Flocculation Treatment BMPs for Construction Water Discharges

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This report presents the evaluation of chemical treatment practices known as flocculation for purifying construction site runoff of sediment, suspended solids and colloidal particles. Flocculation is generally used in combination with traditional sedimentation and filtration methods related to stormwater pollution prevention and dewatering fluid treatment.

In particular, this report presents the best management practices (BMPs) for evaluation and design of flocculant treatment methods and technologies and the associated sizing for flows representative of field operations. Soil samples from across Minnesota, representing the wide range of geologic and geomorphological conditions, were used to identify differences in flocculant applicability and effectiveness.

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Final Report

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Executive Summary

This report presents the evaluation of chemical treatment practices known as flocculation for purifying construction site runoff of sediment, suspended solids and colloidal particles. Flocculation is generally used in combination with traditional sedimentation and filtration methods related to stormwater pollution prevention and dewatering fluid treatment.

In particular, this report presents the best management practices (BMPs) for evaluation and design of flocculant treatment methods and technologies and the associated sizing for flows representative of field operations. Soil samples from across Minnesota, representing the wide range of geologic and geomorphological conditions, were used to identify differences in flocculant applicability and effectiveness.

Chapter 1: Introduction

Construction site runoff carries sediment, suspended solids and colloidal particles. In Minnesota locations with fine-grained soils, traditional stormwater best management practices (silt fences, diversion ditches, temporary seeding, check dams and sediment ponds; Minnesota Stormwater Manual, 2005) are ineffective in removing many fine particles, frustrating construction personnel and leaving construction sites unable to meet stormwater regulations. Flocculation, a chemical treatment to enhance fine particle sedimentation and filtration, is a common technique in the controlled world of water treatment. Work done by the Federal Highway Administration and several states has shown great promise in the application of flocculation to construction site stormwater management, removing fine particles with predictable and flexible approaches robust enough to meet a wide range of runoff conditions.

The focus of this work is to develop treatment practices for construction site runoff that carries sediment, suspended solids and colloidal particles. In particular, this report presents the best management practices (BMPs) for evaluation and design of flocculant treatment methods and technologies and the associated sizing for flows representative of field operations.

This report represents the work done under Mn/DOT Agreement 00734, Flocculation Treatment Best Management Practices for Construction Water Discharges. This work was performed by Minnesota State University (MSU), Mankato in the Environmental Engineering laboratory, as part of the Center for Transportation Research and Implementation.

1.1: Background and Theory of Flocculant Treatment

Flocculation is the chemical treatment of fine sediments in water such that particles aggregate and become larger and heavier in groups than as individual particles. Increasing the combined mass enhances the sedimentation of the particle group by increasing the downward settlement velocity.

Chemical addition to cause flocculation is well known in the controlled situation of water treatment (Crittenden, 2005). Performance is a function of both chemical characteristics (flocculent, sediment concentration, electrostatic charge, dose, pH, alkalinity and temperature) and hydraulic factors (flow, blending, mixing, sedimentation, filtration). Because so many factors apply, performance is typically evaluated using a bench scale “jar test” in which flocculent dose and other conditions are varied to assess the optimum combination. Treatments may include up to three chemical steps involving pH adjustment, coagulation for particle charge reduction and flocculation for particle aggregation. Aggregated particles may be removed from water flow by sedimentation (settlement) or by filtration. Reductions in turbidity from 300 NTUs or greater down to less than 5 NTUs are commonly achieved with proper control.

Crittenden (2005) lists flocculants in several classes including metal salts (ferric chloride, alum, ferric sulfate, polyaluminum chloride), clays (bentonite), chitosan, and polyacrylamide (PAM). PAM is supplied in three ionic states (anionic, cationic and non-ionic) across nearly one hundred different chemical compositions (NSF/ANSI Standard 60). Besides for water treatment, these products are also used in food manufacture and agriculture soil conditioning.

Davis (2010) summarizes flocculation treatment as consisting of three main steps:

- Injection and rapid (flash) mix of coagulant compounds, such that particle surface charge is changed to increase inter-particle attraction;
- Slow mix so that particles bump and aggregate into flocs but flocs do not shear; and,
- Sedimentation, in which particles leave the water column by gravity settlement.

A fourth step may also be implemented, consisting of filtration to "polish" the water and remove particles that did not settle out in the time allotted. Crittenden (2005) describes filtration for flocculant treated water as having three possible classifications, depending upon the actions taken in the filtration treatment sequence:

- Conventional filtration, consisting of rapid mix, slow mix and sedimentation prior to filtration;
- Direct filtration, consisting of rapid mix and slow mix but no sedimentation prior to filtration;
- In line filtration, consisting of rapid mix only prior to filtration.

Conventional filtration is considered appropriate for waters with turbidities up to 1000 NTUs, while direct and in line filtration approaches are considered appropriate for waters with turbidities less than 15 NTUs due to the effort involved in backwashing or cleaning filters.

Davis (2010) makes several points about key characteristics of successful flocculation treatment:

- Rapid mixture of coagulants needs very high mixing velocity gradients to cause particles to contact each other, rather than just ride along and not aggregate. High mixing power may be required. However, ferric chloride in particular can mix into water very quickly and may require a mixing time of less than 10 seconds total, hence the term "flash" mixing. Rapid mixing may be the most important factor for coagulation (chemical) efficiency.
- Slow mixing to encourage floc aggregation from particles in treated waters must be gentle, with low to very low power such that particles come into contact but flocs do not break apart or shear. Slow mixing may be the most important factor for particle size and removal. Slow mixing times are typically 20 to 30 minutes, with shorter times in this range appropriate for summertime water temperatures and longer times appropriate for wintertime temperatures. Water velocities during slow mixing should be 0.5 to 1.0 ft/s to reduce the potential for inadvertent sedimentation that could clog the slow mixing process.
- Sedimentation may be by strict gravity force action with individual particles (called Type I settlement) or be enhanced by enlargement of particles with the associated increase in particle mass and the subsequent increase in particle velocity (called Type II settlement).

Type II settlement can reduce the sedimentation time required. Typical sedimentation times are 60 minutes, after which wind currents can create sufficient water velocities to limit further particle settlement.

Note that Pizzi (2010) recommends that flocs be "pinhead size" for optimum settling. Flocs as large as quarters (3/4 in) may be too buoyant to settle, in spite of their impressive size. Pizzi (2010) also states that floc formation typically takes an average of 30 minutes, although 10 minute formation times are possible under some conditions.

During the preparation of BMPs for flocculant treatment methods and technologies for construction runoff and stormwater treatment field situations, it was assumed that structural tankage would be limited to 10,000 gallons per individual tank, the size of a transportable fractionation tank (tractor trailer size). Particular emphasis has been placed on practices for design of methods that could be implemented in ponds or channel waterways, with the water mixing and control appropriate to construction site conditions rather than "swimming pool" like conditions of drinking water treatment facilities associated with multi decadal-scale treatment durations.

1.2: Application of Flocculant Treatment to Construction Waters

In recent decades, flocculation has been used in mining, construction water treatment and eutrophic lake treatment. Early leaders in flocculation included the States of Washington, Oregon and California to protect the Pacific salmon fishery (Jurries, undated; Bachand, et al., 2010). Minnesota DNR suggests using alum as a flocculent for algae-choked lakes, although the dosing is limited by concerns for aquatic toxicity. The Minnesota Stormwater Manual (2005) notes chemical treatment by flocculation, but gives few details. Discussion with vendors suggests that flocculants are seldom used in Minnesota; this omission may be a lost opportunity.

Hesitation to employ flocculation on construction sites may be caused by: the chemical complexity of flocculation (Crittenden, 2005); the concerns over aquatic toxicity from residual flocculent after treatment (McLaughlin and Zimmerman, 2009); or bad experiences associated with insufficient blending ("the creation of mud balls", Crittenden, 2005; "gelatinous masses or 'fish eyes' McLaughlin and Zimmerman, 2009). Chemical complexity is addressed by pH adjustment and jar testing, residual effects are mitigated by use of anionic compounds that adhere to natural organic sediments rather than aquatic animal tissues, while effective blending may be achieved by:

- In-pipe methods (Iwinski, 2006; McLaughlin and Zimmerman, 2009);
- Passive log or pillow methods (Iwinski, 2006);
- Static mixers (Crittenden, 2005; McLaughlin and Zimmerman, 2009); or,
- Hydraulic (baffle) mixers (Crittenden, 2005).

Previous work at Minnesota State, Mankato for the treatment of construction waters with concrete sediments (Mn/DOT contract 96273 - Concrete Slurry, Wash and Loss Water Mitigation) has shown tremendous benefit from the use of flocculants (Figure 1).

Treatment cost for construction water flocculation has been reported as between $0.01 to $0.03/gallon for continuous reactor (in line) treatment (McLaughlin and Zimmerman, 2009) and $0.08/gallon for batch reactor (off line) treatment (Jurries, undated). Anecdotal reports suggest that contractors comfortable with flocculation performance may reduce construction site BMPs to eliminate operational conflicts such as haul roads crossing silt fences lines or diversion ditches and instead trust the flocculation to catch sediments.

Figure 1: Chitosan flocculent treatment (on left) of Minnesota River silt at ~200g/L. Photo taken 75 seconds after addition of flocculent.

Chapter 2: Sediment Samples

Sediment samples were created from soils collected from across Minnesota, in an attempt to represent the broad span of soil types associated with the geography of the state. This chapter describes the geographic targeting strategy, and provides details of the sample collection and characterization processes and associated results.

2.1: Sample Collection

Soil samples were generally collected by MnDOT from construction projects active during 2012. Additional samples were collected by MSU researchers to represent soil types of interest. Samples were targeted to represent approximately three locations per MnDOT district, and to represent a wide range of geological, geomorphological and ecological conditions. Lastly, sample collectors were encouraged to send samples of soil types that had difficult to manage through traditional stormwater management techniques.

Samples were collected from 30 locations. In many locations, multiple samples were collected to represent different soil layers, resulting in 57 total soil samples. Figure 2 presents a map of Minnesota with sample locations named and indicated.

Appendix A contains a list of samples, with locations and dates of collection.

Soil samples were either brought to MSU directly or picked up by MSU staff from the MnDOT District 7 Soils Laboratory. Samples were logged and tagged then stored in a secure location in the MSU Environmental Engineering Laboratory.

2.2: Characterization

Samples were evaluated for fine grain size (sizes less than 0.03 mm) using hydrometer analysis (ASTM D422), organic content (ASTM D2974), and pH (ASTM D4972). Results are provided in Appendix A, summarized on pages A-1 to A-4 and tabulated for individual soil samples on pages A-5 to A-61. Photomicrographs of the soil specimens are also provided with the individual soil sample information.

The geological and geomorphological characteristics of each sample was obtained from the mapped locations in comparison with the Quaternary geology described by Hobbs and Goebel (1982). A simplified version by Lusardi is included in Appendix B for reference; actual locations were checked against the full sized map. The ecological province for each sample was obtained from the web-based map Ecological Provinces of Minnesota (1999), also included in Appendix B. The natural vegetation for each sample was obtained from Coffin (1988); the key delineation map is also included in Appendix B.

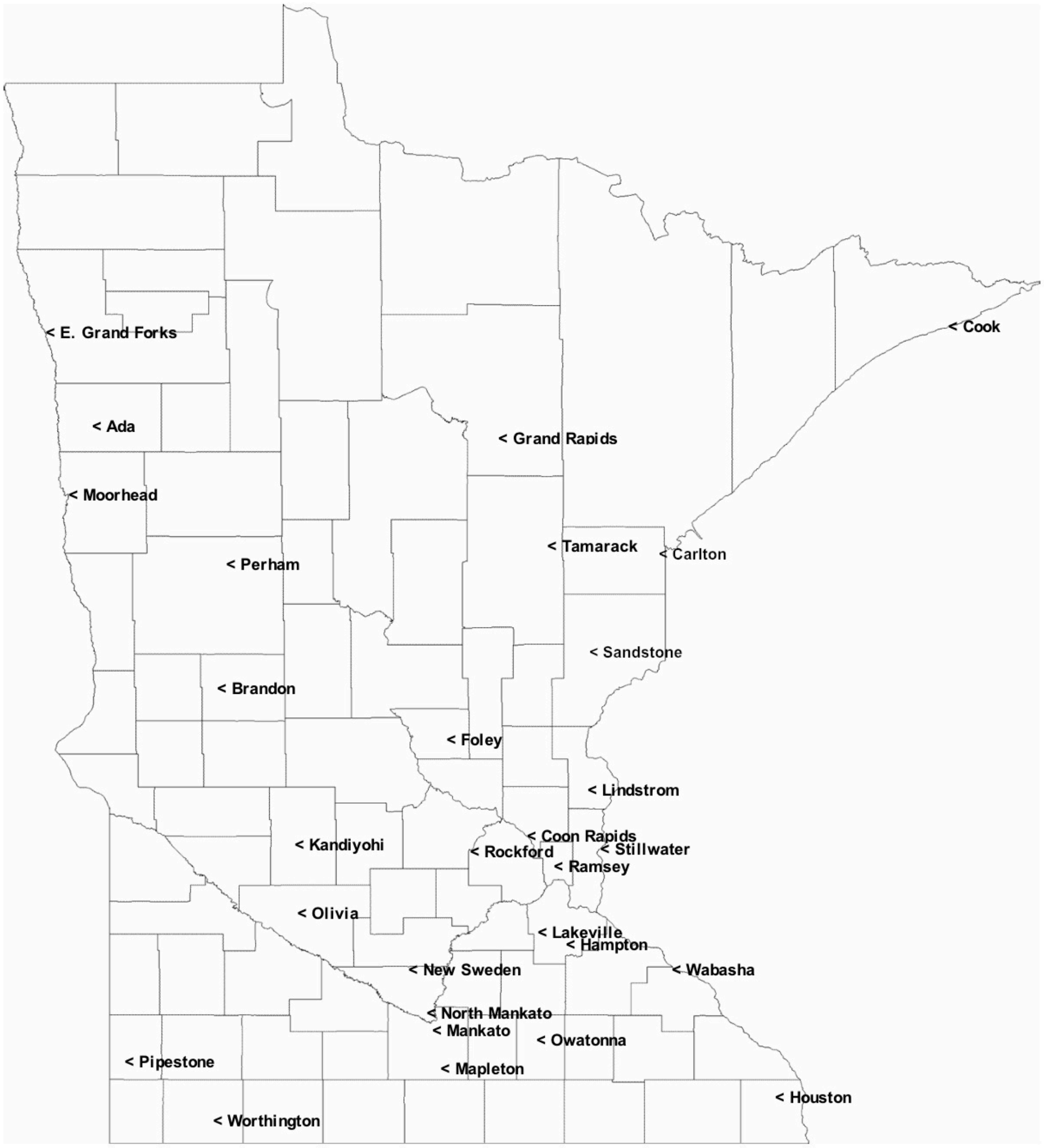

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Figure 2. Sample locations and nomenclature.

Definitions from Hobbs and Goebel (1982) that specifically apply to the soil samples and classification of this task include:

Drift: *All the rock materials transported by a glacier; includes till, outwash, ice-contact stratified drift, glacial lake sediment and loess.*

Lobe: *A major tongue of a continental glacier. Also the body of drift deposited by it.*

Moraine association: *Related bodies of till deposited during a more or less distinct phase of advance and retreat of an ice lobe. Each association contains a ground moraine and either a stagnation or an end moraine.*

Ground moraine: *A body of till deposited mainly from the bottom of a glacier as a more or less uniform blanket. Generally characterized by an undulating surface of hummocks or drumlins separated y swales. Includes some areas of low-relief ice-stagnation features.*

End moraine: *A body of drift deposited at the margin of a glacier when an approximate equilibrium in rates of ice flow and melting stabilized the position of the ice margin. Generally composed of till and ice-contact sand and gravel, but in places includes blocks of local material that was frozen to the sole of the glacier and thrust up into the moraine. Landforms range from belts of hills to a knob-and-kettle topography produced by collapse as the ice melted out.*

Stagnation Moraine: *A body of drift released by the melting of a glacier that has ceased flowing. Commonly, but not always, occurs near ice margins; composed of till, ice-contact, stratified drift, and small areas of glacial lake sediment. Typical landforms are knob-and-kettle topography, locally including ice-walled lake plains. Stagnation moraine is transitional to end moraine, and the distinction between them is rather arbitrary. The Vermilion and the Bemis Moraines are good examples of end moraines; the Alexandria and the Altamont Moraines are good examples of stagnation moraines. Most of the other moraines in Minnesota are transitional.*

Till: *An unsorted unstratified mixture of all sizes of rock material deposited directly by glacial ice with little or no reworking by water.*

Outwash: *Stratified drift, chiefly sand and gravel, which has been transported by glacial meltwater. Commonly pitted and collapsed by the melting of underlying ice, especially near former ice margins. Collapsed outwash is recognized by the uncollapsed remnant of the former depositional surface, as opposed to ice-contact stratified drift (included with moraines on this map).*

Loess: *Windblown silt and fine sand. Source areas include meltwater channels, outwash plains, and exposed glacial lake beds.*

Descriptions from Hobbs and Goebel (1982) that specifically apply to the soil samples and classification of this task include:

Deposits associated with the Des Moines lobe (Pleistocene, Late Wisconsinan): *gray calcareous drift (buff to brown where oxidized) shale and limestone clasts generally common, derived from Manitoba and eastern North Dakota, combined silt and clay typically exceeds 50% of till.*

Deposits associated with the Rainy lobe (Pleistocene, Late Wisconsinan): *brown to gray noncalcareous drift; clasts predominately igneous and metamorphic rocks of the Canadian Shield.*

Deposits associated with the Wadena lobe (Pleistocene, Early and Late Wisconsinan): *gray calcareous drift (buff where oxidized); limestone clasts common, but shale rare or absent.*

Deposits associated with the Superior lobe (Pleistocene, Late Wisconsinan): *reddish-brown non-calcareous drift; clasts predominately igneous and metamorphic rocks of the Canadian Shield, but also present are distinctive clasts from the Superior basin, including red sedimentary rocks, amygdaloidal basalt, red rhyolite and agate.*

Soil classifications were made using the MnDOT Triangle Textural Classification System, described in the MnDOT Draft Geotechnical Manual (MnDOT, 2008), and the Unified Soil Classification System (USCS) (ASTM D2487-00). The USCS classifications are considered presumptive because not all tests necessary for definitive classification were conducted (specifically Atterberg limits); however, sufficient information existed at the completion of the analyses of this study to select the probable classification. When doubt remained, dual USCS symbols were assigned.

Chapter 3: Dosage Study

Samples were evaluated for flocculant effectiveness by dosage using the jar test method (ASTM D2035), in which six 1 L samples (1.00 L tap water plus 25 g selected soil sample, well mixed) are simultaneously dosed with separate flocculant treatments, mixed and analyzed for improvements in clarity (Figures 3 to 5). Water analysis was done using turbidity (Oakton T-100 Waterproof Turbidity Meter) and pH (Hach HQ40d portable meter with IntelliCAL™ PHC201 pH probe) measurements at the start and end of the evaluation. Flash (rapid) mixing was done for 1 minute after flocculant dosing to thoroughly entrain the flocculant and create inter-particle collisions that are the basis for floc formation. Slow mixing was done for 20 minutes, then the samples were settled for an additional 20 minutes prior to determination of (final) treated turbidity level.

3.1: Flocculants

Flocculant chemicals were obtained directly from manufacturers (Hawkins, Roseville, MN; Tramfloc, Tempe, AZ), from a contractor (Standard Contracting, Hampton, MN) or from a construction product supply company (Brock White, St. Paul, MN), as listed in Table 1. No chemical analyses were done on the flocculants to determine characteristics or composition; vendor information was accepted as sufficient. Flocculant products were kept in secure storage away from light and at standard laboratory temperature (20 – 22° C). Flocculant stock solutions were made up by measuring out predetermined amounts of flocculant and mixing with 250.0 mL of tap water (City of Mankato municipal water system), then stored in amber 250 mL Boston bottles with septa caps.

3.2: Dosage Study

In Phase I of the dose evaluation, all 57 soils were tested with all 21 flocculant chemicals at the dose rates provided in Table 1. Dose rates were developed from manufacturer's recommendations, if available, and held constant for each flocculant chemical throughout the Phase I effort. Each soil-flocculant combination was evaluated in duplicate as a check on repeatability (2,394 total Phase I jar tests).

Results of Phase I are presented in Table 2, using symbols to represent the average of the two results determined for each soil and flocculant combination. pH results are provided in the Addendums that contain the analysis log sheets; results generally did not shift significant though a jar test, with most final pH levels around 8.

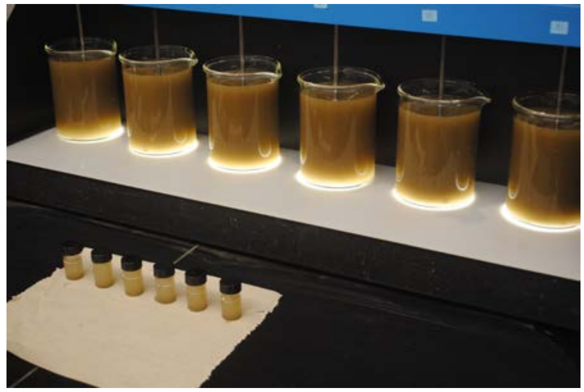
From these Phase I results, seven flocculants were deemed appropriate for further study based on turbidity reduction and representativeness of chemical class. These seven flocculants were continued into Phase II testing.

Table 1. Flocculants and doses used in this study.

Flocculant Chemical	Source	Manufacturer Reported Type[1]	Phase I Dosed Concentration	Phase II Dosed Concentration Range
Alum	Hawkins, Inc., St. Paul, MN	Aluminum Sulfate	0.01 mL/L	0 – 0.1 mL/L
Ferric Chloride 38%		Ferric Chloride	0.02 mL/L	0 – 0.2 mL/L
Biostar CH	Brock White, St. Paul, MN	Chitosen	0.002 mL/L	0 – 0.02 mL/L
Floc Flocculating Agent (called in this analysis Standard Contracting Floc)	Standard Contracting, Inc., Hampton, MN, agent for Innovative Turf Solutions, Cincinnati, OH	Bentonite	0.2 g/L	0 – 2.0 g/L
Floc W Flocculating Agent (called in this analysis Standard Contracting Floc W)		Bentonite	0.2 g/L	n/a[2]
AH[3] 6447	Hawkins, Inc., St. Paul, MN	Polyamine	0.002 mL/L	0 – 0.002 mL/L
AH 6547		Polyamine	0.002 mL/L	n/a[2]
AH 7747		Polymer blend	0.002 mL/L	n/a[2]
AH 117		Aluminium Chlorohydrate / Polyamine	0.002 mL/L	0 – 0.002 mL/L
AH 457		Aluminium Chlorohydrate / Polyamine	0.002 mL/L	n/a[2]
AH 820		Cationic polymer	0.002 mL/L	0 – 0.002 mL/L
AH 846		Cationic polymer	0.002 mL/L	n/a[2]
AH 852		Cationic polymer	0.002 mL/L	n/a[2]
AH 882		Cationic polymer	0.002 mL/L	n/a[2]
Tramfloc 111	Tramfloc, Inc., Tempe, AZ	Anionic polyacrylamide emulsion	0.002 mL/L	n/a[2]
Tramfloc 133		Nonionic polyacrylamide emulsion	0.002 mL/L	n/a[2]
Tramfloc 317		Cationic polyacrylamide emulsion	0.002 mL/L	n/a[2]
Tramfloc 342		Cationic polyacrylamide emulsion	0.002 mL/L	n/a[2]
Tramfloc 550		Polyamine	0.002 mL/L	n/a[2]
Tramfloc 723		Polyamine	0.002 mL/L	n/a[2]
Tramfloc 865A		Polyamine	0.002 mL/L	n/a[2]

Notes: 1: Manufacture reported type from MSDS or www.NSF.org . 2: n/a: not applicable, flocculant not tested in Phase II. 3: AH is notation for Aqua Hawk.

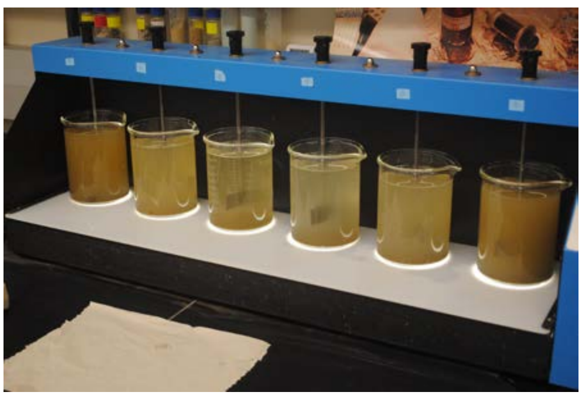
a) Preparation of turbid sediment-filled water.



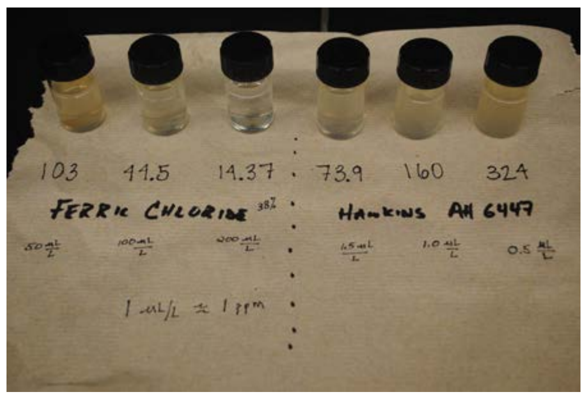
b) Initial turbidity measurement prior to flocculant addition.

c) Simultaneous dosing of flocculants.

d) Rapid (flash) mix to thoroughly blend flocculant.



e) Slow mix for floc formation.



f) Final turbidity measurement at end of test.

Figure 3. Jar testing for flocculant response and/or dose evaluation.

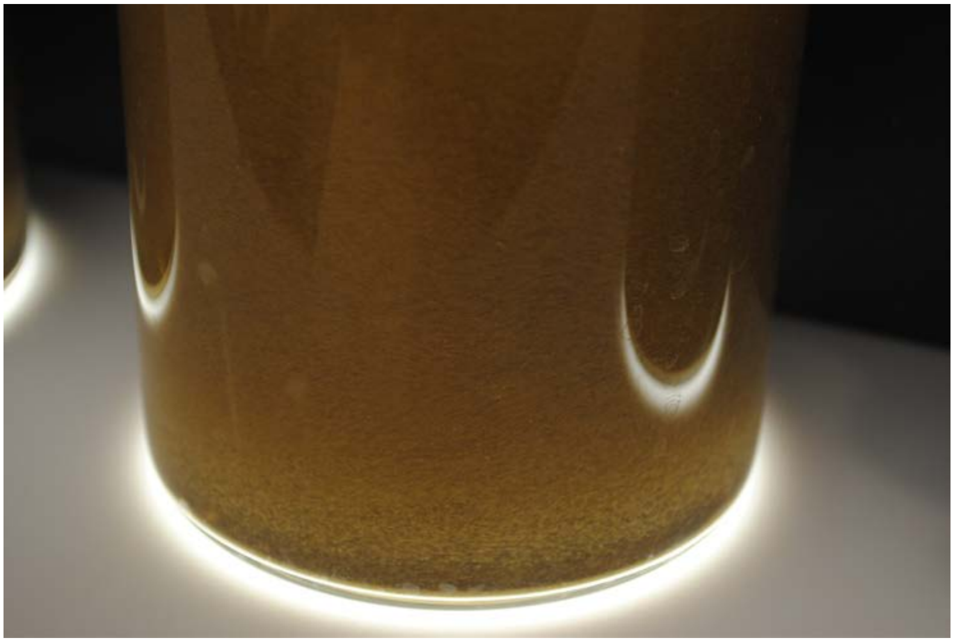


Figure 4. Floc formation (third jar from left in Figure 4) approximately 1 minute after flocculant dosing (end of rapid mix).

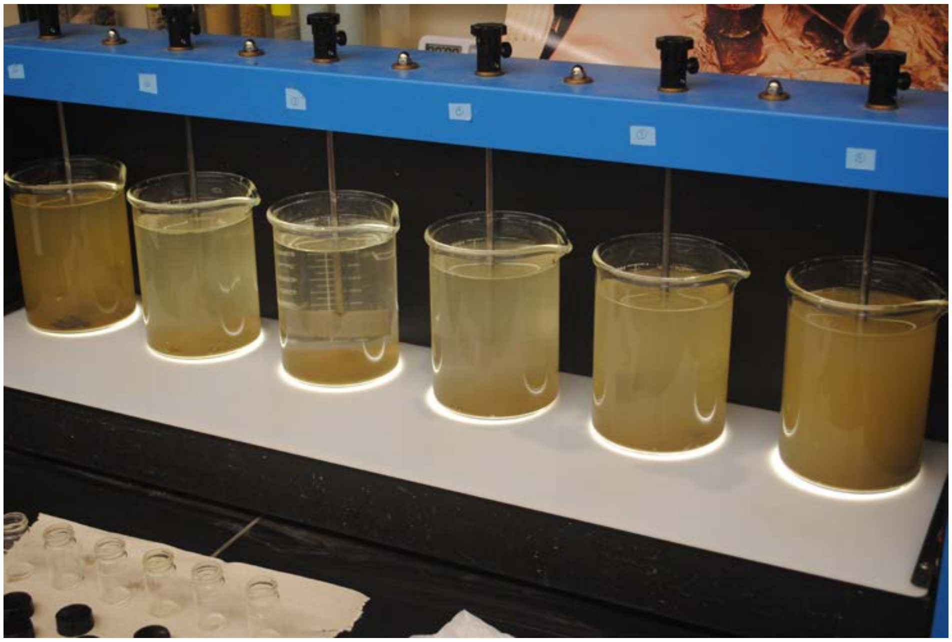


Figure 5. End of test responses for two flocculants across three dose rates for each flocculant; Worthington subsoil sediment mixture. From left to right: Ferric chloride at 0.05 mL/L (103 NTUs), 0.1 mL/L (44.5 NTUs), and 0.2 mL/L (14.37 NTUs); AH 6447 at 0.0015 mL/L (73.9 NTUs), 0.001 mL/L (160 NTUs), and 0.0005 mL/L (324 NTUs).

In Phase II of the dose evaluation, dose rates were varied by increasing or decreasing the amount of flocculant stock added to the soil and water mixture. All 57 soils were tested with the seven selected flocculant chemicals at the dose rate ranges provided in Table 1 (2,133 Phase II jar tests). Results of the Phase II evaluation are presented in Appendix C. Phase II results are graphed with turbidity as a function of flocculant dose rate. Note that the blank (no flocculant added) results are repeated in every graph of a given soil, representing a dose rate of 0 mL/L or 0 g/L.

3.3: Evaluation of Results

Soils have specific turbidity characteristics, as shown by the results from the blank (no flocculent) treatments. As commonly observed in the geotechnical and sedimentation disciplines, soil sediment turbidity is a function of several soil characteristics: fines content, particle size and distribution, particle surface charge and mineral composition. Some soils may have insufficient fines to cause turbidity beyond what can be treated by gravity sedimentation alone. In this study, soil sediment turbidity ranged from a high of 1000 NTUs to a low of 35.9 NTUs, averaging 322 NTUs with a standard deviation of 265 NTUs (relative standard deviation of 82%).

Each flocculent chemical has a highly specific characterization of effectiveness across the range of soil types. Specific dose by turbidity relationships exist for each flocculent chemical and each soil, particularly for polymer compounds that can either work very well or make turbidity worse due to specific surface charge interrelationships.

When effective, dose levels can vary between 0.2 to 100 ppm. This does range is quite large, given the potential for wide cost differences between flocculent chemicals (anecdotally noted as ranging from $2 to $50 per gallon).

Flocculent chemicals found to be broadly effective include ferric chloride, Aqua Hawk 6447 and Tramfloc 865A. Ferric chloride was found to treat turbidity consistently to below 100 NTUs for all soils considered in this study, and typically to below 50 NTUs for most soils, at a dose of 0.2 mL/L (approximately 200 ppm, or 70 gallons of ferric chloride per acre foot of water to be treated).

Levels of pH were not adversely impacted by the dose amounts used in either Phase I or II, as values remained between 7 and 8.5 for most final pH measurements. These values were consistent with the blank treatments for the soils, and suggest sufficient alkalinity exists in waters made up from the soils considered in this study to fully buffer any pH effects from flocculent treatment at the dose levels considered.

Table 2. Phase I analysis: flocculant effectiveness screening results.

Soil	Flocculant Chemical										
	Standard Contr	Standard Contr W	Biostar CH	Alum	Ferric Chloride	Hawkins AH 6447	Hawkins AH 6547	Hawkins AH 7747	Hawkins AH 117	Hawkins AH 457	Hawkins AH 820
Ada Subsoil	~	\	\	\	\	+	+	~	~	~	~
Ada Topsoil	~	~	\	\	~	~	·	\	\	\	~
Brandon Subsoil	\	\	\	\	\	+	+	\	\	\	\
Brandon Topsoil	\	\	\	\	\	~	+	\	\	\	\
Carlton Subsoil	\	\	\	\	\	+	\	\	·	·	~
Carlton Topsoil	\	\	\	~	\	+	+	\	\	~	~
Cook Subsoil	\	\	\	\	\	+	\	\	+	~	~
Cook Topsoil	~	~	~	\	\	+	·	~	~	·	+
Coon Rapids Subsoil	~	\	\	\	\	+	+	\	~	\	~
Coon Rapids Topsoil	·	~	~	·	·	+	+	·	·	·	+
E Grand Forks Subsoil	\	\	\	\	\	~	~	\	\	~	\
E Grand Forks Topsoil	\	\	\	\	\	+	+	\	\	\	\
Foley Subsoil	\	\	\	\	\	+	+	\	~	+	+
Foley Topsoil	\	~	~	\	~	+	+	\	\	~	~
Grand Rapids Subsoil	·	·	+	+	+	+	+	+	+	+	+
Grand Rapids Topsoil	·	·	·	~	~	+	+	·	·	·	+
Hampton Subsoil	**?**	**?**	\	\	\	+	\	\	+	·	\
Hampton Topsoil	\	\	\	\	\	\	~	\	\	\	\
Houston Riverbed	\	\	\	\	\	+	+	\	\	\	~
Houston Topsoil	·	·	·	·	·	·	·	~	~	·	·
Kandiyohi Subsoil	~	~	~	+	+	+	+	+	+	+	+
Kandiyohi Topsoil	~	~	~	~	~	+	+	·	~	·	·
Lakeville Subsoil	\	\	~	+	+	+	+	+	+	+	+
Lakeville Topsoil	~	\	~	~	~	+	+	~	~	·	·
Lindstrom Subsoil	\	\	\	\	+	\	+	\	\	~	~
Lindstrom Topsoil	\	\	\	\	\	·	+	\	\	\	~
Mankato Topsoil	~	·	~	·	+	+	+	+	+	+	+
Mapleton Topsoil	\	\	\	~	+	+	+	·	+	+	+
Moorhead Subsoil	+	+	·	+	+	+	+	+	+	+	+
Moorhead Topsoil	\	\	\	\	\	~	+	\	\	\	\

Legend: + turbidity < 100 NTU ~ turbidity 150 – 250 NTU
· turbidity 100 – 150 NTU \ turbidity > 250 NTU
? conflicting results

Table 2. Phase I analysis: flocculant effectiveness screening results, con't.

Soil	Flocculant Chemical										
	Standard Contr	Standard Contr W	Biostar CH	Alum	Ferric Chloride	Hawkins AH 6447	Hawkins AH 6547	Hawkins AH 7747	Hawkins AH 117	Hawkins AH 457	Hawkins AH 820
N Mankato Subsoil	\	\	\	\	\	\	~	+	\	\	\
N Mankato Topsoil	\	\	\	\	\	\	\	\	\	\	\
New Sweden Topsoil	\	\	\	\	\	+	+	\	~	+	+
Olivia A Subsoil	\	\	\	\	\	+	+	\	\	\	\
Olivia A Topsoil	•	•	•	~	~	•	+	•	•	+	+
Olivia B Clay	\	\	\	\	\	+	+	\	\	~	\
Owatonna Clay	~	~	•	~	•	+	+	•	•	•	+
Owatonna Topsoil	\	\	\	~	+	+	•	+	•	•	+
Perham Subsoil	\	~	\	\	\	+	+	\	\	~	~
Perham Topsoil	\	\	\	\	\	+	+	\	\	~	~
Pipestone Subsoil	\	\	~	~	~	+	+	~	•	+	+
Pipestone Topsoil	+	+	+	+	+	+	+	+	+	+	+
Ramsey Peat	+	+	+	+	+	+	+	+	+	+	+
Rockford Cornfield	+	+	+	+	+	+	+	+	+	+	+
Rockford Subsoil	\	\	\	\	\	+	+	\	\	\	\
Rockford Topsoil	\	\	\	\	\	\	\	\	\	\	\
Sandstone Subsoil	\	\	\	\	\	+	+	•	+	+	+
Sandstone Topsoil	•	•	•	~	~	+	+	•	+	+	+
Stillwater Sediment	\	\	\	~	+	+	+	+	+	+	+
Tamarack Clay	\	\	\	~	+	+	•	~	+	+	~
Tamarack Peat	+	+	+	+	~	+	+	•	~	+	+
Tamarack Topsoil	\	~	~	+	+	+	+	+	+	+	+
Wabasha Sub Box	~	~	~	~	~	+	+	~	~	\	•
Wabasha Subsoil	\	\	~	~	~	+	+	~	+	+	+
Wabasha Topsoil	\	\	\	\	\	\	•	\	\	\	\
Worthington Topsoil	\	~	\	\	\	•	+	~	~	~	~
Worthington Subsoil	\	~	\	+	+	+	+	+	+	+	+

Legend: + turbidity < 100 NTUs; • turbidity 100 – 150 NTUs; ~ turbidity 150 – 250 NTUs; \ turbidity > 250 NTUs; **?** conflicting results

Table 2. Phase I analysis: flocculant effectiveness screening results, con’t.

Soil	Flocculant Chemical									
	Hawkins AH 846	Hawkins AH 852	Hawkins AH 882	Tramfloc 111	Tramfloc 133	Tramfloc 317	Tramfloc 342	Tramfloc 550	Tramfloc 723	Tramfloc 865A
Ada Subsoil	~	•	~	+	+	•	+	~	•	+
Ada Topsoil	~	~	~	+	+	•	•	~	•	•
Brandon Subsoil	\	\	\	~	\	\	\	\	\	~
Brandon Topsoil	\	\	\	**?**	**?**	\	\	\	\	\
Carlton Subsoil	~	\	~	~	~	\	\	\	•	+
Carlton Topsoil	•	\	~	•	~	•	+	\	~	+
Cook Subsoil	•	\	\	~	•	~	~	\	\	~
Cook Topsoil	+	~	~	+	+	+	+	~	•	+
Coon Rapids Subsoil	~	\	\	~	~	~	~	\	~	~
Coon Rapids Topsoil	+	~	~	+	+	•	+	~	~	~
E Grand Forks Subsoil	\	\	\	~	~	\	**?**	\	\	\
E Grand Forks Topsoil	\	\	\	~	\	\	\	\	~	~
Foley Subsoil	+	\	+	~	\	~	~	\	+	+
Foley Topsoil	~	\	~	+	~	~	~	\	~	~
Grand Rapids Subsoil	+	+	+	+	+	+	+	+	+	+
Grand Rapids Topsoil	+	~	•	+	+	•	+	•	+	+
Hampton Subsoil	\	\	\	~	\	\	\	\	+	+
Hampton Topsoil	\	\	\	\	•	\	\	\	\	\
Houston Riverbed	~	•	•	+	+	+	+	~	+	+
Houston Topsoil	+	•	~	+	+	+	+	•	•	+
Kandiyohi Subsoil	+	+	+	+	+	+	+	+	+	+
Kandiyohi Topsoil	+	~	~	+	+	+	+	\	•	+
Lakeville Subsoil	+	~	~	+	+	+	+	\	•	+
Lakeville Topsoil	+	+	+	+	+	+	+	+	+	+
Lindstrom Subsoil	+	\	\	~	+	•	+	~	•	+
Lindstrom Topsoil	~	~	\	•	•	~	•	\	\	~
Mankato Topsoil	+	+	+	~	+	+	•	•	+	+
Mapleton Topsoil	+	+	+	+	+	+	+	~	+	+
Moorhead Subsoil	+	+	+	+	+	+	+	~	+	+
Moorhead Topsoil	\	\	\	\	\	\	\	\	\	~

Legend: + turbidity < 100 NTUs ~ turbidity 150 – 250 NTUs
• turbidity 100 – 150 NTUs \ turbidity > 250 NTUs
? conflicting results

Table 2. Phase I analysis: flocculant effectiveness screening results, con't.

Soil	Flocculant Chemical									
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N Mankato Subsoil	\	\	\	\	\	\	\	\	\	\
N Mankato Topsoil	\	\	\	\	\	\	\	\	\	~
New Sweden Topsoil	+	•	•	•	•	•	+	~	+	+
Olivia A Subsoil	•	\	\	~	\	\	\	\	•	+
Olivia A Topsoil	+	•	•	+	+	+	+	•	+	+
Olivia B Clay	•	\	\	•	\	~	~	\	+	+
Owatonna Clay	+	+	+	+	+	+	+	+	+	+
Owatonna Topsoil	+	~	•	+	+	~	+	~	~	~
Perham Subsoil	+	+	+	+	+	+	+	•	+	+
Perham Topsoil	~	~	~	•	•	•	+	•	+	+
Pipestone Subsoil	+	+	+	+	+	+	+	•	+	+
Pipestone Topsoil	+	+	+	+	+	+	+	+	+	+
Ramsey Peat	+	+	+	+	+	+	+	+	+	+
Rockford Cornfield	+	+	+	+	+	+	+	~	+	+
Rockford Subsoil	\	\	\	\	\	\	\	\	\	~
Rockford Topsoil	\	\	\	\	\	\	\	\	\	\
Sandstone Subsoil	\	\	\	\	\	\	\	\	+	+
Sandstone Topsoil	+	•	+	+	+	+	+	+	+	+
Stillwater Sediment	+	•	+	+	+	+	+	\	+	+
Tamarack Clay	+	\	~	\	\	\	\	\	+	+
Tamarack Peat	+	+	+	+	+	+	+	•	•	+
Tamarack Topsoil	+	+	+	+	+	+	+	•	+	+
Wabasha Sub Box	~	•	•	+	+	+	+	\	+	+
Wabasha Subsoil	+	+	+	+	+	+	+	~	+	+
Wabasha Topsoil	\	\	**?**	\	\	\	~	~	~	~
Worthington Topsoil	~	~	\	+	+	+	+	~	•	•
Worthington Subsoil	+	+	+	+	+	+	+	•	+	+

Legend: + turbidity < 100 NTUs; ~ turbidity150 – 250 NTUs; · turbidity 100 – 150 NTUs; \ turbidity > 250 NTUs; **?** conflicting results

Chapter 4: Design Feature and Scale Study

Flocculation effectiveness is dependent upon the surficial chemical attraction of particles, the dispersion of the flocculant and the contact of the particles. These factors are normally expressed as: (a) what flocculant to add, (b) how to mix the flocculant, and (c) how to mix the particles in the presence of the flocculant. Chapter 3 addressed the question of what flocculant to add. This chapter addresses methods both to mix the flocculant and to mix the particles, using methods and techniques suited for construction fieldwork rather than laboratory determinations or even municipal water treatment.

