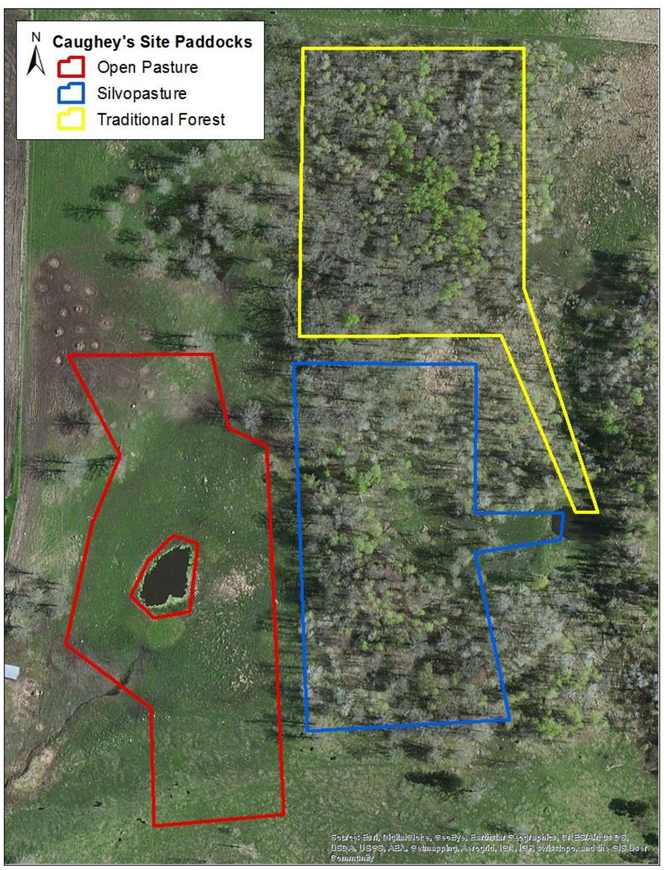

Figure 5. Caughey Research Site

Three soil series were also identified for the Caughey's Farm from the USDA NRCS Web Soil Survey (2016b). These included Chetek-Seelyeville, ponded complex (68.8%), Nokay-Prebish complex (30.7%) and Brainerd-Flak complex (0.5%) (Figure 6). The Chetek-Seelyeville complex is considered a somewhat excessively drained soil, often associated with glacial drainage channels with coarse-loamy glaciofluvial deposits over sandy and gravelly parent material. The textural class as a complex is identified as a sandy loam and is not considered prime farmland. The Chetek component is an alfisol with a coarse-loamy texture, while the Seelyeville component is a muck, originating form herbaceous organic material. The Nokay-Prebish complex is also a sandy loam, is a poorly drained soil with dense lodgment till as the parent material, which can be prime farmland if it is drained. The Nokay and the Prebish components are both associated with interdrumlins and have a coarse-loamy soil texture. The Brainerd-Flak complex encompasses a very small portion of the research site; both are coarse-loamy soil texture, and the complex is considered poorly drained, yet considered prime farmland. This soil series is associated with drumlin landforms in dense lodgment till as the parent material.

Bulk density at 1/3 bar in the 5 to 10 cm ranges from 1.50 to 1.55 g/cm^3 (USDA NRCS, 2016b). The Chetek-Seelyeville complex is in the A Hydrologic Soil Group, while the other two are in the C/D group. Hydrologic Soil Group A represents soils having a high infiltration rate when thoroughly wet, resulting in a low runoff potential. Group C/D is a dual hydrologic group, representing drained/undrained areas and indicating that the soil series has a slow/ very slow infiltration rate when drained/undrained, respectively, and a high runoff potential. Table 3 summarizes these soil properties for the Caughey research site location. A complete NRCS soil survey can be found in Appendix A.

Figure 6. Caughey Soil Map (Source: USDA NRCS, 2015b left; USDA NRCS, 2016b, right)

Table 3. Caughey Soil Properties Summary (Source: USDA NRCS, 2016b)

Map Unit Symbol	Soil Series	Percent AOI	Bulk Density (1/3 bar) (g/cm3)	Texture Class	Clay (%)	Sand (%)	Silt (%)	Drainage Class	Hydrologic Soil Group	Parent Material
2-30D	Chetek-Seelyeville, ponded complex	68.8	1.55	Sandy Loam	9.0	69.0	22.0	Somewhat excessively drained	A	Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash
C164B	Brainerd-Flak complex	0.5	1.52	Sandy Loam	8.0	63.0	29.0	Somewhat poorly drained	C/D	Dense lodgment till
C116A	Nokay-Prebish complex	30.7	1.50	Loam	14.0	51.0	35.0	Poorly drained	C/D	Dense lodgment till

The elevation Caughey's farm ranged from 375 to 388 meters (1232 to 1273 ft.). The annual mean summer and winter temperatures were the same as Booth's site, but Caughey's site receives 71.1 cm of precipitation annually (MNDNR, 2013). The Little Falls-Morrison County Airport reported that in 2014, this area received 51.8 cm of precipitation with an average annual temperature of 3.6 degrees Celsius, and in 2015, it received 50.7 cm of precipitation with an average annual temperature of 6.4 degrees Celsius (Weather Underground, 2016b). In 2014, four cow-calf pairs were allowed to graze for 19 days and 21 days, with a fallow period of 9 days. In 2015, the same amount of cow-calf pairs was grazed for 19 days and 15 days, with a 28-day fallow period (Table 4).

Table 4. Caughey Cow-Calf Grazing Rotation for 2014 and 2015

Year	Treatment	Number of Cow-Calf Pairs	Introduction	Removal	Total Days Grazed: First Period	Total Days Fallow	Introduction	Removal	Total Days Grazed: Second Period	Total Days Grazed: Season
2014	OP	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
	SV	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
	TF	4	6/25/2014	7/14/2014	19	9	7/23/2014	8/13/2014	21	40
2015	OP	4	6/11/2015	6/30/2015	19	28	7/28/2015	8/12/2015	15	34
	SV	4	6/11/2015	6/30/2015	19	28	7/28/2015	8/12/2015	15	34
	TF	4	6/11/2015	6/30/2015	19	28	7/28/2015	8/12/2015	15	34

2.1.4. Steve Moe Site Description

Moe's farm is located approximately 0.5 miles south of the Caughey location, also located in Crow Wing County (Figure 7). No prior land use information is available for this site, however, it is assumed that the pasture and silvopasture paddocks have been used for grazing and crops in the past, while the traditional woodland forest paddock has been left unmanaged and was not grazed. Dominant tree species found on this farm were Jack pine (*Pinus banksiana*) and paper birch (*Betula papyrifera*), with few bur oak (*Quercus macrocarpa*) and black ash (*Fraxinus nigra*) present.

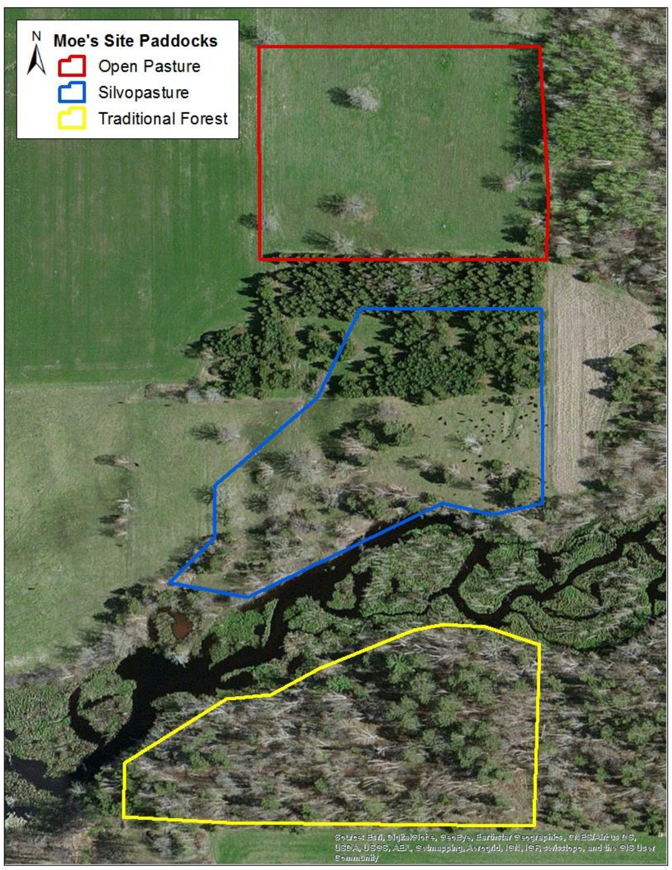

Figure 7. Moe Research Site

The Moe Farm consisted of four different soil series: Chetek-Graycalm complex (62.4%), Bushville loamy sand (22.1%), Brainerd sandy loam (10.9%) and the Lougee-

Totagatic-Bowstring complex (4.5%) (Figure 8). The Chetek-Graycalm consisted of three different slope categories: 0 to 2 percent (10.1%), 2 to 6 percent (23.3%) and 6 to 12 percent (29.0%) slopes. Due to the invariability in soil properties between the different slope categories, these have been grouped and discussed together. The complex is associated with glacial drainage channels, can be identified as a somewhat excessively drained sandy loam soil and is considered farmland of statewide importance. The Chetek component, as discussed in Caughey's site description, is a coarse-loamy alfisol while the Graycalm component is a loamy sand entisol. The parent materials are coarse-loamy glaciofluvial deposits over sandy and gravelly outwash. The Bushville loamy sand is part of the Rainy till phase, associated with drumlins, with a somewhat poorly drained drainage class and parent material of sandy outwash over dense lodgment till. This soil is an alfisol and is also considered farmland of statewide importance. The Brainerd sandy loam is also an alfisol with somewhat poorly drained soils, and is considered prime farmland. The parent material is dense lodgment material. The final soil series for this site is the Lougee-Totagatic-Bowstring complex. This complex is not considered prime farmland because it is very poorly drained and floods frequently, due to its flood plain landform association. The Lougee and Bowstring components are histosols and the Totagatic component is an entisol and all have typical O zones consisting of peat or muck.

Bulk density at 1/3 bar in the 5 to 10 cm ranges from 1.52 to 1.60 g/cm^3, except the Lougee-Totagatic-Bowstring complex that has a bulk density of 0.05 g/cm^3. The Chetek-Graycalm complex is in the A Hydrologic Soil Group, the Bushville loamy sand

and Brainerd sandy loam are in the C/D group, and the Lougee-Totagatic-Bowstring complex is in the A/D group. Table 5 summarizes these soil prosperities for Moe's research site location. A complete NRCS soil survey can be found in Appendix A.

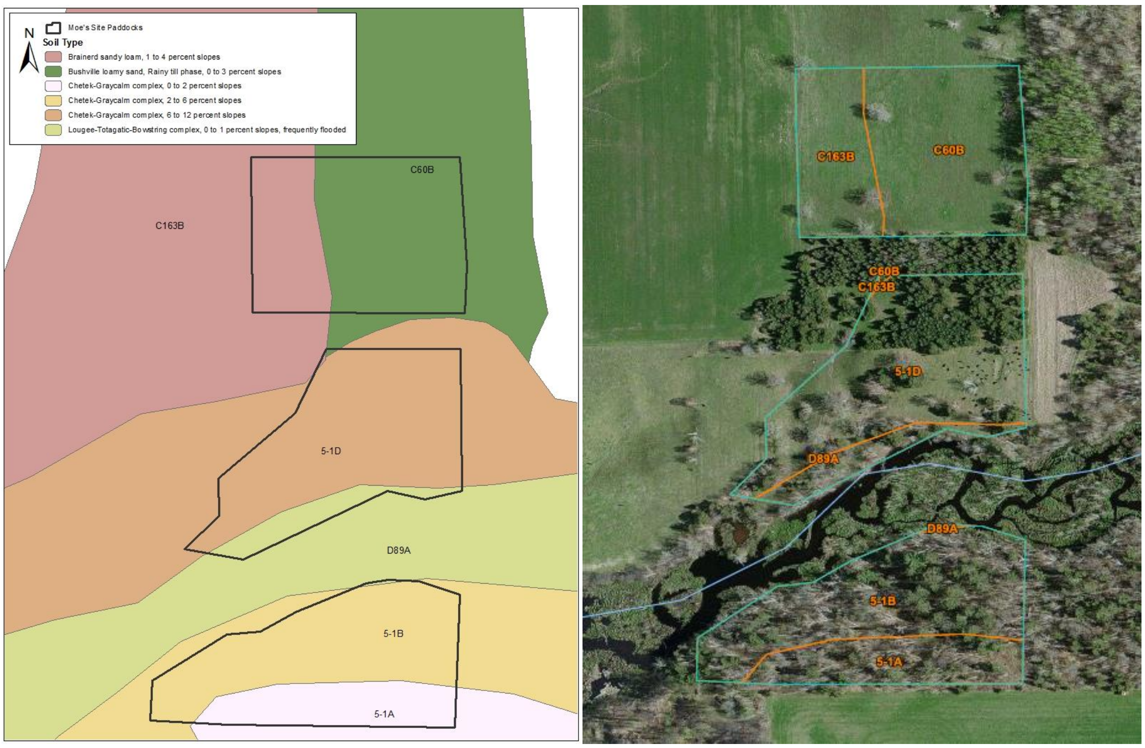

Figure 8. Moe Soil Map (Source: USDA NRCS, 2015b left; USDA NRCS, 2016c, right)

Table 5. Moe Soil Properties Summary (Source: USDA NRCS, 2016c)

Map Unit Symbol	Soil Series	Percent AOI	Bulk Density (1/3 bar) (g/cm3)	Texture Class	Clay (%)	Sand (%)	Silt (%)	Drainage Class	Hydrologic Soil Group	Parent Material
5-1D	Chetek-Graycalm complex	29.0	1.55	Sandy Loam	9.0	69.0	22.0	Somewhat excessively drained	A	Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

C60B	Bushville loamy sand, Rainy till phase	22.1	1.60	Loamy Fine Sand	6.0	78.0	16.0	Somewhat poorly drained	C/D	Sandy outwash over dense lodgment till
C163B	Brainerd sandy loam	10.9	1.52	Sandy Loam	8.0	63.0	29.0	Somewhat poorly drained	C/D	Dense lodgment till
D89A	Lougee-Totagatic-Bowstring complex, frequently flooded	4.5	0.05	Muck				Very poorly drained	A/D	Herbaceous organic material over outwash

Moe's Farm elevation ranged from 376 to 389 meters (1234 to 1278 ft.). All temperature and precipitation data was the same as Caughey's site, due to the close proximity of the research sites. In 2014, four cow-calf pairs were allowed to graze for 11 days and 28 days per paddock, with a fallow period of 39 days. The cow-calf pairs in the traditional forest paddock and the silvopasture paddock were separated by a stream, which was not effective in keeping the livestock in their respective paddocks. Therefore, this is reflected in the "Number of Cow-Calf Pairs" column in the below table (Table 6). In 2015, four cow-calf pairs were grazed in the pasture paddock, while eight cow-calf pairs were grazed in the silvopasture paddock and no grazing occurred in the traditional forest. The grazing periods were for 12 and 14 days with a 60-day fallow period (Table 6).

Table 6. Moe Cow-Calf Grazing Rotation for 2014 and 2015

Year	Treatment	Number of Cow-Calf Pairs	Introduction	Removal	Total Days Grazed: First Period	Total Days Fallow	Introduction	Removal	Total Days Grazed: Second Period	Total Days Grazed: Season
2014	OP	4	6/24/2014	7/5/2014	11	39	8/13/2014	9/10/2014	28	39
	SV	4 (8)	6/24/2014	7/5/2014	11	39	8/13/2014	9/10/2014	28	39
	TF	4 (0)	6/24/2014	7/5/2014	11	39	8/13/2014	9/10/2014	28	39
2015	OP	4	6/8/2015	6/20/2015	12	60	8/19/2015	9/2/2015	14	26
	SV	8	6/8/2015	6/20/2015	12	60	8/19/2015	9/2/2015	14	26
	TF	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0

2.2. Soil Infiltration

Within this large-scale study, soil infiltration was measured as a surrogate metric of the quality of water. Infiltration testing allowed us to indirectly gage water pathway movement based on 1) animal and vegetation management, 2) soil conditions, and 3) glacial geology. Soil infiltration tests were conducted in Fall 2013, Spring 2014, Fall 2014, Fall 2015 and Spring 2016 using the Modified Philip-Dunne (MPD) falling head infiltrometer. The decision to utilize the MPD falling head infiltrometer versus other infiltration data collection methods was due to the ease of construction and functionality of the infiltrometer; the devise required a relatively small amount of water, and data collection occurred quickly (Ahmed et al, 2014). Five infiltrometers were constructed during Spring 2013 of rolled sheet metal, each was approximately 61 cm tall with a 9 cm diameter. A silicon tube was attached approximately eight cm above the base and connected to the top. This clear tube allowed visual measurement of the falling head over time.

Soil infiltration tests were conducted at five sites across each paddock, with a total of 45 for all research sites (Figure 9, 10, 11). The locations were chosen randomly, but subjectively to encompass a representation of the paddock's landscape by choosing differing locations across the soil catena. The infiltration test sites were marked using a customized data collection form through Open Data Kit (ODK) Collect Application for Android mobile devices and the location data was uploaded to a map in Esri ArcGIS 10.3.1 (Environmental Systems Research Institute, geographic information system mapping software). Each test location was labeled according to farm, paddock and number associated with test: B for Booth, C for Caughey and M for Moe, OP for open pasture, SV for silvopasture and TF for traditional forest (i.e. BOP1, BOP2, etc.) (Figure 9, 10, 11).

The surface was exposed, removing loose organic matter and grasses/forbs before inserting the MPD infiltrometer approximately five cm into the ground. Each test started with 30 cm (2600mL) of water and ran for 30 minutes, or until steady state rate had been reached, and it was assumed the water had infiltrated and saturated into the upper soil profile. The soil infiltration data was loaded into an Excel spreadsheet for further analysis; raw data can be referred to in Appendix B, Tables 4-12.

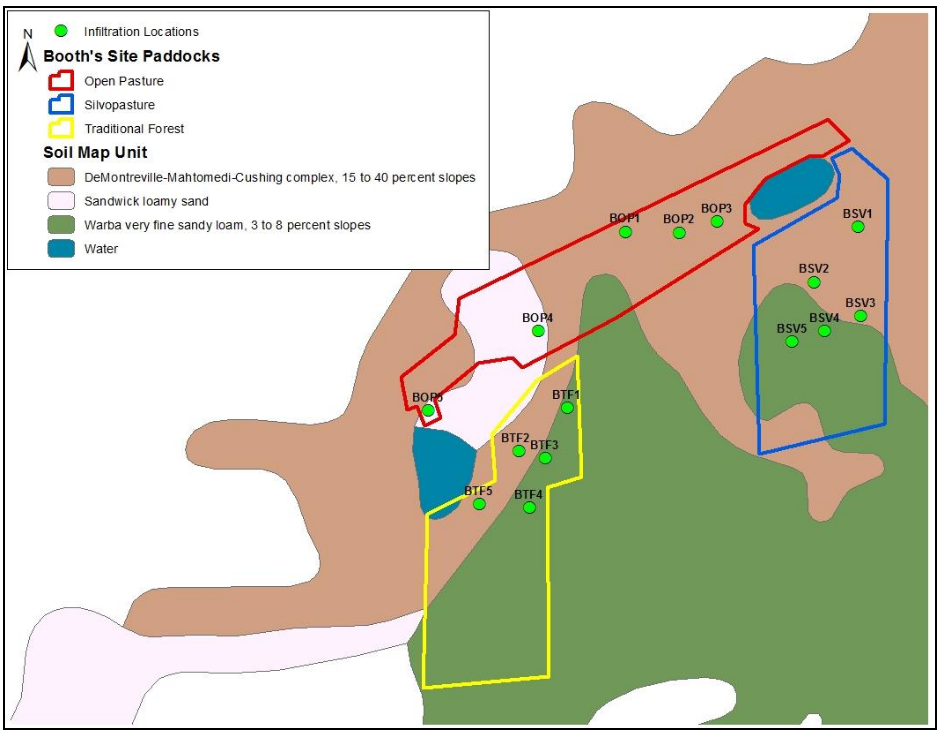

Figure 9. Booth's Soil Infiltration Rate Test Locations per Paddock

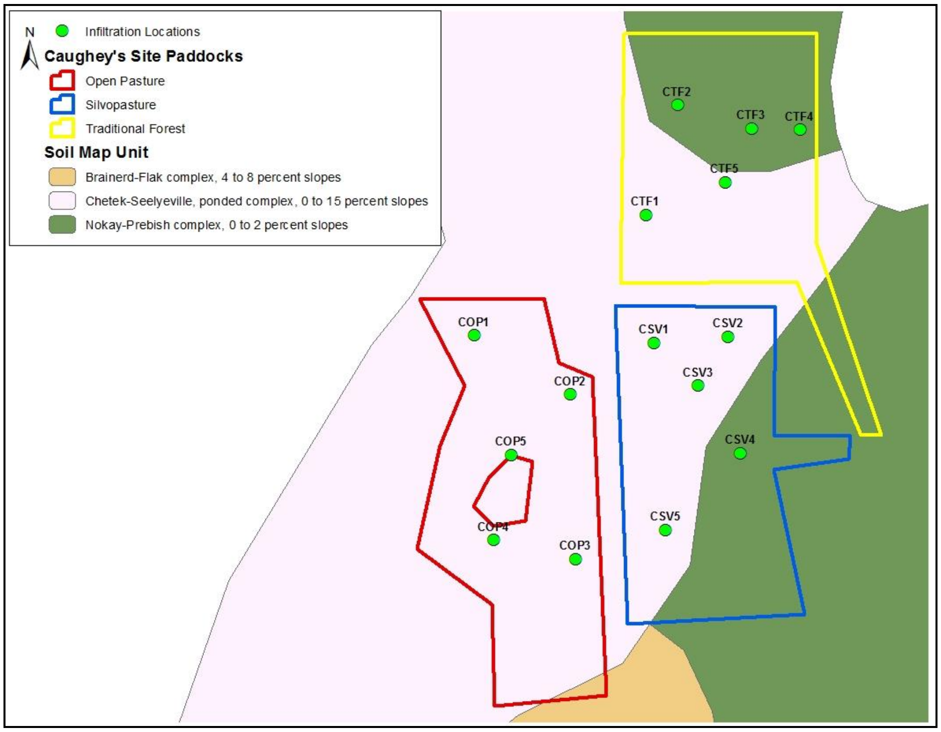

Figure 10. Caughey's Soil Infiltration Rate Test Locations per Paddock

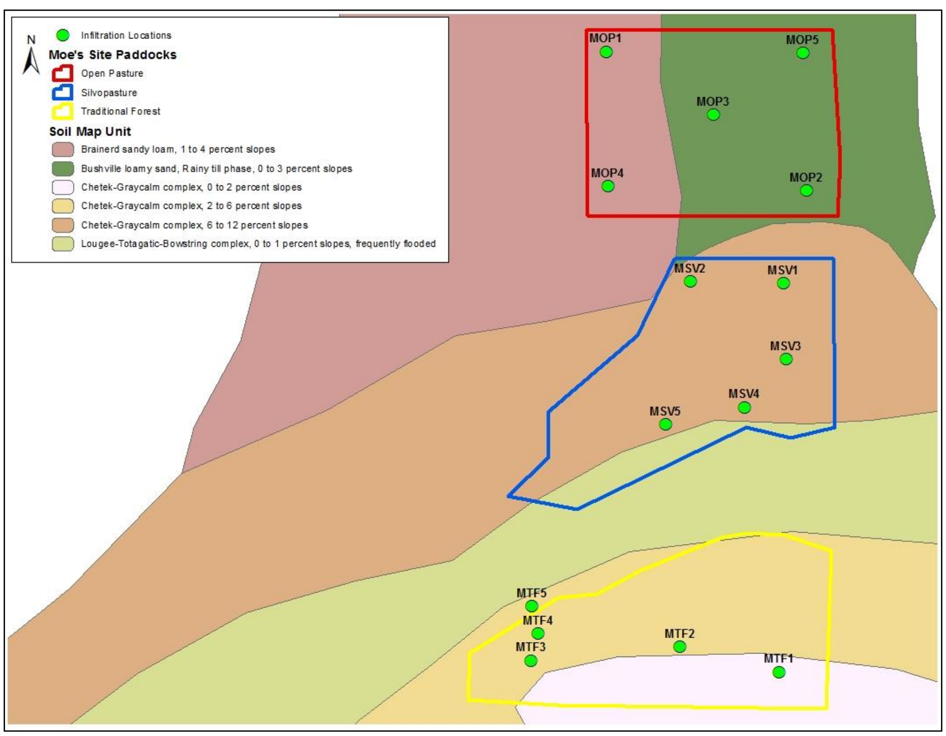

Figure 11. Moe's Soil Infiltration Rate Test Locations per Paddock

Initial infiltration measurements were taken in October and November 2013 to understand geomorphology of the study sites and to measure the baseline infiltration rates before seeding was complete in the silvopasture and open pasture paddocks. Infiltration tests were then completed in Spring 2014, Fall 2014, Fall 2015, and Spring 2016. In Spring 2014, the infiltration rate tests were intended to measure any changes in infiltration rates post-seeding and pre-grazing while evapotranspiration rates were at a minimum. The Spring 2016 infiltration rate tests were conducted to compare to the Spring 2014 data collection. The data collection in Fall 2014 and Fall 2015 were intended to monitor changes associated with the introduction of livestock into the paddocks for the 2014 and 2015 growing seasons. An overall increase in infiltration rates was anticipated due to increased vegetative cover.

Average infiltration rates were calculated by determining the surface area of the MPD infiltrometer and the depth of water infiltrated, which were used to calculate the overall infiltration rate. Surface area was calculated by equation 1, depth of water infiltrated was calculated with equation 2, and the overall infiltration rate was calculated using equation 3.

$$A = \pi r^2$$

(equation 1)

Where *A* is surface area, in cm^2, *r* is the radius of the MPD infiltrometer, in cm.

$$D = V/A$$

(equation 2)

Where *D* is the depth of water infiltrated in cm and *V* is the volume of water infiltrated, in mL.

$$I = D/t$$

(equation 3)

Where I is the infiltration rate and t is the elapsed time, in hours.

2.3. Soil Moisture Content

In addition to soil infiltration tests, soil samples were collected to estimate initial and final soil moisture content. A representative collection of soil was taken before the infiltration test to determine initial soil moisture content by taking three soil samples in a triangular pattern within 15 cm of the infiltration test location, ensuring not to disturb the contact area. Another collection was taken after the infiltration test at assumed saturation status directly from the center of the infiltration test contact area. These were labeled pre- and post- samples at each infiltration collection. The samples were weighed in metal containers in the laboratory and then dried in a drying oven at 65 to 70 degrees Celsius for a minimum of 48 hours. The difference between the wet and dry weight determined the amount of pre-test water present at each infiltration test location. Soil moisture content of each sample was calculated utilizing equation 4 to provide input data to determine the capillary pressure C and saturated hydraulic conductivity (K_{sat}).

$$MC = [(M_{cms} - M_{cds})/(M_{cds} - M_c)] \times 100 = (M_w/M_s) \times 100$$

(equation 4)

Where, MC is the soil moisture content in percent, M_{cms} is the mass of the container and moist soil sample (g), M_{cds} is the mass of container and oven dried soil sample (g), M_c is the mass of the container (g), M_w is the mass of water (g), and M_s is the mass of the oven dried soil sample (g).

2.4. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity (K_{sat}) was determined through a series of calculations. The first step was to determine if there was three-dimensional flow, which occurred when the wetting front extended past the MPD infiltrometer's base that was inserted into the ground. This was done using the Green-Ampt equation (equation 5) for infiltration *f* utilizing the MPD software with Microsoft Excel (2003). The MPD infiltrometer's dimensions, soil moisture content pre- and post- percentages, and the falling head infiltration raw data were inserted into the model, which then calculated the saturated hydraulic conductivity K_{sat} and the capillary pressure *C* at the wetting front. Full description and steps to using this software is included in Appendix C.

Green-Ampt Rate for Infiltration

$$f = K_s\left[1 + \frac{(H + h_{wf})(\theta_f - \theta_i)}{F}\right]$$

(equation 5)

Where *f* is the infiltration rate (cm/hr), K_s is the hydraulic conductivity (in cm/hr), *H* is the depth of water, h_{wf} is the wetting front capillary pressure head (in cm), θ_f is the final (saturated) soil moisture content, θ_i is the initial (antecedent) soil moisture content, and *F* is the cumulative infiltration amount (cm).

If the wetting front did not extend past the infiltrometer's inserted base, this was considered one-dimensional flow and Darcy's Law (equation 6) was used for calculation of K_{sat} (equation 7). Instead of soil moisture content, porosity was used to due to inconsistency with soil moisture content values, where initial soil moisture was greater than final soil moisture. It was assumed this occurred when air pockets formed in the soil sample, skewing the results. Porosity was calculated from bulk density, which was determined by collecting soil samples using a ring method and measuring the ratio of dry soil weight to soil volume (discussed further in section 2.6).

Darcy's Law

$$q = K_{sat}\left(\frac{Df}{L}\right)$$

(equation 6)

$$K_{sat} = \frac{qL}{Df}$$

(equation 7)

Where q was the final two infiltration measurements per site (cm/hr), L was calculated from the final and initial falling head height (cm) as well as saturated and initial soil moisture content, $L = (H_i - H_f)/(q_{sat} - q_i)$, and *Df* is the change in porosity calculated as $Df = (H_f - H_0/2) - (-C - L)$. Capillary pressure *C* values were referenced from Rawls, Brakensiek and Miller (1983) for soil texture per site (see Appendix D).

2.5. Subsurface Nutrient Transport

To measure potential subsurface nutrient transport in the vadose zone, three perched water table access tubes were installed within each paddock, with a total of 12 per research site (Figure 12). The access tubes were made of PVC tubes that were cored into the soil and caped at the ground surface. They were dug to reach 0.61 meters into the water table with the intention of monitoring groundwater level changes, as well as act as a source for water collection. Initial groundwater parameters were collected and recorded for temperature, pH, conductivity, and dissolved oxygen. Bromide was placed within 30 cm of groundwater wells with cow manure added on top of the bromide solution. The bromide acted as a tracer and helped track subsurface nutrient transport while the cow manure represented the maximum nutrient load to a defined unit area. Water samples were collected June and August 2015 and taken back to the lab and analyzed for bromide presence, to determine if the bromide had infiltrated to the water table. Each water sample had 25 mL of water measured out, a bromide ion buffer was added to the sample, and using a Thermo Scientific IonPlus Bromide Electrode (probe) with a Thermo Scientific Orion Star A324 pH/ISE Meter (reader) results in parts per million (ppm) and milivolts (mV), results were recorded. The mV records appeared to have a greater range of results than the ppm values, because it measured the reduction potential and tended to be more sensitive to identifying the presence of bromide as it is reduced.

Figure 12. Vadose Zone Access Tubes Located in Caughey's Traditional Forest Paddock

2.6. Bulk Density, Porosity and Soil Texture

Bulk density and porosity was also determined per infiltration test site location. The bulk density measurements were completed within five to ten centimeters of the soil surface utilizing the ring method using steps and standards according to the USDA NRCS (Figure 13). This method consisted of 1) clearing the top layer of vegetation, 2) driving a 7.62 cm (3 in) diameter metal ring into the soil, 3) removing the ring by digging around it and lifting from the Earth, ensuring not to disturb the soil, 4) removing excess soil around the ring, 5) placing a sample in a plastic bag labeled in accordance to infiltration test site, 6) weighing samples in a lab setting, 7) drying samples in an oven for 24 hours at 60 to 70˚C, 8) calculating bulk density from weights and known volumes utilizing equation 8, 9) calculating porosity from bulk density utilizing equation 9 (See Appendix D for bulk density manual) (USDA NRCS, N.D.). The materials used were a 7.62 cm diameter ring, hand sledge, wood block, flat-bladed knife and sealable bags.

$$BD=S_D/S_V \tag{equation 8}$$

Where S_D is the dry soil weight in grams and S_V is soil volume in cm^3.

$$P=1-(BD/PD)\ x100 \tag{equation 9}$$

Where PD is particle density and is assumed to be 2.65 g/cm^3.

Figure 13. Soil Bulk Density Sample Collection

Soil texture was determined with particle size analysis with a hydrometer, to allow identification of percent sand, silt and clay. The sand size distribution was determined by dry sieving with sieve sizes 2, 1, 0.5, 0.25, 0.106, 0.053 and less than 0.053 mm. The Wentworth (1922) grain size classification chart aided in identifying sand size category (Figure 14).

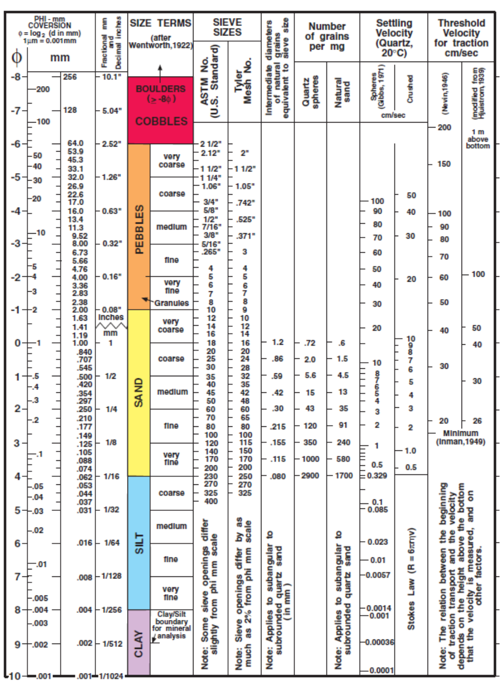

Figure 14. Wentworth Grain Size Classification Chart

2.7. Laboratory Experiment

The lab portion consisted of two parts: infiltration tests and subsurface nutrient transport components. During the 2014 field season, two soil cores were procured with the intention of representing the differing soil types among two of the three sites (Booth and Caughey) (Figure 15). Unfortunately, one of the soil cores was destroyed and the tests were conducted on the one remaining (Caughey). The infiltration tests were intended to identify the fluid and solute flow pathways under a range of drought to saturated conditions, as a way to determine how well water moves when exposed to different climatic conditions, as well as identify the presence of preferential flow paths. A bromide solution tracer was added to represent subsurface nutrient transport.

Figure 15. Soil Core Collection (left) and Lab Preparation (right)

Before the experimental portion began, some preliminary information, such as soil core volume and water volume, was determined. Using the assumption that saturation occurs at a pore volume equal to 50 percent of the soil volume, which is assumed to be the porosity of a soil in good condition for plant growth, the soil core was calculated to need approximately 31700 mL of water. A 3000 ppm concentration of bromide solution was prepared and 100 mL was applied in a single, focused area at the center of the surface of the soil core to emulate plug flow. Nine holes were drilled evenly into the bottom of the soil core container. Plastic adapters were inserted into the holes, along with a cotton ball to minimize soil loss. Silicon tubes were then connected to the holes via hose barbs and routed into containers to collect water as it was infiltrated through the soil core. Figure 16 and 17 display the elevated soil column with tubing routed into the bottle and the numbered system for holes drilled into the bottom of the base.

Figure 16. Soil Core with Infiltrometer (left) and Soil Core Bottom with Bottles (right)

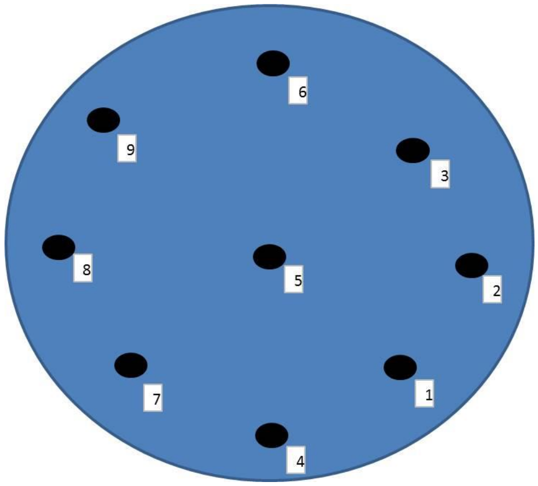

Figure 17. Soil Core Base Schematic: Hole and Tubing Locations

There were three stages to the soil infiltration tests. Infiltration tests started from drought conditions, which equated to allowing the soil cores to dry completely (stage 1). Drought conditions were created by allowing the soil core to dry in a controlled environment at air temperature for approximately 12 months. To coincide with the field tests, 2600 mL of water was added to the MPD falling head infiltrometer and measured while infiltrating through the soil core. The infiltration rate was timed and recorded, as well as the total time needed for the water to filter completely through the soil core. Bromide concentration was measured from the drainage into each of the containers collecting water from the soil core. Once the 2600 mL of water had completely drained, the total amount of water was collected from the soil core and the bromide concentration was measured. The total amount of water collected in each container would help detect macro-pore locations and determine flow paths and hydraulic conductivity.

The next stage (stage 2) was to completely saturate the soil core. This was done by adding water to the soil core equal to the assumed an estimated porosity of 50 percent with the completion of two consecutive soil infiltration tests with the MPD. Water was added until pooling occurred at the top of the soil core, which was the point of assumed saturation. Once a saturated state was attained, an additional infiltration test was conducted (stage 3). Bromide concentration and total drained water volume was measured at the test completion.

2.8. Data Analysis

Statistical analysis was completed using RStudio software, Version 3.2.2 (2015). Two-way analysis of variance (ANOVA) tests were completed on the calculated average soil infiltration by treatment type and by soil texture and treatment type and tested with K_{sat}, season (data collection period), paddock (treatment type), bulk density, landscape position, soil texture, and initial soil moisture content. Once a summary of results from the ANOVA tests were completed, a Tukey Honest Significant Differences (HSD) ($\alpha<0.05$) was computed and plotted. This was done to determine if there were any statistically significant differences between infiltration rate and the other variables. In addition, Pearson's product moment correlation coefficient tests with a confidence level of 95 percent were conducted to identify correlations between variables.

Chapter 3. Results

3.1. Soil Infiltration Results

3.1.1. Booth Soil Infiltration Results

In Booth's open pasture paddock, there was an overall increase in infiltration rates over the extent of the project at infiltration test site BOP1 (r^2=0.59), BOP4 (r^2=0.23) and

BOP5 (r^2=0.67), while there was an overall decrease at BOP2 (r^2=0.43) and BOP3 (r^2=0.43) (Figure 18, Table 7). Over the course of the project, the greatest increase in infiltration occurred at BOP5 (24.80 cm/hr, no Spring 2016 data), while the greatest decline occurred at BOP2 (32.60 cm/hr). As a paddock, infiltration rates ranged from 2.20 cm/hr (BOP5, Fall 2013) to 44.95 cm/hr (BOP3, Spring 2014). From Fall 2013 to Fall 2015, the average infiltration across the paddock as a whole was lowest in Fall of 2014 (13.3 cm/hr) and highest in Spring 2014 (20.1 cm/hr) (Figure 19, Table 7). Spring 2016 data was not included in the seasonal averages, due to only three of the five infiltration tests completed at that time.

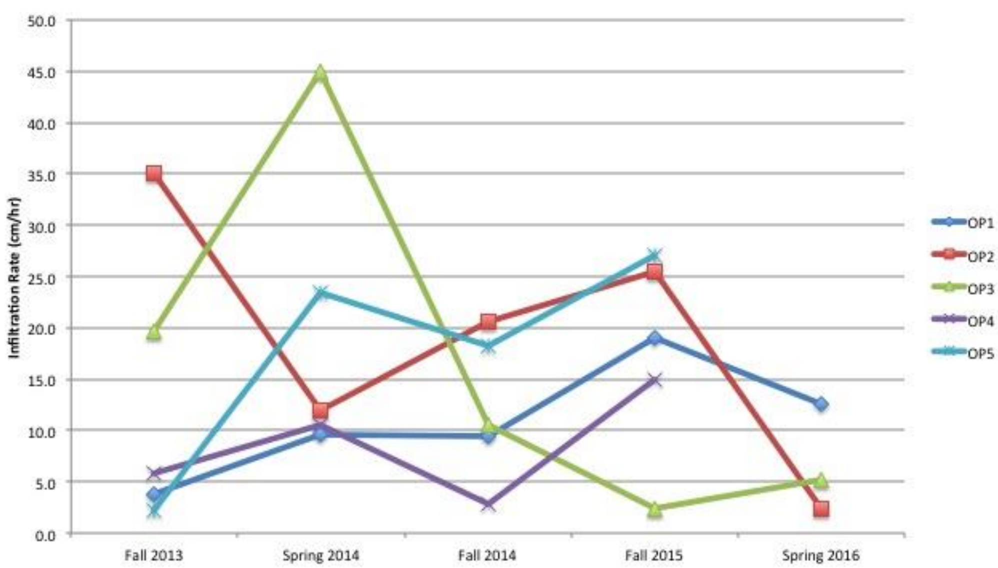

Figure 18. Booth Open Pasture Paddock Infiltration Rates Over Time

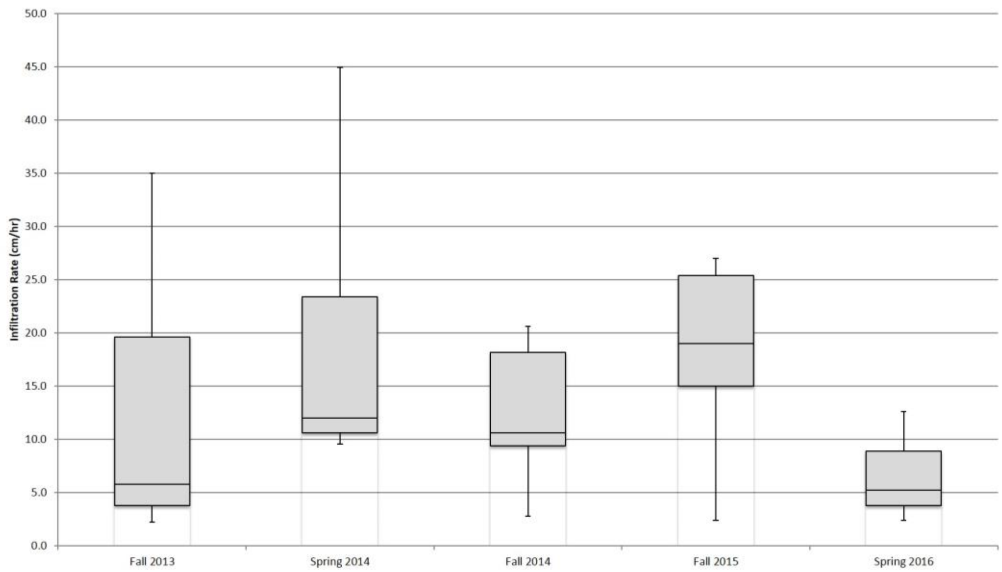

Figure 19. Booth Open Pasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 7. Booth Open Pasture Paddock Infiltration Rates Over Time (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016
BOP1	3.80	9.56	9.40	19.00	12.60
BOP2	35.00	12.00	20.60	25.40	2.40
BOP3	19.60	44.95	10.60	2.40	5.20
BOP4	5.80	10.60	2.80	15.00	
BOP5	2.20	23.40	18.20	27.00	
Average	13.28	20.10	12.32	17.76	6.73

In Booth's silvopasture paddock, there was an overall increase in infiltration rates from Fall 2013 to Spring 2016 at infiltration test site BSV3 (r^2=0.33), BSV2 (r^2=0.0029), BSV5 (r^2=0.22), while there was an overall decrease at BSV1 (r^2=0.062) and BSV4 (r^2=0.024) (Figure 20, Table 8). Infiltration rates had the greatest increase at SV5 (28.80 cm/hr) and decrease at SV4 (6.70 cm/hr, no Spring 2016 data). Infiltration rates ranged from 0.60 cm/hr (BSV2, Fall 2013; BSV4, Spring 2014) to 91.8 cm/hr (BSV1, Fall 2014). By seasonal average, Fall 2014 had the greatest infiltration rates (36.16 cm/hr) and Fall 2013 had the lowest (11.32 cm/hr) (Figure 21, Table 8).

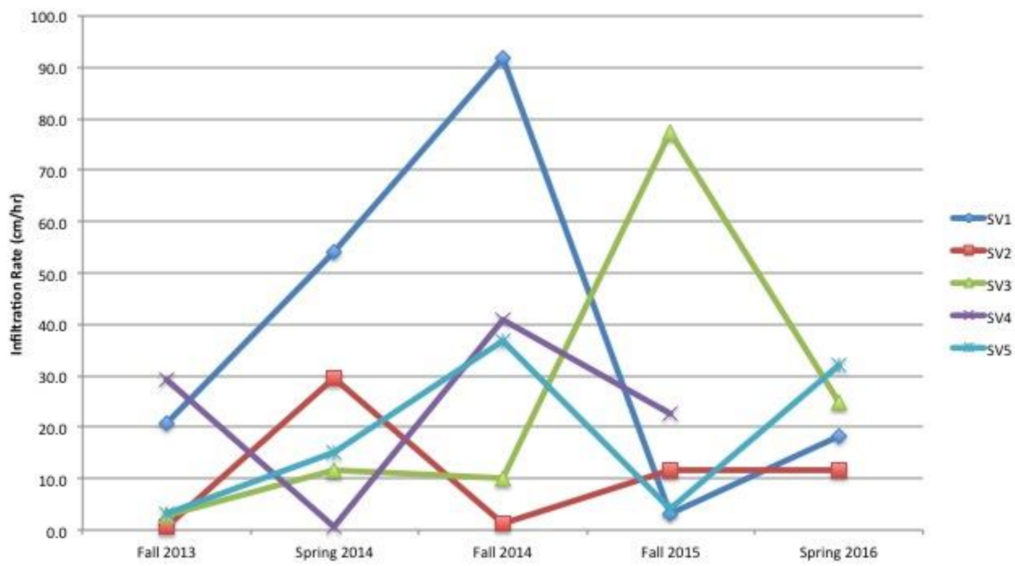

Figure 20. Booth Silvopasture Paddock Infiltration Rates Over Time

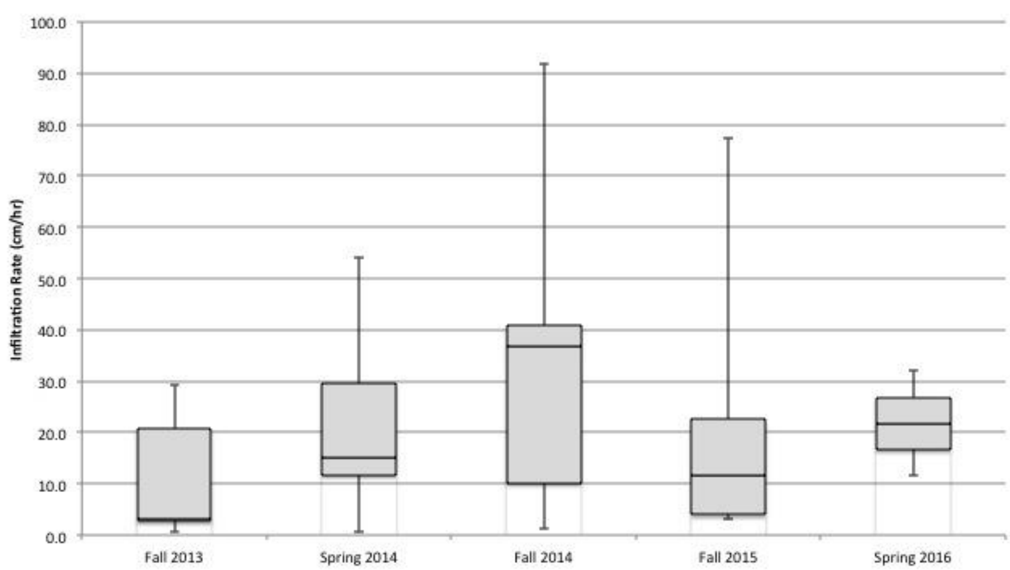

Figure 21. Booth Silvopasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 8. Booth Silvopasture Paddock Infiltration Rates Over Time (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016
SV1	20.80	54.00	91.80	3.00	18.40
SV2	0.60	29.60	1.20	11.60	11.60
SV3	2.80	11.80	10.20	77.33	25.00
SV4	29.20	0.60	40.80	22.50	
SV5	3.20	15.20	36.80	4.00	32.00
Average	11.32	22.24	36.16	23.69	21.75

The traditional forest paddock was not seeded, yet there was an overall increase in infiltration rates from Fall 2013 to Spring 2016 at infiltration test site BTF1 (r^2=0.29), BTF2 (r^2=0.11) and BTF4 (r^2=0.00043), while there was an overall decrease at BTF3 (r^2=0.035) and BTF5 (r^2=0.61) (Figure 22, Table 9). The greatest increase in infiltration rates over the entirety of the project was seen at BTF2 (5.00, no Spring 2016 data) and decrease was at BTF3 (12.00). The range of infiltration rates spanned from 1.00 cm/hr (BTF1, Spring 2014) to 61.93 cm/hr (BTF2, Fall 2014). Seasonally, the highest average infiltration rates occurred during Fall 2014 (37.24 cm/hr) while Spring 2014 had the lowest (6.24 cm/hr) (Figure 23, Table 9).

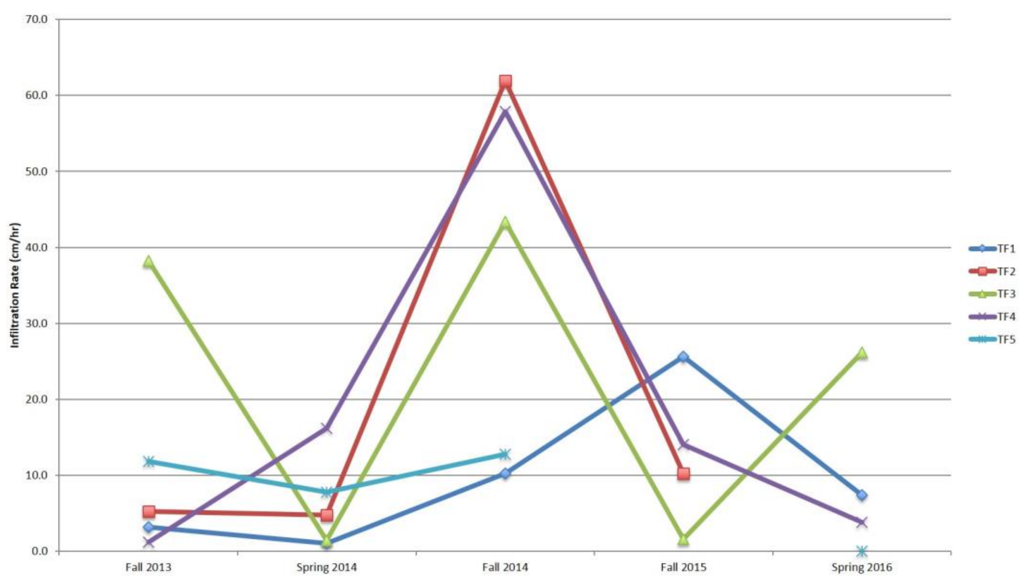

Figure 22. Booth Traditional Forest Paddock Infiltration Rates Over Time

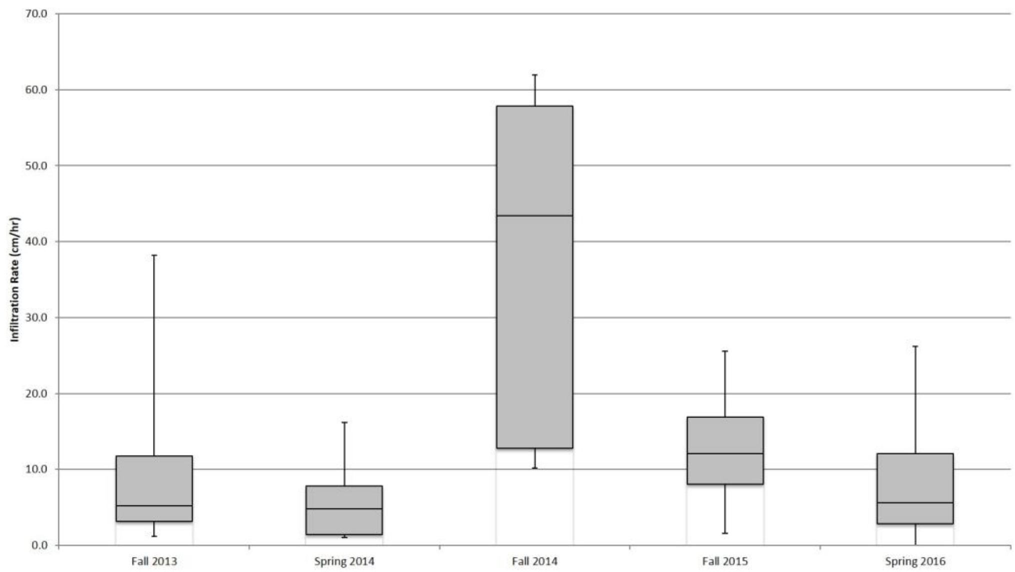

Figure 23. Booth Traditional Forest Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 9. Booth Traditional Forest Paddock Infiltration Rates Over Time (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016
BTF1	3.20	1.00	10.20	25.60	7.40
BTF2	5.20	4.80	61.93	10.20	
BTF3	38.20	1.40	43.40	1.60	26.20
BTF4	1.20	16.20	57.86	14.00	3.80
BTF5	11.79	7.80	12.80		0.00
Average	11.92	6.24	37.24	12.85	9.35

By paddock over the entirety of the project, Booth's open pasture had the lowest overall average infiltration rate (14.7 cm/hr) and the smallest range (2.2 to 44.9 cm/hr) when compared to the other paddocks. The traditional forest paddock had a range (0.0 to 61.93 cm/hr) with an average of 15.90 cm/hr. The silvopasture paddock had the greatest average infiltration of 23.08 cm/hr and a range of 0.60 to 91.80 cm/hr (Table 10, Figure 24).

Two-way ANOVA, Tukey HSD with a 95 percent confidence level and Pearson's product-moment correlation coefficient were used to determine the statistical significance between variables. Averages for infiltration rates, K_{sat}, bulk density, landscape position, initial soil moisture were calculated based on treatment type (paddock). Booth's average infiltration rates did not display any significant differences with these variables in ANOVA tests. Tukey HSD tests determined that the greatest difference in mean levels for infiltration based on treatment type was between the silvopasture and open pasture paddock (8.99 cm/hr). Average infiltration rates based on soil texture type were calculated and ran for two-way ANOVA tests. Average infiltration (by soil texture), displayed a difference when tested against treatment type, texture and season for season ($p<0.1$) (Table 11). Tukey HSD tests determined that the greatest difference in mean levels for texture was sandy loam and loam (8.38 cm/hr), and for season was Fall 2013 and Fall 2014 (19.34). Datasets used in RStudio for Booth can be found in Appendix C, Table 1 and 2.

Table 10. Booth Soil Infiltration Rates per Paddock (cm/hr) (Fall 2013-Spring 2016)

	Open Pasture	**Silvopasture**	**Traditional Forest**
Minimum	2.20	0.60	0.00
Quartile 1	5.50	3.80	3.50
Median	12.00	16.80	10.20
Quartile 3	20.10	30.20	20.90
Maximum	44.95	91.80	61.93
Average	14.67	23.08	15.90

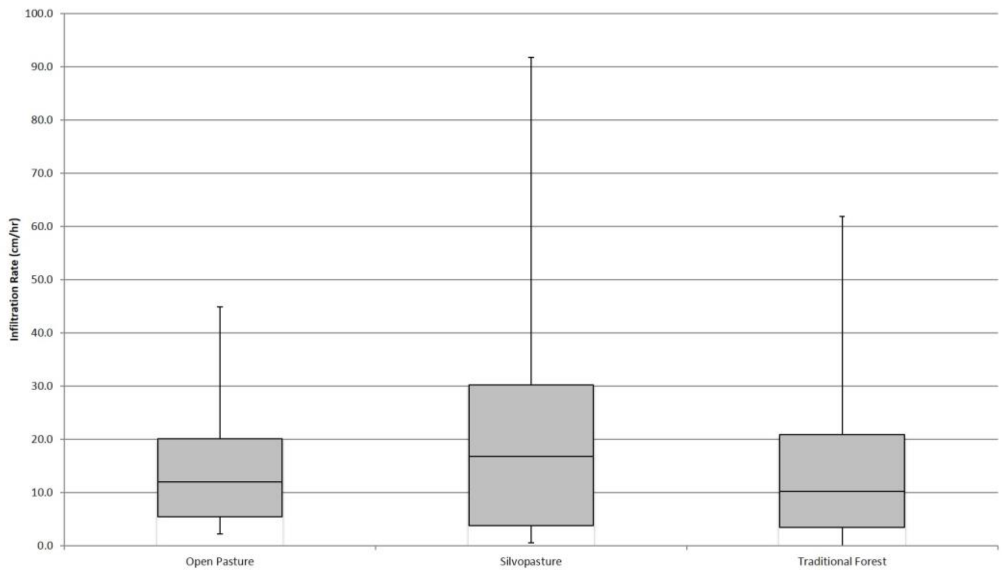

Figure 24. Booth Infiltration Rates by Paddock Over Time (Range, Median, First and Third Quartile)

Table 11. Booth Statistically Significant ANOVA Results

Booth Infiltration by Treatment, Texture and Season						
	Df	Sum Sq	Mean Sq	F Value	Pr(>F)	Signif. Code*
Treatment	2	162.2	81.09	0.626	0.5444	
Texture	2	524.1	262.07	2.023	0.1572	
Season	4	1211.2	302.81	2.338	0.0886	.
Residuals	21	2720.1	129.53			

*Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

3.1.2. Caughey Soil Infiltration Results

Caughey’s open pasture paddock experienced an overall increase in infiltration rates from Fall 2013 to Spring 2016 at test sites COP3 (r^2=0.078), COP4 (r^2=0.309) and COP5 (r^2=0.644), while COP1 (r^2=0.085) and COP2 (r^2=0.370) experienced an overall decrease in infiltration rates (Figure 25, Table 12). The greatest increase over time was observed at COP4 (1.60 cm/hr) and the greatest decrease was at COP1 (70.90 cm/hr). Caughey’s open pasture infiltration rates ranged from 0.00 cm/hr (COP5, Fall 2013 and 2014, Spring 2014; COP3, Fall 2014) to 78.30 cm/hr (COP1, Fall 2013). The greatest average infiltration rates occurred in Fall 2013 (Table 28.02 cm/hr), while Spring 2014 had the lowest average infiltration rates (2.88 cm/hr) (Figure 26, Table 12).