The two mixing efforts are very different in both appearance and imparted energy. Flocculant mixing is done using “flash” or “rapid” mixing, in which the chemical is quickly and fully dispersed within the fluid. Rapid mixture of flocculants needs very high mixing velocity gradients to cause particles to contact each other, rather than just ride along and not aggregate. High mixing power may be required. However, ferric chloride in particular can mix into water very quickly and may require a mixing time of less than 10 seconds total, hence the term “flash” mixing. Rapid mixing may be the most important factor for coagulation (chemical) efficiency (Davis, 2010).

Particle mixing is done using “slow” mixing, in which the particle filled water is gently stirred such that flocculant-rich particles may bump into each other and stick (creating flocs); the energy level is low enough such that the particle flocs aggregate but do not break apart. Slow mixing to encourage floc aggregation from particles in treated waters must be gentle, with low to very low power such that particles come into contact but flocs do not break apart or shear. Slow mixing may be the most important factor for particle size and removal. Slow mixing times are typically 20 to 30 minutes, with shorter times in this range appropriate for summertime water temperatures and longer times appropriate for wintertime temperatures. Water velocities during slow mixing should be 0.5 to 1.0 ft/s to reduce the potential for inadvertent sedimentation that could clog the slow mixing process (Davis, 2010).

4.1: Methods

4.1.1: Turbid Water Stock Preparation

Turbid water stock was prepared by adding selected soil to water at a rate of 25 g/L and mixing (Figure 6). Water was mixed continually for all mixing experiments unless an experiment incorporated settlement during a sedimentation period. Mixing of stock was done using air injection, with particular emphasis on air circulation near the bottom of the stock container.

Figure 6. Turbid water stock prepared in a 30 gallon polyethylene container from soil sediment and tap water mixed by injection of air into bottom of fluid column. Staff gage units are feet of depth.

4.1.2: Turbidity Measurement

Turbidity was measured using 20-ml specimens placed into optical-quality glass vials analyzed in an Oakton Instruments T-100 turbidity meter with a range of 0 to 1000 NTUs (Figure 7).

Figure 7. Turbidity specimens and turbidity meter.

4.2: Evaluation of Flocculant Treatment Methods and Technologies

Four separate evaluations were done of flocculant treatment methods and technologies:

1) Mixing technology evaluation, in which different mixing methods and technologies were tested and compared;
2) Open pond treatment model evaluation, in which potential pond treatments were evaluated;
3) Gravity settlement evaluation, in which depths up to 6 feet were evaluated for occurrence of Type II settlement and sedimentation effectiveness related to extra depth; and,
4) Flocculant aided filtration evaluation, in which filtration effectiveness was evaluated for different conditions of flocculation, slow mix and sedimentation.

Each of these evaluations are described below.

4.2.1: Mixing Technology Evaluation

Mixing technologies were evaluated in a drainage channel/drainage ditch model made from 4-inch wide plastic rain gutter, 10 feet long and placed at an approximate 3% slope (Figure 8). Turbid water was pumped from a 25 gallon stock at a rate of 500 mL/min (+/- 20 mL/min), calibrated by measuring the volume in a graduated cylinder filled per unit of time. Mixing equipment or material was placed in the gutter beginning near the uphill point. The gutter provided laminar (not turbulent) flow representing a condition of no mixing energy imparted to the flow. A solution of ferric choride was typically injected at a rate of 25 mL/min to the mixing equipment, although some mixing technologies were soaked and allowed to passively exude with ferric chloride.

Discharge at the low end of the gutter was to a 20 gallon glass aquarium that acted as a sedimentation tank with a hydraulic retention time of approximately 80 minutes (Figure 9). The aquarium was tilted lengthwise and positioned to discharge over the low edge to a waste container. An inlet zone of the aquarium sedimentation tank was created using a 1-gallon plastic box approximately 4 inches deep by 6 inches long, perforated on the upstream side to limit turbulence within the sedimentation tank and to distribute flow across the whole sedimentation tank width.

Samples were taken at 10-minute intervals from the stock tank, the gutter channel discharge (representing the end of the mixing zone) and the discharge of the aquarium sedimentation tank (representing the point of complete treatment). Samples were measured for turbidity.

Results of the mixing experiment are presented in Appendix D.

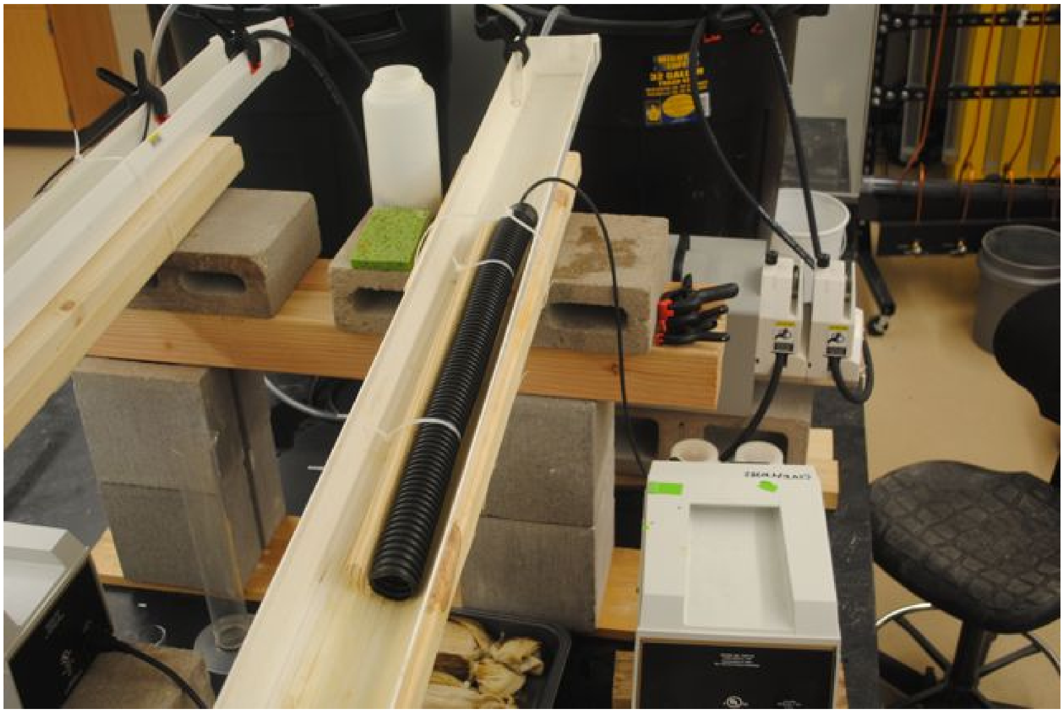


Figure 8. Twin channels for evaluation of mixing technologies, with 2-foot length of corrugated tubing shown in channel on right. Note flocculant stock injection line consisting of small-diameter black tubing at top of corrugated tubing.

Figure 9. Twin 20-gallon sedimentation tanks, with orange snow fence submerged in inlet zone to reduce short-circuiting. Note two sampling locations: the end of channel/prior to inlet and the overflow weir of sedimentation tank.

Mixing technologies evaluated included:

- Laminar flow;
- 1 1/4th inch diameter corrugated pipe, 2 and 8 feet long;
- ½ inch gravel, 2 and 6 feet long;
- Baffled flow, consisting of a gutter section 3.5 feet long with baffles set approximately 3 inches apart alternating side to side with approximately 80% flow blockage;
- Floc pillow, consisting of a sponge material cut to a 40 mm x 190 mm x 25 mm size and injected with 6.0 mL undiluted ferric chloride (supplied at 35% purity);
- Floc log, consisting of five sponge sections cut to the same dimensions as with the floc pillow and soaked to saturation by squeezing and releasing in a pan of 100 mL ferric chloride diluted 10x with tap water;
- Drip line mixing, consisting of an approximately 4 foot length of commercial "soaker hose" placed above the flow to distribute the ferric chloride solution;
- Sump recirculation, consisting of a 1-gallon polyethylene pail with a 8 gpm centrifugal pump recirculating flow, with discharge via the pail overflow;
- Turbulent air injection, consisting of a 3/8 inch pressurized air line fed into the flow transiting a 1 L HDPE bottle;
- Double bladed mixer, consisting of twin, overlapping turbine mixer blades circulating in the flow transiting a 1 gallon polyethylene pail; and,
- Single bladed mixer, consisting of a single turbine mixer blade circulating in the flow transiting a 1 L HDPE bottle.

Technologies are shown in photographs accompanying the applicable results provided in Appendix D. All ferric chloride dose rates were 0.2 mL/L, except for the floc pillow and floc log technologies which were considered passive dosing and therefore with indeterminate doses.

Results of the mixing technology evaluation are provided in Table 3, using a relative performance scale based on discharge turbidity levels.

Table 3. Relative performance of mixing technologies.

High performance (discharge turbidity < 50 NTUs)

- 6 feet of gravel (91% removal)
- 8 feet of corrugated pipe (85% removal)
- Turbulent air injection (95% removal)
- Single bladed mixer (95% removal)

Medium performance (discharge turbidity 51 - 150 NTUs)

- 2 feet of corrugated pipe (78% removal)
- Baffled flow (64% removal)
- Floc log (82% removal)
- Drip line mixing (73% removal)
- Sump recirculation (59% removal)
- Sedimentation only/no flocculation (removal varies by soil)

Low performance (discharge turbidity 151 - 250 NTUs)

- Laminar flow (57% removal)
- Floc pillow (66% removal)
- Double bladed mixer (76% removal)

Very low performance (discharge turbidity > 250 NTUs)

- 2 feet of gravel (36% removal)

4.2.2: Open Pond Treatment Model Evaluation

Larger scale treatment tests were performed with the goal to model open pond treatment and evaluate effectiveness. Two pond surrogates were used: a 6-inch deep, 27-gallon kiddie pool and a 4-foot deep, 80 gallon recycling bin-tank (Figure 10). Turbid water was created by mixing Mankato topsoil into the water at a rate of 25 g/L. Ferric chloride was directly applied to the surface of the pond surrogates. Mixing was done for 2 minutes using either a vertically oriented, drill-mounted

a) Preparation of turbid sediment-filled water.

b) Flocculant addition.

c) Mixing by drill-mounted vertically-oriented turbine to 6-inch deep water in tank made from kiddie pool.

d) Mixing by air injection to 6-inch deep water in tank made from kiddie pool.

e) Mixing by air injection to 36-inch deep water in tank made from recycling bin.

f) Sample collection for turbidity measurement.

Figure 10. Open pond modeling and treatment evaluation.

turbine blade mixer or pressurized air injection. Upon completion of the mixing, samples were taken from the top 3 inches of the pond surrogate water and turbidity measurements made. Turbidity measurements continued for at least 15 minutes and until the measurements were stable and relatively consistent. Results are provided in Appendix E.

The ferric chloride dose of 0.2 mL/L (equivalent to 66 gallons/acre foot) achieved a treatment from 505 and 351 NTUs down to 20 and 45 NTUs in the 4-foot deep tank with 2 minutes of pressurized air injection mixing and the 6-inch deep tank with 2 minutes of turbine blade mixing, respectively. An earlier experiment with a dose of 0.1 mL/L did not achieve much reduction at all (results not provided as the test was not extended beyond 5 minutes).

A repeated test with the 4-foot tank with 2 minutes of pressurized air injection mixing resulted in a reduction from 727 NTUs to 57 NTUs, similar results to the first test. However, using 2 minutes of pressurized air injection mixing with the 6-inch deep tank did not achieve similar results as the turbine blade mixed trial, as a reduction from 530 NTUs to only 280 NTUs was achieved in 26 minutes of sedimentation time. It appears that the pressurized air injection mixing needed more vertical length (depth) in the water column of an open pond to effectively mix the ferric chloride or cause particle aggregation. This result somewhat contrasts with the result for pressurized air injection in the mixing technologies evaluation, which achieved high performance with turbidity consistently below 50 NTUs. However, the pressurized air mixing in the previous evaluation was done in a confined volume (a 1 L bottle), not in an open water column.

4.2.3: Gravity Settlement Evaluation

Sedimentation column treatment tests were performed to model deeper sedimentation and evaluate effectiveness, particularly whether Type II settlement was occurring with the ferric chloride dose used in this study. Columns were constructed of 4 inch diameter PVC piping and were 8-feet tall with sampling ports at 0, 2, 4 and 6 feet depths (Figure 11). Sampling ports consist of a 3/8 inch ball valve connected to a saddle tap, with a ½ inch hole drilled through the pipe wall.

Turbid water was created by mixing Mankato topsoil into 8 gallons of water at a rate of 25 g/L. Ferric chloride was directly applied to the surface of the turbid water at a rate of 0.2 mL/L or 6 mL/8 gallons. Mixing was done for 2 minutes using a vertically oriented, drill-mounted turbine blade mixer. Upon completion of the mixing, water was poured into the sedimentation column. Sampling and turbidity measurements began immediately after and continued for 1 hour at 10 minute increments. Nine tests were performed. Results are provided in Appendix F as both turbidity and removal percentage.

Figure 11. Sedimentation columns. Only bottom third of each 8-foot column shown, with 6-foot depth valved sampling port (attached to blue saddle tap) and two sludge clean outs. Open top and 2-foot and 4-foot depth valved sampling ports not shown.

Results generally showed an achievement of 80% turbidity reduction by 30 minutes, and an average of 94% removal at 60 minutes. Results for times less than 30 minutes suggest substantial variability and poor removal. Type II settlement was observed, as the results are not strictly linear and do show acceleration of removal with increasing time and depth. These results agree with the recommendation of Davis (2010) that a 60 minute sedimentation period should be used for best removals and sufficient factor of safety.

4.2.4: Flocculant-Aided Filtration Evaluation

The additional effectiveness in turbidity removal provided by filtration was evaluated for flocculant treated waters, using both granular (sand) and membrane (geotextile) filtration. Flocculant-aided filtration was evaluated by comparing flocculant treated waters after filtration with non-flocculated (blank) waters after filtration and determining the reduction provided by the flocculant addition. Three different dose levels of ferric chloride were used: 1.25, 2.5 and 5.0 mL/L. The dose range was a response to commentary in Crittenden (2005) that flocs might catch on the filter media then continue to aggregate as additional particles approach the filter, even with incomplete sedimentation after flocculation.

Three filtration processes were evaluated:

- Conventional filtration, consisting of rapid mix, slow mix and sedimentation prior to filtration;
- Direct filtration, consisting of rapid mix and slow mix but no sedimentation prior to filtration;
- In line filtration, consisting of rapid mix only prior to filtration.

As discussed previously, conventional filtration is considered appropriate for waters with turbidities up to 1000 NTUs, while direct and in line filtration approaches are considered appropriate for waters with turbidities less than 15 NTUs due to the effort involved in backwashing or cleaning filters.

As shown in Figure 12, six granular filters were constructed:

- #4 Sieve (passing) Granular Activated Carbon (#4 GAC);
- Sand passing #4 sieve retained on a #10 sieve (4-10 sand);
- Sand passing #10 sieve retained on a #20 sieve (10-20 sand);
- Garnet sand passing a #36 sieve retained on a #54 sieve (54 garnet);
- #4 GAC on top of 10-20 sand, in equal thicknesses; and,
- #4 GAC on top of 54 garnet, in equal thicknesses.

Each granular filter was 2 inches in diameter. Filter media was a total of 6 inches in depth for each filter, whether a mono or a dual media filter. The filter apparatus was a manufactured apparatus designed to pair with the 6-place jar tester used in this study, both manufactured by Phipps and Bird (Richmond, VA).

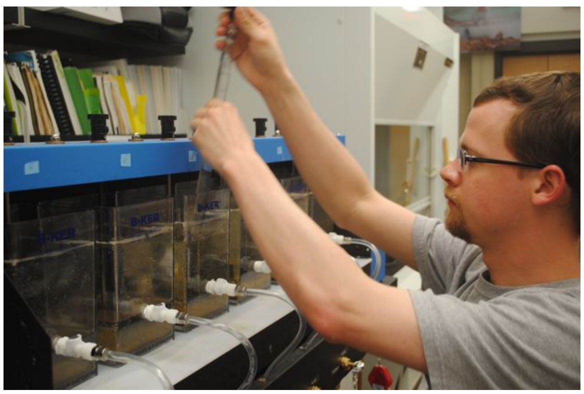
Turbid water was prepared in 2 L batches using Mankato topsoil at 25 g/L. After the sediment was thoroughly mixed, the dose of ferric chloride was added and mixed for 1 minute in the rapid mix phased. Slow mixing for 20 minutes and sedimentation for 20 minutes were employed, depending upon the filtration process being tested. Water was then released through the filter column to pass downward across the filter media. During the middle of the filter run, triplicate samples were taken from the filtrate and analyzed for turbidity.

Membrane filtration evaluation had the same procedure, except that the membrane filters were placed in filter cones for support beneath the stock containers and above beakers that served to collect the filtrate (Figure 13). Three membranes were evaluated in this study:

- Geotex 401 non-woven needle punched geotextile (5 oz/sy, Propex, Inc.);
- Geotex 104 F woven geotextile (7 oz/sy, Propex, Inc., Chattanooga, TN); and
- Paper filter, consisting of a Melita #4 coffee filter.

a) Preparation of turbid sediment-filled water for six different filter columns.

b) Filter columns with 4-inches of granular media in a range of particle sizes.



c) Sampling of flocculant-treated water after being allowed to settle.

d) Sampling of flocculant-treated filtered water (turbidity ~10 NTU).

Figure 12. Flocculation-aided sand filtration evaluation.

Results of the granular filter evaluations and the membrane filter evaluations are summarized in Tables 4 to 9 and Tables 10 and 12, respectively. Full results are provided in Appendix G. The following observations may be made about the results:

- Ferric chloride improves filtration removal of turbidity;
- Granular filter materials are all good, no clear benefit to one filter material than other in regards to turbidity removal, though #36 garnet and #54 garnet both are slower hydraulically and therefore may not be suitable for construction site and stormwater runoff applications;
- Membrane filter materials were all good for conventional filtration, though the non-woven geotextile did not provide results as high as the woven geotextile and paper filters;
- Dose levels higher than 1.25 mL/L appear to provide insignificant improvement for turbidity removal with conventional filtration;

- Direct and in line filtration are not as effective as conventional filtration, and generally require larger doses of ferric chloride, for the conditions investigated;
- Velocity through the filters ranged from 0.3 to 1 L/min for a rate of flow of about 4 to 11 gpm/ft^2, which matches the guidelines presented in Crittenden (2005). Note that these rates assume the granular filter can be backwashed and does not clog; and,
- Filter run time, defined as the time of operation until filter clogging, was not determined in this experiment.

Figure 13. Membrane filtration apparatus with six parallel treatment lines, each consisting of mixing tank, valved delivery tubing, filter cone and filtrate collection beaker.

Table 4. Effectiveness provided by flocculant addition when filtering through 6 inches of #4 sieve retained granulated activated carbon (#4 GAC) as filter media.							
Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	99.7	11.9	33.1	19.7	88.1%	66.8%	80.2%
Direct Filtration[2]	132.1	100.0	69.4	91.6	24.3%	47.5%	30.7%
In Line Filtration[3]	155.1	205.6	138.7	120.3	-32.6%	10.6%	22.4%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 5. Effectiveness provided by flocculant addition when filtering through 6 inches of #4 sieve passing #10 sieve retained sand (4-10 sand) as filter media.							
Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	54.4	11.2	9.1	13.5	79.4%	83.3%	75.2%
Direct Filtration[2]	98.7	61.5	31	9.2	37.7%	68.6%	90.7%
In Line Filtration[3]	129.8	148.4	167.1	172.8	-14.3%	-28.7%	-33.1%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 6. Effectiveness provided by flocculant addition when filtering through 6 inches of #10 sieve passing #20 sieve retained sand (10-20 sand) as filter media.

Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	64.2	9.7	24.6	13.5	84.9%	61.7%	79.0%
Direct Filtration[2]	110.0	65.1	53.9	16.1	40.8%	51.0%	85.4%
In Line Filtration[3]	177.0	301.5	138.8	137.7	-70.3%	21.6%	22.2%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 7. Effectiveness provided by flocculant addition when filtering through 6 inches of #54 sieve retained garnet sand (#54 garnet) as filter media.

Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	52.6	9.2	31.5	10.7	82.5%	40.1%	79.7%
Direct Filtration[2]	87.7	69.6	62.9	11.3	20.6%	28.3%	87.1%
In Line Filtration[3]	200.7	219.7	308.0	200.4	-9.5%	-53.5%	0.1%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 8. Effectiveness provided by flocculant addition when filtering through 3 inches of #4 sieve granulated activated carbon and 3 inches of #10 sieve passing #20 sieve retained sand (#4 GAC + 10-20 sand) as filter media.

Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	103.2	16.3	25.3	11.7	84.2%	75.5%	88.7%
Direct Filtration[2]	99.7	112.3	58.5	30.7	-12.6%	41.3%	69.2%
In Line Filtration[3]	222.5	263.7	361.5	189.4	-18.5%	-62.5%	14.9%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 9. Effectiveness provided by flocculant addition when filtering through 3 inches of #4 sieve granulated activated carbon and 3 inches of #54 sieve garnet sand (#4 GAC + 54 garnet) as filter media.

Filtration Method	Turbidity of Blank (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	64.3	10.4	35.4	10.4	83.8%	44.9%	83.8%
Direct Filtration[2]	138.7	75.7	54.3	11.7	45.4%	60.9%	91.6%
In Line Filtration[3]	196.0	166.3	139.7	166.1	15.2%	28.7%	15.3%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Three replicates analyzed for average filtrate turbidity.

Table 10. Effectiveness provided by flocculant addition when filtering through nonwoven needle punched geotextile filter.

Filtration Method	Turbidity of Blank as Filtered (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	100	24.0	61.3	29.3	76.1%	38.7%	70.0%
Direct Filtration[2]	178	117.1	88.8	113.2	34.1%	50.0%	36.3%
In Line Filtration[3]	261	314.7	223.2	225.5	-20.6%	14.4%	13.5%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Six replicates analyzed for average filtrate turbidity.

Table 11. Effectiveness provided by flocculant addition when filtering through woven geotextile filter.

Filtration Method	Turbidity of Blank as Filtered (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	82	9.3	19.3	7.6	88.7%	76.6%	90.8%
Direct Filtration[2]	121	101.5	62.6	10.3	15.8%	48.0%	91.4%
In Line Filtration[3]	228	185.7	137.9	154.2	18.5%	39.4%	32.3%

Notes:

1) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
2) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
3) In line filtration = 1 minute rapid mix then filter.
4) Six replicates analyzed for average filtrate turbidity.

Table 12. Effectiveness provided by flocculant addition when filtering through paper filter.							
Filtration Method	Turbidity of Blank as Filtered (NTUs)	Average Filtrate Turbidity (NTUs)[4]			Reduction Due to Flocculant Addition		
		1.5 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$	1.25 mL/L $FeCl_3$	2.5 mL/L $FeCl_3$	5 mL/L $FeCl_3$
Conventional Filtration[1]	49	4.1	12.9	4.5	91.7%	74.0%	90.8%
Direct Filtration[2]	40	45.3	31.5	4.1	-13.1%	21.4%	89.7%
In Line Filtration[3]	48	22.6	12.7	13.8	52.5%	73.3%	71.0%

Notes:

5) Conventional filtration = 1 minute rapid mix, 20 minutes slow mix, 20 minutes sedimentation then filter.
6) Direct filtration = 1 minute rapid mix, 20 minutes slow mix then filter.
7) In line filtration = 1 minute rapid mix then filter.
8) Six replicates analyzed for average filtrate turbidity.

4.3: Application of Results to Field Operations

The main results of the lab studies presented here, augmented by the literature recommendations, may be summarized as follows:

- Ferric chloride at a dose rate of 0.2 mL/L, equal to 66 gallons of ferric chloride per acre foot of water, is an effective flocculant under many mixing conditions for Minnesota sediments.
- Rapid mixing of ferric chloride can be done in as little as 6 seconds (Table 13), but requires intentional effort for best results, not simply pouring on a pond surface.

Table 13. Sizing of the flash mix vessel to have 6 seconds of hydraulic retention time.

Flow rate (gpm)	Size of flash mix vessel (gal)
40	4
100	10
200	20
400	40
1000	100

- Mixing to create flocs (slow mix) can be done well with flow through a corrugated pipe, through a small mixing zone with injected air or a turbine blade mixer, or perhaps through a rough surface such as between rip rap stones. In general, a longer slow mix flow path is better, keeping a minimum flow velocity of 1 foot/second.

- Sedimentation following flocculation and slow mix should be 60 minutes in duration before discharge (Table 14).

Table 14. Sizing of the sedimentation basin to provide 60 minutes of hydraulic retention time.

Flow rate (gpm)	Size of sedimentation basin (gal)	Surface area of sedimentation basin if 4 feet deep (sf)
40	2400	80
100	6000	200
200	12,000	400
400	24,000	800
1000	60,000	2000

- Pre-flocculation (untreated) sedimentation should be done for minimization of sediment and the associated ferric flocculant dose rate.

- Deeper sedimentation basins will likely improve turbidity removal; and,

- Filtration can be effective to polish and improve flocculant-treated waters after sedimentation (Table 15).

Table 15. Sizing of a granular filter to provide 2 gpm/sf flow, assuming filter can be cleaned of sediment.

Flow rate (gpm)	Filter area (sf)	Potential length of 3-foot high berm to achieve filter area (ft)
40	20	4
100	50	10
200	100	20
400	200	40
1000	500	100

As a last concern, use of ferric chloride for flocculant treatment of turbid water has the side effect of adding chloride (Cl^-) to surface water upon discharge of the treated water. The question is what is the potential concentration of the Cl^- and how does this concentration compare to ecological standards.

Checking the molar concentrations for the flocculant dose of 0.2 mL/L of ferric chloride, it is estimated that the resulting chloride (only) concentration would be 133 mg Cl^- per liter of treated water. This level is well below the Total Maximum Daily Load (TMDL) concentration of 230 mg Cl^-/L typically set for chloride-impaired waters.

The 230 mg Cl^-/L is also the maximum level allowable for the chronic 96-hour/4-day ecological exposure. The maximum level allowable for the acute level is frequently set as 860 mg Cl^-/L. Acute exposure limits may be more appropriate in discussions of releasing water in a batch as a one-time event such after pond treatment. Therefore, the 133 mg Cl-/L concentration associated with flocculation at a ferric chloride dose of 0.2 mL/L would be well below the acute level, even in undiluted (only treated) waters.

Chapter 5: Best Management Practices

This chapter presents methods of design and implementation for best management practices (BMPs) for the reduction, control and capture of erosion products related to sediments and contact waters potentially released during concrete construction or demolition. This assessment assumes full compliance with and adherence to the guidance of the Minnesota Stormwater Manual (2005) and requirements of MPCA General Permit MN R 100001, Authorization to Discharge Stormwater Associated with Construction Activity Under the National Pollution Discharge Elimination System. This assessment of BMPs for concrete sediments and contact waters primarily addresses what changes and/or adjustments may be required to adapt existing soil sediment BMPs.

5.1: Best Management Practices Overview

Sediments have significant potential to cause habitat loss, change waterway hydraulics, asphyxiate aquatic and benthic creatures, degrade navigation and plug drainage pipes and culverts. Construction sites are of particular concern due to the typical amount of disturbed ground, the stockpiles of earthen or particulate materials, the disturbance caused by construction equipment and operations, and the exposure to precipitation, sun and wind. Before flocculant treatment is considered, general BMPs for sediment control should be implemented to achieve broad reductions in sediment occurrence.

Preventing sediments from leaving a construction site requires a strategy built upon multiple lines of sediment control, if cost- and labor-efficiency is important. Such an approach provides flexibility for adjustment around both changing site operations and shifting seasonal weather, and can be strengthened through proactive maintenance. From the guidance provided in the Minnesota Stormwater Manual (2005), the following general classification of BMPs are suggested for construction sites:

- Diversion to limit run-on water;
- Reduction of erosional forces by surface water velocity reduction;
- Reduction of sediment development through sediment collection or anchoring;
- Sedimentation of mobilized sediments;
- Filtration of sediment-carrying flows;
- Collection of captured or contained sediments;
- Treatment of pH (hydronium and hydroxide);
- General housekeeping, including collection of trash and prevention of hazardous waste releases;
- Maintenance of erosion and sediment control devices/installations;
- Regular inspections; and,
- Recordkeeping.

Beyond guidance, erosion and sediment control are required by Minnesota regulation implanted through the requirements of MPCA General Permit MN R 100001, Authorization to Discharge Stormwater Associated with Construction Activity Under the National Pollution Discharge Elimination System.

5.2: Best Management Practices for Flocculation Treatment

The treatment of construction site waters by flocculation must be approached not as a typical earthwork construction process, likely focused on geometry and materials, but as a treatment process focused on effectiveness, flexibility and resiliency. Geometry and materials must follow, not lead. Guiding objectives may be summarized as in Table 16.

Overall, flocculant treatment of construction site waters occurs with nine phases:

1. Characterization of Design Objectives;
2. Process Design;
3. Treatment Works and Site Design;
4. Installation/Construction;
5. Operation;
6. Evaluation;
7. Adjustment;
8. Maintenance; and,
9. Deconstruction and Salvage.

These nine phases are shown in Figure 14. For best management, each of these nine phases should be considered separate and distinct, with individual sequence direction and review. Skipping a phase evaluation could result in a lack of problem recognition, and strongly contribute to a systematization of problems and ultimate treatment failure, particularly to be true due to the interaction of hydraulic, chemical and physical factors that provides the foundation of flocculant treatment.

Table 16. Guiding objectives of flocculation treatment of construction site waters.

Guiding Objective	Effect(s) If Not Observed	Factors Influencing Success
Select appropriate treatment chemical and dose	Ineffective sedimentation	• Particle mineralogy • Particle size • Particle surface charge • pH • Treatment chemical reactivity • Jar test evaluation effectiveness
Manage hydraulics	System flood; potential incomplete or over dosing; potential ineffective settlement	• Water source quantity and rate • Headworks design • Treatment unit design
Foster optimal conditions of mixing	Poor floc formation; potential overdosing	• Rapid mix unit volume • Rapid mix method • Rapid mix energy
Preserve contrast of very high energy for mixing and very low energy for sedimentation	Poor floc formation; ineffective sedimentation; potential overdosing	• Rapid and slow mix unit volumes • Rapid and slow mix methods • Rapid and slow mix energies
Consider operational details	System difficulty and inflexibility; inability to adjust to potential changes	• Receiving water requirements • Access • Power delivery • Measurement and control strategy and implementation • Sediment sludge removal • Contingencies for unexpected conditions

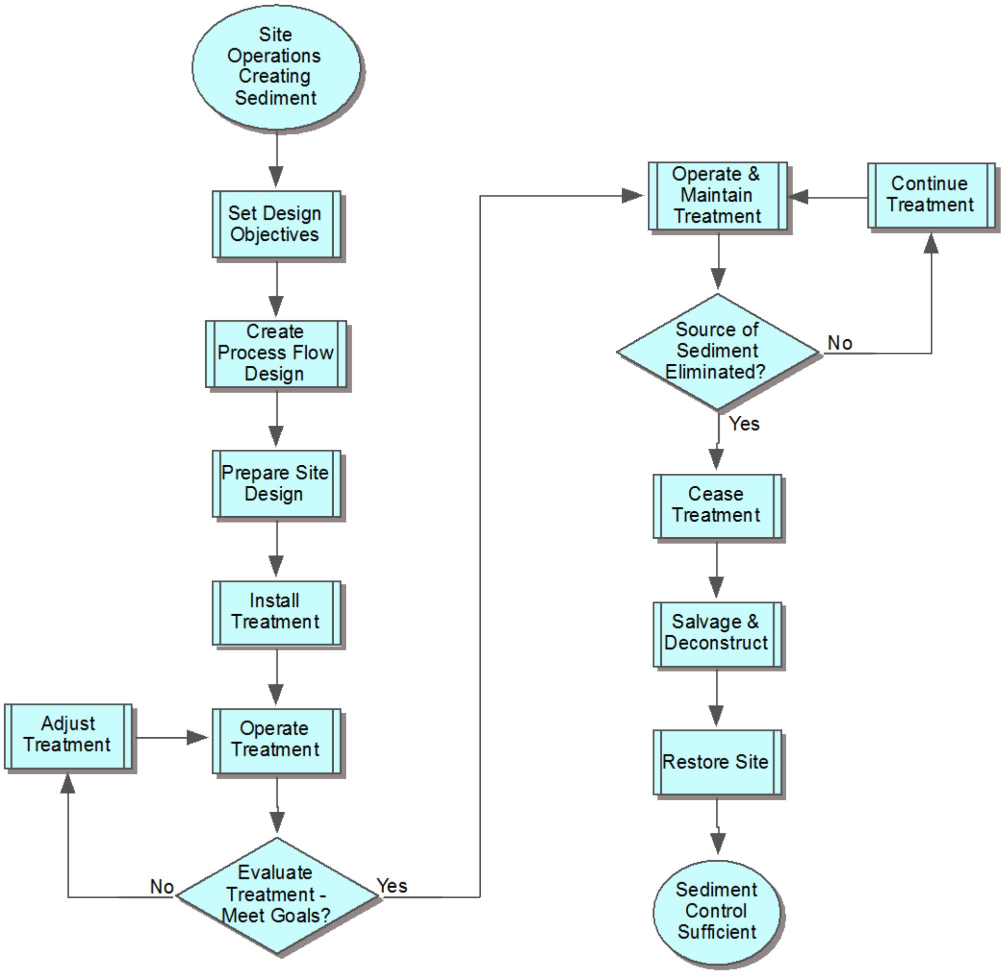


Figure 14. Phases, relative order and evaluation cycles of flocculant treatment of construction site waters.

Process steps for the characterization of design objectives are shown in Figure 15. Flocculant selection, optimization and effectiveness as compared to traditional sediment control approaches are all detailed with consideration of flocculant chemistry and dosing for site-specific sediments.

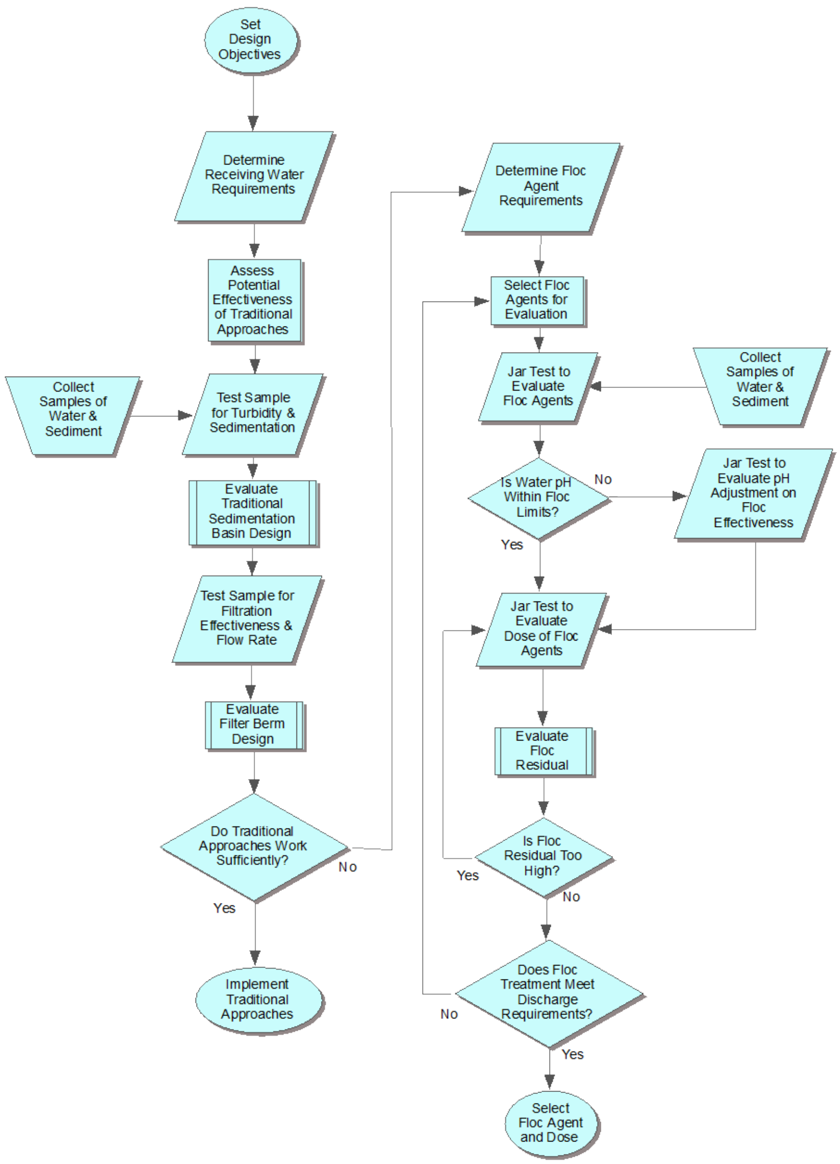


Figure 15. Process steps for the characterization of design objectives.

Treatment process flow design is detailed in Figure 16. Individual treatment processes including hydraulics, mixing, sludge trapping, sludge removal, and monitoring are all described by design steps. Evaluation cycles relate to whether design objectives are met.

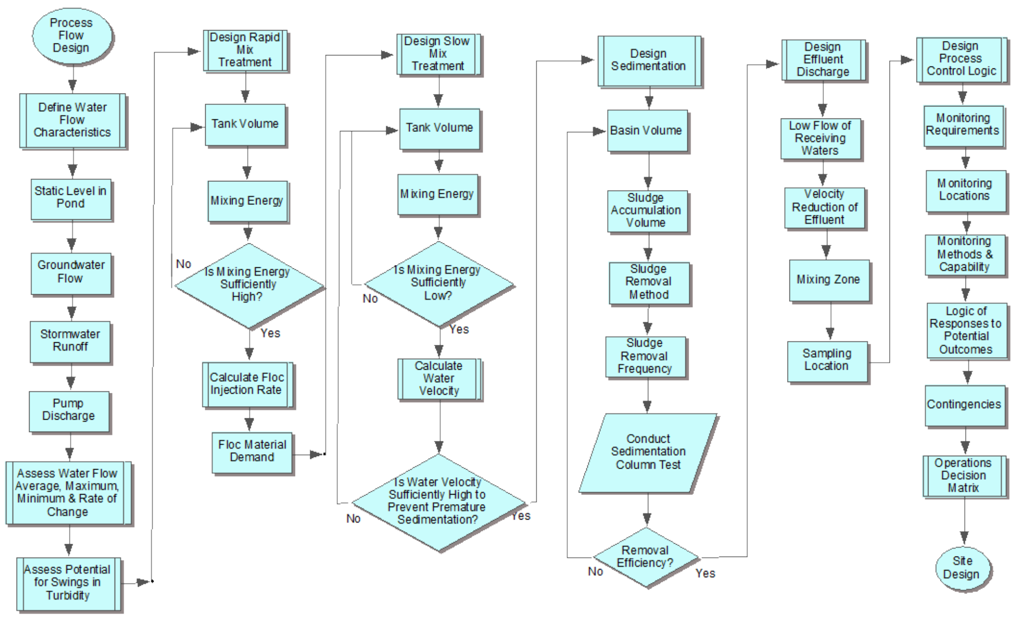


Figure 16. Treatment process flow design.

Treatment works and site design steps are detailed in Figure 17. These operations are the more traditional layout geometry and utility design processes that follow treatment process design.

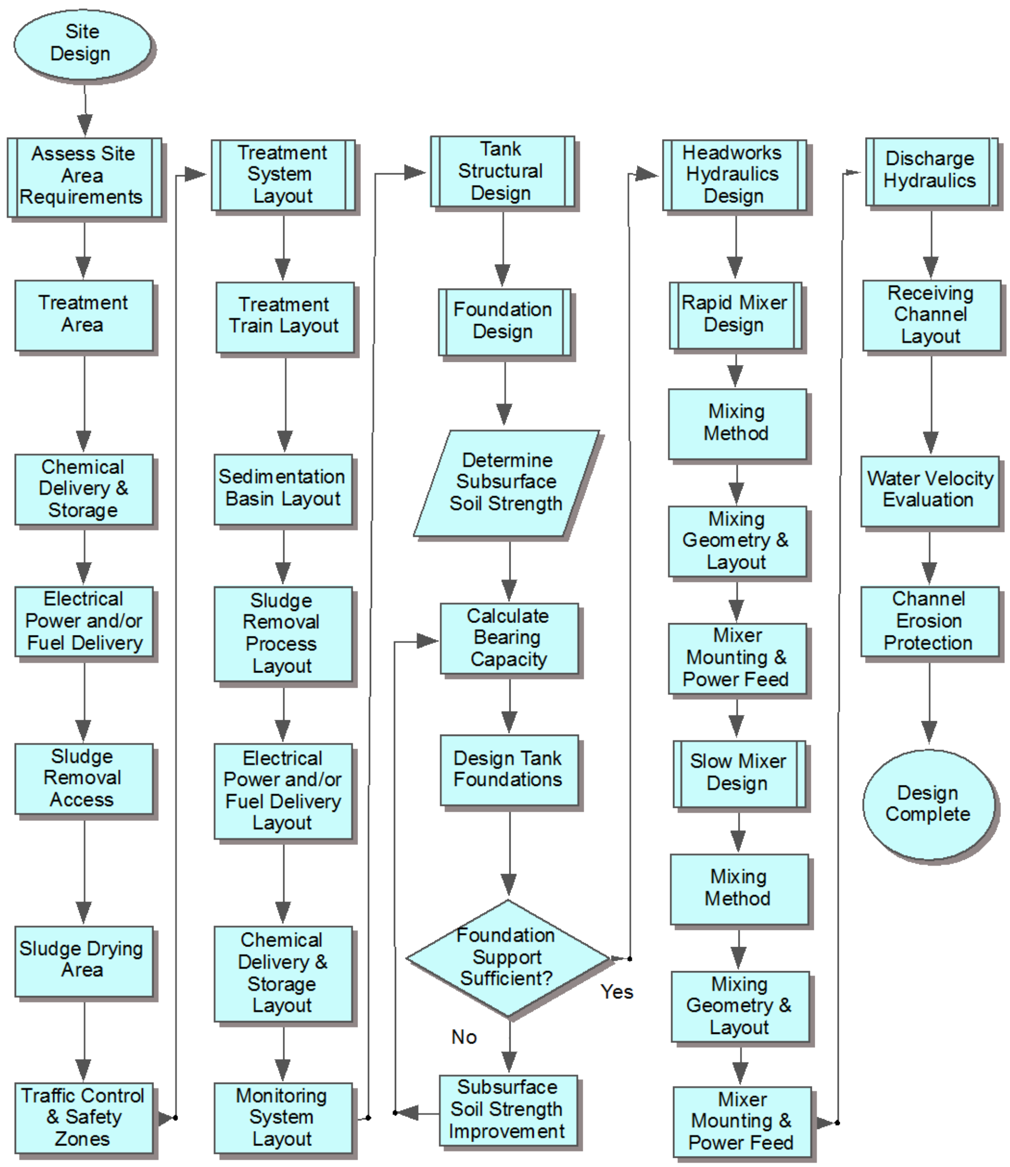


Figure 17. Treatment works and site design steps.

Chapter 6: Conclusions

The chemical treatment practice known as flocculation can be effective for purifying construction site runoff of sediment, suspended solids and colloidal particles. Flocculation is generally used in combination with traditional sedimentation and filtration methods related to stormwater pollution prevention and dewatering fluid treatment.

Soil samples from across Minnesota, representing the wide range of geologic and geomorphological conditions, were used to identify differences in flocculant applicability and effectiveness. Soils were observed to have specific turbidity characteristics, as shown by the results from the blank (no flocculent) treatments. As commonly observed in the geotechnical and sedimentation disciplines, soil sediment turbidity is a function of several soil characteristics: fines content, particle size and distribution, particle surface charge and mineral composition. Some soils were found to have insufficient fines to cause turbidity beyond what can be treated by gravity sedimentation alone. In this study, soil sediment turbidity ranged from a high of 1000 NTUs to a low of 35.9 NTUs, averaging 322 NTUs with a standard deviation of 265 NTUs (relative standard deviation of 82%).

Flocculent chemicals were found to have highly specific effectiveness across the range of soil types. Specific dose by turbidity relationships exist for each flocculent chemical and each soil, particularly for polymer compounds that can either work very well or make turbidity worse due to specific surface charge interrelationships. When effective, dose levels can vary between 0.2 to 100 ppm. This does range is quite large, given the potential for wide cost differences between flocculent chemicals (anecdotally noted as ranging from $2 to $50 per gallon).

Flocculent chemicals found to be broadly effective in this study include: ferric chloride, Aqua Hawk 6447 and Tramfloc 865A. Ferric chloride was found to treat turbidity consistently to below 100 NTUs for all soils considered in this study, and typically to below 50 NTUs for most soils, at a dose of 0.2 mL/L (approximately 200 ppm, or 70 gallons of ferric chloride per acre foot of water to be treated).

Levels of pH were not adversely impacted by the dose amounts used in either Phase I or II, as values remained between 7 and 8.5 for most final pH measurements. These values were consistent with the blank treatments for the soils, and suggest sufficient alkalinity exists in waters made up from the soils considered in this study to fully buffer any pH effects from flocculent treatment at the dose levels considered.

Pre-flocculation (untreated) sedimentation should be done for minimization of sediment and the associated ferric flocculant dose rate.

Rapid mixing of ferric chloride can be done in as little as 6 seconds but requires intentional effort for best results, not simply pouring on a pond surface. Mixing to create flocs (slow mix) can be done well with flow through a corrugated pipe, through a small mixing zone with injected air or a turbine blade mixer, or perhaps through a rough surface such as between rip rap stones. In general, a longer slow mix flow path is better, keeping a minimum flow velocity of 1 foot/second.

Sedimentation following flocculation and slow mix should be 60 minutes in duration before discharge. Deeper sedimentation basins will likely improve turbidity removal. Filtration can be effective to polish and improve flocculant-treated waters after sedimentation, and may involve sedimentation bank infiltration or in-channel check dam features to work as filters.

Best management practices (BMPs) were also developed for evaluation and design of flocculant treatment methods and technologies and the associated sizing for flows representative of field operations.

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Appendix A – Soil Sample Characterization

Soil Characterization Data Sheet
MnDOT Floc
Enviromental Engineering Lab-TN 382
11/14/2012
Revised 03/25/2013

Site & Strata	Hydrometer Reading							pH	Organic Burn			Sample Date	Sample Location
Ada Subsoil	22	19	17	16	16	14	13	8.3	38.1986	37.6312	1.5%	7/25/12	TH 9: RP 192 50'E
Ada Topsoil	31	26	22	21	18	14.5	13	7.8	42.2853	39.7849	5.9%	7/25/12	TH 9: RP 192 50'E
Brandon Subsoil	32.5	30.5	29	27	26.5	24	20	7.4	43.5556	41.6424	4.4%	7/21/12	I 94 SP#8824-100
Brandon Topsoil	36	33.5	30.5	29	27.5	25	20.5	7.2	35.192	32.0479	8.9%	7/21/12	I 94 SP#8824-100
Carlton Subsoil	51.0	45.0	37.5	32.5	27.5	19.5	15.0	8.3	50.2041	49.5052	1.4%	10/10/12	TH 210 / Jay Cooke State Park
Carlton Topsoil	21.0	18.0	15.5	14.5	13.0	12.5	10.5	8.8	57.9638	57.3842	1.0%	10/10/12	TH 210 / Jay Cooke State Park
Cook Subsoil	15	13	12	11.5	10.5	10	8.5	7.6	40.0828	39.3778	1.8%	not stated	not stated
Cook Topsoil	11	10	9	8.5	8	8	7	6.6	39.2792	38.607	1.7%	not stated	not stated
Coon Rapids Subsoil	11.5	11	10	9.5	9.5	9	8	7.9	45.115	44.8176	0.7%	7/27/12	CR 14 & Flintwood Ave.
Coon Rapids Topsoil	10.5	10	9.5	9	9	8.5	8	7.3	42.367	41.0656	3.1%	7/27/12	CR 14 & Flintwood Ave.
East Grand Forks Subsoil	47	39	28.5	26	24.5	21.5	10.5	8.1	38.1747	36.9997	3.1%	7/25/12	TH 220: RP 23 W Ditch
East Grand Forks Topsoil	41.5	33.5	27	25	23.5	21.5	18.5	7.9	38.2869	34.8095	9.1%	7/25/12	TH 220: RP 23 W Ditch
Foley Subsoil	21	18	16.5	15.5	15	12	10.5	7.1	48.6811	48.1813	1.0%	7/9/12	TH 23 SP#0503-75
Foley Topsoil	22	20.5	17.5	16.5	15.5	12.5	11.5	7.3	46.8383	45.6372	2.6%	7/9/12	TH 23 SP#0503-75
Grand Rapids Subsoil	11	10.5	9.5	8.5	8	8	7.5	8.2	47.117	46.64	1.0%	7/5/12	TH 169 SP#3115-51
Grand Rapids Topsoil	15	12.5	11	11	9.5	8	7.5	7.7	43.2758	43.0439	0.5%	7/5/12	TH 169 SP#3115-51
Hampton Subsoil	32	27	22	20	18	16.5	15	7.9	41.6513	40.7795	2.1%	9/21/12	TH 52 NE Pond
Hampton Topsoil	32.5	27.5	23.5	21.5	20	18	15	7.2	38.8719	35.4016	8.9%	9/21/12	TH 52 NE Pond
Houston Riverbed	22	17	15	14	13	12	10	7.6	45.1316	44.3344	1.8%	9/27/12	CSAH 22 & Hop Hollow Rd
Houston Topsoil	22.5	18.5	15	13.5	12.5	11.5	9.5	7.4	44.6971	42.1139	5.8%	9/27/12	CSAH 22 & Hop Hollow Rd
Kandiyohi Subsoil	28.5	25.5	20.5	19.5	18	15.5	13	8.1	38.1984	37.7686	1.1%	8/1/12	CSAH 5 Sta 70+50 CL
Kandiyohi Topsoil	38	34.5	29	27	25.5	22.5	18.5	7.7	46.6952	42.6838	8.6%	8/1/12	CSAH 5 Sta 74+00 Lt
Lakeville Subsoil	31.5	25.5	21.5	20	18.5	16	14	7.6	44.1547	43.2905	2.0%	6/6/12	Holyoke Rd & 194th St W
Lakeville Topsoil	41	31	25.5	23	22	18.5	16	8	36.0307	34.3677	4.6%	6/6/12	Holyoke Rd & 194th St W
Lindstrom Subsoil	18	16.5	15	14.5	13.5	12.5	11	8	45.586	44.9655	1.4%	7/13/12	TH 8 N Lindstrom Lake
Lindstrom Topsoil	22	19	16	15	13.5	11.5	10	7.9	43.7376	42.214	3.5%	7/13/12	TH 8 N Lindstrom Lake
Mankato Topsoil	18	14	12	11.5	11	10.5	9.5	7.79	41.0658	40.3376	1.8%	11/20/12	TH 90 & Blue Earth R
Mapleton Topsoil	37	34.5	31	29	27.5	23	18	7.5	41.9586	40.2246	4.1%	11/4/12	Klein Pond N of TH 30
Moorhead Subsoil	48	40	34	31	28.5	26.5	22.5	8.3	43.4978	42.1036	3.2%	7/21/12	TH 75 & 50th Ave SP#1406-69
Moorhead Topsoil	39	33.5	29	27	25.5	23.5	19.5	7.8	43.5906	40.8702	6.2%	7/21/12	TH 75 & 50th Ave SP#1406-69
New Sweden Topsoil	18	16.5	15	14.5	14	13	11.5	7.97	44.5727	43.8493	1.6%	11/4/12	TH 22 at CD1
North Mankato Subsoil	31.5	29.5	27	25.5	23	21	17	7.6	39.8362	39.1343	1.8%	8/1/12	TH 14 Sta 518+50 Ravine
North Mankato Topsoil	35	32	28	26.5	24.5	22	18.5	7.1	45.1482	42.4729	5.9%	8/1/12	TH 14 Sta 518+50 Ravine
Olivia A Subsoil	24	21.5	17.5	16.5	14.5	13	11.5	8.2	46.0579	45.7711	0.6%	8/21/12	CR 62 at 1/4 mi W of US 71

Soil Characterization Data Sheet
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Site & Strata	Hydrometer Reading							pH	Organic Burn			Sample Date	Sample Location
Olivia A Topsoil	36.5	31	25.5	22.5	20	16.5	13	7.4	44.4135	40.368	9.1%	8/21/12	CR 62 at 1/4 mi W of US 71
Olivia B Clay	32	28.5	25.5	23.5	22	20	16	7.8	44.5888	43.7853	1.8%	8/21/12	CSAH 4 btwn CSAH 1 & US 71
Owatonna Clay	30	28	25.5	24	22.5	20.5	17	7.3	42.9901	41.8209	2.7%	8/21/12	TH 14 Sta 1569+48 SP#7401-34
Owatonna Topsoil	30	27.5	24	22.5	21	19	16	7.2	42.9447	40.8306	4.9%	8/21/12	TH 14 Sta 1569+48 SP#7401-34
Perham Subsoil	9	8.5	8.5	8.5	8	8	7	7	44.8753	44.5782	0.7%	7/21/12	TH 10 & CR 34 SP#5607-42
Perham Topsoil	12	11.5	10.5	10	9.5	9	8	7.5	44.8498	43.736	2.5%	7/21/12	TH 10 & CR 34 SP#5607-42
Pipestone Subsoil	23	21	18.5	17	16	15	13	8.1	40.6169	39.8541	1.9%	not stated	CSAH 10 at 1.5 mi E of TH 75
Pipestone Topsoil	27	22.5	19	17	16	14	12	7.9	39.1515	36.4854	6.8%	not stated	CSAH 10 at 1.5 mi E of TH 75
Ramsey Peat	20.5	17.5	15	13.5	12	10.5	9	6.6	45.8799	36.8351	19.7%	not stated	35 E & Maryland Ave
Rockford Cornfield	24.5	23	20	18.5	17.5	16.5	14	7.5	34.8561	33.306	4.4%	not stated	TH 55
Rockford Subsoil	30	27.5	25	23.5	22	19.5	16.5	6.9	33.5297	32.7203	2.4%	not stated	TH 55
Rockford Topsoil	32.5	28.5	24.5	22	21	17	13.5	7.4	36.8538	35.5014	3.7%	not stated	TH 55
Sandstone Subsoil	43.0	41.0	38.0	36.5	34.0	31.0	24.5	8.0	53.2787	51.9657	2.5%	10/10/12	North of TH 18, West of CH 61
Sandstone Topsoil	21.0	17.5	15.5	14.0	13.0	11.5	10.5	7.9	55.5695	53.2740	4.1%	10/10/12	North of CR 32, East of CH 22
Stillwater Sediment	44.5	34	29	24	19.5	14	10	7.5	35.5434	32.1189	9.6%	7/27/12	Bridge Pier River Boring
Tamarack Clay	50.5	49	47	44	40.5	33	23.5	7.1	38.2459	37.0922	3.0%	9/17/12	CSAH 32 Sta 137+36 40'Lt
Tamarack Peat	29	28	26.5	25	18	13	14	6.9	7.7385	0.7205	90.7%	9/17/12	CSAH 32 Sta 152+85 30'Lt
Tamarack Topsoil	22	19	17	15.5	14.5	11.5	9	6.9	37.4814	35.828	4.4%	9/17/12	CSAH 32 Sta 120+70 34'Lt
Wabasha Subsoil (Box)	27.5	20.5	16	15	13.5	12.5	11	7.8	40.738	39.5298	3.0%	9/21/12	CR 4 @ Handshaw Coulee (?)
Wabasha Subsoil (Rock)	17	16	15.5	15.5	15	14.5	14	8	48.1498	47.2421	1.9%	9/21/12	CR 4 @ Handshaw Coulee (?)
Wabasha Topsoil	34	28	22	20	18.5	16.5	14	7.5	43.8146	41.9462	4.3%	9/21/12	CR 4 @ Handshaw Coulee (?)
Worthington Subsoil	28	25.5	22.5	21	20	18	16.5	7.6	46.2904	45.2711	2.2%	7/16/12	TH 60 SP#5305-58
Worthington Topsoil	26	23	20	18.5	17.5	15	13	7.4	45.0201	42.4371	5.7%	7/16/12	TH 60 SP#5305-58

Soil Characterization Data
MnDOT Floc
Enviromental Engineering
11/14/2012
Revised 03/25/2013

Site & Strata	Strata	Geomorphology	Ecological Province	Natural Vegetation	MnDOT Triangular Textural Classification	Presumptive Unified Classification System Designation
Ada Subsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Upland Prairie	Sandy Loam	SM
Ada Topsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Upland Prairie	Organic Sandy Loam	SM
Brandon Subsoil	Stagnation Moraine	Wadena Lobe	Prairie Parkland	Oak Woodland	Slightly Organic Sandy Clay Loam	SC-SM
Brandon Topsoil	Stagnation Moraine	Wadena Lobe	Prairie Parkland	Oak Woodland	Organic Sandy Clay Loam	SC-SM
Carlton Subsoil	Glacial Lake Sediment	Superior Lobe	Laurentian Mixed Forest	Great Lakes Pine Forest	Loam	ML
Carlton Topsoil	Glacial Lake Sediment	Superior Lobe	Laurentian Mixed Forest	Great Lakes Pine Forest	Sandy Loam	SM
Cook Subsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Boreal Hardwood-Conifer	Sandy Loam	SM
Cook Topsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Boreal Hardwood-Conifer	Sandy Loam	SM
Coon Rapids Subsoil	Outwash	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Sandy Loam	SM
Coon Rapids Topsoil	Outwash	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Loam	SM
East Grand Forks Subsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Floodplain Forest	Slightly Organic Clay Loam	CL-ML-OL
East Grand Forks Topsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Floodplain Forest	Organic Clay Loam	OL
Foley Subsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Maple Basswood Forest	Sandy Loam	SM
Foley Topsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Maple Basswood Forest	Slightly Organic Sandy Loam	SM
Grand Rapids Subsoil	Outwash	Des Moines Lobe	Laurentian Mixed Forest	Boreal Hardwood-Conifer	Sandy Loam	SM
Grand Rapids Topsoil	Outwash	Des Moines Lobe	Laurentian Mixed Forest	Boreal Hardwood-Conifer	Sandy Loam	SM
Hampton Subsoil	Red Drift	Illinoisian Glaciation	Eastern Broadleaf Forest	Upland Prairie	Slightly Organic Sandy Loam	SM
Hampton Topsoil	Red Drift	Illinoisian Glaciation	Eastern Broadleaf Forest	Upland Prairie	Organic Sandy Loam	SM
Houston Riverbed	Colluvuum	Weathered Residual	Eastern Broadleaf Forest	Oak Woodland	Sandy Loam	SM
Houston Topsoil	Colluvuum	Weathered Residual	Eastern Broadleaf Forest	Oak Woodland	Organic Sandy Loam	SM
Kandiyohi Subsoil	Stagnation Moraine	Wadena Lobe	Prairie Parkland	Upland Prairie	Sandy Loam	SM
Kandiyohi Topsoil	Stagnation Moraine	Wadena Lobe	Prairie Parkland	Upland Prairie	Organic Clay Loam	OL
Lakeville Subsoil	Gray Drift	Kansan Glaciation	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Loam	SM
Lakeville Topsoil	Gray Drift	Kansan Glaciation	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Clay Loam	ML-OL
Lindstrom Subsoil	Ground Moraine	Des Moines Lobe	Laurentian Mixed Forest	Maple Basswood Forest	Sandy Loam	SM
Lindstrom Topsoil	Ground Moraine	Des Moines Lobe	Laurentian Mixed Forest	Maple Basswood Forest	Slightly Organic Sandy Loam	SM
Mankato Topsoil	Glacial Lake/Alluvium	Des Moines Lobe	Prairie Parkland	Maple Basswood Forest	Sandy Loam	SM
Mapleton Topsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Prairie Wetland	Slightly Organic Sandy Clay Loam	SC-SM
Moorhead Subsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Floodplain Forest	Slightly Organic Clay Loam	CL-ML-OL
Moorhead Topsoil	Glacial Lake Sediment	Des Moines Lobe	Prairie Parkland	Floodplain Forest	Organic Clay Loam	OL
New Sweden Topsoil	Stagnation Moraine	Des Moines Lobe	Prairie Parkland	Upland Prairie	Sandy Loam	SM
North Mankato Subsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Prairie Wetland	Sandy Clay Loam	SC-SM
North Mankato Topsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Prairie Wetland	Organic Sandy Clay Loam	SC-SM
Olivia A Subsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Upland Prairie	Sandy Loam	SM

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Site & Strata	Strata	Geomorphology	Ecological Province	Natural Vegetation	MnDOT Triangular Textural Classification	Presumptive Unified Classification System Designation
Olivia A Topsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Upland Prairie	Organic Sandy Loam	SM
Olivia B Clay	Ground Moraine	Des Moines Lobe	Prairie Parkland	Prairie Wetland	Sandy Clay Loam	SC-SM
Owatonna Clay	Ground Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Clay Loam	SC-SM
Owatonna Topsoil	Ground Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Clay Loam	SC-SM
Perham Subsoil	Outwash	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Sandy Loam	SM
Perham Topsoil	Outwash	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Loam	SM
Pipestone Subsoil	Gray Drift	Kansan Glaciation	Prairie Parkland	Upland Prairie	Sandy Loam	SM
Pipestone Topsoil	Gray Drift	Kansan Glaciation	Prairie Parkland	Upland Prairie	Organic Sandy Loam	SM
Ramsey Peat	End Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Oak Woodland	Highly Organic Sandy Loam	SM
Rockford Cornfield	End Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Maple Basswood Forest	Slightly Organic Sandy Loam	SM
Rockford Subsoil	End Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Maple Basswood Forest	Slightly Organic Sandy Loam	SM
Rockford Topsoil	End Moraine	Des Moines Lobe	Eastern Broadleaf Forest	Maple Basswood Forest	Slightly Organic Sandy Loam	SM
Sandstone Subsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Northern Hardwood Forest	Slightly Organic Clay Loam	CL-ML-OL
Sandstone Topsoil	Ground Moraine	Superior Lobe	Laurentian Mixed Forest	Northern Hardwood Forest	Slightly Organic Sandy Loam	SM
Stillwater Sediment	End Moraine	Superior Lobe	Eastern Broadleaf Forest	Oak Woodland	Organic Loam	OL
Tamarack Clay	End Moraine	Des Moines Lobe	Laurentian Mixed Forest	Peatland	Slightly Organic Clay	CL-OL
Tamarack Peat	Peat	Des Moines Lobe	Laurentian Mixed Forest	Peatland	Peat	PT
Tamarack Topsoil	End Moraine	Des Moines Lobe	Laurentian Mixed Forest	Peatland	Slightly Organic Sandy Loam	SM
Wabasha Subsoil (Box)	Colluvuum	Weathered Residual	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Loam	SM
Wabasha Subsoil (Rock)	Colluvuum	Weathered Residual	Eastern Broadleaf Forest	Oak Woodland	Sandy Loam	SM
Wabasha Topsoil	Colluvuum	Weathered Residual	Eastern Broadleaf Forest	Oak Woodland	Slightly Organic Sandy Loam	SM
Worthington Subsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Upland Prairie	Slightly Organic Sandy Loam	SM
Worthington Topsoil	Ground Moraine	Des Moines Lobe	Prairie Parkland	Upland Prairie	Organic Sandy Loam	SM

Material	Ada Subsoil
Sample Date	July 25, 2012
Sample Loc	TH 9: RP 192 50'E

Strata: Glacial Lake Sediment
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

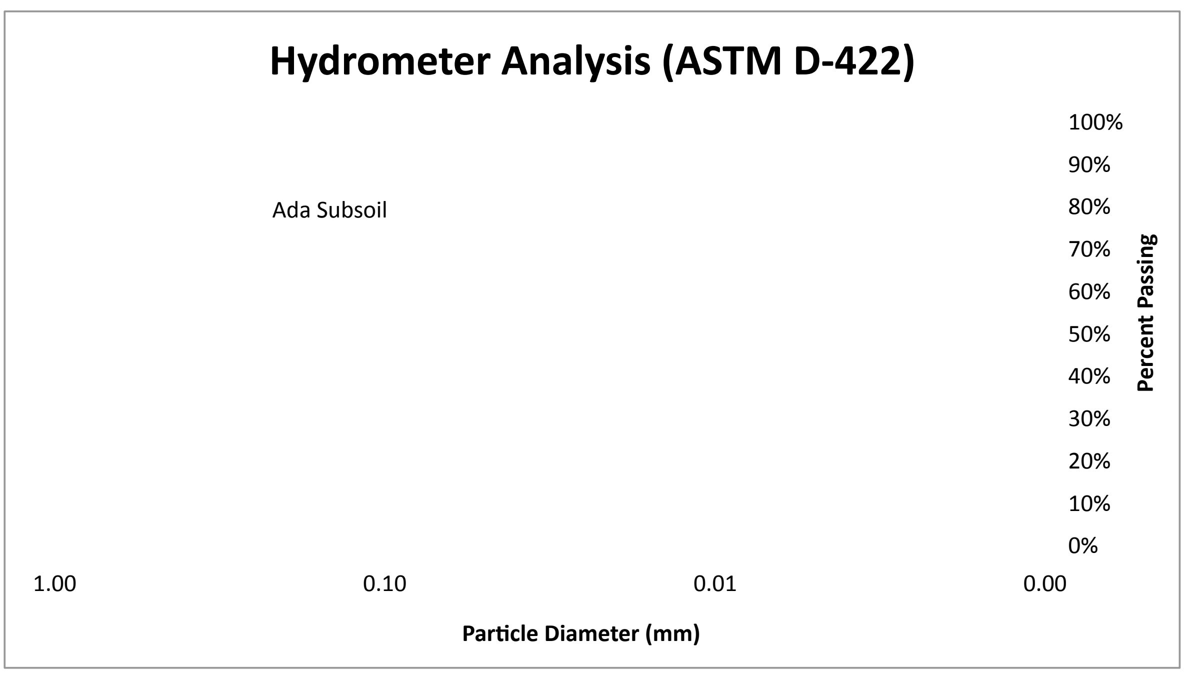
pH (ASTM D4972) = 8.3

Organic Content (ASTM D2974)

Dry Total Mass (g) =	38.1986
Mineral Mass (g) =	37.6312
Organic Content =	1.5%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22	12.69	0.03344737	21.8%
5	19	13.18	0.02156025	18.8%
15	17	13.51	0.01260176	16.8%
30	16	13.67	0.00896473	15.8%
60	16	13.67	0.00633902	15.8%
250	14	14.00	0.00314251	13.9%
1440	13	14.16	0.00131702	12.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Environmental Engineering
S. Druschel, Mn State Mankato

Sediment Characterization

MnDOT Floc
December 10, 2012

Material	Ada Topsoil
Sample Date	July 25, 2012
Sample Loc	TH 9: RP 192 50'E

Strata:	Glacial Lake Sediment
Geomorphology:	Des Moines Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

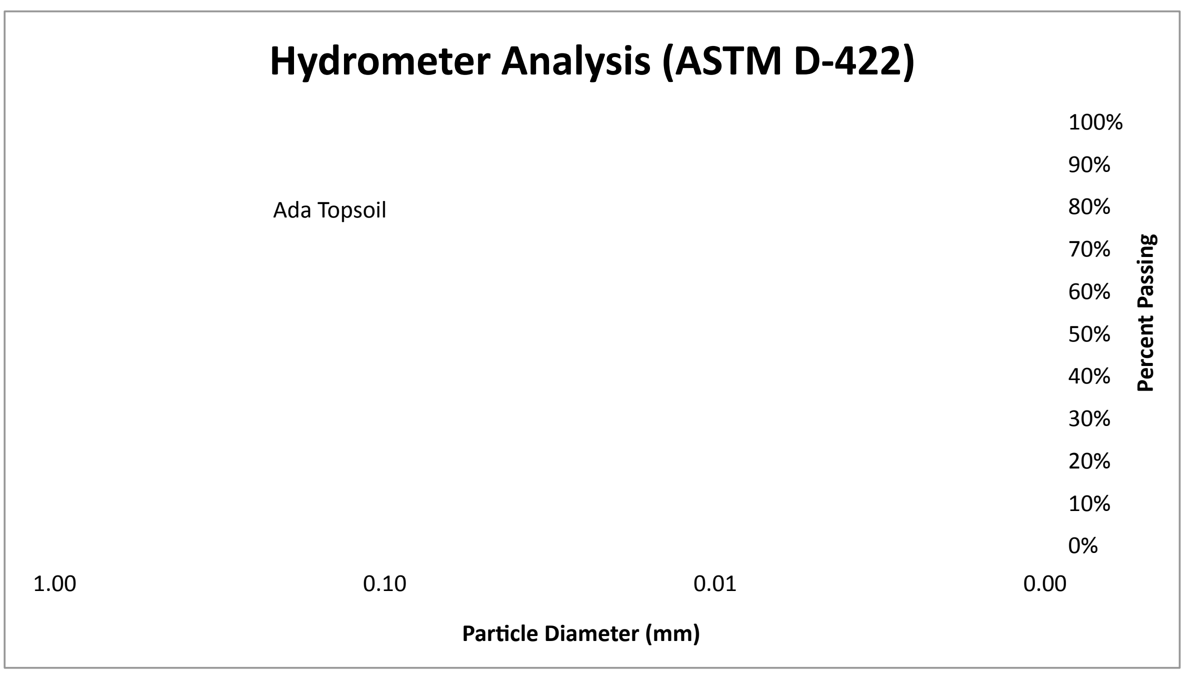
pH (ASTM D4972) = 7.8

Organic Content (ASTM D2974)

Dry Total Mass (g) =	42.2853
Mineral Mass (g) =	39.7849
Organic Content =	5.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	31	11.21	0.03144159	30.7%
5	26	12.03	0.02059981	25.7%
15	22	12.69	0.01221325	21.8%
30	21	12.85	0.00869171	20.8%
60	18	13.34	0.00626251	17.8%
250	14.5	13.92	0.00313329	14.4%
1440	13	14.16	0.00131702	12.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Organic Sandy Loam SM

Material	Brandon Subsoil
Sample Date	July 21, 2012
Sample Loc	I 94 SP#8824-100

Strata:	Stagnation Moraine
Geomorphology:	Wadena Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Oak Woodland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

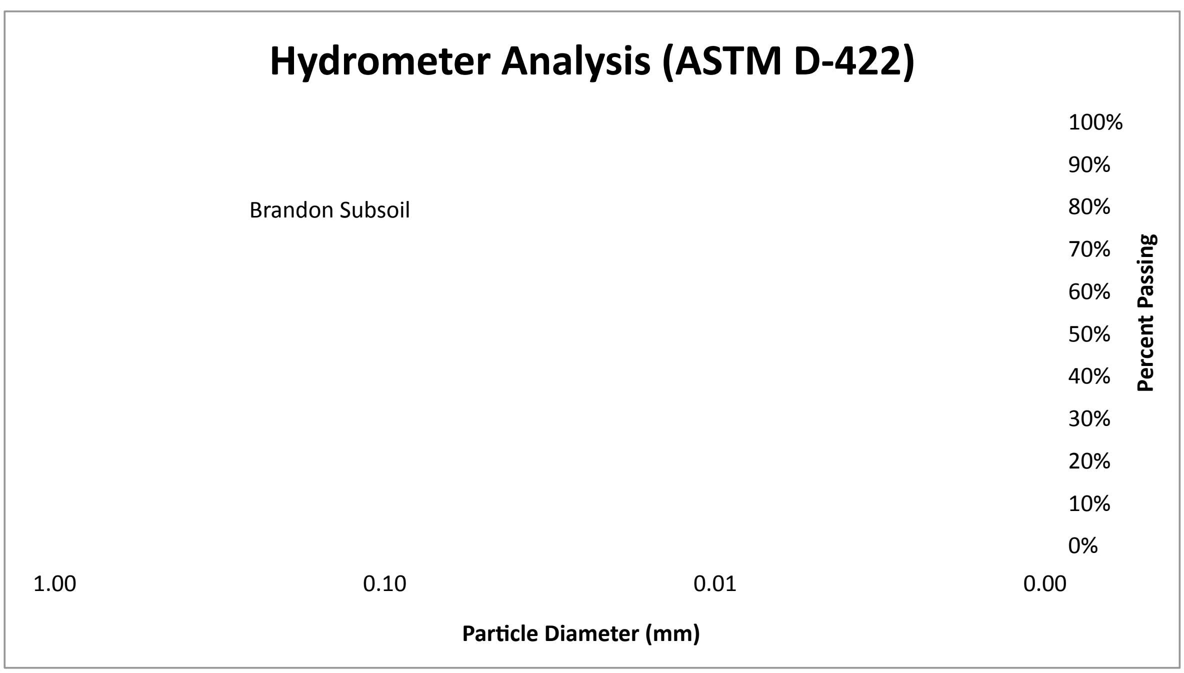
pH (ASTM D4972) = 7.4

Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.5556
Mineral Mass (g) =	41.6424
Organic Content =	4.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	32.5	10.96	0.03109472	32.2%
5	30.5	11.29	0.019958	30.2%
15	29	11.54	0.01164758	28.7%
30	27	11.87	0.00835232	26.7%
60	26.5	11.95	0.00592635	26.2%
250	24	12.36	0.0029527	23.8%
1440	20	13.01	0.00126252	19.8%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Clay Loam SC-SM

Material	Brandon Topsoil
Sample Date	July 21, 2012
Sample Loc	I 94 SP#8824-100

Strata: Stagnation Moraine
Geomorphology: Wadena Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

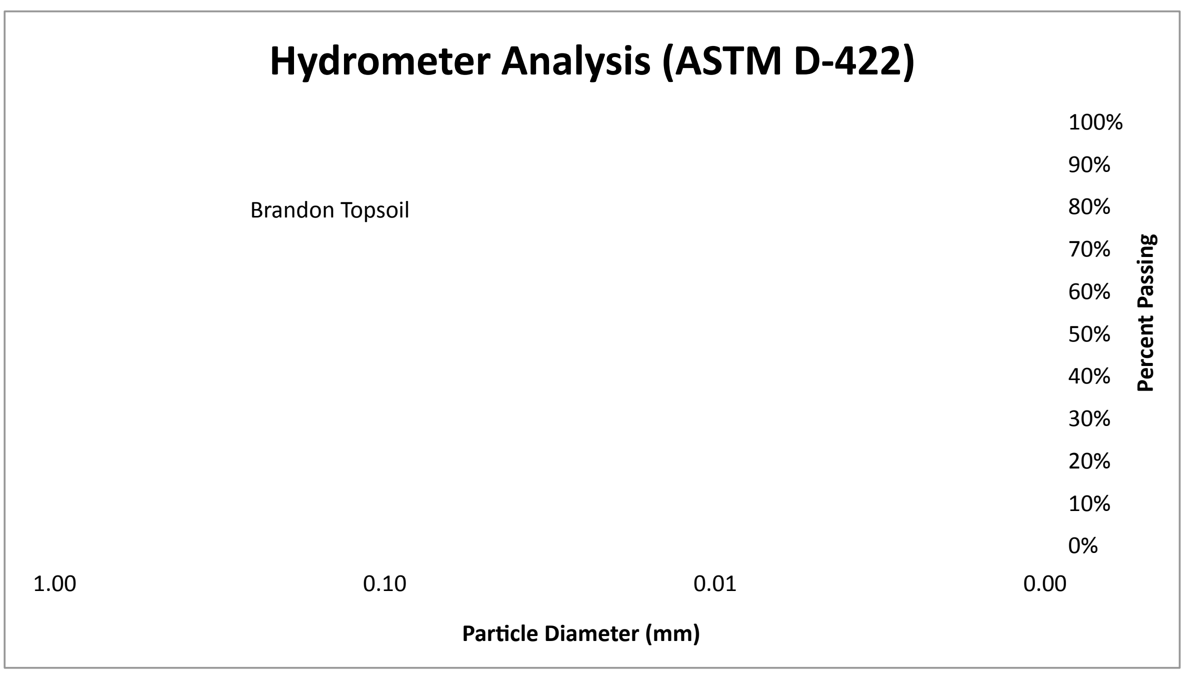
pH (ASTM D4972) = 7.2

Organic Content (ASTM D2974)

Dry Total Mass (g) =	35.192
Mineral Mass (g) =	32.0479
Organic Content =	8.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	36	10.39	0.0302699	35.6%
5	33.5	10.80	0.01951841	33.2%
15	30.5	11.29	0.01152276	30.2%
30	29	11.54	0.00823609	28.7%
60	27.5	11.78	0.00588554	27.2%
250	25	12.19	0.00293304	24.8%
1440	20.5	12.93	0.00125854	20.3%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Organic Sandy Clay Loam SC-SM

Material	Carlton Subsoil
Sample Date	October 10, 2012
Sample Loc	TH 210 / Jay Cooke State Park

Strata: Glacial Lake Sediment
Geomorphology: Superior Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Great Lakes Pine Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

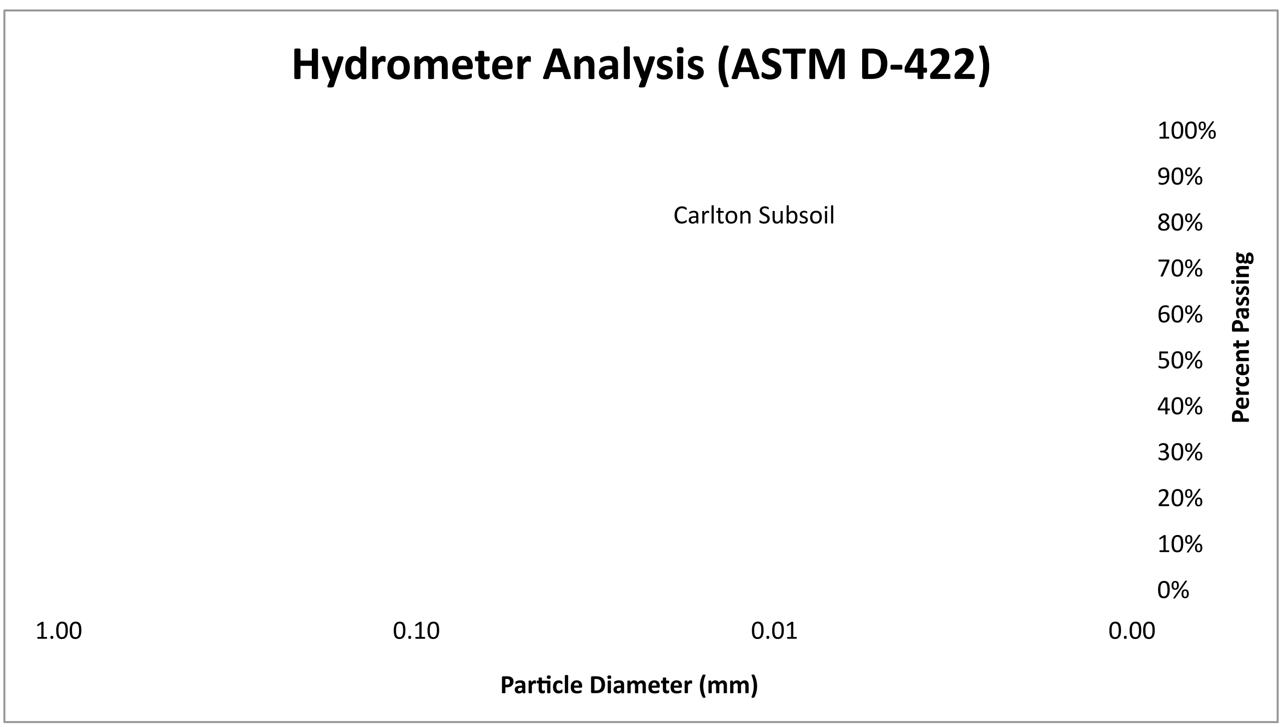
pH (ASTM D4972) = 8.3

Organic Content (ASTM D2974)

Dry Total Mass (g) =	50.2041
Mineral Mass (g) =	49.5052
Organic Content =	1.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	51	7.93	0.02644515	50.5%
5	45	8.91	0.01773262	44.6%
15	37.5	10.14	0.01092138	37.1%
30	32.5	10.96	0.00802862	32.2%
60	27.5	11.78	0.00588554	27.2%
250	19.5	13.10	0.00303958	19.3%
1440	15	13.83	0.00130168	14.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Loam ML

Material	Carlton Topsoil
Sample Date	October 10, 2012
Sample Loc	TH 210 / Jay Cooke State Park

Strata: Glacial Lake Sediment
Geomorphology: Superior Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Great Lakes Pine Forest

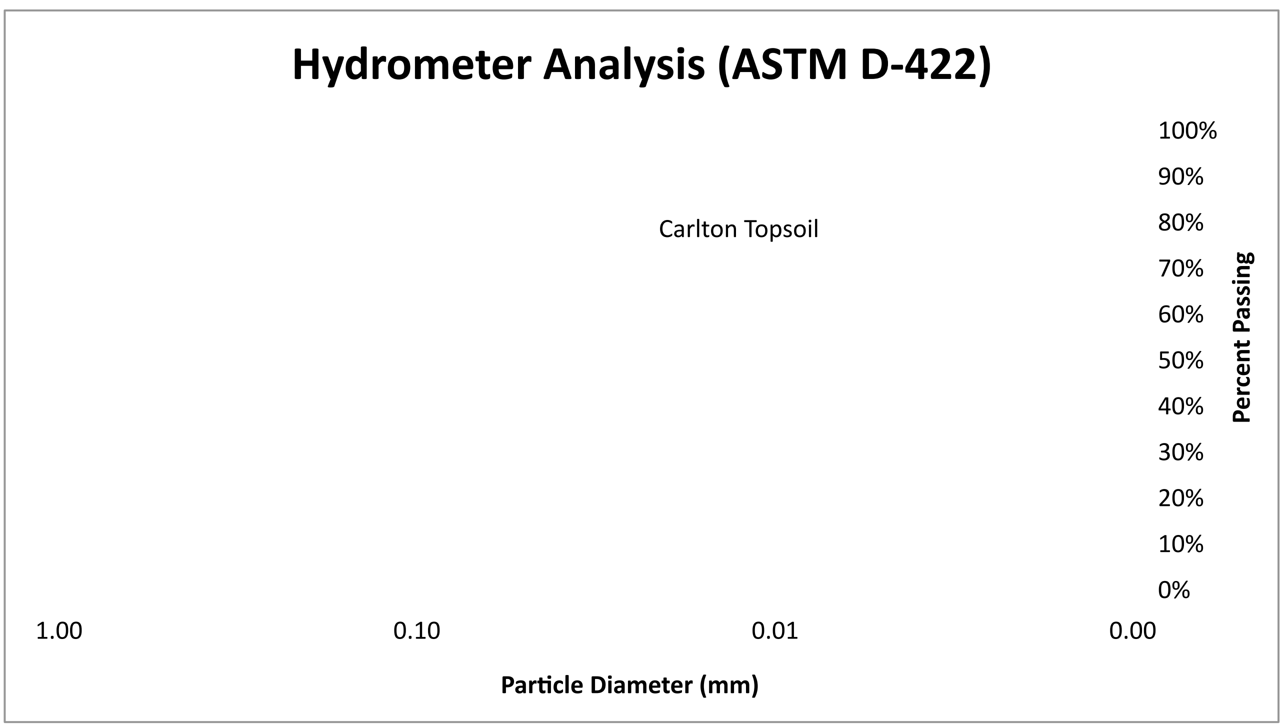
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 8.8

Organic Content (ASTM D2974)
Dry Total Mass (g) = 8.8
Mineral Mass (g) = 8.8
Organic Content = 0.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	21	12.85	0.03366285	20.8%
5	18	13.34	0.02169398	17.8%
15	15.5	13.75	0.012716	15.3%
30	14.5	13.92	0.00904502	14.4%
60	13	14.16	0.00645208	12.9%
250	12.5	14.24	0.00317	12.4%
1440	10.5	14.57	0.00133595	10.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Material	Cook Subsoil
Sample Date	not stated
Sample Loc	not stated

Strata: Ground Moraine
Geomorphology: Superior Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Boreal Hardwood-Conifer

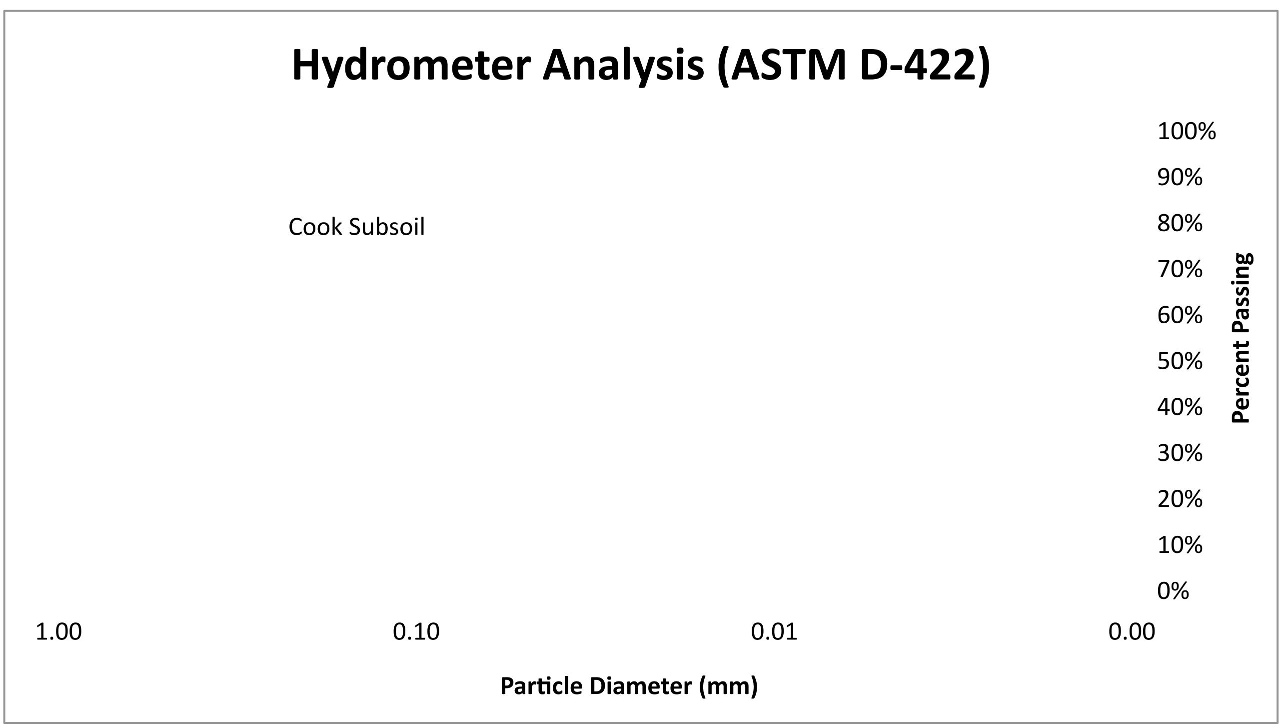
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 7.6

Organic Content (ASTM D2974)
Dry Total Mass (g) = 40.0828
Mineral Mass (g) = 39.3778
Organic Content = 1.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	15	13.83	0.03492787	14.9%
5	13	14.16	0.02235065	12.9%
15	12	14.33	0.01297865	11.9%
30	11.5	14.41	0.00920352	11.4%
60	10.5	14.57	0.0065448	10.4%
250	10	14.65	0.00321529	9.9%
1440	8.5	14.90	0.0013509	8.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Loam ML

Material	Cook Topsoil	Strata:	Ground Moraine
Sample Date	not stated	Geomorphology:	Superior Lobe
Sample Loc	not stated	Ecological Province:	Laurentian Mixed Forest
		Natural Vegetation:	Boreal Hardwood-Conifer

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

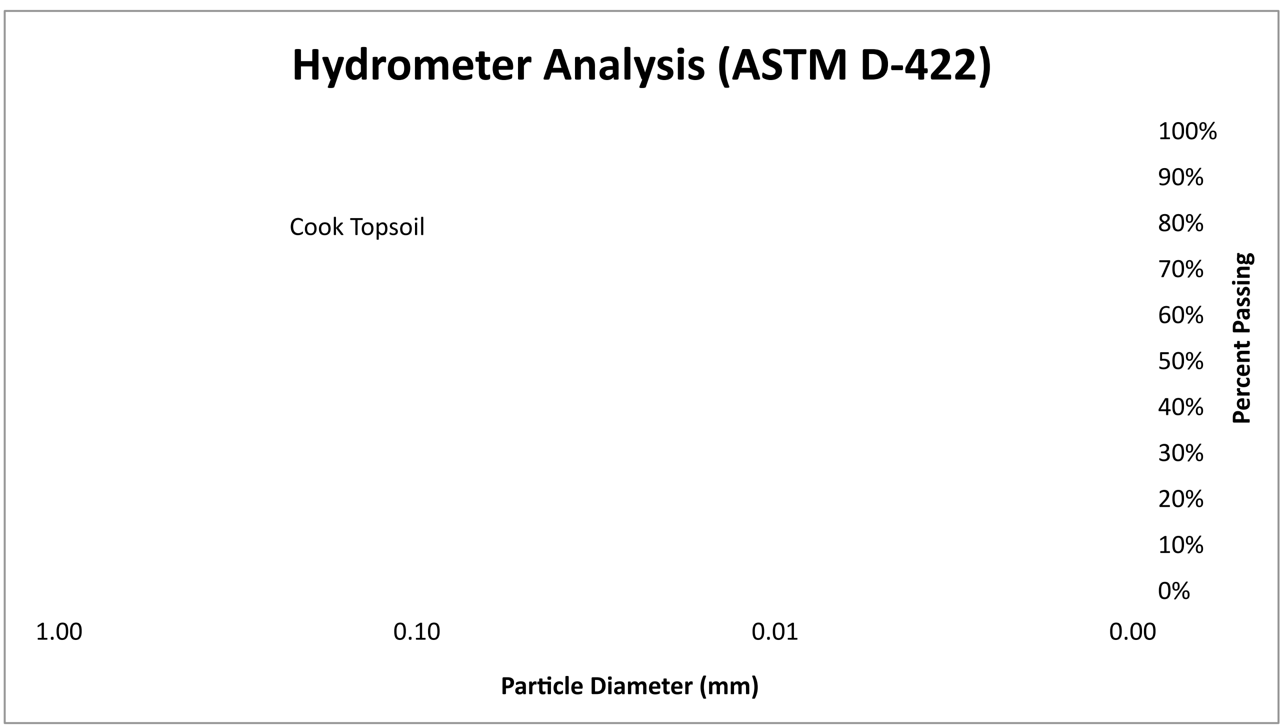
pH (ASTM D4972) =	6.6

Organic Content (ASTM D2974)

Dry Total Mass (g) =	39.2792
Mineral Mass (g) =	38.607
Organic Content =	1.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	11	14.49	0.03574635	10.9%
5	10	14.65	0.02273555	9.9%
15	9	14.82	0.01319962	8.9%
30	8.5	14.90	0.00935933	8.4%
60	8	14.98	0.00663623	7.9%
250	8	14.98	0.00325107	7.9%
1440	7	15.15	0.00136201	6.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Material	Coon Rapids Subsoil
Sample Date	July 27, 2012
Sample Loc	CR 14 & Flintwood Ave.