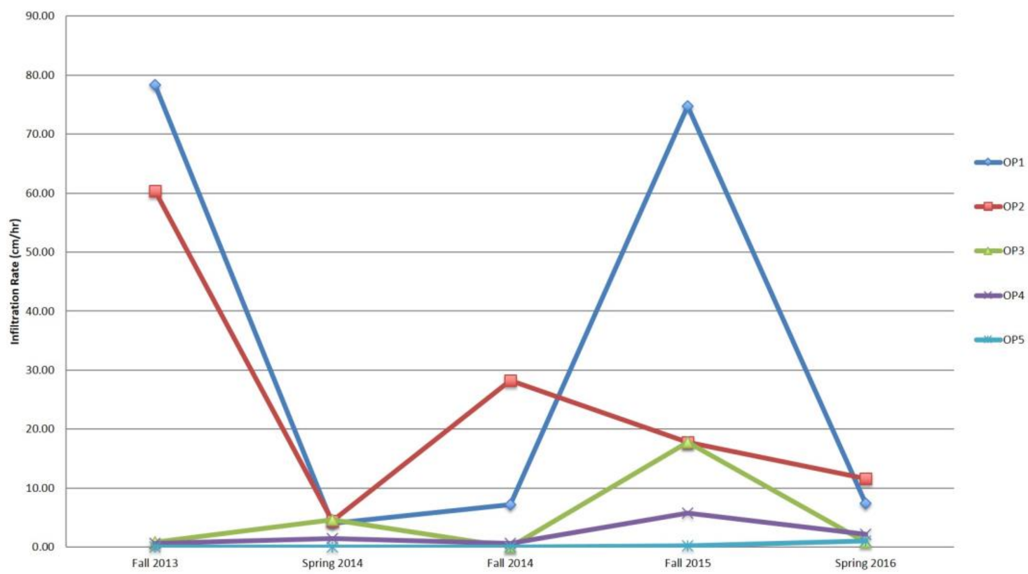

Figure 25. Caughey Open Pasture Paddock Infiltration Rates Over Time

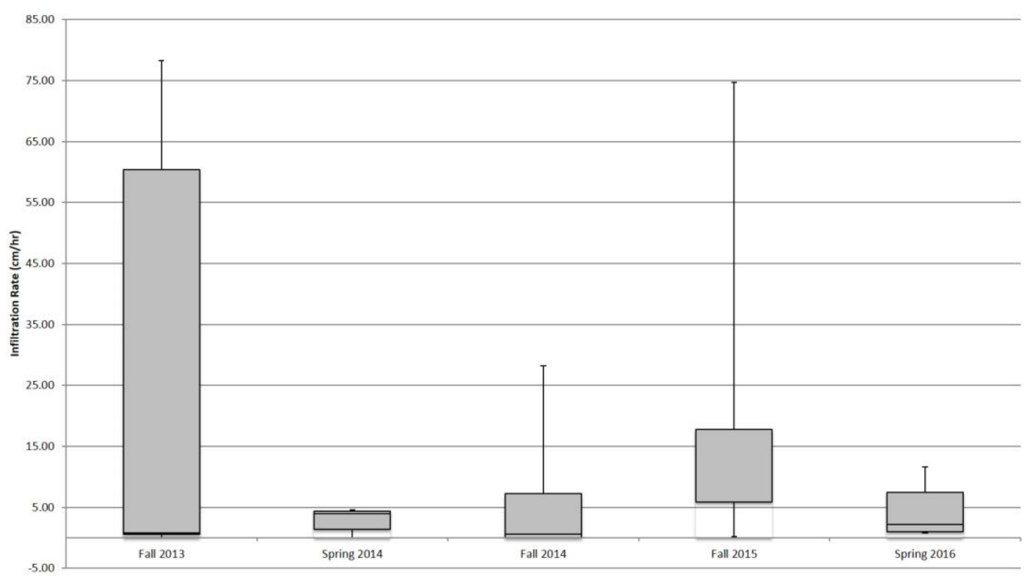

Figure 26. Caughey Open Pasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 12. Caughey Open Pasture Paddock Infiltration Rates Over Time (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016
COP1	78.30	4.00	7.20	74.73	7.40
COP2	60.40	4.40	28.20	17.80	11.60
COP3	0.80	4.60	0.00	17.80	0.80
COP4	0.60	1.40	0.60	5.80	2.20
COP5	0.00	0.00	0.00	0.20	1.00
Average	28.02	2.88	7.20	23.27	4.60

Caughey's silvopasture paddock experienced an overall increase in infiltration rates at four of the five locations CSV1 (r^2=0.023), CSV2 (r^2=0.012), CSV3 (r^2=0.249) and CSV5 (r^2=0.0064) while CSV4 (r^2=0.011) experienced an overall decrease (Figure 27, Table 13). Infiltration rates increased the most at CSV3 (50.80 cm/hr) and decreased by 6.40 cm/hr at BSV4. The paddock's infiltration rates ranged from 0.00 cm/hr (CSV4, Spring 2016) to 67.44 cm/hr (CSV3, Fall 2014). When averaging all of the infiltration test sites, the highest average infiltration for Caughey's silvopasture paddock occurred during Fall 2014 (29.41 cm/hr), while the lowest infiltration mean was in Fall 2015 (4.76 cm/hr) (Figure 28, Table 13).

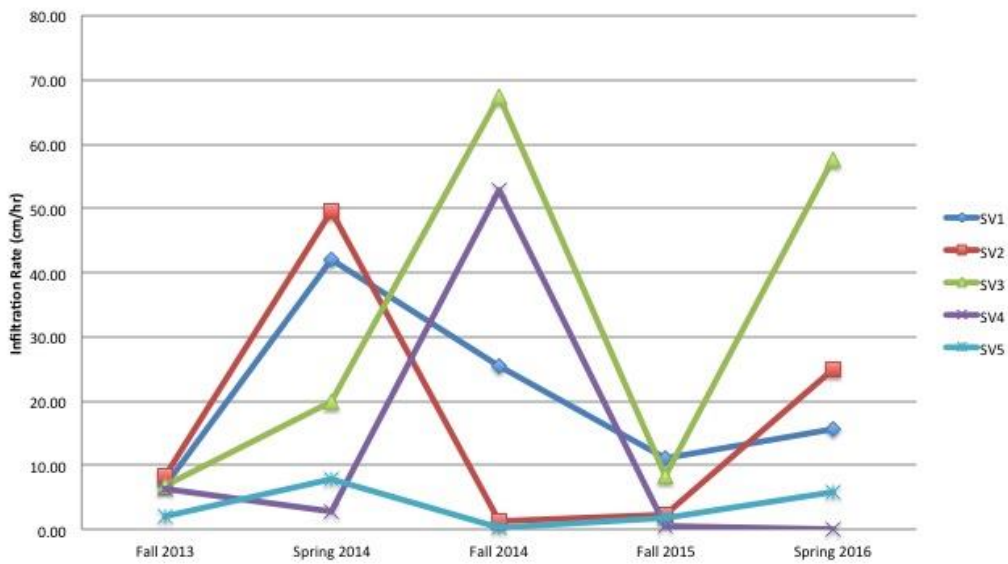

Figure 27. Caughey Silvopasture Paddock Infiltration Rates Over Time

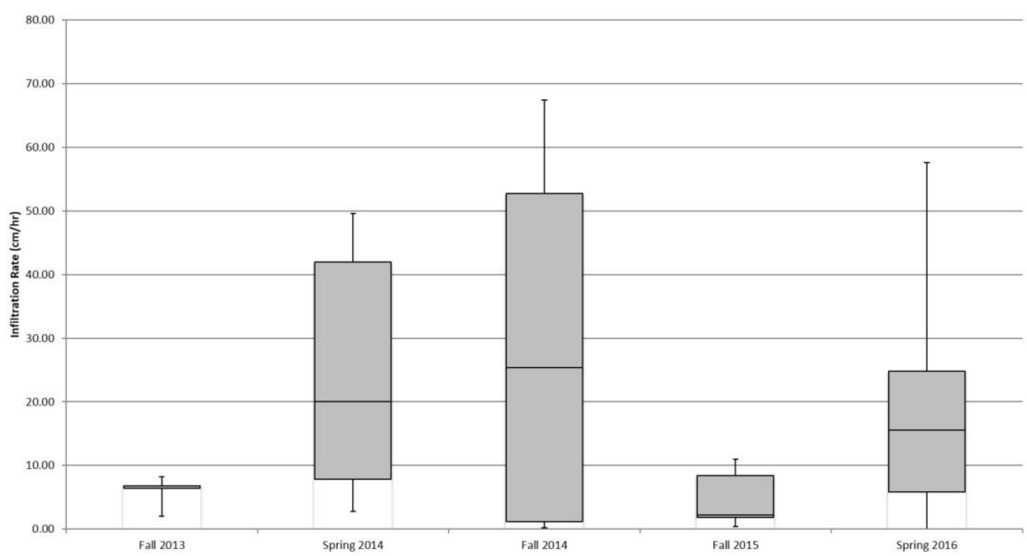

Figure 28. Caughey Silvopasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 13. Caughey Silvopasture Paddock Infiltration Rates by Season (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016
CSV1	6.80	42.00	25.40	11.00	15.60
CSV2	8.20	49.60	1.20	2.20	24.80
CSV3	6.80	20.00	67.44	8.40	57.60
CSV4	6.40	2.80	52.80	0.40	0.00
CSV5	2.00	7.80	0.20	1.80	5.80
Average	6.04	24.44	29.41	4.76	20.76

Caughey's traditional forest paddock experienced an overall decrease at all infiltration test site locations: CTF1 (r^2=0.164), CTF2 (r^2=0.021), CTF3 (r^2=0.804), CTF4 (r^2=0.256), and CTF5 (r^2=0.194) (Figure 29, Table 14). The greatest of these declines occurred at CTF4 (40.60 cm/hr). The range of infiltration rates spanned 0.00 cm/hr (CTF4, Fall 2014) to 116.13 cm/hr (CTF1, Spring 2014). The greatest average infiltration for all sites within the traditional forest paddock occurred in Fall 2013 (37.81 cm/hr) and gradually declined to the lowest average infiltration rates in Fall 2015 (8.28 cm/hr) (Figure 30, Table 14).

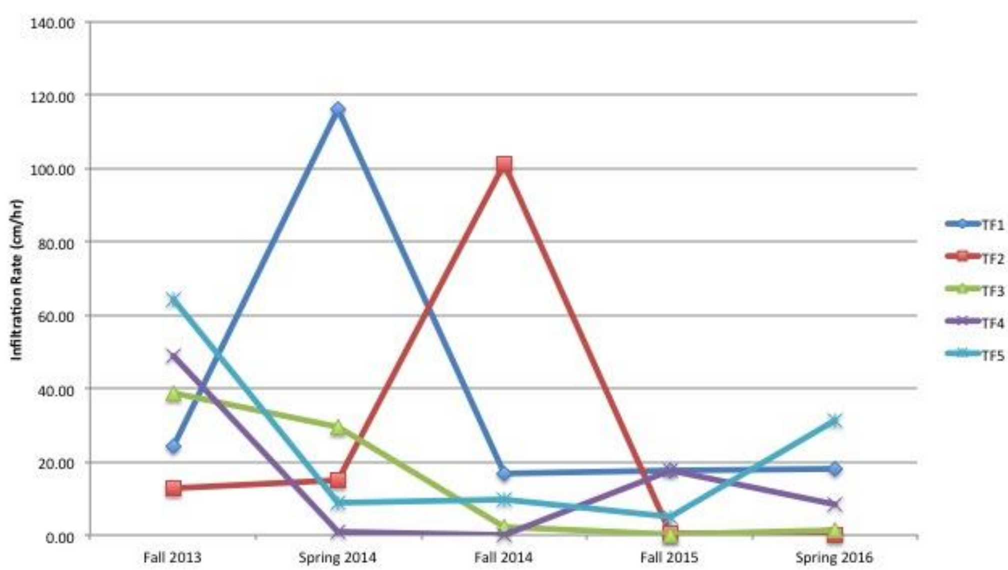

Figure 29. Caughey Traditional Forest Paddock Infiltration Rates Over Time

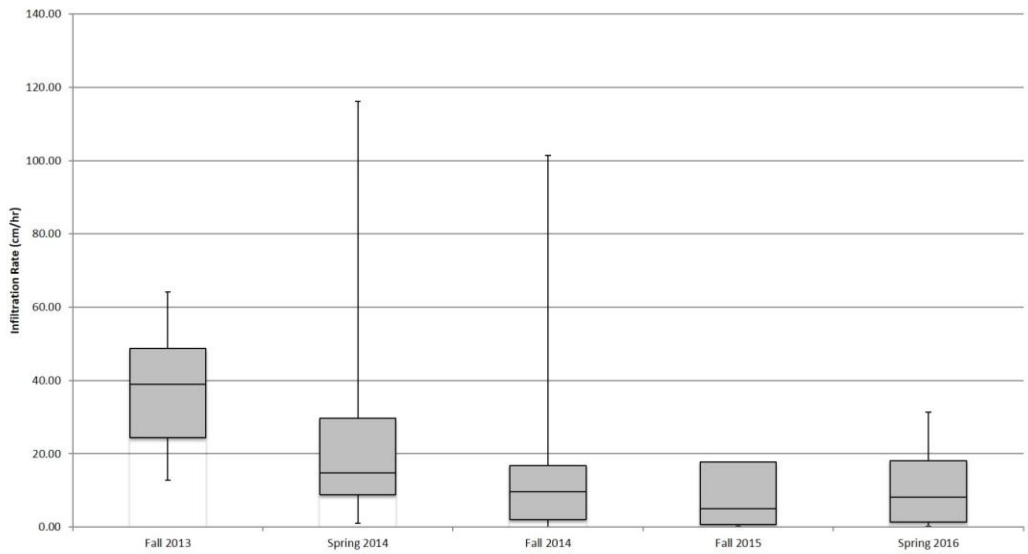

Figure 30. Caughey Traditional Forest Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 14. Caughey Traditional Forest Paddock Infiltration Rates (cm/hr)

Test Site	**Fall 2013**	**Spring 2014**	**Fall 2014**	**Fall 2015**	**Spring 2016**
CTF1	24.40	116.13	16.80	17.81	18.00
CTF2	12.80	14.80	101.37	0.60	0.20
CTF3	38.94	29.60	2.00	0.20	1.40
CTF4	48.80	1.00	0.00	17.80	8.20
CTF5	64.09	8.80	9.55	5.00	31.40
Average	37.81	34.07	25.94	8.28	11.84

When analyzing the infiltration rates by paddock over the course of the silvopasture project, it was determined that Caughey's open pasture experienced the lowest overall average (13.19 cm/hr), with silvopasture next (17.08 cm/hr), and traditional forest with the highest overall average infiltration rates (23.59 cm/hr) (Table 15). The traditional forest paddock also experienced the greatest range of values from 0.00 to 116.13 cm/hr, with open pasture second (0.00 to 78.30 cm/hr), and silvopasture with the smallest range (0.00 to 67.44 cm/hr) (Table 15, Figure 31).

The same statistical analysis was conducted for Caughey's Farm. Again, averages were calculated for infiltration rates based on treatment type and ANOVA tests were completed for infiltration versus K_{sat}, bulk density, landscape position and initial soil moisture. Caughey's average infiltration rates indicated a significant difference with K_{sat} values ($p<0.05$) (Table 16), with a moderate correlation ($r=0.52$). Tukey HSD tests identified the greatest difference in mean levels for infiltration based on treatment type was between the traditional forest and open pasture paddocks (10.09 cm/hr). Average infiltration rates based on soil texture type were ran in two-way ANOVA tests with a combination of soil texture, treatment type and season, which yielded no statistical differences in mean levels. Tukey HSD tests determined that the greatest difference in mean levels for texture was loam and loamy sand (27.25 cm/hr), and for season was Fall 2014 and Fall 2015 (15.09 cm/hr). Datasets used in RStudio for Caughey's statistical analysis can be found in Appendix C, Table 3 and 4.

Table 15. Caughey Soil Infiltration Rates per Paddock (cm/hr) (Fall 2013-Spring 2016)

	Open Pasture	**Silvopasture**	**Traditional Forest**
Minimum	0.00	0.00	0.00
Quartile 1	0.60	2.20	2.00
Median	4.00	7.80	14.80
Quartile 3	11.60	24.80	29.60
Maximum	78.30	67.44	116.13
Average	13.19	17.08	23.59

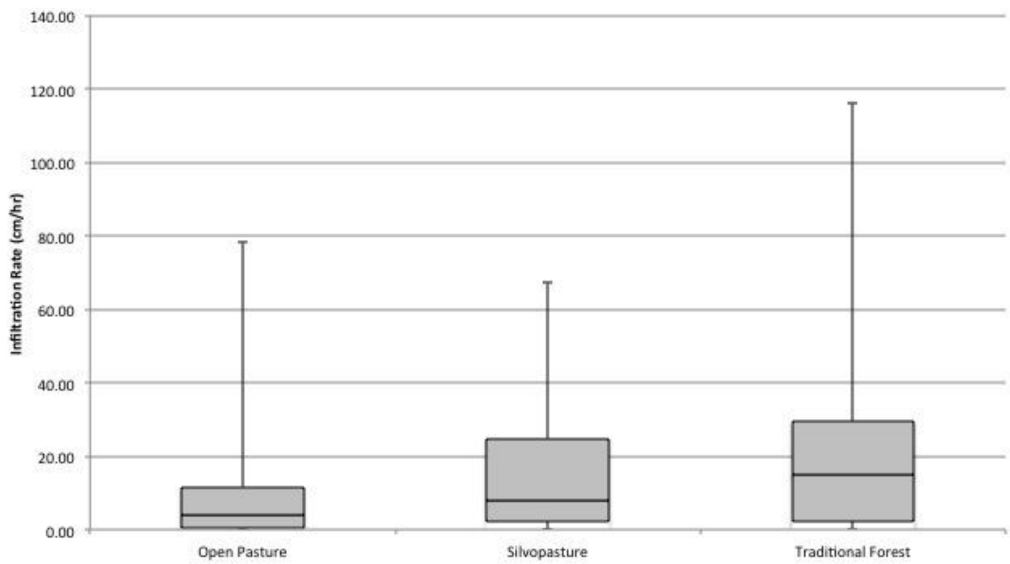

Figure 31. Caughey Infiltration Rates by Paddock (Range, Median, First and Third Quartile)

Table 16. Caughey Statistically Significant ANOVA Results

Caughey Infiltration by Treatment						
	Df	Sum Sq	Mean Sq	F Value	Pr(>F)	Signif. Code*
Ksat	1	519.3	519.3	4.724	0.0488	*
Residuals	13	1428.8	109.9			

*Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

3.1.3. Moe Soil Infiltration Results

At Moe's site, infiltration tests were taken Fall 2013, Spring 2014, Fall 2014 and Fall 2015. There was no Spring 2016 data. The Open Pasture at Moe's Farm experienced an overall increase in infiltration rates at MOP1 (r^2=0.066), MOP2 (r^2=0.039) and MOP3 (r^2=0.016). MOP4 (r^2=0.601) and MOP5 (r^2=0.045) had decreases in overall infiltration rates over the course of the project (Figure 32, Table 17). MOP1 experienced the greatest increase over the course of the project (20.80 cm/hr) and MOP4 had the greatest decrease (33.60 cm/hr). The open pasture paddock had a range of infiltration rates from 2.80 cm/hr (MOP1, Fall 2013) to 50.20 cm/hr (MOP1, Spring 2014). The greatest average infiltration rates by season occurred during Fall 2014 (24.28 cm/hr), while the lowest infiltration rates were in Fall 2015 (11.64 cm/hr) (Figure 33, Table 17).

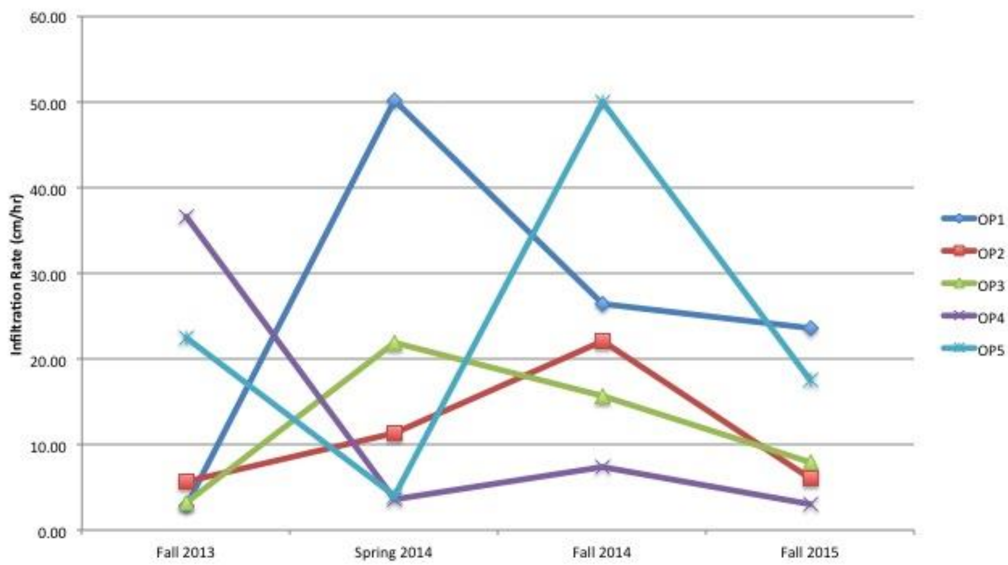

Figure 32. Moe Open Pasture Paddock Infiltration Rates Over Time

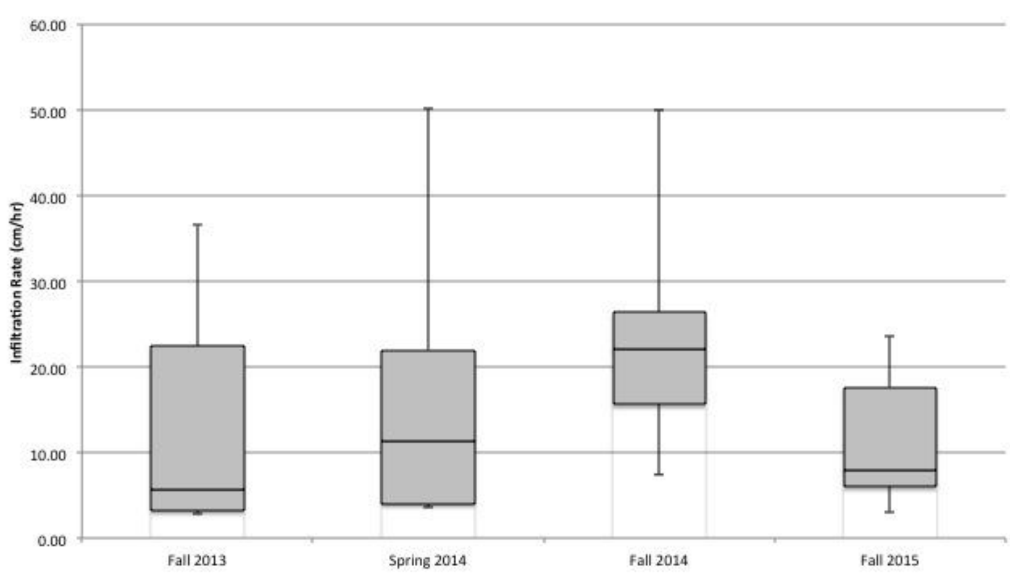

Figure 33. Moe Open Pasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 17. Moe Open Pasture Paddock Infiltration Rates (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015
MOP1	2.80	50.20	26.40	23.60
MOP2	5.60	11.40	22.00	6.00
MOP3	3.20	21.97	15.60	8.00
MOP4	36.60	3.60	7.40	3.00
MOP5	22.40	4.00	50.00	17.60
Average	14.12	18.23	24.28	11.64

In Moe's silvopasture paddock, there was an overall average increase in infiltration at four of the five test locations. MSV1 (r^2=0.92), MSV3 (r^2=0.43), MSV4 (r^2=0.72) and MSV5 (r^2=0.018) all increased over time, while MSV2 (r^2=0.035) decreased overall from Fall 2013 to Fall 2015 (Figure 34, Table 18). The greatest increase in infiltration occurred at MSV1 by increasing 28.40 cm/hr over time, while the greatest decrease occurred at MSV2 with a decline of 1.70 cm/hr. Moe's silvopasture paddock ranged from 0.00 cm/hr (MSV1, Fall 2013) to 58.20 cm/hr (MSV5, Fall 2014). On average by season for this paddock, the highest infiltration occurred in Spring 2014 (32.60 cm/hr) with gradual decreases over one and two grazing seasons, while the lowest infiltration occurred before seeding in Fall 2013 (8.18 cm/hr) (Figure 35, Table 18).

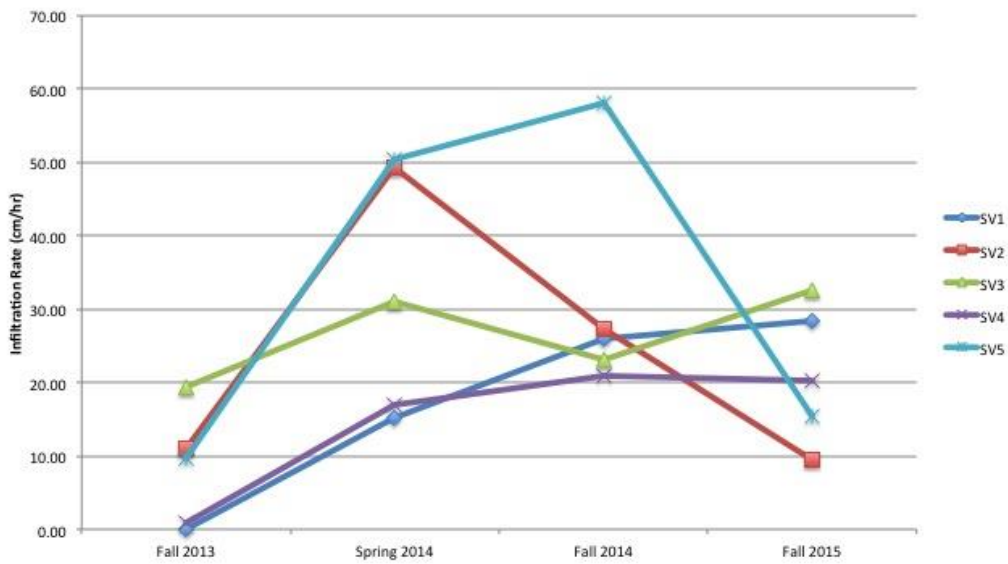

Figure 34. Moe Silvopasture Paddock Infiltration Rates Over Time

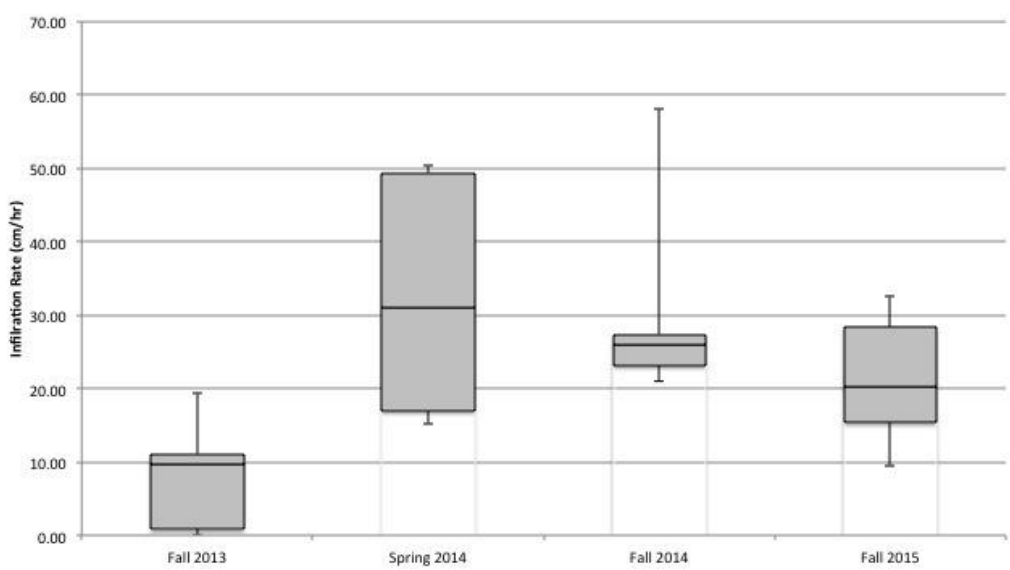

Figure 35. Moe Silvopasture Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 18. Moe Silvopasture Paddock Infiltration Rates (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015
MSV1	0.00	15.20	26.00	28.40
MSV2	11.10	49.40	27.40	9.40
MSV3	19.40	31.00	23.20	32.60
MSV4	0.80	17.00	21.00	20.20
MSV5	9.60	50.40	58.20	15.40
Average	8.18	32.60	31.16	21.20

Moe's traditional forest paddock experienced alternating overall average infiltration rates where MTF2 (r^2=0.99) and MTF4 (r^2=0.46) had increasing overall average infiltration rates while MTF1 (r^2=0.88), MTF3 (r^2=0.63) and MTF5 (r^2=0.47) had decreasing infiltration rates (Figure 36, Table 19). From Fall 2013 to Fall 2015, the greatest overall increase occurred at MTF4 (103.33 cm/hr) and greatest overall decrease occurred at MTF3 (186.58 cm/hr). The range of infiltration rates spanned 8.00 cm/hr (MTF5, Fall 2014) to 344.40 cm/hr (MTF5, Spring 2014). The highest average infiltration rates by season occurred in Fall 2013 (121.10 cm/hr) and the lowest average infiltration rates occurred in Fall 2014 (29.80 cm/hr) (Figure 27, Table 19).

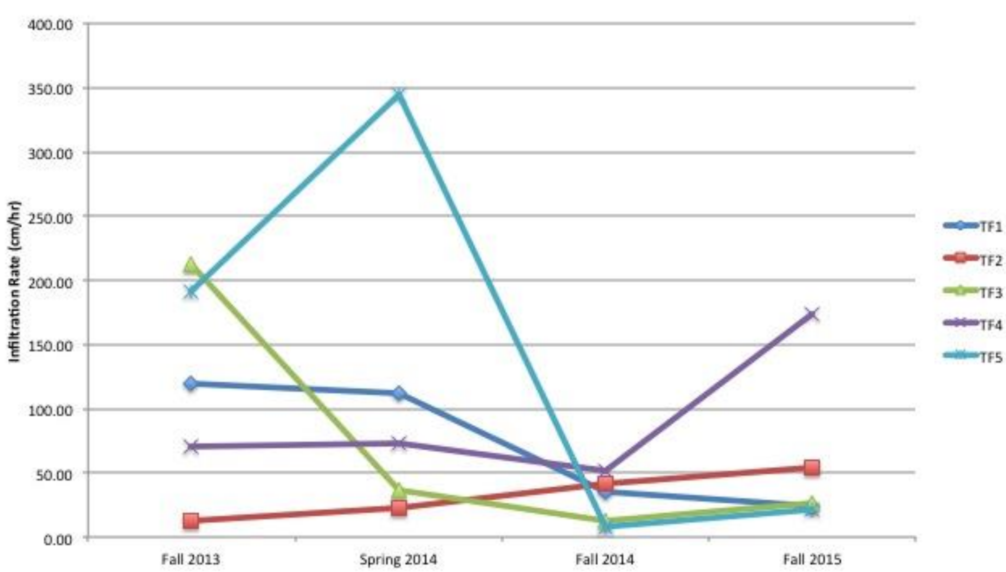

Figure 36. Moe's Traditional Forest Paddock Infiltration Rates Over Time

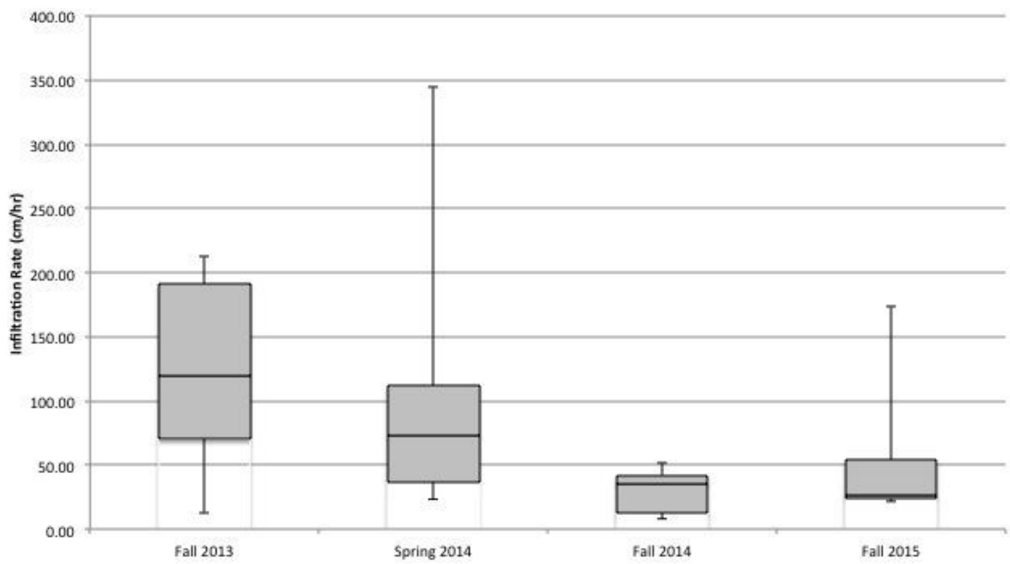

Figure 37. Moe's Traditional Forest Infiltration Rates Over Time (Range, Median, First and Third Quartile)

Table 19. Moe's Traditional Forest Paddock Infiltration Rates (cm/hr)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015
TF1	119.64	112.00	35.40	24.20
TF2	12.00	23.20	42.00	53.60
TF3	213.18	36.00	12.20	26.60
TF4	70.00	72.40	51.40	173.33
TF5	190.67	344.40	8.00	21.60
Average	121.10	117.60	29.80	59.87

By paddock, Moe's open pasture had the smallest range (2.80 to 50.20 cm/hr) and the lowest overall average infiltration rates (17.07 cm/hr) from Fall 2013 to Fall 2015. The silvopasture paddock had a range of 0.00 cm/hr to 58.20 cm/hr with an overall average of 23.29 cm/hr. The traditional forest experienced the greatest range (8.00 cm/hr to 344.40 cm/hr) and the greatest average (82.09 cm/hr) over the entirety of the project (Table 20, Figure 38).

Again, average infiltration rates based on treatment type were calculated and ANOVA tests were completed to determine differences between infiltration and K_{sat}, bulk density, landscape position, initial soil moisture and treatment type. Moe's average infiltration rates indicated significant differences with bulk density ($p<0.01$), landscape position and by paddock ($p<0.05$) (Table 21). The correlation between infiltration and bulk density, and infiltration and landscape position was strongly negative ($r=-0.74$ and $r=-0.70$, respectively). The Tukey HSD tests identified the greatest difference in mean levels for infiltration based on treatment type was between the traditional forest and open pasture paddocks (65.03 cm/hr). Two-way ANOVA tests for average infiltration based on soil texture for a combination of soil texture, treatment type and season deemed statistical differences in mean levels for treatment ($p<0.01$) (Table 21). Tukey HSD tests determined that the greatest difference in mean levels for texture was loamy sand and sand (33.60 cm/hr) and between Spring 2014 and Fall 2014 (29.40 cm/hr) for season. Datasets used in RStudio for Moe's statistical analysis can be found in Appendix C, Table 5 and 6.

Table 20. Moe Soil Infiltration Rates per Paddock (cm/hr) (Fall 2013-Fall 2015)

	Open Pasture	**Silvopasture**	**Traditional Forest**
Minimum	2.80	0.00	8.00
Quartile 1	5.20	14.18	23.95
Median	13.50	20.60	46.70
Quartile 3	22.70	29.05	113.91
Maximum	50.20	58.20	344.40
Average	17.07	23.29	82.09

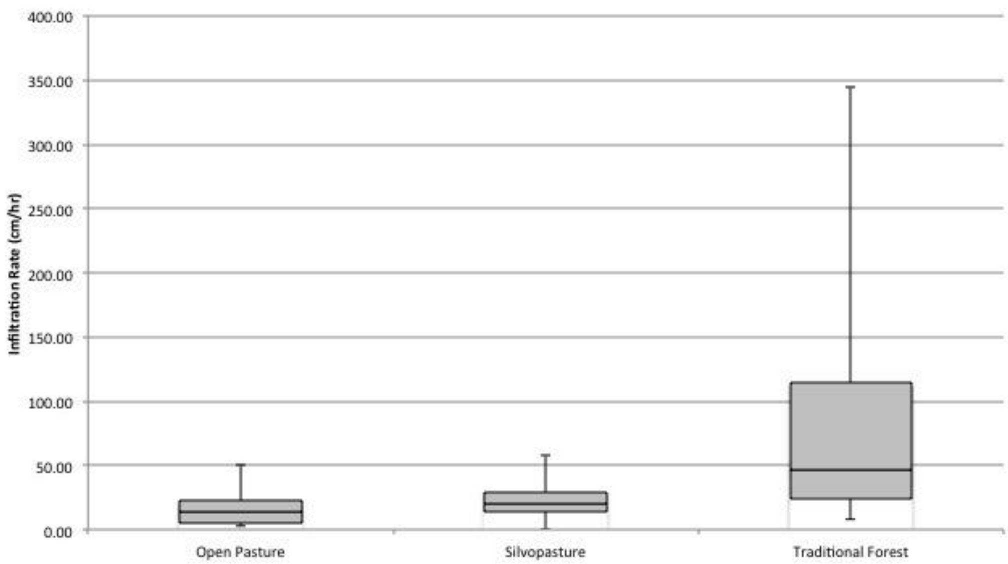

Figure 38. Moe Infiltration Rates by Paddock (Range, Median, First and Third Quartile)

Table 21. Statistically Significant Infiltration ANOVA Results

Moe Infiltration by Treatment						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Bulk Density	1	9183	9183	12.08	0.00596	**
Residuals	10	13400	1340			
Treatment	2	10300	5150	7.149	0.0138	*
Residuals	9	6484	720			
Elevation	1	8296	8296	9.775	0.0108	*
Residuals	10	8487	849			
Moe Infiltration by Texture and Treatment						
	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
Treatment	2	18523	9261	8.084	0.00375	**
Texture	2	795	398	0.347	0.71201	
Season	3	3633	1211	1.057	0.39475	
Residuals	16	18330	1145.58			

Signif. Codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

3.2. Soil Moisture Content Results

Soil moisture content was collected with the infiltration rates, as discussed in section 2.3. Post (or soil moisture final) collected samples were assumed to be at saturation when all soil pores are filled with water, causing minimally varying results. The pre samples (or soil moisture initial) determined the amount of moisture in the soil before infiltration tests had occurred.

For all seasons for all data collection for Booth's Farm, the open pasture had the lowest average initial soil moisture content (19.80%), followed by silvopasture (29.08%), while traditional forest had the highest (34.62%) (Table 22). Seasonally, the driest data collection time for all paddocks was in Fall 2015, yielding the lowest average initial soil moisture content (19.61%). The wettest collection time was in Spring 2016 (35.47%). All soil moisture content percentages for Booth's Farm can be seen in Appendix B, Table 1.

Statistical analysis was conducted for average initial soil moisture content by paddock to determine differences between the variables treatment type, season, bulk density, K_{sat}, infiltration and landscape position. The only significant difference was seen by treatment type ($p<0.05$), with the greatest difference between the traditional forest and open pasture paddock (14.63 cm/hr). Also noted was a negative correlation between initial soil moisture content and landscape position ($r=-0.44$). When initial soil moisture content was averaged by soil texture, ANOVA tests identified a difference with texture ($p<0.1$) with greatest differences between silty clay loam and sandy loam (11.30 cm/hr), while a two-way ANOVA determined that initial soil moisture content with soil texture and season had a significant difference ($p<0.05$ and $p<0.01$, respectively) with greatest difference between seasons between Spring 2016 and Fall 2015 (19.42 cm/hr).

Table 22. Booth's Average Initial Soil Moisture Content (%)

	Open Pasture	Silvopasture	Traditional Forest	Seasonal Average
Paddock Average	19.80	29.08	34.62	
Fall 2013	20.11	25.26	33.63	26.33
Spring 2014	21.84	34.78	41.85	32.82
Fall 2014	16.20	29.39	36.96	27.52
Fall 2015	17.52	21.08	20.23	19.61
Spring 2016	25.73	36.36	41.89	35.47

At Caughey's Farm, over the course of the project, the average initial soil moisture content was lowest in the traditional forest paddock (32.19%), followed by the open pasture paddock (40.71%), with the silvopasture paddock having the highest average initial soil moisture content (51.88%) (Table 23). This farm also experienced the driest data collection in Fall 2015 with an overall average initial soil moisture content percentage of 28.67 while the greatest overall average initial soil moisture content percentage was in Spring 2016 (53.83%) (Table 23). Full initial and final soil moisture content values can be found in Appendix B, Table 2.

The initial soil moisture content was averaged by paddock and analyzed to determine statistical differences between treatment type, season, bulk density, K_{sat}, infiltration and landscape position. A difference was seen by treatment type ($p<0.1$), where the greatest difference was within the silvopasture and traditional forest paddock (19.69 cm/hr). Initial soil moisture content was also averaged by soil texture and analyzed for differences between soil texture, treatment type and season, and a combination of the three variables. ANOVA tests identified a difference with season ($p<0.1$) with greatest differences between Spring 2016 and Fall 2015 (28.45 cm/hr), and initial soil moisture by season, treatment and soil texture had a significant difference for both season and treatment ($p<0.01$).

Table 23. Caughey's Average Initial Soil Moisture Content (%)

	Open Pasture	Silvopasture	Traditional Forest	Seasonal Average
Paddock Average	40.71	51.88	32.19	
Fall 2013	54.65	69.81	26.14	50.20
Spring 2014	40.89	46.25	32.55	39.90
Fall 2014	35.59	39.89	30.61	35.36
Fall 2015	22.28	34.43	39.32	28.67
Spring 2016	50.13	69.02	42.33	53.83

Moe's Farm had soil infiltration tests and soil moisture content collected from Fall 2013 to Fall 2015 with no Spring 2016 data. By paddock for all seasons, the open pasture paddock had the lowest initial soil moisture content (14.72%), second was the silvopasture paddock (17.85%), and the greatest was the traditional forest paddock (21.76%) (Table 24). As with the other farms, the driest data collection for overall average initial soil moisture content occurred during Fall 2015 (10.75%) while the wettest season for data collection was Spring 2014 (22.79%) (Table 24). Full initial and final soil moisture content values for Moe's farm can be found in Appendix B, Table 3.

The same statistical analysis was conducted for Moe's average initial soil moisture content by paddock. Of the variables tested by paddock, there were no apparent significant differences. Although moderate, there was a negative correlation between initial soil moisture content and landscape position ($r=-0.44$) and a positive correlation with infiltration ($r=0.44$). The greatest differences for season were between Spring 2014 and Fall 2014 (12.04) and for treatment were between traditional forest and open pasture paddocks (7.04). Initial soil moisture content was averaged by soil texture, a difference between average initial soil moisture content and season was apparent ($p<0.1$). When average initial soil moisture content was tested against season, treatment and texture, there was a significant difference between season ($p<0.05$) and treatment ($p<0.1$).

Table 24. Moe's Average Soil Moisture Content (%)

	Open Pasture	Silvopasture	Traditional Forest	Seasonal Average
Paddock Average	14.72	17.85	21.76	
Fall 2013	15.31	21.16	27.43	21.30
Spring 2014	16.32	29.23	22.81	22.79
Fall 2014	14.76	12.74	25.30	17.60
Fall 2015	12.50	8.25	11.49	10.75

3.3. Saturated Hydraulic Conductivity Results

Saturated hydraulic conductivity values were compiled from results from the MPD model for three-dimensional flow and Darcy's Law calculations for one-dimensional flow through the infiltrometer. Two-way ANOVA and Pearson's Correlation tests were conducted for K_{sat} and soil infiltration differences.

Booth's Farm K_{sat} results did not exhibit a statistically significant correlation with infiltration rates (r=0.19). When analyzed average K_{sat} by season, the range of values differed greatly, from 11.37 to 155.46 µm/sec (Table 25). From lowest to highest average K_{sat} values, the seasons ranked: Fall 2013, Fall 2015, Fall 2014, Spring 2014 and Spring 2016. By paddock, the lowest average K_{sat} over the entirety of the project was in the open pasture with an average of 14.10 µm/sec, the traditional forest paddock had an average of 21.50 µm/sec, and the silvopasture had the greatest average K_{sat} at 138.88 µm/sec (Table 25).

Caughey's Farm exhibited a significant difference between K_{sat} and infiltration rates ($p<0.001$, r=0.53). Seasonally, the average K_{sat} values did not differ widely and ranged from 12.68 to 19.69 µm/sec with Fall 2013 having the greatest K_{sat} values and Spring 2016 having the lowest (Table 26). The open pasture paddock had an average overall K_{sat} value of 11.33 µm/sec, while silvopasture was 16.29 µm/sec, and traditional forest paddock had 19.76 µm/sec (Table 26).

Moe's farm also displayed significant relationships between K_{sat} and infiltration rates ($r=0.35$, $p<0.01$). Average K_{sat} values by season ranged from 12.61 to 183.13 µm/sec, ranking highest to lowest by Spring 2014, Fall 2013, Fall 2015, Fall 2014 (Table 27). By paddock, the average K_{sat} for the open pasture was 103.27 µm/sec, the silvopasture was 11.38 µm/sec, and the traditional forest was 85.88 µm/sec (Table 27).

Table 25. Booth K_{sat} Results (µm/sec)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016	Paddock Average
BOP1	3.11	8.92	4.69	1.42	0.22	14.10
BOP2	15.31	16.61	14.61	17.08	0.00	
BOP3	15.83	32.11	15.59	0.00	5.10	
BOP4	5.39	8.56	0.00	121.17		
BOP5	2.14	18.39	10.81	7.19		
BSV1	13.44	48.36	104.92	3.11	106.29	138.88
BSV2	0.00	1235.31	0.00	12.28	22.62	
BSV3	0.00	7.00	5.58	139.33	1257.25	
BSV4	17.00	0.00	34.11	18.92		
BSV5	11.72	11.50	28.25	5.72	250.35	
BTF1	0.00	0.00	9.33	30.22	5.81	21.50
BTF2	4.29	5.20	61.81	1.31		
BTF3	66.56	0.00	26.81	0.00	58.72	
BTF4	0.00	21.53	112.50	1.44	3.65	
BTF5	15.73	6.48	17.31	67.31	0.00	
Season Average	11.37	94.66	29.75	28.43	155.46	

Table 26. Caughey K_{sat} Results (µm/sec)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Spring 2016	Paddock Average
COP1	111.33	16.16	5.31	21.56	7.21	11.33
COP2	0.00	4.10	42.42	13.67	27.24	
COP3	0.00	7.97	0.00	12.39	0.00	
COP4	0.00	0.00	5.75	5.42	0.00	
COP5	0.00	0.00	0.00	0.00	2.64	
CSV1	4.93	4.42	17.47	0.00	43.59	16.29
CSV2	13.17	73.83	0.00	2.17	18.17	
CSV3	5.97	37.06	45.61	5.33	56.39	
CSV4	5.50	7.66	54.97	0.00	0.00	
CSV5	0.00	5.40	0.00	1.64	3.98	
CTF1	25.97	2.25	14.47	22.48	13.11	19.76
CTF2	7.19	11.44	59.25	0.00	0.00	
CTF3	28.08	24.56	0.00	0.00	0.00	
CTF4	33.44	0.00	0.00	159.06	6.16	
CTF5	59.81	7.69	7.31	0.00	11.72	
Season Average	19.69	13.50	16.84	16.25	12.68	

Table 27. Moe K_{sat} Results (µm/sec)

Test Site	Fall 2013	Spring 2014	Fall 2014	Fall 2015	Paddock Average
MOP1	3.06	1895.75	36.95	15.83	103.27
MOP2	3.72	9.47	17.58	1.19	
MOP3	2.83	17.86	11.69	1.33	
MOP4	16.50	4.86	5.50	1.33	
MOP5	2.25	2.56	1.89	13.31	
MSV1	0.00	0.56	2.42	12.64	11.38
MSV2	13.91	31.22	1.86	7.39	
MSV3	12.42	14.25	1.14	23.22	
MSV4	0.00	2.28	1.00	7.92	
MSV5	6.32	67.87	1.97	19.27	
MTF1	266.73	44.64	28.14	1.25	85.88
MTF2	13.32	0.92	18.44	16.25	
MTF3	148.50	1.31	28.97	19.89	
MTF4	0.42	24.47	26.83	309.62	
MTF5	117.86	628.86	4.73	16.36	
Season Average	40.52	183.13	12.61	31.12	

3.4. Subsurface Nutrient Transport Results

Subsurface nutrient transport was monitored by collecting water samples from the perched water table access tubes installed in each paddock. Once the water had been pumped from the well, the water samples were tested for bromide concentration.

At Booth's Farm, detections of bromide were identified in all of the water samples (range 0.006 to 1 ppm or 6.6 to -39.7 mV) in June 2015 (Table 28). BTF2 had a 0 ppm reading, but a 6.6 mV value. The average was 0.38 ppm, or -17.66 mV. Low concentrations of bromide were also identified in the control access tube located at Booth's Farm at a 0.5 ppm (-23.9 mV) concentration, indicating a baseline level of bromide at approximately 0.5 ppm. Two months later in August 2015, 8 of the 10 access tubes at Booth's Farm were dry and could not be sampled, including the control. The two access tubes that were not dry had undetectable levels of bromide with an average mV reading of 9.65.

Caughey's Farm also had initial detections of bromide ranging from 0.5 to 2.0 ppm (or -24.7 to -57.4 mV) during the first water collection in June (Table 29). The average for June data collection was 1.37 ppm, or -42.41 mV. At this farm, all access tubes had adequate levels of water to capture samples during the August sampling. The results ranged from 0.06 to 0.4 ppm (-3.6 to -20.1 mV) with an average of 0.23 (-12.94 mV) (Table 29).

Moe's Farm also experienced initial detections of bromide ranging from 0.003 to 1 ppm (1 to -42.6 mV) in June, averaging 0.51 ppm (-22.69 mV) (Table 30). Three of the eight access tubes at Moe's Farm were dry in August (MOP1, MOP2 and MOP3), and all access tubes yielded lower levels of bromide, except in MTF2. These bromide concentrations ranged from 0.01 to 0.8 ppm (0.1 to -31.7 mV) with an average of 0.29 ppm (-13.36 mV).

Table 28. Booth Bromide Field Results

	16-Jun-15		13-Aug-15	
Well	**mV**	**ppm**	**mV**	**ppm**
Control	-23.9	0.5		
BOP1	-25.4	0.5		
BOP2	-21.1	0.4		
BOP3	0.8	0.006	11.4	0
BSV1	-23.5	0.5	7.9	0
BSV2	-16.4	0.3		
BSV3	-16.3	0.3		
BTF1	-39.7	1		
BTF2	6.6	0		
BTF3	-17.7	0.3		
Average	-17.66	0.38	9.65	0

Table 29. Caughey Bromide Field Results

	16-Jun-15		13-Aug-15	
Well	**mV**	**ppm**	**mV**	**ppm**
COP1	-24.7	0.5	-3.6	0.06
COP2	-32.8	0.8	-5.2	0.08
COP3	-45.8	1	-12	0.2
CSV1	-46.6	2	-20.1	0.4
CSV2	-45.4	1	-13.9	0.2
CSV3	-44.6	2	-12.7	0.2
CTF1	-39.8	1	-17.3	0.3
CTF2	-57.4	3	-20.2	0.4
CTF3	-44.6	1	-11.5	0.2
Average	-42.41	1.37	-12.94	0.23

Table 30. Moe Bromide Field Results

	16-Jun-15		13-Aug-15	
Well	**mV**	**ppm**	**mV**	**ppm**
MOP1	-26.5	0.6		
MOP2	-6	0.1		
MOP3	-23.8	0.5		
MSV1	-38.2	1	-31.7	0.8
MSV2	-42.6	1	-18.1	0.4
MSV3	-31.2	0.7	-12	0.2
MTF1	-14.2	0.2	-5.1	0.08
MTF2	1	0.003	0.1	0.01
Average	-22.69	0.51	-13.36	0.29

3.5. Soil Property Results: Bulk Density, Porosity and Texture

3.5.1. Bulk Density and Porosity

All bulk density and porosity calculations were determined from soil samples collected with the ring method. Each soil infiltration test site had a sample collected and sent to the lab where bulk density and porosity were calculated.

At Booth's Farm, bulk density ranged from 1.23 to 1.63 g/cm^3, with the silvopasture paddock having the lowest average bulk density (1.35 g/cm^3), open pasture had an average of 1.43 g/cm^3 and traditional forest paddock had the highest bulk density at 1.52 g/cm^3 (Table 31). Porosity ranged from 38.65 to 53.51 percent. The average bulk density for all of Booth's paddocks was 1.44 g/cm^3, while the average porosity was 45.80 percent.

Table 31. Booth Bulk Density and Porosity Results

Test Site	Bulk Density (g/cm^3)	Bulk Density Average (g/cm^3)	Porosity (%)	Porosity Average (%)
BOP1	1.35	1.43	49.04	45.86
BOP2	1.35		48.96	
BOP3	1.46		45.04	
BOP4	1.52		42.67	
BOP5	1.49		43.62	
BSV1	1.50	1.35	43.24	48.89
BSV2	1.38		47.85	
BSV3	1.36		48.72	
BSV4	1.29		51.15	
BSV5	1.23		53.51	
BTF1	1.48	1.52	44.05	42.65
BTF2	1.52		42.64	
BTF3	1.63		38.65	
BTF4	1.50		43.49	
BTF5	1.47		44.44	

Caughey's bulk density ranged from 0.78 to 1.65 g/cm^3 (Table 32). The average bulk density for Caughey's open pasture was 1.48 g/cm^3 (highest), silvopasture was 1.16 g/cm^3 (lowest), and traditional forest was 1.29 g/cm^3. Porosity ranged from 37.74 to 70.73 percent. Overall the average bulk density for all paddocks was 1.31 g/cm^3 and average porosity for all paddocks was 50.58 percent.

Table 32. Caughey Bulk Density and Porosity Results

Test Site	Bulk Density (g/cm^3)	Bulk Density Average (g/cm^3)	Porosity (%)	Porosity Average (%)
COP1	1.40	1.48	47.19	43.98
COP2	1.49		43.73	
COP3	1.58		40.41	
COP4	1.65		37.74	
COP5	1.30		50.82	
CSV1	1.38	1.16	47.84	56.27
CSV2	1.48		44.04	
CSV3	0.78		70.73	

CSV4	1.04		60.69	
CSV5	1.11		58.05	
CTF1	1.33	1.29	49.73	51.50
CTF2	1.34		49.29	
CTF3	1.10		58.38	
CTF4	1.30		50.88	
CTF5	1.35		49.23	

Moe's Farm bulk density ranged from 1.22 to 1.67 g/cm^3 (Table 33). The open pasture had an average bulk density of 1.47 g/cm^3, the silvopasture paddock had the highest average bulk density at 1.50 g/cm^3, while the traditional forest paddock had the lowest average bulk density at 1.41 g/cm^3 (Table 33). The overall average bulk density was 1.42 g/cm^3. The porosity ranged from 37.13 to 53.79 percent with an average porosity for all paddocks of 50.34 percent.

Table 33. Moe Bulk Density and Porosity Results

Test Site	Bulk Density (g/cm^3)	Bulk Density Average (g/cm^3)	Porosity (%)	Porosity Average (%)
MOP1	1.57	1.47	40.71	44.35
MOP2	1.36		48.63	
MOP3	1.57		40.64	
MOP4	1.59		39.91	
MOP5	1.28		51.88	
MSV1	1.56	1.50	41.21	43.54
MSV2	1.33		49.97	
MSV3	1.52		42.58	
MSV4	1.52		42.64	
MSV5	1.55		41.33	
MTF1	1.29	1.41	51.29	46.83
MTF2	1.42		46.49	
MTF3	1.67		37.13	
MTF4	1.45		45.44	
MTF5	1.22		53.79	

3.5.2. Soil Texture

According to the USDA NRCS soil survey (2016a), Booth's Farm has three primary soil series encompassing the area: DeMontreville-Mahtomedi-Cushing complex, Sandwick loamy sand, and Warba very fine sandy loam. The soil textures associated with the complex in the upper soil profile (0 to 12.7 cm) were loamy sand (DeMontreville and Mahtomedi) and fine sandy loam (Cushing). Since soil texture can vary greatly within close proximity, soil texture was determined for each of the infiltration test locations by measuring the percentage of sand, silt and clay.