Strata: Outwash
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

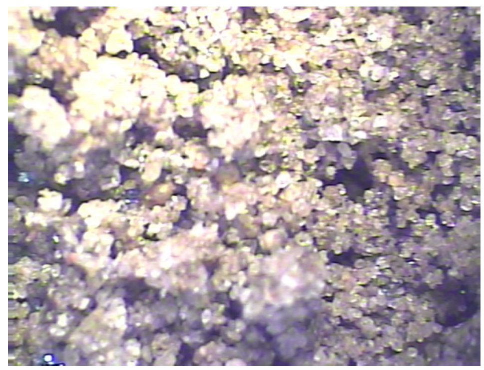
pH (ASTM D4972) = 7.9

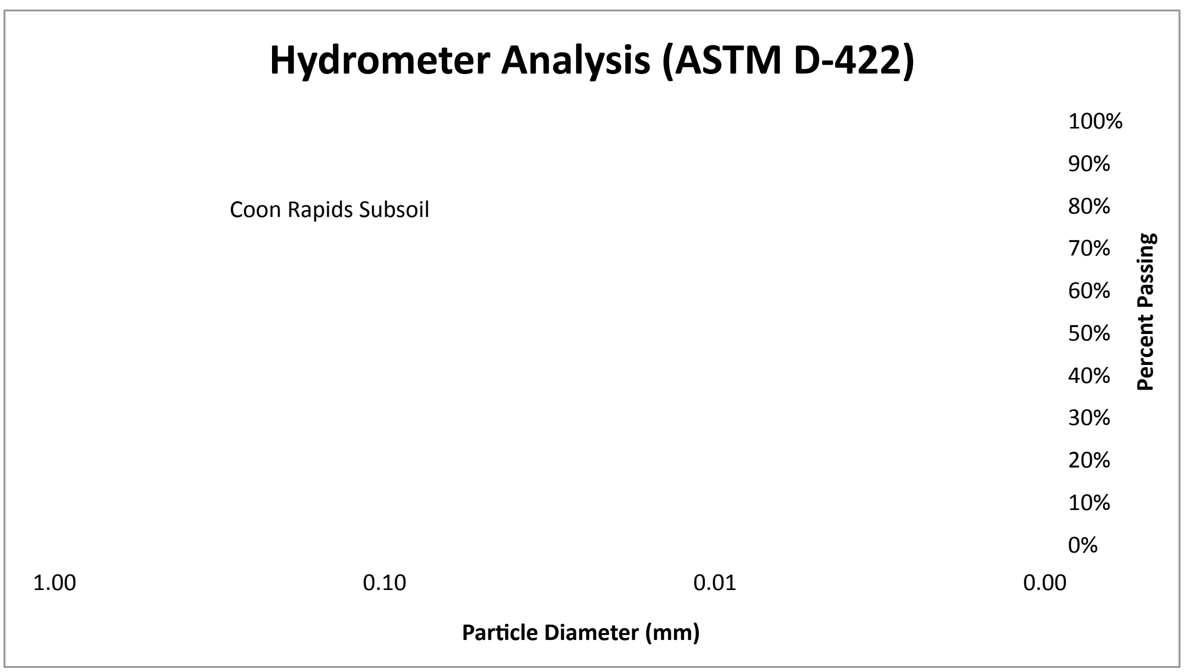
Organic Content (ASTM D2974)

Dry Total Mass (g) =	45.115
Mineral Mass (g) =	44.8176
Organic Content =	0.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	11.5	14.41	0.03564507	11.4%
5	11	14.49	0.02260798	10.9%
15	10	14.65	0.01312638	9.9%
30	9.5	14.74	0.00930768	9.4%
60	9.5	14.74	0.00658152	9.4%
250	9	14.82	0.00323323	8.9%
1440	8	14.98	0.00135461	7.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Sandy Loam SM

Material	Coon Rapids Topsoil
Sample Date	July 27, 2012
Sample Loc	CR 14 & Flintwood Ave.

Strata: Outwash
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

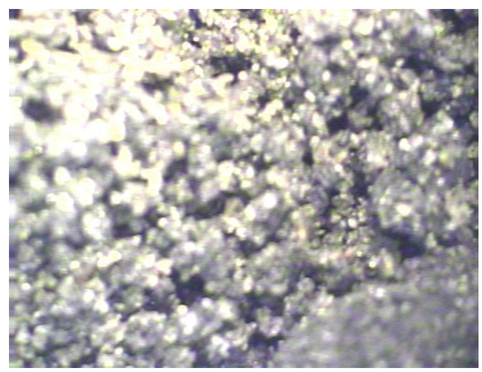
pH (ASTM D4972) =	7.3

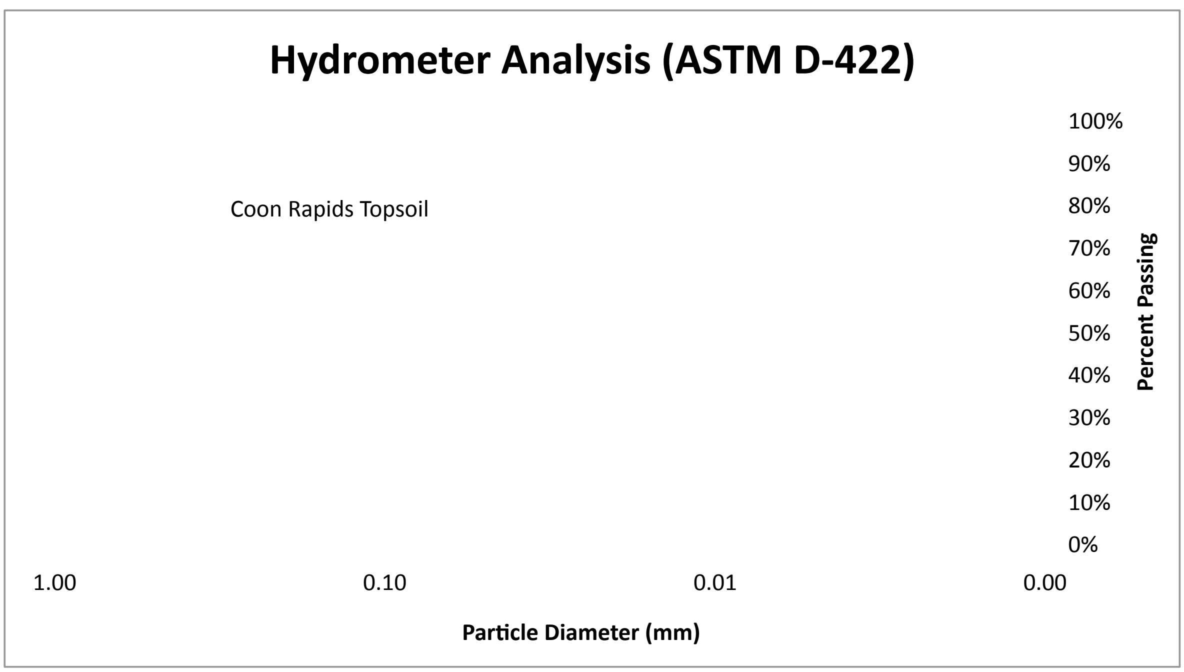
Organic Content (ASTM D2974)

Dry Total Mass (g) =	42.367
Mineral Mass (g) =	41.0656
Organic Content =	3.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	10.5	14.57	0.03584735	10.4%
5	10	14.65	0.02273555	9.9%
15	9.5	14.74	0.01316305	9.4%
30	9	14.82	0.00933354	8.9%
60	9	14.82	0.00659981	8.9%
250	8.5	14.90	0.00324217	8.4%
1440	8	14.98	0.00135461	7.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Environmental Engineering
S. Druschel, Mn State Mankato

Sediment Characterization

MnDOT Floc
December 10, 2012

Material	East Grand Forks Subsoil
Sample Date	July 25, 2012
Sample Loc	TH 220: RP 23 W Ditch

Strata:	Glacial Lake Sediment
Geomorphology:	Des Moines Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Floodplain Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

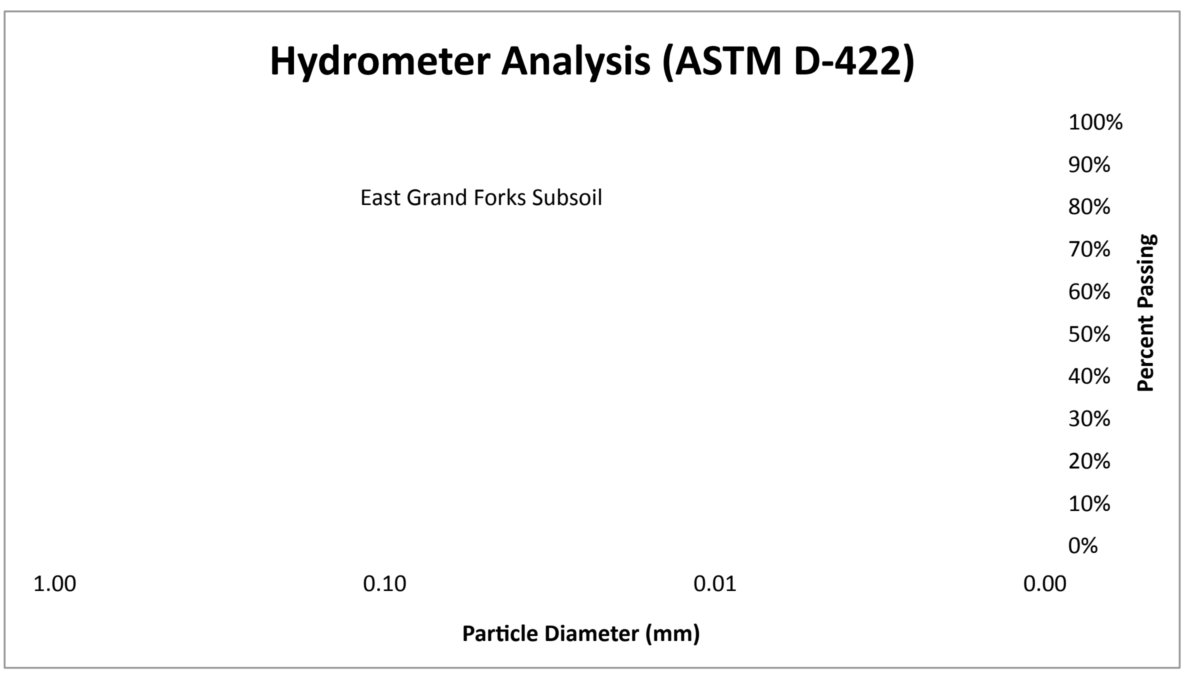
pH (ASTM D4972) =	8.1

Organic Content (ASTM D2974)

Dry Total Mass (g) =	38.1747
Mineral Mass (g) =	36.9997
Organic Content =	3.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	47	8.59	0.02751712	46.5%
5	39	9.90	0.01868564	38.6%
15	28.5	11.62	0.0116889	28.2%
30	26	12.03	0.00840984	25.7%
60	24.5	12.28	0.00600714	24.3%
250	21.5	12.77	0.00300128	21.3%
1440	10.5	14.57	0.00133595	10.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Clay Loam CL-ML-OL

Environmental Engineering | Sediment Characterization | MnDOT Floc
S. Druschel, Mn State Mankato | | December 10, 2012

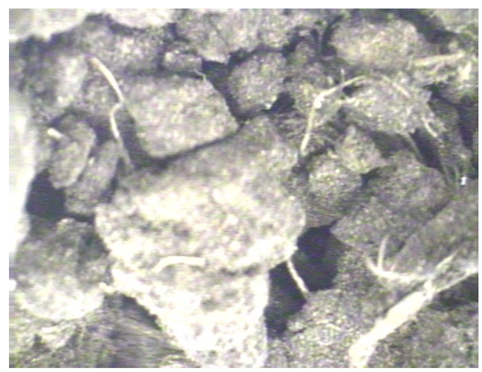
Material	East Grand Forks Topsoil	Strata:	Glacial Lake Sediment
Sample Date	July 25, 2012	Geomorphology:	Des Moines Lobe
Sample Loc	TH 220: RP 23 W Ditch	Ecological Province:	Prairie Parkland
		Natural Vegetation:	Floodplain Forest

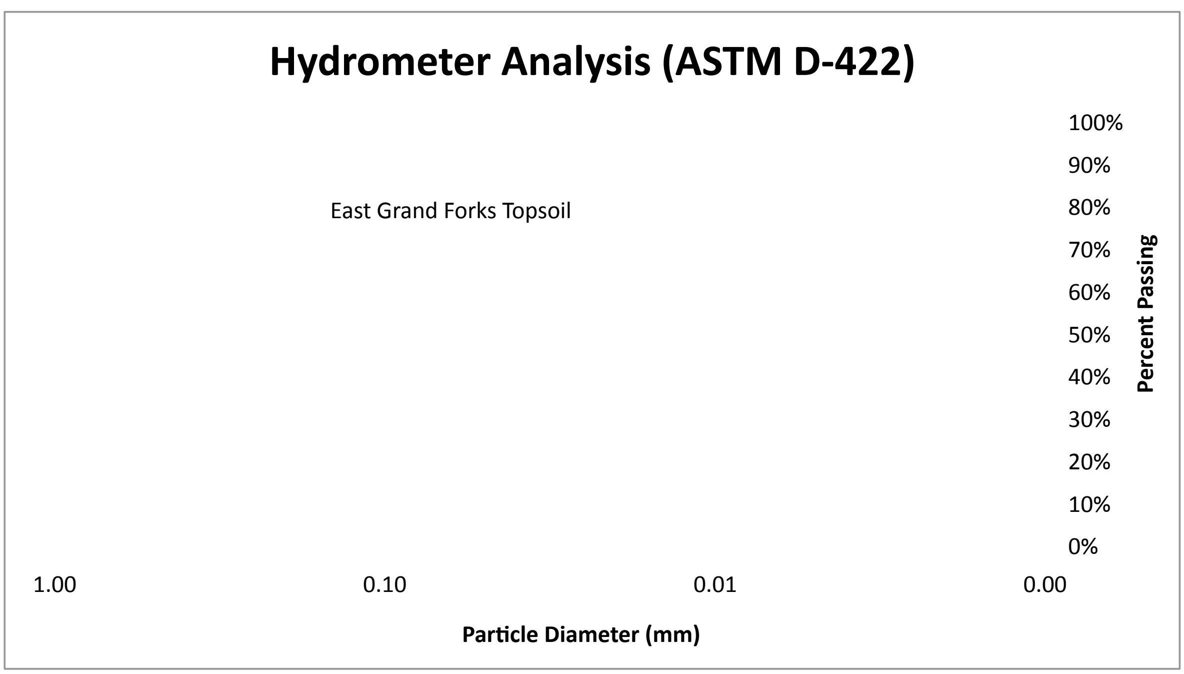
Hydrometer (ASTM D422)	100.0	g		pH (ASTM D4972) =	7.9
Estimated Gs =	2.65				
Gs Corr, a =	0.99	ASTM D-422 Table 1		Organic Content (ASTM D2974)	
Lab Temp =	21	deg C		Dry Total Mass (g) =	38.2869
K factor =	0.01328	ASTM D-422 Table 3		Mineral Mass (g) =	34.8095
Effective L (cm) =	(10.5 cm - 8.2 cm*R / 50 g/L)			Organic Content =	9.1%

+ 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	41.5	9.49	0.02892627	41.1%
5	33.5	10.80	0.01951841	33.2%
15	27	11.87	0.01181197	26.7%
30	25	12.19	0.00846696	24.8%
60	23.5	12.44	0.00604713	23.3%
250	21.5	12.77	0.00300128	21.3%
1440	18.5	13.26	0.0012744	18.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Clay Loam OL

Material	Foley Subsoil
Sample Date	July 9, 2012
Sample Loc	TH 23 SP#0503-75

Strata:	Ground Moraine
Geomorphology:	Superior Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Maple Basswood Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

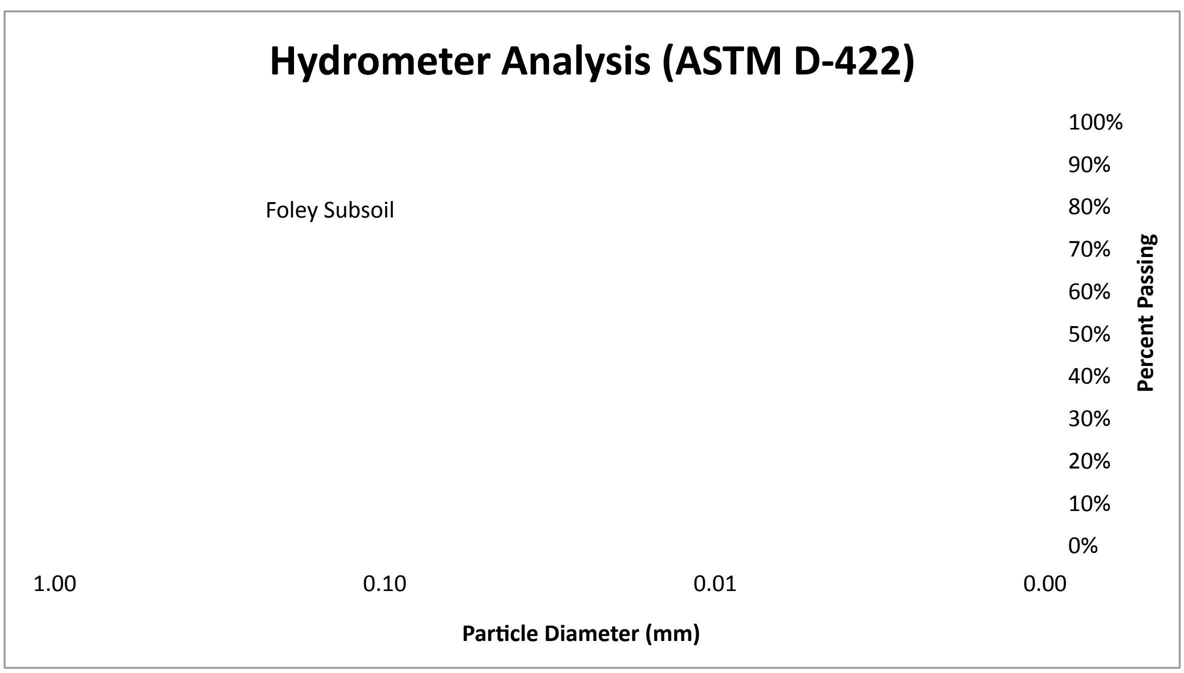
pH (ASTM D4972) =	7.1

Organic Content (ASTM D2974)

Dry Total Mass (g) =	48.6811
Mineral Mass (g) =	48.1813
Organic Content =	1.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	21	12.85	0.03366285	20.8%
5	18	13.34	0.02169398	17.8%
15	16.5	13.59	0.01263996	16.3%
30	15.5	13.75	0.00899157	15.3%
60	15	13.83	0.00637693	14.9%
250	12	14.33	0.00317911	11.9%
1440	10.5	14.57	0.00133595	10.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification:	Sandy Loam	SM

Material	Foley Topsoil
Sample Date	July 9, 2012
Sample Loc	TH 23 SP#0503-75

Strata: Ground Moraine
Geomorphology: Superior Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Maple Basswood Forest

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

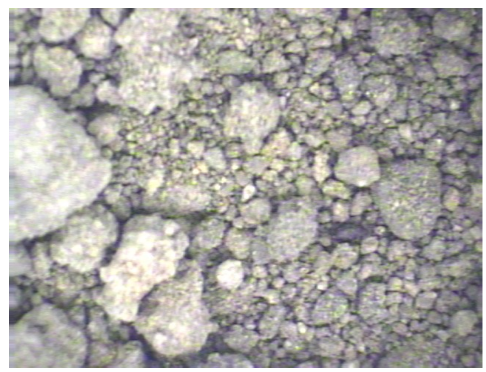
pH (ASTM D4972) = 7.3

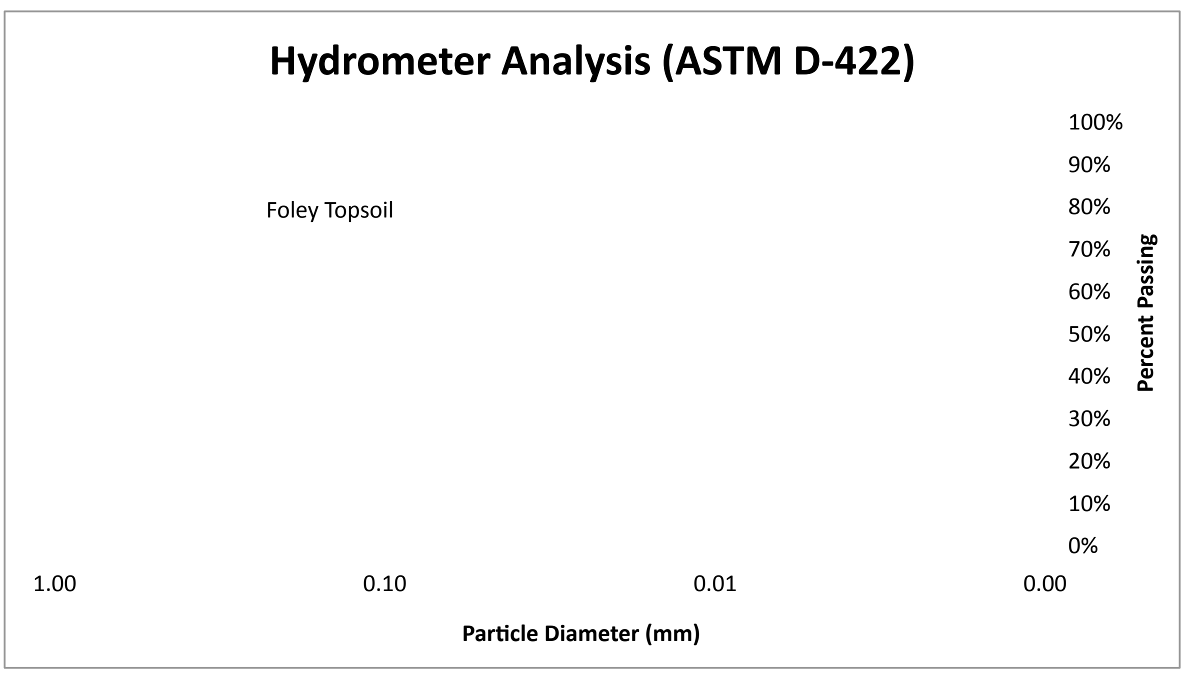
Organic Content (ASTM D2974)

Dry Total Mass (g) =	46.8383
Mineral Mass (g) =	45.6372
Organic Content =	2.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22	12.69	0.03344737	21.8%
5	20.5	12.93	0.02135808	20.3%
15	17.5	13.42	0.01256345	17.3%
30	16.5	13.59	0.0089378	16.3%
60	15.5	13.75	0.006358	15.3%
250	12.5	14.24	0.00317	12.4%
1440	11.5	14.41	0.00132841	11.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Grand Rapids Subsoil
Sample Date	July 5, 2012
Sample Loc	TH 169 SP#3115-51

Strata:	Outwash
Geomorphology:	Des Moines Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Boreal Hardwood-Conifer

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

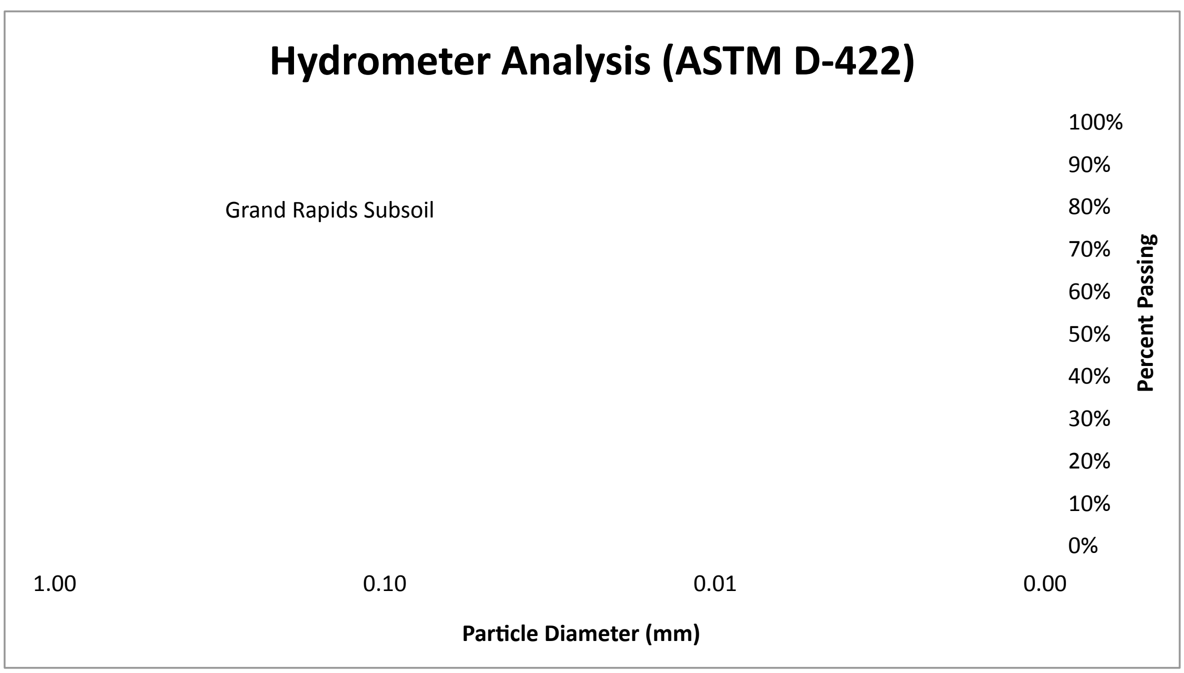
pH (ASTM D4972) =	8.2

Organic Content (ASTM D2974)

Dry Total Mass (g) =	47.117
Mineral Mass (g) =	46.64
Organic Content =	1.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	11	14.49	0.03574635	10.9%
5	10.5	14.57	0.02267185	10.4%
15	9.5	14.74	0.01316305	9.4%
30	8.5	14.90	0.00935933	8.4%
60	8	14.98	0.00663623	7.9%
250	8	14.98	0.00325107	7.9%
1440	7.5	15.06	0.00135832	7.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification:	Sandy Loam	SM

Material	Grand Rapids Topsoil
Sample Date	July 5, 2012
Sample Loc	TH 169 SP#3115-51

Strata:	Outwash
Geomorphology:	Des Moines Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Boreal Hardwood-Conifer

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

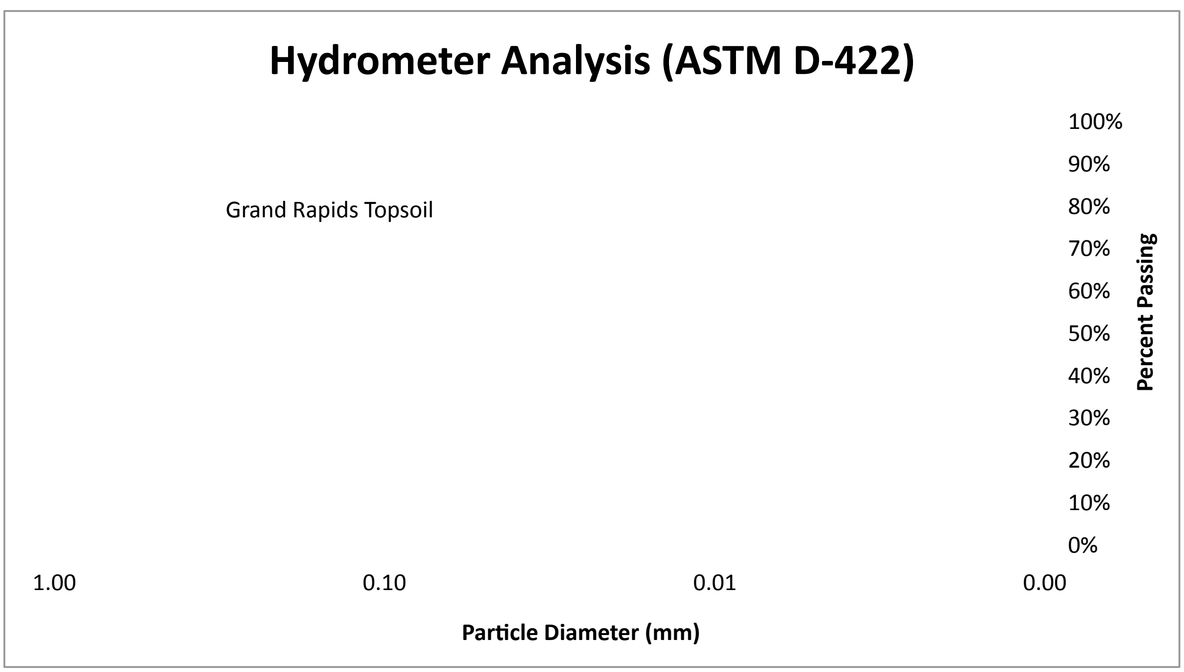
pH (ASTM D4972) =	7.7

Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.2758
Mineral Mass (g) =	43.0439
Organic Content =	0.5%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	15	13.83	0.03492787	14.9%
5	12.5	14.24	0.02241526	12.4%
15	11	14.49	0.01305272	10.9%
30	11	14.49	0.00922967	10.9%
60	9.5	14.74	0.00658152	9.4%
250	8	14.98	0.00325107	7.9%
1440	7.5	15.06	0.00135832	7.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification:	Sandy Loam	SM

Material	Hampton Subsoil
Sample Date	September 21, 2012
Sample Loc	TH 52 NE Pond

Strata: Red Drift
Geomorphology: Illinoisian Glaciation
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

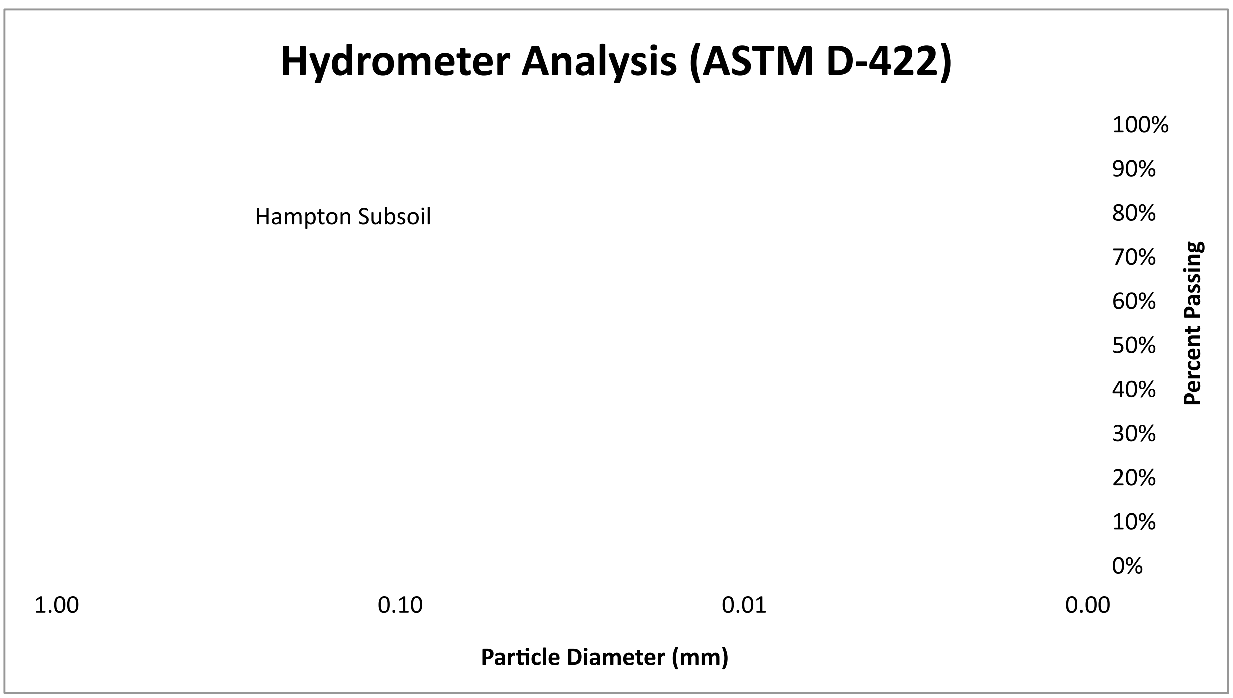
pH (ASTM D4972) = 7.9

Organic Content (ASTM D2974)

Dry Total Mass (g) =	41.6513
Mineral Mass (g) =	40.7795
Organic Content =	2.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	32	11.05	0.03121077	31.7%
5	27	11.87	0.02045893	26.7%
15	22	12.69	0.01221325	21.8%
30	20	13.01	0.008747	19.8%
60	18	13.34	0.00626251	17.8%
250	16.5	13.59	0.00309614	16.3%
1440	15	13.83	0.00130168	14.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Hampton Topsoil
Sample Date	September 21, 2012
Sample Loc	TH 52 NE Pond

Strata: Red Drift
Geomorphology: Illinoisian Glaciation
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Upland Prairie

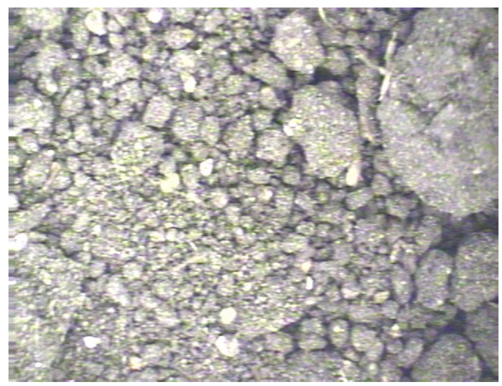
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

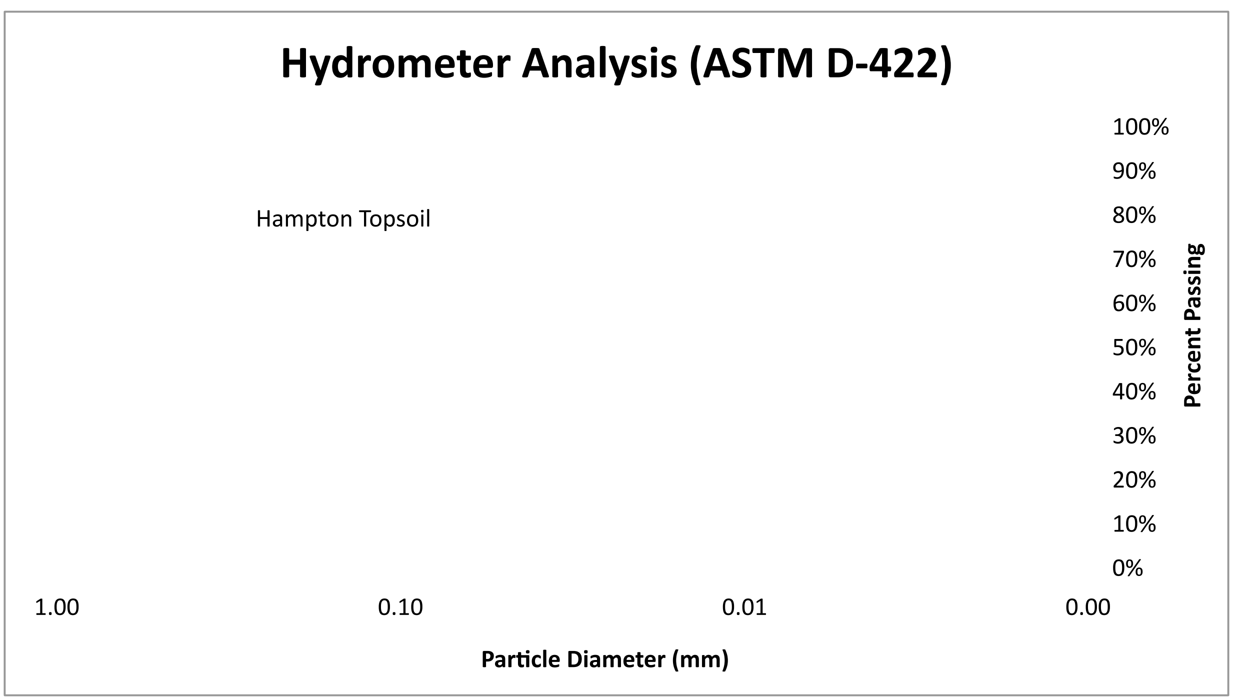
pH (ASTM D4972) = 7.2

Organic Content (ASTM D2974)
Dry Total Mass (g) = 38.8719
Mineral Mass (g) = 35.4016
Organic Content = 8.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	32.5	10.96	0.03109472	32.2%
5	27.5	11.78	0.02038812	27.2%
15	23.5	12.44	0.01209426	23.3%
30	21.5	12.77	0.00866394	21.3%
60	20	13.01	0.00618506	19.8%
250	18	13.34	0.00306799	17.8%
1440	15	13.83	0.00130168	14.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Sandy Loam SM

Material	Houston Riverbed
Sample Date	September 27, 2012
Sample Loc	CSAH 22 & Hop Hollow Rd

Strata: Colluvuum
Geomorphology: Weathered Residual
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