Three soil textures were identified at Booth's Farm: sandy loam (73.3%), loam (20.0%) and silty clay loam (6.7%) (Table 34). Additionally, sand size distribution was determined for BOP2 and BSV4 utilizing the Wentworth (1922) grain size classification chart, identifying that the greatest percentage of sand was fine sand (30.9% and 32.2%, respectively) (Table 35).

Table 34. Booth Soil Texture Analysis

Test Site	% Sand	% Silt	% Clay	USDA Textural Class
BOP1	74	15	10.6	Sandy Loam
BOP2	73			Sandy Loam
BOP3	60	27	12.6	Sandy Loam
BOP4	75	13	11.6	Sandy Loam
BOP5	70	15	14.6	Sandy Loam
BSV1	76	13	10.6	Sandy Loam
BSV2	50	32	17.6	Loam
BSV3	66	21	12.6	Sandy Loam
BSV4	82			Sandy Loam
BSV5	17	52	30.6	Silty Clay Loam
BTF1	46	36	17.6	Loam
BTF2	31	45	23.6	Loam
BTF3	58	28	13.6	Sandy Loam
BTF4	73	13	14	Sandy Loam
BTF5	70	19	10.6	Sandy Loam

Table 35. Booth Percent Sand Size Distribution for BOP2 and BSV4

Sieve Size	BOP2	BSV4
2 mm		
1 mm	9.75	12.24
0.5 mm	22.31	23.03
0.25 mm	30.95	32.18
0.106 mm	23.81	18.72
0.053 mm	13.18	13.83
< 0.053 mm		
Total	100.00	99.99

Caughey's Farm was identified to have three soil series by the USDA NRCS soil survey. These included the Chetek-Seelyeville, ponded complex, the Brainerd-Flak complex, and the Nokay-Prebish complex. The soil textures associated with these soil series in the top 0 to 12.7 cm were fine sandy loam (Chetek), muck (Seelyeville, ponded), sandy loam (Brainerd and Flak) and loam (Nokay an Prebish). The results from the soil texture tests completed from the soil infiltration test sites identified that the primary soil texture was sandy loam (73.3%), followed by loamy sand (6.7%), loam (6.7%), clay loam (6.7%) and sandy clay loam (6.7%) (Table 36). The sand size distribution tests were done on COP1 and CTF4, which yielded that the primary sand size was very fine sand (33.7% and 37.7%, respectively) (Table 37).

Table 36. Caughey Soil Texture Classification

Test Site	% Sand	% Silt	% Clay	USDA Textural Class
COP1	82			Sandy Loam
COP2	71	15	13.6	Sandy Loam
COP3	85	5	9.6	Loamy Sand
COP4	63	17	19.6	Sandy Loam
COP5	70	12	17.6	Sandy Loam

CSV1	66	20	13.6	Sandy Loam
CSV2	69	16	14.6	Sandy Loam
CSV3	49	35	15.6	Loam
CSV4	35	26	38.6	Clay Loam
CSV5	62	19	18.6	Sandy Loam
CTF1	76	12	11.6	Sandy Loam
CTF2	68	17	14.6	Sandy Loam
CTF3	58	20	21.6	Sandy Clay Loam
CTF4	67	15	17.6	Sandy Loam
CTF5	62	22	15.6	Sandy Loam

Table 37. Caughey Percent Sand Size Distribution for COP1 and CTF4

Sieve Size	COP1	CTF4
2 mm		
1 mm	10.75	5.73
0.5 mm	15.61	14.17
0.25 mm	30.74	34.78
0.106 mm	33.70	37.74
0.053 mm	9.20	7.58
< 0.053 mm		
Total	100.00	100.00

The soil series for Moe’s Farm were identified by the USDA NRCS Soil Survey to include the Chetek-Graycalm complex, Bushville loamy sand, Brainerd sandy loam, and Lougee-Totagatic-Bowstring complex. The complexes’ soil textures in the upper soil profile were fine sandy loam (Chetek), loamy sand (Graycalm), peat (Lougee) and muck (Totagatic and Bowstring). The soil texture classes from our analysis were identified as primarily sandy loam (40.0%) and loamy sand (40.0%), with some in areas of sand (20.0%) (Table 38). Percent sand size distribution was completed for MOP1, MOP2 and MSV4, determining that the greatest percent sand for MOP1 was very fine sand (49.8%), while MOP2 and MSV4 were fine sands (42.2% and 48.4%, respectively) (Table 39).

Table 38. Moe Soil Texture Classification

Test Site	% Sand	% Silt	% Clay	USDA Textural Class
MOP 1	95			Sand
MOP 2	74	12	13.6	Sandy Loam
MOP 3	77	11	11.6	Sandy Loam
MOP 4	72	15	12.6	Sandy Loam
MOP 5	73	14	12.6	Sandy Loam
MSV 1	85	5	9.6	Loamy Sand
MSV 2	82	8	9.6	Loamy Sand
MSV 3	88	5	6.6	Sand
MSV 4	92			Sand
MSV 5	84	6	9.6	Loamy Sand
MTF 1	60	26	13.6	Sandy Loam
MTF 2	81	9	9.6	Loamy Sand
MTF 3	78	12	9.6	Sandy Loam
MTF 4	86	4	9.6	Loamy Sand
MTF 5	87	4	8.6	Loamy Sand

Table 39. Moe Percent Sand Size Distribution for MOP1, MOP2 and MSV4

Sieve Size	MOP1	MOP2	MSV4
2 mm			
1 mm	0.96	5.69	1.91
0.5 mm	3.12	9.63	6.03
0.25 mm	40.67	42.17	48.37
0.106 mm	49.82	36.94	38.14
0.053 mm	5.43	5.59	5.55
< 0.053 mm			
Total	100.00	100.00	100.00

3.6. Temperature and Precipitation

The annual mean summer (June to August) temperature for Booth's Farm is on average 18.3 degrees Celsius, while the mean winter (December to February) temperature is -12.2 degrees Celsius, and on average, this area receives 68.6 cm of precipitation annually (MNDNR, 2013). Based on temperature and precipitation data collected at the

Brainerd-Crow Wing County Regional Airport, this area received a total 49.4 cm of precipitation with an average annual temperature of 4.5 degrees Celsius in 2014 (Table 40 and 41). In 2015, there was a total of 45.3 cm of precipitation with an average annual temperature of 6.3 degrees Celsius (Table 40 and 41).

Table 40. Monthly Sum of Precipitation for Brainerd-Crow Wing County Regional Airport (Source: Weather Underground, 2016a)

Monthly Precipitation (cm)			
	2014	**2015**	**2016**
Jan	0.13	0.08	1.35
Feb	0.28	0.36	0.00
Mar	0.89	0.66	3.91
Apr	3.68	1.57	6.50
May	9.12	10.46	10.29
Jun	10.74	2.13	10.44
July	5.49	7.42	27.41
Aug	14.43	5.13	12.95
Sept	3.02	2.64	
Oct	0.43	3.25	
Nov	0.71	9.35	
Dec	0.48	2.29	
Average	4.12	3.78	
Sum	49.40	45.34	

Table 41. Monthly Average Mean Temperature for Brainerd-Crow Wing County Regional Airport (Source: Weather Underground, 2016a)

Monthly Average Mean Temperature (C°)			
	2014	**2015**	**2016**
Jan	-14.44	-10.00	-11.11
Feb	-13.33	-14.44	-7.22
Mar	-5.00	-1.11	2.22
Apr	5.56	6.67	5.56
May	15.00	11.67	12.78
Jun	20.56	17.78	18.33
July	20.00	21.11	20.56

Aug	18.89	18.89	20.00
Sept	13.89	17.22	
Oct	6.67	8.33	
Nov	-6.67	2.78	
Dec	-6.67	-3.89	
Average	4.54	6.25	

Caughey and Moe's Farm had the same annual mean summer and winter temperatures as Booth's Farm, but Caughey's site receives on average 71.1 cm of precipitation annually (MNDNR, 2013). The Little Falls-Morrison County Airport reported that in 2014, this area received 51.8 cm of precipitation with an average annual temperature of 3.6 degrees Celsius, and in 2015, it received 50.7 cm of precipitation with an average annual temperature of 6.4 degrees Celsius (Table 42 and 43)

Table 42. Monthly Sum of Precipitation for Little Falls-Morrison County Airport (Source: Weather Underground, 2016b)

Monthly Precipitation (cm)			
	2014	**2015**	**2016**
Jan	0.28	0.05	0.79
Feb	0.58	0.25	0.89
Mar	0.61	0.53	2.92
Apr	4.72	1.32	4.11
May	7.98	8.38	6.53
Jun	8.13	6.30	4.88
July	5.66	10.64	20.37
Aug	13.89	8.43	11.23
Sept	7.21	2.29	
Oct	0.91	4.57	
Nov	1.52	6.58	
Dec	0.33	1.40	
Average	4.32	4.23	
Sum	51.84	50.75	

Table 43. Monthly Average Mean Temperature for Little Falls-Morrison County Airport (Source: Weather Underground, 2016b)

Monthly Average Mean Temperature (C°)			
	2014	**2015**	**2016**
Jan	-15.56	-8.89	-10.00
Feb	-15.56	-12.78	-6.11
Mar	-6.11	-0.56	2.78
Apr	3.33	6.67	5.56
May	12.22	11.67	12.78
Jun	18.33	17.78	18.33
July	18.89	20.00	20.00
Aug	19.44	18.33	19.44
Sept	13.89	17.22	
Oct	6.67	8.33	
Nov	-6.11	2.78	
Dec	-5.56	-3.33	
Average	3.66	6.44	

3.7. Summary of Paddock Differences

Booth's Farm had the highest overall average infiltration rates from Fall 2013 to Spring 2016 in the silvopasture paddock (23.08 cm/hr). This also coincided with the greatest average K_{sat} value (138.88 µm/sec), the lowest bulk density values (1.35 g/cm^3) and mid-ranged average initial soil moisture content (29.08%). The primary soil texture for this paddock was sandy loam. Following was the traditional forest with an overall average infiltration rate of 19.16 cm/hr, an average K_{sat} of 21.50 µm/sec and the highest bulk density at 1.52 g/cm^3. This paddock had a mixture of sandy loam and loam soils as the primary soil texture. The highest initial soil moisture content was measured in the traditional forest paddock, which indicated that the soils retained their moisture greater than in the silvopasture and open pasture. The open pasture had the lowest overall average infiltration (14.67 cm/hr) and K_{sat} values (14.10 µm/sec) with a mid-ranged bulk density (1.43 g/cm^3). The predominate soil texture was sandy loam, but the paddock had the lowest average initial soil moisture content (19.80%).

The predominant soil texture for all of the paddocks at Caughey's Farm was sandy loam. At this location, the overall average soil infiltration and K_{sat} values was highest in the traditional forest paddock (23.29 cm/hr and 19.76 µm/sec), followed by the silvopasture (17.08 cm/hr and 16.29 µm/sec), then the open pasture paddock (13.19 cm/hr and 11.33 µm/sec). The silvopasture paddock had the lowest average bulk density (1.16 g/cm^3) and highest average initial soil moisture content (51.88%). The traditional forest paddock had the lowest initial soil moisture content (32.19%) and an average bulk density of 1.29 g/cm^3. The open pasture paddock had the highest average bulk density (1.48 g/cm^3) with an average initial soil moisture content of 40.71%.

Moe's Farm experienced similar results at Caughey's Farm. The traditional forest paddock had the greatest overall average infiltration (82.09 cm/hr), but not the highest K_{sat} values (85.88 cm/hr). This paddock had the lowest average bulk density (1.41 g/cm^3) and the highest average initial soil moisture content (21.76%) when compared to the other paddocks. The traditional forest paddock also had a mixture of sandy loam and loamy sand soil textures. The silvopasture paddock had the second highest overall average infiltration rate (23.29 cm/hr), the lowest average K_{sat} value (11.38 µm/sec), the highest average bulk density (1.50 g/cm^3), a mid-ranged average initial soil moisture content (17.85%) and sand and loamy sand soil texture. Moe's open pasture paddock had the lowest average infiltration rates (17.07 cm/hr), highest average K_{sat} (103.27 µm/sec), had predominately sandy loam for soil texture, an average 1.47 g/cm^3 bulk density, and the lowest average initial soil moisture content (14.72%). Table 44 summarizes the average findings for Booth, Caughey and Moe's farms from this project.

Table 44. All Farm Paddocks, Averages Summary

	Paddock	Infiltration (cm/hr)	K_{sat} (μm/sec)	Soil Texture (Primary)	Bulk Density (g/cm^3)	Soil Moisture, Initial (%)
Booth	BOP	14.67	14.10	Sandy Loam	1.43	19.80
	BSV	23.08	138.88	Sandy Loam	1.35	29.08
	BTF	15.90	21.50	Sandy Loam, Loam	1.52	34.62
Caughey	COP	13.19	11.33	Sandy Loam	1.48	40.71
	CSV	17.08	16.29	Sandy Loam	1.16	51.88
	CTF	23.29	19.76	Sandy Loam	1.29	32.19
Moe	MOP	17.07	103.27	Sandy Loam	1.47	14.72
	MSV	23.29	11.38	Sand, Loamy Sand	1.50	17.85
	MTF	82.09	85.88	Sandy Loam, Loamy Sand	1.41	21.76

3.8. Laboratory Experiment Results

Infiltration tests were completed on the soil core collected from Caughey's Farm during Fall 2015. Stage 1 was completed by running an infiltration test from drought conditions, stage 2 was completed after the initial infiltration test was complete and all water had infiltrated through the soil core, stage 3 was completed after two consecutive infiltration tests and the core was assumed to be saturated. The highest average soil infiltration rate occurred from drought conditions (45.7 cm/hr), while stage 2 had the lowest infiltration rate of 16.1 cm/hr and stage 3 (at saturation) had a 34.2 cm/hr infiltration rate (Table 45).

Table 45. Lab Infiltration Rate Results at the Different Stages

Test Stage	Infiltration Rate (cm/hr)
1	45.72
2	16.13
3	34.20

Volume of water and bromide concentrations were recorded after stage 2 and 3. The initial results from the water samples yielded that the average volume in the bottles was 155 mL, ranging from 26 to 224 mL (Table 46). The bromide concentration ranged from 10 to 20 ppm (-96.4 to -115.3 mV). A crack in the base of the soil column leaked water out the side, which was also collected and measured (218 mL, 30 ppm).

The final results were collected after saturation had been reached. The seal at the base had become a greater problem at this point. The volume in the bottles ranged from 0 to 515 mL, while the captured leaked water was 1705 mL (Table 47). The bromide concentration ranged from 8 to 20 ppm (-87.3 to -108.5 mV). The leaked portion of the water also decreased in bromide concentration, from 30 to 20 ppm (-116.7 to -107.6 mV).

Table 46. Soil Core Infiltration Test: Initial Results

Sample	ISE (ppm)	Voltage (mV)	Volume (mL)
1	20	-108.1	51
2	20	-114.2	26
3	20	-115.3	224
4	20	-107.6	167
5	10	-96.4	202
6	20	-115.8	228
7	20	-107.3	168
8	20	-111.8	203
9	20	-112.5	128
Leaked	30	-116.7	218

Table 47. Soil Core Infiltration Test: Final Results

Sample	ISE (ppm)	Voltage (mV)	Volume (mL)
1	N/A	N/A	0
2	8	-87.3	29
3	N/A	N/A	0
4	10	-98	84
5	20	-102.4	55
6	20	-107.3	515
7	N/A	N/A	0
8	20	-108.5	47
9	10	-96.7	5
Leaked	20	-107.6	1705

Chapter 4. Discussion

4.1. Project Results Discussion

There was an overall increase in infiltration at 47 percent (21 sites), one site had no change, and the remaining experienced a decline in infiltration over the course of the project (Table 48). By paddock, the silvopastures had an overall increase in soil infiltration at 11 sites, open pastures had an increase at six sites, and traditional forest paddocks had an increase at four sites (Table 48). In ideal situations where vegetation management was the determining factor for infiltration rates (as was originally hypothesized), the trend expected to be observed in seeded paddocks would be an increase from Fall 2013 to Spring 2014 (due to seeding), a decrease in infiltration from Spring 2014 to Fall 2014 (from loss of vegetation from grazing), an increase from Fall 2014 to Fall 2015 (due to greater establishment of vegetation), and a decrease in infiltration from Fall 2015 to Spring 2016 (due to minimal growth and evapotranspiration after winter), with an overall increase in infiltration rates from the beginning to end of the project. However, this specific pattern was only observed at 6 of the 45 soil infiltration test locations, indicating that other factors are playing roles in soil infiltration changes.

Soil infiltration rates altered between treatment type and research site. Statistical analysis confirmed that although there were some significant differences and correlations, there was no specific or consistent variables that indicated the reason for changes in infiltration found during this project. With no resounding trend identified or statistically significant results, it is implied that there are many complex factors that influence soil infiltration in this project, not just vegetation and animal management. We explored the concept that soil infiltration rates were likely influenced by several different factors that can be linked to a combination of drivers. The key drivers identified in this study are vegetation and animal management, geology and soils, climate change, and previous land use that affect bulk density, antecedent soil moisture, resiliency to disturbances, secondary porosity development, organic matter, and others. Table 49 summarizes the drivers and factors that they affect, which are further discussed in the sections below.

Table 48. Differences in Infiltration between Seasons

	Fall 2013 To Spring 2014	**Spring 2014 To Fall 2014**	**Fall 2014 To Fall 2015**	**Fall 2015 To Spring 2016**	**Fall 2013 To Spring 2016**	**Fall 2013 to Spring 2016 r^2**
BOP1	+	-	+	-	+	0.59
BOP2	-	+	+	-	-	0.43
BOP3	+	-	-	+	-	0.43
BOP4	+	-	+		-	0.23
BOP5	+	-	+		-	0.67
BSV1	+	+	-	+	-	0.06
BSV2	+	-	+	0	+	0.00
BSV3	+	-	+	-	+	0.33
BSV4	-	+	-		-	0.02
BSV5	+	+	-	+	+	0.22
BTF1	-	+	+	-	+	0.29

BTF2	-	+	-		-	0.11
BTF3	-	+	-	+	-	0.04
BTF4	+	+	-	-	+	0.00
BTF5	-	+		-	-	0.61
COP1	-	+	+	-	-	0.08
COP2	-	+	-	-	-	0.37
COP3	+	-	+	-	0	0.08
COP4	+	-	+	-	+	0.31
COP5	+	0	+	+	+	0.64
CSV1	+	-	-	+	+	0.02
CSV2	+	-	+	+	+	0.01
CSV3	+	+	-	+	+	0.25
CSV4	-	+	-	-	-	0.01
CSV5	+	-	+	+	+	0.01
CTF1	+	-	+	+	-	0.16
CTF2	+	+	-	-	-	0.02
CTF3	-	-	-	+	-	0.80
CTF4	-	-	+	-	-	0.26
CTF5	-	+	-	+	-	0.19
MOP1	+	-	-		+	0.07
MOP2	+	+	-		+	0.04
MOP3	+	-	-		+	0.02
MOP4	-	+	-		-	0.61
MOP5	-	+	-		-	0.04
MSV1	+	+	+		+	0.92
MSV2	+	-	-		-	0.04
MSV3	+	-	+		+	0.43
MSV4	+	+	-		+	0.72
MSV5	+	+	-		+	0.02
MTF1	-	-	-		-	0.88
MTF2	+	+	+		+	0.99
MTF3	-	-	+		-	0.63
MTF4	+	-	+		+	0.46
MTF5	+	-	+		-	0.47

+ indicates increase, - indicates decrease, 0 indicates no change in infiltration rates

Table 49. Key Drivers and Related Factors that Affect Infiltration

Driver	Factors
Vegetative Management	Secondary porosity
	Bulk density
	Antecedent soil moisture
	Organic matter
	Evapotranspiration
Livestock Management	Bulk density
	Organic matter
	Vegetation growth
Geology and Soils	Resiliency to disturbances
	Bulk density
	Landscape variations
	Soil texture
	Secondary porosity
Climate Change	Vegetation growth
	Animal health
	Antecedent soil moisture
Historical Land Use	Bulk density
	Resiliency to disturbances

4.2. Vegetative and Livestock Management

Central Minnesota has been identified as an area of importance when it comes to land management. Since this area is considered unsuitable for annual crops (corn and soybeans), it is utilized for livestock grazing, which often is not effectively managed. When the silvopastoral project was initially being developed, the hypothesis was that vegetation is key in water quality and that with effective management, through seeding perennial grasses and forbs and reducing grazing intensity, soil infiltration and health would improve. This assumption was based on literature research that identified that vegetation management can 1) modify bulk density and create secondary porosity through the extensive and varying root system (Neary et al., 2009; Huang et al., 2013), 2) lower bulk density through this structure modification (OCSCD, 2001; Alaoui, 2015), 3) alter soil moisture content with increased organic matter and higher evapotranspiration rates (Wang, et al., 2012; Brooks et al., 2013), and 4) minimize soil loss through reduced overland flow and rainfall impact by providing protection to the soil surface through vegetative cover (Meeuwig, 1970; Owens et al., 1996; Huang et al., 2013). Besides seeding, managing livestock density can also play a role in vegetation performance. Higher rates of livestock can increase the bulk density through hoof compaction and reduce vegetation and the corresponding root structures through high grazing demands (Mwendera and Saleem, 1997; Bharati et. al, 2002; Stavi et al., 2008).

Overall, soil infiltration rates were greatest in the traditional forest, then silvopasture, and lastly the open pasture. The highest average initial soil moisture content was found in the silvopasture paddocks, then the traditional forest paddocks, followed by the open pastures. This indicates that although seeding grasses and forbs may alter the soil structure and create greater secondary porosity with a network of varying root depths, the presence of trees may be a significant factor in increased infiltration and soil moisture by providing greater preferential flow, evapotranspiration and shade (Neary et al., 2009; Thompson et al., 2010). Saturated hydraulic conductivity was highest in the silvopasture paddocks, while open pasture and traditional forest paddocks had equivalent K_{sat} values.

Forage quantity assessment by Ford (2016) identified that average biomass production for all farms was greatest in the open pasture (1000.67 k/ha), followed by silvopasture (755.17 kg/ha), then traditional forest paddocks (563.17 kg/ha) for 2014 and 2015. Soil infiltration, initial soil moisture, K_{sat} and bulk density for all research sites were also averaged by paddock over the course of the project to compare with the forage production results, which yielded no significant trends.

Grazing and fallow periods were considered in analysis of vegetative development. Four cow-calf pairs were introduced to each paddock when vegetation had reached an average height of 20 cm and removed when vegetation had been reduced to 7 to 10 cm. This was done twice during each field season. The grazing and fallow periods varied as vegetative growth and consumption varied. At Booth's Farm, the grazing periods were similar in length (19 and 21 days) with a nine-day fallow period in-between and a total of 40 days grazed. In 2015, the first grazing period was 19 days, the second was 12 days and there was a 29-day fallow period in-between. The total number of days grazed was 31. Caughey had the same amount of days as Booth in 2014, but in 2015 the grazing periods were 19 days and 15 days with a 28-day fallow, totaling 34 days grazed. Moe's Farm was grazed for 11 days and 28 days with a 39-day fallow period in 2014. In 2015, grazed 12 days and 14 days, with a 60-day fallow period, totaling 26 days grazed. Tables 2, 4 and 6 list a detailed account of grazing rotations for 2014 and 2015. Also, it is important to note that Moe did not graze the traditional forest paddock in 2015 due to difficulty of access to the paddock (across the stream) and containment of the cows to that paddock. Instead, eight cow-calf pairs grazed the silvopasture paddock. The differences in fallow and grazing periods did not appear to affect the amount of forage production, since 2014 had greater averages than 2015. This also discredited the original hypothesis that vegetative management was the key driver to improved infiltration and soil health, leading to geology and soils analysis.

4.3. Geology and Soils

Geology was thoroughly described in the project description in section 2.1.1, identifying the glacial influence and soils present. The soils are primarily sandy loam, with some sand and loamy sand. The advancement and retreat of glaciers have left this area with complex landscapes and compacted soils that make the land marginal and unfit for mono-agricultural use. It is assumed that with this type of landscape, bulk density is high, which leads to stunted vegetative growth and slow soil infiltration.

In addition to soil compaction from glacial geology, research has determined that grazing can have a greater impact on bulk density in fine-textured soils (Van Haveren, 1983). Although this area has been identified as having primarily sandy loam soils, they are considered fine-textured with high percentage of sand size distribution in the very fine and fine sand texture category, making them more vulnerable to compaction from livestock grazing. ANOVA tests revealed a significant difference between bulk density and treatment type ($p<0.001$) for all research sites. Tukey HSD results indicated the greatest differences were between silvopasture and traditional forest paddocks at Booth and Moe's farms, while Caughey's greatest difference occurred between the open pasture and silvopasture paddocks. On average, bulk density was greatest in the open pasture, followed by the traditional forest paddock, with silvopasture paddocks having the lowest average bulk density.

However, there are more inconsistencies with bulk density than would be expected. Glacial till bulk density tends to have a greater bulk density at the soil surface, ranging from 1.6 to 2.0 g/cm^3, compared to sandy soils that range from 1.1 to 1.3 g/cm^3 (MPCA, 2015). The average bulk densities by paddocks range from 1.16 to 1.52 g/cm^3, which falls within the range of silt loams (1.2 to 1.5 g/cm^3) (MPCA, 2015). Lower than expected bulk density ranges is most likely from the presence of very fine and fine sand size, which tend to have lower bulk densities than course grained soils; therefore, it can be assumed that the sandy loam soils within the research areas are performing more like silt loams.

To further measure soil infiltration and structure, in situ bromide testing and a laboratory experiment were added to the project. Bromide tests were conducted in June and August of 2015. In June, all sites showed bromide detections (expect BTF2), although at low concentrations and August samples had even lower concentrations. Although this was not expected, it was attributed to the presence of macropores or fractures being present, but at a minimally developed level. During the laboratory experiment, it was expected that the highest infiltration rate would occur during the drought stage (stage 1), and it was also assumed that water would move through the entirety of the soil core and filter out the bottom tubes quickly, which did not occur until stage 2. In addition, there was a relative uniformity of water volume and bromide concentration in each of the bottles when water was able to completely infiltrate through the column. These findings confirm the results and assumptions made with the in situ bromide readings and that secondary porosity may be present, but minimally and not well developed. As water infiltrated through the soil profile, it had to fill all macropores and micropores completely, instead of flowing preferentially. Therefore, it can be assumed that the soils found in this geologic region are not subject to well-defined fracturing and preferential flow patterns.

In summary, this area is highly influenced by glacial geology, but bulk density is lower than expected from typical glacial tills and well-developed secondary porosity is not present. This may possibly indicate that the implementation of livestock and vegetation management is already displaying beneficial impacts on soil structure through complex and varying root systems and land cover. There will undoubtedly be an improvement of soil health eventually, but long-term monitoring by periodically measuring bulk density and soil infiltration is necessary to provide clarification and confirmation of these changes.

4.4. Climate Change (Seasonal Fluctuations)

Climate is a variable that we are unable to control. There have been many indicators of a warming climate, such as earlier ice-out and later ice-on timing for lakes, earlier spring runoff, increased stream temperatures and base flows, increased annual mean and peak flows, and increased rainfall intensities and storm events (Johnson and Stefan, 2006; Novotny and Stefan, 2006; Seeley 2006). According to the departure from normal precipitation maps (MNDNR, 2016), in 2014 the majority of Central Minnesota experienced between 5.08 to 25.4 cm greater precipitation than normal, while in 2015, the area received an average of 5.08 cm less precipitation than normal (Figure 39). Additionally, Central Minnesota has experienced a significant increase in average annual precipitation for the last 100 years ($p<0.001$) (Figure 40).

Site-specific precipitation sums also confirmed that there was higher precipitation during summer months in 2014 versus 2015, while summer temperature were comparable. Higher precipitation may increase forage production, as was indicated by

Ford's research (2016). Greater rain events may also affect livestock behaviors by decreasing their tendency to graze and compact soils, by preferring to stay in a protected area or lying down. Average infiltration rates for all paddocks per season also appeared to be higher in Fall 2014 than in Fall 2015, although a correlation is not clear (Figure 41).

Differences in precipitation were also observed during the subsurface nutrient portion of the project. There was greater precipitation prior to the June 2015 water sample collection when compared to the August 2015 water sample collection. There was a recorded 10.5 cm of total precipitation in May 2015 versus 7.4 cm total precipitation in July 2015 at Booth's farm, demonstrating why many of the access tubes did not have adequate water present to collect a water sample for bromide testing at this location. Caughey and Moe's farm received 8.4 cm of precipitation in May and 10.64 cm in July 2015, which is why samples were able to be collected at these sites. It can be assumed that the combination of higher precipitation and soil moisture along with the presence of minimally developed macropores (discussed previously) allowed for an initial movement of water and bromide through the soil profile.

As climate continues to change, management of perennial vegetation will be more economical and environmentally friendly to accommodate an increase in wet and dry seasons and greater storm events. Higher rain intensities can be harmful to the soil surface if unprotected, and as storm events increase in size and number, perennial vegetation is a good option for mitigation.

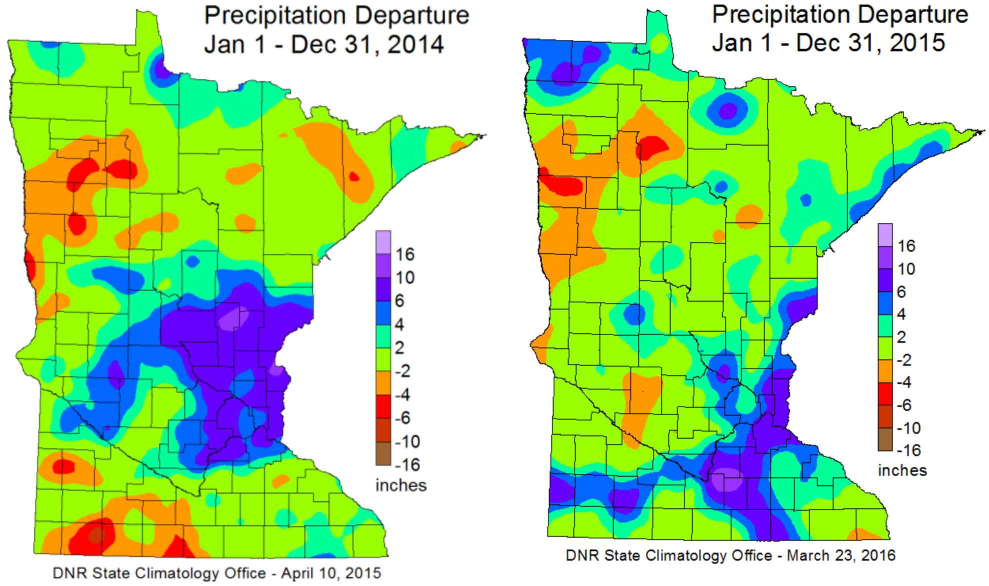

Figure 39. Precipitation Departure from Normal for 2014 (left) and 2015 (right) (Source: MNDNR, State Climatology Office, 2016)

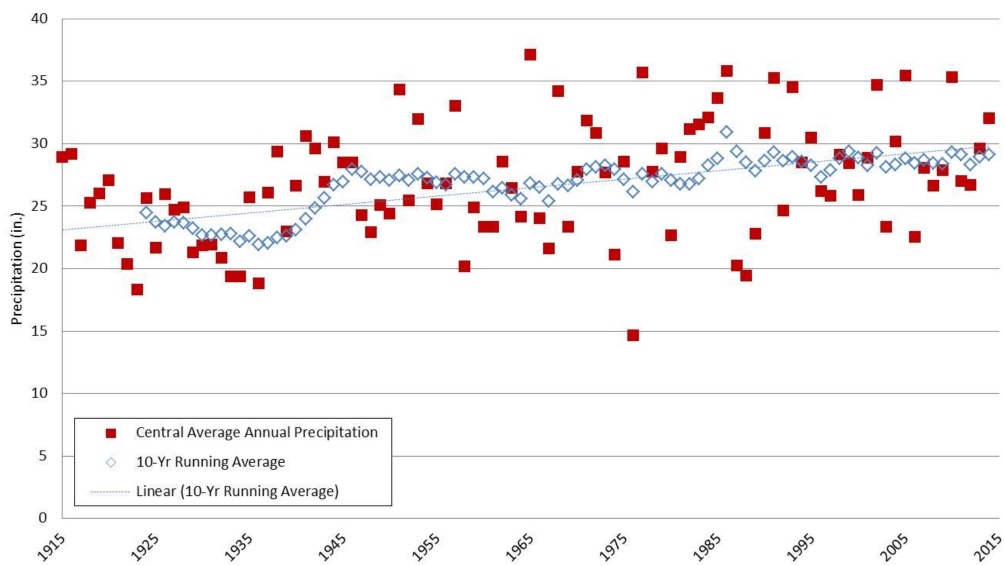

Figure 40. Average Annual Precipitation for Central Minnesota (1915-2015) (Source: WRCC, 2016)

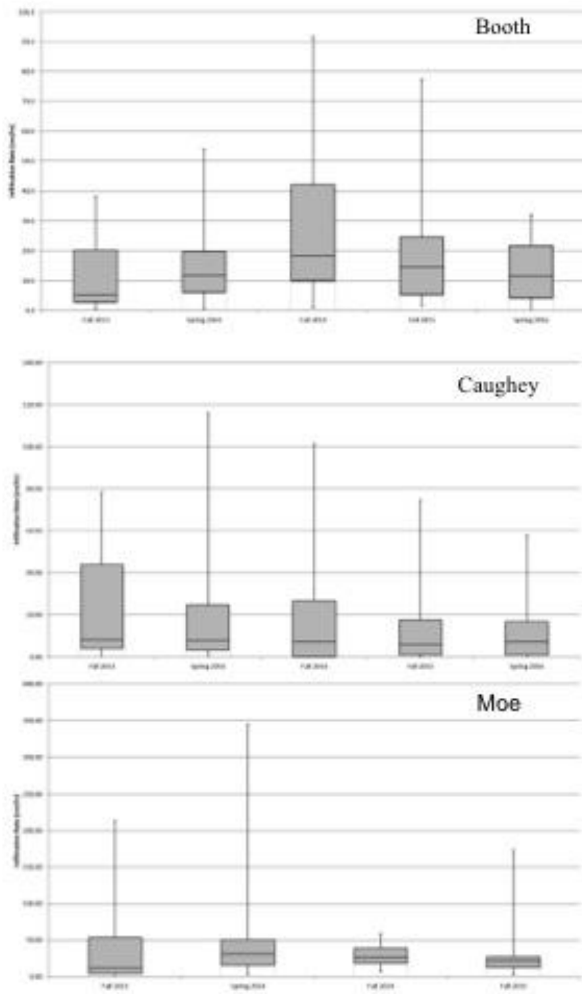

Figure 41. Infiltration by Season Across Project: Booth, Caughey, Moe (Range, Median, First and Third Quartile)

4.5. Historical Land Use

Historical land use can greatly influence the results from this project. The level of disturbance and difference from prior land usage can influence results from the project, as observed with infiltration rates and bulk density.

Previous land use was briefly reviewed in the site descriptions (Section 2.1.2, 2.1.3, 2.1.4), however, it is important to further discuss the land usage for each of the farms. At Booth's Farm, the research area was identified as continuously grazed until 2009, when the landowners switched to rotational grazing. Caughey's research area had also been continuously grazed long term. The open pasture was purchased ten years before the silvopasture area, implying that the open pasture paddock had been more heavily grazed in comparison. Moe's Farm experienced different results than the other two sites, despite the close proximity to Caughey's Farm. The open pasture paddock had been cropland prior to the project, while livestock had grazed the silvopasture continuously over time. The traditional forest was across the stream, which made access difficult for the cows and consequently, had not been grazed in past years.

Another factor that may contribute to differences, or lack thereof, is disturbance level to the paddocks. If a paddock had been continually grazed in the past (i.e. Caughey's open pasture), it may not respond as quickly to changes in livestock and vegetation management as a paddock that had not been grazed in the past (i.e. Moe's traditional forest).

4.6. Soil Survey Comparison

Another aspect to assess from this project was the validity of the NRCS soil surveys with actuality. The surveys were originally utilized to identify soil series with soil texture, bulk density, and K_{sat} values, which were later tested and determined for each soil infiltration test location. It is important to note the differences between the soil survey and project results, due to the great variability and complexity of geology and soils within Minnesota. By comparing the idealism of the survey with reality, natural resource professionals might base their confidence in certain variables provided by the surveys, while choosing to measure field data for other variables.

The soil texture from the project results and the soil survey are very comparable with 60 percent completely accurate (soil survey = results), 33 percent were similar (i.e. sandy loam = loamy sand), while the remaining were different (i.e. sandy loam = silty clay loam). Average bulk density results from the soil survey were consistently higher than the average results from the project (11%). The soil survey bulk density values range from 1.25 to 1.60 g/cm^3 with a median of 1.55 g/cm^3, which may be lower than glacial till bulk density, but falls within categories like urban lawns and rock parking lots (MPCA, 2015). This is compared to the bulk density results from the project that ranges from 0.78 to 1.65 g/cm^3 with a median of 1.36 g/cm^3 (silt or silty sands). The K_{sat} values appeared to be very different with a range of 9.00 to 92.00 µm/sec in the soil survey, while the project calculation results ranged from 0.53 to 281.83 µm/sec. However, when the averages and medians were compared, there was not as great of a difference. The soil survey had an overall average of 47.75 µm/sec with a median of 28.23 µm/sec, while the project results had an average of 36.02 µm/sec with a median of 15.66 µm/sec. The differences between the soil survey and the project K_{sat} results may have been due to methodology of infiltration data collection and/or inconsistencies with data collection that would affect calculations, which is discussed in section 4.9 and 4.10.

Comparisons of NRCS soil survey and project results for soil texture, bulk density and K_{sat} are listed in tables 50, 51 and 52. In general, the soil survey appears to be a viable option for natural resource professionals and land owners that wish to determine if silvopasture implementation is a good option by understanding the basics of a specific area without preforming vigorous soil analyses. However, caution should be considered when utilizing the soil surveys, since results are generalized and not definite.

Table 50. Booth Comparison of NRCS Soil Survey and Project Results (Soil Texture, Bulk Density and K_{sat})

	NRCS Soil Survey Results				**Project Results**		
	Soil Series	Soil Texture	Bulk Density (g/cm^3)	K_{sat} (µm/sec)	Soil Texture	Bulk Density (g/cm^3)	K_{sat}, Average (µm/sec)
BOP1	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.35	3.67
BOP2	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.35	12.72
BOP3	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.46	13.73
BOP4	Sandwick Loamy Sand	Loamy Sand	1.50	92.00	Sandy Loam	1.52	33.78
BOP5	Sandwick Loamy Sand	Loamy Sand	1.50	92.00	Sandy Loam	1.49	9.63
BSV1	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.50	55.22
BSV2	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Loam	1.38	254.04
BSV3	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.36	281.83
BSV4	Warba Very Fine Sandy Loam	Sandy Loam	1.25	28.00	Sandy Loam	1.29	17.51
BSV5	Warba Very Fine Sandy Loam	Sandy Loam	1.25	28.00	Silty Clay Loam	1.23	61.51
BTF1	Warba Very Fine Sandy Loam	Sandy Loam	1.25	28.00	Loam	1.48	9.07
BTF2	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Loam	1.52	18.15
BTF3	DeMontreville-Mahtomedi-Cushing Complex	Loamy Sand/Sandy Loam	1.59	92.00	Sandy Loam	1.63	30.42
BTF4	Warba Very Fine Sandy Loam	Sandy Loam	1.25	92.00	Sandy Loam	1.50	27.82
BTF5	Warba Very Fine Sandy Loam	Sandy Loam	1.25	92.00	Sandy Loam	1.47	21.37

Table 51. Caughey Comparison of NRCS Soil Survey and Project Results (Soil Texture, Bulk Density and K_{sat})

	NRCS Soil Survey Results				Project Results		
	Soil Series	Soil Texture	Bulk Density (g/cm^3)	K_{sat} (µm/sec)	Soil Texture	Bulk Density (g/cm^3)	K_{sat}, Average (µm/sec)
COP1	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.40	32.31
COP2	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.49	17.49
COP3	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Loamy Sand	1.58	4.07
COP4	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.65	2.23
COP5	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.30	0.53
CSV1	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.38	14.08
CSV2	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.48	21.47
CSV3	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Loam	0.78	30.07
CSV4	Nokay-Prebish Complex	Loam	1.50	9.00	Clay Loam	1.04	13.63
CSV5	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.11	2.20
CTF1	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.33	15.66
CTF2	Nokay-Prebish Complex	Loam	1.50	9.00	Sandy Loam	1.34	15.58
CTF3	Nokay-Prebish Complex	Loam	1.50	9.00	Sandy Clay Loam	1.10	10.53
CTF4	Nokay-Prebish Complex	Loam	1.50	9.00	Sandy Loam	1.30	39.73
CTF5	Chetek-Seelyeville Complex	Sandy Loam/Muck	1.55	28.23	Sandy Loam	1.35	17.31

Table 52. Moe Comparison of NRCS Soil Survey and Project Results (Soil Texture, Bulk Density and K_{sat})

	NRCS Soil Survey Results				Project Results		
	Soil Series	Soil Texture	Bulk Density (g/cm^3)	K_{sat} (µm/sec)	Soil Texture	Bulk Density (g/cm^3)	K_{sat}, Average (µm/sec)
MOP1	Brainerd Sandy Loam	Sandy Loam	1.52	28.00	Sand	1.40	18.61
MOP2	Bushville Loamy Sand	Loamy Sand	1.60	92.00	Sandy Loam	1.49	7.99
MOP3	Bushville Loamy Sand	Loamy Sand	1.60	92.00	Sandy Loam	1.58	8.43
MOP4	Brainerd Sandy Loam	Sandy Loam	1.52	28.00	Sandy Loam	1.65	7.05
MOP5	Bushville Loamy Sand	Loamy Sand	1.60	92.00	Sandy Loam	1.30	5.00
MSV1	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.38	3.91
MSV2	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.48	13.60
MSV3	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Sand	0.78	12.76
MSV4	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Sand	1.04	2.80
MSV5	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.11	23.86
MTF1	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Sandy Loam	1.33	85.19
MTF2	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.34	12.23
MTF3	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Sandy Loam	1.10	49.67
MTF4	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.30	90.34
MTF5	Chetek-Graycalm Complex	Sandy Loam/Loamy Sand	1.55	28.23	Loamy Sand	1.35	191.95

4.7. Design Considerations

Soil infiltration, the measure of how well the soil absorbs rainfall, is inversely related to overland flow, and related to saturated hydraulic conductivity, which is why we chose this option. There are other ways to measure water quality, yet infiltration seemed the most logical for this project due to the site characteristics, such as the presence of perennial vegetation, and the relatively short duration of the project. It is for these reasons that erosion was not a reasonable metric for water and soil health. In addition, many of the water sources within the paddocks were intermittent and often ceased during the dry months of the field season and thereby, could not be utilized for consistent water sample data collection.

Soil infiltration rate data collection is measured using different methods and apparatuses. Methods being rain simulation (flooding or sprinkling) or cylinder measurements (infiltrometers) (Johnson, 1963) and apparatuses such as single- or double-ring infiltrometers, the Philip-Dunne permeameter, mini disk infiltrometer and the Modified Philip-Dunne falling head infiltrometer, which was used for this project. The reason that we utilized the MPD infiltrometer was because it was inexpensive, easily constructed and required a minimal amount of water. Johnson (1963) identified that large-diameter ring infiltrometers or infiltration pits and ponds are considered the most accurate for soil infiltration rate data collection in the field. It can also be assumed that many of the infiltration rates were higher than actual results, due to the condensed intensity of water being measured from a cylinder infiltrometer (Dunne et al., 1991). Thereby, in hindsight, other collection methods may have been more accurate in measuring infiltration, especially with many of the test locations that yielded low infiltration capacity.

4.8. Limitations and Issues

There were many limitations and issues that arose during the course of this project. The largest of these limitations was the restricted amount of time allowed for a project of this magnitude and complexity. Although good progress was made on the project, many aspects would have benefited from a longer research time period. An extended time period could have included monitoring of tree growth and sap flow for evapotranspiration rates, an implemented erosional study, yearly bulk density measurements, and more data collection of soil infiltration rates. Additionally, the original belief that vegetative management was the key factor affecting soil infiltration rates was deemed non-inclusive after initial soil infiltration and soil moisture content results were analyzed. It was realized later in the project that geology and soils were also key indicators and the focus shifted to include these components, which added physical soil properties (texture, bulk density, porosity, sand size distribution) into the data collection and analysis. In order to see any kind of measurable change there would need to be another four to five years of research completed at these sites.

Human error seemed to be an issue with the data collection and data management. Falling head measurements were dependent on placement of the ruler and the one reading the measurements. This could, and most likely did, alter from individual to individual. Also, soil moisture data collection samples proved to be inconsistent, where the final percentage of soil moisture content was higher than the initial, causing those samples to be considered unusable, which is why porosity was used for K_{sat} calculations for one-dimensional flow (see below). Additionally, better data management practices should have been used throughout the project. Due to many different research assistants and aids, there was often an issue of misplaced data or miscommunication, although in the end, it all came together.

The MPD model that was originally used to calculate saturated hydraulic conductivity was intended for three-dimensional infiltration. However, the infiltration rates at these sites were so low that the wetting front potential did not extend past the base of the infiltrometer, indicating one-dimensional infiltration. This caused the MPD model calculations to yield "N/A" values, causing us to seek out other calculations for one-dimensional soil infiltration. Because of the errors with the MPD model and the inconsistencies with the soil moisture content data, porosity, not soil moisture content, was utilized in the calculations for one-dimensional flow.

Chapter 5. Conclusions and Future Work

Growing populations and increasing demands for meat production have resulted in an exponential increase in livestock farming. Minnesota has over 527,000 acres of grazed woodlands and has been ranked in the top ten states in the United States for red meat production, milk cows, cattle/calves, poultry and hog production (MDA, 2016). However, the majority of the woodland grazing has little to no management. As negative effects can arise associated with unmanaged woodland grazing, silvopastoral implementation has been proposed as an environmentally and economically beneficial practice for the livestock farmers in Central Minnesota.

A three-year study to assess the adoptability and merits of silvopastoral systems in this region of Minnesota was conducted from July 2013 to June 2016 at three farms in Cass and Crow Wing County. The project included assessment of forage production and quality, livestock productivity and species diversity (Ford, 2016), in addition to the water quality study. Water quality was assessed through the measurement of soil infiltration, and included data collection for soil moisture content, saturated hydraulic conductivity, soil properties (bulk density, porosity, soil texture), as well as subsurface nutrient transport and laboratory experiment components. The purpose of focusing on Central Minnesota was because this region has great influences from glacial geology, which has left behind compacted soils with differing landscapes that make the land marginal and unfit for mono-agricultural use. It is for this reason that livestock farming is so prevalent in this area.

Soil infiltration tests were conducted for 45 test locations (5 per paddock, 15 per farm) in Fall 2013, Spring 2014, Fall 2014, Fall 2015 and Spring 2016 utilizing Modified Philip-Dunne falling head infiltrometers. Timing of this testing was complete to assess differences in soil infiltration over time to correlate with vegetative management strategies (i.e. pre- and post-seeding, after one and two grazing seasons, limited evapotranspiration influences). Statistical analysis was conducted to identify significant differences and correlations between average infiltration and K_{sat}, soil texture, bulk density, landscape position, initial soil moisture and treatment type. The soil infiltration results identified that there was an increase in overall infiltration from the beginning to the end of the project at 47 percent of the test locations. Although there were some significant results, p-values and correlations were predominately low. Across all research sites, there were no consistent significant trends that emerged to identify why there was an increase or decrease in infiltration rates. Drivers were identified, to include vegetation and livestock management, glacial geology influence and soils, climate change and prior land use. All of these drivers could be linked to numerous factors that affect soil infiltration, such as bulk density, initial soil moisture, organic matter and vegetative growth (above and belowground), landscape variations, secondary porosity (presence of macropores and fractures), evapotranspiration and resiliency to disturbances. In order to effectively and accurately make conclusive determinations on what factors have significant influence on soil infiltration, at least an additional four to five years are necessary to monitor any changes associated with silvopasture implementation. A comparison of NRCS soil surveys and project results was also conducted. It was determined that although the soil property values varied from the surveys to the results, the soil surveys are a reasonable option for natural resource professionals and landowners that want to assess their land for generalized soil properties in order to consider their land for silvopastoral implementation. Nevertheless, it is important to be mindful that the soil surveys are a theoretical and general representation of an area and most likely alter from complex reality.

In conclusion, silvopastoral implementation is a beneficial land use on marginal soils and landscapes. The results from this project indicate that this area of Central

Minnesota has a primarily sandy loam soil texture, with predominantly fine and very fine sand size, which helps inhibit vertical subsurface nutrient transport. Therefore, based on research completed by Ford (2016), literature review, and this study, it can be assumed that farmers that practice unmanaged woodland grazing can improve soil infiltration without increasing the risk of associated water pollution by implementing silvopasture. A longer trial period would be necessary to determine if there are any consistent and significant changes in soil infiltration rates with the adoption of silvopastoral practices. This would also help identify if vegetative (and livestock) management, geology and soils, or climate have a greater impact on soil infiltration rates and thereby, water quality. Additional research would greatly contribute to understanding the expansive and complex variability of this region in Minnesota and the water quality benefits associated with silvopasture.

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Appendix A. USDA NRCS Soil Surveys

Custom Soil Resource Report for Booth

United States Department of Agriculture

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Cass County, Minnesota (Booth)

May 4, 2016

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units).

Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

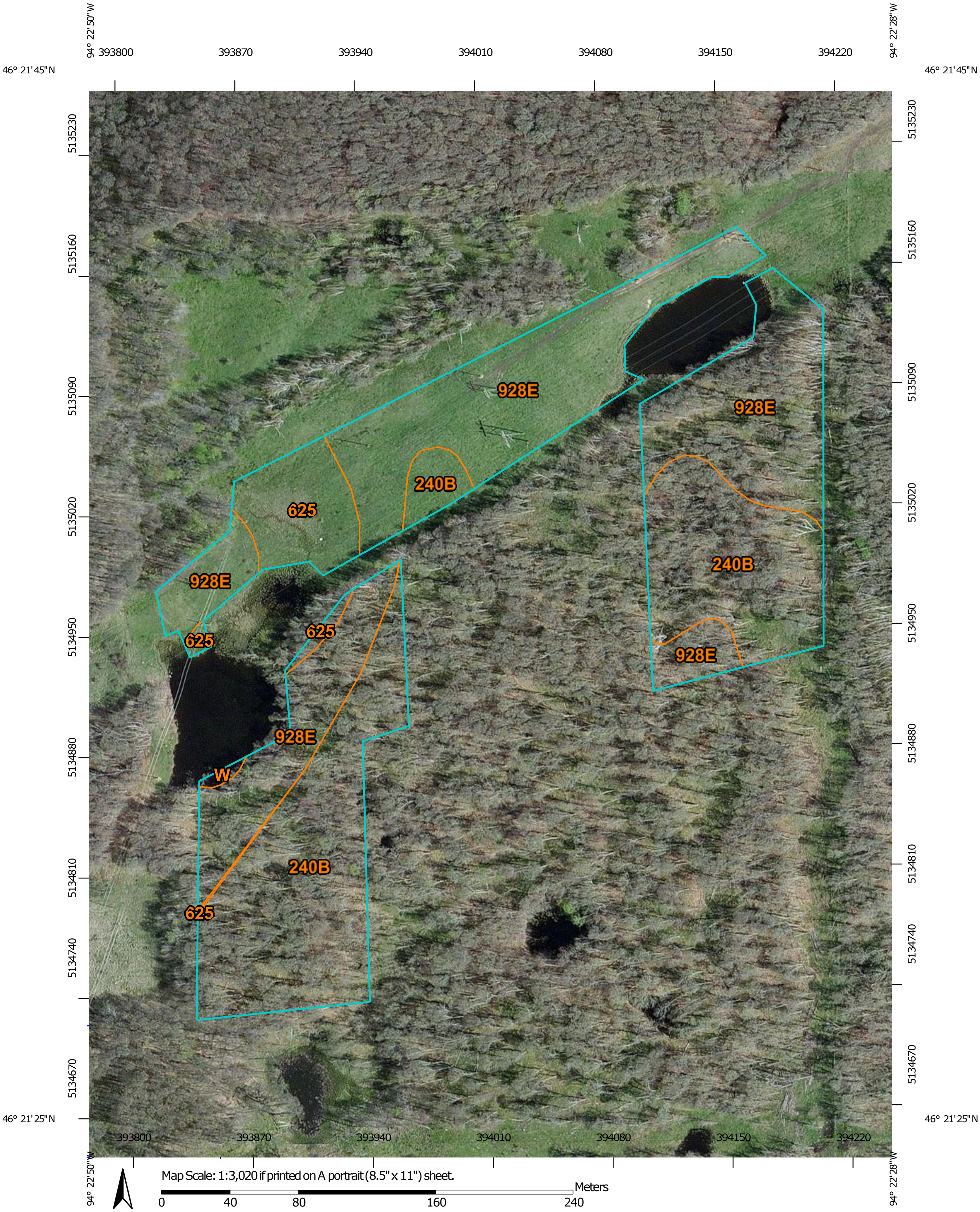
While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.


94° 22' 50" W
94° 22' 28" W
46° 21' 45" N
46° 21' 25" N
393800
393870
393940
394010
394080
394150
394220
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
928E
625
240B
W
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Cass County, Minnesota (MN021)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	6.1	40.5%
625	Sandwick loamy sand	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	7.7	51.6%
W	Water	0.0	0.3%
Totals for Area of Interest		**15.0**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha- Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

240B—Warba very fine sandy loam, 3 to 8 percent slopes

Map Unit Setting

National map unit symbol: fbvs
Elevation: 1,000 to 1,600 feet
Mean annual precipitation: 22 to 28 inches
Mean annual air temperature: 36 to 43 degrees F
Frost-free period: 90 to 135 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Warba and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of

Warba Setting

Landform: Hillslopes on moraines
Landform position (two-dimensional): Backslope, shoulder, summit
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loamy glacial till

Typical profile

A,E - 0 to 11 inches: very fine sandy loam
E/B,B/E,Bt - 11 to 37 inches: clay loam
C - 37 to 60 inches: loam

Properties and qualities

Slope: 3 to 8 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.14 to 0.57 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 15 percent
Available water storage in profile: High (about 11.1 inches)

Interpretive groups

Land capability classification (irrigated): None specified *Land capability classification (nonirrigated):* 2e *Hydrologic Soil Group:* C
Other vegetative classification: Sloping Upland, Acid (G057XN006MN)

Minor Components

Stuntz

Percent of map unit: 5 percent

Warba

Percent of map unit: 4 percent

Menahga

Percent of map unit: 3 percent

Very poorly drained organic soils

Percent of map unit: 3 percent
Landform: Depressions on moraines

625—Sandwick loamy sand

Map Unit Setting

National map unit symbol: fbwl
Elevation: 900 to 1,400 feet
Mean annual precipitation: 24 to 30 inches
Mean annual air temperature: 36 to 43 degrees F
Frost-free period: 90 to 120 days
Farmland classification: Not prime farmland

Map Unit Composition

Sandwick and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Sandwick

Setting

Landform: Swales on moraines, drainageways on moraines
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Sandy outwash over loamy glacial till

Typical profile

A - 0 to 5 inches: loamy sand
E,Bw - 5 to 28 inches: loamy sand
2B/E,2Btg - 28 to 43 inches: clay
loam *2Cg - 43 to 60 inches:* loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.14 to 0.57 in/hr)
Depth to water table: About 6 to 18 inches
Frequency of flooding: None

Frequency of ponding: None
Calcium carbonate, maximum in profile: 20 percent
Available water storage in profile: Low (about 5.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w

Hydrologic Soil Group: C/D
Other vegetative classification: Level Swale, Low AWC, Acid (G057XN007MN)

Minor Components

Cutaway
Percent of map unit: 5 percent

Stuntz
Percent of map unit: 5 percent

Warba
Percent of map unit: 5 percent

928E—DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes

Map Unit Setting
National map unit symbol: fbxq
Elevation: 670 to 1,600 feet
Mean annual precipitation: 22 to 34 inches
Mean annual air temperature: 36 to 45 degrees F
Frost-free period: 88 to 160 days
Farmland classification: Not prime farmland

Map Unit Composition
Demontreville and similar soils: 40
percent *Mahtomedi and similar soils:* 25
percent *Cushing and similar soils:* 20
percent *Minor components:* 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Demontreville

Setting
Landform: Hillslopes on moraines
Landform position (two-dimensional): Backslope, shoulder
Down-slope shape: Convex
Across-slope shape: Linear
Parent material: Sandy outwash over loamy glacial till

Typical profile
A - 0 to 4 inches: loamy sand
Bw - 4 to 33 inches: sand
2B/E,2Bt - 33 to 42 inches: fine sandy loam
2C - 42 to 60 inches: sandy loam

Properties and qualities
Slope: 15 to 40 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained

Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.14 to 0.57 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Available water storage in profile: Low (about 5.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7e
Hydrologic Soil Group: C
Other vegetative classification: Steep; Coarse Texture; Low AWC (G090XN018MN)

Description of Mahtomedi

Setting

Landform: Hillslopes on moraines
Landform position (two-dimensional): Backslope, shoulder
Down-slope shape: Convex
Across-slope shape: Linear
Parent material: Sandy and gravelly outwash deposits

Typical profile

A - 0 to 3 inches: loamy sand
Bw - 3 to 23 inches: sand
C - 23 to 60 inches: gravelly sand

Properties and qualities

Slope: 15 to 40 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (5.95 to 19.98 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 15 percent
Available water storage in profile: Low (about 4.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7s
Hydrologic Soil Group: A
Other vegetative classification: Sandy (G090XN022MN)

Description of Cushing

Setting

Landform: Hillslopes on moraines
Landform position (two-dimensional): Backslope
Down-slope shape: Convex
Across-slope shape: Linear
Parent material: Loamy glacial till

Typical profile

A - 0 to 7 inches: fine sandy loam
E,B/E - 7 to 16 inches: loam
Bt - 16 to 49 inches: clay loam
C - 49 to 60 inches: sandy clay loam

Properties and qualities

Slope: 15 to 30 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Well drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.14 to 0.57 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum in profile: 10 percent
Available water storage in profile: High (about 9.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: B
Other vegetative classification: Steep; Fine Texture (G090XN017MN)

Minor Components

Very poorly drained organic soils

Percent of map unit: 5 percent
Landform: Depressions on moraines

Meehan

Percent of map unit: 5 percent

Alstad

Percent of map unit: 5 percent

W—Water

Map Unit Composition

Water: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit

Soil Information for All Uses

Soil Properties and Qualities

The Soil Properties and Qualities section includes various soil properties and qualities displayed as thematic maps with a summary table for the soil map units in the selected area of interest. A single value or rating for each map unit is generated by aggregating the interpretive ratings of individual map unit components. This aggregation process is defined for each property or quality.

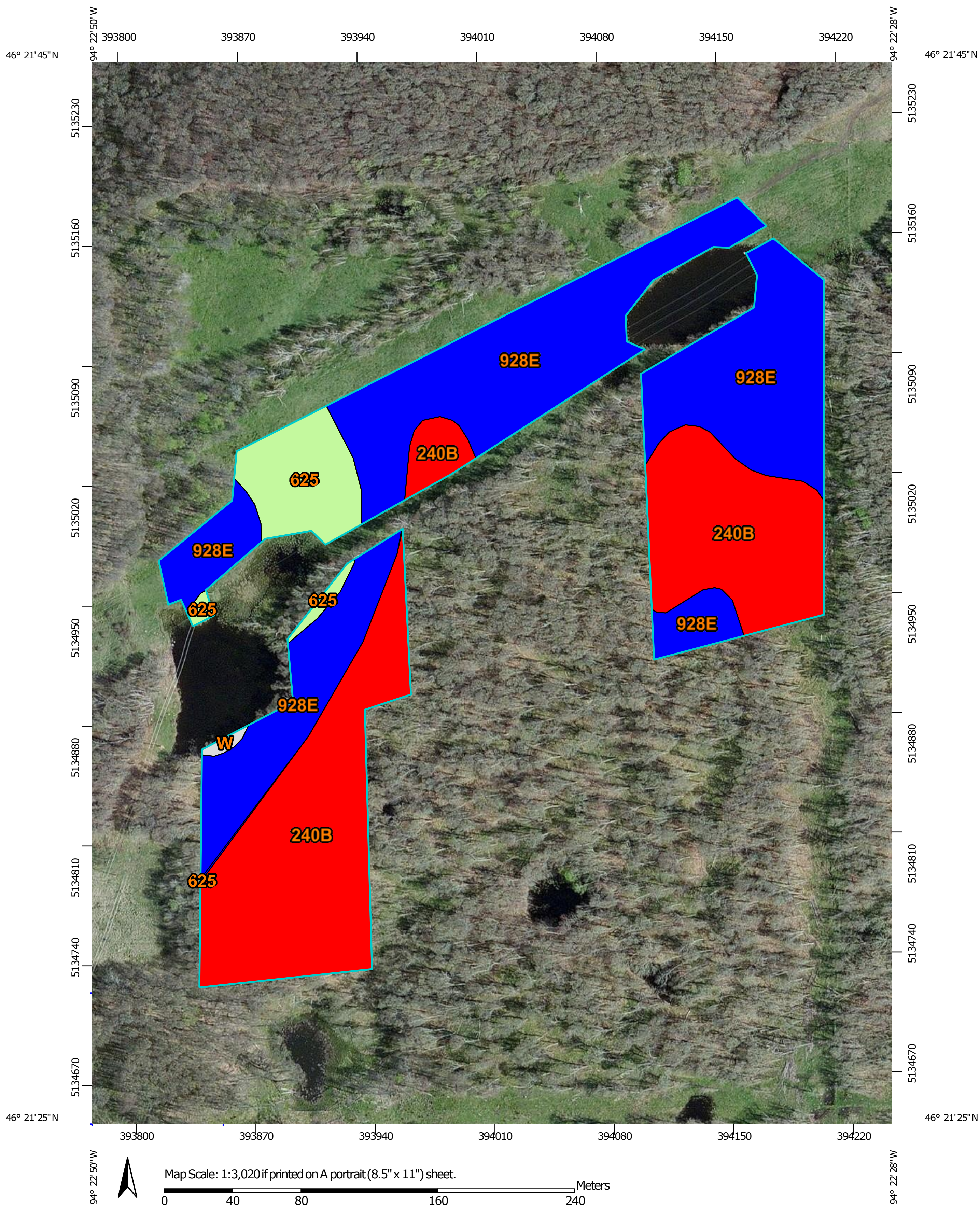
Soil Physical Properties

Soil Physical Properties are measured or inferred from direct observations in the field or laboratory. Examples of soil physical properties include percent clay, organic matter, saturated hydraulic conductivity, available water capacity, and bulk density.

Bulk Density, One-Third Bar (Booth)

Bulk density, one-third bar, is the ovendry weight of the soil material less than 2 millimeters in size per unit volume of soil at water tension of 1/3 bar, expressed in grams per cubic centimeter. Bulk density data are used to compute linear extensibility, shrink-swell potential, available water capacity, total pore space, and other soil properties. The moist bulk density of a soil indicates the pore space available for water and roots. Depending on soil texture, a bulk density of more than 1.4 can restrict water storage and root penetration. Moist bulk density is influenced by texture, kind of clay, content of organic matter, and soil structure.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



928E
928E
240B
625
928E
240B
625
625
928E
928E
W
240B
625
393800
393870
393940
394010
394080
394150
394220
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
46° 21'45"N
46° 21'25"N
94° 22'50"W
94° 22'28"W
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 1.25

> 1.25 and <= 1.50

> 1.50 and <= 1.59

Not rated or not available

Soil Rating Lines

<= 1.25

> 1.25 and <= 1.50

> 1.50 and <= 1.59

Not rated or not available

Soil Rating Points

<= 1.25

> 1.25 and <= 1.50

> 1.50 and <= 1.59

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Bulk Density, One-Third Bar (Booth)

Bulk Density, One-Third Bar— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating (grams per cubic centimeter)**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	1.25	6.1	40.5%
625	Sandwick loamy sand	1.50	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	1.59	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Bulk Density, One-Third Bar (Booth)

Units of Measure: grams per cubic centimeter
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Clay (Booth)

Clay as a soil separate consists of mineral soil particles that are less than 0.002 millimeter in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The amount and kind of clay affect the fertility and physical condition of the soil and the ability of the soil to adsorb cations and to retain moisture. They influence shrink-swell potential, saturated hydraulic conductivity (Ksat), plasticity, the ease of soil dispersion, and other soil properties. The amount and kind of clay in a soil also affect tillage and earth-moving operations.

Most of the material is in one of three groups of clay minerals or a mixture of these clay minerals. The groups are kaolinite, smectite, and hydrous mica, the best known member of which is illite.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


928E
928E
240B
625
928E
625
625
240B
928E
928E
W
240B
625
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0 40 80 160 240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 4.0

> 4.0 and <= 10.0

Not rated or not available

Soil Rating Lines

<= 4.0

> 4.0 and <= 10.0

Not rated or not available

Soil Rating Points

<= 4.0

> 4.0 and <= 10.0

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Clay (Booth)

Percent Clay— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
240B	Warba very fine sandy loam, 3 to 8 percent slopes	10.0	6.1	40.5%
625	Sandwick loamy sand	4.0	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	4.0	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Percent Clay (Booth)

Units of Measure: percent

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)

Top Depth: 5

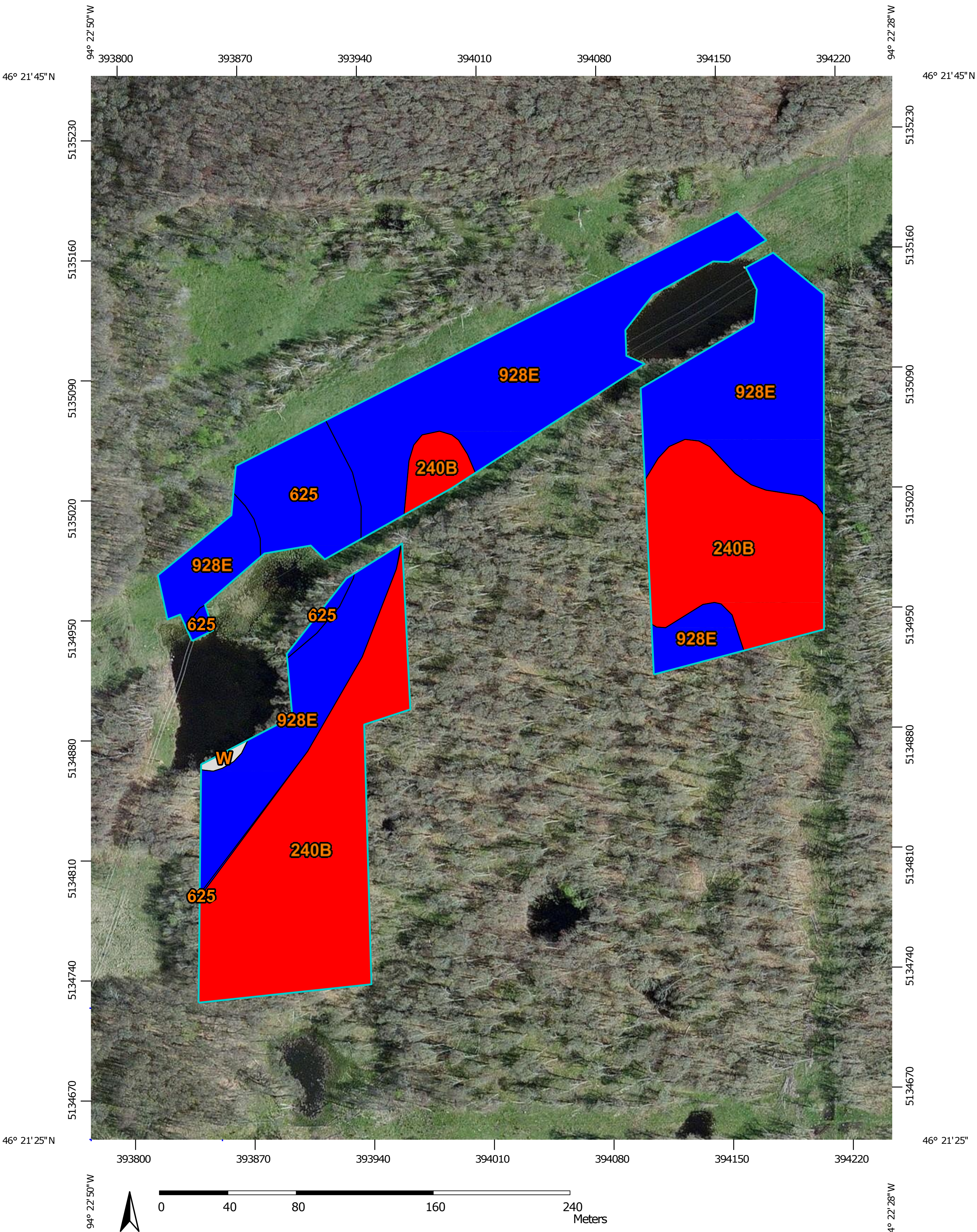
Bottom Depth: 10

Units of Measure: Centimeters

Percent Sand (Booth)

Sand as a soil separate consists of mineral soil particles that are 0.05 millimeter to 2 millimeters in diameter. In the database, the estimated sand content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 22' 50" W
94° 22' 28" W
46° 21' 45" N
46° 21' 25" N
393800
393870
393940
394010
394080
394150
394220
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
928E
928E
240B
625
240B
928E
625
625
928E
928E
W
240B
625
0
40
80
160
240
Meters

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 63.8

> 63.8 and <= 79.2

Not rated or not available

Soil Rating Lines

<= 63.8

> 63.8 and <= 79.2

Not rated or not available

Soil Rating Points

<= 63.8

> 63.8 and <= 79.2

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Sand (Booth)

Percent Sand— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
240B	Warba very fine sandy loam, 3 to 8 percent slopes	63.8	6.1	40.5%
625	Sandwick loamy sand	79.2	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	79.2	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Percent Sand (Booth)

Units of Measure: percent

Aggregation Method: Dominant

Component *Component Percent Cutoff:*

None Specified Tie-break Rule: Higher

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)

Top Depth: 5

Bottom Depth: 10

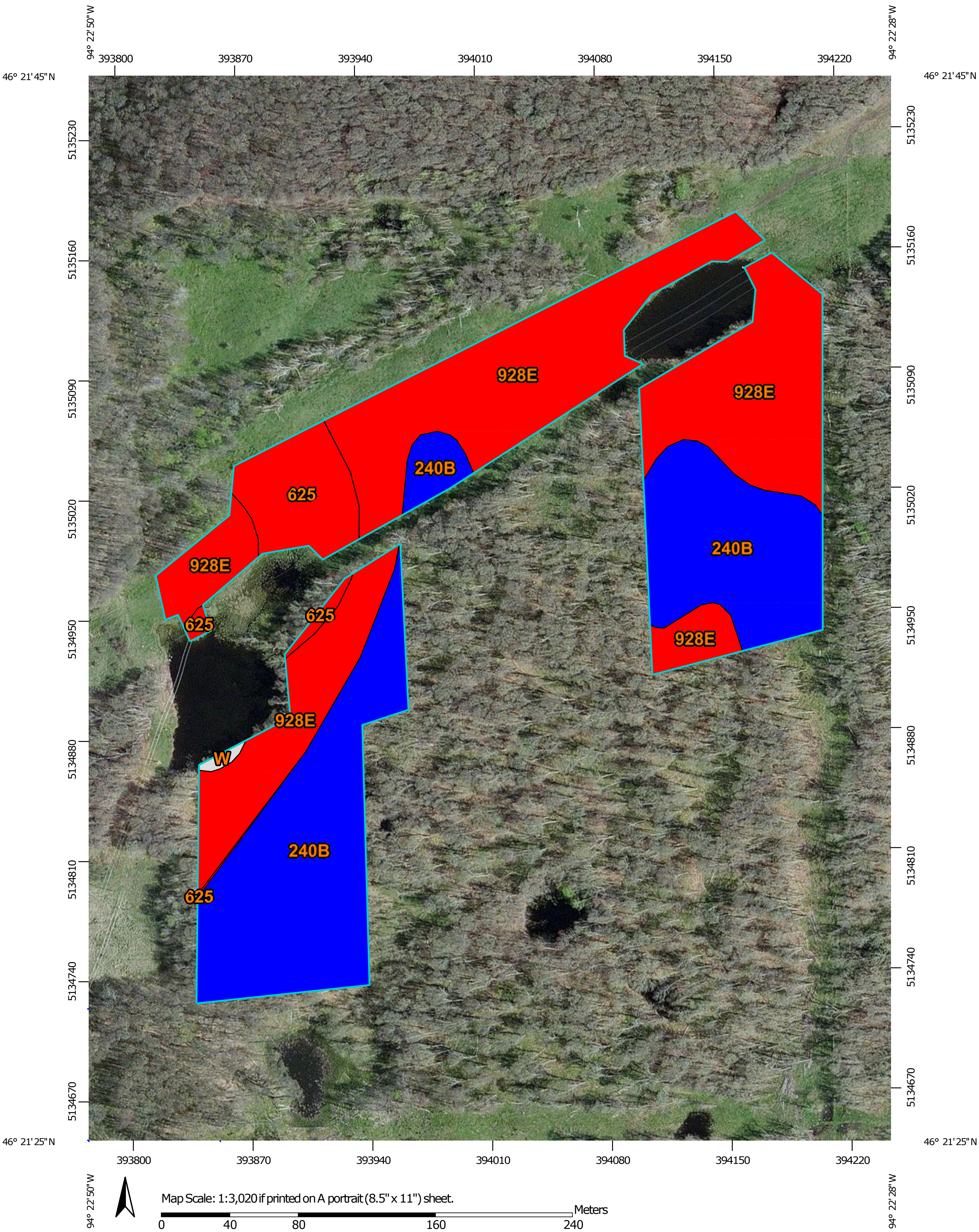
Units of Measure: Centimeters

Percent Silt (Booth)

Silt as a soil separate consists of mineral soil particles that are 0.002 to 0.05 millimeter in diameter. In the database, the estimated silt content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.

The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 22' 50" W
94° 22' 28" W
46° 21' 45" N
46° 21' 25" N
393800
393870
393940
394010
394080
394150
394220
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
928E
928E
240B
625
928E
625
625
240B
928E
928E
W
240B
625
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 16.8
- > 16.8 and <= 26.2
- Not rated or not available

Soil Rating Lines

- <= 16.8
- > 16.8 and <= 26.2
- Not rated or not available

Soil Rating Points

- <= 16.8
- > 16.8 and <= 26.2
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Silt (Booth)

Percent Silt— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating (percent)**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	26.2	6.1	40.5%
625	Sandwick loamy sand	16.8	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	16.8	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Percent Silt (Booth)

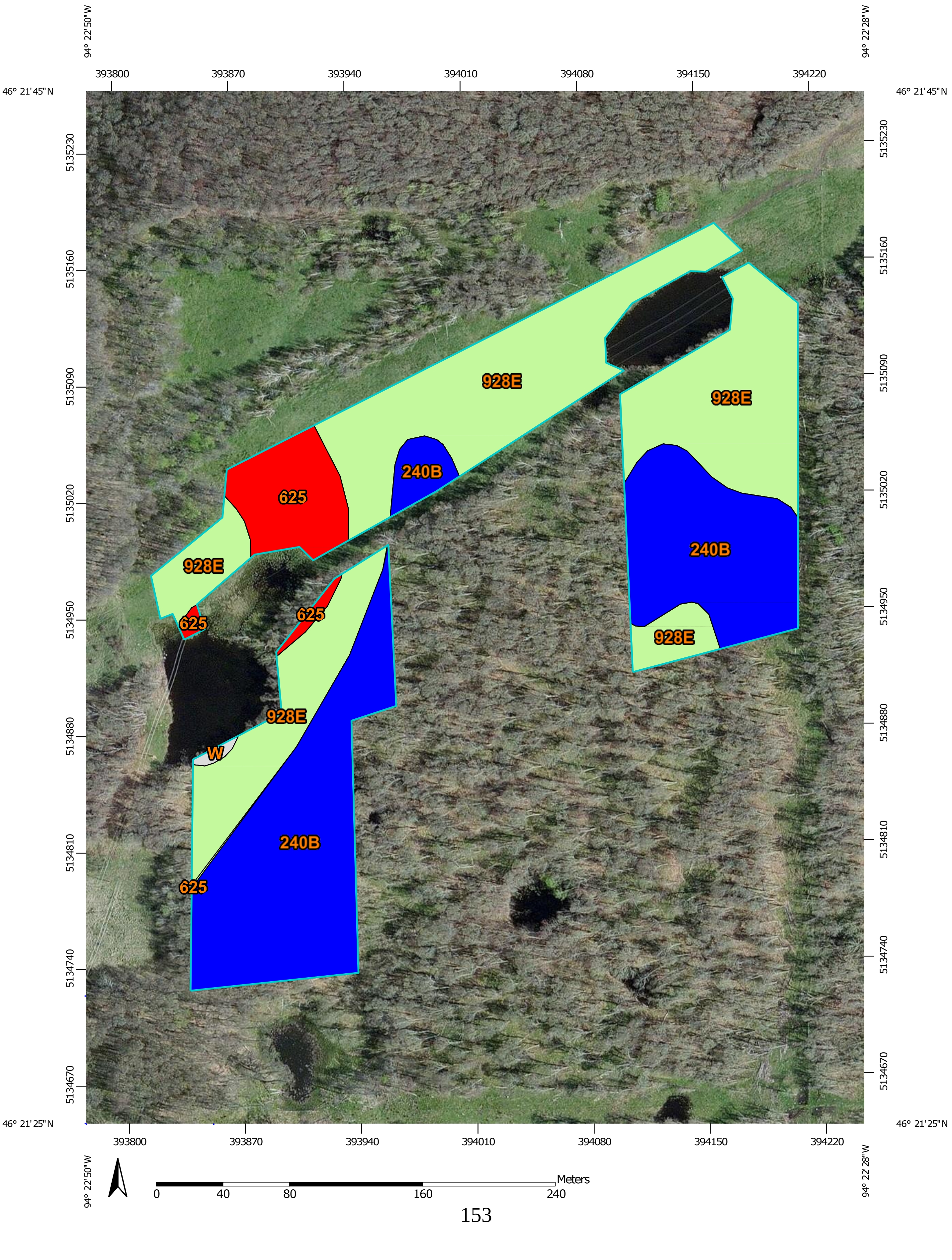
Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Available Water Capacity (Booth)

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. It is not an estimate of the quantity of water actually available to plants at any given time.

Available water supply (AWS) is computed as AWC times the thickness of the soil. For example, if AWC is 0.15 cm/cm, the available water supply for 25 centimeters of soil would be 0.15 x 25, or 3.75 centimeters of water.

For each soil layer, AWC is recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 22'50"W
94° 22'28"W
393800
393870
393940
394010
394080
394150
394220
46° 21'45"N
46° 21'25"N
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
928E
625
240B
W
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.09
- > 0.09 and <= 0.11
- > 0.11 and <= 0.21
- Not rated or not available

Soil Rating Lines

- <= 0.09
- > 0.09 and <= 0.11
- > 0.11 and <= 0.21
- Not rated or not available

Soil Rating Points

- <= 0.09
- > 0.09 and <= 0.11
- > 0.11 and <= 0.21
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Available Water Capacity (Booth)

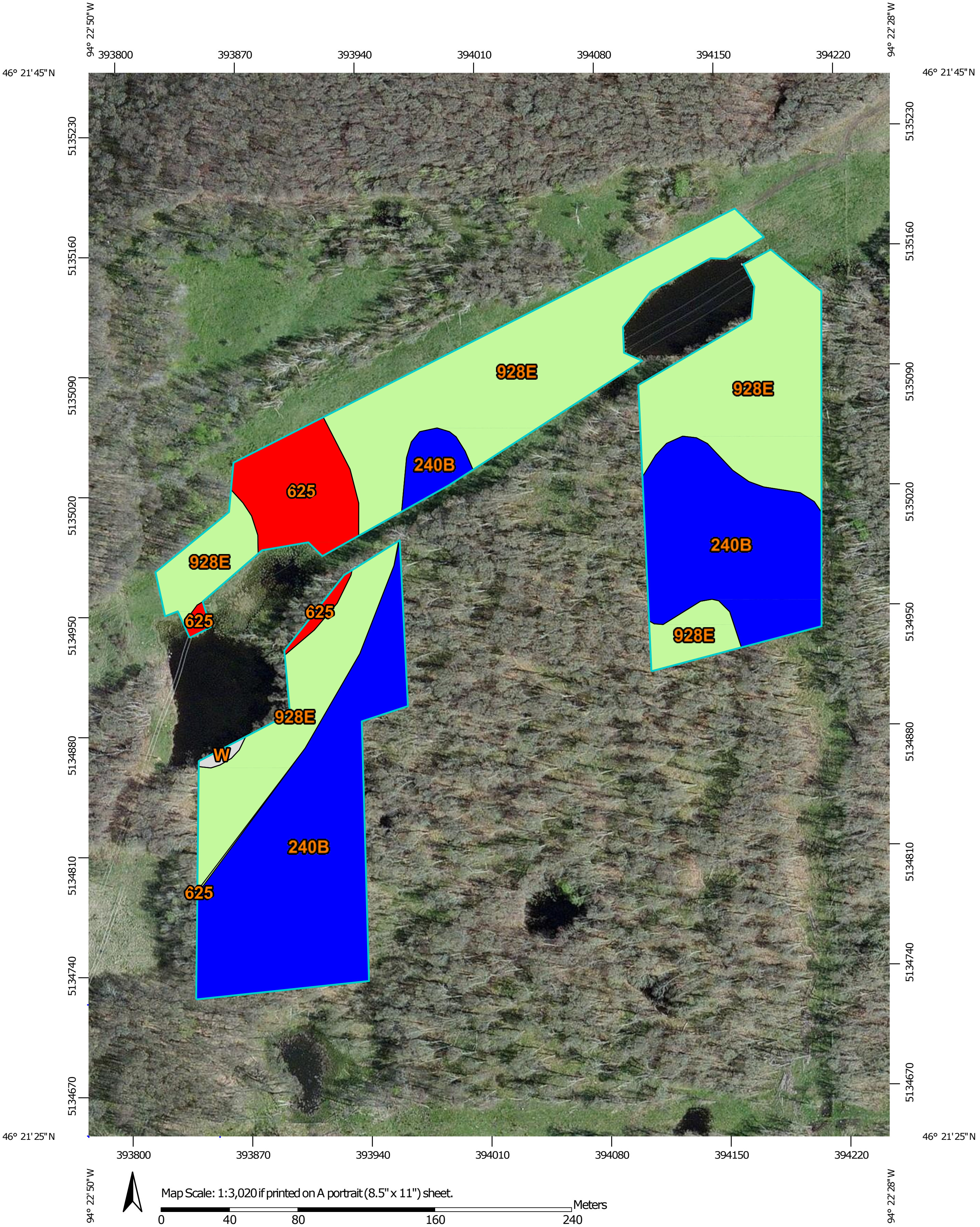
Available Water Capacity— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating (centimeters per centimeter)**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	0.21	6.1	40.5%
625	Sandwick loamy sand	0.09	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	0.11	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Available Water Capacity (Booth)

Units of Measure: centimeters per centimeter
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Available Water Storage (Booth)

Accumulates the AWC for a specified depth range. Used to produce data for the muaggatt table.



94° 22' 50" W
94° 22' 28" W
46° 21' 45" N
46° 21' 25" N
393800
393870
393940
394010
394080
394150
394220
5135230
5135160
5135090
5135020
5134950
5134880
5134810
5134740
5134670
928E
928E
928E
928E
928E
625
625
625
625
240B
240B
240B
W
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 0.45

> 0.45 and <= 0.59

> 0.59 and <= 1.05

Not rated or not available

Soil Rating Lines

<= 0.45

> 0.45 and <= 0.59

> 0.59 and <= 1.05

Not rated or not available

Soil Rating Points

<= 0.45

> 0.45 and <= 0.59

> 0.59 and <= 1.05

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Cass County, Minnesota
Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Available Water Storage (Booth)

Available Water Storage— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	Map unit name	Rating (centimeters per centimeter)	Acres in AOI	Percent of AOI
240B	Warba very fine sandy loam, 3 to 8 percent slopes	1.05	6.1	40.5%
625	Sandwick loamy sand	0.45	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	0.59	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Available Water Storage (Booth)

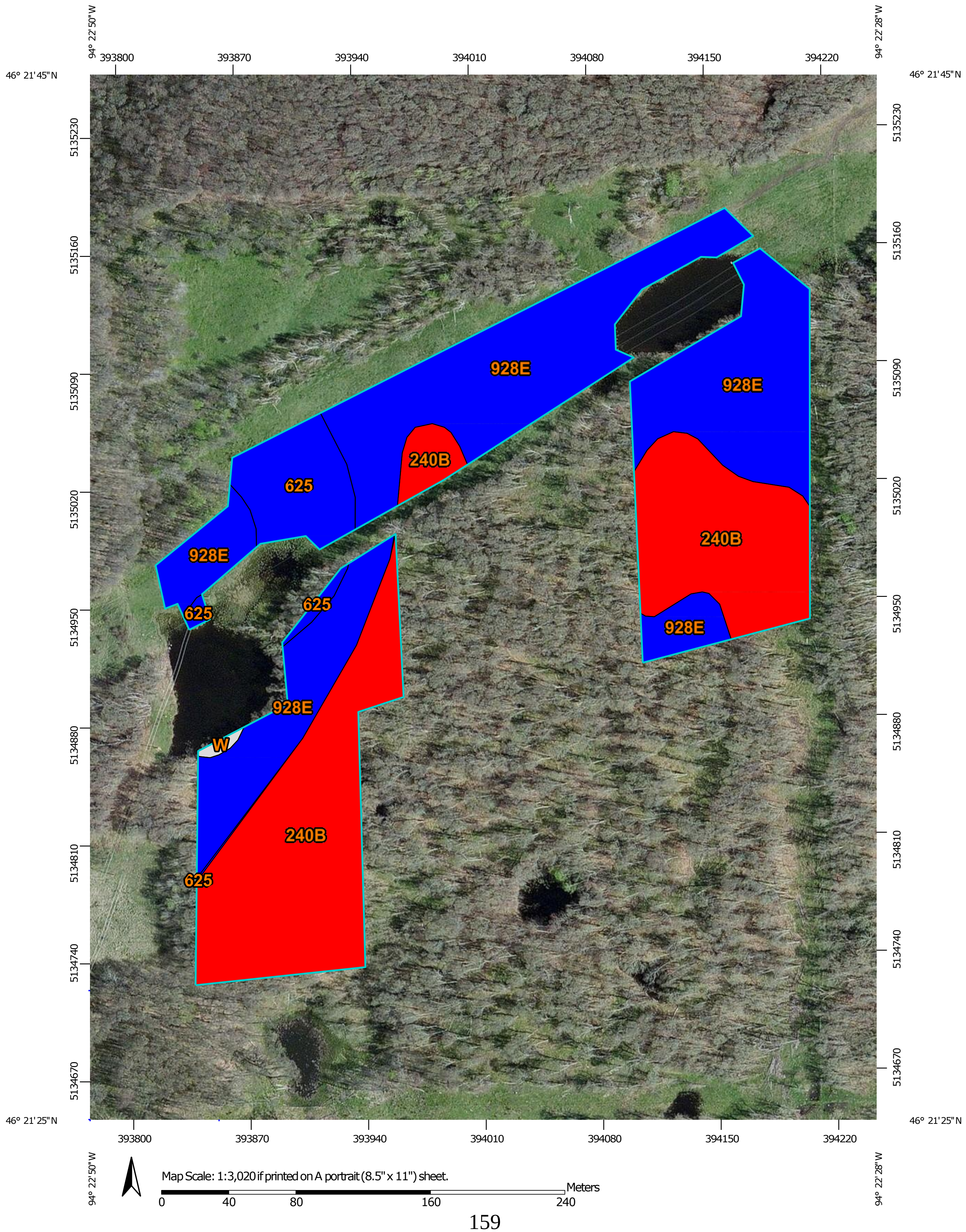
Units of Measure: centimeters per centimeter
Aggregation Method: Weighted Average
Component Percent Cutoff: None
Specified Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Sum)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Saturated Hydraulic Conductivity (Ksat) (Booth)

Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The estimates are expressed in terms of micrometers per second. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity is considered in the design of soil drainage systems and septic tank absorption fields.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

The numeric Ksat values have been grouped according to standard Ksat class limits.


94° 22' 50" W
393800
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394220
94° 22' 28" W
46° 21' 45" N
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5135090
5135020
5134950
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5134740
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46° 21' 25" N
928E
928E
240B
625
240B
928E
625
625
928E
928E
W
240B
625
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 28.0000

> 28.0000 and <= 92.0000

Not rated or not available

Soil Rating Lines

<= 28.0000

> 28.0000 and <= 92.0000

Not rated or not available

Soil Rating Points

<= 28.0000

> 28.0000 and <= 92.0000

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:20,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Survey Area Data: Version 11, Sep 18, 2015

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Date(s) aerial images were photographed: Data not available.

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Table—Saturated Hydraulic Conductivity (Ksat) (Booth)

Saturated Hydraulic Conductivity (Ksat)— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating (micrometers per second)**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	28.0000	6.1	40.5%
625	Sandwick loamy sand	92.0000	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	92.0000	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Saturated Hydraulic Conductivity (Ksat) (Booth)

Units of Measure: micrometers per second
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Fastest
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeter

Soil Qualities and Features

Soil qualities are behavior and performance attributes that are not directly measured, but are inferred from observations of dynamic conditions and from soil properties.

Example soil qualities include natural drainage, and frost action. Soil features are attributes that are not directly part of the soil. Example soil features include slope and depth to restrictive layer. These features can greatly impact the use and management of the soil.

Drainage Class (Booth)

"Drainage class (natural)" refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized-excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained. These classes are defined in the "Soil Survey Manual."


94° 22' 50" W
94° 22' 28" W
46° 21' 45" N
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625
928E
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W
240B
625
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Lines

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Points

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

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Survey Area Data: Version 11, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

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Table—Drainage Class (Booth)

Drainage Class— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	Well drained	6.1	40.5%
625	Sandwick loamy sand	Poorly drained	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	Well drained	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Drainage Class (Booth)

Aggregation Method: Dominant Condition
Component Percent Cutoff: *None Specified*
Tie-break Rule: Higher

Hydrologic Soil Group (Booth)

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long- duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

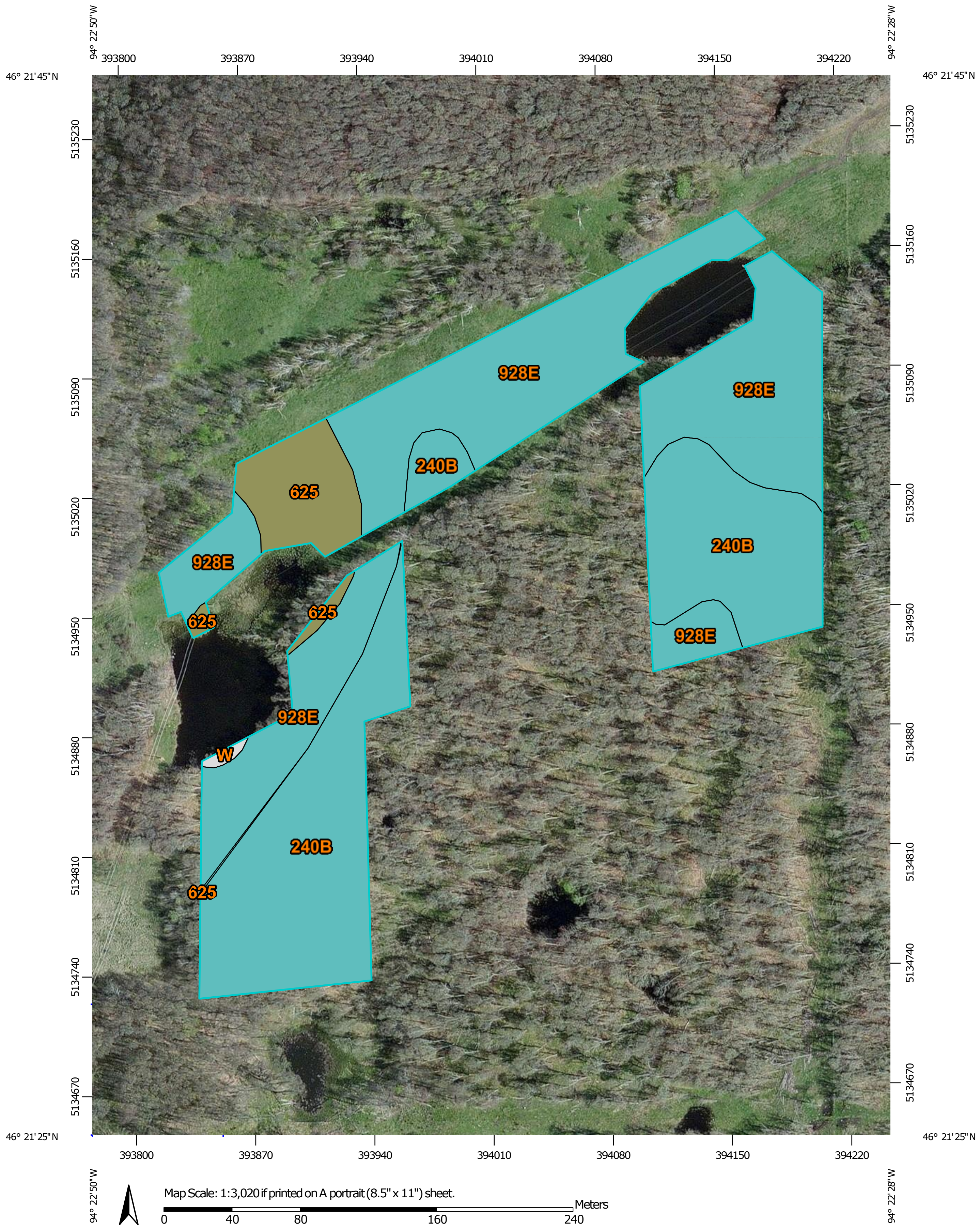
Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.


94° 22' 50" W
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5134740
5134670
928E
928E
240B
625
928E
625
625
240B
928E
928E
W
240B
625
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Lines

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Points

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

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Table—Hydrologic Soil Group (Booth)

Hydrologic Soil Group— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
240B	Warba very fine sandy loam, 3 to 8 percent slopes	C	6.1	40.5%
625	Sandwick loamy sand	C/D	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	C	7.7	51.6%
W	Water		0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Hydrologic Soil Group (Booth)

Aggregation Method: Dominant Condition
Component Percent Cutoff: *None Specified*
Tie-break Rule: Higher

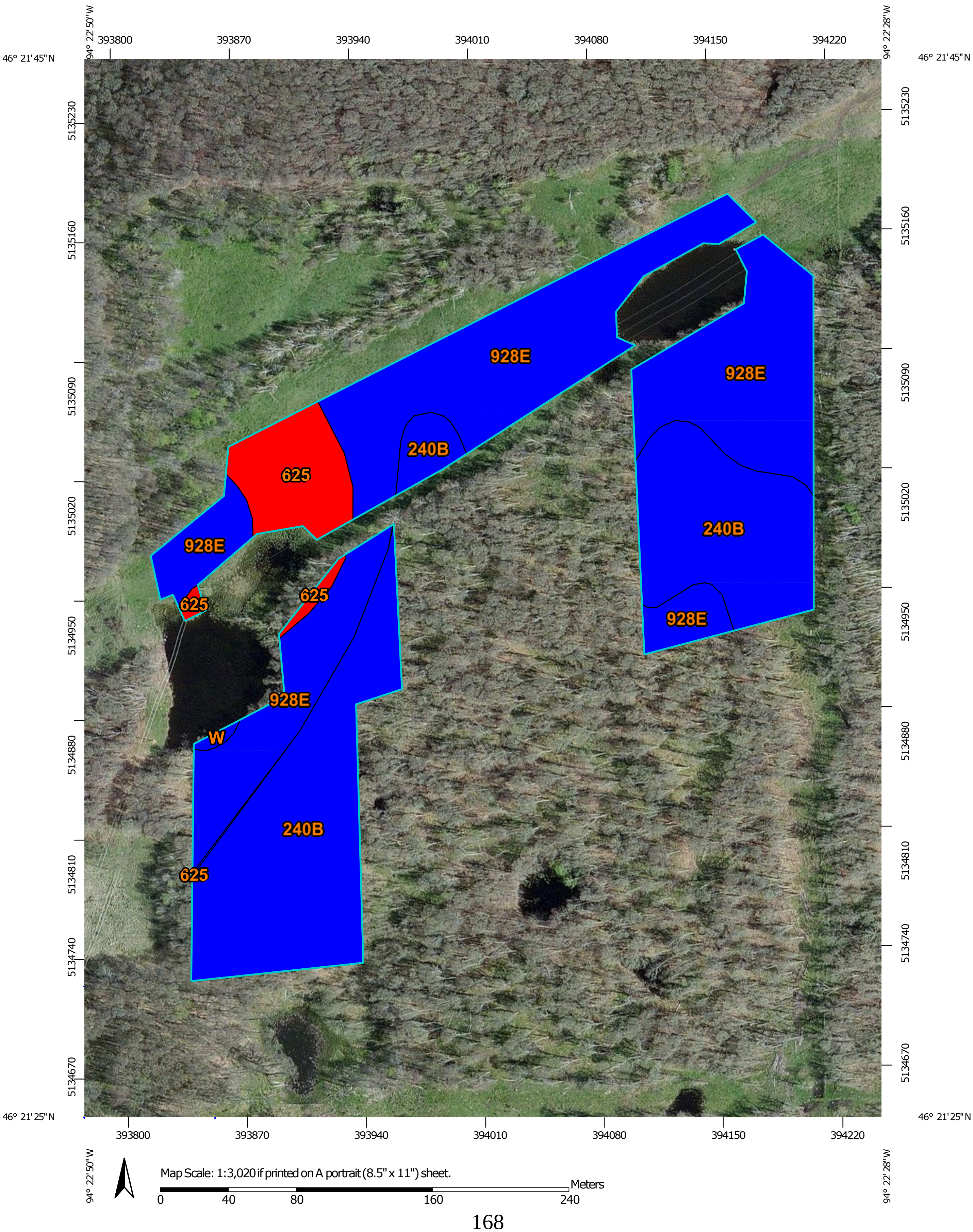
Water Features

Water Features include ponding frequency, flooding frequency, and depth to water table.

Depth to Water Table (Booth)

"Water table" refers to a saturated zone in the soil. It occurs during specified months. Estimates of the upper limit are based mainly on observations of the water table at selected sites and on evidence of a saturated zone, namely grayish colors (redoximorphic features) in the soil. A saturated zone that lasts for less than a month is not considered a water table.

This attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.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240B
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240B
928E
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240B
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928E
Map Scale: 1:3,020 if printed on A portrait (8.5" x 11") sheet.
Meters
0
40
80
160
240

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Soil Rating Lines

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Soil Rating Points

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

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Table—Depth to Water Table (Booth)

Depth to Water Table— Summary by Map Unit — Cass County, Minnesota (MN021)				
Map unit symbol	Map unit name	Rating (centimeters)	Acres in AOI	Percent of AOI
240B	Warba very fine sandy loam, 3 to 8 percent slopes	>200	6.1	40.5%
625	Sandwick loamy sand	15	1.1	7.6%
928E	DeMontreville-Mahtomedi-Cushing complex, 15 to 40 percent slopes	>200	7.7	51.6%
W	Water	>200	0.0	0.3%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Depth to Water Table (Booth)

Units of Measure: centimeters

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Lower

Interpret Nulls as Zero: No

Beginning Month: January

Ending Month: December

References

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United States Department of Agriculture

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Crow Wing County, Minnesota (Caughey)

May 4, 2016

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units).

Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

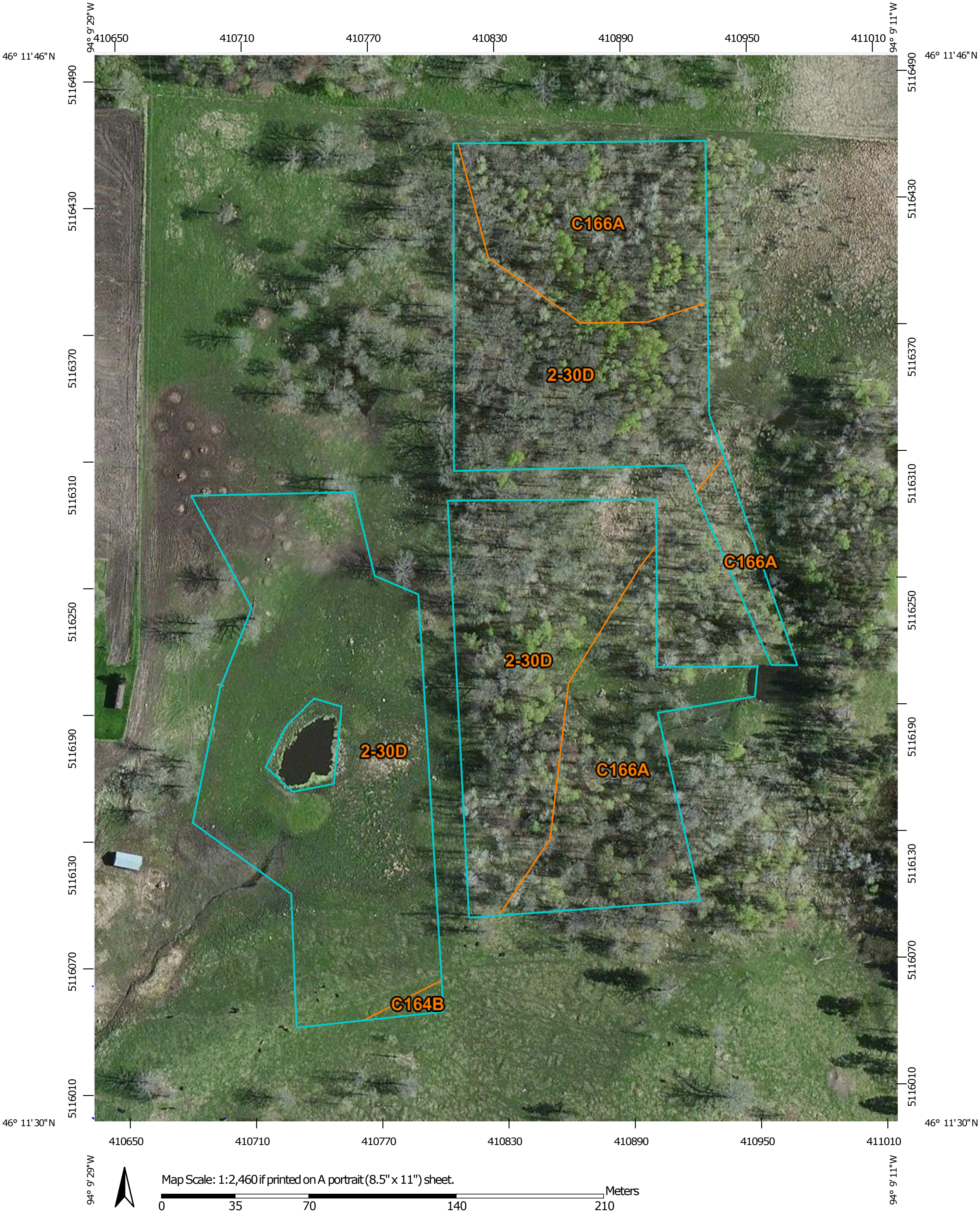
While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.



94° 9' 29"W
410650
410710
410770
410830
410890
410950
411010
94° 9' 11"W
46° 11' 46"N
46° 11' 30"N
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Map Unit Polygons

Soil Map Unit Lines

Soil Map Unit Points

Special Point Features

Blowout

Borrow Pit

Clay Spot

Closed Depression

Gravel Pit

Gravelly Spot

Landfill

Lava Flow

Marsh or swamp

Mine or Quarry

Miscellaneous Water

Perennial Water

Rock Outcrop

Saline Spot

Sandy Spot

Severely Eroded Spot

Sinkhole

Slide or Slip

Sodic Spot

Spoil Area

Stony Spot

Very Stony Spot

Wet Spot

Other

Special Line Features

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Crow Wing County, Minnesota (MN035)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	4.6	30.7%
Totals for Area of Interest		**15.1**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha- Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

2-30D—Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes

Map Unit Setting

National map unit symbol: 2slp6
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Not prime farmland

Map Unit Composition

Chetek and similar soils: 66 percent
Seelyeville, ponded, and similar soils: 20 percent
Minor components: 14 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Chetek

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Summit, shoulder, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear
Parent material: Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

Typical profile

Ap - 0 to 5 inches: fine sandy loam
E - 5 to 12 inches: fine sandy loam
Bt1 - 12 to 18 inches: sandy loam
2Bt2 - 18 to 25 inches: gravelly loamy coarse sand
2BC - 25 to 79 inches: gravelly coarse sand

Properties and qualities

Slope: 8 to 15 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified *Land capability classification (nonirrigated):* 6s *Hydrologic Soil Group:* A

Other vegetative classification: Sandy (G090AN022MN)

Description of Seelyeville, Ponded

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Side slope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Herbaceous organic material

Typical profile

Oa1 - 0 to 10 inches: muck
Oa2-Oa5 - 10 to 79 inches: muck

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.20 to 6.00 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Very high (about 23.9 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8w
Hydrologic Soil Group: A/D
Other vegetative classification: Not Suited (G090AN024MN)

Minor Components

Rosholt

Percent of map unit: 14 percent
Landform: Glacial drainage channels
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

C164B—Brainerd-Flak complex, 4 to 8 percent slopes

Map Unit Setting

National map unit symbol: 2slmq
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days

Farmland classification: All areas are prime farmland

Map Unit Composition

Brainerd and similar soils: 80 percent
Flak and similar soils: 15 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit

Description of Brainerd

Setting

Landform: Drumlins
Landform position (two-dimensional): Summit, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Dense lodgment till

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 11 inches: sandy loam
Bt - 11 to 23 inches: sandy loam
BC - 23 to 41 inches: sandy loam
BCd - 41 to 79 inches: sandy loam

Properties and qualities

Slope: 4 to 8 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: 39 to 59 inches to densic material
Natural drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 6 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 5.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: C/D
Other vegetative classification: Level Swale, Acid (G090AN005MN)

Description of Flak

Setting

Landform: Drumlins
Landform position (two-dimensional): Backslope, shoulder, summit
Landform position (three-dimensional): Side slope
Down-slope shape: Convex, linear
Across-slope shape: Convex, linear
Parent material: Dense lodgment till

Typical profile

Ap - 0 to 7 inches: sandy loam
E - 7 to 15 inches: sandy loam
Bt - 15 to 23 inches: sandy loam
BC - 23 to 43 inches: sandy loam
BCd - 43 to 79 inches: sandy loam

Properties and qualities

Slope: 4 to 8 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: 39 to 59 inches to densic material
Natural drainage class: Moderately well drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 20 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 5.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified *Land capability classification (nonirrigated):* 2e *Hydrologic Soil Group:* C/D
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

Minor Components

Nokay

Percent of map unit: 5 percent
Landform: Drumlins
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Talf
Down-slope shape: Concave
Across-slope shape: Linear
Other vegetative classification: Level Swale, Acid (G090AN005MN)

C166A—Nokay-Prebish complex, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 2q129
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Nokay and similar soils: 60 percent
Prebish and similar soils: 35 percent
Minor components: 5 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Nokay

Setting

Landform: Interdrumlins
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Talf
Down-slope shape: Concave
Across-slope shape: Linear
Parent material: Dense lodgment till

Typical profile

A - 0 to 6 inches: loam
E - 6 to 14 inches: fine sandy loam
Bt - 14 to 31 inches: sandy loam
BC - 31 to 41 inches: sandy loam
Cd - 41 to 79 inches: sandy loam

Properties and qualities

Slope: 0 to 2 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: 39 to 59 inches to densic material
Natural drainage class: Poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 5.8 inches)

Interpretive groups

Land capability classification (irrigated): None specified *Land capability classification (nonirrigated):* 3w *Hydrologic Soil Group:* C/D
Other vegetative classification: Level Swale, Acid (G090AN005MN)

Description of Prebish

Setting

Landform: Interdrumlins
Landform position (two-dimensional): Toeslope
Landform position (three-dimensional): Dip
Down-slope shape: Concave
Across-slope shape: Concave, linear
Parent material: Loamy alluvium over dense lodgment till

Typical profile

A - 0 to 8 inches: loam
Eg - 8 to 12 inches: fine sandy loam
Btg - 12 to 30 inches: fine sandy loam

BC1 - 30 to 38 inches: sandy loam
2BC2 - 38 to 55 inches: sandy loam
2Cd - 55 to 79 inches: sandy loam

Properties and qualities

Slope: 0 to 1 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: 39 to 59 inches to densic material *Natural drainage class:* Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Moderate (about 8.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6w *Hydrologic Soil Group:* C/D
Other vegetative classification: Ponded If Not Drained (G090AN013MN)

Minor Components

Brainerd

Percent of map unit: 5 percent
Landform: Interdrumlins
Landform position (two-dimensional): Backslope, summit
Landform position (three-dimensional): Rise
Down-slope shape: Linear
Across-slope shape: Linear
Other vegetative classification: Level Swale, Acid (G090AN005MN)

Soil Information for All Uses

Soil Properties and Qualities

The Soil Properties and Qualities section includes various soil properties and qualities displayed as thematic maps with a summary table for the soil map units in the selected area of interest. A single value or rating for each map unit is generated by aggregating the interpretive ratings of individual map unit components. This aggregation process is defined for each property or quality.

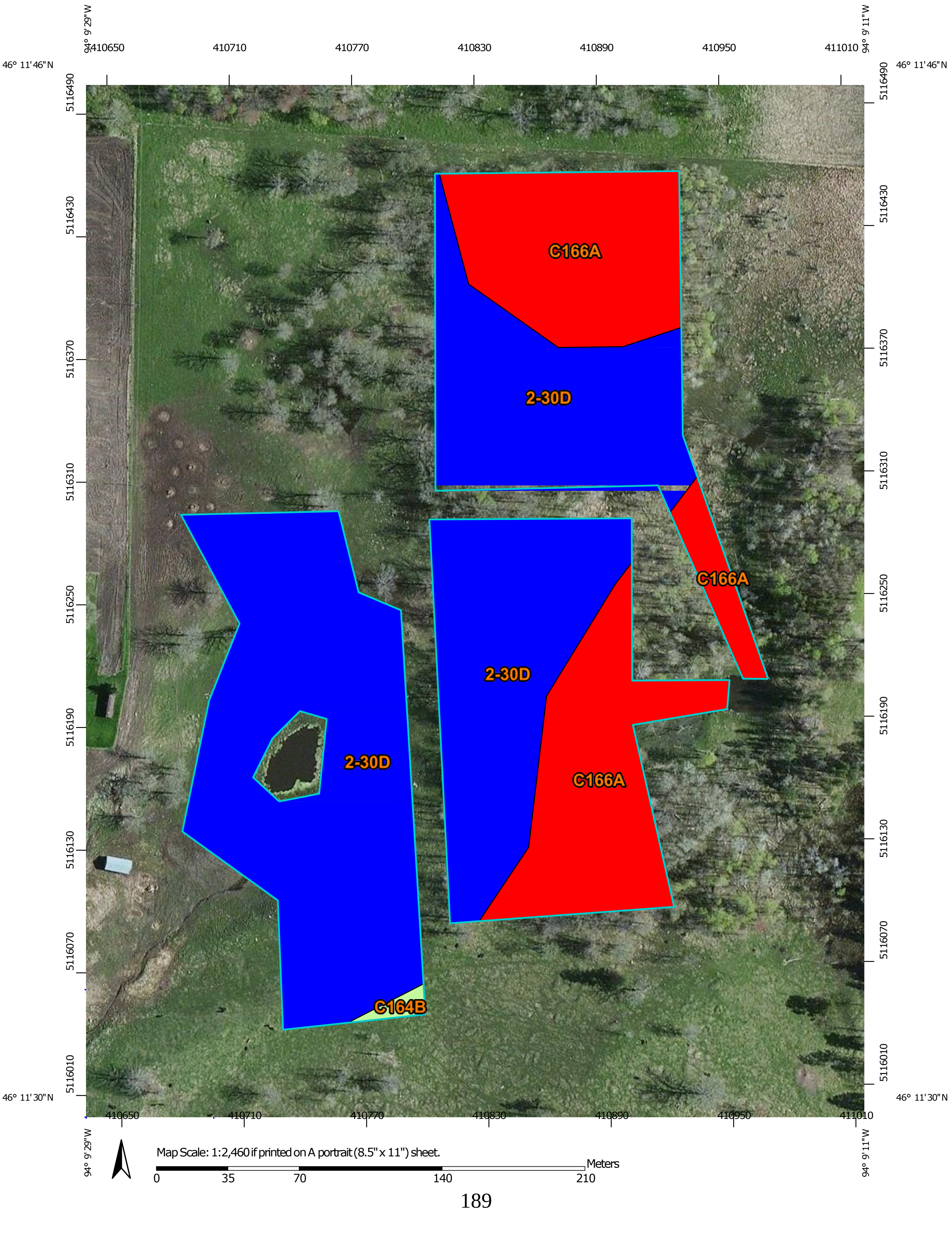
Soil Physical Properties

Soil Physical Properties are measured or inferred from direct observations in the field or laboratory. Examples of soil physical properties include percent clay, organic matter, saturated hydraulic conductivity, available water capacity, and bulk density.