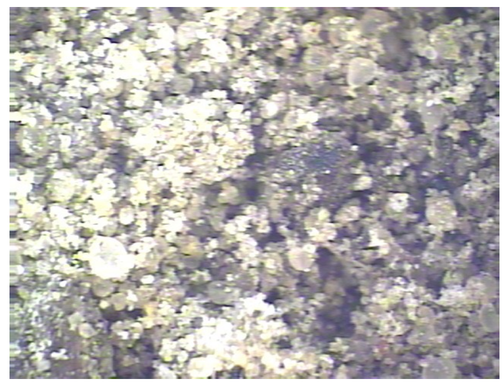
pH (ASTM D4972) =	7.6

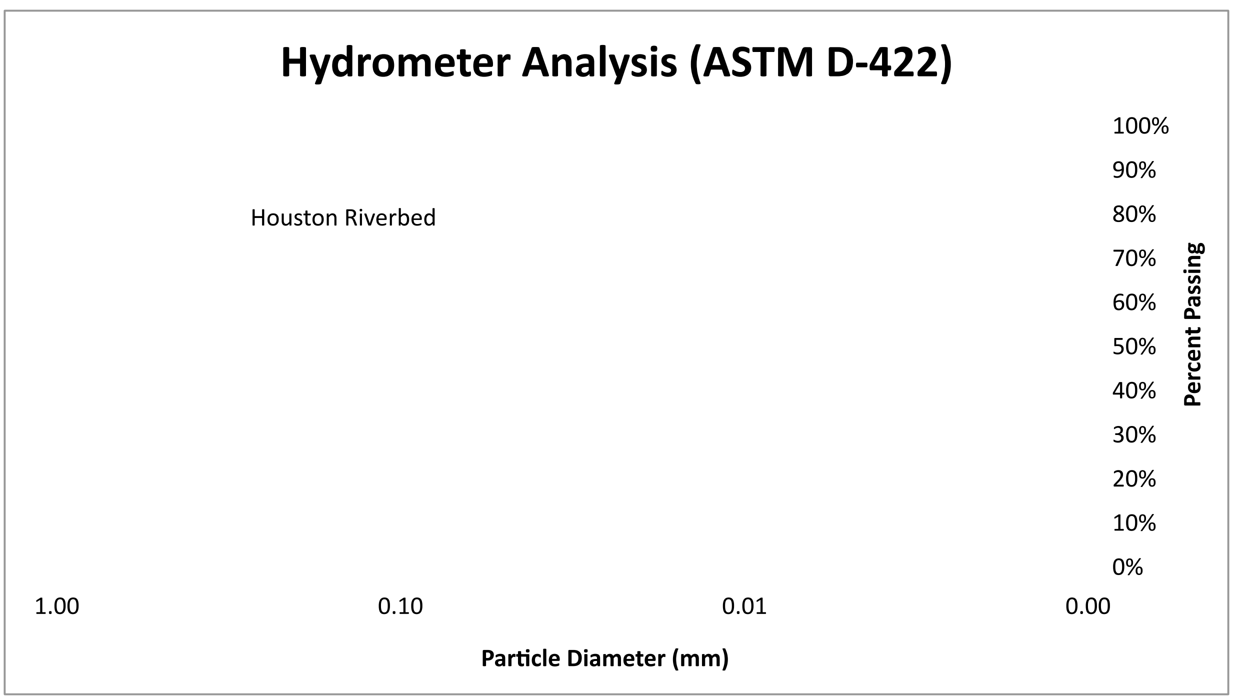
Organic Content (ASTM D2974)

Dry Total Mass (g) =	45.1316
Mineral Mass (g) =	44.3344
Organic Content =	1.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22	12.69	0.03344737	21.8%
5	17	13.51	0.02182689	16.8%
15	15	13.83	0.01275385	14.9%
30	14	14.00	0.00907163	13.9%
60	13	14.16	0.00645208	12.9%
250	12	14.33	0.00317911	11.9%
1440	10	14.65	0.00133971	9.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification:	Sandy Loam	SM

Material	Houston Topsoil
Sample Date	September 27, 2012
Sample Loc	CSAH 22 & Hop Hollow Rd

Strata: Colluvuum
Geomorphology: Weathered Residual
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

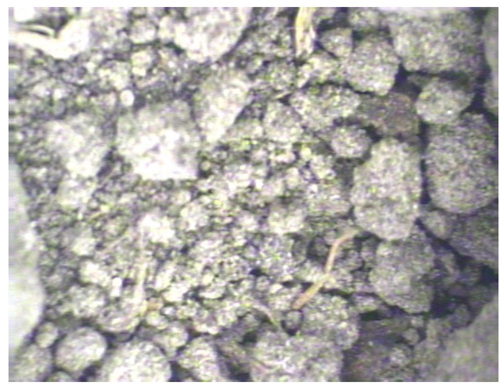
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

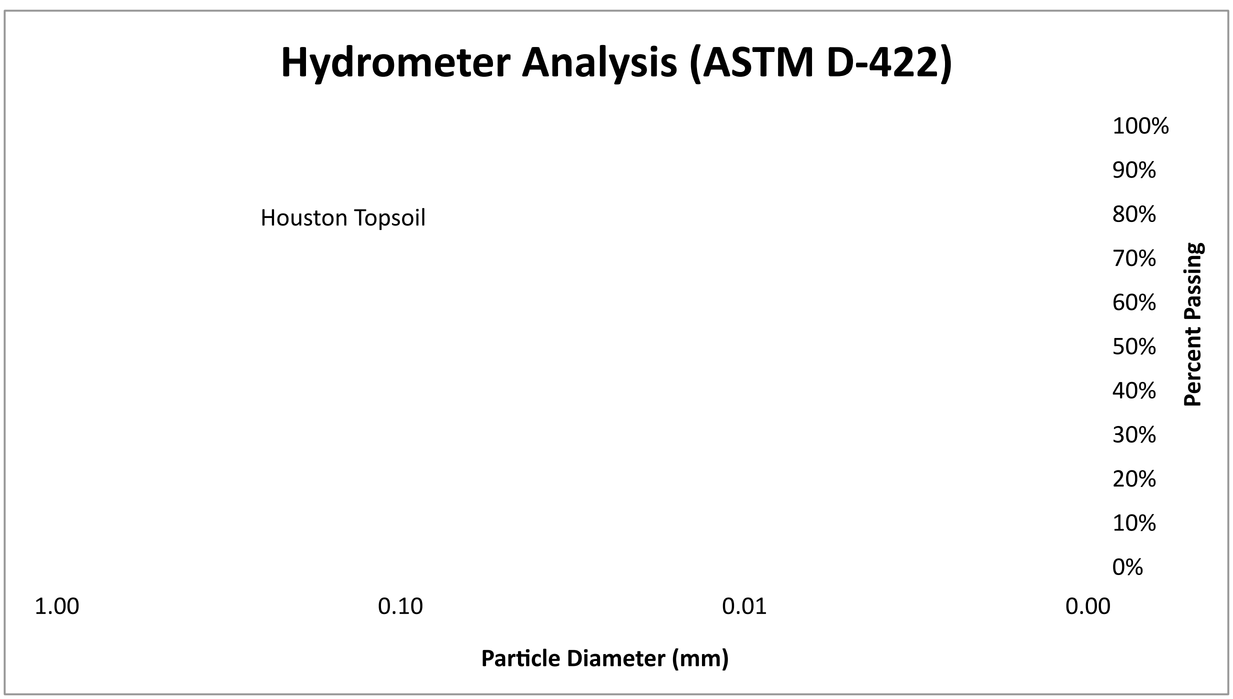
pH (ASTM D4972) = 7.4

Organic Content (ASTM D2974)
Dry Total Mass (g) = 44.6971
Mineral Mass (g) = 42.1139
Organic Content = 5.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22.5	12.60	0.0333391	22.3%
5	18.5	13.26	0.02162722	18.3%
15	15	13.83	0.01275385	14.9%
30	13.5	14.08	0.00909816	13.4%
60	12.5	14.24	0.00647073	12.4%
250	11.5	14.41	0.00318819	11.4%
1440	9.5	14.74	0.00134345	9.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Sandy Loam SM

Material	Kandiyohi Subsoil
Sample Date	August 1, 2012
Sample Loc	CSAH 5 Sta 70+50 CL

Strata: Stagnation Moraine
Geomorphology: Wadena Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

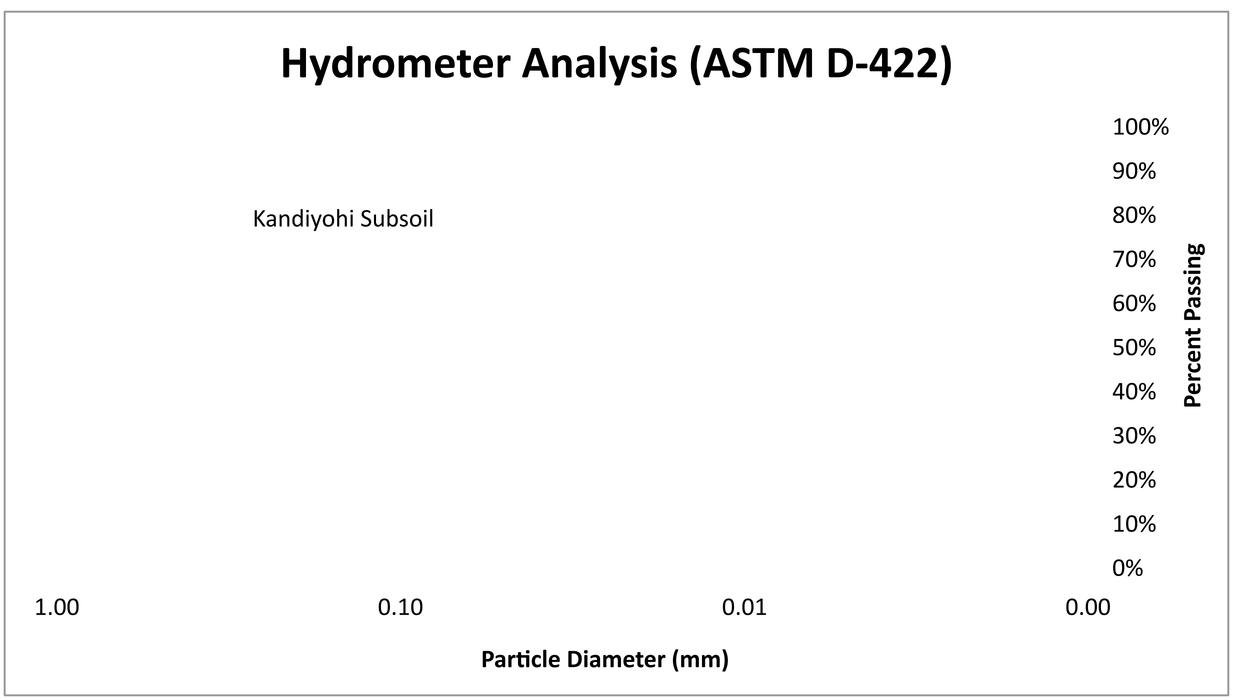
pH (ASTM D4972) =	8.1

Organic Content (ASTM D2974)

Dry Total Mass (g) =	38.1984
Mineral Mass (g) =	37.7686
Organic Content =	1.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	28.5	11.62	0.03201136	28.2%
5	25.5	12.11	0.0206699	25.2%
15	20.5	12.93	0.01233109	20.3%
30	19.5	13.10	0.00877451	19.3%
60	18	13.34	0.00626251	17.8%
250	15.5	13.75	0.00311477	15.3%
1440	13	14.16	0.00131702	12.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification:	Sandy Loam	OL

Material	Kandiyohi Topsoil
Sample Date	August 1, 2012
Sample Loc	CSAH 5 Sta 74+00 Lt

Strata: Stagnation Moraine
Geomorphology: Wadena Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

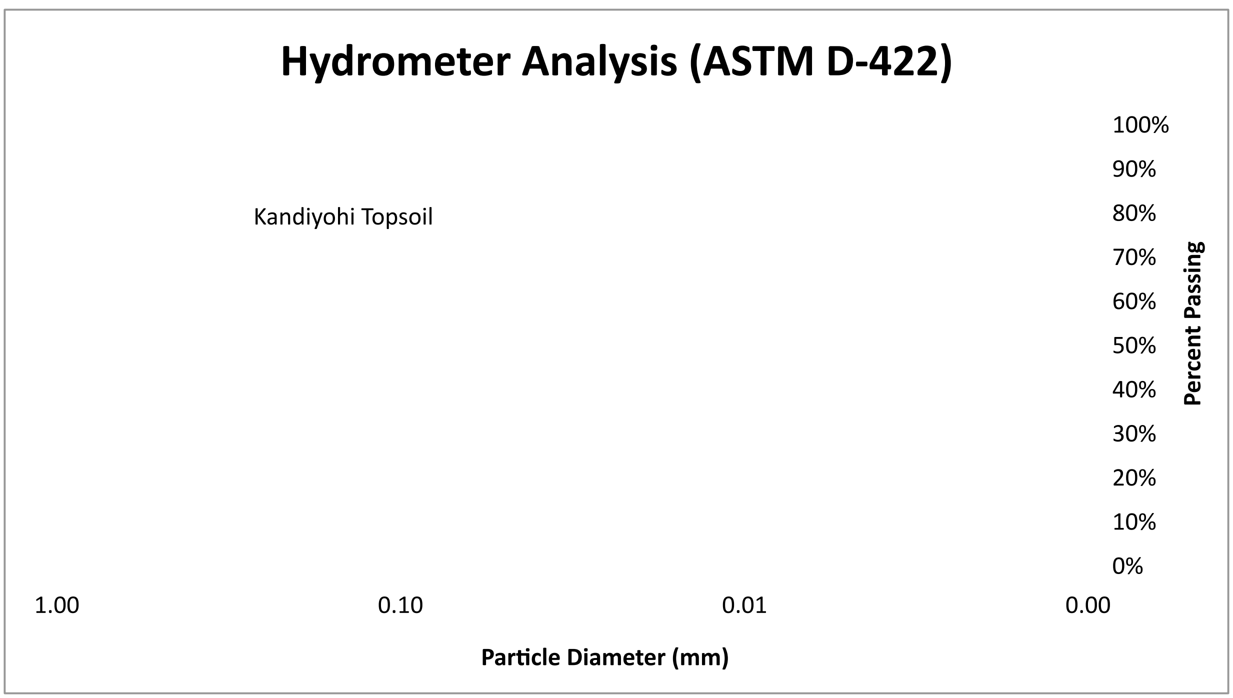
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 7.7

Organic Content (ASTM D2974)
Dry Total Mass (g) = 46.6952
Mineral Mass (g) = 42.6838
Organic Content = 8.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	38	10.06	0.02978832	37.6%
5	34.5	10.64	0.01936966	34.2%
15	29	11.54	0.01164758	28.7%
30	27	11.87	0.00835232	26.7%
60	25.5	12.11	0.00596688	25.2%
250	22.5	12.60	0.00298194	22.3%
1440	18.5	13.26	0.0012744	18.3%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Organic Clay Loam OL

Material	Lakeville Subsoil
Sample Date	June 6, 2012
Sample Loc	Holyoke Rd & 194th St W

Strata: Gray Drift
Geomorphology: Kansan Glaciation
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

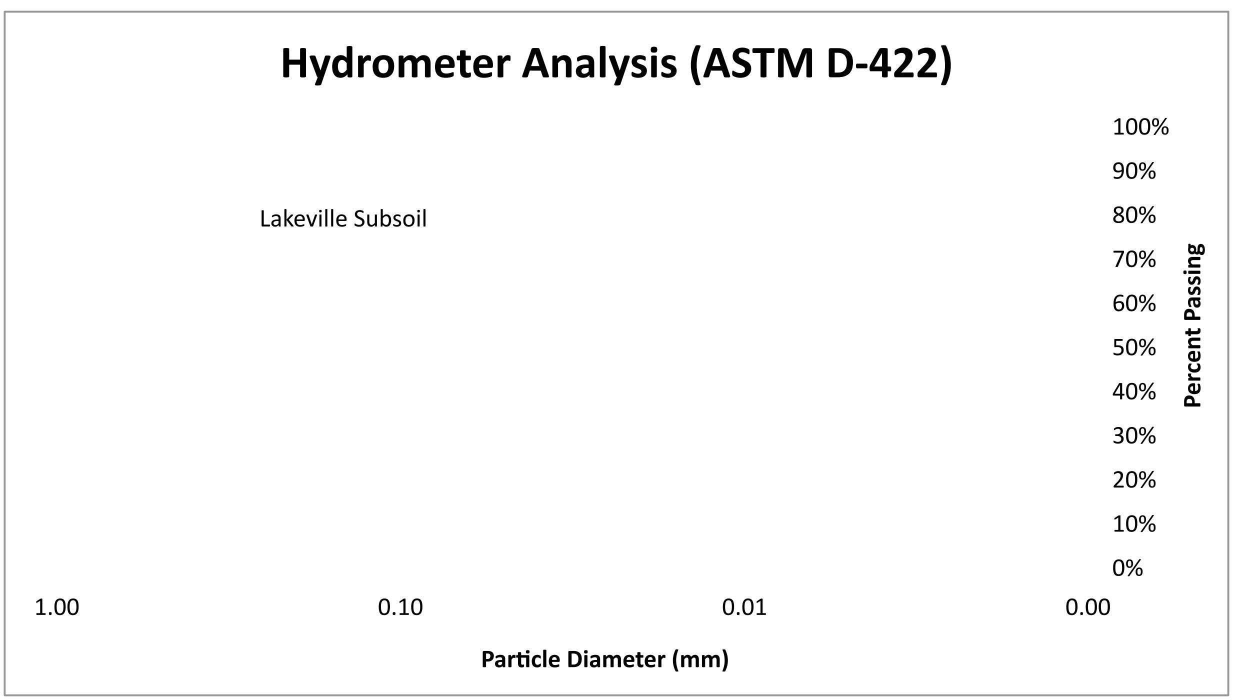
pH (ASTM D4972) = 7.6

Organic Content (ASTM D2974)

Dry Total Mass (g) =	44.1547
Mineral Mass (g) =	43.2905
Organic Content =	2.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	31.5	11.13	0.0313264	31.2%
5	25.5	12.11	0.0206699	25.2%
15	21.5	12.77	0.01225266	21.3%
30	20	13.01	0.008747	19.8%
60	18.5	13.26	0.00624324	18.3%
250	16	13.67	0.00310547	15.8%
1440	14	14.00	0.00130938	13.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Lakeville Topsoil
Sample Date	June 6, 2012
Sample Loc	Holyoke Rd & 194th St W

Strata:	Gray Drift
Geomorphology:	Kansan Glaciation
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Oak Woodland

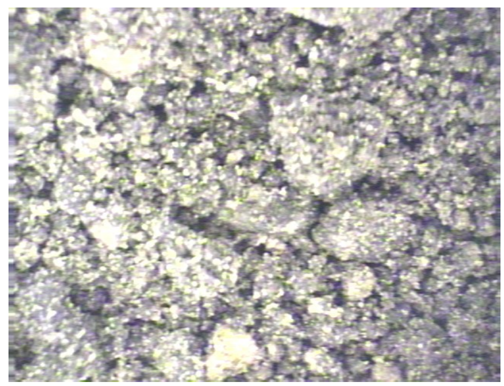
Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

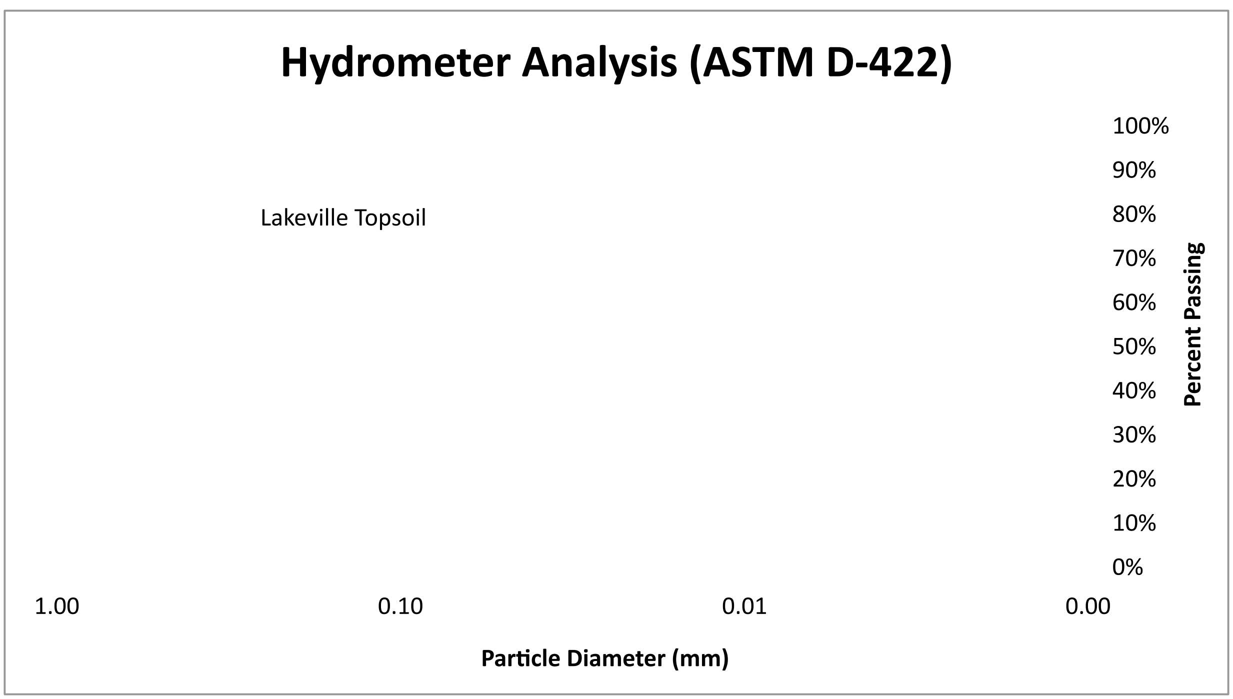
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) =	8
Organic Content (ASTM D2974)	
Dry Total Mass (g) =	36.0307
Mineral Mass (g) =	34.3677
Organic Content =	4.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	41	9.57	0.02905099	40.6%
5	31	11.21	0.01988541	30.7%
15	25.5	12.11	0.01193377	25.2%
30	23	12.52	0.00858007	22.8%
60	22	12.69	0.00610663	21.8%
250	18.5	13.26	0.00305855	18.3%
1440	16	13.67	0.00129395	15.8%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Clay Loam ML-OL

Material	Lindstrom Subsoil
Sample Date	July 13, 2012
Sample Loc	TH 8 N Lindstrom Lake

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Maple Basswood Forest

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

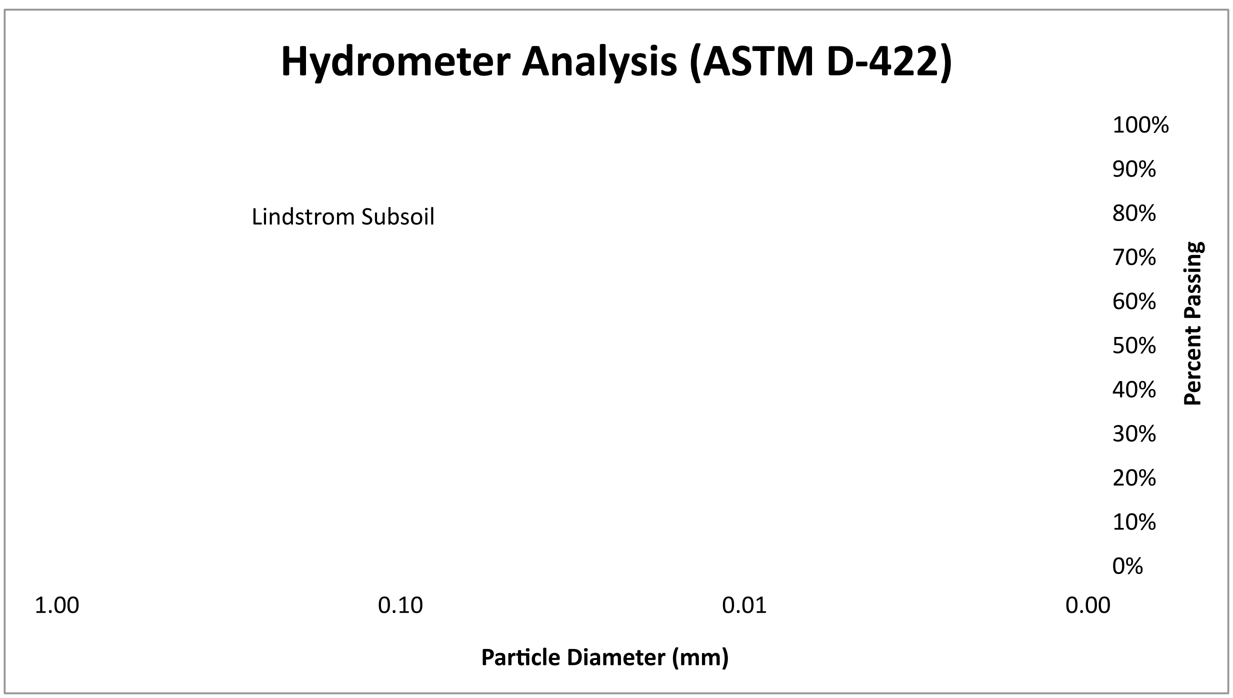
pH (ASTM D4972) = 8

Organic Content (ASTM D2974)

Dry Total Mass (g) =	45.586
Mineral Mass (g) =	44.9655
Organic Content =	1.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	18	13.34	0.03430119	17.8%
5	16.5	13.59	0.02189305	16.3%
15	15	13.83	0.01275385	14.9%
30	14.5	13.92	0.00904502	14.4%
60	13.5	14.08	0.00643337	13.4%
250	12.5	14.24	0.00317	12.4%
1440	11	14.49	0.00133219	10.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Material	Lindstrom Topsoil
Sample Date	July 13, 2012
Sample Loc	TH 8 N Lindstrom Lake

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Laurentian Mixed Forest
Natural Vegetation: Maple Basswood Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

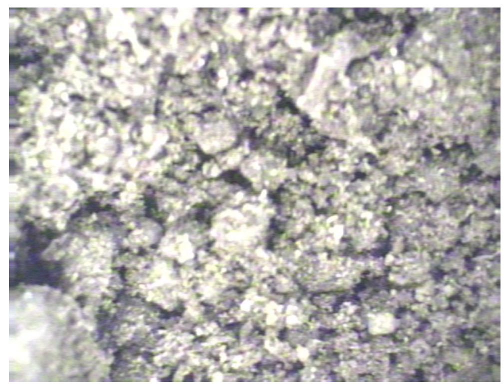
pH (ASTM D4972) = 7.9

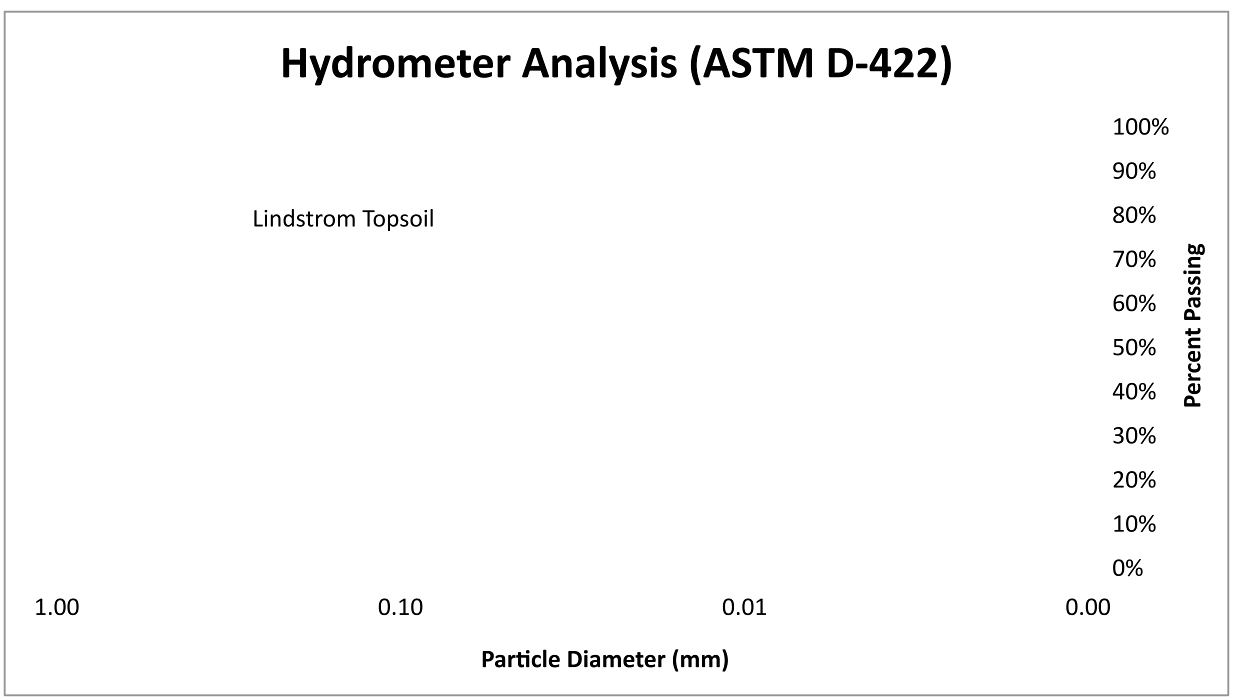
Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.7376
Mineral Mass (g) =	42.214
Organic Content =	3.5%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22	12.69	0.03344737	21.8%
5	19	13.18	0.02156025	18.8%
15	16	13.67	0.01267804	15.8%
30	15	13.83	0.00901834	14.9%
60	13.5	14.08	0.00643337	13.4%
250	11.5	14.41	0.00318819	11.4%
1440	10	14.65	0.00133971	9.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Environmental Engineering | Sediment Characterization | MnDOT Floc
S. Druschel, Mn State Mankato | | December 10, 2012

Material	Mankato Topsoil	Strata:	Glacial Lake/Alluvium
Sample Date	November 20, 2012	Geomorphology:	Des Moines Lobe
Sample Loc	TH 90 & Blue Earth R	Ecological Province:	Prairie Parkland
		Natural Vegetation:	Maple Basswood Forest

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

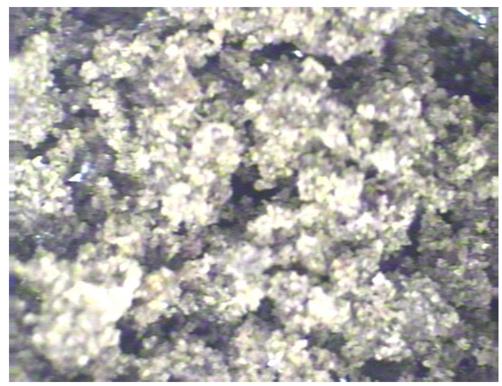
pH (ASTM D4972) = 7.79

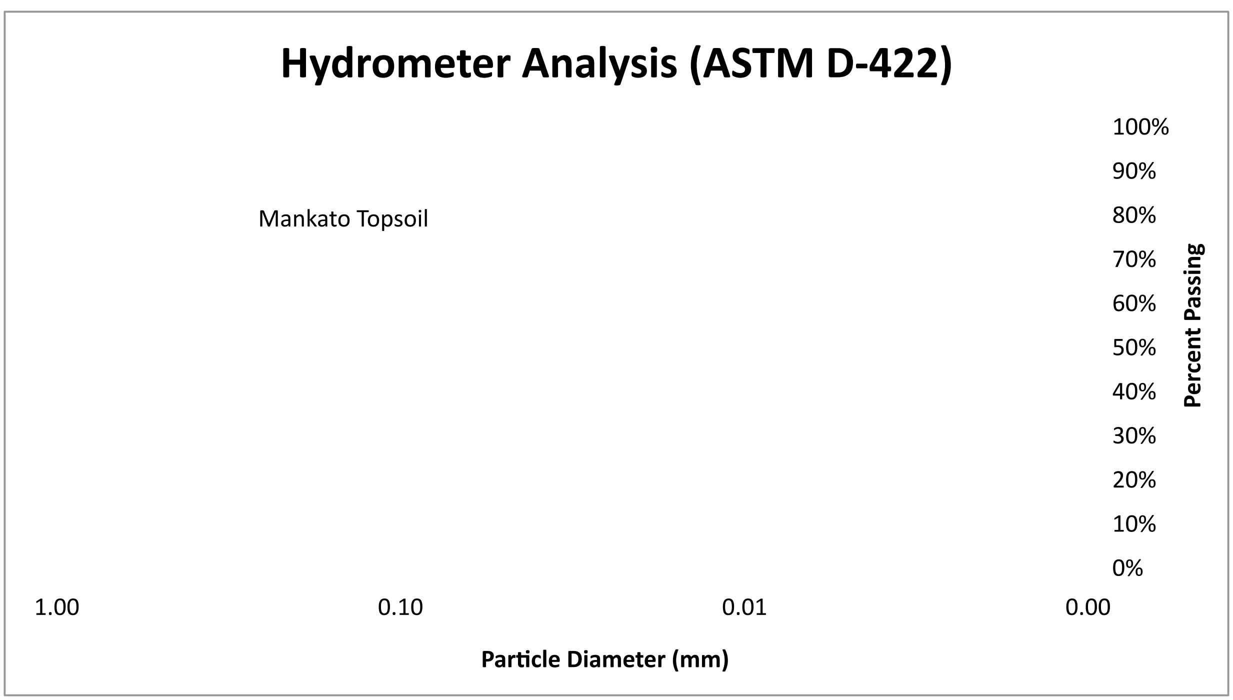
Organic Content (ASTM D2974)

Dry Total Mass (g) =	41.0658
Mineral Mass (g) =	40.3376
Organic Content =	1.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	18	13.34	0.03430119	17.8%
5	14	14.00	0.02222087	13.9%
15	12	14.33	0.01297865	11.9%
30	11.5	14.41	0.00920352	11.4%
60	11	14.49	0.00652636	10.9%
250	10.5	14.57	0.00320628	10.4%
1440	9.5	14.74	0.00134345	9.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Sandy Loam SM

Material	Mapleton Topsoil
Sample Date	November 4, 2012
Sample Loc	Klein Pond N of TH 30

Strata:	Glacial Lake Sediment
Geomorphology:	Des Moines Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Prairie Wetland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

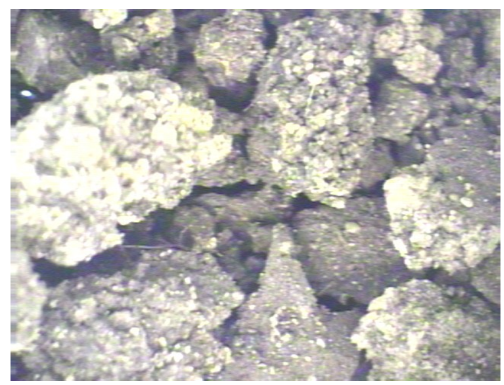
pH (ASTM D4972) = 7.5

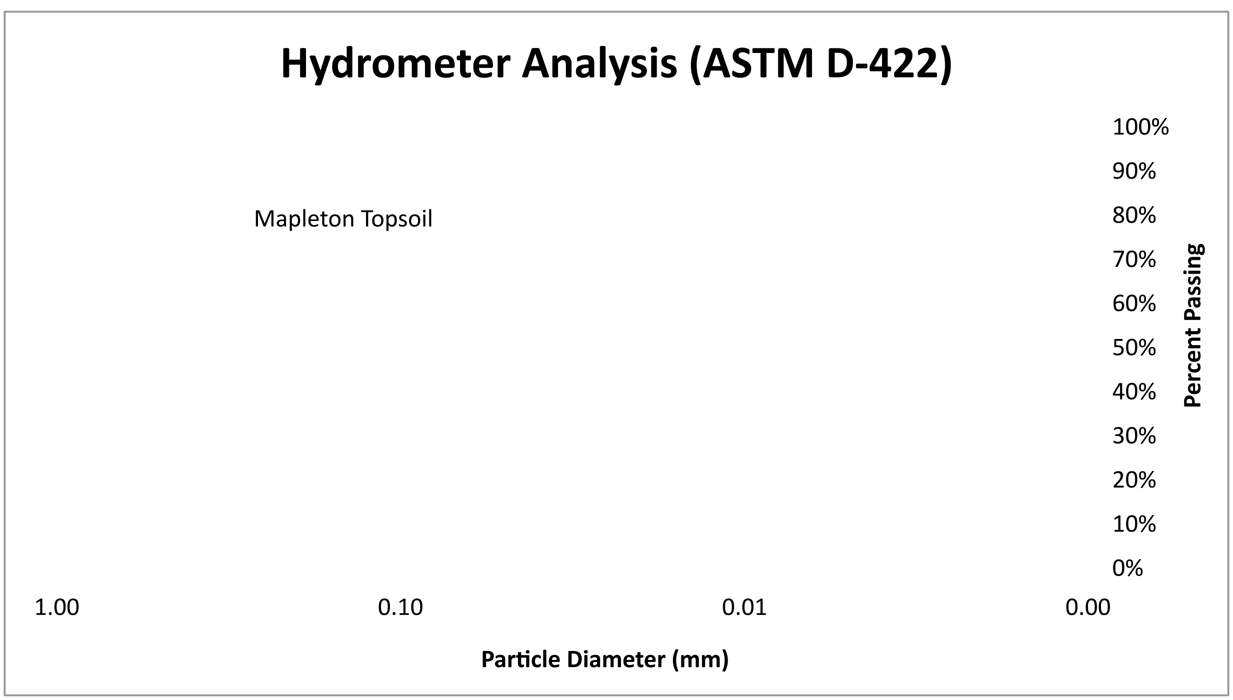
Organic Content (ASTM D2974)

Dry Total Mass (g) =	41.9586
Mineral Mass (g) =	40.2246
Organic Content =	4.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	37	10.23	0.03003008	36.6%
5	34.5	10.64	0.01936966	34.2%
15	31	11.21	0.01148085	30.7%
30	29	11.54	0.00823609	28.7%
60	27.5	11.78	0.00588554	27.2%
250	23	12.52	0.00297222	22.8%
1440	18	13.34	0.00127833	17.8%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Clay Loam SC-SM

Material	Moorhead Subsoil
Sample Date	July 21, 2012
Sample Loc	TH 75 & 50th Ave SP#1406-69

Strata: Glacial Lake Sediment
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Floodplain Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

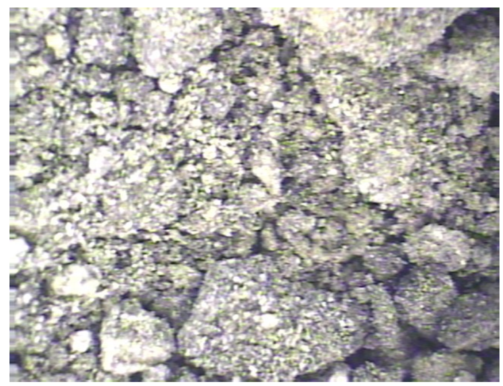
pH (ASTM D4972) =	8.3

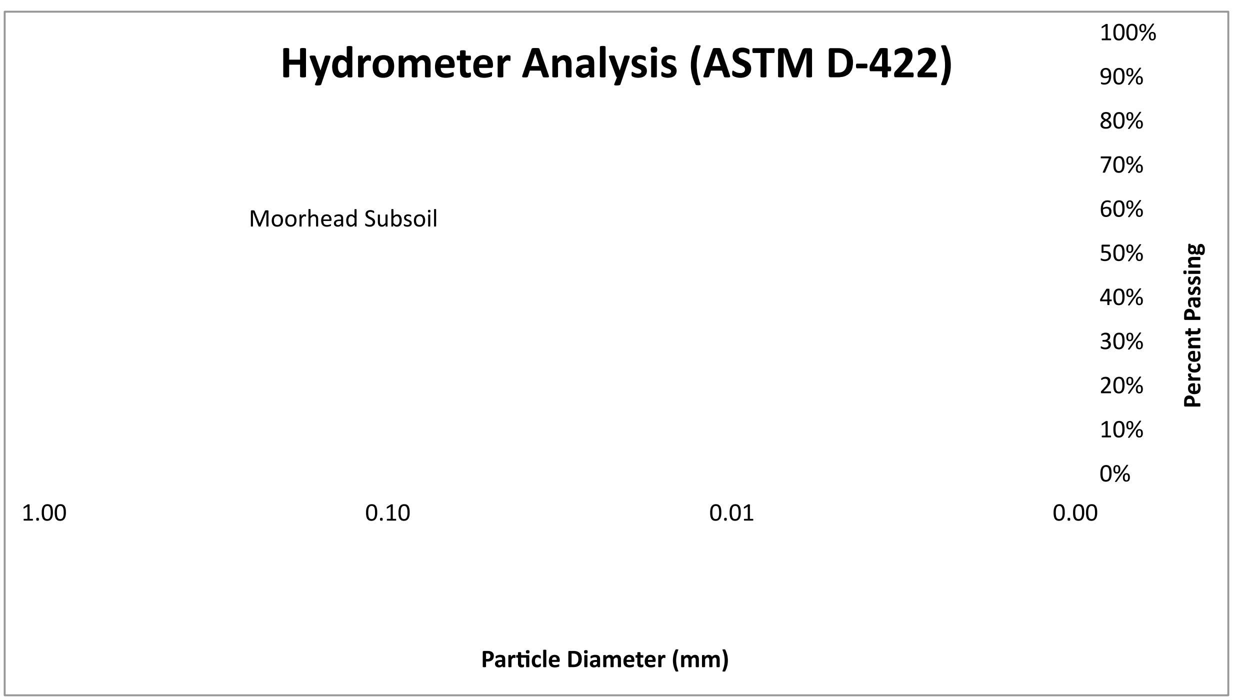
Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.4978
Mineral Mass (g) =	42.1036
Organic Content =	3.2%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	48	8.42	0.02725308	47.5%
5	40	9.73	0.01853021	39.6%
15	34	10.72	0.0112261	33.7%
30	31	11.21	0.00811818	30.7%
60	28.5	11.62	0.00584445	28.2%
250	26.5	11.95	0.00290331	26.2%
1440	22.5	12.60	0.00124247	22.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Clay Loam CL-ML-OL

Material	Moorhead Topsoil
Sample Date	July 21, 2012
Sample Loc	TH 75 & 50th Ave SP#1406-69

Strata: Glacial Lake Sediment
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Floodplain Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

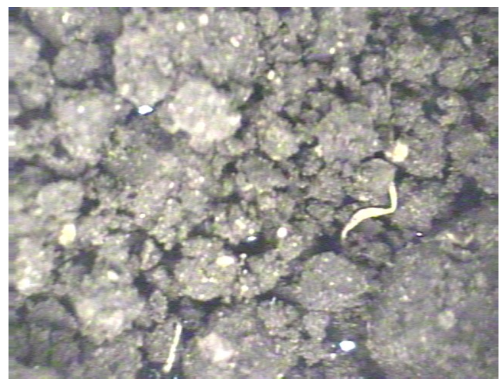
pH (ASTM D4972) = 7.8

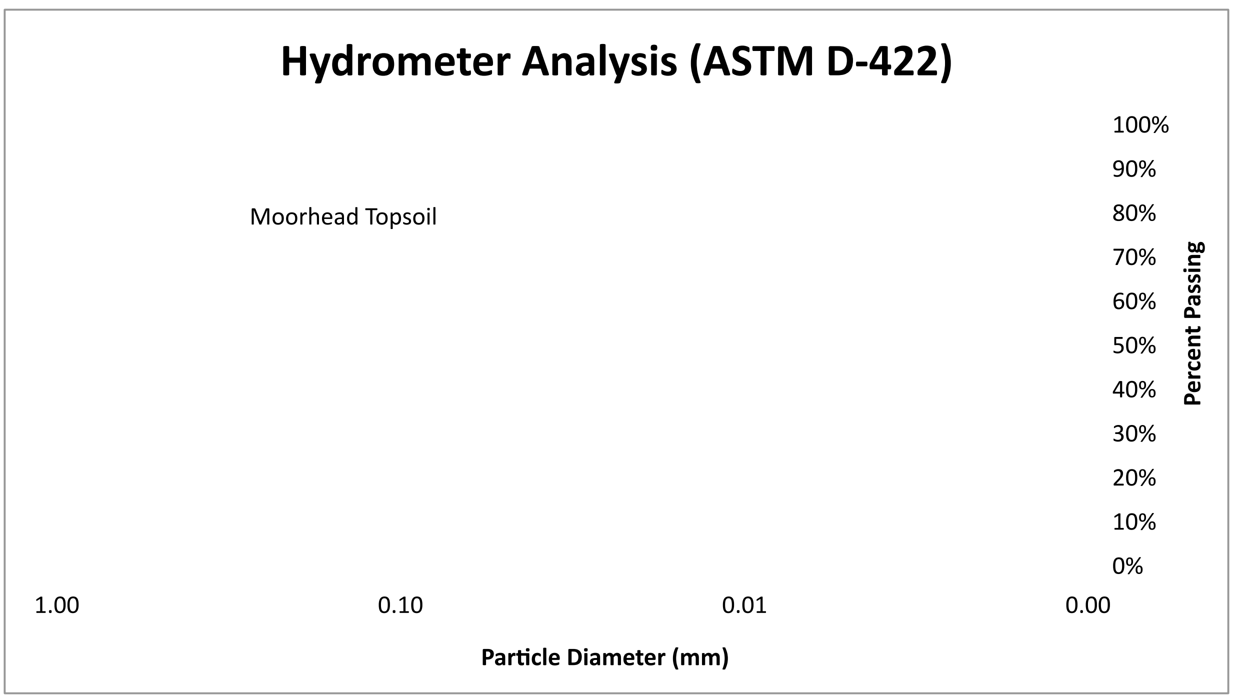
Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.5906
Mineral Mass (g) =	40.8702
Organic Content =	6.2%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	39	9.90	0.02954459	38.6%
5	33.5	10.80	0.01951841	33.2%
15	29	11.54	0.01164758	28.7%
30	27	11.87	0.00835232	26.7%
60	25.5	12.11	0.00596688	25.2%
250	23.5	12.44	0.00296248	23.3%
1440	19.5	13.10	0.00126649	19.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Clay Loam OL

Material	New Sweden Topsoil
Sample Date	November 4, 2012
Sample Loc	TH 22 at CD1

Strata: Stagnation Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

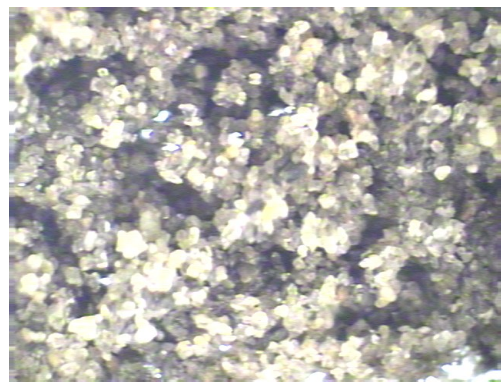
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

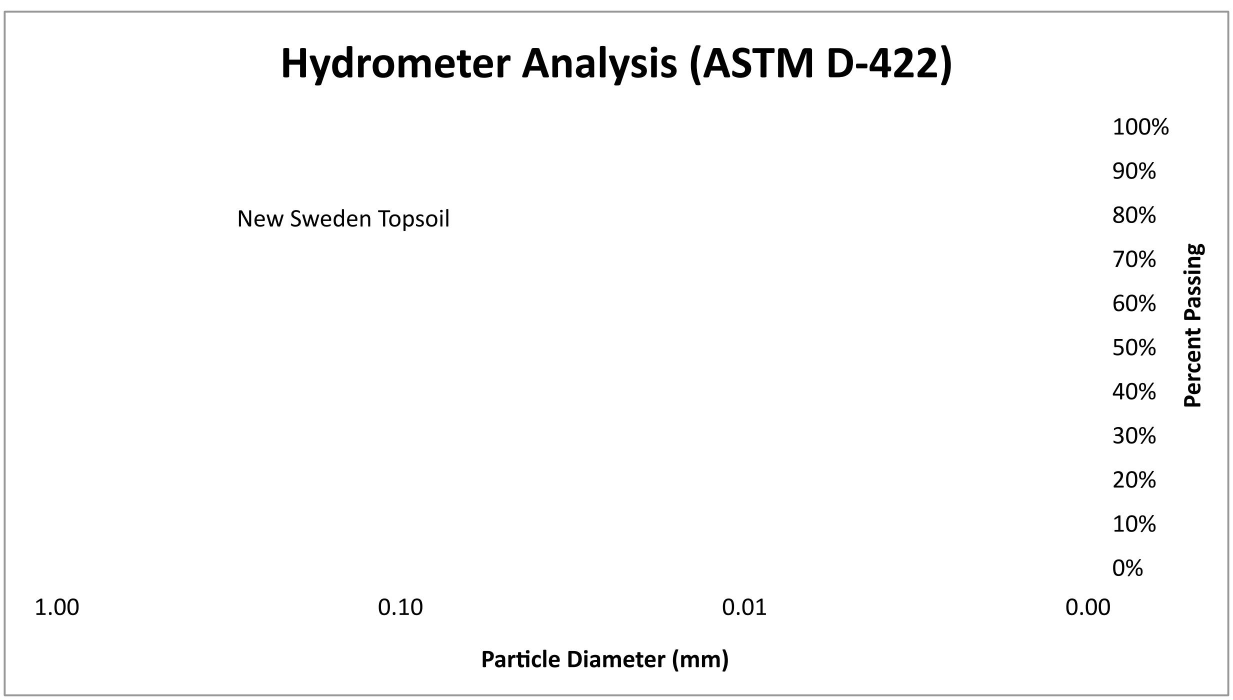
pH (ASTM D4972) = 7.97

Organic Content (ASTM D2974)
Dry Total Mass (g) = 44.5727
Mineral Mass (g) = 43.8493
Organic Content = 1.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	18	13.34	0.03430119	17.8%
5	16.5	13.59	0.02189305	16.3%
15	15	13.83	0.01275385	14.9%
30	14.5	13.92	0.00904502	14.4%
60	14	14.00	0.00641461	13.9%
250	13	14.16	0.00316086	12.9%
1440	11.5	14.41	0.00132841	11.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Sandy Loam SM

Material	North Mankato Subsoil
Sample Date	August 1, 2012
Sample Loc	TH 14 Sta 518+50 Ravine

Strata:	Ground Moraine
Geomorphology:	Des Moines Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Prairie Wetland

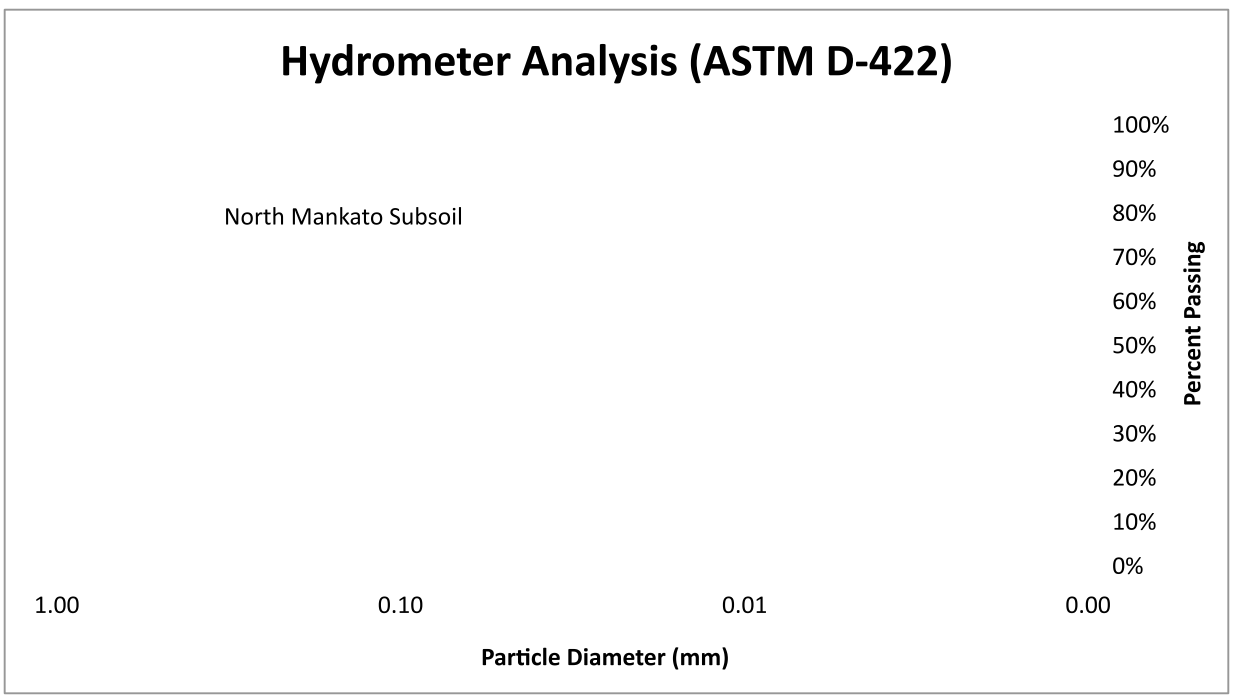
Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) =	7.6
Organic Content (ASTM D2974)	
Dry Total Mass (g) =	39.8362
Mineral Mass (g) =	39.1343
Organic Content =	1.8%

Photomicroscopy (field of view 9 x 12 mm)

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	31.5	11.13	0.0313264	31.2%
5	29.5	11.46	0.0201024	29.2%
15	27	11.87	0.01181197	26.7%
30	25.5	12.11	0.00843845	25.2%
60	23	12.52	0.00606703	22.8%
250	21	12.85	0.0030109	20.8%
1440	17	13.51	0.00128616	16.8%



Soil Classification: Sandy Clay Loam SC-SM

Material	North Mankato Topsoil
Sample Date	August 1, 2012
Sample Loc	TH 14 Sta 518+50 Ravine

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Prairie Wetland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

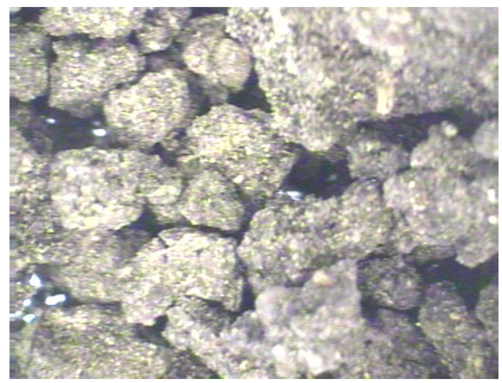
pH (ASTM D4972) = 7.1

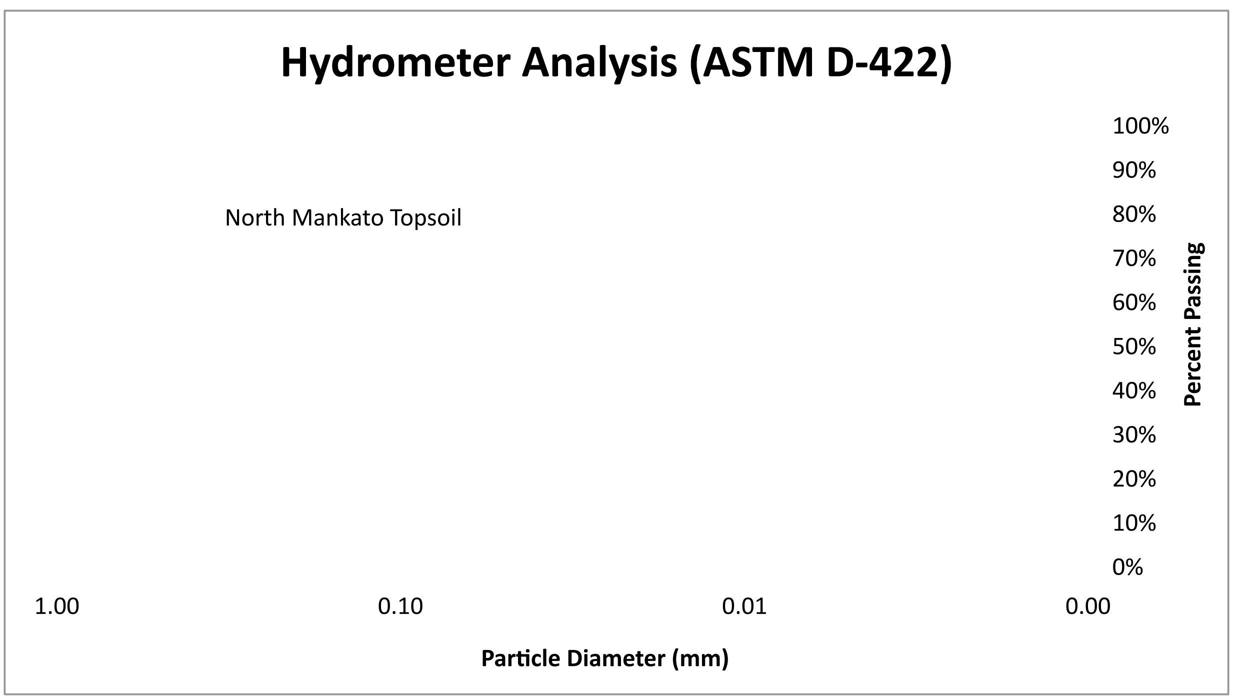
Organic Content (ASTM D2974)

Dry Total Mass (g) =	45.1482
Mineral Mass (g) =	42.4729
Organic Content =	5.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	35	10.55	0.03050784	34.7%
5	32	11.05	0.01973943	31.7%
15	28	11.70	0.01173006	27.7%
30	26.5	11.95	0.00838113	26.2%
60	24.5	12.28	0.00600714	24.3%
250	22	12.69	0.00299162	21.8%
1440	18.5	13.26	0.0012744	18.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Sandy Clay Loam SC-SM

Material	Olivia A Subsoil
Sample Date	August 21, 2012
Sample Loc	CR 62 at 1/4 mi W of US 71

Strata:	Ground Moraine
Geomorphology:	Des Moines Lobe
Ecological Province:	Prairie Parkland
Natural Vegetation:	Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

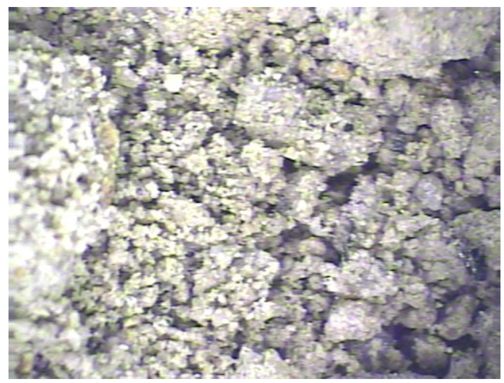
pH (ASTM D4972) = 8.2

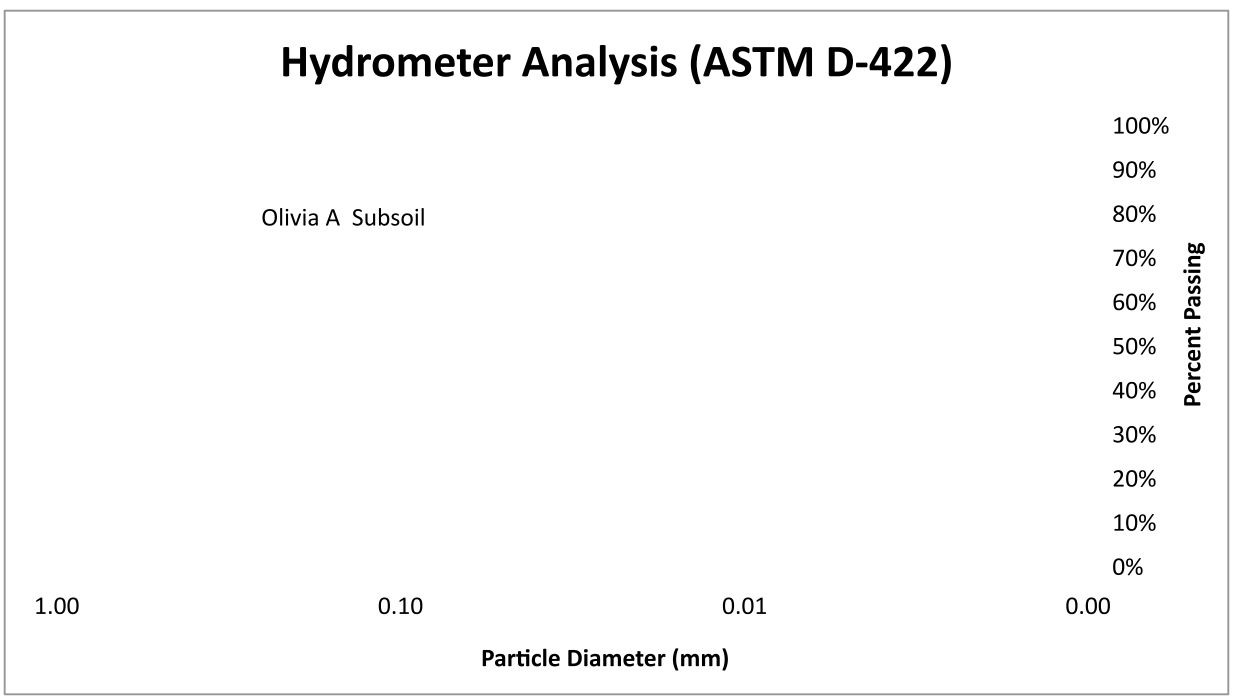
Organic Content (ASTM D2974)

Dry Total Mass (g) =	46.0579
Mineral Mass (g) =	45.7711
Organic Content =	0.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	24	12.36	0.03301217	23.8%
5	21.5	12.77	0.02122222	21.3%
15	17.5	13.42	0.01256345	17.3%
30	16.5	13.59	0.0089378	16.3%
60	14.5	13.92	0.0063958	14.4%
250	13	14.16	0.00316086	12.9%
1440	11.5	14.41	0.00132841	11.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Sandy Loam SM

Material	Olivia A Topsoil
Sample Date	August 21, 2012
Sample Loc	CR 62 at 1/4 mi W of US 71

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

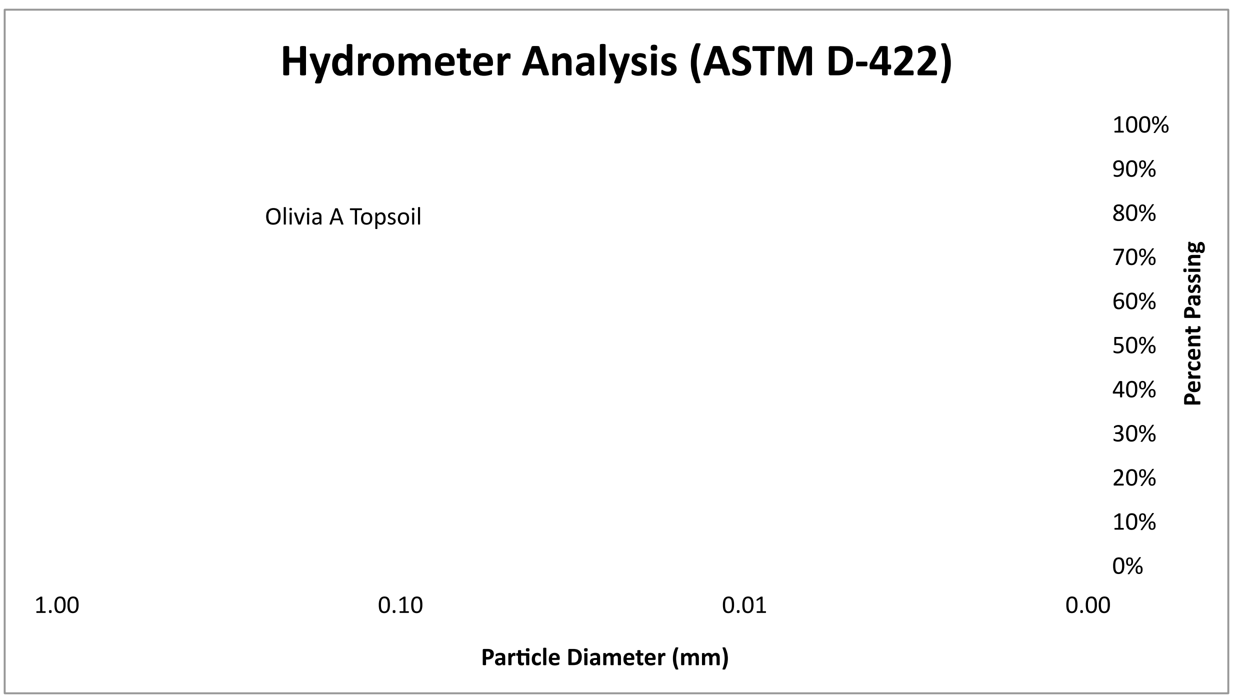
pH (ASTM D4972) = 7.4

Organic Content (ASTM D2974)

Dry Total Mass (g) =	44.4135
Mineral Mass (g) =	40.368
Organic Content =	9.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	36.5	10.31	0.03015023	36.1%
5	31	11.21	0.01988541	30.7%
15	25.5	12.11	0.01193377	25.2%
30	22.5	12.60	0.00860812	22.3%
60	20	13.01	0.00618506	19.8%
250	16.5	13.59	0.00309614	16.3%
1440	13	14.16	0.00131702	12.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Organic Sandy Loam SM

Material	Olivia B Clay
Sample Date	August 21, 2012
Sample Loc	CSAH 4 btwn CSAH 1 & US 71

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Prairie Wetland

Hydrometer (ASTM D422) 100.0 g

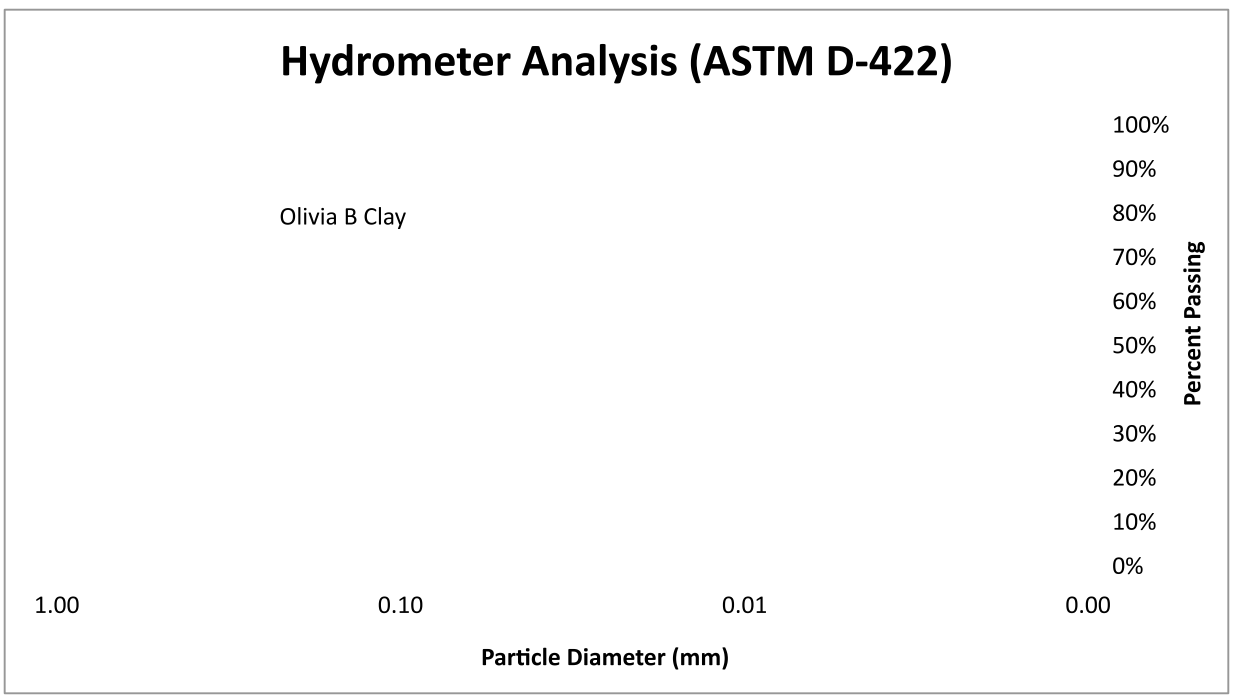
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 7.8

Organic Content (ASTM D2974)
Dry Total Mass (g) = 44.5888
Mineral Mass (g) = 43.7853
Organic Content = 1.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	32	11.05	0.03121077	31.7%
5	28.5	11.62	0.02024576	28.2%
15	25.5	12.11	0.01193377	25.2%
30	23.5	12.44	0.00855194	23.3%
60	22	12.69	0.00610663	21.8%
250	20	13.01	0.00303005	19.8%
1440	16	13.67	0.00129395	15.8%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Clay Loam SC-SM

Material	Owatonna Clay
Sample Date	August 21, 2012
Sample Loc	TH 14 Sta 1569+48 SP#7401-34

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

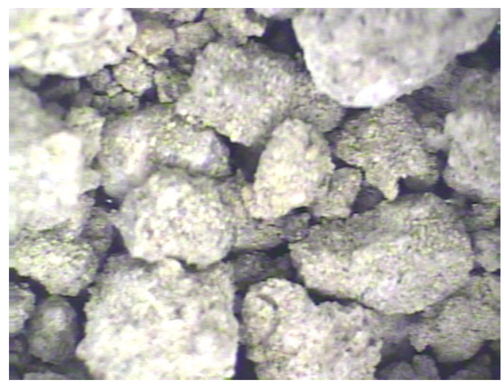
pH (ASTM D4972) = 7.3

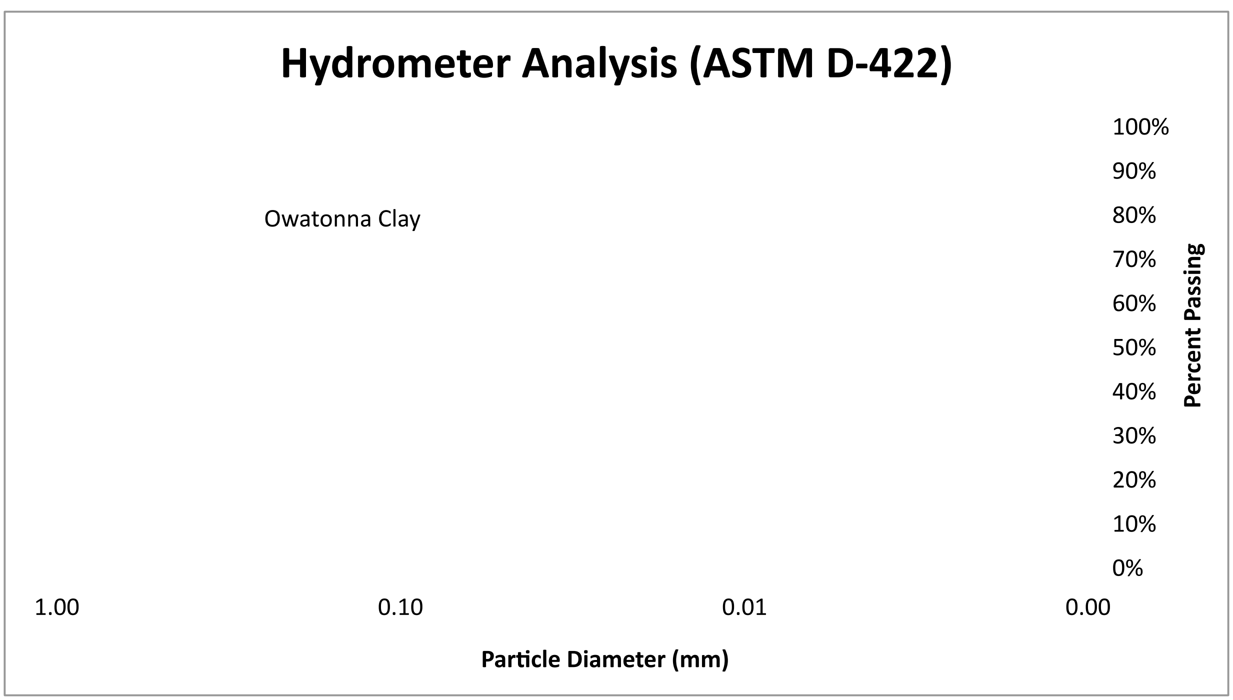
Organic Content (ASTM D2974)

Dry Total Mass (g) =	42.9901
Mineral Mass (g) =	41.8209
Organic Content =	2.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	30	11.37	0.03167073	29.7%
5	28	11.70	0.02031707	27.7%
15	25.5	12.11	0.01193377	25.2%
30	24	12.36	0.00852371	23.8%
60	22.5	12.60	0.00608686	22.3%
250	20.5	12.93	0.00302049	20.3%
1440	17	13.51	0.00128616	16.8%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Clay Loam SC-SM

Material	Owatonna Topsoil
Sample Date	August 21, 2012
Sample Loc	TH 14 Sta 1569+48 SP#7401-34

Strata:	Ground Moraine
Geomorphology:	Des Moines Lobe
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L)
+ 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

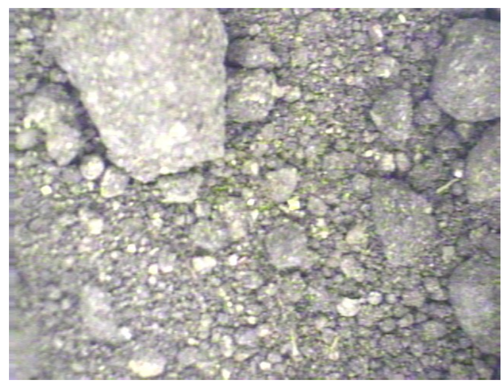
pH (ASTM D4972) =	7.2

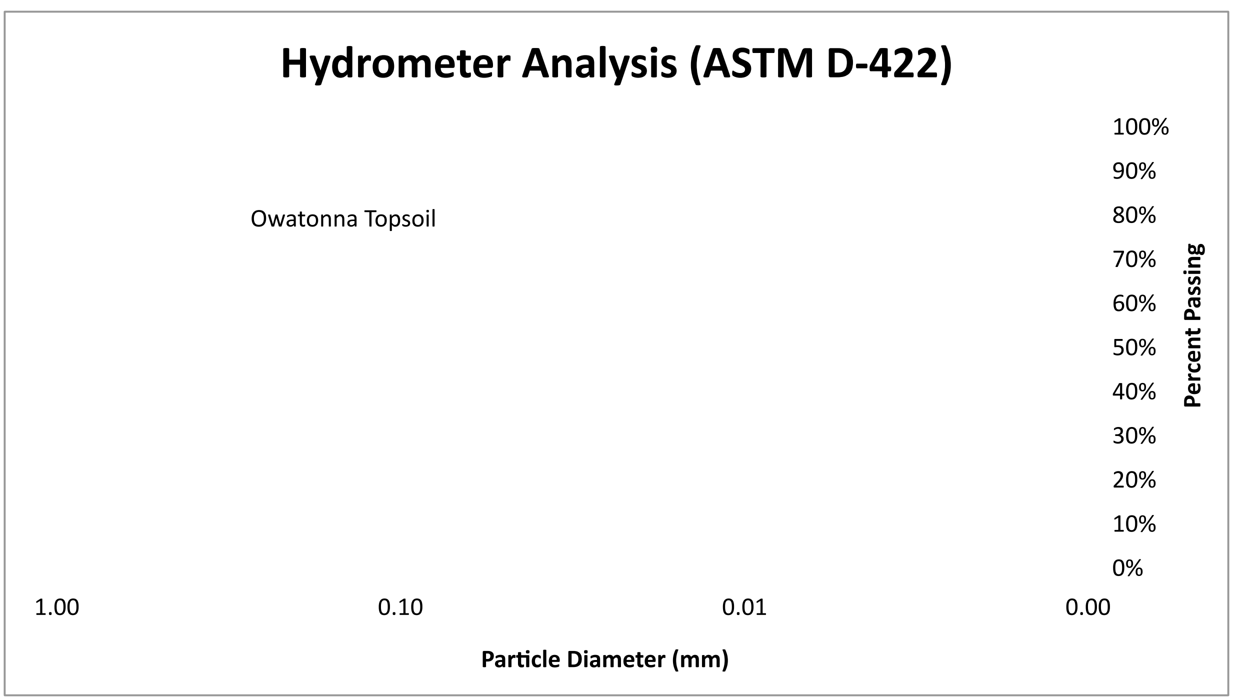
Organic Content (ASTM D2974)

Dry Total Mass (g) =	42.9447
Mineral Mass (g) =	40.8306
Organic Content =	4.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	30	11.37	0.03167073	29.7%
5	27.5	11.78	0.02038812	27.2%
15	24	12.36	0.01205434	23.8%
30	22.5	12.60	0.00860812	22.3%
60	21	12.85	0.00614597	20.8%
250	19	13.18	0.00304908	18.8%
1440	16	13.67	0.00129395	15.8%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Clay Loam SC-SM

Material	Perham Subsoil
Sample Date	July 21, 2012
Sample Loc	TH 10 & CR 34 SP#5607-42

Strata: Outwash
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422) 100.0 g

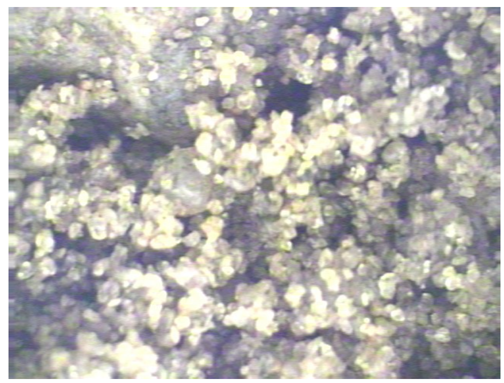
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

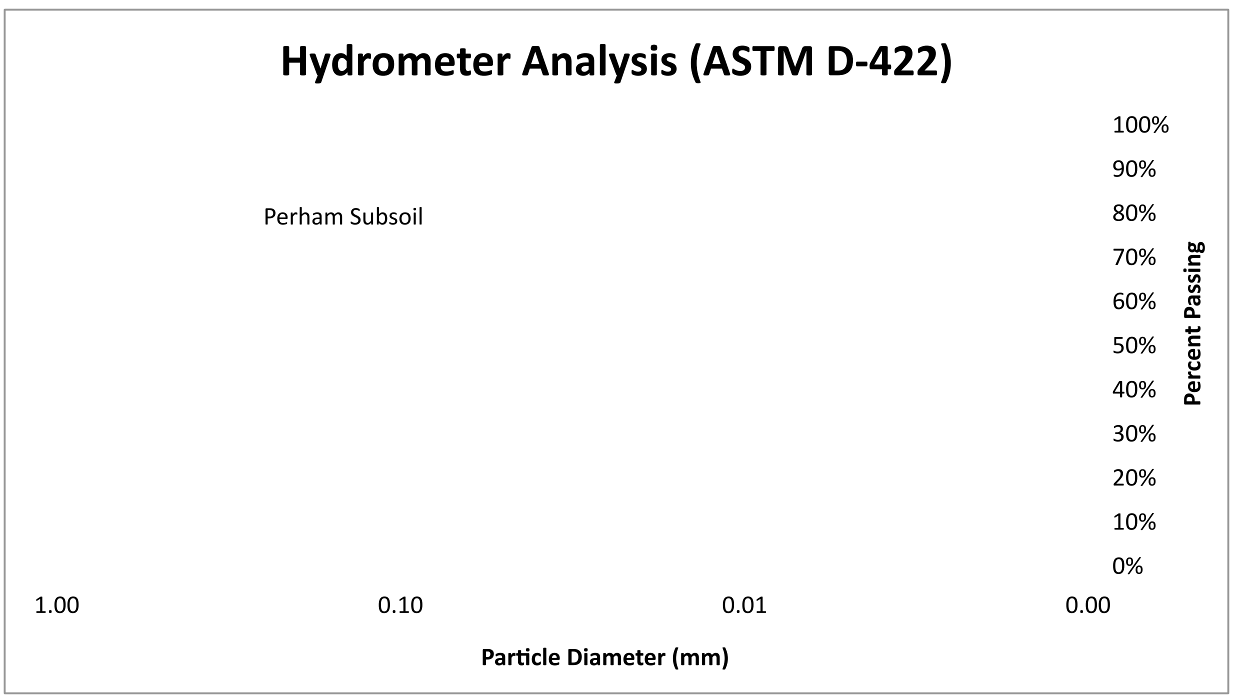
pH (ASTM D4972) = 7

Organic Content (ASTM D2974)
Dry Total Mass (g) = 44.8753
Mineral Mass (g) = 44.5782
Organic Content = 0.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	9	14.82	0.03614864	8.9%
5	8.5	14.90	0.02292558	8.4%
15	8.5	14.90	0.01323609	8.4%
30	8.5	14.90	0.00935933	8.4%
60	8	14.98	0.00663623	7.9%
250	8	14.98	0.00325107	7.9%
1440	7	15.15	0.00136201	6.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Sandy Loam SM

Environmental Engineering
S. Druschel, Mn State Mankato

Sediment Characterization

MnDOT Floc
December 10, 2012

Material	Perham Topsoil
Sample Date	July 21, 2012
Sample Loc	TH 10 & CR 34 SP#5607-42

Strata:	Outwash
Geomorphology:	Des Moines Lobe
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

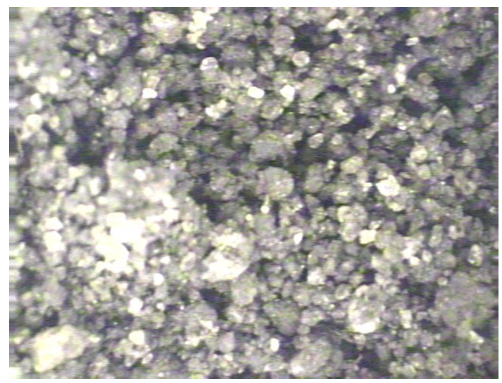
pH (ASTM D4972) =	7.5

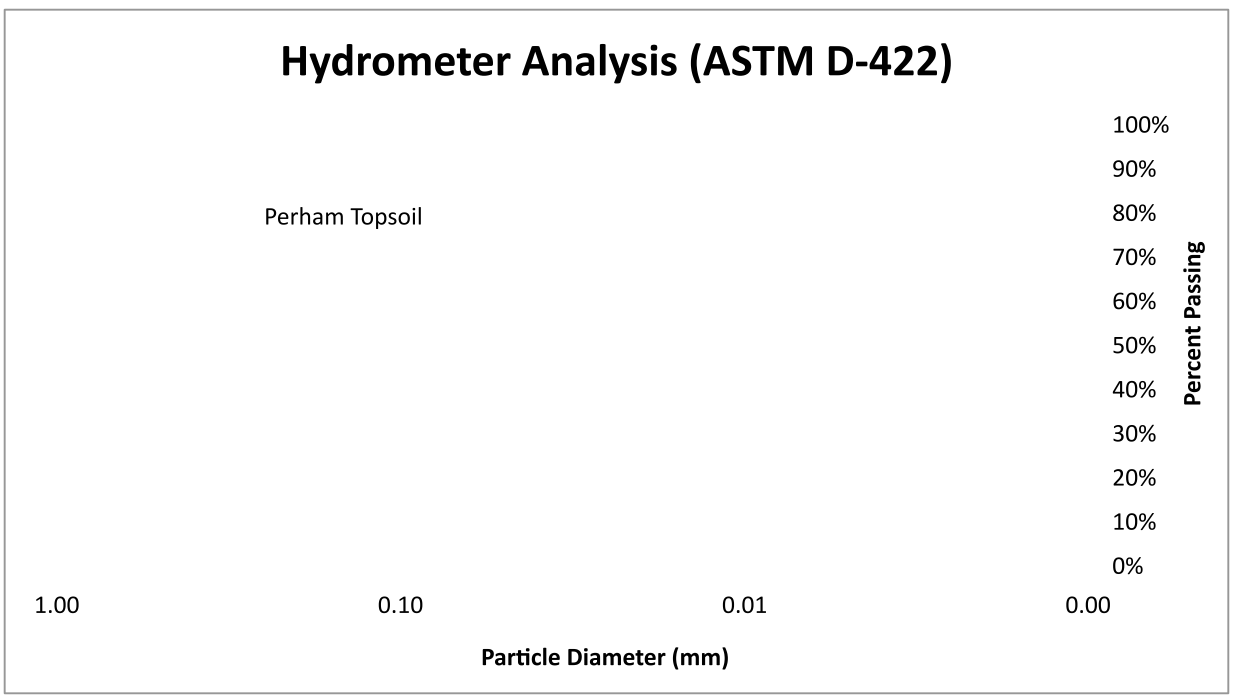
Organic Content (ASTM D2974)

Dry Total Mass (g) =	44.8498
Mineral Mass (g) =	43.736
Organic Content =	2.5%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	12	14.33	0.0355435	11.9%
5	11.5	14.41	0.02254392	11.4%
15	10.5	14.57	0.0130896	10.4%
30	10	14.65	0.00928175	9.9%
60	9.5	14.74	0.00658152	9.4%
250	9	14.82	0.00323323	8.9%
1440	8	14.98	0.00135461	7.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Pipestone Subsoil
Sample Date	not stated
Sample Loc	CSAH 10 at 1.5 mi E of TH 75

Strata: Gray Drift
Geomorphology: Kansan Glaciation
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