Bulk Density, One-Third Bar (Caughey)

Bulk density, one-third bar, is the ovendry weight of the soil material less than 2 millimeters in size per unit volume of soil at water tension of 1/3 bar, expressed in grams per cubic centimeter. Bulk density data are used to compute linear extensibility, shrink-swell potential, available water capacity, total pore space, and other soil properties. The moist bulk density of a soil indicates the pore space available for water and roots. Depending on soil texture, a bulk density of more than 1.4 can restrict water storage and root penetration. Moist bulk density is influenced by texture, kind of clay, content of organic matter, and soil structure.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 9'29"W
410650
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410770
410830
410890
410950
411010
94° 9'11"W
46° 11'46"N
46° 11'30"N
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 1.50
- > 1.50 and <= 1.52
- > 1.52 and <= 1.55
- Not rated or not available

Soil Rating Lines

- <= 1.50
- > 1.50 and <= 1.52
- > 1.52 and <= 1.55
- Not rated or not available

Soil Rating Points

- <= 1.50
- > 1.50 and <= 1.52
- > 1.52 and <= 1.55
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Bulk Density, One-Third Bar (Caughey)

Bulk Density, One-Third Bar— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (grams per cubic centimeter)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	1.55	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	1.52	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	1.50	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Bulk Density, One-Third Bar (Caughey)

Units of Measure: grams per cubic centimeter
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Saturated Hydraulic Conductivity (Ksat) (Caughey)

Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The estimates are expressed in terms of micrometers per second. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity is considered in the design of soil drainage systems and septic tank absorption fields.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

The numeric Ksat values have been grouped according to standard Ksat class limits.

94° 9'29"W
94° 9'11"W
46° 11'46"N
46° 11'30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
C166A
2-30D
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 9.0000
- > 9.0000 and <= 28.0000
- > 28.0000 and <= 28.2250
- Not rated or not available

Soil Rating Lines

- <= 9.0000
- > 9.0000 and <= 28.0000
- > 28.0000 and <= 28.2250
- Not rated or not available

Soil Rating Points

- <= 9.0000
- > 9.0000 and <= 28.0000
- > 28.0000 and <= 28.2250
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Saturated Hydraulic Conductivity (Ksat) (Caughey)

Saturated Hydraulic Conductivity (Ksat)— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (micrometers per second)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	28.2250	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	28.0000	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	9.0000	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Saturated Hydraulic Conductivity (Ksat) (Caughey)

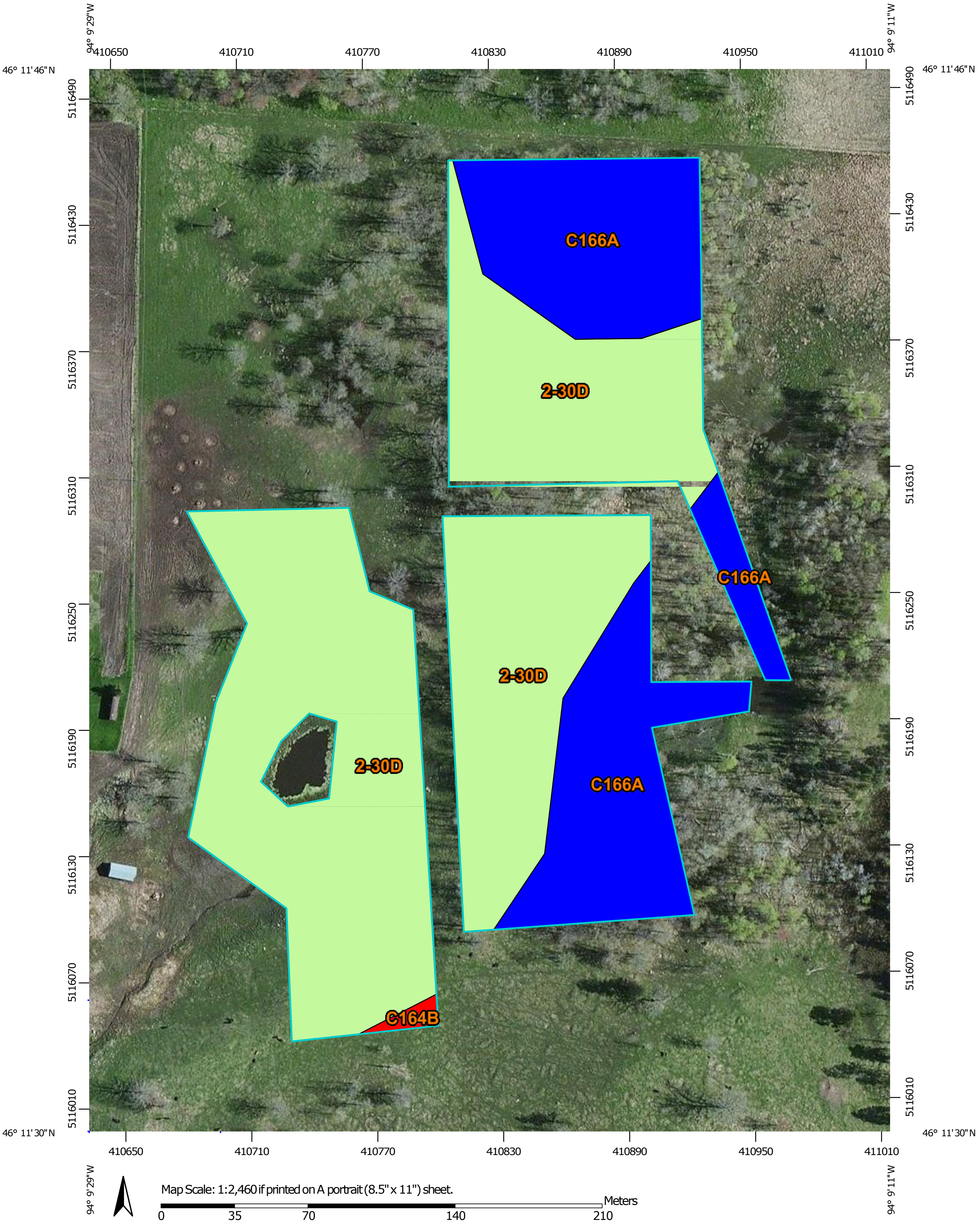
Units of Measure: micrometers per second
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Fastest
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Available Water Capacity (Caughey)

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. It is not an estimate of the quantity of water actually available to plants at any given time.

Available water supply (AWS) is computed as AWC times the thickness of the soil. For example, if AWC is 0.15 cm/cm, the available water supply for 25 centimeters of soil would be 0.15 x 25, or 3.75 centimeters of water.

For each soil layer, AWC is recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 9'29"W
94° 9'11"W
46° 11'46"N
46° 11'30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.21
- Not rated or not available

Soil Rating Lines

- <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.21
- Not rated or not available

Soil Rating Points

- <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.21
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Available Water Capacity (Caughey)

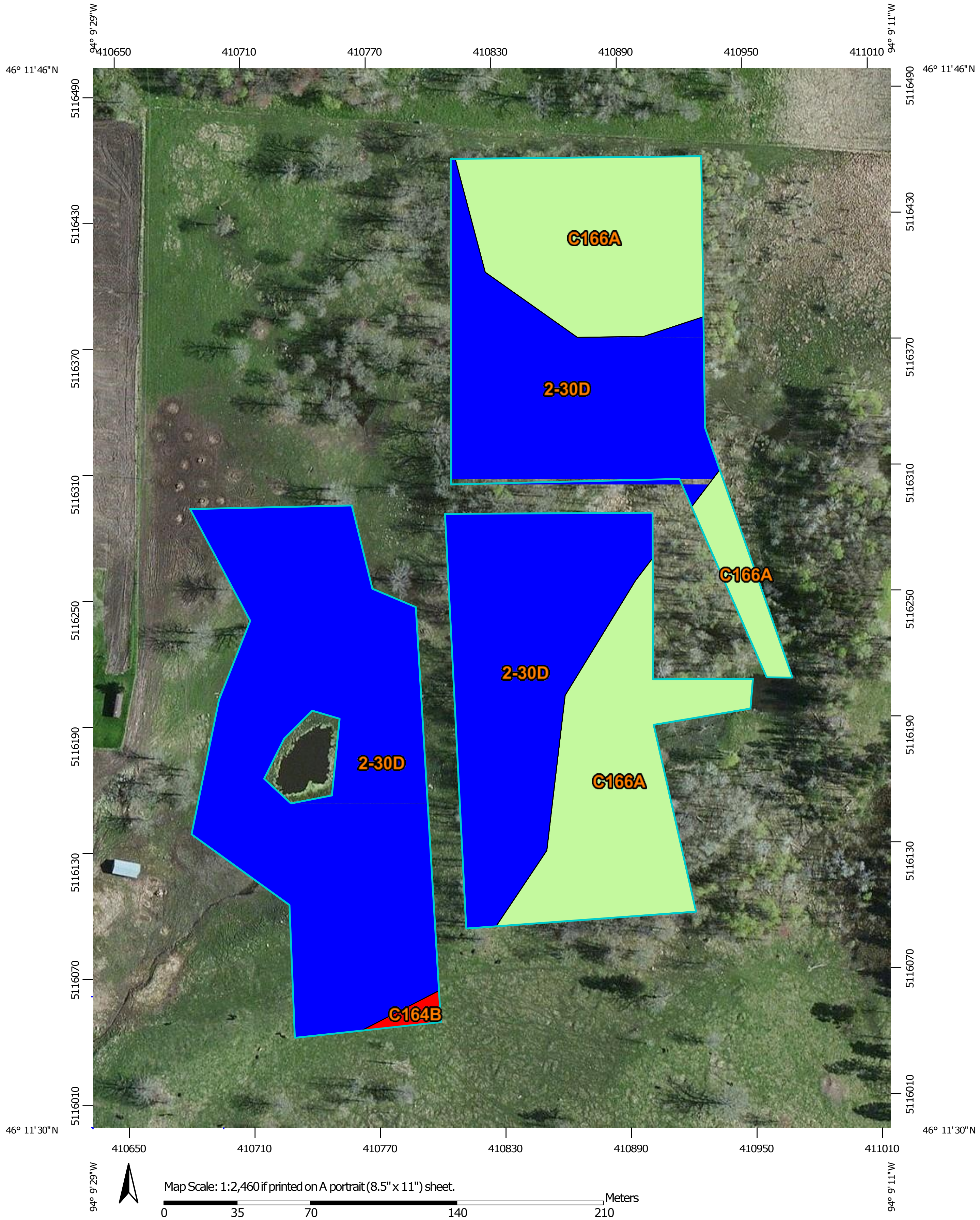
Available Water Capacity— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (centimeters per centimeter)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	0.16	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	0.13	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	0.21	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Available Water Capacity (Caughey)

Units of Measure: centimeters per centimeter
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Available Water Storage (Caughey)

Accumulates the AWC for a specified depth range. Used to produce data for the muaggatt table.


94° 9' 29"W
94° 9' 11"W
46° 11' 46"N
46° 11' 30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.67
- > 0.67 and <= 1.03
- > 1.03 and <= 1.05
- Not rated or not available

Soil Rating Lines

- <= 0.67
- > 0.67 and <= 1.03
- > 1.03 and <= 1.05
- Not rated or not available

Soil Rating Points

- <= 0.67
- > 0.67 and <= 1.03
- > 1.03 and <= 1.05
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Survey Area Data: Version 10, Sep 18, 2015

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Date(s) aerial images were photographed: Data not available.

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Table—Available Water Storage (Caughey)

Available Water Storage— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (centimeters per centimeter)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	1.05	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	0.67	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	1.03	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Available Water Storage (Caughey)

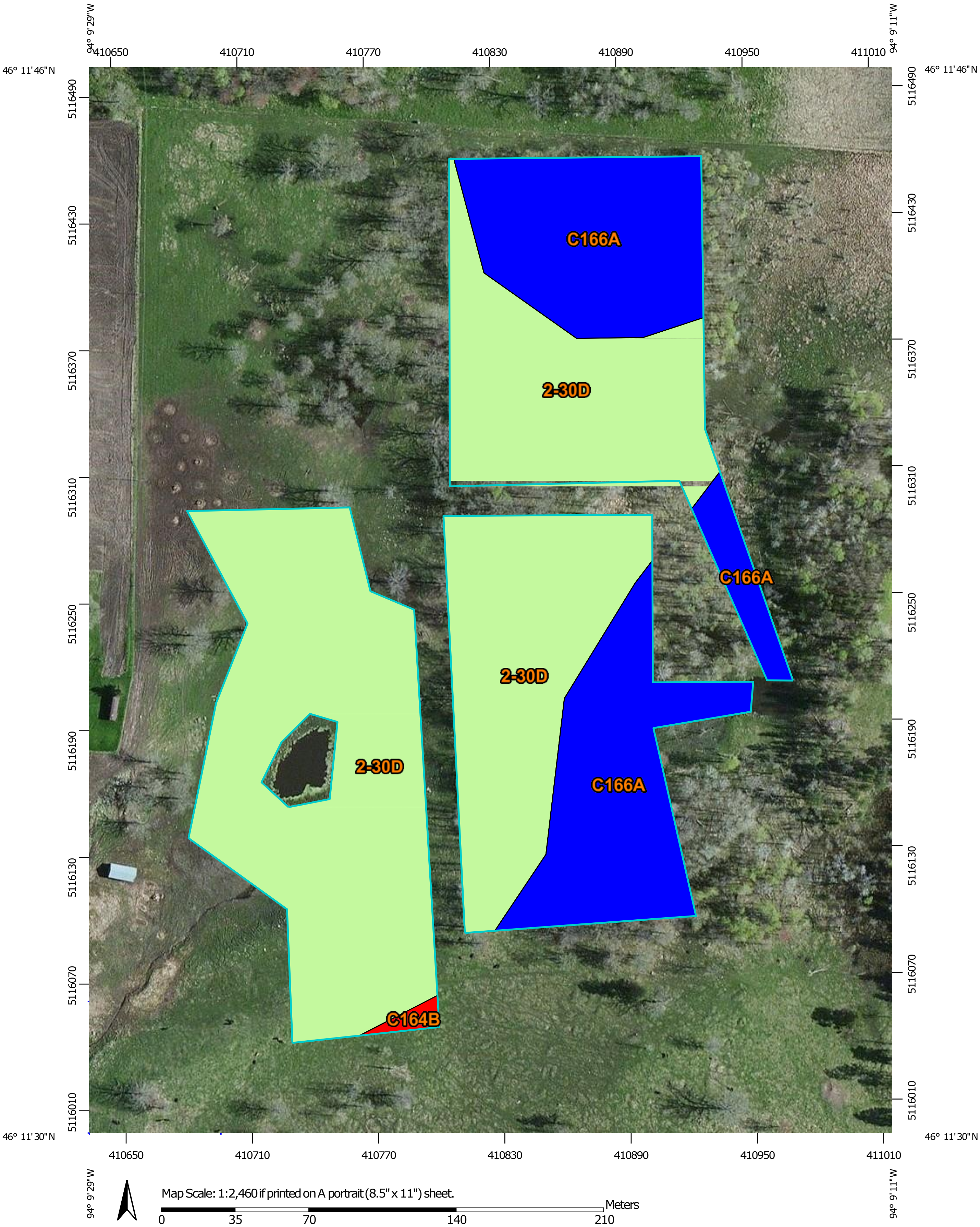
Units of Measure: centimeters per centimeter
Aggregation Method: Weighted Average
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Sum)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Clay (Caughey)

Clay as a soil separate consists of mineral soil particles that are less than 0.002 millimeter in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The amount and kind of clay affect the fertility and physical condition of the soil and the ability of the soil to adsorb cations and to retain moisture. They influence shrink- swell potential, saturated hydraulic conductivity (Ksat), plasticity, the ease of soil dispersion, and other soil properties. The amount and kind of clay in a soil also affect tillage and earth-moving operations.

Most of the material is in one of three groups of clay minerals or a mixture of these clay minerals. The groups are kaolinite, smectite, and hydrous mica, the best known member of which is illite.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


C166A
2-30D
C166A
2-30D
C166A
2-30D
C164B
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
46° 11'46"N
46° 11'30"N
94° 9'29"W
94° 9'11"W
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 8.0
- > 8.0 and <= 9.0
- > 9.0 and <= 14.0
- Not rated or not available

Soil Rating Lines

- <= 8.0
- > 8.0 and <= 9.0
- > 9.0 and <= 14.0
- Not rated or not available

Soil Rating Points

- <= 8.0
- > 8.0 and <= 9.0
- > 9.0 and <= 14.0
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

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Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Clay (Caughey)

Percent Clay— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	9.0	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	8.0	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	14.0	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Percent Clay (Caughey)

Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Sand (Caughey)

Sand as a soil separate consists of mineral soil particles that are 0.05 millimeter to 2 millimeters in diameter. In the database, the estimated sand content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

94° 9'29"W
94° 9'11"W
46° 11'46"N
46° 11'30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
C166A
2-30D
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 51.0
- > 51.0 and <= 63.0
- > 63.0 and <= 69.0
- Not rated or not available

Soil Rating Lines

- <= 51.0
- > 51.0 and <= 63.0
- > 63.0 and <= 69.0
- Not rated or not available

Soil Rating Points

- <= 51.0
- > 51.0 and <= 63.0
- > 63.0 and <= 69.0
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

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Table—Percent Sand (Caughey)

Percent Sand— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	69.0	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	63.0	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	51.0	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Percent Sand (Caughey)

Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Silt (Caughey)

Silt as a soil separate consists of mineral soil particles that are 0.002 to 0.05 millimeter in diameter. In the database, the estimated silt content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.

The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

94° 9'29"W
94° 9'11"W
46° 11'46"N
46° 11'30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
C166A
2-30D
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 22.0
- > 22.0 and <= 29.0
- > 29.0 and <= 35.0
- Not rated or not available

Soil Rating Lines

- <= 22.0
- > 22.0 and <= 29.0
- > 29.0 and <= 35.0
- Not rated or not available

Soil Rating Points

- <= 22.0
- > 22.0 and <= 29.0
- > 29.0 and <= 35.0
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

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Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

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Table—Percent Silt (Caughey)

Percent Silt— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (percent)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	22.0	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	29.0	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	35.0	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Percent Silt (Caughey)

Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Soil Qualities and Features

Soil qualities are behavior and performance attributes that are not directly measured, but are inferred from observations of dynamic conditions and from soil properties.

Example soil qualities include natural drainage, and frost action. Soil features are attributes that are not directly part of the soil. Example soil features include slope and depth to restrictive layer. These features can greatly impact the use and management of the soil.

Drainage Class (Caughey)

"Drainage class (natural)" refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized-excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained. These classes are defined in the "Soil Survey Manual."


C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
94° 9'29"W
94° 9'11"W
46° 11'46"N
46° 11'30"N
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Lines

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Points

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Drainage Class (Caughey)

Drainage Class— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	Somewhat excessively drained	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	Somewhat poorly drained	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	Poorly drained	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Drainage Class (Caughey)

Aggregation Method: Dominant Condition

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Hydrologic Soil Group (Caughey)

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long- duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.


C166A
2-30D
C166A
2-30D
2-30D
C166A
C164B
410650
410710
410770
410830
410890
410950
411010
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
46° 11'46"N
46° 11'30"N
94° 9'29"W
94° 9'11"W
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Lines

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Points

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

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Table—Hydrologic Soil Group (Caughey)

Hydrologic Soil Group— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	A	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	C/D	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	C/D	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Hydrologic Soil Group (Caughey)

Aggregation Method: Dominant Condition

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Parent Material Name (Caughey)

Parent material name is a term for the general physical, chemical, and mineralogical composition of the unconsolidated material, mineral or organic, in which the soil forms. Mode of deposition and/or weathering may be implied by the name.

The soil surveyor uses parent material to develop a model used for soil mapping. Soil scientists and specialists in other disciplines use parent material to help interpret soil boundaries and project performance of the material below the soil. Many soil properties relate to parent material. Among these properties are proportions of sand, silt, and clay; chemical content; bulk density; structure; and the kinds and amounts of rock fragments. These properties affect interpretations and may be criteria used to separate soil series. Soil properties and landscape information may imply the kind of parent material.

For each soil in the database, one or more parent materials may be identified. One is marked as the representative or most commonly occurring. The representative parent material name is presented here.

Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

dense lodgment till

Not rated or not available

Soil Rating Lines

coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

dense lodgment till

Not rated or not available

Soil Rating Points

coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

dense lodgment till

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Survey Area Data: Version 10, Sep 18, 2015

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Table—Parent Material Name (Caughey)

Parent Material Name— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	coarse-loamy glaciofluvial deposits over sandy and gravelly outwash	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	dense lodgment till	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	dense lodgment till	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Parent Material Name (Caughey)

Aggregation Method: Dominant Condition

Component Percent Cutoff: None Specified

Tie-break Rule: Lower

Water Features

Water Features include ponding frequency, flooding frequency, and depth to water table.

Depth to Water Table (Caughey)

"Water table" refers to a saturated zone in the soil. It occurs during specified months. Estimates of the upper limit are based mainly on observations of the water table at selected sites and on evidence of a saturated zone, namely grayish colors (redoximorphic features) in the soil. A saturated zone that lasts for less than a month is not considered a water table.

This attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

94° 9'29"W
94° 9'11"W
410650
410710
410770
410830
410890
410950
411010
46° 11'46"N
46° 11'30"N
5116490
5116430
5116370
5116310
5116250
5116190
5116130
5116070
5116010
C166A
2-30D
C166A
2-30D
C166A
2-30D
C164B
Map Scale: 1:2,460 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

0 - 25

25 - 50

50 - 100

100 - 150

150 - 200

> 200

Not rated or not available

Soil Rating Lines

0 - 25

25 - 50

50 - 100

100 - 150

150 - 200

> 200

Not rated or not available

Soil Rating Points

0 - 25

25 - 50

50 - 100

100 - 150

150 - 200

> 200

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
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Table—Depth to Water Table (Caughey)

Depth to Water Table— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (centimeters)**	**Acres in AOI**	**Percent of AOI**
2-30D	Chetek-Seelyeville, ponded complex, 0 to 15 percent slopes	>200	10.4	68.8%
C164B	Brainerd-Flak complex, 4 to 8 percent slopes	15	0.1	0.5%
C166A	Nokay-Prebish complex, 0 to 2 percent slopes	0	4.6	30.7%
Totals for Area of Interest			**15.1**	**100.0%**

Rating Options—Depth to Water Table (Caughey)

Units of Measure: centimeters

Aggregation Method: Dominant Component

Component Percent Cutoff: None

Specified Tie-break Rule: Lower

Interpret Nulls as Zero: No

Beginning Month: January

Ending Month: December

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Custom Soil Resource Report for Moe

United States Department of Agriculture

NRCS

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for

Crow Wing County, Minnesota (Moe)

May 4, 2016

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (http://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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Contents

How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

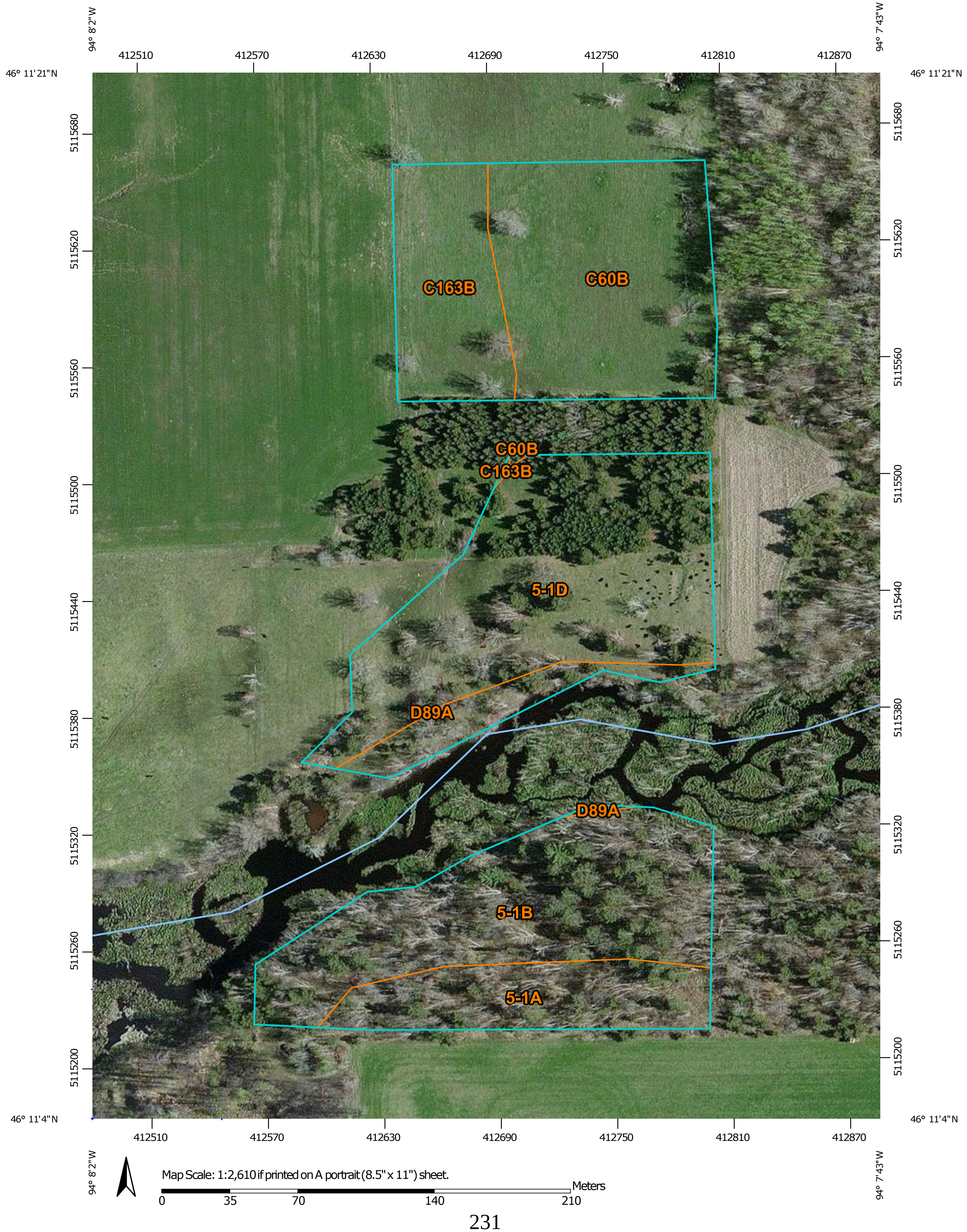
While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.



94° 8'2"W
94° 7'43"W
412510
412570
412630
412690
412750
412810
412870
46° 11'21"N
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
46° 11'4"N
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features

- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

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Please rely on the bar scale on each map sheet for map measurements.

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Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Crow Wing County, Minnesota (MN035)			
Map Unit Symbol	**Map Unit Name**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	0.7	4.5%
Totals for Area of Interest		**15.0**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used.

Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha- Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

5-1A—Chetek-Graycalm complex, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 2slq1
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Chetek and similar soils: 70 percent
Graycalm and similar soils: 30 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Chetek

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

Typical profile

Ap - 0 to 5 inches: fine sandy loam
E - 5 to 12 inches: fine sandy loam
Bt1 - 12 to 18 inches: sandy loam
2Bt2 - 18 to 25 inches: gravelly loamy coarse sand
2BC - 25 to 79 inches: gravelly coarse sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6s
Hydrologic Soil Group: A
Other vegetative classification: Sandy (G090AN022MN)

Description of Graycalm

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Outwash

Typical profile

A - 0 to 4 inches: loamy sand
Bw1 - 4 to 20 inches: loamy sand
Bw2 - 20 to 31 inches: sand
E and Bt - 31 to 79 inches: sand

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (6.00 to 20.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 4.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: A
Other vegetative classification: Sloping Upland, Low AWC, Acid (G091AN008MN)

5-1B—Chetek-Graycalm complex, 2 to 6 percent slopes

Map Unit Setting

National map unit symbol: 2slq2
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Chetek and similar soils: 70 percent
Graycalm and similar soils: 30 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Chetek

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Shoulder, backslope, summit
Landform position (three-dimensional): Side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear, convex
Parent material: Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

Typical profile

Ap - 0 to 5 inches: fine sandy loam
E - 5 to 12 inches: fine sandy loam
Bt1 - 12 to 18 inches: sandy loam
2Bt2 - 18 to 25 inches: gravelly loamy coarse sand
2BC - 25 to 79 inches: gravelly coarse sand

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified *Land capability classification (nonirrigated):* 6s *Hydrologic Soil Group:* A
Other vegetative classification: Sandy (G090AN022MN)

Description of Graycalm

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Summit, shoulder, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear, convex
Parent material: Outwash

Typical profile

A - 0 to 4 inches: loamy sand
Bw1 - 4 to 20 inches: loamy sand
Bw2 - 20 to 31 inches: sand
E and Bt - 31 to 79 inches: sand

Properties and qualities

Slope: 2 to 6 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (6.00 to 20.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 4.4 inches)

Interpretive groups

Land capability classification (irrigated): None
specified *Land capability classification (nonirrigated):*
4s *Hydrologic Soil Group:* A
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

5-1D—Chetek-Graycalm complex, 6 to 12 percent slopes

Map Unit Setting

National map unit symbol: 2v44w
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Not prime farmland

Map Unit Composition

Chetek and similar soils: 65 percent
Graycalm and similar soils: 30 percent
Minor components: 5 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Chetek

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Shoulder, backslope, summit
Landform position (three-dimensional): Side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear, convex
Parent material: Coarse-loamy glaciofluvial deposits over sandy and gravelly outwash

Typical profile

Ap - 0 to 5 inches: fine sandy loam
E - 5 to 12 inches: fine sandy loam
Bt1 - 12 to 18 inches: sandy loam
2Bt2 - 18 to 25 inches: gravelly loamy coarse sand

2BC - 25 to 79 inches: gravelly coarse sand

Properties and qualities

Slope: 6 to 12 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 3.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6s
Hydrologic Soil Group: A
Other vegetative classification: Sandy (G090AN022MN)

Description of Graycalm

Setting

Landform: Glacial drainage channels
Landform position (two-dimensional): Summit, shoulder, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear, convex
Across-slope shape: Linear,
convex *Parent material:* Outwash

Typical profile

A - 0 to 4 inches: loamy sand
Bw1 - 4 to 20 inches: loamy sand
Bw2 - 20 to 31 inches: sand
E and Bt - 31 to 79 inches: sand

Properties and qualities

Slope: 6 to 12 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Somewhat excessively drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (6.00 to 20.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 4.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 4s
Hydrologic Soil Group: A

Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

Minor Components

Pequaywan

Percent of map unit: 5 percent
Landform: Moraines
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Side slope
Down-slope shape: Concave
Across-slope shape: Concave
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

C60B—Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes

Map Unit Setting

National map unit symbol: 2slmt
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Bushville and similar soils: 85 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Bushville

Setting

Landform: Drumlins
Landform position (two-dimensional): Backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Sandy outwash over dense lodgment till

Typical profile

A - 0 to 10 inches: loamy sand
E - 10 to 24 inches: loamy sand
2Bt1 - 24 to 30 inches: sandy loam
2Bt2 - 30 to 42 inches: sandy loam
2BCd - 42 to 79 inches: sandy loam

Properties and qualities

Slope: 0 to 3 percent
Depth to restrictive feature: 39 to 59 inches to densic material
Natural drainage class: Somewhat poorly drained

Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 6 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 4.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3s
Hydrologic Soil Group: C/D
Other vegetative classification: Level Swale, Low AWC, Acid (G090AN007MN)

Minor Components

Watab

Percent of map unit: 10 percent
Landform: Drumlins
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Other vegetative classification: Level Swale, Low AWC, Acid (G090AN007MN)

Pomroy

Percent of map unit: 5 percent
Landform: Drumlins
Landform position (two-dimensional): Summit, backslope, shoulder
Landform position (three-dimensional): Side slope
Down-slope shape: Convex
Across-slope shape: Linear
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

C163B—Brainerd sandy loam, 1 to 4 percent slopes

Map Unit Setting

National map unit symbol: 2q125
Elevation: 790 to 1,970 feet
Mean annual precipitation: 27 to 36 inches
Mean annual air temperature: 37 to 46 degrees F
Frost-free period: 80 to 150 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Brainerd and similar soils: 85 percent
Minor components: 15 percent

Estimates are based on observations, descriptions, and transects of the mapunit.

Description of

Brainerd Setting

Landform: Drumlins
Landform position (two-dimensional): Summit, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Dense lodgment till

Typical profile

Ap - 0 to 6 inches: sandy loam
E - 6 to 11 inches: sandy loam
Bt - 11 to 23 inches: sandy loam
BC - 23 to 41 inches: sandy loam
BCd - 41 to 79 inches: sandy loam

Properties and qualities

Slope: 1 to 4 percent
Percent of area covered with surface fragments: 0.1 percent
Depth to restrictive feature: 39 to 59 inches to densic material
Natural drainage class: Somewhat poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Very low to moderately high (0.00 to 0.20 in/hr)
Depth to water table: About 6 inches
Frequency of flooding: None
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 5.0 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: C/D
Other vegetative classification: Level Swale, Acid (G090AN005MN)

Minor Components

Nokay

Percent of map unit: 10 percent
Landform: Drumlins
Landform position (two-dimensional): Footslope
Landform position (three-dimensional): Talf
Down-slope shape: Concave
Across-slope shape: Linear
Other vegetative classification: Level Swale, Acid (G090AN005MN)

Flak

Percent of map unit: 5 percent
Landform: Drumlins

Landform position (two-dimensional): Backslope, shoulder, summit
Landform position (three-dimensional): Side slope
Down-slope shape: Convex, linear
Across-slope shape: Convex, linear
Other vegetative classification: Sloping Upland, Low AWC, Acid (G090AN008MN)

D89A—Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded

Map Unit Setting

National map unit symbol: 2ndrf
Elevation: 660 to 1,710 feet
Mean annual precipitation: 25 to 33 inches
Mean annual air temperature: 37 to 48 degrees
F*Frost-free period:* 120 to 170 days
Farmland classification: Not prime farmland

Map Unit Composition

Lougee, frequently flooded, and similar soils: 45 percent
Bowstring, frequently flooded, and similar soils: 20 percent
Totagatic, frequently flooded, very poorly drained, and similar soils: 20 percent
Minor components: 15 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Lougee, Frequently

Flooded Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear, concave
Across-slope shape: Linear, concave
Parent material: Herbaceous organic material over outwash

Typical profile

Oi - 0 to 12 inches: peat
Oe - 12 to 28 inches: mucky peat
A - 28 to 31 inches: mucky loamy fine sand
ACg - 31 to 46 inches: fine sand
Cg - 46 to 79 inches: fine sand

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): High to very high (2.00 to 20.00 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)

Available water storage in profile: Very high (about 17.7 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D
Other vegetative classification: Organic (G090BN014MN)

Description of Totagatic, Frequently Flooded, Very Poorly

Drained Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Sandy alluvium

Typical profile

Oa - 0 to 4 inches: muck
Bw1 - 4 to 8 inches: loamy fine sand
Bw2 - 8 to 17 inches: fine sand
Cg1 - 17 to 28 inches: fine sand
Cg2 - 28 to 46 inches: sand
C - 46 to 70 inches: sand
C'g - 70 to 79 inches: sand

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: None
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Low (about 5.4 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D
Other vegetative classification: Frequently Flooded (G091AN016MN)

Description of Bowstring, Frequently

Flooded Setting

Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Herbaceous organic material over sandy alluvium over herbaceous organic material

Typical profile

Oa - 0 to 38 inches: muck
Cg - 38 to 47 inches: fine sand
O'a - 47 to 79 inches: muck

Properties and qualities

Slope: 0 to 1 percent
Depth to restrictive feature: More than 80 inches
Natural drainage class: Very poorly drained
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 6.00 in/hr)
Depth to water table: About 0 inches
Frequency of flooding: Frequent
Frequency of ponding: Frequent
Salinity, maximum in profile: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water storage in profile: Very high (about 21.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 7w
Hydrologic Soil Group: A/D
Other vegetative classification: Not Suited (G091AN024MN)

Minor Components

Winterfield, occasionally flooded

Percent of map unit: 10 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Convex
Across-slope shape: Linear
Other vegetative classification: Frequently Flooded (G091AN016MN)

Carlos, frequently flooded

Percent of map unit: 5 percent
Landform: Flood plains
Landform position (three-dimensional): Tread
Down-slope shape: Linear
Across-slope shape: Linear
Other vegetative classification: Not Suited (G091AN024MN)

Soil Information for All Uses

Soil Properties and Qualities

The Soil Properties and Qualities section includes various soil properties and qualities displayed as thematic maps with a summary table for the soil map units in the selected area of interest. A single value or rating for each map unit is generated by aggregating the interpretive ratings of individual map unit components. This aggregation process is defined for each property or quality.

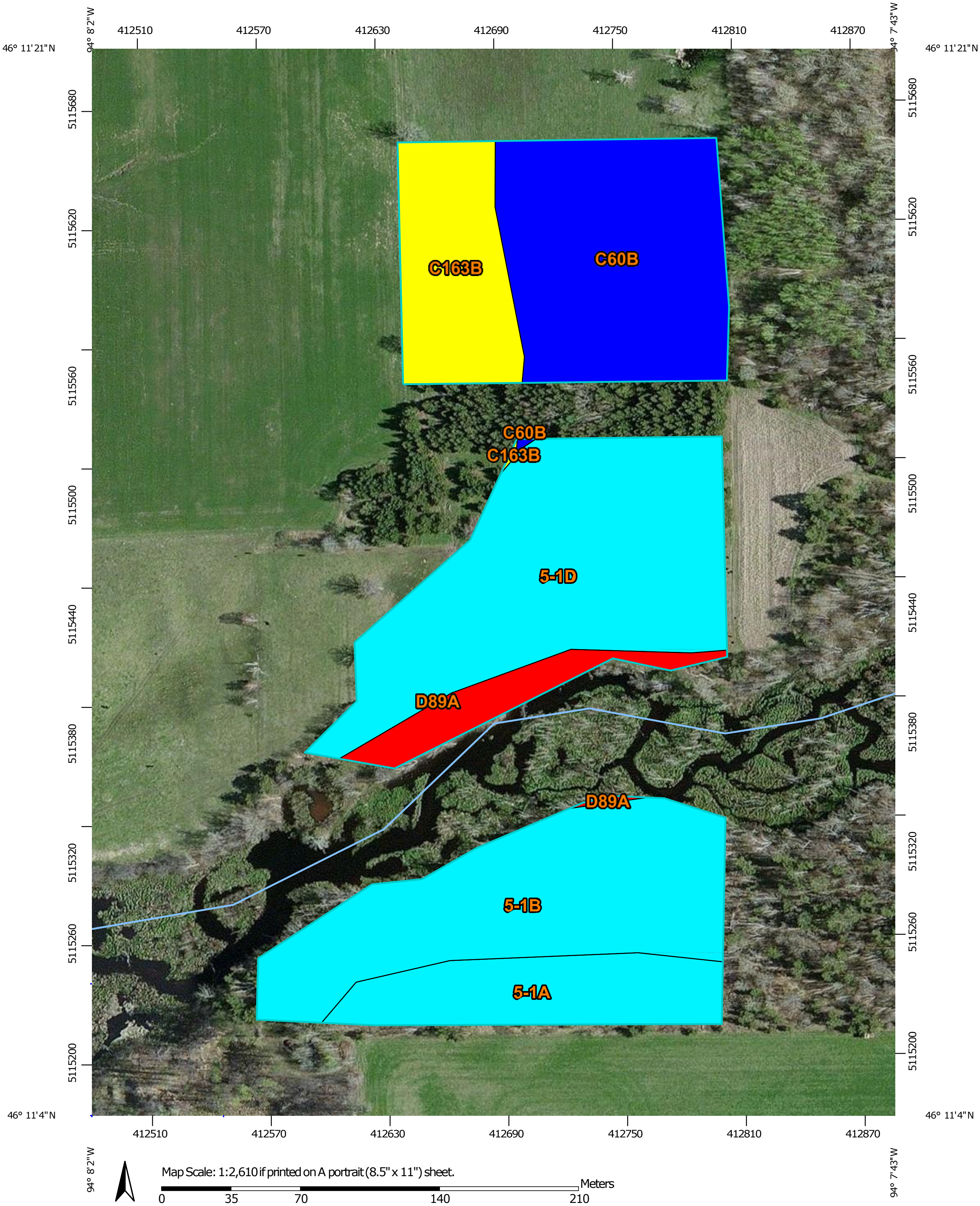
Soil Physical Properties

Soil Physical Properties are measured or inferred from direct observations in the field or laboratory. Examples of soil physical properties include percent clay, organic matter, saturated hydraulic conductivity, available water capacity, and bulk density.

Bulk Density, One-Third Bar (Moe)

Bulk density, one-third bar, is the ovendry weight of the soil material less than 2 millimeters in size per unit volume of soil at water tension of 1/3 bar, expressed in grams per cubic centimeter. Bulk density data are used to compute linear extensibility, shrink-swell potential, available water capacity, total pore space, and other soil properties. The moist bulk density of a soil indicates the pore space available for water and roots. Depending on soil texture, a bulk density of more than 1.4 can restrict water storage and root penetration. Moist bulk density is influenced by texture, kind of clay, content of organic matter, and soil structure.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


94° 8'2"W
412510
412570
412630
412690
412750
412810
412870
94° 7'43"W
46° 11'21"N
46° 11'4"N
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.05
- > 0.05 and <= 1.52
- > 1.52 and <= 1.55
- > 1.55 and <= 1.60
- Not rated or not available

Soil Rating Lines

- <= 0.05
- > 0.05 and <= 1.52
- > 1.52 and <= 1.55
- > 1.55 and <= 1.60
- Not rated or not available

Soil Rating Points

- <= 0.05
- > 0.05 and <= 1.52
- > 1.52 and <= 1.55
- > 1.55 and <= 1.60
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Bulk Density, One-Third Bar (Moe)

Bulk Density, One-Third Bar— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (grams per cubic centimeter)**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	1.55	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	1.55	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	1.55	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	1.60	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	1.52	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	0.05	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Bulk Density, One-Third Bar (Moe)

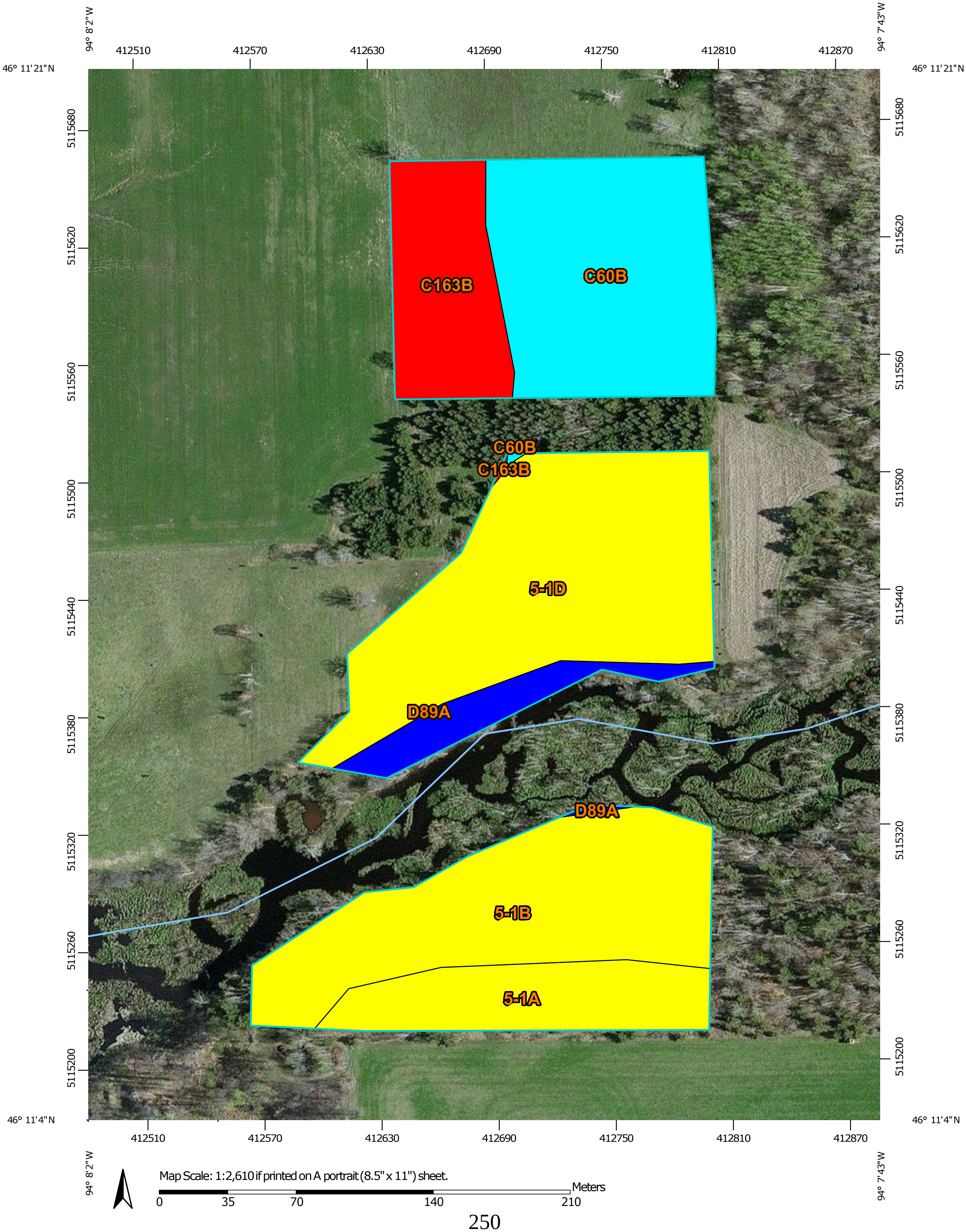
Units of Measure: grams per cubic centimeter
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Saturated Hydraulic Conductivity (Ksat) (Moe)

Saturated hydraulic conductivity (Ksat) refers to the ease with which pores in a saturated soil transmit water. The estimates are expressed in terms of micrometers per second. They are based on soil characteristics observed in the field, particularly structure, porosity, and texture. Saturated hydraulic conductivity is considered in the design of soil drainage systems and septic tank absorption fields.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.

The numeric Ksat values have been grouped according to standard Ksat class limits.



94° 8'2"W
94° 7'43"W
46° 11'21"N
46° 11'4"N
412510
412570
412630
412690
412750
412810
412870
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 28.0000
- > 28.0000 and <= 28.2250
- > 28.2250 and <= 92.0000
- > 92.0000 and <= 423.0000
- Not rated or not available

Soil Rating Lines

- <= 28.0000
- > 28.0000 and <= 28.2250
- > 28.2250 and <= 92.0000
- > 92.0000 and <= 423.0000
- Not rated or not available

Soil Rating Points

- <= 28.0000
- > 28.0000 and <= 28.2250
- > 28.2250 and <= 92.0000
- > 92.0000 and <= 423.0000
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Saturated Hydraulic Conductivity (Ksat) (Moe)

Saturated Hydraulic Conductivity (Ksat)— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (micrometers per second)**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	28.2250	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	28.2250	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	28.2250	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	92.0000	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	28.0000	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	423.0000	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Saturated Hydraulic Conductivity (Ksat) (Moe)

Units of Measure: micrometers per second

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Fastest

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)

Top Depth: 5

Bottom Depth: 10

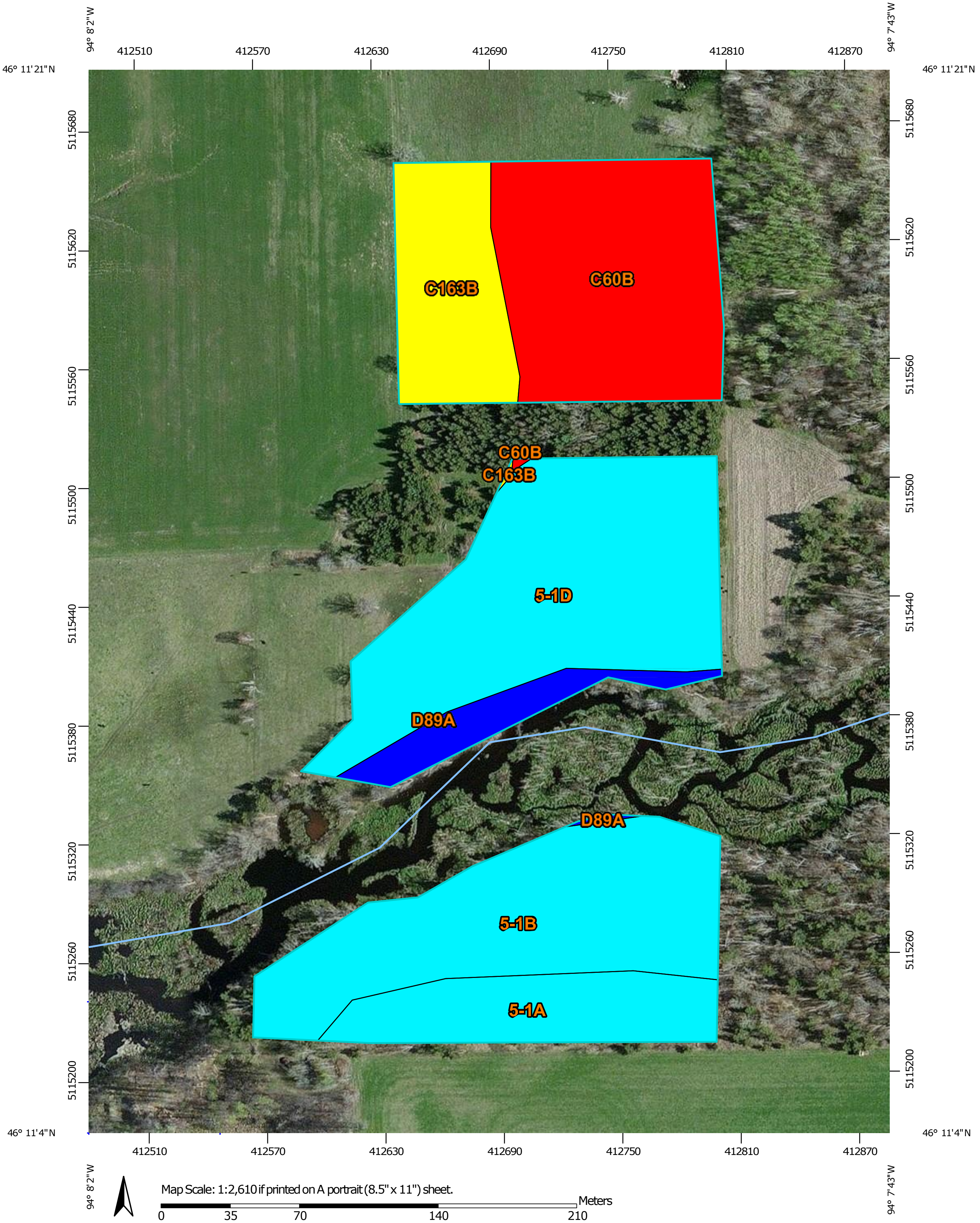
Units of Measure: Centimeters

Available Water Capacity (Moe)

Available water capacity (AWC) refers to the quantity of water that the soil is capable of storing for use by plants. The capacity for water storage is given in centimeters of water per centimeter of soil for each soil layer. The capacity varies, depending on soil properties that affect retention of water. The most important properties are the content of organic matter, soil texture, bulk density, and soil structure, with corrections for salinity and rock fragments. Available water capacity is an important factor in the choice of plants or crops to be grown and in the design and management of irrigation systems. It is not an estimate of the quantity of water actually available to plants at any given time.

Available water supply (AWS) is computed as AWC times the thickness of the soil. For example, if AWC is 0.15 cm/cm, the available water supply for 25 centimeters of soil would be 0.15 x 25, or 3.75 centimeters of water.

For each soil layer, AWC is recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 8'2"W
94° 7'43"W
46° 11'21"N
46° 11'4"N
412510
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412630
412690
412750
412810
412870
5115680
5115620
5115560
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5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.10
- > 0.10 and <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.60
- Not rated or not available

Soil Rating Lines

- <= 0.10
- > 0.10 and <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.60
- Not rated or not available

Soil Rating Points

- <= 0.10
- > 0.10 and <= 0.13
- > 0.13 and <= 0.16
- > 0.16 and <= 0.60
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Available Water Capacity (Moe)

Available Water Capacity— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating (centimeters per centimeter)	Acres in AOI	Percent of AOI
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	0.16	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	0.16	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	0.16	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	0.10	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	0.13	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	0.60	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Available Water Capacity (Moe)

Units of Measure: centimeters per centimeter

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)

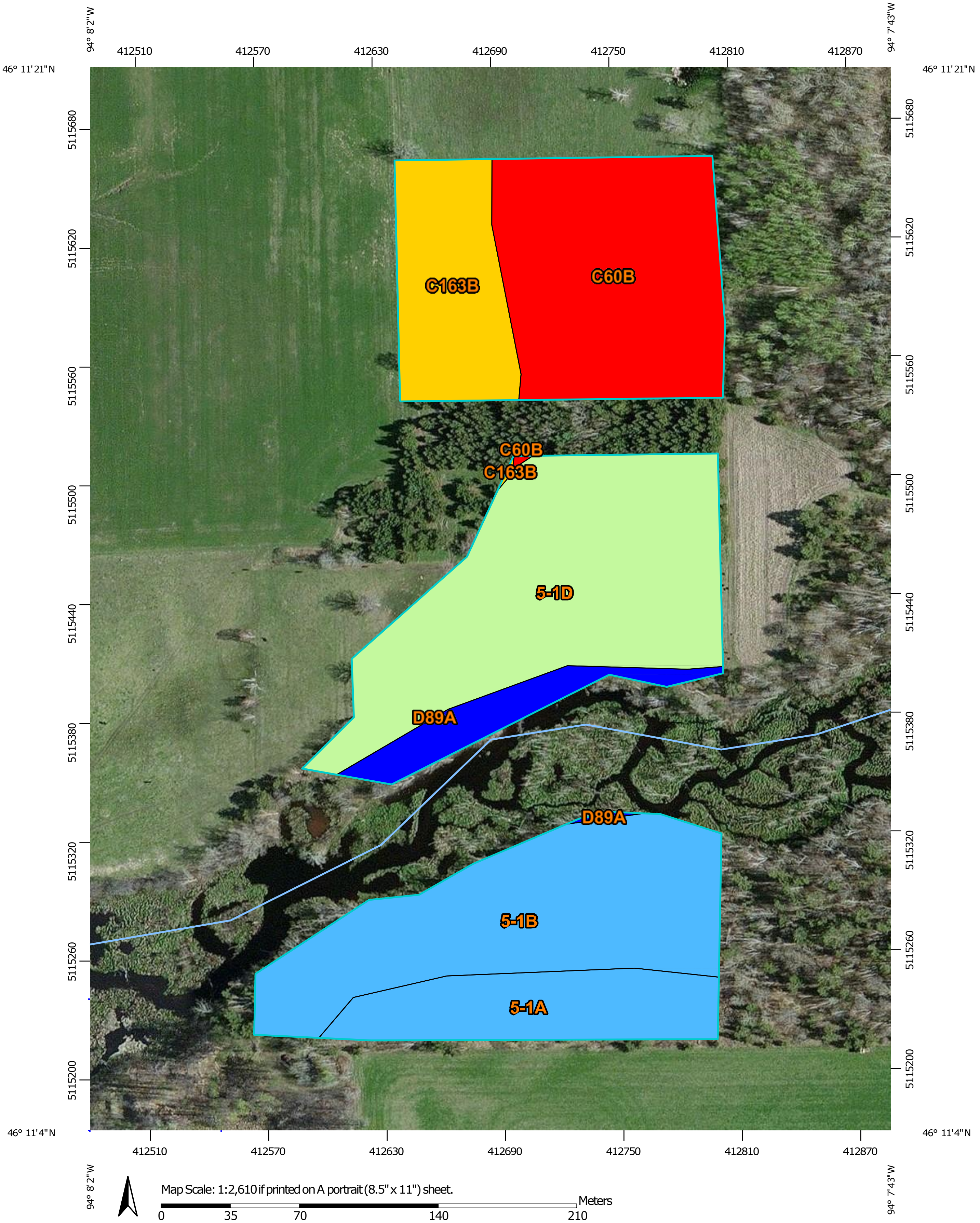
Top Depth: 5

Bottom Depth: 10

Units of Measure: Centimeters

Available Water Storage (Moe)

Accumulates the AWC for a specified depth range. Used to produce data for the muaggatt table.



94° 8'2"W
94° 7'43"W
412510
412570
412630
412690
412750
412810
412870
46° 11'21"N
46° 11'21"N
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5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
46° 11'4"N
46° 11'4"N
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 0.50
- > 0.50 and <= 0.69
- > 0.69 and <= 0.70
- > 0.70 and <= 0.71
- > 0.71 and <= 2.32
- Not rated or not available

Soil Rating Lines

- <= 0.50
- > 0.50 and <= 0.69
- > 0.69 and <= 0.70
- > 0.70 and <= 0.71
- > 0.71 and <= 2.32
- Not rated or not available

Soil Rating Points

- <= 0.50
- > 0.50 and <= 0.69
- > 0.69 and <= 0.70
- > 0.70 and <= 0.71
- > 0.71 and <= 2.32
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Available Water Storage (Moe)

Available Water Storage— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (centimeters per centimeter)**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	0.71	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	0.71	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	0.70	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	0.50	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	0.69	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	2.32	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Available Water Storage (Moe)

Units of Measure: centimeters per centimeter

Aggregation Method: Weighted Average

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Sum)

Top Depth: 5

Bottom Depth: 10

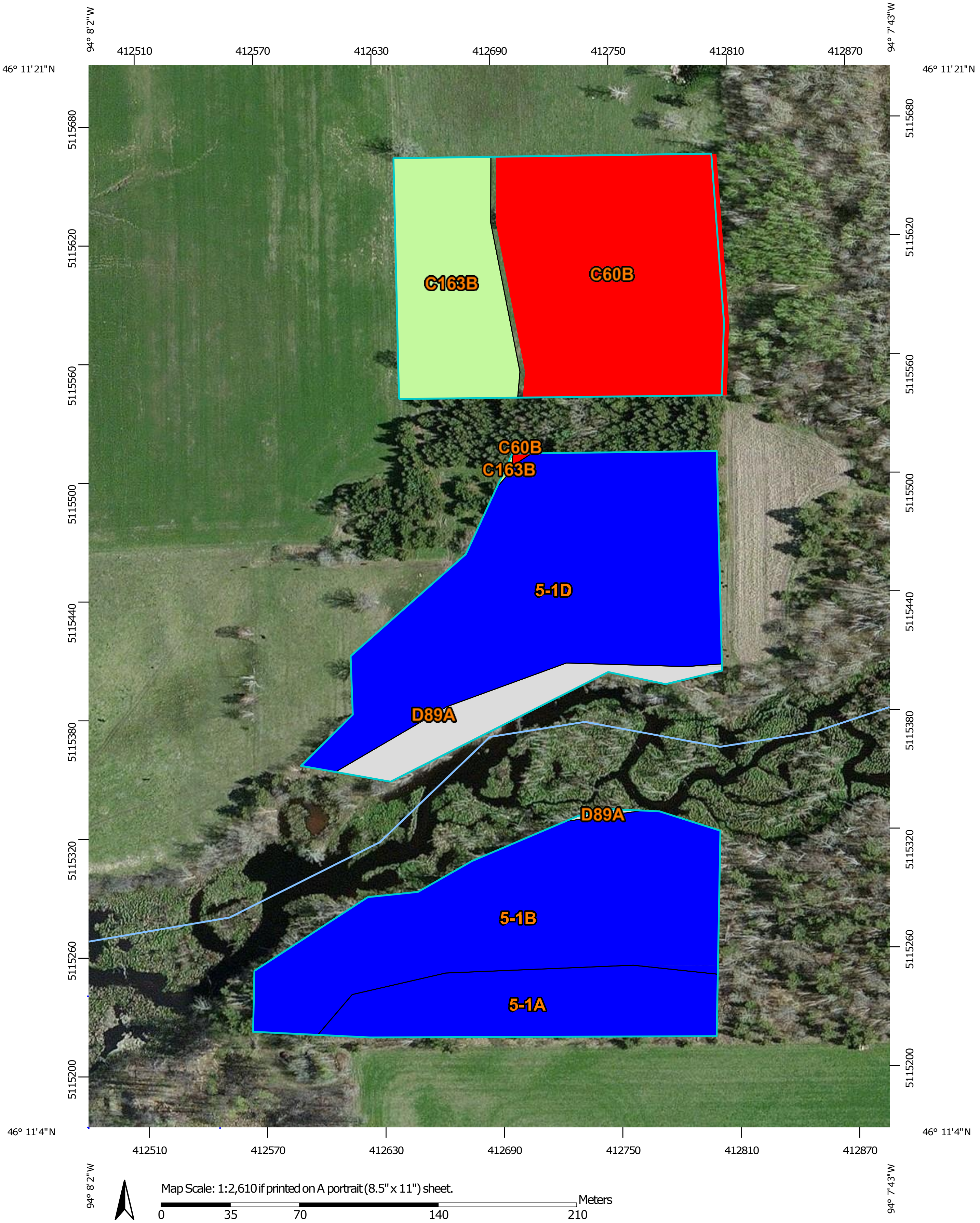
Units of Measure: Centimeters

Percent Clay (Moe)

Clay as a soil separate consists of mineral soil particles that are less than 0.002 millimeter in diameter. The estimated clay content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The amount and kind of clay affect the fertility and physical condition of the soil and the ability of the soil to adsorb cations and to retain moisture. They influence shrink- swell potential, saturated hydraulic conductivity (Ksat), plasticity, the ease of soil dispersion, and other soil properties. The amount and kind of clay in a soil also affect tillage and earth-moving operations.

Most of the material is in one of three groups of clay minerals or a mixture of these clay minerals. The groups are kaolinite, smectite, and hydrous mica, the best known member of which is illite.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


94° 8'2"W
94° 7'43"W
412510
412570
412630
412690
412750
412810
412870
46° 11'21"N
46° 11'4"N
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

<= 6.0

> 6.0 and <= 8.0

> 8.0 and <= 9.0

Not rated or not available

Soil Rating Lines

<= 6.0

> 6.0 and <= 8.0

> 8.0 and <= 9.0

Not rated or not available

Soil Rating Points

<= 6.0

> 6.0 and <= 8.0

> 8.0 and <= 9.0

Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Clay (Moe)

Percent Clay— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (percent)**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	9.0	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	9.0	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	9.0	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	6.0	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	8.0	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded		0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

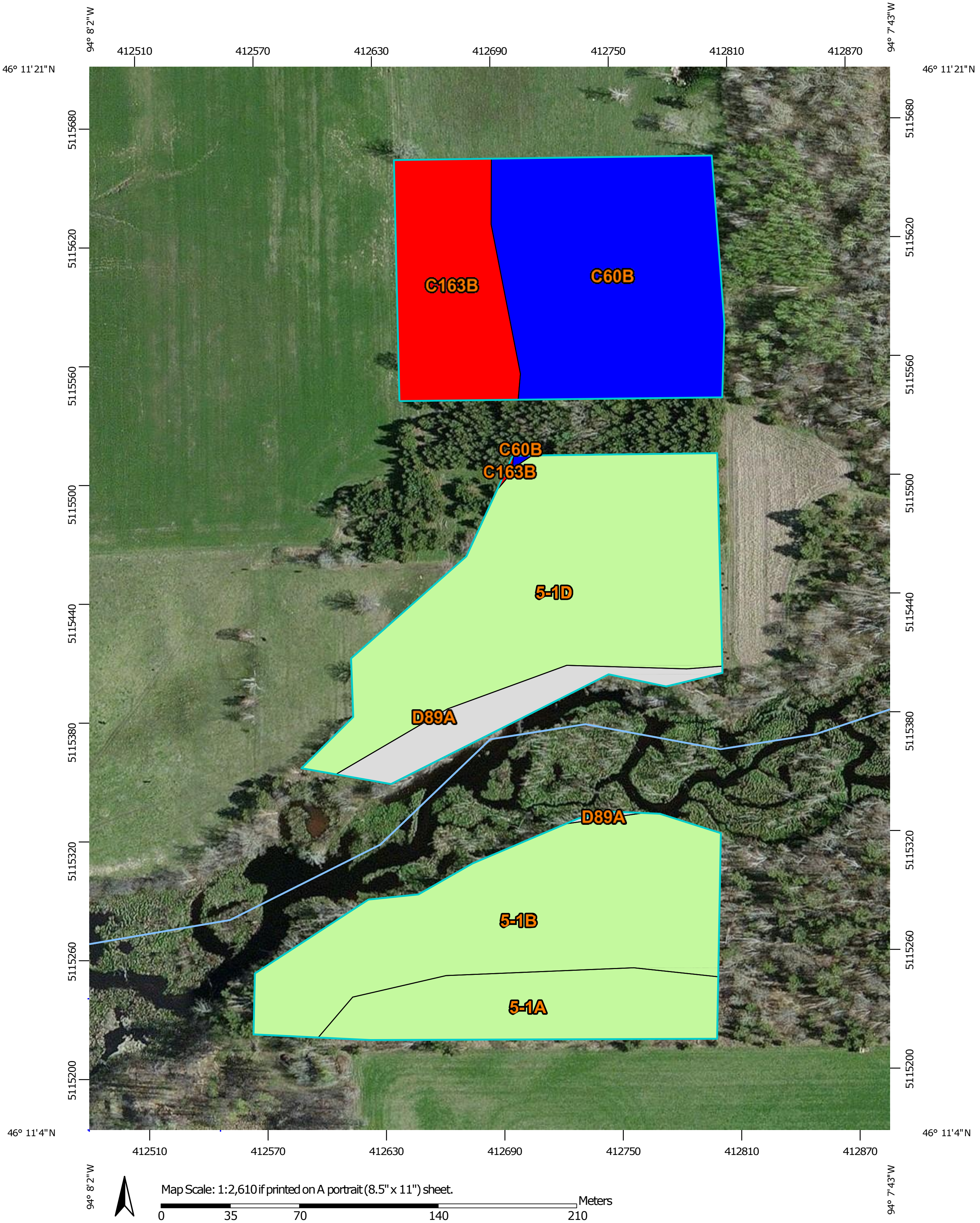
Rating Options—Percent Clay (Moe)

Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None Specified
Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Sand (Moe)

Sand as a soil separate consists of mineral soil particles that are 0.05 millimeter to 2 millimeters in diameter. In the database, the estimated sand content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter. The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


94° 8'2"W
94° 7'43"W
46° 11'21"N
46° 11'4"N
412510
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412690
412750
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412870
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
5-1D
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 63.0
- > 63.0 and <= 69.0
- > 69.0 and <= 78.0
- Not rated or not available

Soil Rating Lines

- <= 63.0
- > 63.0 and <= 69.0
- > 69.0 and <= 78.0
- Not rated or not available

Soil Rating Points

- <= 63.0
- > 63.0 and <= 69.0
- > 69.0 and <= 78.0
- Not rated or not available

Water Features

Streams and Canals

Transportation

Rails

Interstate Highways

US Routes

Major Roads

Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Sand (Moe)

Percent Sand— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	69.0	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	69.0	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	69.0	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	78.0	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	63.0	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded		0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Percent Sand (Moe)

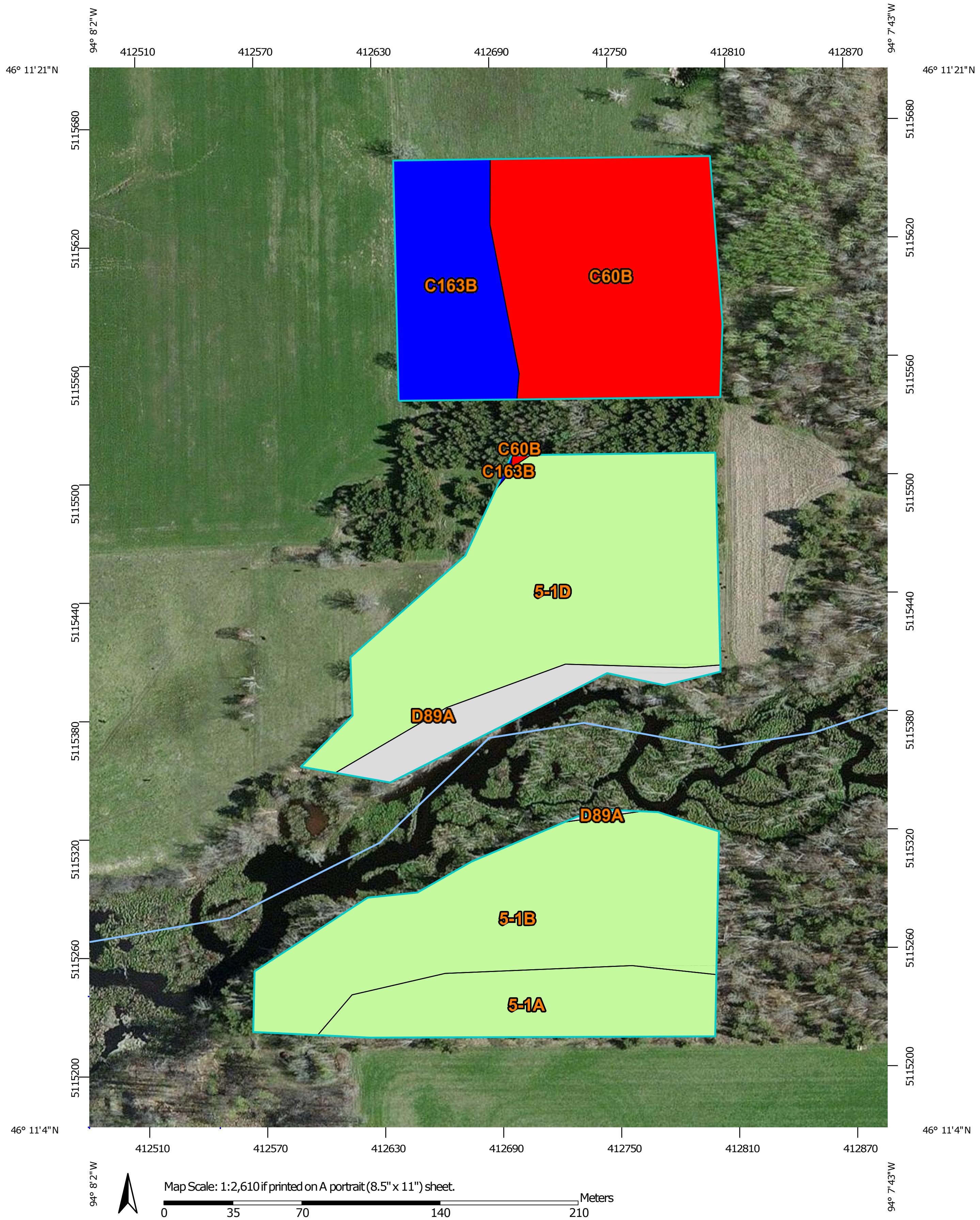
Units of Measure: percent
Aggregation Method: Dominant Component
Component Percent Cutoff: None
Specified Tie-break Rule: Higher
Interpret Nulls as Zero: No
Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)
Top Depth: 5
Bottom Depth: 10
Units of Measure: Centimeters

Percent Silt (Moe)

Silt as a soil separate consists of mineral soil particles that are 0.002 to 0.05 millimeter in diameter. In the database, the estimated silt content of each soil layer is given as a percentage, by weight, of the soil material that is less than 2 millimeters in diameter.

The content of sand, silt, and clay affects the physical behavior of a soil. Particle size is important for engineering and agronomic interpretations, for determination of soil hydrologic qualities, and for soil classification.

For each soil layer, this attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.


94° 8'2"W
94° 7'43"W
46° 11'21"N
46° 11'4"N
412510
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5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- <= 16.0
- > 16.0 and <= 22.0
- > 22.0 and <= 29.0
- Not rated or not available

Soil Rating Lines

- <= 16.0
- > 16.0 and <= 22.0
- > 22.0 and <= 29.0
- Not rated or not available

Soil Rating Points

- <= 16.0
- > 16.0 and <= 22.0
- > 22.0 and <= 29.0
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Percent Silt (Moe)

Percent Silt— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating (percent)	Acres in AOI	Percent of AOI
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	22.0	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	22.0	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	22.0	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	16.0	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	29.0	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded		0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Percent Silt (Moe)

Units of Measure: percent

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Higher

Interpret Nulls as Zero: No

Layer Options (Horizon Aggregation Method): Depth Range (Weighted Average)

Top Depth: 5

Bottom Depth: 10

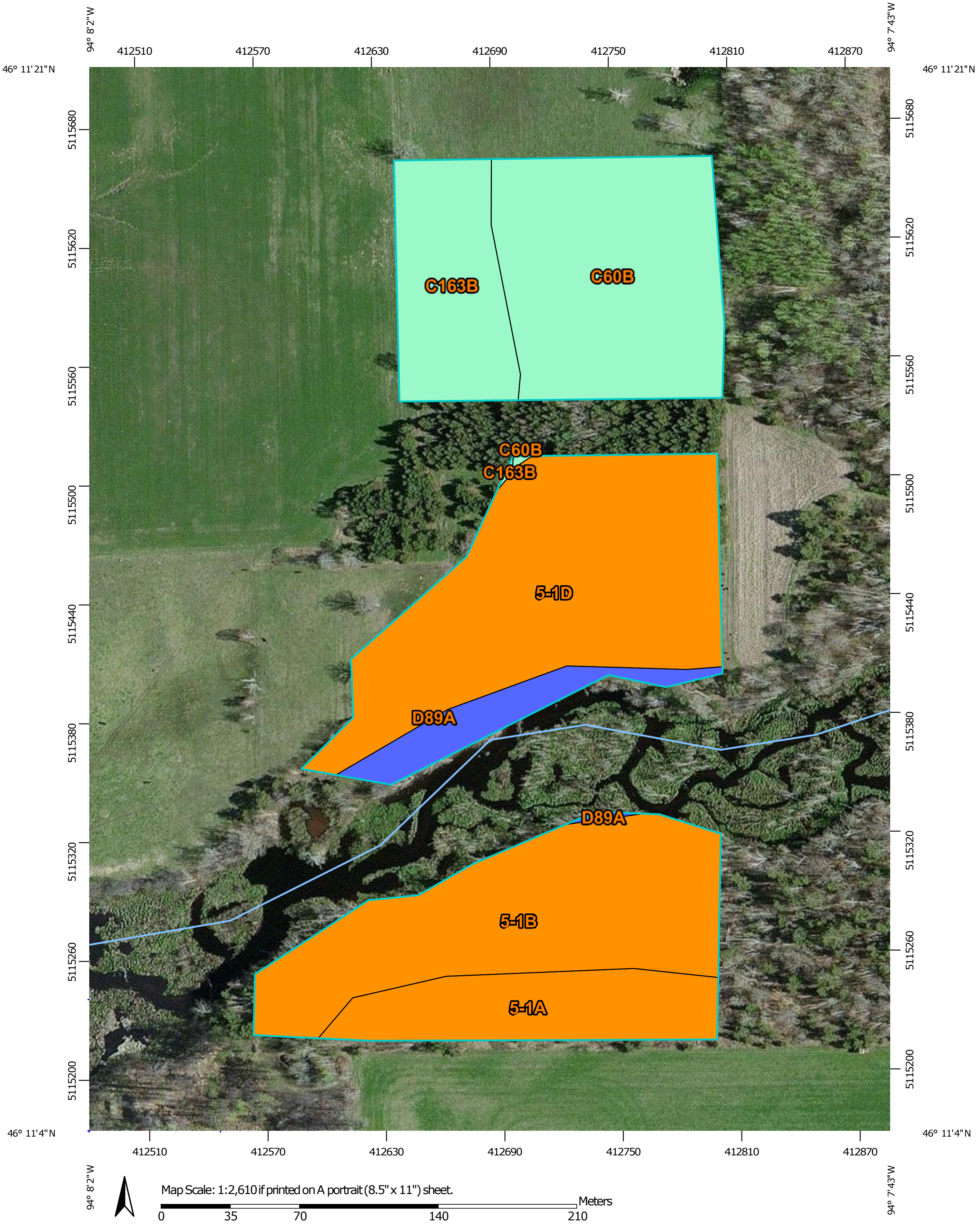
Units of Measure: Centimeters

Soil Qualities and Features

Soil qualities are behavior and performance attributes that are not directly measured, but are inferred from observations of dynamic conditions and from soil properties. Example soil qualities include natural drainage, and frost action. Soil features are attributes that are not directly part of the soil. Example soil features include slope and depth to restrictive layer. These features can greatly impact the use and management of the soil.

Drainage Class (Moe)

"Drainage class (natural)" refers to the frequency and duration of wet periods under conditions similar to those under which the soil formed. Alterations of the water regime by human activities, either through drainage or irrigation, are not a consideration unless they have significantly changed the morphology of the soil. Seven classes of natural soil drainage are recognized-excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained, and very poorly drained. These classes are defined in the "Soil Survey Manual."


94° 8'2"W
94° 7'43"W
412510
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412630
412690
412750
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412870
46° 11'21"N
46° 11'4"N
5115680
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5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Lines

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Soil Rating Points

- Excessively drained
- Somewhat excessively drained
- Well drained
- Moderately well drained
- Somewhat poorly drained
- Poorly drained
- Very poorly drained
- Subaqueous
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Drainage Class (Moe)

Drainage Class— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	Somewhat excessively drained	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	Somewhat excessively drained	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	Somewhat excessively drained	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	Somewhat poorly drained	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	Somewhat poorly drained	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	Very poorly drained	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Drainage Class (Moe)

Aggregation Method: Dominant Condition

Component Percent Cutoff: *None Specified*

Tie-break Rule: Higher

Hydrologic Soil Group (Moe)

Hydrologic soil groups are based on estimates of runoff potential. Soils are assigned to one of four groups according to the rate of water infiltration when the soils are not protected by vegetation, are thoroughly wet, and receive precipitation from long-duration storms.

The soils in the United States are assigned to four groups (A, B, C, and D) and three dual classes (A/D, B/D, and C/D). The groups are defined as follows:

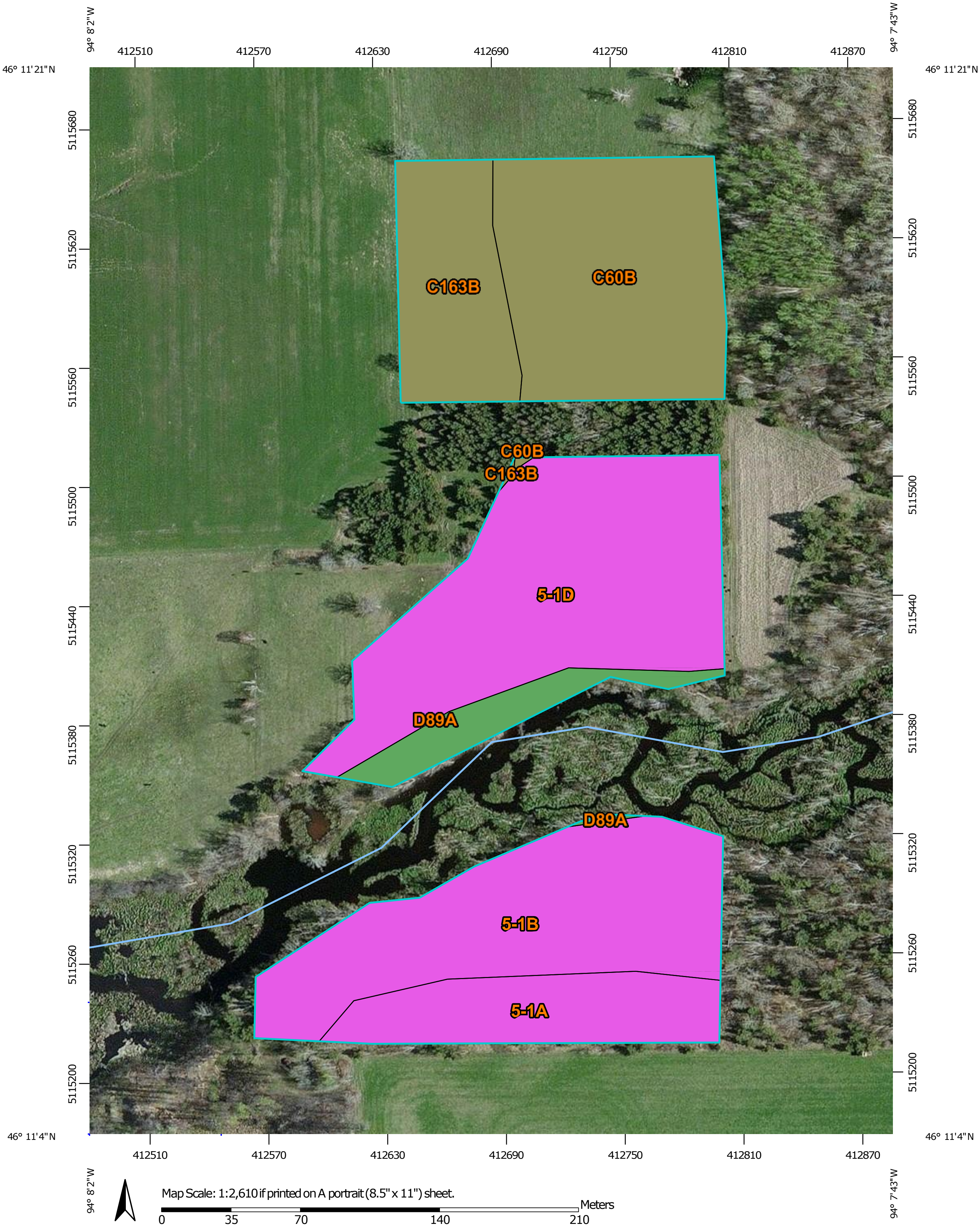
Group A. Soils having a high infiltration rate (low runoff potential) when thoroughly wet. These consist mainly of deep, well drained to excessively drained sands or gravelly sands. These soils have a high rate of water transmission.

Group B. Soils having a moderate infiltration rate when thoroughly wet. These consist chiefly of moderately deep or deep, moderately well drained or well drained soils that have moderately fine texture to moderately coarse texture. These soils have a moderate rate of water transmission.

Group C. Soils having a slow infiltration rate when thoroughly wet. These consist chiefly of soils having a layer that impedes the downward movement of water or soils of moderately fine texture or fine texture. These soils have a slow rate of water transmission.

Group D. Soils having a very slow infiltration rate (high runoff potential) when thoroughly wet. These consist chiefly of clays that have a high shrink-swell potential, soils that have a high water table, soils that have a claypan or clay layer at or near the surface, and soils that are shallow over nearly impervious material. These soils have a very slow rate of water transmission.

If a soil is assigned to a dual hydrologic group (A/D, B/D, or C/D), the first letter is for drained areas and the second is for undrained areas. Only the soils that in their natural condition are in group D are assigned to dual classes.



94° 8'2"W
94° 7'43"W
412510
412570
412630
412690
412750
412810
412870
46° 11'21"N
46° 11'4"N
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Lines

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Soil Rating Points

- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil Survey Area: Crow Wing County, Minnesota
Survey Area Data: Version 10, Sep 18, 2015

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Hydrologic Soil Group (Moe)

Hydrologic Soil Group— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	A	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	A	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	A	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	C/D	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	C/D	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	A/D	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Hydrologic Soil Group (Moe)

Aggregation Method: Dominant Condition

Component Percent Cutoff: None

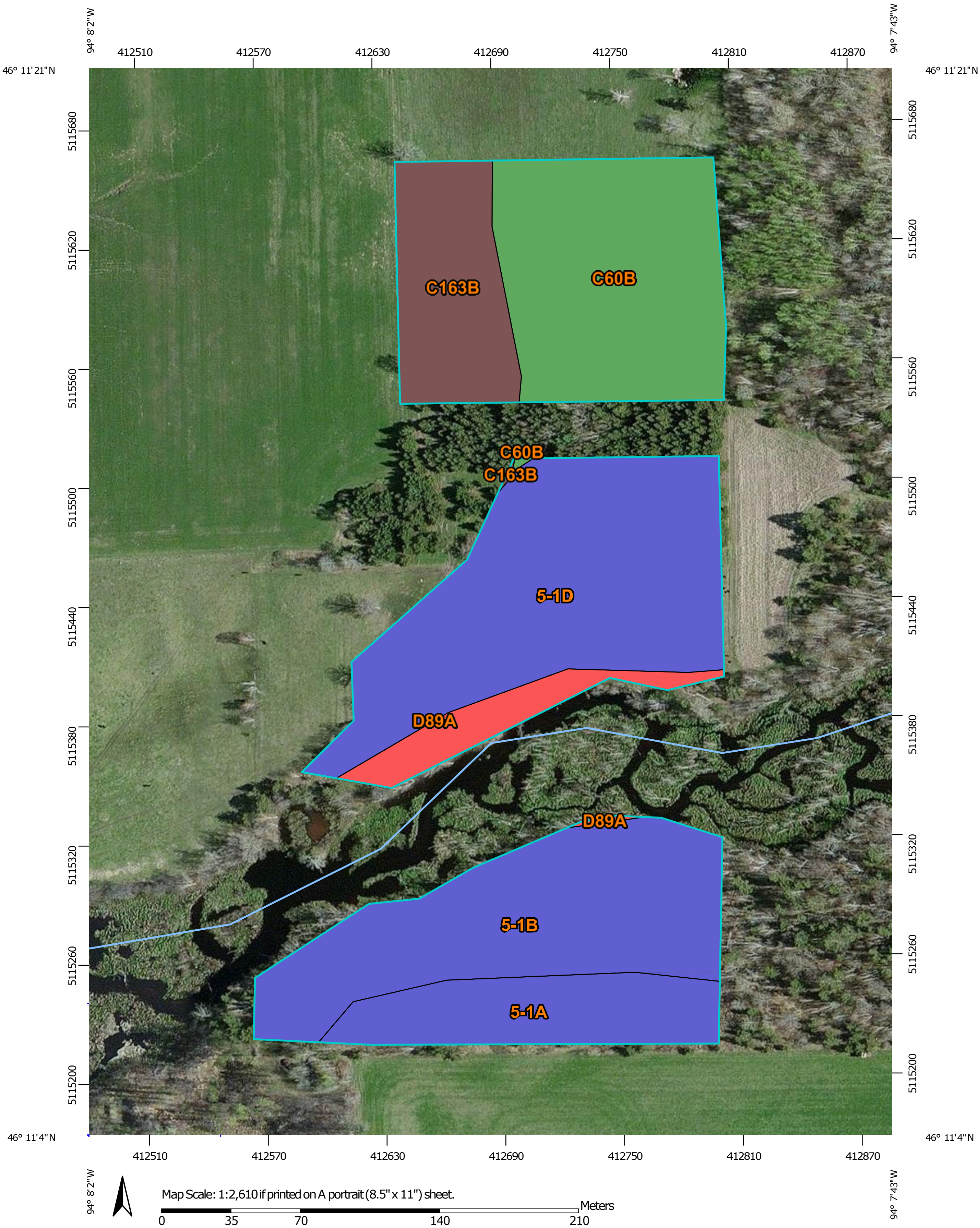
Specified Tie-break Rule: Higher

Parent Material Name (Moe)

Parent material name is a term for the general physical, chemical, and mineralogical composition of the unconsolidated material, mineral or organic, in which the soil forms. Mode of deposition and/or weathering may be implied by the name.

The soil surveyor uses parent material to develop a model used for soil mapping. Soil scientists and specialists in other disciplines use parent material to help interpret soil boundaries and project performance of the material below the soil. Many soil properties relate to parent material. Among these properties are proportions of sand, silt, and clay; chemical content; bulk density; structure; and the kinds and amounts of rock fragments. These properties affect interpretations and may be criteria used to separate soil series. Soil properties and landscape information may imply the kind of parent material.

For each soil in the database, one or more parent materials may be identified. One is marked as the representative or most commonly occurring. The representative parent material name is presented here.



94° 8'2"W
94° 7'43"W
46° 11'21"N
46° 11'4"N
412510
412570
412630
412690
412750
412810
412870
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

Area of Interest (AOI)

Soils

Soil Rating Polygons

- coarse-loamy glaciofluvial deposits over sandy and gravelly outwash
- dense lodgment till
- herbaceous organic material over outwash
- sandy outwash over dense lodgment till
- Not rated or not available

Soil Rating Lines

- coarse-loamy glaciofluvial deposits over sandy and gravelly outwash
- dense lodgment till
- herbaceous organic material over outwash
- sandy outwash over dense lodgment till
- Not rated or not available

Soil Rating Points

- coarse-loamy glaciofluvial deposits over sandy and gravelly outwash
- dense lodgment till
- herbaceous organic material over outwash
- sandy outwash over dense lodgment till
- Not rated or not available

Water Features

Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

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Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: Web Mercator (EPSG:3857)

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Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Data not available.

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table—Parent Material Name (Moe)

Parent Material Name— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	coarse-loamy glaciofluvial deposits over sandy and gravelly outwash	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	coarse-loamy glaciofluvial deposits over sandy and gravelly outwash	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	coarse-loamy glaciofluvial deposits over sandy and gravelly outwash	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	sandy outwash over dense lodgment till	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	dense lodgment till	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	herbaceous organic material over outwash	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Parent Material Name (Moe)

Aggregation Method: Dominant
Condition *Component Percent Cutoff:*
None Specified Tie-break Rule: Lower

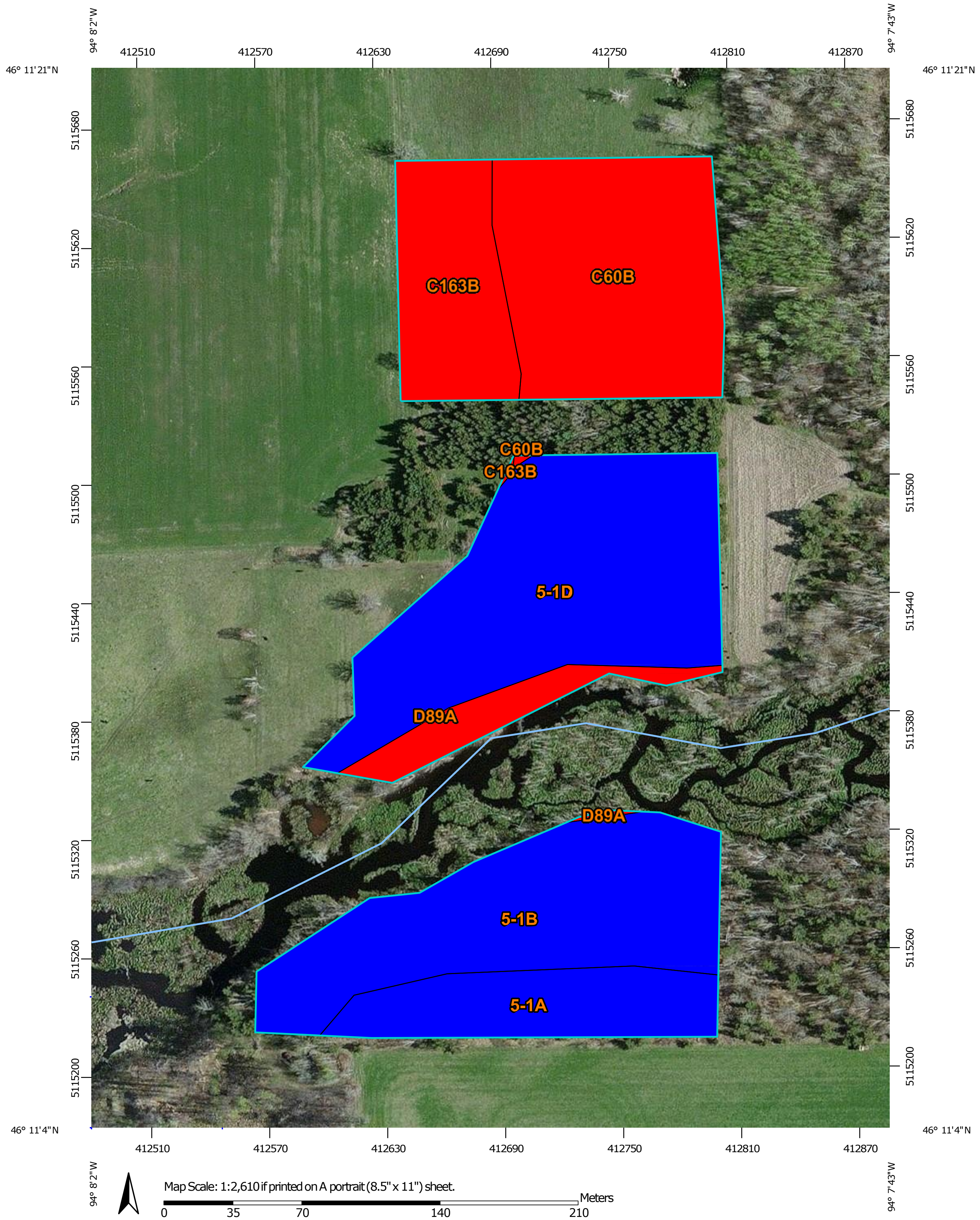
Water Features

Water Features include ponding frequency, flooding frequency, and depth to water table.

Depth to Water Table (Moe)

"Water table" refers to a saturated zone in the soil. It occurs during specified months. Estimates of the upper limit are based mainly on observations of the water table at selected sites and on evidence of a saturated zone, namely grayish colors (redoximorphic features) in the soil. A saturated zone that lasts for less than a month is not considered a water table.

This attribute is actually recorded as three separate values in the database. A low value and a high value indicate the range of this attribute for the soil component. A "representative" value indicates the expected value of this attribute for the component. For this soil property, only the representative value is used.



94° 8'2"W
94° 7'43"W
412510
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412630
412690
412750
412810
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46° 11'21"N
46° 11'4"N
5115680
5115620
5115560
5115500
5115440
5115380
5115320
5115260
5115200
C163B
C60B
C60B
C163B
5-1D
D89A
D89A
5-1B
5-1A
Map Scale: 1:2,610 if printed on A portrait (8.5" x 11") sheet.
Meters
0
35
70
140
210

MAP LEGEND

Area of Interest (AOI)

- Area of Interest (AOI)

Soils

Soil Rating Polygons

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Soil Rating Lines

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Soil Rating Points

- 0 - 25
- 25 - 50
- 50 - 100
- 100 - 150
- 150 - 200
- > 200
- Not rated or not available

Water Features

- Streams and Canals

Transportation

- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background

- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:24,000.

Warning: Soil Map may not be valid at this scale.

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Coordinate System: Web Mercator (EPSG:3857)

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Date(s) aerial images were photographed: Data not available.

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Table—Depth to Water Table (Moe)

Depth to Water Table— Summary by Map Unit — Crow Wing County, Minnesota (MN035)				
Map unit symbol	**Map unit name**	**Rating (centimeters)**	**Acres in AOI**	**Percent of AOI**
5-1A	Chetek-Graycalm complex, 0 to 2 percent slopes	>200	1.5	10.1%
5-1B	Chetek-Graycalm complex, 2 to 6 percent slopes	>200	3.5	23.3%
5-1D	Chetek-Graycalm complex, 6 to 12 percent slopes	>200	4.4	29.0%
C60B	Bushville loamy sand, Rainy till phase, 0 to 3 percent slopes	15	3.3	22.1%
C163B	Brainerd sandy loam, 1 to 4 percent slopes	15	1.6	10.9%
D89A	Lougee-Totagatic-Bowstring complex, 0 to 1 percent slopes, frequently flooded	0	0.7	4.5%
Totals for Area of Interest			**15.0**	**100.0%**

Rating Options—Depth to Water Table (Moe)

Units of Measure: centimeters

Aggregation Method: Dominant Component

Component Percent Cutoff: None Specified

Tie-break Rule: Lower

Interpret Nulls as Zero: No

Beginning Month: January

Ending Month: December

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Appendix B: Soil Infiltration and Soil Moisture Content Data

Table 1. Booth Soil Moisture Content, Initial and Final

	Fall 2013		Spring 2014		Fall 2014		Fall 2015		Spring 2016	
Test Loc	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)
BOP1	21.68	51.72	25.62	25.91	24.08	41.97	13.31	27.28	22.64	39.26
BOP2	13.49	38.72	26.52	55.49	11.26	34.62	15.07	24.31	23.37	36.08
BOP3	18.97	21.09	19.81	24.77	12.38	47.69	24.03	32.58	31.16	53.11
BOP4	25.06	37.30	20.70	25.34	14.98	36.47	17.96	20.75		
BOP5	21.33	39.44	16.54	23.43	18.29	44.24	17.21	31.79		
BSV1	14.58	44.76	28.82	42.69	21.80	47.45	21.12	39.41	26.75	72.85
BSV2	35.81	43.90	42.35	66.27	24.86	17.43	15.07	15.16	32.97	65.09
BSV3	19.79	35.47	33.96	45.14	23.31	33.81	29.58	27.59	28.62	52.37
BSV4	24.29	43.49	32.30	25.63	30.04	46.22	21.30	33.40		
BSV5	31.82	38.21	36.47	53.05	46.96	69.18	18.36	19.49	57.11	115.21
BTF1	45.62	30.31	34.56	57.05	29.95	32.77	21.67	48.85		
BTF2	34.84	25.60	54.13	41.50	27.11	54.32	16.76	21.60	50.29	73.64
BTF3	27.67	6.00	62.74	66.67	16.08	34.31	21.88	26.91	49.19	90.10
BTF4	46.66	29.38	22.79	18.07	54.26	26.39	22.54	30.76	45.35	42.40
BTF5	13.38	33.44	35.00	33.81	57.43	117.61	18.31	28.37	22.73	34.12

Table 2. Caughey Soil Moisture Content, Initial and Final

	Fall 2013		Spring 2014		Fall 2014		Fall 2015		Spring 2016	
Test Loc	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)	Soil Moisture Initial (%)	Soil Moisture Final (%)
COP1	65.99	72.30	25.34	47.97	25.51	34.09	21.92	31.03	46.40	20.65
COP2	26.10	33.64	80.27	48.53	40.65	32.13	30.71	45.59	54.10	38.24
COP3	29.01	96.55	35.80	35.90	60.68	59.58	15.36	46.02	79.70	61.89
COP4	70.24	84.46	24.76	15.48	22.84	22.90	21.36	24.20	43.63	55.88
COP5	81.90	187.41	38.28	34.08	28.26	18.80	22.02	27.09	26.82	28.22
CSV1	24.08	19.69	33.39	50.51	15.35	47.84	22.39	54.00	35.20	31.40
CSV2	115.15	174.28	60.73	46.95	37.48	42.79	28.28	40.26	102.69	115.73
CSV3	32.82	34.32	33.81	615.82	21.32	68.27	25.05	37.88	47.37	48.40
CSV4	35.32	19.34	55.80	21.43	25.89	71.19	74.80	117.48	103.96	139.51
CSV5	141.67	285.45	47.53	67.50	99.39	121.50	21.62	35.70	55.91	74.41
CTF1	20.64	23.10	12.83	35.12	21.30	21.93	25.32	62.21	25.60	47.76
CTF2	25.18	39.68	33.45	60.63	32.06	67.48	26.01	35.04	55.58	87.53
CTF3	30.04	57.60	38.02	40.82	42.67	51.08	38.53	91.57	48.94	64.05
CTF4	27.80	40.17	33.40	43.71	28.65	60.98	25.68	37.18	40.48	64.34
CTF5	27.02	38.63	45.07	59.46	28.35	35.89	31.05	66.45	41.05	76.95

Table 3. Moe Soil Moisture Content, Initial and Final

	Fall 2013		Spring 2014		Fall 2014		Fall 2015	
Test Loc	**Soil Moisture Initial (%)**	**Soil Moisture Final (%)**	**Soil Moisture Initial (%)**	**Soil Moisture Final (%)**	**Soil Moisture Initial (%)**	**Soil Moisture Final (%)**	**Soil Moisture Initial (%)**	**Soil Moisture Final (%)**
MOP1	21.32	21.71	6.92	34.79	5.21	23.30	6.96	23.19
MOP2	11.72	18.78	23.57	39.90	21.84	30.71	15.13	23.00
MOP3	20.84	21.00	11.46	32.80	19.20	30.72	13.21	26.02
MOP4	16.42	32.38	21.33	25.17	17.18	25.84	15.47	16.83
MOP5	6.25	20.33	18.32	28.33	10.37	29.59	11.74	23.07
MSV1	14.01	23.19	52.12	78.09	23.46	25.25	4.58	23.04
MSV2	17.30	18.22	12.24	31.29	11.71	22.01	12.23	16.46
MSV3	12.15	30.33	9.86	28.72	9.56	26.65	9.20	20.38
MSV4	47.66	40.67	15.64	27.40	9.75	31.71	8.29	21.31
MSV5	14.66	41.13	56.32	47.94	9.24	99.21	6.95	42.08
MTF1	31.82	27.94	26.52	60.57	28.76	41.26	9.47	21.22
MTF2	17.68	57.12	21.73	55.40	19.49	37.68	10.64	23.97
MTF3	33.50	45.61	14.74	46.00	22.06	60.92	10.02	22.21
MTF4	26.59	33.21	7.66	24.20	10.67	45.05	15.75	20.42
MTF5	27.54	36.59	43.40	38.70	45.53	61.71	11.57	25.45

Table 4. Booth Open Pasture Soil Infiltration Raw Data

	Booth Open Pasture: Fall 2013					Booth Open Pasture: Spring 2014					Booth Open Pasture: Fall 2014					Booth Open Pasture: Fall 2015					Booth Open Pasture: Spring 2016		
Time (sec)	BOP1	BOP2	BOP3	BOP4	BOP5	BOP1	BOP2	BOP3	BOP4	BOP5	BOP1	BOP2	BOP3	BOP4	BOP5	BOP1	BOP2	BOP3	BOP4	BOP5	BOP1	BOP2	BOP3
0	31.2	29	30	29.7	30.5	30.2	30.4	30	30	30.0	30	30	31	32	32.5	27	30	29	29.5	30	31.7	27.1	28
30		28.7				30	30.3	29.6	30	29.7	29.4	30	30.7	31.8	31.4	27	30	28.9	29	30			
60	31.2	28	29.5	29.5	30.5	29.9	30.2	29.4	29.9	29.2	29	29.9	30.6	31.7	31.1	27	30	28.9	28.7	30	31.4	27	27.8
90						29.7	30.1	29.2	29.8	28.8		29.5	30.5	31.7	31	26.5	29.6	28.8	28.6	30			
120	31.2	27.2	29	29.4	30.5	29.6	30	27.8	29.7	28.5	28.6	29.1	30.3	31.7	30.8	26.5	29.3	28.8	28.5	29.5	31.1		
150						29.4	30	27.4	29.6	28.3		28.8	30.2	31.7	30.5	26.5	29.2	28.8	28.2	29.25			
180	30.9	26.5	28.2	29.3	30.5	29.3	29.9	26.9	29.5	28.1	28.5	28.4	30.1	31.7	30.3	26.25	29	28.8	28.1	29	30.7	26.8	27.6
210						29.2	29.8	26.5	29.4	27.8		28.1	30		30.2	26	28.9	28.8	28	28.5			
240	30.9	25.9	27.7	29.2	30.5	29.1	29.8	26	29.3	27.5	28.4	28	30	31.6	30.1	25.75	28.6	28.8	27.9	28.5	30.5		
270						29.1	29.7	25.5	29.2	27.3		27.7	29.8		30	25.5	28.4	28.8	27.8	28			
300	30.9	25	27.4	29.1	30.5	29	29.6	25	29.1	27.1	28.3	27.4	29.7	31.6	29.8	25.5	28	28.8	27.6	27.5	30.3	26.7	27.5
330						28.9	29.5	24.4	29	26.9		27.2	29.6		29.6	25.25	27.7	28.8	27.6	27.5			
360	30.8	24.5	27	29	30.5	28.9	29.4	24.2	28.9	26.6	28.2	27	29.5	31.5	29.4	25	27.3	28.8	27.4	27.25	30		
390						28.8	29.3	23.7	28.8	26.4		26.8	29.4		29.2	24.75	27	28.8	27.3	27			
420	30.7	23.9	26.8	28.9	30.5	28.7	29.2	23.3	28.7	26.3	28	26.7	29.3	31.4	29.1	24.75	26.9	28.8	27.1	26.75	29.8		27.4
450						28.6	29.1	22.8	28.6	25.9		26.5	29.3		29	24.5	26.7	28.8	27	26.5			
480	30.6	23	26.4	28.8	30.5	28.5	29	22.4	28.5	25.8	27.9	26.3	29.2	31.4	28.8	24.25	26.5	28.8	27	26.25	29.6	26.6	
510						28.5	28.9	22	28.4	25.5		26.1	29.1		28.6	24.25	26.3	28.8	26.8	26			
540	30.5	22.5	26.2	28.7	30.5	28.3	28.8	21.6	28.3	25.3	27.8	26	29	31.3	28.5	24	26.1	28.7	26.5	25.75	29.3		27.3

570						28.3	28.6	21.1	282	25.2		25.8	28.9		28.4	24	25.7	28.6	26.3	25.5			
600	30.5	22	26	28.6	30.3	28.1	28.5	20.8	28.1	25.1	27.6	25.5	28.8	31.3	28.3	23.75	25.5	28.6	26.3	25.25	29.2		
630						28.1	28.4	20.2	27.9	24.9		25.3	28.8		28.1	23.5	25.2	28.5	26.1	25			
660	30.5	21.3	25.7	28.5	30.2	28	28.3	19.9	27.8	24.7	27.5	25.2	28.7	31.3	27.9	23.5	25	28.5	26.1	24.75	29		
690						28	28.2	19.5	27.8	24.5		25	28.6		27.8	23	24.7	28.5	26.1	24.5			
720	30.4	20.8	25.4	28.4	30.1	27.9	28.1	19	27.8	24.4	27.4	24.9	28	31.2	27.7	23	24.5	28.5	26	24.25	28.7	26.5	
750						27.8	28	18.8	27.7	24.3		24.8	28.4		27.5	23	24.3	28.5	25.9	24			
780	30.4	20	25	28.3	30	27.7	27.8	18.3	27.6	24.2	27.2	24.6	28.3	31.2	27.4	22.75	24	28.5	28.7	23.5	28.5		27.1
810						27.6	27.7	18	27.5	23.9		24.4	28.2		27.3	22.5	23.9	28.4	25.6	23.5			
840	30.3	19.5	24.8	28.2	30	27.6	27.6	17.6	27.3	23.5	27.1	24.3	28.1	31.2	27.2	22.5	23.7	28.4	25.5	23.25	28.3	26.4	26.8
870						27.5	27.5	17.1	27.2	23.4		24.1	28.1		27	22.25	23.5	28.4	25.4	23			
900	30.3	19	24.5	28.2	30	27.5	27.4	16.8	27.1	23.3	27	23.9	28	31.15	26.9	22.25	23.3	28.4	25.3	22.75	28.2		
930						27.4	27.3	16.5	27	23.0		23.8	28		26.8	22	23	28.4	25.1	22.5			
960	30.2	18.4	24.2	28.1	29.9	27.4	27.2	16	26.9	22.9	26.9	23.5	27.9	31.1	26.6	21.75	22.8	28.4	25	22.25	27.9	26.3	26.6
990						27.3	27.1	15.7	26.9	22.7		23.4	27.8		26.5	21.5	22.5	28.4	24.8	22			
1020	30	17.9	23.7	28	29.9	27.1	27	15.4	26.8	22.5	26.8	23.3	27.7	31.1	26.4	21.5	22.3	28.3	24.8	21.75	27.7		
1050						27	26.9	15.1	26.6	22.4		23.1	27.6		26.3	21.5	22.1	28.3	24.6	21.5			
1080	30	17.2	23.4	27.9	29.9	27	26.7	14.8	26.5	22.3	26.6	22.9	27.5	31.05	26.1	21.25	21.9	28.3	24.5	21.22	27.5		26.4
1110						26.9	26.5	14.4	26.4	22.0		22.8	27.5	31	26	21	21.8	28.3	24.2	21			
1140	30	16.7	23.2	27.8	29.9	26.8	26.4	14	26.4	21.9	26.5	22.6	27.3	31	25.8	21	21.7	28.3	24.2	21	27.3	26.2	
1170						26.8	26.3	13.8	26.3	21.7		22.5	27.3		25.8	20.75	21.5	28.3	24.1	20.75			
1200	29.9	16.2	22.9	27.7	29.9	26.7	26.2	13.4	26.2	21.5	26.4	22.3	27.2	31	25.7	20.5	21.3	28.2	24	20.5	27.1		
1230						26.6	26.1	13.1	26.1	21.4		22.1	27.1		25.5	20.5	21	28.2	23.8	20.25			
1260	29.8	15.9	22.6	27.7	29.8	26.6	26	12.8	26	21.3	26.3	22	27.1	30.9	25.4	20.25	20.8	28.1	23.8	20	26.9		26
1290						26.5	26	12.3	25.9	21.1		21.8	27		25.3	20	20.6	28.1	23.7	19.75			

1320	29.8	15	22.4	27.6	29.8	26.4	25.9	12	25.8	20.9	26.2	21.8	27	30.9	25.2	20	20.4	28.1	23.6	19.5	26.7		
1350						26.4	25.8	11.8	25.7	20.7		21.7	26.8		25	19.75	20.2	28.1	23.5	19.5			
1380	29.7	14.8	22.1	27.5	29.8	26.3	25.7	11.4	25.6	20.5	26.1	21.5	26.8	30.8	24.9	19.5	20	28	23.4	19.25	26.5	26.1	25.9
1410						26.3	25.6	11.1	25.5	20.4		21.4	26.7		24.8	19.5	19.8	28	23.3	19			
1440	29.6	14	22	27.4	29.7	26.3	25.5	10.8	25.4	20.2	26	21.2	26.6	30.8	24.7	19.5	19.6	28	23.2	18.75	26.3		
1470						26.2	25.4	10.5	25.4	20.0		21.1	26.6		24.6	19.5	19.4	28	23.1	18.5			
1500	29.5	13.8	21.6	27.3	29.7	26.1	25.3	10	25.4	19.8	25.9	20.9	26.5	30.7	24.6	19	19.3	28	23	18.5	26.1	26	25.8
1530						26.1	25.2	9.7	25.3	19.7		20.8	26.4		24.5	19	19	28	22.8	18.25			
1560	29.5	13.4	21.3	27.2	29.6	26	25.1	9.5	25.2	19.5	25.7	20.7	26.3	30.7	24.3	19	18.8	27.9	22.8	18	25.9	26	
1590						25.9	25	9.2	25.1	19.4		20.5	26.3		24.2	18.5	18.5	27.9	22.4	17.75			
1620	29.4	13	21	27.1	29.6	25.7	24.8	8.8	25	19.3	25.6	20.3	26.2	30.7	24.1	18.5	18.4	27.9	22.4	17.5	25.7		25.7
1650						25.6	24.7	8.7	25	19.2		20.3	26.1		23.9	18.5	18.2	27.9	22.3	17.25			
1680	29.4	12.4	20.8	27	29.6	25.5	24.7	8.5	24.9	19.0	25.5	20.2	26	30.6	23.9	18.25	18	27.9	22.3	17.25	25.5	26	25.6
1710						25.5	24.6	8.1	24.9	18.8		20.1	26		23.8	18	17.8	27.9	22.2	17			
1740	29.4	12	20.5	26.9	29.5	25.4	24.6	8	24.8	18.6	25.4	20	25.9	30.6	23.7	18	17.7	27.8	22.2	16.75	25.3	25.9	25.5
1770						25.4	24.5	7.7	24.7	18.5		19.8	25.8		23.5	17.75	17.5	27.8	22.1	16.5			
1800	29.3	11.5	20.2	26.8	29.4	25.3	24.4	7.5	24.7	18.3	25.3	19.7	25.7	30.6	23.4	17.5	17.3	27.8	22	16.5	25.1	25.9	25.4

Table 5. Booth Silvopasture Soil Infiltration Raw Data

	Booth Silvopasture: Fall 2013					Booth Silvopasture: Spring 2014					Booth Silvopasture: Fall 2014					Booth Silvopasture: Fall 2015					Booth Silvopasture: Spring 2016			
Time (sec)	BSV1	BSV2	BSV3	BSV4	BSV5	BSV1	BSV2	BSV3	BSV4	BSV5	BSV1	BSV2	BSV3	BSV4	BSV5	BSV1	BSV2	BSV3	BSV4	BSV5	BSV1	BSV2	BSV3	BSV5
0	30.5	30	30.3	30.5	30.2	26.5	31	30	30	30.0	30.6	30	33.7	34	31.7	29	29.5	29	30	29.5	30.0	30.5	30.8	30.0
30				30.4		25	30	29.5	30	29.7	29.1	30	33.5	33.1	30.8	29	29	28.8	29.5	29.4				

60	29.7	30	30.3	30	30.2	24	29.6	29.3	30	29.6	28	29.9	33.5	32.5	30.4	29	28.9	28.4	29.5	29.3	29.7	30.4	30.4	29.8
90						23.5	29.2	29.2	30	29.3	27.8	29.9	33.3	32.4	29.8	29	28.8	27.8	29	29.3				
120	29.2	30	30.3	29.5	30.2	22.8	28.9	29.2	30	29.0	27.2	29.9	33.2	32	29.1	29	28.8	27.4	28.75	29.3	29.5			
150						21.8	28.8	29.1	30	28.7	26.2	29.9	33	31.7	28.4	29	28.7	26.9	28.5	29.2				
180	28.8	30	30.2	29.1	30.2	21.5	28.4	28.9	30	28.5	25.5	29.9	32.9	30.2	27.9	28.9	28.7	26.4	28.25	29.2		30.3	29.4	
210						21	28	28.7	30	28.4	24.2	29.9	32.8	29.8	27.5	28.9	28.7	25.8	28	29.1				
240	28.5	30	30.2	28.6	30.2	20.5	27.7	28.6	30	28.4	22	29.9	32.7	29.2	26.8	28.8	28.6	25.1	27.75	29.1			29.1	
270						19.9	27.4	28.5	30	28.2	21	29.8	32.6	28.8	26.4	28.8	28.4	24.5	27.5	29				
300	27.9	30	30.1	27.3	30.2	19.4	27.2	28.4	30	28.0	20	29.8	32.5	28.3	26.1	28.8	28.3	23.7	27.25	29	28.0		28.7	28.5
330						18.9	27	28.3	30	27.9	19	29.8	32.4	27.8	25.6	28.8	28.2	22.7	27	29				
360	27.5	30	30.1	26.7	30.1	18.3	26.6	28.2	30	27.8	18.5	29.8	32.3	27.4	25.3	28.7	28	21.7	26.75	29		29.9	28.2	
390						17.8	26.3	28.1	30	27.6	17.5	29.8	32.2	27	24.8	28.7	28	20.7	26.5	29				
420	27.2	30	30	26.2	30.1	17.2	26	28	30	27.5	16.6	29.8	32.1	26.6	24.4	28.7	27.9	19.8	26.25	29				
450						16.7	25.8	27.9	30	27.4	15	29.8	32	26.2	24.1	28.7	27.8	18.9	26	28.9				
480	26.9	29.9	30	25.7	30	16.3	25.5	27.8	30	27.2	14	29.8		25.9	23.8	28.7	27.6	18	26	28.9	27.0		27.5	27.5
510						15.7	25.2	27.7	30	27.2	13.2	29.8	31.9	25.4	23.4	28.7	27.6	17.2	25.75	28.9				
540	26.5	29.9	29.9	25.2	30	15.5	25	27.6	30	27.0	12.5	29.7	31.8	25	23.1	28.7	27.5	16.3	25.5	28.9		29.9	28.2	
570						15.1	24.3	27.5	30	26.9	11.9	29.7		24.8	22.8	28.7	27.3	15.5	25.5	28.8				
600	26.2	29.9	29.9	24.6	30	14.7	24.5	27.4	30	26.9	11.1	29.7	31.6	24.3	22.4	28.6	27.2	14.6	25	28.8			26.4	
630						14	24.3		30	26.7	10.5	29.7		24.1	22.2	28.5	27	13.9	25	28.8				
660	25.8	29.9	29.8	24.2	29.9	13.7	24.2	27.2	30	26.6	9.9	29.7		23.7	21.9	28.4	26.9	13.2	24.75	28.8	25.5			26.2
690						13	24		30	26.5	9.3	29.7	31.3	23.3	21.6	28.4	26.8	12.4	24.5	28.7				
720	25.5	29.8	29.8	23.6	29.9	12.6	23.6	27	30	26.4	8.8	29.7	31.3	22.9	21.4	28.4	26.8	11.7	24.5	28.7		28.8	25.6	
750						12.2	23.3		30	26.3	8	29.7		22.6	20.9	28.4	26.7	10.9	24.25	28.6				
780	25.2	29.8	29.8	23.2	29.8	11.8	23	26.8	29.98	26.2	7.5	29.7	31.1	22.3	20.5	28.4	26.6	10.3	24	28.5				25.8