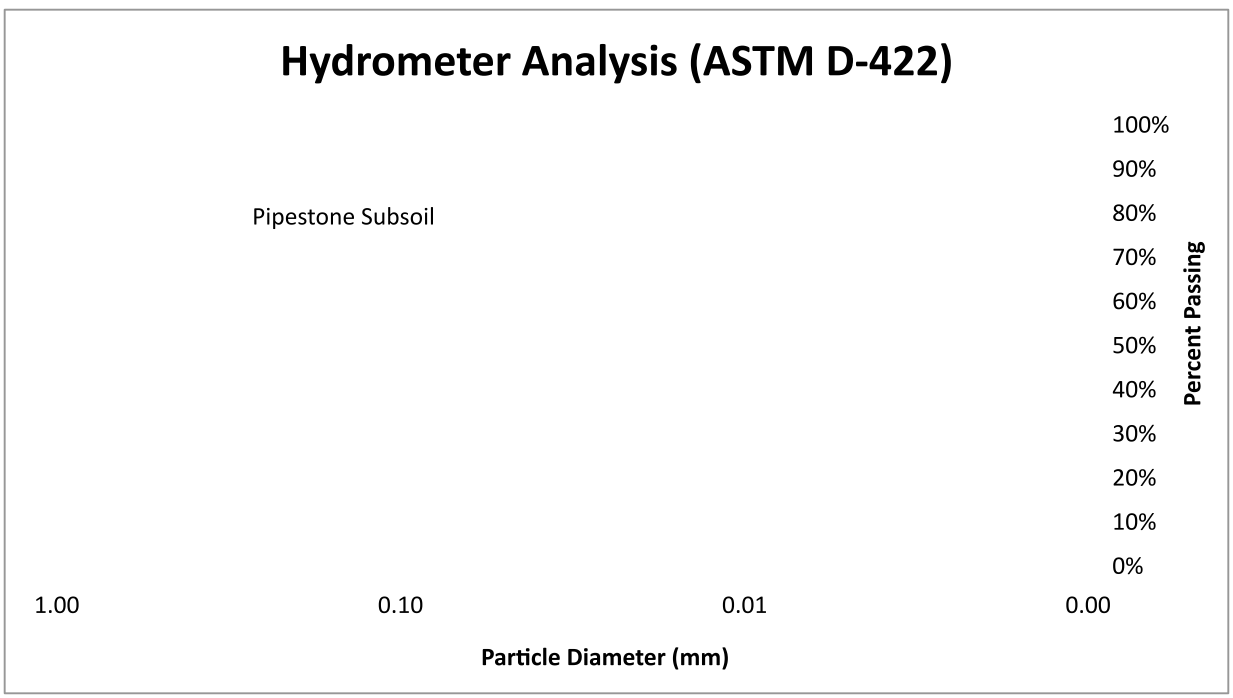
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 8.1

Organic Content (ASTM D2974)
Dry Total Mass (g) = 40.6169
Mineral Mass (g) = 39.8541
Organic Content = 1.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	23	12.52	0.03323048	22.8%
5	21	12.85	0.02129026	20.8%
15	18.5	13.26	0.01248648	18.3%
30	17	13.51	0.00891079	16.8%
60	16	13.67	0.00633902	15.8%
250	15	13.83	0.00312404	14.9%
1440	13	14.16	0.00131702	12.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Material	Pipestone Topsoil
Sample Date	not stated
Sample Loc	CSAH 10 at 1.5 mi E of TH 75

Strata: Gray Drift
Geomorphology: Kansan Glaciation
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L)
+ 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

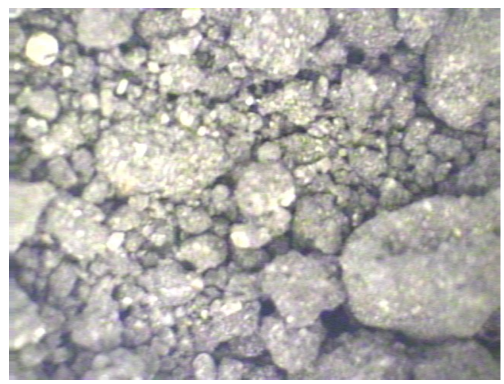
pH (ASTM D4972) = 7.9

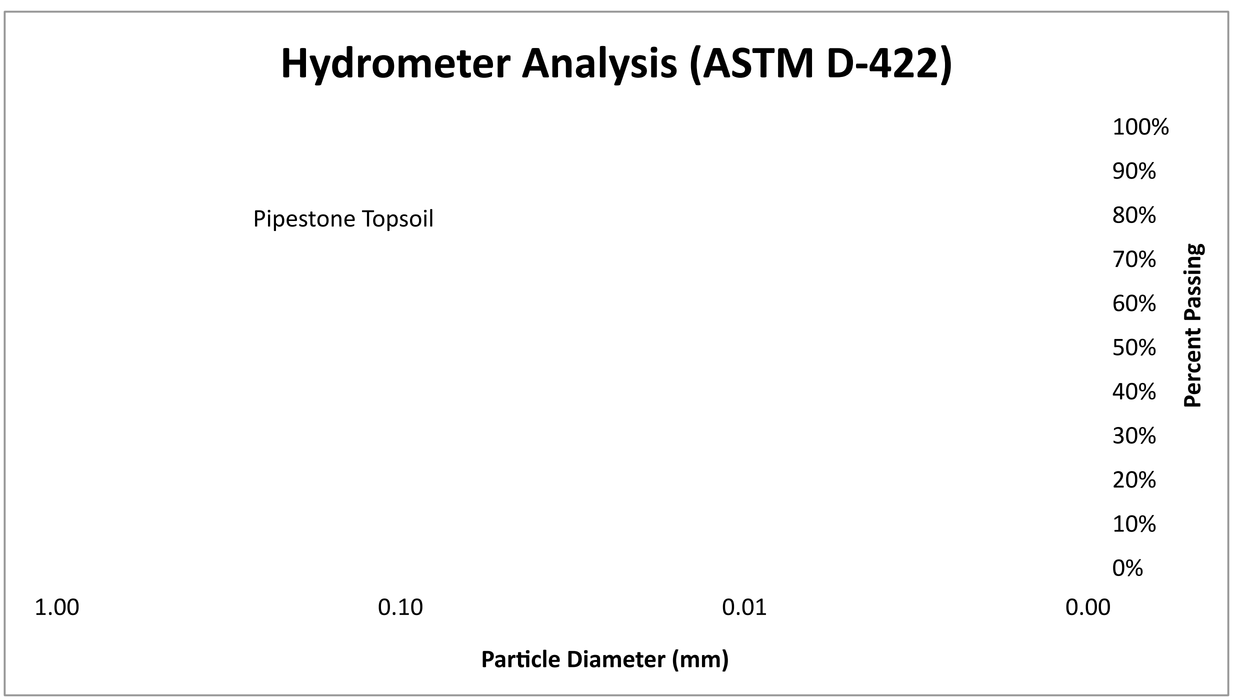
Organic Content (ASTM D2974)

Dry Total Mass (g) =	39.1515
Mineral Mass (g) =	36.4854
Organic Content =	6.8%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	27	11.87	0.03234841	26.7%
5	22.5	12.60	0.0210855	22.3%
15	19	13.18	0.01244781	18.8%
30	17	13.51	0.00891079	16.8%
60	16	13.67	0.00633902	15.8%
250	14	14.00	0.00314251	13.9%
1440	12	14.33	0.00132463	11.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Organic Sandy Loam SM

Material	Ramsey Peat
Sample Date	not stated
Sample Loc	35 E & Maryland Ave

Strata: Glacial Lake Sediment
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L)
+ 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

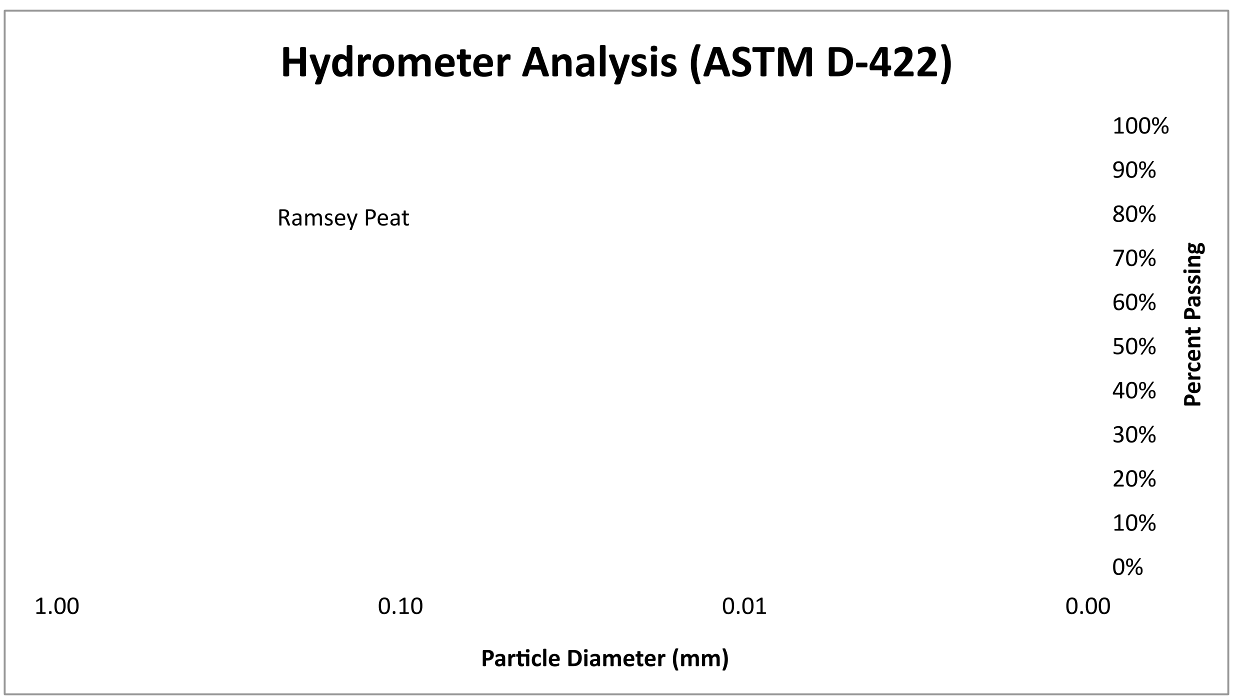
pH (ASTM D4972) = 6.6

Organic Content (ASTM D2974)

Dry Total Mass (g) =	45.8799
Mineral Mass (g) =	36.8351
Organic Content =	19.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	20.5	12.93	0.03377008	20.3%
5	17.5	13.42	0.02176054	17.3%
15	15	13.83	0.01275385	14.9%
30	13.5	14.08	0.00909816	13.4%
60	12	14.33	0.00648933	11.9%
250	10.5	14.57	0.00320628	10.4%
1440	9	14.82	0.00134718	8.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Highly Organic Sandy Loam SM

Material	Rockford Cornfield
Sample Date	not stated
Sample Loc	TH 55

Strata: End Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Maple Basswood Forest

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

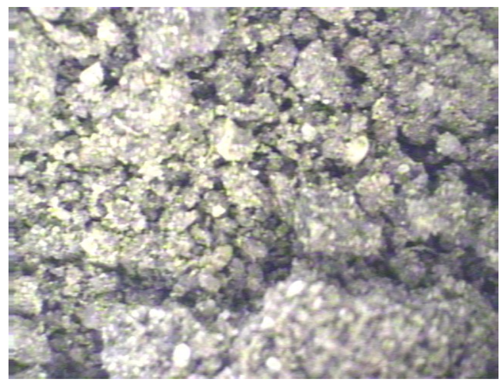
pH (ASTM D4972) = 7.5

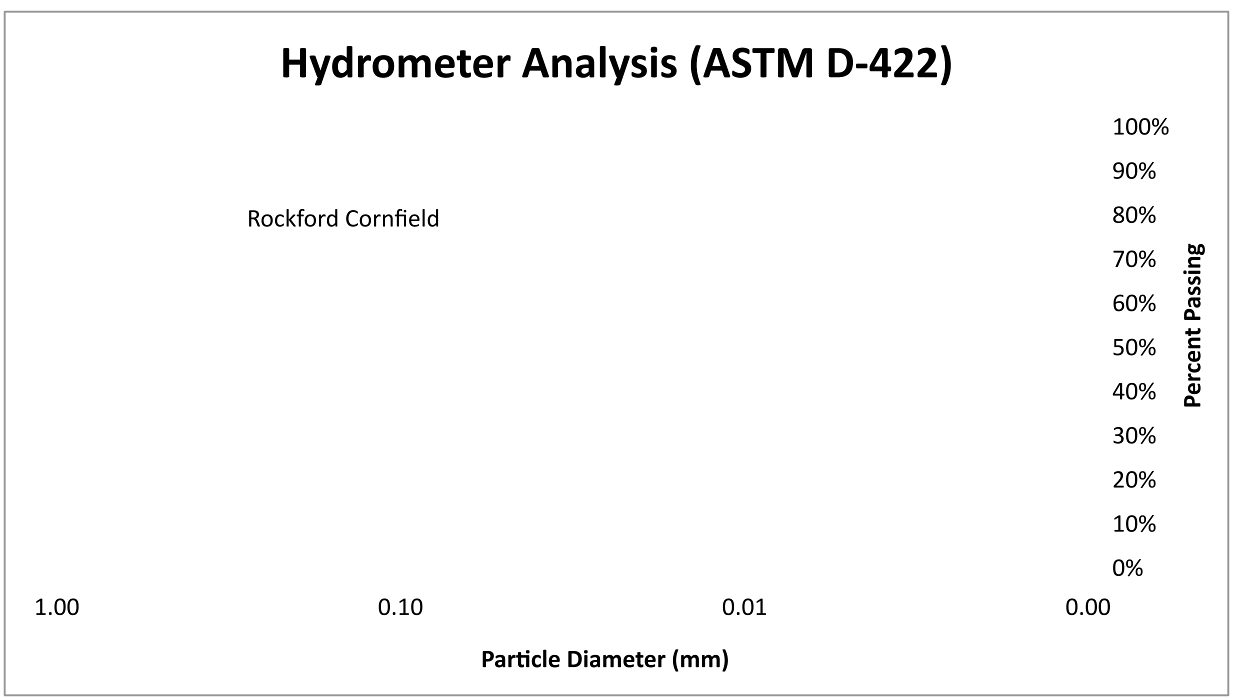
Organic Content (ASTM D2974)

Dry Total Mass (g) =	34.8561
Mineral Mass (g) =	33.306
Organic Content =	4.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	24.5	12.28	0.03290248	24.3%
5	23	12.52	0.0210168	22.8%
15	20	13.01	0.01237012	19.8%
30	18.5	13.26	0.00882927	18.3%
60	17.5	13.42	0.00628173	17.3%
250	16.5	13.59	0.00309614	16.3%
1440	14	14.00	0.00130938	13.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Rockford Subsoil
Sample Date	not stated
Sample Loc	TH 55

Strata: End Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Maple Basswood Forest

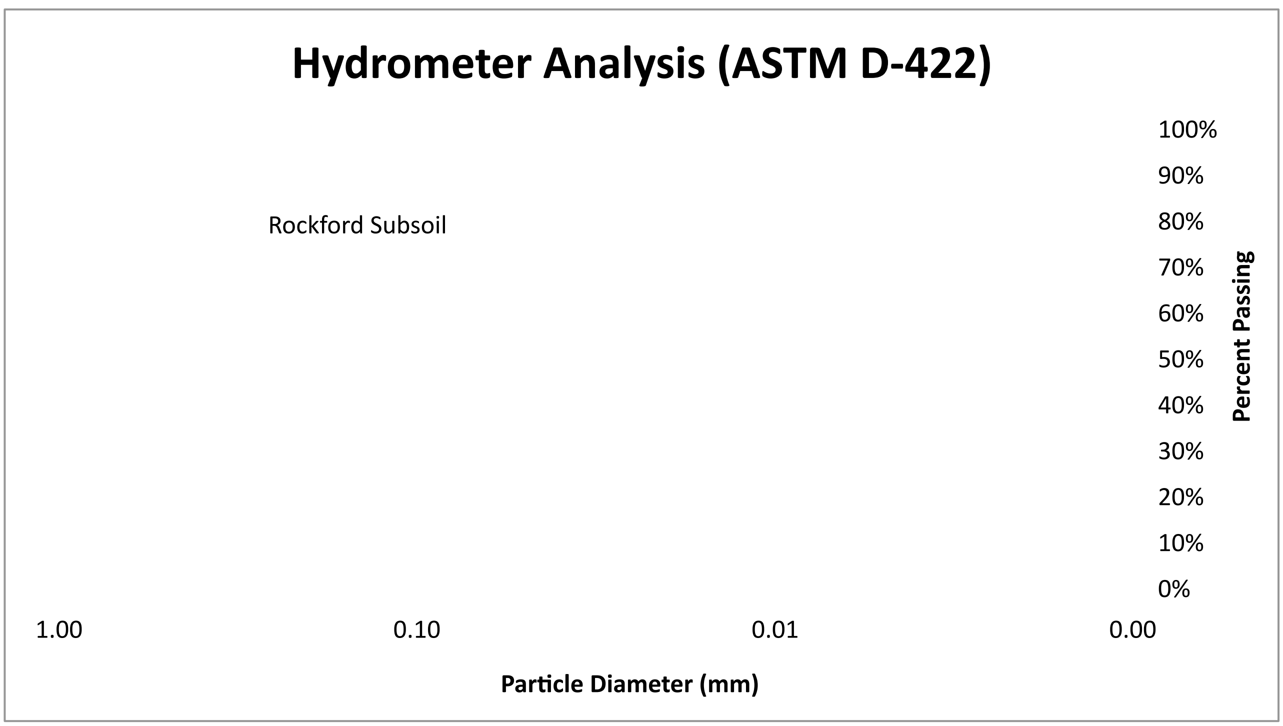
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 6.9

Organic Content (ASTM D2974)
Dry Total Mass (g) = 33.5297
Mineral Mass (g) = 32.7203
Organic Content = 2.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	30	11.37	0.03167073	29.7%
5	27.5	11.78	0.02038812	27.2%
15	25	12.19	0.0119741	24.8%
30	23.5	12.44	0.00855194	23.3%
60	22	12.69	0.00610663	21.8%
250	19.5	13.10	0.00303958	19.3%
1440	16.5	13.59	0.00129006	16.3%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Rockford Topsoil
Sample Date	not stated
Sample Loc	TH 55

Strata:	End Moraine
Geomorphology:	Des Moines Lobe
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Maple Basswood Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

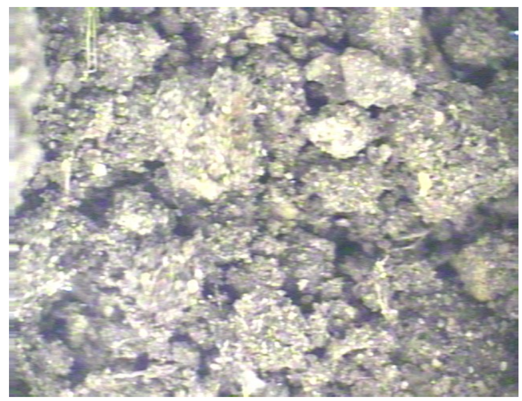
pH (ASTM D4972) =	7.4

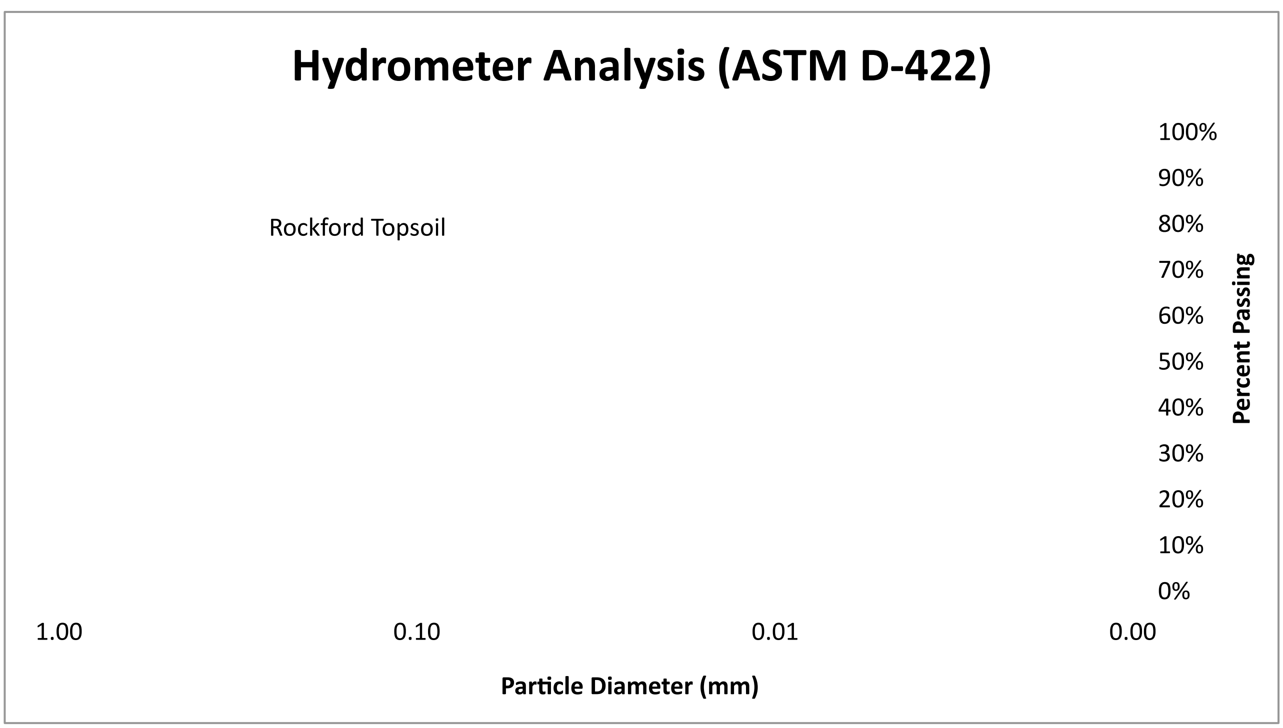
Organic Content (ASTM D2974)

Dry Total Mass (g) =	36.8538
Mineral Mass (g) =	35.5014
Organic Content =	3.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	32.5	10.96	0.03109472	32.2%
5	28.5	11.62	0.02024576	28.2%
15	24.5	12.28	0.01201429	24.3%
30	22	12.69	0.00863607	21.8%
60	21	12.85	0.00614597	20.8%
250	17	13.51	0.00308679	16.8%
1440	13.5	14.08	0.00131321	13.4%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Sandstone Subsoil
Sample Date	October 10, 2012
Sample Loc	North of TH 18, West of CH 61

Strata:	Ground Moraine
Geomorphology:	Superior Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Norther Hardwood Forest

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

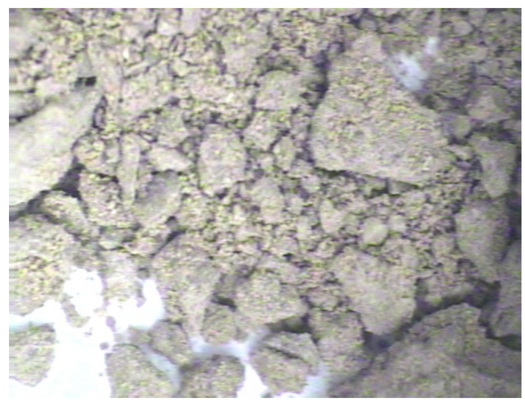
pH (ASTM D4972) = 8

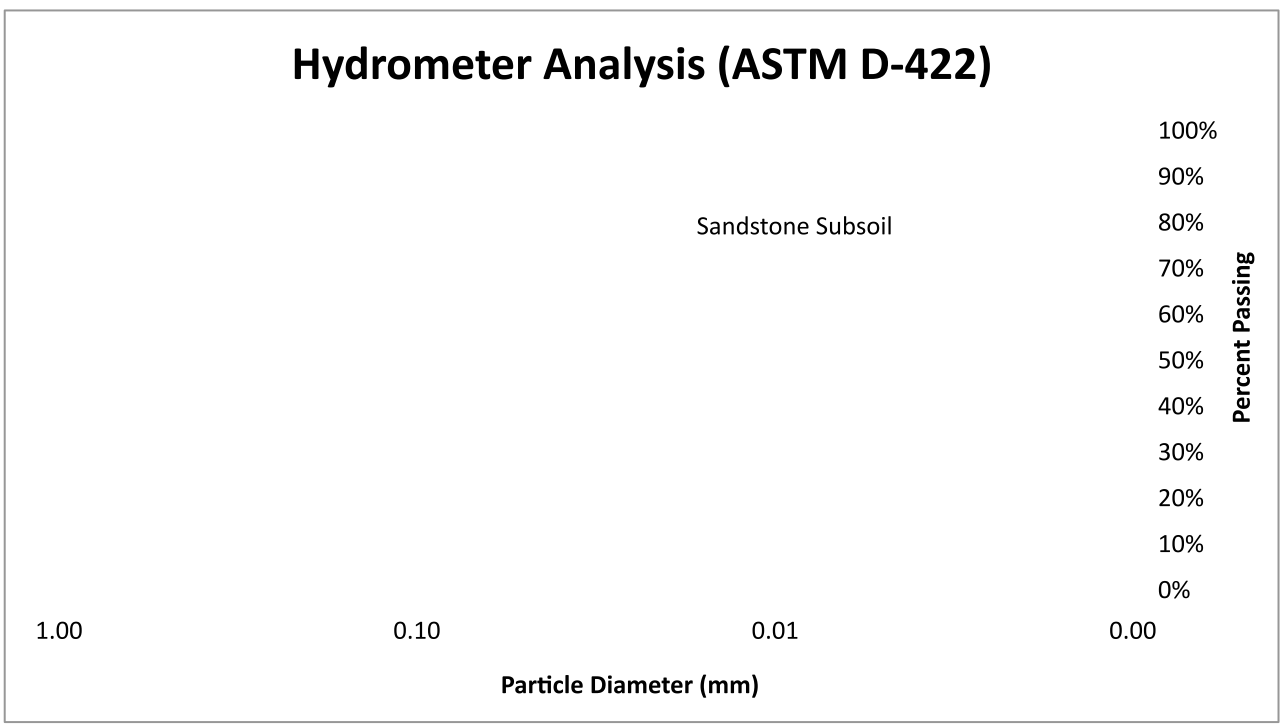
Organic Content (ASTM D2974)

Dry Total Mass (g) =	53.2787
Mineral Mass (g) =	51.9657
Organic Content =	2.5%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	43	9.24	0.02854886	42.6%
5	41	9.57	0.01837346	40.6%
15	38	10.06	0.01087716	37.6%
30	36.5	10.31	0.00778476	36.1%
60	34	10.72	0.00561305	33.7%
250	31	11.21	0.00281222	30.7%
1440	24.5	12.28	0.0012262	24.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Clay Loam CL-ML-OL

Material	Sandstone Topsoil
Sample Date	October 10, 2012
Sample Loc	North of CR 32, East of CH 22

Strata:	Ground Moraine
Geomorphology:	Superior Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Norther Hardwood Forest

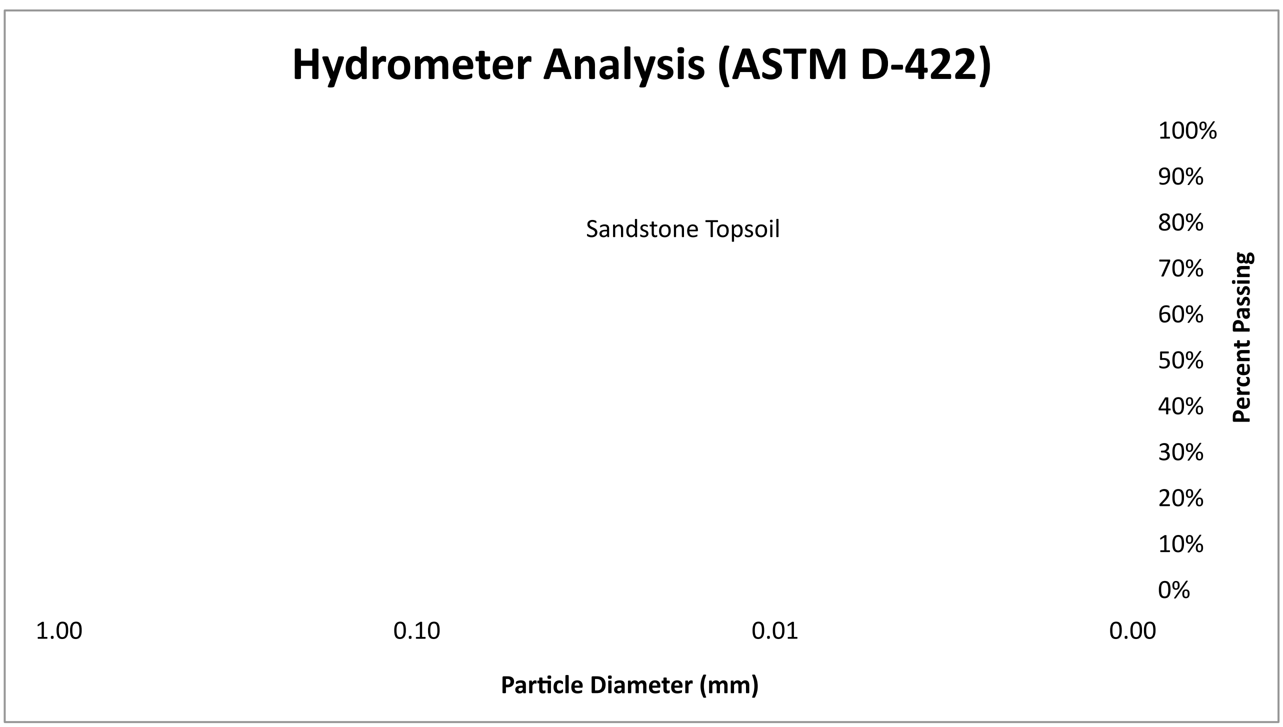
Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) =	7.9
Organic Content (ASTM D2974)	
Dry Total Mass (g) =	55.5695
Mineral Mass (g) =	53.274
Organic Content =	4.1%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	21	12.85	0.03366285	20.8%
5	17.5	13.42	0.02176054	17.3%
15	15.5	13.75	0.012716	15.3%
30	14	14.00	0.00907163	13.9%
60	13	14.16	0.00645208	12.9%
250	11.5	14.41	0.00318819	11.4%
1440	10.5	14.57	0.00133595	10.4%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Stillwater Sediment
Sample Date	July 27, 2012
Sample Loc	Bridge Pier River Boring

Strata: End Moraine
Geomorphology: Superior Lobe
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

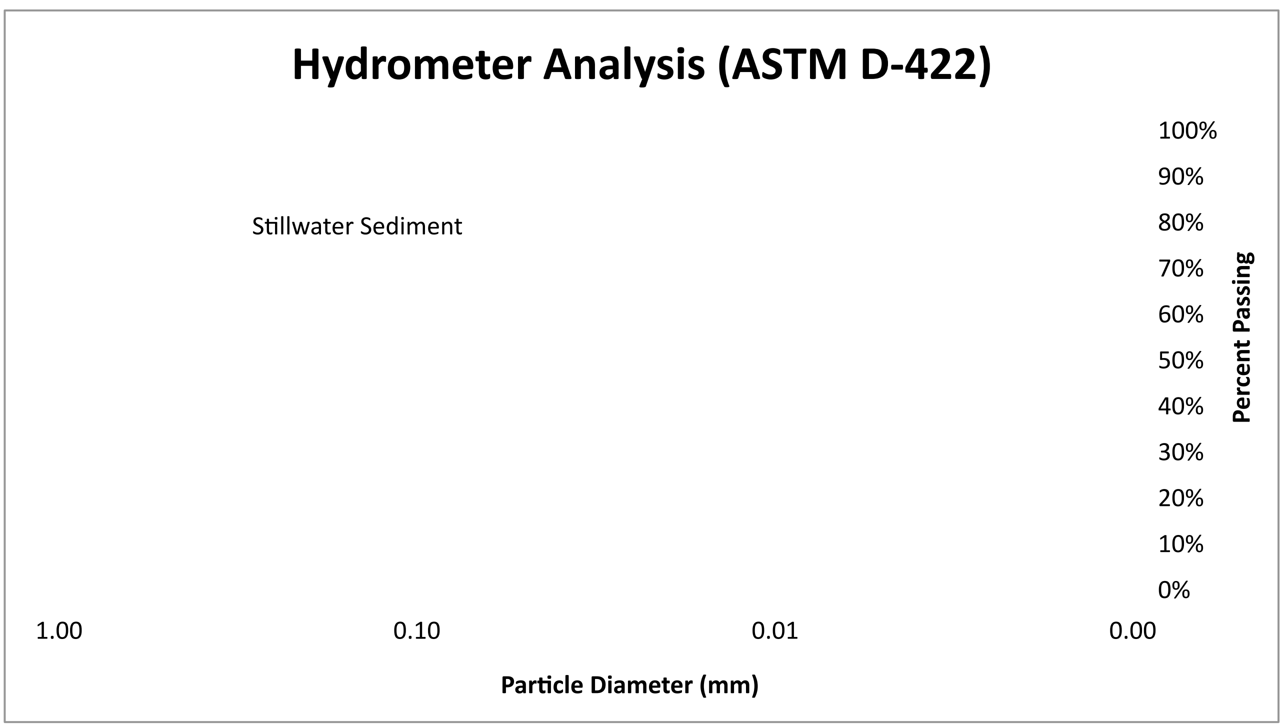
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 7.5

Organic Content (ASTM D2974)
Dry Total Mass (g) = 35.5434
Mineral Mass (g) = 32.1189
Organic Content = 9.6%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	44.5	9.00	0.02816638	44.1%
5	34	10.72	0.01944417	33.7%
15	29	11.54	0.01164758	28.7%
30	24	12.36	0.00852371	23.8%
60	19.5	13.10	0.00620451	19.3%
250	14	14.00	0.00314251	13.9%
1440	10	14.65	0.00133971	9.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Organic Loam OL

Material	Tamarack Clay
Sample Date	September 17, 2012
Sample Loc	CSAH 32 Sta 137+36 40'Lt

Strata:	End Moraine
Geomorphology:	Des Moines Lobe
Ecological Province:	Laurentian Mixed Forest
Natural Vegetation:	Peatland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

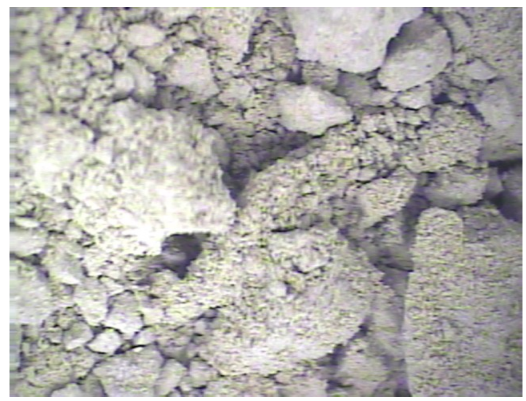
pH (ASTM D4972) =	7.1

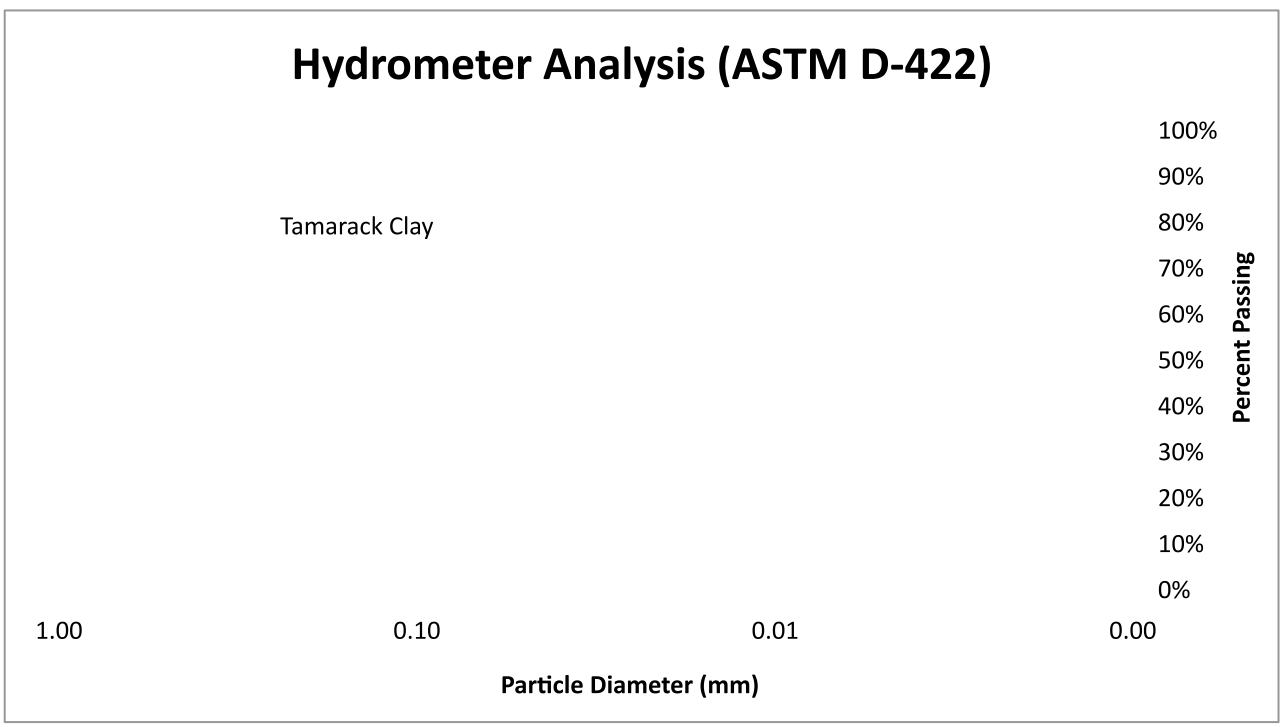
Organic Content (ASTM D2974)

Dry Total Mass (g) =	38.2459
Mineral Mass (g) =	37.0922
Organic Content =	3.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	50.5	8.01	0.02658151	50.0%
5	49	8.26	0.01706773	48.5%
15	47	8.59	0.01004783	46.5%
30	44	9.08	0.0073056	43.6%
60	40.5	9.65	0.00532663	40.1%
250	33	10.88	0.00277078	32.7%
1440	23.5	12.44	0.00123437	23.3%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification:	Slightly Organic Clay	CL-OL

Material	Tamarack Peat	Strata:	Peat
Sample Date	September 17, 2012	Geomorphology:	Des Moines Lobe
Sample Loc	CSAH 32 Sta 152+85 30'Lt	Ecological Province:	Laurentian Mixed Forest
		Natural Vegetation:	Peatland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs = 2.65

Gs Corr, a = 0.99 ASTM D-422 Table 1

Lab Temp = 21 deg C

K factor = 0.01328 ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 6.9

Organic Content (ASTM D2974)

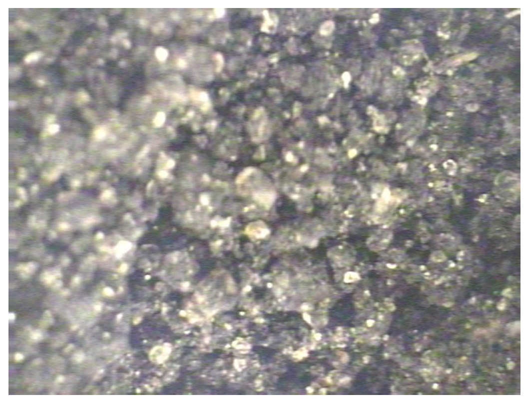
Dry Total Mass (g) = 7.7385

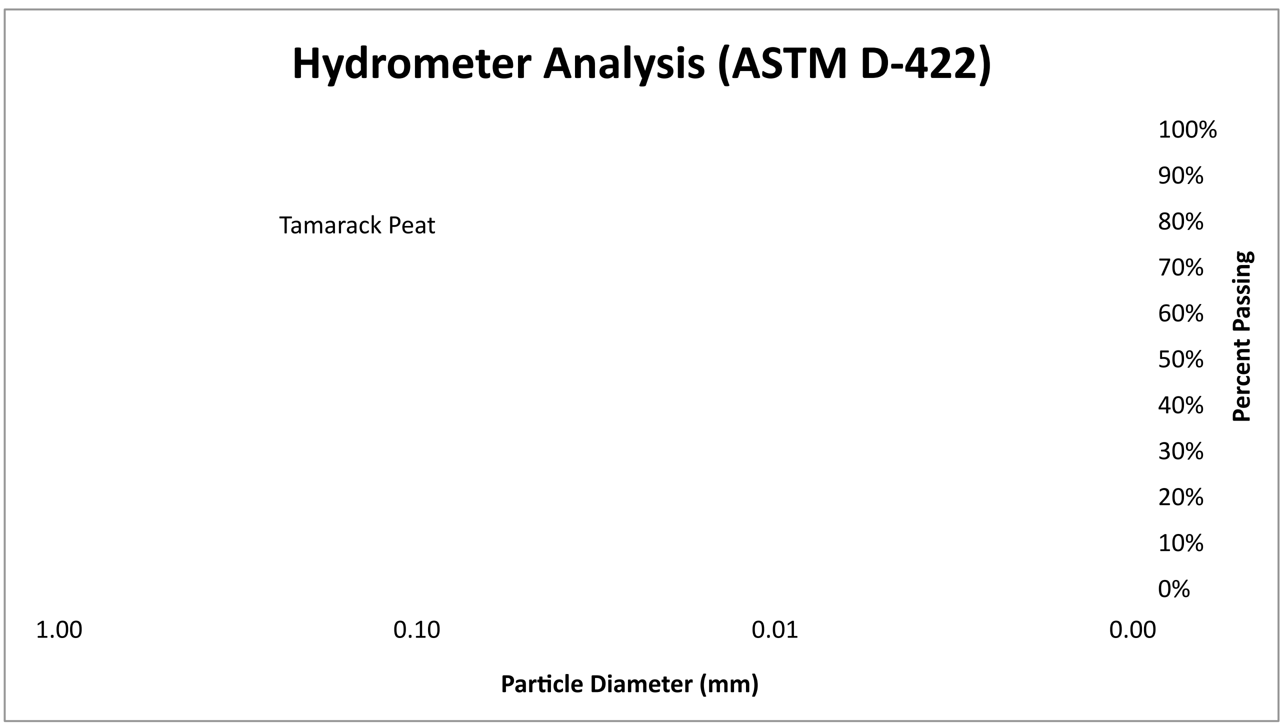
Mineral Mass (g) = 0.7205

Organic Content = 90.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	29	11.54	0.03189822	28.7%
5	28	11.70	0.02031707	27.7%
15	26.5	11.95	0.01185271	26.2%
30	25	12.19	0.00846696	24.8%
60	18	13.34	0.00626251	17.8%
250	13	14.16	0.00316086	12.9%
1440	14	14.00	0.00130938	13.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Peat PT

Material	Tamarack Topsoil	Strata:	End Moraine
Sample Date	September 17, 2012	Geomorphology:	Des Moines Lobe
Sample Loc	CSAH 32 Sta 120+70 34'Lt	Ecological Province:	Laurentian Mixed Forest
		Natural Vegetation:	Peatland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

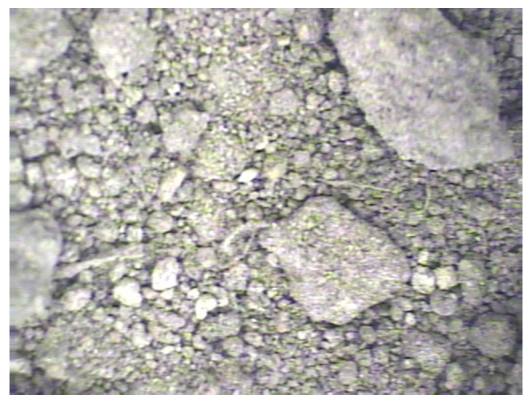
pH (ASTM D4972) =	6.9

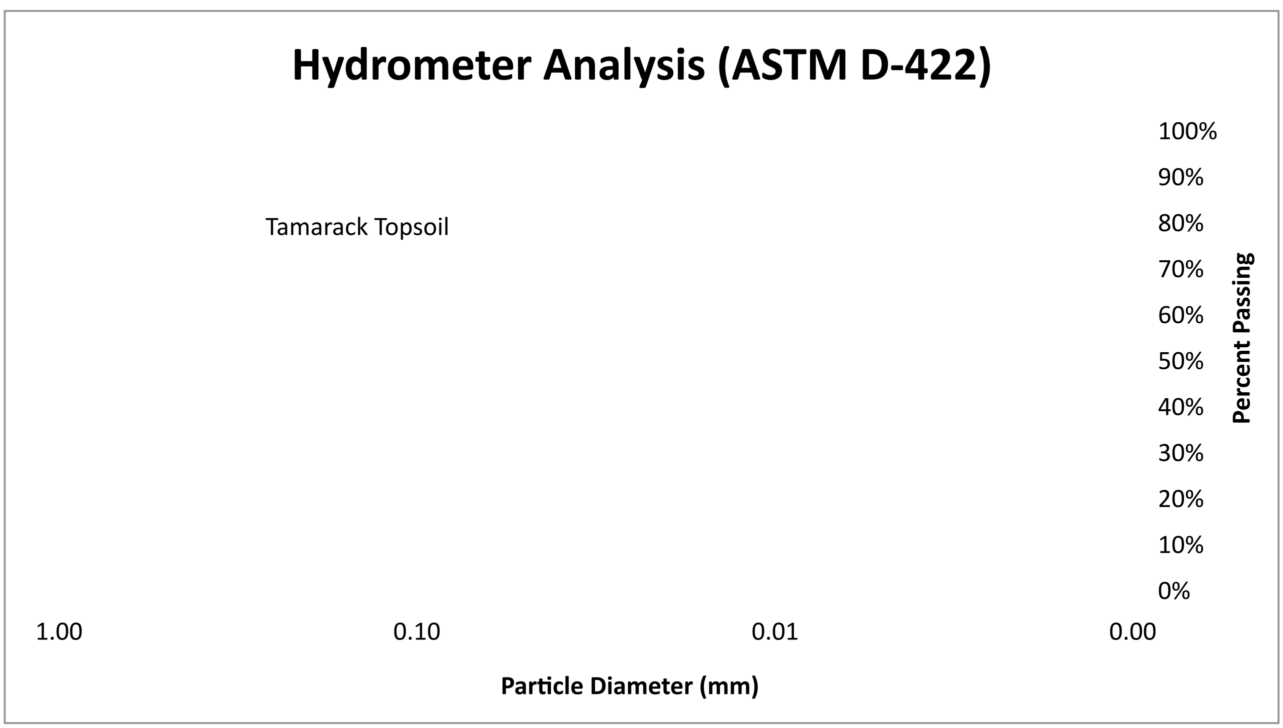
Organic Content (ASTM D2974)

Dry Total Mass (g) =	37.4814
Mineral Mass (g) =	35.828
Organic Content =	4.4%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	22	12.69	0.03344737	21.8%
5	19	13.18	0.02156025	18.8%
15	17	13.51	0.01260176	16.8%
30	15.5	13.75	0.00899157	15.3%
60	14.5	13.92	0.0063958	14.4%
250	11.5	14.41	0.00318819	11.4%
1440	9	14.82	0.00134718	8.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Wabasha Subsoil (Box)
Sample Date	September 21, 2012
Sample Loc	CR 4 @ Handshaw Coulee (?)