810						11.4	22.8			26.0	7.0	29.7		21.9	20.4	28.4	26.5	9.6	23.75	28.5				
840	24.9	29.8	29.7	22.6	29.8	11	22.6	26.6	29.98	25.9	6.6	29.7	30.9	21.6	20.2	28.4	26.5	8.9	23.5	28.5	25.2		24.8	
870						10.5	22.4			25.7	6.1	29.7		21.2	19.9	28.3	26.4	8.2	23.5	28.5				
900	24.5	29.8	29.6	22.1	29.7	10.3	22.2	26.5	29.97	25.6	5.6	29.6	30.7	21.1	19.7	28.3	26.3	7.6	23.25	28.4		28.1		25.0
930						10	22			25.6	5.3	29.6		20.8	19.5	28.2	26	6.9	23.25	28.4				
960	24.2	29.8	29.6	21.7	29.7	9.6	21.9	26.4	29.96	25.6	4.9	29.6	30.6	20.4	19.3	28.2	26	6.3	23	28.4			23.9	
990						9.3	21.7			25.3	4.4	29.6		20.3	18.9	28.2	25.9	5.7	22.75	28.4				
1020	23.9	29.8	29.5	21.3	29.6	9	21.5	26.2	28.95	25.3	4	29.6	30.5	19.9	18.7	28.2	25.8	27.1	22.75	28.3	24.6			
1050						8.6	21.3			25.1	3.6	29.6		19.6	18.5	28.2	25.8	4.5	22.5	28.3				
1080	23.6	29.8	29.5	20.9	29.5	8.3	21	26	28.94	25.1	3.1	29.6	30.4	19.4	18.3	28.1	25.8	4.1	22.25	28.3		27.7	22.9	23.3
1110						8	20.8			24.9	2.8	29.6		19.2	18	28.1	25.7	3.5	22	28.3				
1140	23.4	29.8	29.4	20.3	29.4	7.6	20.5	25.8	28.92	24.8	2.4	29.5	30.2	18.9	17.9	28.1	25.5	2.8	22	28.2			22.5	
1170						7.3	20.3			24.7	1.8	29.5		18.6	17.4	28.1	25.4	2.2	21.75	28.2				
1200	23.1	29.8	29.4	20	29.3	6.9	20.1	25.6	28.92	24.5	0	29.5	30	18.4	17.4	28	25.4	1.7	21.5	28.1	23.8			
1230						6.5	19.9			24.5		29.5		18.1	17.2	28	25.4	1.2	21.5	28.1				
1260	22.7	29.8	29.3	19.5	29.2	6.3	19.7	25.5	28.91	24.4		29.5	29.8	17.8	17	28	25.2	0.8	21.25	28.1		26.9		20.5
1290						6	19.5			24.2		29.5		17.5	16.8	27.9	25	0.5	21.25	28				
1320	22.4	29.8	29.3	19	29.2	5.6	9.3	25.3	28.9	24.1		29.5	29.7	17.4	16.4	27.9	24.9	0.1	21	28			21.5	
1350						5.5	19			24.0		29.5		16.9	16.3	27.9	24.9	0	21	28				
1380	22.1	29.8	29.3	18.6	29.2	5.2	18.9	25.1	28.9	23.9		29.5	29.6	16.8	16	27.9	24.8		20.75	28	23.0			
1410						5	18.6			23.7		29.5		16.4	15.8	27.8	24.8		20.5	28				
1440	21.8	29.8	29.2	18.2	29.1	4.7	18.4	24.9	28.9	23.6		29.5	29.4	16.3	15.6	27.8	24.7		20.5	27.9		26.0		18.0
1470						4.5	18.3			23.4		29.5		16.1	15.4	27.8	24.5		20.25	27.9				
1500	21.5	29.7	29.2	17.8	29	4	18	24.7	28.8	23.4		29.5	29.3	15.8	15.2	27.8	24.5		20.25	27.8	22.2		20.2	
1530							18			23.3		29.5		15.7	15.1	27.8	24.4		20	27.8				

1560	21.2	29.7	29.1	17.5	29		17.6	24.5	28.8	23.3		29.5	29.1	15.4	14.9	27.7	24.4		20	27.8				
1590							17.4			23.2		29.5		15.2	14.6	27.7	24.3		19.75	27.8				
1620	20.9	29.7	29	17.1	28.9		17.3	24.4	28.8	23.1		29.4	29	14.9	14.4	27.7	24.2		19.5	27.8		25.4		16.2
1650							17			23.0		29.4		14.8	14.4	27.7	24.1		19.5	27.7				
1680	20.7	29.7	29	16.7	28.8		16.9	24.3	28.8	22.8		29.4	28.8	14.5	13.9	27.7	24		19.25	27.6			19.2	
1710							16.7			22.8		29.4		14.3	13.8	27.7	23.9		19.25	27.5				
1740	20.4	29.7	28.9	16.3	28.7		16.4	24.2	28.7	22.7		29.4	28.7	13.9	13.7	27.6	23.8		19	27.5	21.4	25.0	18.8	14.9
1770							16.3			22.5		29.4		13.9	13.3	27.6	23.7		19	27.5				
1800	20.1	29.7	28.9	15.9	28.6		16.2	24.1	28.7	22.4		29.4	28.6	13.6	13.3	27.5	23.7		18.75	27.5	20.5	24.7	18.3	14.0

Table 6. Booth Traditional Forest Soil Infiltration Raw Data

	Booth Traditional Forest: Fall 2013					Booth Traditional Forest: Spring 2014					Booth Traditional Forest: Fall 2014					Booth Traditional Forest: Fall 2015					Booth Traditional Forest: Spring 2016			
Time (sec)	BTF1	BTF2	BTF3	BTF4	BTF5	BTF1	BTF2	BTF3	BTF4	BTF5	BTF1	BTF2	BTF3	BTF4	BTF5	BTF1	BTF2	BTF3	BTF4	BTF5	BTF1	BTF2	BTF3	BTF5
0	30	31	30	28	32.5	30.4	25.0	31	30.4	30.2	30.1	30	30	30	32.1	30	29.5	30	28	30	30	29.8	30	30
30						30.4	24.9	30.9	30	30	30	29	29.5	29.1	31.8	30	29.5	30	28	29				
60	29.3	30.5	28.7	28	32	30.4	24.7	30.9	29.6	29.9	30	28	28.7	28.2	31.6	29.7	29.5	29.7	28	28	30	29.3	29.6	30
90						30.4	24.5	30.9	29.2	29.8	30	27		27.7	31.4	29.7	29.5	29.7	28	26.5				
120	28.8	30.5	27.8	28	31.4	30.4	24.4	30.8	29	29.7	30	26	27.7	27.5	31.3	29.2	29.5	29.7	28	25	29.9	28.8	29.6	30
150						30.4	24.4	30.8	28.8	29.6	29.9			27.3	31.1	28.9	29.5	29.7	28	24				
180	28.5	30.3	26.9	28	31	30.4	24.4	30.8	28.5	29.5	29.8	23.1	26.6	27.2	31	28.6	29.5	29.7	28	23	29.9		29.6	30
210						30.4	24.4	30.8	28.3	29.4	29.8			27	30.9	28.4	29.5	29.7	28	22				
240	28.5	30	26.3	28	30.8	30.4	24.4	30.8	28.1	29.2	29.7	21.8	25.7	26.2	30.7	28	29.5	29.7	28	20.75		27.7	29.6	30

270						30.4	24.4	30.8	27.9	29.2	29.6			23.3	30.6	27.7	29.5	29.7	28	19.5				
300	28.5	30	25.5	28	30.5	30.4	24.4	30.7	27.8	29.1	29.5	20	24.8	21.9	30.5	27.5	29.4	29.7	28	19			29.5	30
330						30.4		30.7	27.6	29	29.4			20.8	30.3	27.2	28.3	29.7	28	18				
360	28.5	30	24.8	27.9	30.3	30.3	24.4	30.7	27.5	29	29.4	18.8	23.8	20	30.2	27	28.2	29.7	28	17		26.7	29.5	30
390						30.3		30.7	27.4	29	29.4			19.4	30.1	26.7	28.1	29.7	28	16				
420	28.5	30	24.2	27.9	30.1	30.3	24.3	30.7	27.3	29	29.3	17.5	23	18.5	30	26.5	28	29.7	27.5	15	29.5		29.4	30
450						30.3		30.7	27.1		29.2			17.9	29.9	26.3	27.8	29.6	27	14.5				
480	28.5	30	23.4	27.9	30	30.3	24.3	30.7	27	28.9	29.1	16.2	22.2	17.3	29.7	26	27.8	29.6	26.7	13.75		25.7	29.3	30
510						30.3		30.7	26.8		29			16.6	29.6	25.8	27.8	29.6	26.7	13				
540	28.5	29.9	22.8	27.8	29.7	30.3	24.2	30.7	26.7	28.7	28.8	15	21.4	16.1	29.5	25.5	27.7	29.6	26.5	12	29		29.3	30
570						30.3		30.6	26.5		28.7			15.6	29.5	25.3	27.6	29.6	26.5	11.5				
600	28.5	29.8	22.1	27.8	29.5	30.3	24.1	30.6	26.4	28.5	28.5	13.9	20.6	15	29.4	25	27.5	29.6	26.5	11		25	29.2	30
630						30.3		30.6	26.3		28.4			14.4	29.3	24.8	27.4	29.6	26.4	10.25				
660	28.5	29.8	21.4	27.8	29.4	30.2	24.0	30.6	26.2	28.4	28.3	12.7	19.8	13.8	29.2	24.5	27.3	29.6	26.3	9.5			29.1	30
690						30.2		30.6	26.1		28.2			13.3	29.1	24.2	27.2	29.5	26.3	9				
720	28.5	29.6	20.7	27.8	29.2	30.2	24.0	30.6	25.9	28.2	28.1	11.7	19.1	12.8	29	24	27.1	29.5	26.2	8.25	28.8	24	29.1	30
750						30.2		30.6	25.8		27.9			12.4	28.9	23.8	27	29.5	26.2	7.5				
780	28.5	29.5	20.1	27.8	29	30.2	23.9	30.6	25.7	28.1	27.7	10.8	18.4	11.9	28.8	23.5	27	29.5	26	7			29	30
810						30.2		30.5	25.6		27.5			11.3	28.7	23.4	26.9	29.5	25.9	6.5				
840	28.5	29.4	19.5	27.7	28.8	30.2	23.7	30.5	25.5	28	27.4	10.1	17.7	10.8	28.7	23.2	26.9	29.5	25.8	6	28.5	23	29	30
870						30.2		30.5	25.4		27.3			10.4	28.6	23	26.8	29.5	25.8	5.25				
900	28.5	29.2	19	27.7	28.7	30.2	23.6	30.5	25.3	27.8	27.3	9.1	17	9.9	28.5	22.8	26.8	29.5	25.8	4.75	28.3		28.9	30
930						30.2		30.5	25.1		27.3			9.5	28.4	22.5	26.8	29.5	25.7	4				
960	28.5	29.2	18.4	27.7	28.5	30.2	23.5	30.5	25	27.7	27.2	8.5	16.4	9.1	28.3	21.4	26.7	29.5	25.6	3		22.4	28.8	30
990						30.1		30.5	24.9		27.1			8.8	28.2	22.2	26.7	29.5	25.5	2.5				

1020	28.5	29	17.7	27.7	28.4	30.1	23.4	30.5	24.8	27.6	26.9	7.7	15.7	8.5	28.1	22	26.6	29.5	25.4	2			28.8	30
1050						30.1		30.5	24.7		26.8			8	28	21.8	26.5	29.5	25.3	1.75				
1080	28.5	29	17.1	27.7	28.2	30.1	23.3	30.5	24.6	27.5	26.8	7	15	7.7	27.9	21.7	26.4	29.5	25.3	1.5	28.1	21.3	28.7	30
1110						30.1		30.5	24.5		26.7			7.1	27.8	21.5	26.3	29.4	25.2	1				
1140	28.5	28.9	16.5	27.6	28.1	30.1	23.3	30.5	24.4	27.5	26.6	6.1	14.4	6.8	27.7	21.3	26.3	29.4	25.1				28.7	30
1170						30.1		30.5	24.3		26.5			6.5	27.7	21	26.1	29.4	25					
1200	28.4	28.9	16	27.6	27.9	30.1	23.3	30.5	24.2	27.3	26.4	5.5	13.7	6.1	27.6	20.8	26.1	29.4	25		27.7	20.5	28.6	30
1230						30.1		30.5	24.2		26.4			5.7	27.5	20.6	26	29.3	24.9					
1260	28.4	28.9	15.4	27.6	27.8	30	23.3	30.5	24.2	27.1	26.3	4.8	13.3	5.3	27.4	20.4	25.8	29.3	24.7				28.6	30
1290						30		30.5	24.1		26.2			5	27.4	20.2	25.8	29.2	24.5					
1320	28.4	28.9	14.9	27.6	27.6	30	23.2	30.4	24	27.1	26.1	4.3	12.8	4.8	27.3	20	25.8	29.2	24.4		27.5	19.7	28.5	30
1350						30		30.4	23.9		26			4.6	27.2	19.8	25.7	29.2	24.3					
1380	28.4	28.8	14.4	27.5	27.4	30	23.1	30.4	23.8	27	25.9	3.7	12.1	4.4	27.1	19.6	25.6	29.2	24				28.5	30
1410						30		30.4	23.7		25.9			4.3	27	19.4	25.6	29.2	23.8					
1440	28.4	28.8	13.9	27.5	27.3	30	23.1	30.4	23.6	26.8	25.8	3.1	11.4	4.2	26.6	19.2	25.6	29.2	23.5		27.1	18.8	28.4	30
1470						30		30.4	23.5		25.7			4.1	26.5	19.1	25.5	29.2	23					
1500	28.4	28.6	13.4	27.5	27.1	30	23.0	30.4	23.4	26.6	25.7	2.7	10.8	4	26.5	18.8	25.4	29.2	22.9		26.9		28.4	30
1530						30		30.4	23.2		25.6			3.9	26.4	18.6	25.3	29.2	22.9					
1560	28.4	28.6	12.8	27.4	27	30	23.0	30.4	23.1	26.5	25.5	2.1	10.3	3.9	26.4	18.4	25.2	29.2	22.6			17.8	28.3	30
1590						30		30.4	23		25.4			3.9	26.3	18.2	25.1	29.2	22.5					
1620	28.4	28.5	12.3	27.4	26.8	30	22.9	30.4	22.9	26.4	25.4	1.7	9.8	3.7	26.3	18	25	29.2	22.2				28.3	30
1650						30		30.3	22.8		25.3			3.6	26.2	17.9	24.6	29.2	22.1					
1680	28.4	28.5	11.7	27.4	26.6	29.9	22.8	30.3	22.7	26.3	25.3	1.1	9.3	3.4	26.1	17.8	24.8	29.2	21.9		26.5	17	28.2	30
1710						29.9		30.3	22.6		25.2			3	26	17.6	24.8	29.2	21.6					
1740	28.4	28.5	11.3	27.4	26.5	29.9	22.7	30.3	22.5	26.2	25.1		8.8		25.9	17.4	24.7	29.2	21.2		26.4	16.6	28.2	30

1770						29.9		30.3	22.4		25.1				25.8	17.3	24.5	29.2	21.1					
1800	28.4	28.4	10.9	27.4	26.3	29.9	22.6	30.3	22.3	26.1	25		8.3		25.7	17.2	24.4	29.2	21		26.3	16.2	28.1	30

Table 7. Caughey Open Pasture Soil Infiltration Raw Data

	Caughey Open Pasture: Fall 2013					Caughey Open Pasture: Spring 2014					Caughey Open Pasture: Fall 2014					Caughey Open Pasture: Fall 2015					Caughey Open Pasture: Spring 2016				
Time (sec)	COP 1	COP 2	COP 3	COP 4	COP 5	COP 1	COP 2	COP 3	COP 4	COP 5	COP 1	COP 2	COP 3	COP 4	COP 5	COP 1	COP 2	COP 3	COP 4	COP 5	COP 1	COP 2	COP 3	COP 4	COP 5
0	30	30.2	31.3	29.6	25.7	30	30.2	30	30.5	30	31	31.4	30	30.5	30	29.4	27.8	27.8	30	30	26	20	27.8	25.4	29.7
30						30	30.2	30	30.5	30	31	31.2	30	30.5	30	28.4	27.6	27.6	29.8	30					
60	24	30.2	31.2	29.6	25.7	30	30.2	30	30.4	30	30.5	31	30	30.5	30	27.1	27.3	27.3	29.7	30	25.9	19.6	27.6	25.4	29.7
90						30	30.2	30	30.3	30	30.5	30.6	30	30.5	30	26.8	26.9	26.9	29.6	30					
120	21.4	30.1	31.2	29.6	25.7	30	30.1	30	30.3	30	30.5	30.3	30	30.5	30	25.9	26.7	26.7	29.6	30	25.8	19.5	27.5	25.4	29.6
150						30	30.1	30	30.2	30	30.4	30	30	30.5	30	24.9	26.5	26.5	29.5	30					
180	17.7	30.1	31.2	29.6	25.7	30	30	30	30.2	30	30.4	29.7	30	30.5	30	24.2	26.3	26.3	29.5	30	25.7	19.2	27.4	25.3	29.5
210						30	30	29.8	30.2	30	30.1	29.5	30	30.5	30	22.8	26.1	26.1	29.5	30					
240	15.1	30.1	31.1	29.6	25.7	30	30	29.8	30.2	30	30	29.1	30	30.5	30	22.5	25.8	25.8	29.4	30	25.5	19.1	27.5	25.3	29.5
270						30	29.9	29.6	30.2	30	30	28.9	30	30.5	30	21.6	25.8	25.8	29.4	30					
300	12	30	31.1	29.6	25.7	30	29.9	29.6	30.2	30	29.9	28.5	30	30.5	30	21.1	25.7	25.7	29.3	30	25.4	18.9	27.5	25.2	29.5
330						29.5	29.8	29.6	30.2	30	29.9	28.3	30	30.5	30	20.2	25.4	25.4	29.3	30					
360	9.2	30	31.1	29.6	25.7	29.5	29.8	29.5	30.2	30	29.9	28	30	30.5	30	19.5	25.2	25.2	29.2	30	25.3	18.6	27.5	25.1	29.4
390						29.5	29.7	29.5	30.2	30	29.8	27.6	30	30.5	30	18.8	25	25	29.2	30					
420	7.3	30	31.1	29.5	25.7	29.5	29.7	29.5	30.2	30	29.8	27.4	30	30.5	30	18.2	24.9	24.9	29.1	30	25.1	18.4	27.5	25	29.4
450						29.5	29.7	29.5	30.2	30	29.7	27.1	30	30.5	30	17.4	24.8	24.8	29.1	30					
480	4.8	30	31.1	29.5	25.7	29.5	29.6	29.5	30.2	30	29.6	26.8	30	30.5	30	16.8	24.7	24.7	29	30	25	18.2	27.5	25	29.4

510						29.5	29.6	29.5	30.2	30	29.6	26.6	30	30.5	30	16.4	24.5	24.5	29	30					
540	3	30	31.1	29.5	25.7	29.5	29.5	29.5	30.2	30	29.5	26.4	30	30.5	30	15.8	24.3	24.3	28.9	30	24.8	18	27.5	24.9	29.4
570						29.5	29.5	29.4	30.2	30	29.5	26.2	30	30.5	30	15	24.2	24.2	28.9	30					
600	32	29.9	31.1	29.5	25.7	29.5	29.5	29.4	30.1	30	29.5	25.9	30	30.5	30	14.4	24	24	28.8	30	24.6	17.9	27.5	24.9	29.3
630						29.5	29.4	29.3	30.1	30	29.4	25.6	30	30.5	30	13.7	23.8	23.8	28.8	30					
660	27.7	29.9	31.1	29.5	25.7	29.5	29.4	29.3	30.1	30	29.3	25.4	30	30.5	30	13.2	23.8	23.8	28.7	30	24.5	17.7	27.5	24.9	29.3
690						29.5	29.4	29.3	30.1	30	29.2	25.1	30	30.5	30	12.7	23.5	23.5	28.7	30					
720	24.4	29.9	31.1	29.5	25.7	29.5	29.3	29.2	30.1	30	29.2	24.9	30	30.5	30	12	23.4	23.4	28.7	30	24.4	17.4	27.5	24.8	29.3
750						29	29.3	29.2	30.1	30	29.1	24.6	30	30.5	30	11.3	23.3	23.3	28.7	30					
780	21.8	29.9	31.1	29.5	25.7	29	29.2	29.2	30	30	29	24.4	30	30.5	30	10.5	23.2	23.2	28.7	30	24.4	17.3	27.5	24.8	29.3
810						29	29.2	29.2	30	30	29	24.2	30	30.5	30	10.3	23	23	28.6	30					
840	18.1	29.9	31.1	29.5	25.7	29	29.2	29.1	30	30	28.9	24	30	30.4	30	8.9	22.9	22.9	28.6	30	24.3	17.1	27.5	24.8	29.3
870						29	29.1	29.1	30	30	28.8	23.7	30	30.4	30	8.3	22.7	22.7	28.5	30					
900	15.2	29.8	31.1	29.5	25.7	29	29.1	29.1	30	30	28.8	23.5	30	30.4	30	8.1	22.5	22.5	28.4	30	24.1	17	27.5	24.7	29.3
930						29	29.1	29.1	30	30	28.8	23.3	30	30.4	30	8	22.4	22.4	28.4	30					
960	12.5	29.8		29.5		29	29	29	30	30	28.8	23.1	30	30.4	30	7.3	22.2	22.2	28.3	30	23.9	16.8	27.5	24.7	29.3
990						29	29	28.9	30	30	28.8	22.8	30	30.4	30	6.3	22.2	22.2	28.3	30					
1020	10	29.8		29.5		29	28.9	28.9	30	30	28.7	22.6	30	30.4	30	5.9	22.1	22.1	28.3	30	23.8	16.6	27.5	24.6	29.3
1050						29	28.9	28.9	30	30	28.7	22.3	30	30.4	30	5.1	22	22	28.3	30					
1080	7.7	29.8		29.5		29	28.8	28.9	30	30	28.6	22.1	30	30.4	30	5	21.8	21.8	28.2	30	23.7	16.4	27.4	24.6	29.3
1110						29	28.8	28.8	30	30	28.6	21.9	30	30.4	30	4.9	21.7	21.7	28.2	30					
1140	5.6	29.7		29.5		29	28.8	28.8	30	30	28.5	21.7	30	30.3	30	3.9	21.6	21.6	28.2	30	23.6	16.3	27.4	24.5	29.3
1170						29	28.8	28.8	30	30	28.5	21.5	30	30.3	30	3.9	21.5	21.5	28.1	30					
1200	3.9	29.7		29.4		29	28.7	28.8	30	30	28.4	21.3	30	30.3	30	3.4	21.4	21.4	28.1	29.9	23.4	16.1	27.4	24.5	29.3

1230						29	28.7	28.5	29.9	30	28.36	21.1	30	30.3	30	3.1	21.3	21.3	28	29.9					
1260		29.7		29.4		29	28.6	28.5	29.9	30	28.3	20.9	30	30.3	30	2.9	21	21	28	29.9	23.4	15.9	27.4	24.5	29.3
1290						29	28.6	28.5	29.9	30	28.2	20.6	30	30.3	30	2.2	20.9	20.9	27.9	29.9					
1320		29.7		29.4		28.5	28.6	28.4	29.9	30	28.1	20.3	30	30.3	30	2	20.8	20.8	27.9	29.9	23.2	15.7	27.4	24.5	29.3
1350						28.5	28.5	28.4	29.9	30	28.1	20.1	30	30.3	30		20.6	20.6	27.9	29.9					
1380		29.7		29.4		28.5	28.5	28.3	29.9	30	28	20.1	30	30.3	30		20.5	20.5	27.8	29.9	23.1	15.5	27.4	24.5	29.3
1410						28.5	28.4	28.3	29.9	30	28	19.9	30	30.3	30		20.4	20.4	27.8	29.9					
1440		29.7		29.4		28.5	28.4	28.3	29.8	30	28	19.6	30	30.3	30		20.3	20.3	27.8	29.9	22.9	15.4	27.4	24.5	29.3
1470						28.5	28.4	28.3	29.8	30	28	19.5	30	30.3	30		20.2	20.2	27.7	29.9					
1500		29.7		29.3		28.5	28.3	28.2	29.8	30	27.9	19.2	30	30.3	30		20.1	20.1	27.7	29.9	22.8	15.3	27.4	24.4	29.2
1530						28.5	28.3	28.2	29.8	30	27.8	19	30	30.3	30		19.9	19.9	27.6	29.9					
1560		29.6		29.3		28.5	28.2	28.1	29.8	30	27.7	18.9	30	30.3	30		19.7	19.7	27.5	29.9	22.7	15	27.4	24.4	29.2
1590						28.5	28.2	28.1	29.8	30	27.7	18.7	30	30.3	30		19.6	19.6	27.5	29.9					
1620		29.6		29.3		28.5	28.2	28	29.8	30	27.6	18.5	30	30.3	30		19.5	19.5	27.4	29.9	22.5	14.8	27.4	24.4	29.2
1650						28.5	28.1	28	29.8	30	27.6	18.3	30	30.3	30		19.4	19.4	27.4	29.9					
1680		29.6		29.3		28.5	28.1	27.9	29.8	30	27.5	18	30	30.3	30		19.3	19.3	27.4	29.9	22.5	14.6	27.4	24.4	29.2
1710						28.5	28.1	27.9	29.8	30	27.5	17.9	30	30.3	30		19.3	19.3	27.3	29.9					
1740		29.6		29.3		28.5	28.1	27.8	29.8	30	27.5	17.6	30	30.2	30		19.2	19.2	27.3	29.9	22.4	14.4	27.4	24.3	29.2
1770						28.5	28	27.8	29.8	30	27.5	17.6	30	30.2	30		19.1	19.1	27.3	29.9					
1800		29.6		29.3		28	28	27.7	29.8	30	27.4	17.3	30	30.2	30		18.9	18.9	27.1	29.9	22.3	14.2	27.4	24.3	29.2

Table 8. Caughey Silvopasture Soil Infiltration Raw Data

	Caughey Silvopasture: Fall 2013					Caughey Silvopasture: Spring 2014					Caughey Silvopasture: Fall 2014					Caughey Silvopasture: Fall 2015					Caughey Silvopasture: Spring 2016				
Time (sec)	CSV 1	CSV 2	CSV 3	CSV 4	CSV 5	CSV 1	CSV 2	CSV 3	CSV 4	CSV 5	CSV 1	CSV 2	CSV 3	CSV 4	CSV 5	CSV 1	CSV 2	CSV 3	CSV 4	CSV 5	CSV 1	CSV 2	CSV 3	CSV 4	CSV 5
0	33	30.7	34.5	35.5	30.5	30	29.5	30.6	30	30	31.5	30	30	30	30.3	29	30	30	28.9	26.5	28	26.4	31	29.8	31
30						29	28	30.6	30	30	30.6	30	28.1	28.4	30.3	28.9	30	30	28.9	26.5					
60	32.9	30	33.5	35.4	30.1	28.6	27.5	30.5	29.9	30	30.5	29.8	26.9	27.1	30.3	28.8	30	30	28.9	26.5	27.5	26	28.8	29.8	31
90						28.1	26.5	30.3	29.9	29.7	30.2	29.7	25.9	26.5	30.3	28.6	30	30	28.9	26.4					
120	32.6	29.9	33.4	35.2	29.8	27.1	26	30.2	29.9	29.5	30	29.7	25	25.7	30.3	28.4	30	29.8	28.8	26.4	27.3	25.5	26.9	29.8	
150						27.4	25.3	30	29.8	29.4	29.8	29.7	24.2	24.8	30.3	28.3	30	29.6	28.8	26.4					
180	32.5	29.8	33.3	35	29.8	27	25	29.8	29.8	29.3	29.5	29.7	23.4	24	30.3	28.2	29.9	29.5	28.8	26.3	27	24.8	25.6	29.8	
210						26.6	24.1	29.6	29.8	29.2	29.2	29.7	22.5	23.4	30.2	28.1	29.9	29.4	28.8	26.3					
240	32.4	29.7	33.3	34.8	29.8	26.2	23.6	29.5	29.8	29.1	29	29.7	21.5	22.5	30.2	28	29.8	29.3	28.8	26.2			23.7	29.8	30.8
270						25.7	22.9	29.3	29.8	29	28.8	29.7	20.8	21.8	30.2	27.8	29.8	29.1	28.8	26.1					
300	32.2	29.6	33.2	34.7	29.8	25	22.4	29.1	29.7	28.9	28.4	29.7	20	21	30.2	27.7	29.7	28.9	28.8	26.1		23.4	22.3	29.8	
330						24.7	21.9	29	29.7	28.8	28.2	29.7	19.3	20.6	30.2	27.6	29.7	28.8	28.8	26.1					
360	32.1	29.6	33.1	34.6	29.8	24.5	21.3	28.8	29.7	28.7	27.9	29.7	18.6	19.9	30.2	27.5	29.7	28.8	28.8	26.1		22.9	21	29.8	
390						24.2	20.8	28.7	29.7	28.7	27.8	29.7	17.9	19.3	30.2	27.4	29.7	28.7	28.8	26.1					
420	32.1	29.6	33	34.5	29.8	23.6	20.2	28.5	29.6	28.6	27.5	29.7	17.2	18.8	30.2	27.2	29.7	28.6	28.8	26.1			20	29.8	
450						23.2	19.7	28.3	29.6	28.6	27.4	29.7	16.8	18.3	30.2	27.2	29.7	28.5	28.8	26.1					

480	31.9	29.3	32.9	34.4	29.7	22.8	19.3	28.2	29.6	28.6	27.1	29.7	16.4	17.7	30.2	27.1	29.7	28.4	28.8	26.1	25.7		18.9	29.8	30.2
510						22.5	18.8	28	29.6	28.5	27	29.7	15.6	17.4	30.2	26.9	29.7	28.4	28.8	26.1					
540	31.8	29.3	32.8	34.3	29.7	22.2	18.1	27.8	29.6	28.5	26.7	29.7	15	16.9	30.2	26.8	29.7	28.3	28.8	26.1	25.5	21.5	17.8	29.8	30.2
570						21.7	17.7	27.6	29.5	28.5	26.6	29.7	14.6	16.4	30.2	26.8	29.7	28.2	28.8	26.1					
600	31.7	29.3	32.7	34.1	29.7	21.3	17.4	27.4	29.5	28.4	26.4	29.7	14.1	15.8	30.2	26.7	29.7	28	28.8	26		21.2	16.8	29.8	
630						21	17	27.2	29.5	28.4	26.2	29.7	13.5	15.4	30.2	26.7	29.7	27.9	28.8	26					
660	31.6	29.2	32.6	34	29.7	20.5	16.5	27.1	29.5	28.3	25.8	29.7	12.9	14.7	30.2	26.4	29.6	27.9	28.8	26			15.9	29.8	
690						20	16.1	26.9	29.5	28.3	25.6	29.7	12.5	14.5	30.2	26.3	29.6	27.8	28.8	26					
720	31.5	29.1	32.5	34	29.7	19.8	15.6	26.8	29.5	28.1	25.4	29.7	11.9	14.1	30.2	26.2	29.6	27.8	28.8	26	24.8		14.9	29.8	
750						19.4	15.2	26.6	29.5	28.1	25.2	29.7	11.6	13.7	30.2	26.1	29.6	27.7	28.8	26					
780	31.4	28.9	32.4	33.9	29.7	19.2	14.8	26.4	29.4	28	25	29.7	11.1	12.8	30.2	26	29.5	27.6	28.8	26			14	29.8	29.9
810						18.8	14.4	26.3	29.4	27.8	24.7	29.7	10.5	12.7	30.2	26	29.5	27.5	28.8	26					
840	31.3	28.8	32.4	33.8	29.7	18.6	14	26.1	29.4	27.8	24.5	29.7	10.2	12.5	30.2	26	29.5	27.5	28.8	25.9		19.5	13.1	29.8	
870						18.2	13.7	26	29.4	27.7	24.3	29.7	9.7	12.2	30.2	25.9	29.5	27.4	28.8	25.9					
900	31.2	28.7	32.3	33.7	29.7	17.8	13.1	25.8	29.4	27.7	24.2	29.7	9.3	11.9	30.2	25.8	29.5	27.4	28.8	25.9		19.2	12.3	29.8	
930						17.4	12.6	25.5	29.4	27.5	23.8		9	11.5	30.2	25.7	29.5	27.3	28.8	25.8					
960	31.1	28.6	32.2	33.6	29.7	17.2	12.4	25.3	29.4	27.5	23.6		8.5	11	30.2	25.6	29.4	27.3	28.8	25.8	23.8	18.9	11.5	29.8	
990						16.9	12.1	25.2	29.3	27.4	23.5		8.2	10.8	30.2	25.6	29.4	27.2	28.8	25.8					
1020	31	28.5	32.2	33.5	29.7	16.5	11.9	25	29.3	27.4	23.4		7.6	10.5	30.2	25.5	29.4	27.2	28.8	25.8	23.5		10.8	29.8	
1050						16.	11.	24.	29.	27.	23.		7.2	10	30.	25.	29.	27.	28.	25.					

						3	6	8	3	3	2				2	4	4	1	8	8					
1080	30.9	28.3	32.1	33.4	29.6	15.9	11.1	24.6	29.3	27.3	22.9		6.8	9.9	30.2	25.2	29.4	27	28.8	25.8			10	29.8	29.4
1110						15.6	10.9	24.5	29.3	27.2	22.8		6.5	9.5	30.2	25	29.4	26.9	28.8	25.8					
1140	30.8	28.2	32	33.4	29.6	15.2	10.6	24.4	29.3	27.2	22.7		6.1	9.1	30.2	25	29.3	26.9	28.8	25.8			9.4	29.8	
1170						15	10.4	24.2	29.2	27.2	22.5		5.7	8.7	30.2	25	29.3	26.8	28.8	25.7					
1200	30.7	28	31.9	33.2	29.6	14.7	10	24	29.2	27.1	22.4		5.4	8.5	30.2	24.9	29.3	26.8	28.8	25.7		17.5	8.6	29.8	29.3
1230						14.3	9.7	23.8	29.2	27.1	22.1		5	8.1	30.2	24.8	29.3	26.7	28.8	25.7					
1260	30.6	28	31.9	33.1	29.6	14	9.5	23.6	29.2	27	21.9		4.7	8	30.2	24.7	29.3	26.6	28.8	25.7		17.1	7.9	29.8	29
1290						13.7	9.1	23.5	29.2	27	21.7		4.3	7.5	30.2	24.6	29.3	26.6	28.8	25.7					
1320	30.4	27.8	31.8	33	29.6	13.4	8.8	23.4	29.1	26.9	21.6		4	7.4	30.2	24.5	29.3	26.5	28.8	25.7	22.3		7.3	29.8	29
1350						13.1	8.4	23.3	29.1	26.9	21.3		3.7	7.1	30.2	24.4	29.3	26.5	28.8	25.7					
1380	30.3	27.7	31.7	32.9	29.6	12.8	8.1	23.1	29.1	26.7	21.2		3.3	6.8	30.2	24.3	29.2	26.4	28.8	25.7	22.1		6.7	29.8	
1410						12.3	7.9	22.9	29.1	26.7	21		3.1	6.5	30.2	24.1	29.2	26.4	28.8	25.7					
1440	30.2	27.5	31.6	32.8	29.6	12	7.7	22.7	29	26.5	20.8		2.7	6.3	30.2	24	29.2	26.3	28.8	25.7			6.1	29.8	28.7
1470						11.8	7.4	22.5	29	26.5	20.6		2.4	5.9	30.2	24	29.2	26.3	28.8	25.7					
1500	30.1	27.4	31.5	32.7	29.6	11.7	7.1	22.2	29	26.4	20.5		1.9	5.9	30.2	24	29.1	26.2	28.8	25.7		15.6	5.4	29.8	
1530						11.4	6.8	22	29	26.4	20.3			5.7	30.2	23.9	29.1	26.2	28.8	25.7					
1560	30	27.3	31.5	32.7	29.6	11.1	6.5	21.9	29	26.4	20.1			5.5	30.2	23.9	29.1	26.1	28.7	25.7			4.6	29.8	28.5
1590						11	6.3	21.8	29	26.4	20			5.2	30.2	23.9	29.1	26	28.7	25.7					
1620	29.9	27	31.4	32.6	29.6	10.7	6	21.6	28.9	26.3	19.9			5	30.2	23.8	29	26	28.7	25.7	21.2		4	29.8	

1650						10.4	5.9	21.4	28.9	26.3	19.7			4.8	30.2	23.7	29	25.9	28.7	25.7					
1680	29.8	26.9	31.3	32.4	29.5	10.1	5.6	21.3	28.9	26.3	19.5			4.5	30.2	23.7	29	25.9	28.7	25.7	20.9		3.5	29.8	28.3
1710						9.8	5.3	21.1	28.9	26.3	19.4			4.4	30.2	23.6	29	25.8	28.7	25.7					
1740	29.7	26.8	31.2	32.4	29.5	9.6	5.1	21	28.8	26.2	19.2			4	30.2	23.5	29	25.8	28.7	25.7	20.6	14.5	3	29.8	28.2
1770						9.3	5	20.8	28.8	26.2	19.1			3.9	30.2	23.5	28.9	25.8	28.7	25.7					
1800	29.6	26.6	31.1	32.3	29.5	9	4.7	20.6	28.6	26.1	18.8			3.6	30.2	23.5	28.9	25.8	28.7	25.6	20.2	14	2.2	29.8	28.1

Table 9. Caughey Traditional Forest Soil Infiltration Raw Data

	Caughey Traditional Forest: Fall 2013					Caughey Traditional Forest: Spring 2014					Caughey Traditional Forest: Fall 2014					Caughey Traditional Forest: Fall 2015					Caughey Traditional Forest: Spring 2016				
Time (sec)	CTF 1	CTF 2	CTF3	CTF 4	CTF 5	CTF 1	CTF 2	CTF 3	CTF 4	CTF 5	CTF 1	CTF 2	CTF 3	CTF 4	CTF 5	CTF 1	CTF 2	CTF 3	CTF 4	CTF 5	CTF 1	CTF 2	CTF 3	CTF 4	CTF 5
0	31.4	34.5	30.5	30.6	30.1	30	30	28.7	30	31	30	32.1	30	30	30.8	29.3	29.7	29.7	29.3	27.2	26.5	28.6	30.7	30.1	27
30			30			28.5	30	29.5	30	31	29.7	30.5	29.9	30	30.8	29	29.7	29.7	29	27					
60	30	34.3	29.6		28.6	27.3	30	29.4	30	31	29.5	30	29.6	30	30.8	28.8	29.7	29.7	28.8	27	26.1	28.6	30.7	30	26.4
90			29.1			26.6	30	28.8	30	31	29.3	27.9	29.6	30	30.6	28.6	29.6	29.7	28.6	26.9					
120	29.1	34.1	28.7	28.5	26.5	25.8	29.8	28.3	29.9	30.9	29	26	29.6	30	30.5	28.4	29.6	29.7	28.4	26.8	25.9	28.6	30.7	30	25.8
150			28.4			24.9	29.6	28	29.9	30.8	28.8	24.5	29.5	30	30.5	28.2	29.6	29.7	28.2	26.8					
180	29.2	33.9	27.9	27.5	24.5	24.2	29.5	27.5	29.9	30.7	28.7	23.4	29.5	30	30.4	28	29.6	29.7	28	26.8	25.6	28.6	30.6	29.9	
210			27.5			23.5	29.5	27	29.9	30.6	28.5	22	29.5	30	30.4	27.6	29.6	29.7	27.6	26.7					
240	29.1	33.7	27.1	26.5	23.1	22.8	29.3	26.6	29.9	30.6	28.2	20.5	29.5	30	30.3	27.6	29.6	29.7	27.6	26.6		28.6	30.6	29.7	24.3

270			26.6			22.1	29.1	26.4	29.9	30.5	28.1	19.5	29.5	30	30.2	27.4	29.6	29.7	27.4	26.6					
300	28.9	33.4	26.3	25.4	21.6	21.6	28.8	26	29.9	30.4	28	18.6	29.5	30	30	27.3	29.5	29.7	27.3	26.6		28.6	30.5	29.7	24
330			25.9			20.8	28.7	25.7	29.9	30.2	27.8	17.5	29.5	30	29.9	27.2	29.5	29.7	27.2	26.5					
360	28	33.1	25.6	24.5	20.2	20.2	28.6	25.5	29.9	30	27.6	16.7	29.5	30	29.8	27	29.5	29.7	27	26.5	24.5	28.6	30.5		
390			25.2			19.8	28.5	25.3	29.9	30	27.5	15.7	29.5	30	29.7	26.7	29.5	29.7	26.7	26.5					
420	27.5	32.9	24.9	23.5	19.1	19.5	28.3	24.7	29.9	29.9	27.3	14.9	29.5	30	29.6	26.5	29.5	29.7	26.5	26.4		28.6	30.5		22.7
450			24.6			19	28	24.5	29.9	29.9	27.2	14.2	29.5	30	29.4	26.4	29.5	29.7	26.4	26.3					
480	27.2	32.6	24.1	22.5	17.9	18.6	27.9	24.3	29.9	29.9	27.1	13.4	29.5	30	29.4	26.2	29.5	29.7	26.2	26.3		28.6	30.4		
510			23.8			18.2	27.7	24	29.9	29.8	27	12.5	29.5	30	29.3	25.9	29.5	29.7	25.9	26.2					
540	25.9	32.4	23.4	21.6	16.9	17.9	27.6	23.5	29.9	29.7	26.8	11.9	29.5	30	29.2	25.7	29.5	29.7	25.7	26.4		28.6	30.4		
570			23			17.7	27.5	23.2	29.9	29.7	26.7	11.1	29.5	30	29.1	25.5	29.5	29.7	25.5	26.4					
600	25.1	32.1	22.7	20.6	15.8	17.4	27.5	23.2	29.9	29.7	26.6	10.6	29.5	30	29	25.4	29.5	29.6	25.4	26.4		28.6	30.4	28.9	21.1
630			22.4			17	27.4	23	29.9	29.6	26.5	10.1	29.5	30	28.9	25.3	29.5	29.6	25.3	26.4					
660	24.7	31.9	22	19.8	15	16.8	27.3	22.7	29.9	29.6	26.3	9.2	29.5	30	28.9	25.1	29.5	29.6	25.1	26	23.1	28.6	30.3	28.7	
690			21.8			16.4	27.2	22.5	29.9	29.6	26.1	8.8	29.5	30	28.8	25	29.5	29.6	25	26					
720	24.1	31.7	21.2	18.9	14	15.3	27	22.1	29.9	29.5	26.1	8.1	29.5	30	28.7	24.9	29.5	29.6	24.9	25.9	22.9	28.6	30.3		19.4
750			21			12.9	26.8	22.1	29.8	29.5	25.9	7.4	29.5	30	28.6	24.7	29.5	29.6	24.7	25.8					
780	23.6	31.4	20.9	17.9	13.3	10.8	26.7	22	29.8	29.5	25.7	6.9	29.5	30	28.5	24.6	29.5	29.6	24.6	25.8		28.6	30.3	28.4	
810			20.5			8.9	26.6	21.8	29.8	29.4	25.5	6.3	29.5	30	28.5	24.5	29.5	29.6	24.5	25.8					
840	23.3	31.2	20.1	17.	12.4	6.8	26.	21.	29.	29.	25.	5.7	29.	30	28.	25.	29.	29.	25.	25.	22.	28.	30.	28.	18.

				2			5	5	8	4	4		5		4	3	5	6	3	8	1	6	2	3	6
870			19.9			4.8	26.3	21.2	29.8	29.3	25.3	5.3	29.5	30	28.4	24.2	29.4	29.6	24.2	25.8					
900	22.9	31	19.6	16.3	11.2	3.1	26.2	20.9	29.8	29.3	25.2	5	29.5	30	28.2	24	29.4	29.6	24	25.7	21.9	28.6	30.2		
930			19.2				26.1	20.6	29.8	29.3	25.1	4.3			28.2	23.6	29.4	29.6	23.6	25.7					
960	22.5	30.8	18.9	15.5	10.7		26	20.6	29.8	29.3	25	3.9			28.1	23.8	29.4	29.6	23.8	25.6		28.6	30.2		17.5
990			18.7				25.9	20.2	29.8	29.2	24.9	3.1			28	23.7	29.4	29.6	23.7	25.6					
1020	22.1	30.5	18.3	14.3	10.1		25.8	19.9	29.8	29.1	24.8	2.5			27.9	23.5	29.4	29.6	23.5	25.6		28.6	30.1		17
1050			18				25.6	19.6	29.8	29.1	24.5	1.9			27.9	23.4	29.4	29.6	23.4	25.5					
1080	21.7	30.4	17.8	13.7	9.5		25.5	19.4	29.8	29	24.5	1.2			27.8	23.2	29.4	29.6	23.2	25.5		28.6	30.1		16.6
1110			17.6				25.3	19.2	29.7	28.9	24.3	0.5			27.7	26.1	29.4	29.6	26.1	25.5					
1140	21.5	30.2	17.3	13	8.9		25.2	18.9	29.7	28.8	24.3				27.6	23	29.4	29.6	23	25.5	20.8	28.5	30.1	27.5	
1170			17				25.1	18.6	29.7	28.6	24				27.5	22.8	29.4	29.6	22.8	25.5					
1200	21.3	30	16.8	12.2	8.2		25	18.3	29.7	28.5	23.8				27.5	22.7	29.4	29.6	22.7	25.4	20.5	28.5	30	27.5	15.5
1230			16.6				24.9	18.2	29.7	28.3	23.7				27.4	22.6	29.4	29.6	22.6	25.4					
1260	21	29.8	16.4	11.6	7.5		24.8	18.1	29.7	28.1	23.7				27.4	22.4	29.4	29.6	22.4	25.3		28.5	30		
1290			15.9				24.6	17.8	29.7	28	23.6				27.4	22.3	29.4	29.6	22.3	25.3					
1320	20.8	29.6	15.8	10.9	6.6		24.6	17.8	29.7	28	23.5				27.2	22.2	29.4	29.6	22.2	25.2		28.5	30	27	14.7
1350			15.6				24.5	17.6	29.7	28	23.4				27.1	22.1	29.4	29.6	22.1	25.2					
1380	20.6	29.3	15.4	10.1			24.3	17.3	29.6	27.9	23.2				27.1	22	29.4	29.6	22	25.1	19.6	28.5	30		14.2
1410			15.1				24.2	17	29.6	27.8	23.1				27	21.9	29.4	29.6	21.9	25.1					

1440	20.3	29.1	14.8	9.6			24	16.7	29.6	27.6	23				27	21.8	29.4	29.6	21.8	25.1	19.3	28.5	30	26.6	
1470			14.6				24	16.5	29.6	27.5	22.9				26.9	21.6	29.4	29.6	21.6	25					
1500	20.2	28.9		8.9			23.9	16.3	29.6	27.4	22.7					21.5	29.4	29.6	21.5	24.9		28.5	30	26.5	13.5
1530							23.8	16.1	29.6	27.3	22.6					21.4	29.4	29.6	21.4	24.9					
1560	20.1	28.7		8.4			23.6	15.9	29.6	27.2	22.5					21.3	29.4	29.6	21.3	24.8		28.5	30		12.9
1590							23.5	15.7	29.6	27.1	22.4					21.2	29.4	29.6	21.2	24.8					
1620	19.8	28.6		7.9			23.4	15.4	29.5	27.1	22.3					21	29.4	29.6	21	24.8	18.4	28.5	30	26.3	12.5
1650							23.3	15.2	29.5	27	22.3					20.9	29.4	29.6	20.9	24.8					
1680	19.6	28.4		7.4			23.2	15	29.5	26.9	22.1					20.8	29.4	29.6	20.8	24.7	18.2	28.5	30	26.2	12
1710							23	14.9	29.5	26.9	22					20.7	29.4	29.6	20.7	24.7					
1740	19.4	28.2		6.9			22.9	14.7	29.5	26.8	21.8					20.6	29.4	29.6	20.6	24.7	17.9	28.5	30	26.1	11.7
1770							22.8	14.4	29.5	26.7	21.7					20.5	29.4	29.6	20.5	24.7					
1800	19.2	28.1		6.2			22.6	13.9	29.5	26.6	21.6					20.4	29.4	29.6	20.4	24.7	17.5	28.5	30	26	11.3

Table 10. Moe Open Pasture Soil Infiltration Raw Data

	Moe Open Pasture: Fall 2013					Moe Open Pasture: Spring 2014					Moe Open Pasture: Fall 2014					Moe Open Pasture: Fall 2015				
Time (sec)	MOP 1	MOP 2	MOP 3	MOP 4	MOP 5	MOP 1	MOP 2	MOP 3	MOP 4	MOP 5	MOP 1	MOP 2	MOP 3	MOP 4	MOP 5	MOP 1	MOP 2	MOP 3	MOP 4	MOP 5
0	30.6	30.7	32.8	32.1	30.4	30	26.0	30	31.5	31.0	30.9	30.2	30.1	30.9	30	26.3	27.8	27.4	24.6	26
30						29.8		29.9	31.4		30.7	30	29.7	30.9	29.6	26	27.7	27	24.6	25.7

60	30.5	30.2	32.7	31.4	29.8	29.3	25.7	29.7	31.3	30.9	30.5	29.9	29.2	30.9	29.3	25.8	27.7	26.8	24.5	25.4
90						28.5		29.3	31.2		30.2	29.8	29.3	30.9	29.1	25.5	27.5	26.5	24.4	25.1
120	30.4	30.1	32.7	30.5	29.4	28	25.3		31.2	30.9	30	29.6	29.2	30.9	29	25.3	27.4	26.5	24.3	24.8
150						27.5		29	31.1		29.9	29.5	29.1		28.8	25	27.3	26.5	24.2	24.65
180	30.4	30.1	32.6	29.7	29	26.6	25.0	28.6	31.1	30.9	29.6	29.4	29	30.9	28.2	24.7	27.2	26.4	24.2	24.5
210						25.9			31.1		29.5		28.8		28.1	24.5	27.2	26.3	24.2	24.3
240	30.3	30	32.6	28.9	28.6	25.4	25.0	28.2	31	30.7	29.4	29	28.7	30.8	28	24.3	27.2	26.2	24.2	24.1
270						24.8		27.9	31		29		28.5		27.8	24	27.1	26.1	24.2	23.95
300	30.2	30	32.6	28.2	28.1	24.4	24.8	27.7	31	30.7	28.9	28.7	28.4	30.6	27.7	23.7	27.1	26	24.2	23.8
330						23.9		27.5	31		28.7		28.3		27.4	23.6	27.1	25.9	24.1	23.6
360	30.2	29.9	32.5	27.6	27.8	23.3	24.7	27.3	31	30.7	28.4	28.4	28.1	30.6	27	23.2	27	25.8	24.1	23.4
390						22.9		27.1	31		28.1		28		26.9	23	27	25.8	24.1	23.2
420	30.1	29.8	32.4	27	27.4	22.3	24.5	26.9	31	30.6	27.9	28	27.8	30.5	26.7	22.8	27	25.7	24.1	23.05
450						21.1		26.6	30.9		27.6		27.7		26.5	22.6	26.9	25.7	24.1	22.9
480	30.1	29.7	32.3	26.2	27.2	20.6	24.4	26.4	30.9	30.5	27.4	27.6	27.6	30.5	26.1	22.4	26.8	25.6	24.1	22.8
510						20.1		26.3	30.9		27.2		27.4		25.6	22.2	26.7	25.6	24.1	22.65
540	30.1	29.6	32.2	25.5	26.7	19.6	24.4	26	30.9	30.5	26.9	27.2	27.2	30.1	25.5	22.1	26.5	25.5	24.1	22.5
570						19.1		25.8	30.8		26.6		27		25.3	21.9	26.5	25.5	24	22.35
600	30	29.5	32.2	24.8	26.3	18.7	24.0	25.6	30.8	30.4	26.4	26.8	26.9	30	25	21.6	26.5	25.4	24	22.2
630						18.2		25.4	30.8		26.2		26.8		24.8	21.4	26.4	25.3	24	22.1
660	30	29.4	32.1	24.2	25.9	17.7	23.9	25.3	30.8	30.3	25.9	26.3	26.6	29.9	24.6	21.3	26.4	25.3	23.9	21.95
690						17.3		25.2	30.8		25.6		26.5		24.3	21	26.4	25.2	23.9	21.8
720	30	29.2	32.1	23.6	25.6	16.9	23.7	24.9	30.7	30.3	25.3	26	26.4	29.6	24.1	20.9	26.3	25.2	23.9	21.65
750						16.5		24.8	30.7		25.2		26.3		23.9	20.7	26.3	25.1	23.9	21.5
780	29.9	29.1	32	22.9	25.2	16.1	23.5	24.6	30.7	30.3	24.9	25.5	26.3	29.5	23.6	20.4	26.3	25	23.9	21.4
810						15.7		24.8	30.7		24.7		26.1		23.4	20.2	26.3	25	23.9	21.2

840	29.9	29	32	22.2	24.8	15.2	23.2	24.6	30.6	30.1	24.5	25	26	29.4	23.2	20	26.2	24.9	23.9	21.05
870						14.8		24.3	30.6		24.2		25.9		23	19.9	26.2	24.9	23.9	20.9
900	29.8	29	32	21.5	24.4	14.4	23.0	24	30.6	29.9	24	24.7	25.8	29.1	22.8	19.7	26.2	24.8	23.8	20.8
930						14		23.9	30.5		23.7		25.7		22.5	19.5	26.2	24.8	23.8	20.7
960	29.8	29	31.9	21	24	13.7	22.7		30.5	29.7	23.5	24	25.5	29	22.1	19.3	26.1	24.7	23.8	20.6
990						13.3		23.7	30.5		23.3		25.4		22	19	26.1	24.7	23.8	20.4
1020	29.8	28.9	31.9	20.6	23.7	12.9	22.5	23.5	30.5	29.5	23	23.7	25.3	28.9	21.9	18.9	26	24.6	23.8	20.2
1050								23.3	30.5		22.9		25.2		21.8	18.8	25.9	24.5	23.8	20.1
1080	29.7	28.8	31.8	20	23.4	12.1	22.4	23.2	30.4	29.3	22.6	23.2	25.1	28.8	21.6	18.5	25.9	24.5	23.7	20
1110						11.8		23.1	30.4		22.4		25		21.4	18.4	25.8	24.5	23.7	19.85
1140	29.7	28.7	31.8	19.5	23	11.5	22.1	22.9	30.4	29.3	22.2	23	24.9	28.7	21.1	18.2	25.8	24.4	23.7	19.7
1170						11.2		22.6	30.4		22		24.8		21	18	25.8	24.4	23.7	19.6
1200	29.6	28.6	31.7	18.9	22.7	10.8	22.0	22.5	30.3	29.3	21.7	22.6	24.6	28.5	20.6	17.8	25.8	24.3	23.6	19.5
1230						10.5		22.3	30.3		21.5		24.4		20.3	17.6	25.7	24.2	23.6	19.35
1260	29.6	28.6	31.7	18.2	22.3	10.1	21.7	22.1	30.3	29.3	21.3	22.2	24.3	28.4	20	17.5	25.7	24.2	23.6	19.2
1290						9.7		21.8	30.2		21.1		24.1		19	17.3	25.7	24.1	23.5	19.1
1320	29.6	28.5	31.6	17.8	21.9	9.5	21.4	21.7	30.2	29.2	20.9	21.9	24.1	28.2	17.1	17.2	25.6	24.1	23.5	18.95
1350						9.2		21.4	30.1		20.6		24		17.4	17	25.6	24	23.5	18.8
1380	29.5	28.4	31.5	17.3	21.6	8.9	21.2	21.3	30.1	29.2	20.5	21.5	23.9	28.1	16.5	16.8	25.5	24	23.5	18.65
1410						8.6		21.2	30.1		20.3		23.7		15.5	16.7	25.5	23.9	23.4	18.5
1440	29.5	28.4	31.4	16.8	21.2	8.2	21.1	21	30.1	29.2	20.1	21.2	23.5	28	14.8	16.5	25.4	23.8	23.4	18.4
1470						7.9		20.8	30		19.8		23.4		13.7	16.3	25.4	23.8	23.4	18.3
1500	29.5	28.3	31.4	16.4	20.9	7.6	21.0	20.6	30	29.1	19.6	20.8	23.2	27.8	12.6	16	25.3	23.7	23.3	18.2
1530						7.3		20.4	30		19.4		23.2		12	15.8	25.2	23.6	23.3	18.1
1560	29.4	28.3	31.4	15.8	20.6	7	20.9	20.3	30	29.1	19.3	20.5	23	27.7	11.1	15.7	25.2	23.6	23.3	17.9
1590						6.8		20.1	29.9		19		22.9		10.7	15.55	25.2	23.5	23.3	17.9

1620	29.4	28.2	31.3	15.4	20.2	6.5	20.7	19.9	29.9	29.1	18.8	20.1	22.8	27.5	9.6	15.4	25.2	23.5	23.2	17.8
1650						6.3		19.8	29.9		18.5		22.8		8.9	15.25	25.1	23.5	23.2	17.7
1680	29.3	28.1	31.3	14.8	19.9	5.9	20.5	19.6	29.9	29.1	18.4	19.8	22.7	27.3	8	15.1	25	23.5	23.2	17.6
1710						5.7		19.5	29.8		18.2		22.5		7.2	14.95	25	23.4	23.2	17.5
1740	29.2	28	31.2	14.3	19.5	5.4	20.4	19.4	29.8	29.0	18	19.5	22.4	27.3	6.5	14.8	24.9	23.4	23.2	17.4
1770						5.1		19.2	29.7		17.8		22.4		5.7	14.65	24.9	23.4	23.1	17.3
1800	29.2	27.9	31.2	13.8	19.2	4.9	20.3		29.7	29.0	17.7	19.2	22.3	27.2	5	14.5	24.8	23.4	23.1	17.2

Table 11. Moe Silvopasture Soil Infiltration Raw Data

	Moe Silvopasture: Fall 2013					Moe Silvopasture: Spring 2014					Moe Silvopasture: Fall 2014					Moe Silvopasture: Fall 2015				
Time (sec)	MSV1	MSV2	MSV3	MSV4	MSV5	MSV1	MSV2	MSV3	MSV4	MSV5	MSV1	MSV2	MSV3	MSV4	MSV5	MSV1	MSV2	MSV3	MSV4	MSV5
0	30.5	30.5	30	30.4	32.3	30.3	30.0	30.0	29.1	30.0	30	30	31	30	32.6	19.5	26.5	24	25.4	29
30	30.5	30.5				29.7	29.0	29.4	28.7	28.6	29.5	29.9	30.7	29.8	31.9	18.9	26.3	23.5	25	28.8
60	30.5	30.4	28.6	30.4	31.8	29.5	28.3		28.5	27.5	29.4	29.4	30.5	29.7	31	18.3	26.1	23.4	24.7	28.5
90	30.5	30.3				29.5	27.7	28.5	28.2	27.0	29.2	29.1	30.3	29.6	30.5	18.1	25.9	23	24.4	28.4
120	30.5	30.2	28.3	30.4	31.6	29.4	27.1		28.0	26.6	29.1	28.9	30.2	29.5	29	17.8	25.7	22.5	24.1	28.1
150	30.5	30.2				29.1	26.3	27.9	27.8	26.0	29	28.6	30	29.2	28.2	17.5	25.7	22	24	27.8
180	30.5	30	28	30.4	31.4	28.9	26.0	27.6	27.7	25.0	28.7	28.2	29.9	29	27.4	17.1	25.7	21.7	23.8	27.6
210	30.5	29.9				28.7	25.5	27.4	27.5	24.0	28.5	28	29.7	28.8	26.8	16.9	25.6	21.4	23.6	27.6
240	30.5	29.8	27.6	30.3	31.3	28.6	25.0	27.0	27.4	23.5	2833	27.7	29.5	28.6	26.1	16.6	25.5	21	23.4	27.5
270	30.5	29.7				28.5	24.5	26.5	27.2	23.1	28	27.4	29.2	28.5	25.4	16.3	25.4	20.7	23.2	27.4
300	30.5	29.6	27.3	30.3	31.2	28.3	24.1	26.3	27.1	23.1	27.8	27.2	29	28.3	25	16.1	25.3	20.4	23	27.3
330	30.5	29.5				28.2	23.8	26.0	26.9	22.5	27.5	27.1	28.8	28.1	24.2	15.8	25.3	20	22.7	27.2

360	30.5	29.4	27	30.3	31	28.1	22.9	25.6	26.7	22.0	27.2	26.7	28.5	27.9	23.6	15.6	25.2	19.7	22.5	27
390	30.5	29.4				27.9	22.3	25.4	26.5	21.7	27	26.5	28.3	27.7	22.9	15.4	25.2	19.4	22.2	26.8
420	30.5	29.3	26.7	30.3	30.9	27.7	22.0	25.1	26.4	21.0	26.8	26.4	28	27.5	22.4	15.1	25	19.1	22.1	26.6
450	30.5	29.2				27.6	21.4	24.8	26.3	20.5	26.2	26.1	27.9	27.3	21.8	14.8	25	18.8	22	26.4
480	30.5	29.1	26.5	30.3	30.7	27.5	21.2	24.6	26.2	20.0	25.8	25.8	27.7	27.2	21.4	14.5	24.9	18.5	21.8	26.2
510	30.5	29				27.4	20.8	24.4	26.0	19.3	25.5	25.5	27.5	27	20.6	14.3	24.8	18	21.6	26.1
540	30.5	28.9	26.2	30.3	30.6	27.3	20.3	24.0	25.8	19.0	25.3	25.3	27.4	26.7	20.1	14.1	24.7	17.5	21.4	26
570	30.5	28.9				27.2	19.7	23.8	25.7	18.4	25	25.1	27.2	26.5	19.5	13.9	24.6	17.4	21.3	25.9
600	30.5	28.8	25.9	30.3	30.4	27.1	19.3	23.6	25.6	18.0	24.7	24.8	27	26.3	19.1	13.7	24.5	17.1	21	25.8
630	30.5	28.7				27.0	18.7	23.3	25.4	17.4	24.4	24.5	26.9	26.2	18.9	13.4	24.4	16.8	20.9	25.7
660	30.5	28.5	25.6	30.3	30.2	26.9	18.6	23.0	25.3	17.0	24.3	24.3	26.7	26	17.9	13.2	24.4	16.5	20.8	25.6
690	30.5	28.4				26.8	18.1	22.8	25.2	17.0	24.2	23.9	26.5	25.8	17.5	13	24.3	16.4	20.7	25.5
720	30.5	28.3	25.2	30.3	30.1	26.6	17.4	22.5	25.1	16.6	23.6	23.8	26.3	25.6	17.1	12.7	24.3	16.1	20.5	25.4
750	30.5	28.3				26.5	17.0	22.1	25.0	16.0	23.6	23.6	26.2	25.5	16.8	12.5	24.2	15.7	20.3	25.28
780	30.5	28.2	24.9	30.3	30	26.4	16.8	21.9	24.8	15.7	23.4	23.3	26	25.3	16.2	12.4	24.1	15.4	20.1	25.1
810		28.1				26.3	16.6	21.7	24.7	15.3	23.3	23.1	25.9	25	15.6	12.1	24.1	15.2	19.9	25
840		28	24.6	30.2	29.9	26.2	16.3	21.5	24.5	15.0	23	22.9	25.8	24.9	15.2	11.8	24	15	19.7	24.9
870		27.9				26.0	15.9	21.3	24.4	14.6	22.5	22.6	25.5	24.8	14.8	11.7	23.9	14.7	19.6	24.8
900		27.8	24.4	30.2	29.7	25.9	15.2	21.0	24.3	14.0	22.3	22.4	25.3	24.5	14.5	11.5	23.8	14.4	19.5	24.7
930		27.8				25.8	14.8	20.9	24.1	13.8	22	22.3	25.1	24.4	14	11.3	23.7	14.2	19.3	24.6
960		27.7	24.1	30.2	29.5	25.7	14.6	20.8	23.9	13.6	21.7	22.1	24.8	24.2	13.7	11	23.7	14	19.2	24.5
990		27.5				25.6	14.2	20.5	23.8	13.0	21.5	21.9	24.7	24	13.2	10.8	23.6	13.75	19.1	24.35
1020		27.4	23.8	30.2	29.4	25.5	13.6	20.2	23.7	12.5	21.3	21.6	24.6	23.8	12.6	10.6	23.5	13.5	18.9	24.2
1050		27.4				25.4	13.4	20.0	23.6	12.1	20.8	21.4	24.4	23.7	12.1	10.5	23.5	13.3	18.7	24.02
1080		27.3	23.6	30.2	29.2	25.3	13.2	19.9	23.4	11.9	20.6	21.1	24.2	23.5	11.8	10.2	23.4	13.1	18.5	23.9
1110		27.3				25.2	12.8	19.5	23.3	11.5	20.4	21	24	23.3	11.3	10	23.3	12.9	18.4	23.8

1140		27.1	23.2	30.2	29	25.1	12.4	19.2	23.2	11.3	20	20.7	23.8	23.2	10.9	9.7	23.2	12.6	18.3	23.7
1170		27				25.0	12.0	19.1	23.1	10.9	19.9	20.5	23.6	23	10.7	9.5	23.1	12.3	18.2	23.6
1200		26.8	22.9	30.2	28.9	24.7	11.7	18.9	23.0	10.5	19.6	20.3	23.4	22.8	10.4	9.3	23	12	18	23.5
1230						24.6	11.3	18.5	22.9	10.1	19.5	20.1	23.2	22.7	9.9	9.1	22.9	11.75	17.9	23.4
1260			22.6	30.2	28.7	24.5	10.9	18.4	22.7	9.9	19.3	19.9	23.1	22.5	9.5	8.8	22.8	11.5	17.7	23.3
1290						24.4	10.6	18.1	22.6	9.7	19	19.6	22.8	22.3	9.2	8.7	22.8	11.3	17.6	23.15
1320			22.4	30.2	28.5	24.4	10.5	17.9	22.4	9.6	19	19.4	22.6	22.2	8.7	8.4	22.7	11.1	17.5	23
1350						24.3	10.0	17.8	22.3	9.0	18.9	19.3	22.5	22	8.5	8.3	22.7	10.9	17.4	22.9
1380			22.1	30.2	28.4	24.2	9.8	17.5	22.3	8.7	18.8	19	22.3	21.7	8.1	8.1	22.6	10.7	17.2	22.8
1410						24.1	9.3	17.3	22.2	8.5	18.8	18.8	22.2	21.6	7.8	7.9	22.6	10.5	17.1	22.7
1440			21.9	30.2	28.3	23.9	9.0	17.1	22.0	8.3	18.7	18.6	22	21.4	7.5	7.7	22.5	10.3	16.9	22.6
1470						23.7	8.5	16.9	21.9	7.9	18.5	18.5	21.8	21.2	7.2	7.5	22.5	10.1	16.6	22.45
1500			21.6	30.1	28.2	23.6	8.3	16.7	21.8	7.6	18.5	18.3	21.7	21	6.8	7.2	22.4	9.9	16.6	22.3
1530						23.5	8.0	16.5	21.7	7.4	18.4	18	21.4	20.9	6.6	7.1	22.4	9.7	16.5	22.2
1560			21.4	30.1	28	23.4	7.7	16.2	21.6	6.9	18.2	17.9	21.2	20.7	6.1	6.9	22.3	9.5	16.4	22.1
1590						23.3	7.4	16.0	21.4	6.4	17.9	17.6	21	20.6	5.9	6.7	22.3	9.3	16.2	22
1620			21.1	30.1	27.9	23.2	7.0	15.8	21.3	6.2	17.7	17.5	20.8	20.5	5.7	6.5	22.2	8.9	16	21.9
1650						23.1	6.8	15.6	21.1	5.9	17.1	17.2	20.6	20.2	5.4	6.3	22.1	8.9	15.9	21.8
1680			20.9	30.1	27.7	23.0	6.5	15.4	21.0	5.8	17.1	17	20.4	20.1	5.1	6.1	22	8.7	15.7	21.7
1710						22.9	6.3	15.2	20.9	5.5	17.1	16.8	20.3	20	4.7	5.9	22	8.5	15.7	21.6
1740			20.6	30	27.6	22.9	6.1	14.9	20.9	5.2	17	16.7	19.8	19.9	4.4	5.7	21.9	8.1	15.5	21.5
1770						22.7	5.7	14.8	20.7	5.0	17	16.4	19.7	19.7	4.2	5.5	21.9	8	15.4	21.4
1800			20.3	30	27.5	22.7	5.3	14.5	20.6	4.8	17	16.3	19.4	19.5	3.5	5.3	21.8	7.7	15.3	21.3

Table 12. Moe Traditional Forest Soil Infiltration Data

	Moe Traditional Forest: Fall 2013					Moe Traditional Forest: Spring 2014					Moe Traditional Forest: Fall 2014					Moe Traditional Forest: Fall 2015				
Time (sec)	MTF1	MTF2	MTF3	MTF4	MTF5	MTF1	MTF2	MTF3	MTF4	MTF5	MTF1	MTF2	MTF3	MTF4	MTF5	MTF1	MTF2	MTF3	MTF4	MTF5
0	34.5	33.4	32.5	30.4	30	30	30.0	36.7	40	30.5	30.5	30	30.4	30.6	30.5	28.4	29.5	28.8	26	29
30	33		30		27	28	29.8	35.9	39	23.58	30	29.3	30	30.2	30.2	27.9	28.5	28.5	23	28.5
60	31.2	33.2	27.6	28.2	25.2	26.5	29.3	35.5	38.1	20.1	29.8	29	29.8	29.8	30.2	27.8	27.9	28.4	20.2	28.3
90	30		25.2		22.8	25.2	29.1	35.2	37.3	17	29.7	28.5	29.5	29.5	30.2	27.7	27.2	28	18	28
120	28.4	33.2	23.1	26.8	21	23.9	28.8	34.8	36.3	14	29.5	28	29.1	28.7	30.1	27.5	26.6	27.7	16	27.7
150	26.8		20.7		18.8	22.6	28.5	34.4	35.5	11.5	29	27.5	29	28	30.1	27	26.2	27.4	14.5	27.6
180	25.5	33.1	18.8	25.1	17	21.5	28.4	34.2	34.9	9.5	28.5	27.1	28.9	27.3	30	27	25.7	27.1	12.8	27.1
210	24.2		17		15.3	20.5	28.4	34	34.1	7.4	28.2	26.7	28.9	26.8	30	26.9	25	26.9	11.2	27.1
240	23	33	15.3	23.5	13.8	19.4	28.2	33.6	33.3	5.4	27.8	26.3	28.9	26.4	29.9	26.8	24.5	26.4	9.8	26.9
270	21.6		13.6		12.3	18.3	27.9	33.3	32.5	3.5	27.3	26		25.8	29.8	26.5	23.8	26.4	8.8	26.6
300	20.4	32.6	12	21.8	10.9	17.5	27.7	33	31.8	1.8	27	25.5	28.7	25.3	29.7	26.3	23.2	26.1	7.5	26.4
330	19.4		10.5		9.8	16.4	27.5	32.7	31		26.5	25.2		24.8	29.6	26.1	22.8	25.8	6.1	26.2
360	18.3	32.4	9.2	20.6	8.4	15.4	27.4	32.3	30.3		26.1	24.8	28.4	24.1	29.5	25.9	22.1	25.6	5.3	26
390	17.3		7.9		7.2	14.6	27.2	32	29.5		25.7	24.3		23.5	29.5	25.7	21.7	25.3	4.1	25.8
420	16.2	32.1	6.6	19.3	6.1	13.5	27.0	31.7	28.7		25.5	24	28.2	23	29.4	25.5	21.2	25	3.1	25.6
450	15.3		5.4		4.9	12.8	26.9	31.4	27.8		25	23.6		22.6	29.3	25.4	20.7	24.7	2.3	25.4
480	14.3	31.9	4.3	18	3.6	11.9	26.7	31.1	27.2		24.7	23.2	28	22	29.3	25	20.2	24.6	1.4	25.1
510	13.3		3.3		2.5	11.2	26.5	30.7	26.6		24.5	22.8		21.4	29.2	24.8	19.6	24.4	0.6	25
540	12.4	31.7	2.3	16.6	1.4	10.3	26.1	30.5	26		24.2	22.4	27.8	21.2	29.1	24.7	19.1	24.1	0	24.9
570	11.5					9.7	26.0	30.1	25.3		23.8	22		20.4	29	24.6	18.7	23.7		24.7
600	10.7	31.5		15.7		8.9	25.9	29.7	24.7		23.5	21.6	27.6	20	29	24.3	18.3	23.5		24.6

630	10					8.1	25.7	29.5	24.1		23.4	21.2		19.5	28.9	4.3	17.8	23.3		24.2
660	9.2	31.2		14.4		7.4	25.4	29.1	23.5		23.2	20.9	27.5	19	28.9	24.1	17.2	23.1		24.1
690	8.3					6.6	25.2	28.7	22.9		22.7	20.5		18.4	28.8	24	16.9	22.9		24
720	7.7	31.1		13.1		6.1	25.0	28.5	22.2		22.4	20.2	27.2	18.2	28.7	23.2	16.3	22.6		23.8
750	6.9					5.4	24.8	28.3	21.5		22	19.8		17.8	28.6	23.5	15.8	22.4		23.6
780	6.2	30.9		12		4.7	24.7	28	21		21.6	19.6	27.1	17.3	28.5	23.3	15.4	22.2		23.5
810	5.6					4.3	24.4	27.7	20.5		21.4	19.3		16.7	28.5	23.6	15	22		23.4
840	4.8	30.6		10.9		3.7	24.3	27.3	19.9		21	19	26.9	16.4	28.5	22.8	14.7	21.8		23.2
870	4.2					2.8	24.0	27	19.2		20.5	18.5		15.9	28.4	22.7	14.3	21.5		23
900	3.6	30.4		10		2	24.0	26.8	18.6		20.1	18.2	26.7	15.6	28.3	22.5	13.8	21.3		22.8
930	3						23.7	26.4	18.2		20	18		14.9	28.2	22.3	13.3	21.1		22.7
960	2.4	30.2		8.9			23.5	26.1	17.5		19.9	17.5	26.5	14.6	28.1	22.1	13	20.9		22.5
990	1.6						23.3	25.9	16.9		19.7	17		14.2	28.1	21.9	12.6	20.7		22.3
1020		30		8			23.2	25.5	16.3		19.5	16.6	26.4	14	28	21.7	12.2	20.6		22.2
1050							22.9	25.2	15.8		18.8	16.3		13.4	28	21.5	11.8	20.3		22
1080		29.9		7.1			22.7	24.9	15.3		18.3	16	26.2	12.8	27.9	21.4	11.4	20.1		21.8
1110							22.5	24.6	14.8		18	15.6		12.4	27.8	21.2	11	19.9		21.7
1140		29.7		6.1			22.3	24.4	14.2		17.5	15.2	26.1	11.8	27.7	21	10.6	19.7		21.5
1170							22.1	24.1	13.7		17.2	15		11.6	27.6	20.8	10.3	19.5		21.3
1200		29.4		5.2			21.9	23.9	13.1		17	14.8	25.9	11.4	27.5	20.7	9.8	19.3		21.2
1230							21.7	23.5	12.7		16.8	14.5		10.9	27.5	20.5	9.5	19.1		21
1260		29.2		4.3			21.6	23.3	12.2		16.5	14.2	25.7	10.6	27.4	20.3	9.1	18.9		20.9
1290							21.5	23	11.7		16.2	13.7		9.8	27.4	20.1	8.8	18.7		20.8
1320		28.9		3.6			21.3	22.8	11.4		16	13.5	25.5	9.7	27.4	19.9	8.5	18.5		20.6
1350							21.1	22.5	10.8		15.8	13.1		9.7	27.4	19.7	8.1	18.3		20.4
1380		28.7		3.1			20.9	22.2	10.2		15.6	12.8	25.5	9.4	27.3	19.5	7.7	18.1		20.3

1410							20.7	21.9	9.6		15.3	12.5		9	27.3	19.3	7.4	17.9		20.2
1440		28.6		2.4			20.5	21.7	9.1		15.1	12.3	25.4	8.4	27.2	19	7	17.7		20
1470							20.3	21.4	8.7		15	12		7.9	27.1	18.8	6.7	17.5		19.8
1500		28.4					20.2	21.2	8.4		14.9	11.7	25.3	7.7	27.1	18.6	6.4	17.3		19.6
1530							20.0	20.9	7.7		14.5	11.5		7.2	27	18.4	5.8	17.1		19.5
1560		28.1					19.8	20.6	7.3		14.2	11.2	24.9	7	27	18.1	5.5	16.9		19.3
1590							19.7	20.4	6.8		14.2	11		6.9	26.9	17.9	4.8	16.7		19.2
1620		28					19.4	20.2	6.4		14	10.7	24.8	6.6	26.9	17.6	4.4	16.6		19
1650							19.4	19.9	6		14	10.5		6.4	26.8	17.4	4.4	16.4		18.8
1680		27.8					19.3	19.6	5.6		13.6	10	24.6	6.2	26.8	17.2	4	16.2		18.7
1710							19.0	19.4	5		13.4	9.8		5.8	26.7	17	3.8	16		18.5
1740		27.6					18.8	19.2	4.7		13.1	9.5	24.6	5.5	26.6	16.8	3.5	15.8		18.4
1770							18.5	19	4.2		13.1	9.3		5.3	26.6	16.5	3	15.7		18.3
1800		27.4					18.4	18.7	3.8		12.8	9	24.3	4.9	26.5	16.3	2.7	15.5		18.2

Appendix C: RStudio Datasets

Table 1. Booth All Variable Averages Based on Paddock

Treatment	Season	Infiltration (cm/hr)	Ksat (μm/sec)	ISM* (%)	BD* (g/cm^3)	Elevation (ft)
OP	Fall 2013	13.28	8.36	20.11	1.43	1284.60
SV	Fall 2013	11.32	8.43	25.26	1.35	1291.20
TF	Fall 2013	11.92	17.32	33.63	1.52	1258.60
OP	Spring 2014	20.10	16.92	21.84	1.43	1284.60
SV	Spring 2014	22.24	260.43	34.78	1.35	1291.20
TF	Spring 2014	6.24	6.64	41.84	1.52	1258.60
OP	Fall 2014	12.32	9.14	16.20	1.43	1284.60
SV	Fall 2014	36.16	34.57	29.39	1.35	1291.20
TF	Fall 2014	37.24	45.55	36.97	1.52	1258.60
OP	Fall 2015	17.76	29.37	17.52	1.43	1284.60
SV	Fall 2015	23.69	35.87	21.09	1.35	1291.20
TF	Fall 2015	12.85	20.06	20.23	1.52	1258.60
OP	Spring 2016	6.73	1.77	25.72	1.39	1304.67
SV	Spring 2016	21.75	409.13	36.36	1.37	1292.50
TF	Spring 2016	9.35	17.05	41.89	1.52	1258.75

*Note: ISM-initial soil moisture content, BD-bulk density

Table 2. Booth Averages Based on Soil Texture

Treatment	Season	Texture	Infiltration (cm/hr)	ISM (%)
OP	Fall 2013	Sandy Loam	13.28	20.11
SV	Fall 2013	Sandy Loam	17.60	19.55
SV	Fall 2013	Loam	0.60	35.81
SV	Fall 2013	Silty Clay Loam	3.20	31.82
TF	Fall 2013	Loam	4.20	40.23
TF	Fall 2013	Sandy Loam	17.06	29.24
OP	Spring 2014	Sandy Loam	20.10	21.84
SV	Spring 2014	Sandy Loam	22.13	31.69
SV	Spring 2014	Loam	29.60	42.35
SV	Spring 2014	Silty Clay Loam	15.20	36.47
TF	Spring 2014	Loam	2.90	44.35
TF	Spring 2014	Sandy Loam	8.47	40.18
OP	Fall 2014	Sandy Loam	12.32	16.20
SV	Fall 2014	Sandy Loam	47.60	25.05
SV	Fall 2014	Loam	1.20	24.86
SV	Fall 2014	Silty Clay Loam	36.80	46.96
TF	Fall 2014	Loam	36.06	28.53
TF	Fall 2014	Sandy Loam	38.02	42.59

OP	Fall 2015	Sandy Loam	17.76	17.52
SV	Fall 2015	Sandy Loam	34.28	24.00
SV	Fall 2015	Loam	11.60	15.07
SV	Fall 2015	Silty Clay Loam	4.00	18.36
TF	Fall 2015	Loam	17.90	19.22
TF	Fall 2015	Sandy Loam	36.55	22.21
OP	Spring 2016	Sandy Loam	6.73	25.72
SV	Spring 2016	Sandy Loam	21.70	27.69
SV	Spring 2016	Loam	11.60	32.97
SV	Spring 2016	Silty Clay Loam	32.00	57.11
TF	Spring 2016	Loam	7.40	50.29
TF	Spring 2016	Sandy Loam	10.00	39.09

Table 3. Caughey All Variable Averages Based on Paddock

Treatment	Season	Infiltration (cm/hr)	Ksat (μm/sec)	ISM* (%)	BD* (g/cm^3)	Elevation (ft)
OP	Fall 2013	28.02	22.27	54.65	1.48	1249.00
SV	Fall 2013	6.04	5.91	69.81	1.16	1240.40
TF	Fall 2013	37.81	30.90	26.14	1.28	1240.80
OP	Spring 2014	2.88	5.65	40.89	1.48	1249.00
SV	Spring 2014	24.44	25.67	46.25	1.16	1240.40
TF	Spring 2014	32.36	9.19	32.55	1.28	1240.80
OP	Fall 2014	7.20	10.70	35.59	1.48	1249.00
SV	Fall 2014	29.41	23.61	39.89	1.16	1240.40
TF	Fall 2014	26.17	16.21	30.61	1.28	1240.80
OP	Fall 2015	23.27	10.61	22.27	1.48	1249.00
SV	Fall 2015	4.76	1.83	34.43	1.16	1240.40
TF	Fall 2015	8.28	36.31	29.32	1.28	1240.80
OP	Spring 2016	4.60	7.42	50.13	1.48	1249.00
SV	Spring 2016	20.76	24.43	69.03	1.16	1240.40
TF	Spring 2016	11.84	6.20	42.33	1.28	1240.80

*Note: ISM-initial soil moisture content, BD-bulk density

Table 4. Caughey Averages Based on Soil Texture

Treatment	Season	Texture	Infiltration (cm/hr)	ISM (%)
OP	Fall 2013	Sandy Loam	34.83	61.06
OP	Fall 2013	Loamy Sand	0.80	29.01
SV	Fall 2013	Sandy Loam	5.67	93.63

SV	Fall 2013	Loam	6.80	32.82
SV	Fall 2013	Clay Loam	6.40	35.32
TF	Fall 2013	Sandy Loam	37.52	25.16
TF	Fall 2013	Sandy Clay Loam	38.94	30.04
OP	Spring 2014	Sandy Loam	2.45	42.16
OP	Spring 2014	Loamy Sand	4.60	35.80
SV	Spring 2014	Sandy Loam	33.13	47.22
SV	Spring 2014	Loam	20.00	33.81
SV	Spring 2014	Clay Loam	2.80	55.80
TF	Spring 2014	Sandy Loam	33.05	31.19
TF	Spring 2014	Sandy Clay Loam	29.60	38.02
OP	Fall 2014	Sandy Loam	9.00	29.32
OP	Fall 2014	Loamy Sand	0.00	60.68
SV	Fall 2014	Sandy Loam	8.93	50.74
SV	Fall 2014	Loam	67.44	21.32
SV	Fall 2014	Clay Loam	52.80	25.89
TF	Fall 2014	Sandy Loam	32.21	27.59
TF	Fall 2014	Sandy Clay Loam	2.00	42.67
OP	Fall 2015	Sandy Loam	24.63	24.00
OP	Fall 2015	Loamy Sand	17.80	15.36
SV	Fall 2015	Sandy Loam	5.00	24.10
SV	Fall 2015	Loam	8.40	25.05
SV	Fall 2015	Clay Loam	0.40	74.80
TF	Fall 2015	Sandy Loam	10.30	27.02
TF	Fall 2015	Sandy Clay Loam	0.20	38.53
OP	Spring 2016	Sandy Loam	5.55	42.74
OP	Spring 2016	Loamy Sand	0.80	79.70
SV	Spring 2016	Sandy Loam	15.40	64.60
SV	Spring 2016	Loam	57.60	47.37
SV	Spring 2016	Clay Loam	0.00	103.96
TF	Spring 2016	Sandy Loam	14.45	40.68
TF	Spring 2016	Sandy Clay Loam	1.40	48.94

Table 5. Moe All Variable Averages Based on Paddock

Treatment	Season	Infiltration (cm/hr)	Ksat (µm/sec)	ISM* (%)	BD* (g/cm^3)	Elevation (ft)
OP	Fall 2013	14.12	5.67	15.31	1.47	1275.60
SV	Fall 2013	8.18	6.53	21.16	1.50	1257.60
TF	Fall 2013	121.10	109.37	27.43	1.41	1240.80
OP	Spring 2014	18.23	386.10	16.32	1.47	1275.60

SV	Spring 2014	32.60	23.24	29.24	1.50	1257.60
TF	Spring 2014	117.60	140.04	22.81	1.41	1240.80
OP	Fall 2014	24.28	14.72	14.76	1.47	1275.60
SV	Fall 2014	31.16	1.68	12.74	1.50	1257.60
TF	Fall 2014	29.80	21.42	25.30	1.41	1240.80
OP	Fall 2015	11.64	6.60	12.50	1.47	1275.60
SV	Fall 2015	21.20	14.09	8.25	1.50	1257.60
TF	Fall 2015	59.87	72.67	11.49	1.41	1240.80

*Note: ISM-initial soil moisture content, BD-bulk density

Table 6. Moe Averages Based on Soil Texture

Treatment	Season	Texture	Infiltration (cm/hr)	ISM (%)
OP	Fall 2013	Sand	2.80	21.32
OP	Fall 2013	Sandy Loam	16.95	13.81
SV	Fall 2013	Loamy Sand	6.90	15.32
SV	Fall 2013	Sand	10.10	29.91
TF	Fall 2013	Sandy Loam	166.41	32.66
TF	Fall 2013	Loamy Sand	90.89	23.94
OP	Spring 2014	Sand	50.20	6.92
OP	Spring 2014	Sandy Loam	10.24	18.67
SV	Spring 2014	Loamy Sand	38.33	40.23
SV	Spring 2014	Sand	24.00	12.75
TF	Spring 2014	Sandy Loam	74.00	20.63
TF	Spring 2014	Loamy Sand	146.67	24.26
OP	Fall 2014	Sand	26.40	5.21
OP	Fall 2014	Sandy Loam	23.75	17.15
SV	Fall 2014	Loamy Sand	37.20	14.80
SV	Fall 2014	Sand	22.10	9.66
TF	Fall 2014	Sandy Loam	23.80	25.41
TF	Fall 2014	Loamy Sand	33.80	25.23
OP	Fall 2015	Sand	23.60	6.96
OP	Fall 2015	Sandy Loam	8.65	13.89
SV	Fall 2015	Loamy Sand	17.73	7.92
SV	Fall 2015	Sand	26.40	8.75
TF	Fall 2015	Sandy Loam	25.40	9.75
TF	Fall 2015	Loamy Sand	82.84	12.65

Appendix D: Manuals Utilized

Manual for Modified Philip-Dunne (MPD) Infiltrometer (Source: Ahmed et al., 2011)

I. Introduction

The Modified Philip-Dunne (MPD) Infiltrometer is a modification of the Philip-Dunne Permeameter (*Nestingen,2007*) to measure the saturated hydraulic conductivity of the soil surface. Knowledge of the saturated hydraulic conductivity is important to model infiltration rates for a range of storms and antecedent soil moistures. This falling head device is suitable for infiltration practices because it can be performed relatively quickly to capture the large spatial variability that commonly occurs with infiltration rates. In the analysis, a Green-Ampt formulation for infiltration is assumed in that wetting front for infiltrating water is assumed to be sharp between the initial value ahead of the front and the saturated soil behind the front.

The MPD infiltrometer is suitable for assessment of the required maintenance of an infiltration practice because accumulation of fine particles can limit the infiltration rate. Using the spreadsheet program and the initial and final moisture content of the soil, the saturated hydraulic conductivity of the soil, *K*, can be determined, along with the capillary pressure at the wetting front, *C*. Because *K* values typically have a large variability (*Warrick and Nielson, 1980; Asleson, et al., 2009)* it is useful to have a number of measurements to estimate the mean infiltration rate of the practice. The MPD infiltrometer has been used at up to 20 locations simultaneously, allowing for up to 40 measurements per day, with a three-person team. The MPD infiltrometer, however, is designed to measure only the hydraulic conductivity of the top 30 cm of media and does not typically detect a confining layer below 20 cm. To detect confining layers below 20 cm of depth, permeameter measurements in boreholes cored to the depth of interest are recommended (*Philip, 1993*).

II. Description of the MPD Infiltrometer

The MPD infiltrometer, shown in Figure.1, is an open ended, 6 mm thick, 10 cm inner diameter cylinder that comes in two parts. The top is 37cm long constructed of clear acrylic pipe and the detachable bottom is 7cm long made of finished steel. The bottom portion has been lathed from steel pipe to form a “collar,” with inner diameter equal to the inner diameter of the clear acrylic pipe and a thickness of 1cm. The MPD is ready for operation when the two parts are attached, using vacuum grease to eliminate leakage between the outer face of the acrylic and the inner face of the collar. The bottom edge of the cylinder is beveled from the outside to ease the process of inserting the device into the soil surface. A metric measuring tape is adhered to the outside of the clear acrylic cylinder.

Figure 1: Modified Philip-Dunne Infiltrometer

III. Device Operation:

1. If the ground is dry and hard, the steel collar of the MPD infiltrometer is pounded into the soil to the bottom edge of the collar, so that it will rest on the soil surface at a depth of 5cm (Figure 2). The top of the collar should be close to horizontal, which can be arranged with a small level. The inner face of the collar must be clean to form a tight seal.

(a) Place the permeameter base in an area that permeability (Ksat) is to be measured.

(b) Place ring weight inside the base and use a hammer to force the permeameter base into the soil up to the bottom of upper ring.

Figure 2. Placement of steel collar.

2. Place a small amount of vacuum grease around the inside of the collar to result in a tight seal when the acrylic is inserted.

3. The acrylic portion of the MPD is then inserted into the collar. The arrangement is such that the bottom of the acrylic is in contact with the screen and the screen is in contact with soil surface (Figure 3a).

a) Place the permeameter clear tube on the secured base and use gentle force to fully insert clear tube into the base, level it evenly and fill with water.

b) Wait for water surface to stabilize, read water level and start timing. Continue to read water level and time.

Figure 3 Operation of the Modified Philip-Dunne Infiltrometer

4. If the soil is wet, a rubber mallet can be used with a block of wood to pound both sections of the MPD together into the soil. In this case, item 1 is unnecessary, and item 2 and 3 can be completed before insertion into the soil.

5. Initial soil moisture content needs to measured (Sections V, and VI) or estimated (Sections VII). The measurements are typically made gravimetrically. One also needs to know the dry bulk density of the soil (Section IV) to convert the gravimetric moisture content into volumetric soil moisture (*Klute, A. 1986*).

6. The infiltration test is performed by filling the device with water within 5~10 sec up to a predetermined height (H_0). H_0 should be at least 20 cm (Figure 3a).

7. As soon as the device is filled to the desired level, a stopwatch is started and the height of water in the cylinder is recorded with respect to time. The height of the water at time zero is H_0 (Figure 3b). The 2^{nd} reading should be made when water level drops by approximately 1 cm. All subsequent readings should be collected at regular intervals, the length of which can be determined from Table i.

Table i. Guideline for the time between head measurements of the MPD infiltrometer

Initial time required to drop 1cm	<10 s	10 s	20 s	40 s	1 min	2 min	5 min	≥ 10 min
Time interval between 2 subsequent head measurements	20~ 30 s	40 s	1 min	2 min	4 min	6 min	10 min	30 min

8. Typically, 12~15 readings for a location are desired for an accurate optimization of *K* and *C*. A large water level drop over the test will incorporate more soil depth into the optimization of *K* and *C* and is thus recommended. If the water surface drop is slow, head versus time data should be taken until the water level is at least 10 cm from H_0.

9. The gravimetric final moisture content is measured from the porosity of the soil and then converted to the volumetric moisture content by multiplying it with the dry bulk density of the soil.

10. The head vs. time readings, initial and final volumetric moisture contents, are then entered into the MPD software to determine hydraulic conductivity and capillary pressure at the wetting front.

The MPD infiltrometer has been used on land surface slopes up to 4:1. The device may not function properly, however, if the soil is saturated because the soil may not have sufficient strength to hold the MPD.

IV. Determination of Bulk Density of the Soil Sample
(Revised from ASTM, 2004):

Soil dry bulk density is the ratio of the mass of dry solids to the bulk volume of the soil. The bulk volume includes the volume of the solids and the pore space. It is needed for converting water percentage by weight to content by volume. The mass is determined after drying to constant weight at 105 °C and the volume is that of the sample as taken in the field.

There are four methods of determining the dry bulk density of soil: core method, clod method, excavation method, and radiation method. The determination usually consists of drying and weighing a soil sample, the volume of which is known (core method) or must be determined (clod method and excavation method). A different principle is employed in the radiation method. The core method (A.S.T.M. D 2937-04, 2004) is the most straightforward. This method is not recommended for use in organic or friable soils, and may not be applicable if the soil cannot be retained in the drive cylinder.

The MPD test and the bulk density sample collection should not be done at the same time if these two locations are very close to each other. This is due to the fact that driving the sampler through the soil might cause disturbance in the soil which will affect the MPD test (for example, the water might move more quickly through the soil). But if someone is doing the bulk density sample collection 10~15 m or more from the MPD location then the vibration during the sampling should not affect the MPD test.

V. Determination of Initial Moisture Content of the Soil Sample

(Revised from Klute, 1986)

Moisture content of soil is the ratio of mass of water contained in the soil's pore space to the solid mass of particles in the soil, expressed as a fraction or percentage. A test specimen is weighed, and then dried in an oven at a temperature of 110 ± 5 °C until the mass is constant. The loss of mass due to drying is considered to be water. The water content is calculated using the ratio of the mass of water and the mass of the dry specimen.

Specimen containers- Choose a suitable container made of materials resistant to corrosion and change in mass upon repeated heating, cooling, and exposure to materials of varying pH and cleaning. Containers with close-fitting lids are required for testing specimens having a mass of less than about 200g. For specimens having a mass of greater than 200g, containers without a lid may be used. The purpose of close-fitting lids is to prevent loss of moisture from specimens before initial mass determination and to prevent adsorption of moisture from the atmosphere following drying and before final mass determination.

Test specimen selection- To measure initial moisture content, take 3~5 soil samples in the vicinity of the the device at the soil surface and combine all of the soil samples to prepare the test specimen. The samples should be taken at a distance of at least 30 cm from the edge of the MPD wall to prevent disturbance of the soil volume being tested for infiltration.

Procedure- Determine and record the mass of the clean and dry specimen container and its lid, along with its identification number. Place the moist test specimen in the container and set the lid securely in position. Determine the mass of the container and moist specimen using a balance and record the value.

Remove the lid (if used) and place the container with the moist specimen in the drying oven. Dry the specimen to a constant mass. Maintain the drying oven at 110 ± 5 °C. In most cases, drying a test specimen overnight (about 12 to 16 hr) is sufficient. As a rapid check to see if a relatively large specimen (> than about 100g of material) is dry, place a small strip of torn paper on the top of the material while it is in the oven or just upon removal from the oven; if the paper strip curls the material is not dry. Sand may often be dried to a constant mass in a period of about 4 hr. Because some dry materials may absorb moisture, dried specimens shall be removed before placing moist specimens in the same oven; unless they are being dried overnight.

After the specimen has dried to constant mass, remove the container from the oven (and replace the lid if used). Allow the specimen and container to cool to room temperature or until the container can be handled comfortably with bare hands and the operation of the balance will not be affected by convection currents and/or being heated. Determine the mass of the container and the oven-dried specimen. Record this value. Calculate the moisture content with the following equation:

Calculation

$$w = [(M_{cms} - M_{cds})/(M_{cds} - M_c)] \times 100 = (M_w/M_s) \times 100$$

where,
w = water content, %,
M_{cms} = mass of container and moist specimen, g,
M_{cds} = mass of container and oven dry specimen, g,
M_c = mass of container, g,
M_w = mass of water, g,
M_s = mass of oven dry specimen, g.

VI. Determination of Final Moisture Content of the Soil Sample

(Revised from Jury and Horton, 2004)

After the test has been performed the soil surface is assumed to be fully saturated, which means that the pores of the soil surface are filled with water. There are two techniques that can be used to determine the final moisture content of the soil:

1. Run a gravimetric moisture content procedure similar to the procedure for acquiring initial moisture content. The saturated moisture content occurs when the soil is saturated, but neither liquefied nor drained. It can be difficult to wait until the soil has drained the excess water, but is still saturated. There can be considerable scatter in the resulting final moisture content.

2. The final moisture content of the soil sample can be considered to be the effective porosity of that soil, which is determined using the following equation:

$$\Phi = 1 - \frac{\rho_b}{\rho_s}$$

$$\Phi_{eff} = \Phi - \Phi_{air}$$

where,
Φ = Total porosity
Φ_{eff} = Effective Porosity of the soil
ρ_b = Dry bulk density of the soil
ρ_s = Soil particle density
Φ_{air} = Fractional porosity of air (Table 4)

The dry bulk density of the soil can be measured once for every three locations following the ASTM standard. The particle density of the soil can be estimated from the weighted average of the solid component using the following equation:

$$\rho_s = \rho_m X_m + \rho_{om} X_{om}$$

where,
ρ_{om}= Density of the organic matter = 2.65 g/cm^3
ρ_m= Density of the mineral= 1.3 g/cm^3
X_{om}= Organic volume fraction
X_m= Mineral volume fraction=1-X_{om}

The organic volume fraction in soil varies from 1 to 10%, but typically less than 5%. Some typical values for organic fraction in different types of soil are provided in Table ii.

Table ii. Typical values for organic fraction of soil (Weiner, 2008).

Type of soil	Organic volume fraction (%)
Coarse soil	7
Silty loam	8.5
Silty Clayey loam	5
Clayey silty loam	0.9
Clayey loam	0.7
Sand	0.09
Glaciofluvial	0.017

Some typical values of porosity of different types of soil are given later. This second technique will result in improved precision in the final soil moisture values, if the porosity of the soil is known.

VII. Estimation of Moisture Content of the Soil Sample:

If the tools required to determine the bulk density and the gravimetric moisture content are not available, then one can estimate the initial volumetric moisture content of the soil by using Table iii. It has been found that the change in moisture content has a less than a 20% effect on saturated hydraulic conductivity which can be considered as minor relative to the orders of magnitude spatial differences (Regalado et. al., 2005). In Table iii one can estimate the volumetric moisture content of the soil by feeling the soil by hand.

Table iii. Guide for estimating soil water moisture content based on soil feel and appearance for several soil textures

Loamy Sand	**Θ (%)**	**Sandy Loam**	**Θ (%)**	**Loam**	**Θ (%)**	**Clay Loam**	**Θ (%)**
Leaves wet outline on hand when	15	Appears very dark, leaves wet outline on hand, makes	20	Appears very dark, leaves wet outline on hand, will ribbon out	28	Appears very dark, leaves slight moist. on hands when squeezed,	29
Appears moist, makes a	12.5	Quite dark color, makes a	17.5	Dark color, forms plastic ball, slicks	25	Dark color, will slick and ribbons easily	27
Appears slightly moist, sticks together	10	Fairly dark color, makes a good ball	15	Quite dark, forms a hard ball	22	Quite dark, will make thick ribbon, may slick when	25
Appears to be dry, will not form a ball under	7.5	Slightly dark color, makes a weak ball	12.5	Fairly dark, forms a good ball	19	Fairly dark, makes a good ball	23
Dry, loose, single grained flows through fingers	5	Lightly colored by moisture, no ball	10	Slightly dark, forms a weak ball	16	Will ball, small clods will flatten out	21
		Very slight color due to moisture, loose, flows through fingers	7.5	Lightly colored, small clods crumble	13	Slightly darks, clods crumble	19
				Slightly colored due to moisture,	10	Some darkness due to unavailable moisture, hard,	17

* Jerry Wright, Fred Bergsrud (1991); Irrigation Scheduling Checkbook Method

After the identification of the soil type and the initial moisture content from Table iii, the final moisture content is assumed to be the effective porosity for that soil, which can also be estimated from the Table iv, given in Section XI.

8. MPD Software:

Microsoft Excel (2003 or 2007) with Microsoft Visual basic is needed to run the MPD software because the necessary equations used for optimization are written in this language. Windows XP or later is needed to run the software.

9. Spreadsheet Recipe:

1. Open the *MPD spreadsheet(for 2007 excel)* or *MPDspreadsheet(for 2003 excel).*xls file. If a Security Warning window appears select the "Enable Macros" option.

2. Click the *Check Solver Installation* button. If a message window appears that says "The solver add-in is not installed" click *OK* and continue with step 3. If the message window says "The solver add-in is installed" click *OK* and skip to step 4.

3. To install the Solver Add-in go to the *Tools* menu, select "*Add-Ins"*, check the *Solver Add-in* box, and select *OK*. If Solver Add-in is not listed click *Browse* to locate it. If you see a message that tells you the Solver Add-in is not currently installed on your computer, click *Yes* to install it.

4. Enter initial and final volumetric moisture content(%), and initial height of the water into cells C2:C6. Enter the stopwatch time (h: mm: sec) and height (in centimeters) below the appropriate column headings in cells I1 and K1.

5. In M2 specify the number of cells of data for a cubic spline curve fit of the original data. For example, if the time and height data set ranges from I2 through I15 and from K2 through K15 respectively then in M2 the function would be written as *cubic_spline ($J$2:$J$15,$K$2:$K$15,L2)*. Click "*Autofill for Cubic Spline"* located in cell A22 to calculate the midpoint between two successive times and the corresponding head data.

6. Automatically fill all the rows in the remaining columns by clicking the "*Auto-fill Columns"*
button located in cell A23.

7. Calculate the distance to the wetting front at each time step by clicking the "*Solve for R(t)"*
button located in cell A24.

8. Find values for mean hydraulic conductivity (*K*) and capillary pressure at the wetting front (*C*) by clicking the "*Solve for K and C for T"* button located in cell A25. Solver's solution for *K* and *C* will appear automatically in cells C11 and C12, respectively.

9. Repeat step 8 until the 3rd digit of *K* and *C* remain constant.

10. Again find values for mean hydraulic conductivity (*K*) and wetting front potential (*C*) by clicking the "*Solve for K and C for H"* button located in cell A26. Solver's solution for *K* and *C* will appear automatically in cells E11 and E12, respectively.

11. The root mean square error for optimization with ΔH and for optimization with Δt will appear in cells C14 and E14, respectively. The corresponding head vs. time curve will also appear on the spreadsheet at the same time. Both graphs show the comparison between head vs. time curve of spline fit and optimized data. The spreadsheet will compare C14 and E14 and choose the values of *K* and *C* that correspond to the smallest error. The result will be shown in C20 (*K*) and C22 (*C*) cells.

12. Record values for *K* and *C* from cells C20 and C22, respectively, and then click the *Clear Template* button. To perform another calculation, repeat the procedure beginning at step 4.

X. Graphical Representation of Optimized Curve Fits

The spreadsheet shows two graphs for optimizing *K* and *C*, one by minimizing the RMS error in Δt and the other by minimizing the RMS error in ΔH. Δt is the difference between two successive times while ΔH is the difference between two successive head values. Each graph shows two curves, spline fit and optimized curve of H vs t data. The purpose of the cubic spline fit of the original data is to give a more accurate gradient of H vs t. A cubic spline fit with the original data is first performed and this is then to interpolate to the midpoint between two successive data points.

These midpoint data will be used for optimization. Both the spline fit and the optimized data should be exponential curves. The optimized value of *K* and *C* should result in curves that approximate the spline fit because optimization was performed using spline fit data. Two values of *K* and *C* are determined, one by optimizing Δt and other by optimizing ΔH. One should select the *K* and *C* for which the optimized data and spline data are the most similar (minimum RMS error); the spreadsheet does this automatically.

XI. Interpretation of the results:

Typical values of porosity, saturated hydraulic conductivity and capillary pressure are given in Table iv (Rawls, Brakensiek, Miller, 1983). Two thirds of the values that result from the optimization should be within the values given in the parenthesis.

Table iv. Typical measurements taken on soils. Two thirds of the measurements are within the values given in parenthesis.

Soil type	Porosity	Φ_{air}	Capillary pressure (cm)	Hydraulic conductivity (cm/sec)
Sand	0.43 (0.374~0.5)	0.02	-4.95 (-0.97~-25.36)	$3.25*10^{-3}$
Loamy sand	0.43 (0.363~0.506)	0.036	-6.13 (-1.35~-27.94)	$8.3*10^{-4}$
Sandy loam	0.45 (0.351~0.555)	0.041	-11.01 (-2.67~-45.47)	$3*10^{-4}$
Loam	0.46 (0.375~0.551)	0.029	-8.89 (-1.33~-59.38)	$9.4*10^{-5}$
Silt loam	0.50 (0.42~0.582)	0.015	-16.68 (-2.92~-95.39)	$1.8*10^{-4}$
Sandy clay loam	0.39 (0.332~0.464)	0.068	-21.85 (-4.42~-108)	$4.2*10^{-5}$
Clay loam	0.46 (0.409~0.519)	0.155	-20.88 (-4.79~-91.1)	$2.8*10^{-5}$
Silty clay loam	0.47 (0.418~0.524)	0.039	-27.3 (-5.67~-131.5)	$2.8*10^{-5}$
Sandy clay	0.43 (0.37~0.49)	0.109	-23.9 (-4.08~-140.2)	$1.7*10^{-5}$
Silty clay	0.47 (0.425~0.533)	0.056	-29.22 (-6.13~-139.4)	$1.4*10^{-5}$
Clay	0.47 (0.427~0.523)	0.09	-31.63 (-6.39~-156.5)	$8.3*10^{-6}$

A positive capillary pressure (*C*) indicates that the soil is hydrophobic (repels water) and a negative *C* value indicates the soil is hydrophilic (attracts water). Most soil is hydrophilic. In addition, positive *C* values have been shown to occur when a high conductivity layer is surrounded by a low conductivity region, even though the soil is hydrophilic. The optimized results for saturated hydraulic conductivity are not highly sensitive to the value of *C*, so small deviations in the data resulting in the spline fit and optimization can result in a positive value of *C*.

XII. Maintenance:

Inside the collar needs to be kept clean.

XIII. Safety:

One needs to wear safety glasses when using a hammer on the driver to pound the bottom part of the MPD infiltrometer into the soil.

XIV. References:

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Philip, J. R. 1993. Approximate Analysis of Falling-Head Lined Borehole Permeameter. Water Resources Research 29:3763-3768.

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Manual for Bulk Density Collection and Calculations (USGS, no date)

Bulk Density Test

The bulk density measurement should be performed at the soil surface and/or in a compacted zone (plow pan, etc.) if one is present. Measure bulk density near (between 1 and 2 feet) the site of the respiration and infiltration tests. To get a more representative bulk density measurement of the area, additional samples may be taken.

Materials needed to measure bulk density:

- 3-inch diameter ring
- hand sledge
- wood block
- garden trowel
- flat-bladed knife
- sealable bags and marker pen
- scale (0.1 g precision)
- 1/8 cup (30 mL) measuring scoop
- paper cups
- 18-inch metal rod
- access to a microwave oven

> Did You Know? Bulk density is the weight of soil for a given volume. It is used to mea- sure compaction. In general, the greater the density, the less pore space for water move- ment, root growth and penetration, and seedling germination.

Considerations: For rocky or gravelly soils, use the alternate procedure on page 11.

1. Drive Ring into Soil

Using the hand sledge and block of wood, drive the 3-inch diameter ring, beveled edge down, to a depth of 3 inches (Figure 4.1).

Figure 4.1

The exact depth of the ring must be determined for accurate measurement of soil volume. To do this, the height of the ring above the soil should be measured. Take four measurements (evenly spaced) of the height from the soil surface to the top of the ring and calculate the average. Record the average on the Soil Data worksheet.

NOTE: Use the metal rod to probe the soil for depth to a compacted zone. If one is found, dig down to the top of this zone and make a level surface. Proceed with Step 1.

2. Remove 3-inch Ring

Dig around the ring and with the trowel underneath it, carefully lift it out to prevent any loss of soil.

3. Remove Excess Soil

Remove excess soil from the sample with a flat- bladed knife. The bottom of the sample should be flat and even with the edges of the ring (see Figure 4.2).

Figure 4.2

4. Place Sample in Bag and Label

Touch the sample as little as possible. Using the flat- bladed knife, push out the sample into a plastic sealable bag. Make sure the entire sample is placed in the plastic bag. Seal and label the bag.

NOTE: Steps 5-7 can be done in a lab or office if a scale is not available in the field. Step 8 requires access to a microwave.

5. Weigh and Record Sample

Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

6. Extract Subsample to Determine Water Content and Dry Soil Weight

Mix sample thoroughly in the bag by kneading it with your fingers.

Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

7. Weigh and Record Subsample

Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

8. Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four- minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet. NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4- minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (See page 13)

Bulk Density Test for Gravelly and Rocky Soils

This method is to be used when rocks or gravels prevent sampling bulk density by the core method described in the first part of this Chapter. This excavation method will require the user to sieve out the coarse material greater than 2 mm in size.

Materials needed to measure bulk density:

- Plastic wrap
- 140-cc syringe
- water
- garden trowel
- sealable bags and marker pen
- 2-mm sieve
- scale (0.1 g precision)
- 1/8-cup (30 mL) measuring scoop
- paper cup or bowl
- access to a microwave oven

Considerations: Choose a spot that is as level as possible to allow water to fill the hole evenly. If the soil is too wet to sieve, ignore the part in Step 2 about replacing rocks, and proceed to Step 3. Soil will have to be dried and sieved later. The volume of gravel will need to be determined and subtracted from the total volume of the soil sample taken in the field.

1. Dig Hole

Dig a bowl shaped hole three inches deep and approximately five inches in diameter using the trowel (Figure 4.3). Avoid compacting the soil in the hole while digging. Place all of the soil and gravel removed from the hole in a plastic bag.

Using the 2-mm sieve, sieve the soil in the plastic bag to separate the gravel. Collect the soil in a plastic sealable bag. Put the gravel aside to be used in Step 2. Seal and label the plastic bag. [Note: See Considerations above if soil is wet.]

Figure 4.3

2. **Line the Hole**

Figure 4.4

Line the hole with plastic wrap as shown in Figure 4.4. Leave some excess plastic wrap around the edge of the hole. Place the sieved rocks and gravel care- fully in the center of the hole on top of the plastic wrap. Assure that the pile of rocks do not protrude above the level of the soil surface.

3. **Add Water to Hole**

Use the 140 cc syringe to keep track of how much water is needed to fill the lined hole. The level of the water should be even with the soil surface.

The amount of water represents the volume of soil removed. Record the total amount of water in cubic centimeters (1 cc = 1 cm^3) on the Soil Data worksheet.

NOTE: Steps 4-6 can be done in a lab or office if a scale is not available in the field. Step 7 requires access to a microwave.

4. **Weigh and Record Sample**

Weigh the soil sample in its bag. [If the sample is too heavy for the scale, transfer about half of the sample to another plastic bag. The weights of the two sample bags will need to be added together. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

Weigh an empty plastic bag to account for the weight of the bag. Enter the weight (sum of two bags, if applicable) on the Soil Data worksheet.

5. **Extract Subsample to Determine Water Content and Dry Soil Weight**

Mix sample thoroughly in the bag by kneading it with your fingers.

Take a 1/8-cup level scoop subsample of loose soil (not packed down) from the plastic bag and place it in a paper cup (a glass or ceramic cup may be used).

6. **Weigh and Record Subsample**

Weigh the soil subsample in its paper cup. Enter the weight on the Soil Data worksheet.

Weigh an empty paper cup to account for its weight. Enter the weight on the Soil Data worksheet.

7. Dry Subsample

Place the paper cup containing the subsample in a microwave and dry for two or more four- minute cycles at full power. Open the microwave door for one minute between cycles to allow venting. Weigh the dry subsample in its paper cup and enter the weight on the Soil Data worksheet.

NOTE: To determine if the soil is dry, weigh the sample and record its weight after each 4- minute cycle. When its weight does not change after a drying cycle, then it is dry.

CALCULATIONS (for both bulk density methods):

$$\text{Soil water content (g/g)} = \frac{\text{(weight of moist soil - weight of oven dry soil)}}{\text{weight of oven dry soil}}$$

$$\text{Soil bulk density (g/cm}^3\text{)} = \frac{\text{oven dry weight of soil}}{\text{volume of soil}}$$

$$\text{Soil water-filled pore space (\%)} = \frac{\text{volumetric water content x 100}}{\text{soil porosity}}$$

Volumetric water content (g/cm^3) = soil water content (g/g) x bulk density (g/cm^3)

$$\text{Soil porosity (\%)} = \left(1 - \frac{\text{soil bulk density}}{2.65}\right)$$

Volume of Rocks (cm^3) = Fill 1/3 of a graduated cylinder with water, and record the amount. Add the rocks to the cylinder and record the change in the water level. The difference is the volume of rocks (1 mL = 1 cm^3).

Volume of Soil (cm^3) = Total soil volume - volume of rocks