Strata:	Colluvuum
Geomorphology:	Weathered Residual
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

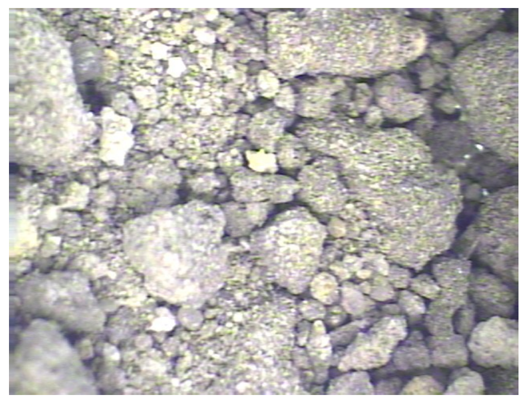
pH (ASTM D4972) =	7.8

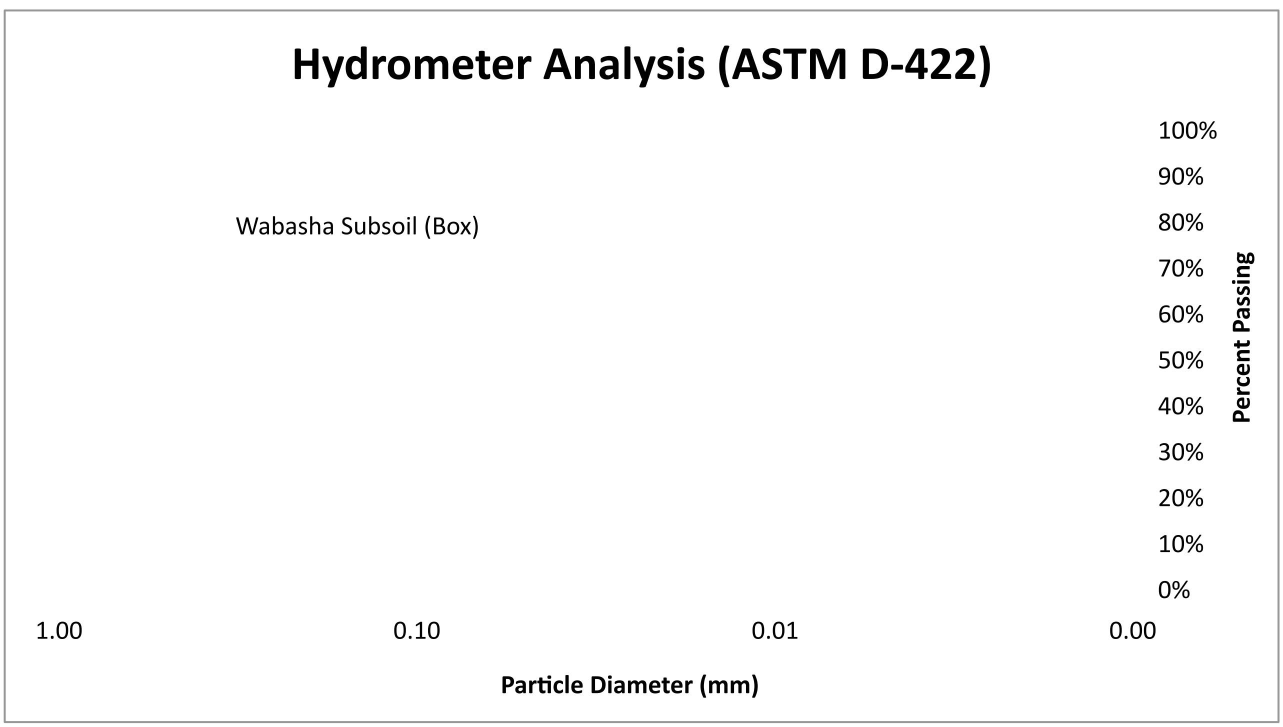
Organic Content (ASTM D2974)

Dry Total Mass (g) =	40.738
Mineral Mass (g) =	39.5298
Organic Content =	3.0%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	27.5	11.78	0.03223645	27.2%
5	20.5	12.93	0.02135808	20.3%
15	16	13.67	0.01267804	15.8%
30	15	13.83	0.00901834	14.9%
60	13.5	14.08	0.00643337	13.4%
250	12.5	14.24	0.00317	12.4%
1440	11	14.49	0.00133219	10.9%

Photomicroscopy (field of view 9 x 12 mm)





Soil Classification: Slightly Organic Sandy Loam SM

Material	Wabasha Subsoil (Rock)
Sample Date	September 21, 2012
Sample Loc	CR 4 @ Handshaw Coulee (?)

Strata: Colluvuum
Geomorphology: Weathered Residual
Ecological Province: Eastern Broadleaf Forest
Natural Vegetation: Oak Woodland

Hydrometer (ASTM D422) 100.0 g

Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

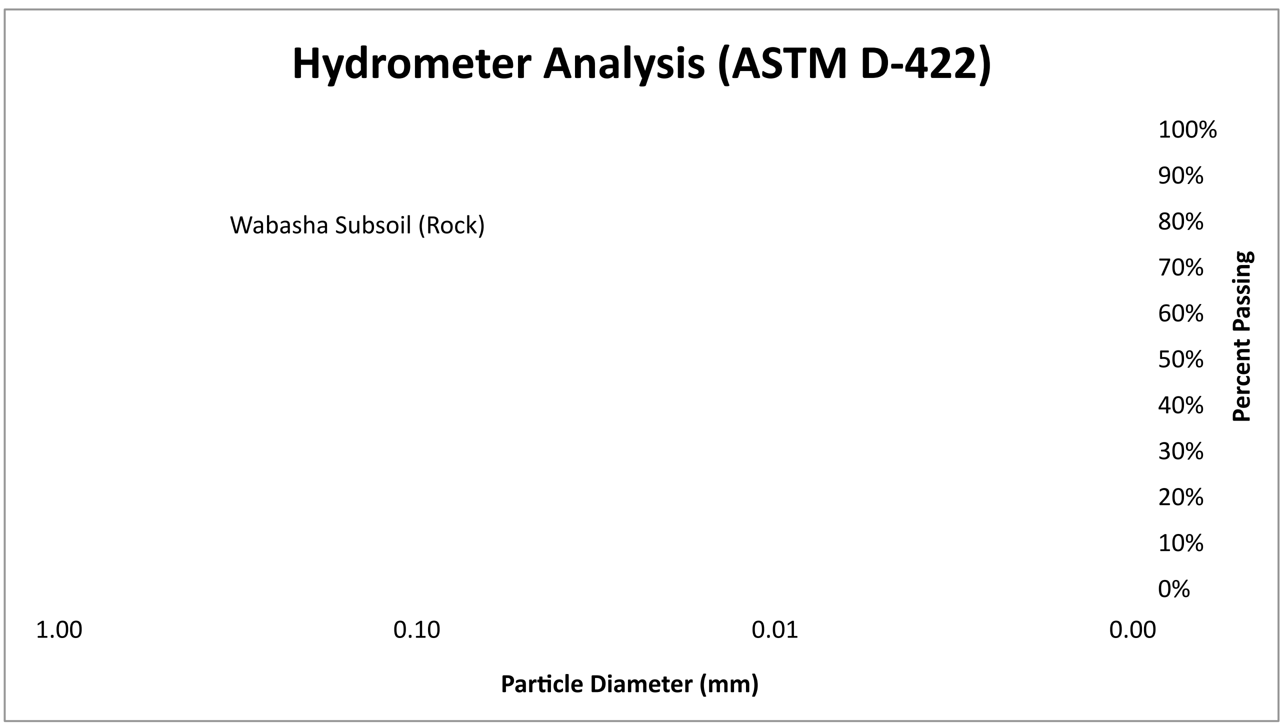
pH (ASTM D4972) = 8

Organic Content (ASTM D2974)

Dry Total Mass (g) =	48.1498
Mineral Mass (g) =	47.2421
Organic Content =	1.9%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	17	13.51	0.03451135	16.8%
5	16	13.67	0.021959	15.8%
15	15.5	13.75	0.012716	15.3%
30	15.5	13.75	0.00899157	15.3%
60	15	13.83	0.00637693	14.9%
250	14.5	13.92	0.00313329	14.4%
1440	14	14.00	0.00130938	13.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Sandy Loam SM

Material	Wabasha Topsoil
Sample Date	September 21, 2012
Sample Loc	CR 4 @ Handshaw Coulee (?)

Strata:	Colluvuum
Geomorphology:	Weathered Residual
Ecological Province:	Eastern Broadleaf Forest
Natural Vegetation:	Oak Woodland

Hydrometer (ASTM D422)	100.0	g
Estimated Gs =	2.65	
Gs Corr, a =	0.99	ASTM D-422 Table 1
Lab Temp =	21	deg C
K factor =	0.01328	ASTM D-422 Table 3

Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

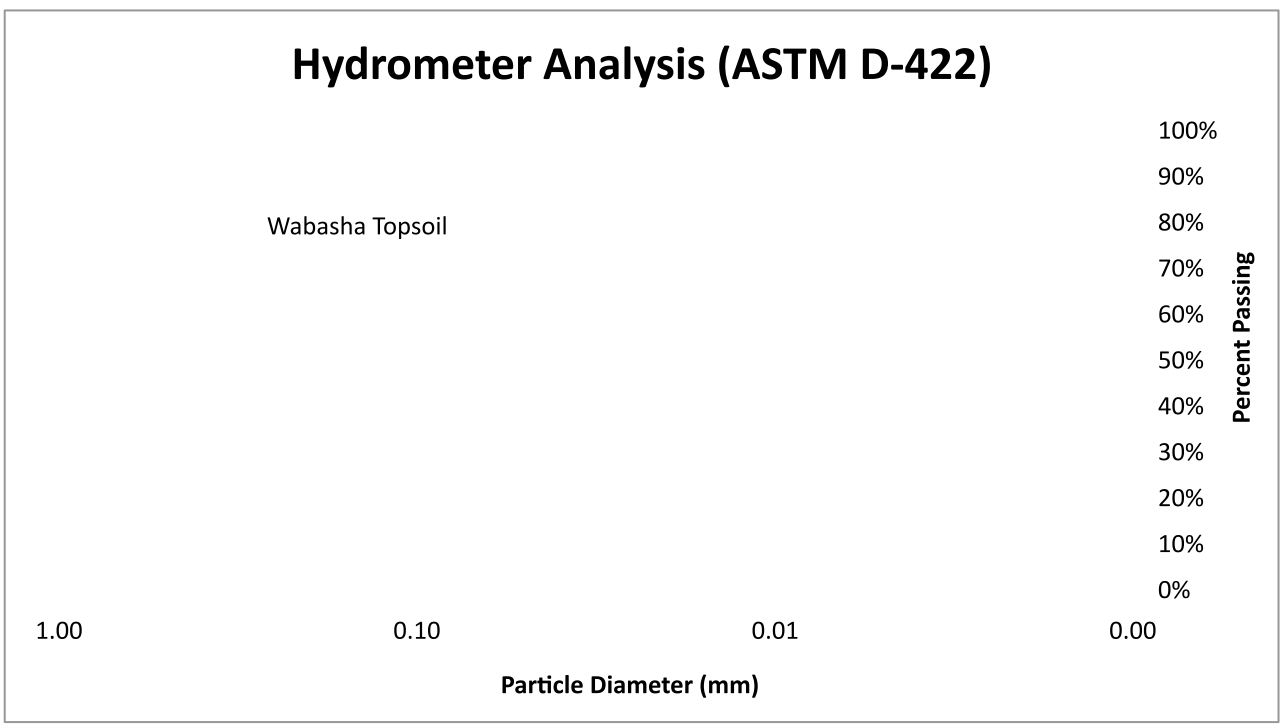
pH (ASTM D4972) = 7.5

Organic Content (ASTM D2974)

Dry Total Mass (g) =	43.8146
Mineral Mass (g) =	41.9462
Organic Content =	4.3%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	34	10.72	0.03074394	33.7%
5	28	11.70	0.02031707	27.7%
15	22	12.69	0.01221325	21.8%
30	20	13.01	0.008747	19.8%
60	18.5	13.26	0.00624324	18.3%
250	16.5	13.59	0.00309614	16.3%
1440	14	14.00	0.00130938	13.9%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Worthington Subsoil
Sample Date	July 16, 2012
Sample Loc	TH 60 SP#5305-58

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

Hydrometer (ASTM D422) 100.0 g

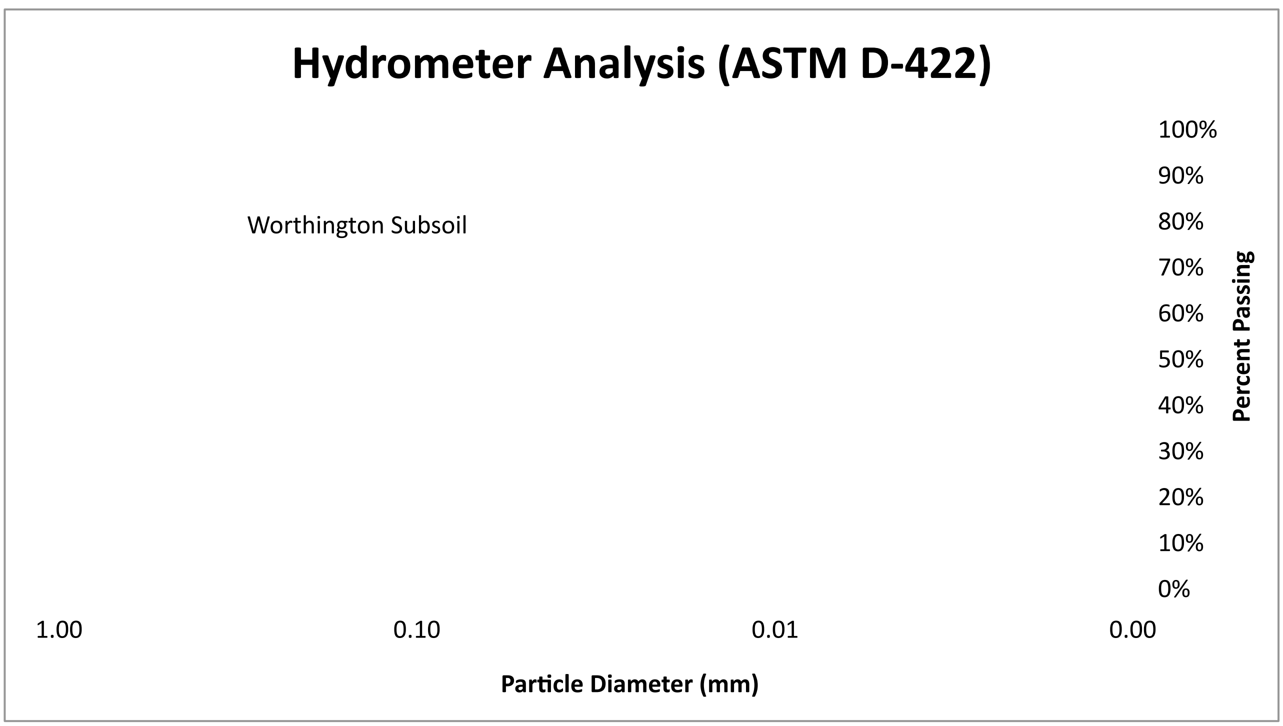
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

pH (ASTM D4972) = 7.6

Organic Content (ASTM D2974)
Dry Total Mass (g) = 46.2904
Mineral Mass (g) = 45.2711
Organic Content = 2.2%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	28	11.70	0.0321241	27.7%
5	25.5	12.11	0.0206699	25.2%
15	22.5	12.60	0.01217372	22.3%
30	21	12.85	0.00869171	20.8%
60	20	13.01	0.00618506	19.8%
250	18	13.34	0.00306799	17.8%
1440	16.5	13.59	0.00129006	16.3%

Photomicroscopy (field of view 9 x 12 mm)



Soil Classification: Slightly Organic Sandy Loam SM

Material	Worthington Topsoil
Sample Date	July 16, 2012
Sample Loc	TH 60 SP#5305-58

Strata: Ground Moraine
Geomorphology: Des Moines Lobe
Ecological Province: Prairie Parkland
Natural Vegetation: Upland Prairie

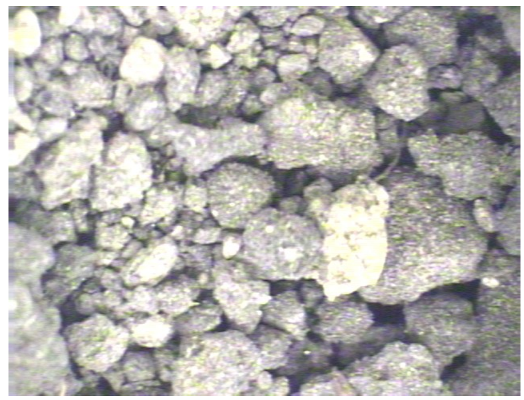
Hydrometer (ASTM D422) 100.0 g
Estimated Gs = 2.65
Gs Corr, a = 0.99 ASTM D-422 Table 1
Lab Temp = 21 deg C
K factor = 0.01328 ASTM D-422 Table 3
Effective L (cm) = (10.5 cm - 8.2 cm*R / 50 g/L) + 0.5*(14.0 cm - 67.0 cm^3/27.8 cm^2)

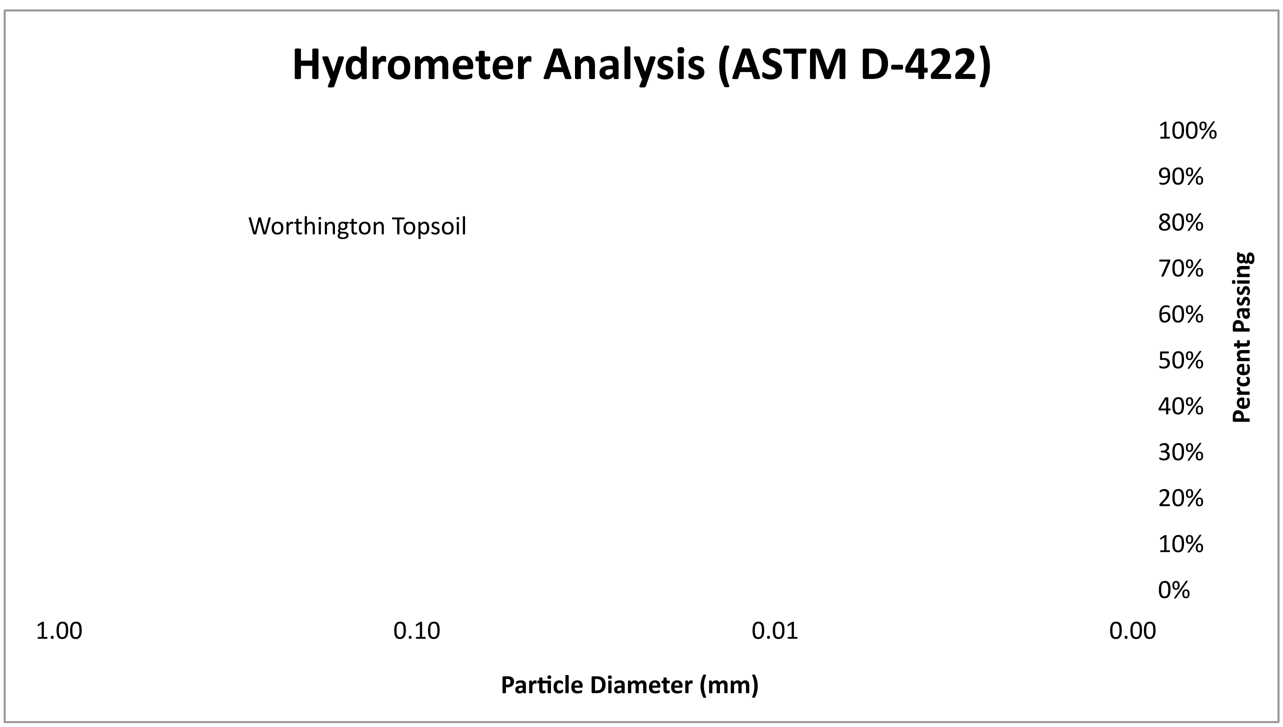
pH (ASTM D4972) = 7.4

Organic Content (ASTM D2974)
Dry Total Mass (g) = 45.0201
Mineral Mass (g) = 42.4371
Organic Content = 5.7%

Time (min)	Hydrometer Reading	Effective Length (cm)	Diameter (mm)	Passing (%)
0			2.00	100%
2	26	12.03	0.03257116	25.7%
5	23	12.52	0.0210168	22.8%
15	20	13.01	0.01237012	19.8%
30	18.5	13.26	0.00882927	18.3%
60	17.5	13.42	0.00628173	17.3%
250	15	13.83	0.00312404	14.9%
1440	13	14.16	0.00131702	12.9%

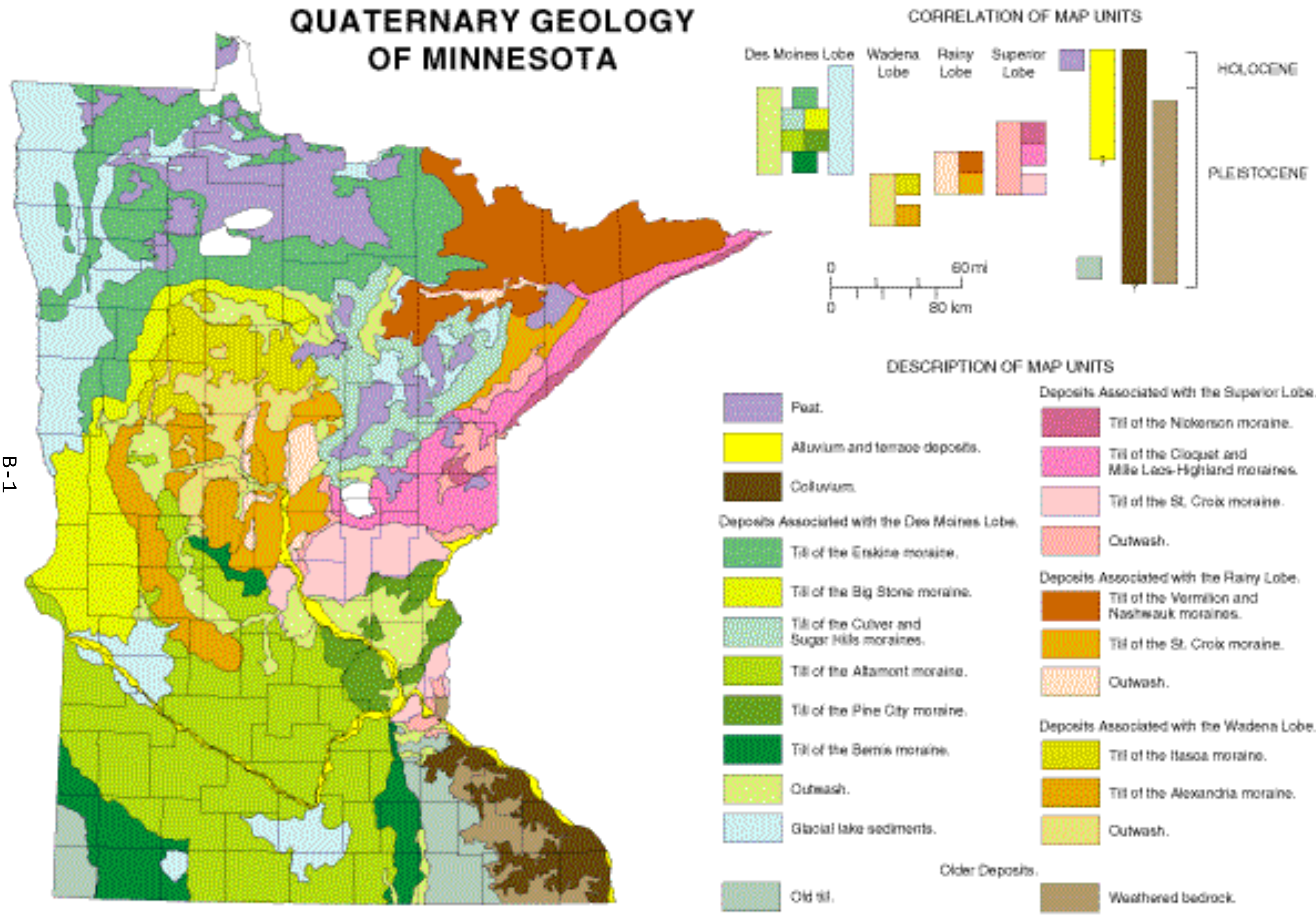
Photomicroscopy (field of view 9 x 12 mm)



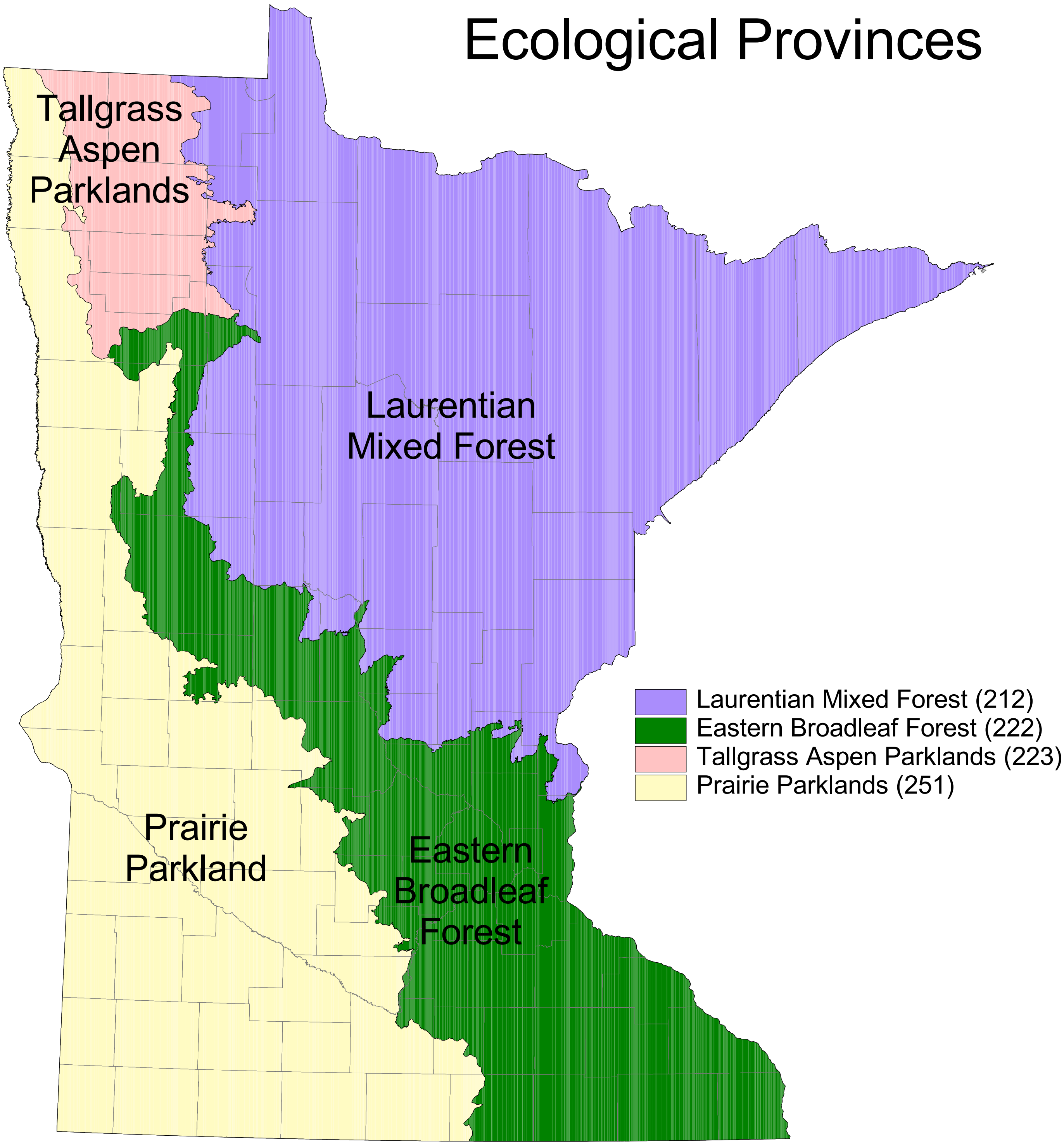


Soil Classification: Organic Sandy Loam SM

Appendix B – Geological, Geomorphological, Ecological and Botanical Maps


QUATERNARY GEOLOGY
OF MINNESOTA
CORRELATION OF MAP UNITS
Des Moines Lobe
Wadena Lobe
Rainy Lobe
Superior Lobe
HOLOCENE
PLEISTOCENE
0
60 mi
0
80 km
DESCRIPTION OF MAP UNITS
Peat.
Alluvium and terrace deposits.
Colluvium.
Deposits Associated with the Des Moines Lobe.
Till of the Erskine moraine.
Till of the Big Stone moraine.
Till of the Culver and Sugar Hills moraines.
Till of the Altamont moraine.
Till of the Pine City moraine.
Till of the Bemis moraine.
Outwash.
Glacial lake sediments.
Deposits Associated with the Superior Lobe.
Till of the Nickerson moraine.
Till of the Cloquet and Mille Lacs-Highland moraines.
Till of the St. Croix moraine.
Outwash.
Deposits Associated with the Rainy Lobe.
Till of the Vermilion and Nashwauk moraines.
Till of the St. Croix moraine.
Outwash.
Deposits Associated with the Wadena Lobe.
Till of the Itasca moraine.
Till of the Alexandria moraine.
Outwash.
Older Deposits.
Old till.
Weathered bedrock.

Ecological Provinces



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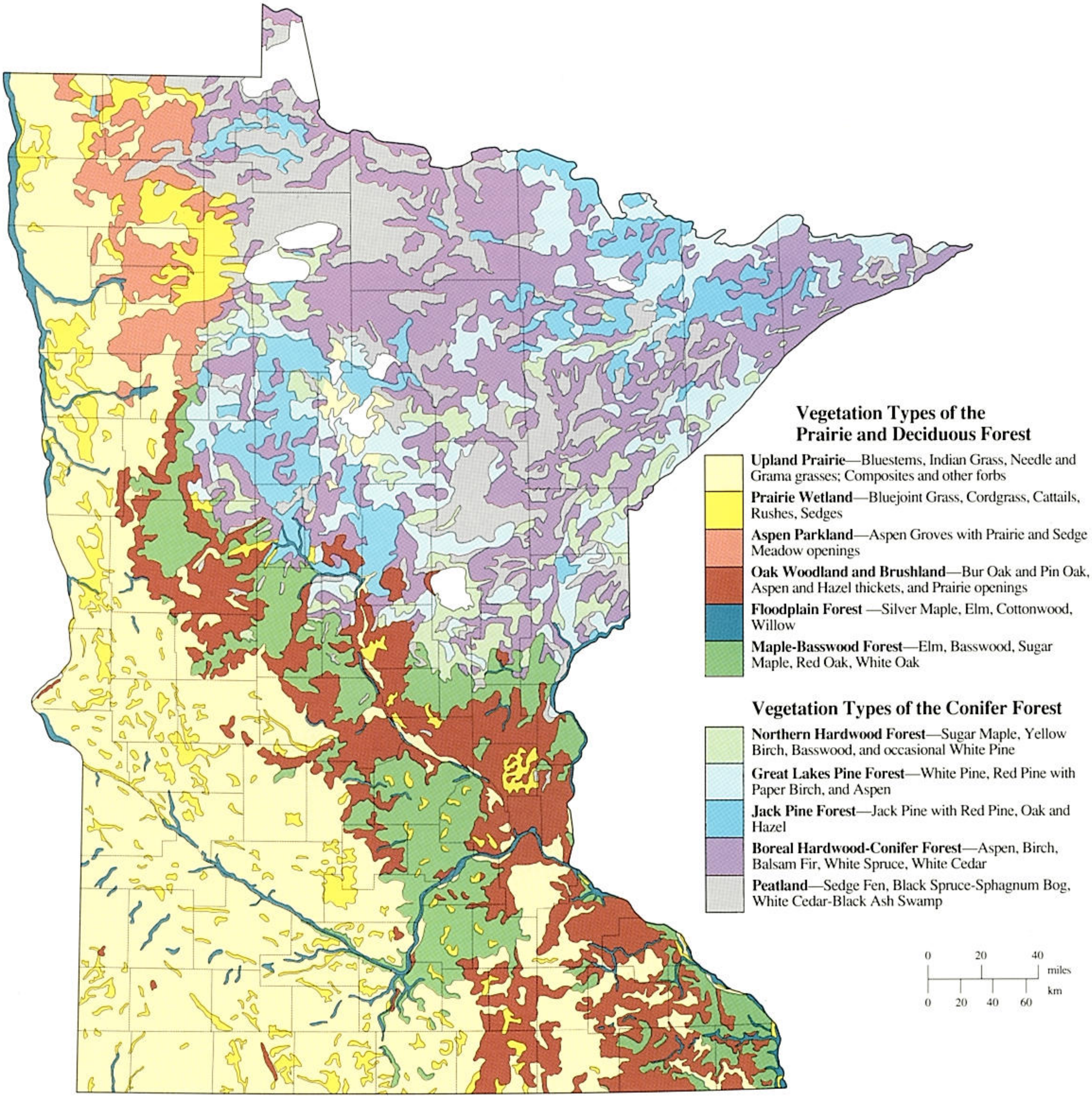
MN Department of Agriculture
MN Department of Natural Resources
Natural Resources Conservation Service
Potlatch Corporation
USDA Forest Service
U.S. Fish and Wildlife Service

For more information contact:
ECS Specialist
MN DNR, Division of Forestry
Resource Assessment Program
413 SE 13 Street
Grand Rapids, MN 55744
(218) 327-4449 ext 239

September, 2000

Division of Forestry
Ecological Land Classification Program

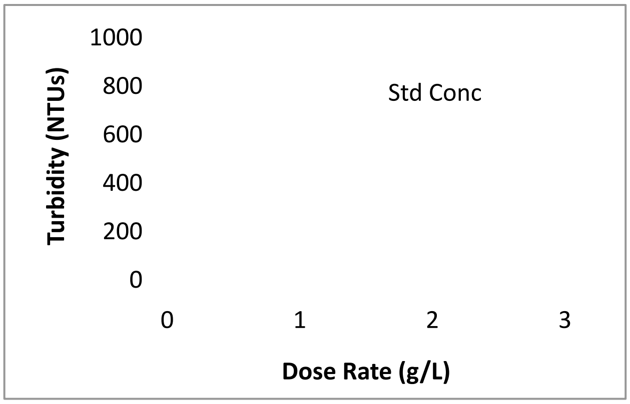


The Natural Vegetation of Minnesota at the Time of the Public Land Survey: 1847-1907

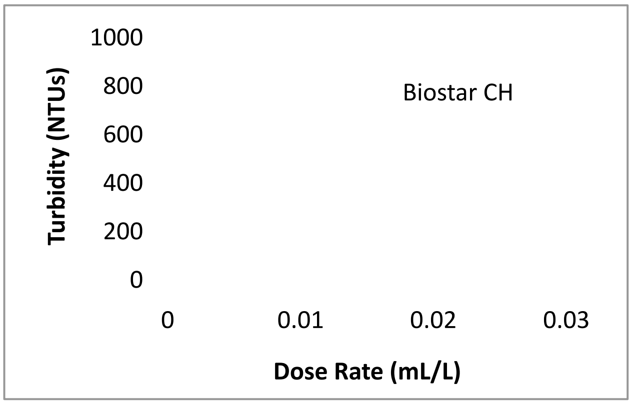
This map was adapted by Barbara Coffin of the DNR, Natural Heritage Program from *The Original Vegetation of Minnesota*, a map compiled in 1930 by F. J. Marschner from the U. S. General Land Office Survey Notes and published in 1974 under the direction of M. L. Heinselman of the U. S. Forest Service. It was produced by the Cartography Laboratory of the Department of Geography, University of Minnesota.

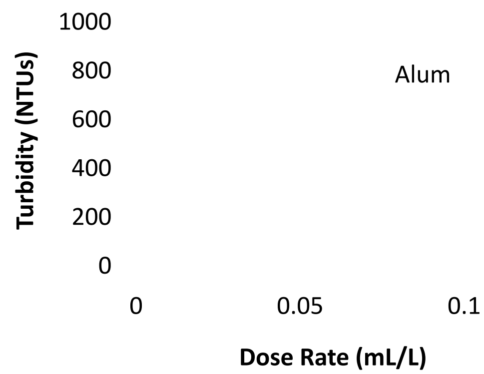
Published by the Natural Heritage Program, Minnesota Department of Natural Resources, 1988©

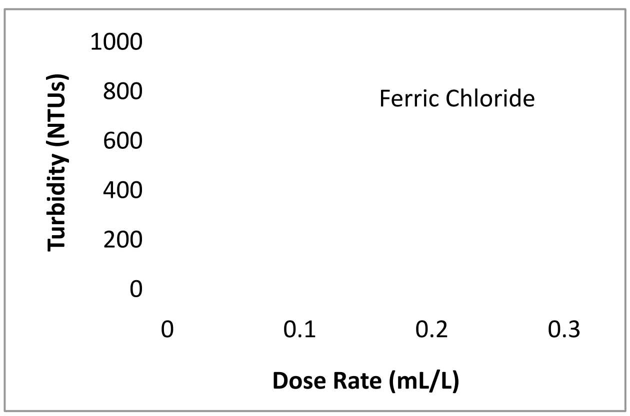
Appendix C – Flocculant Dose Testing Results

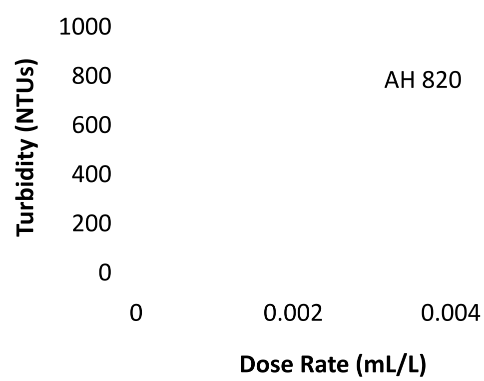


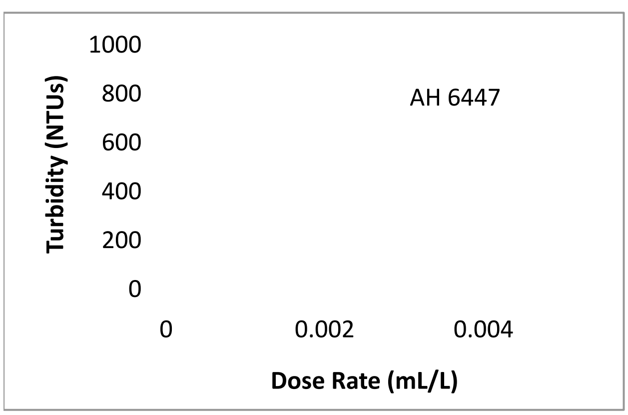
Material	Ada Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

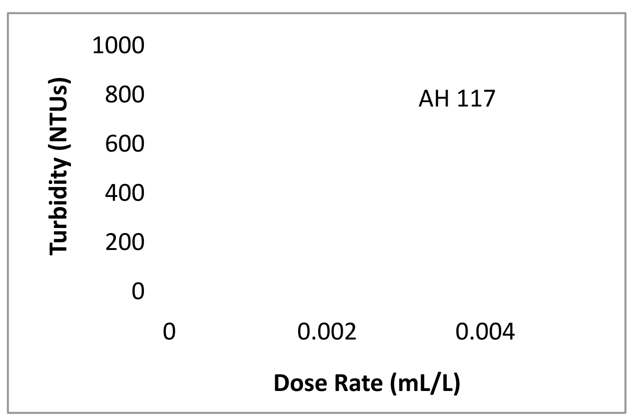


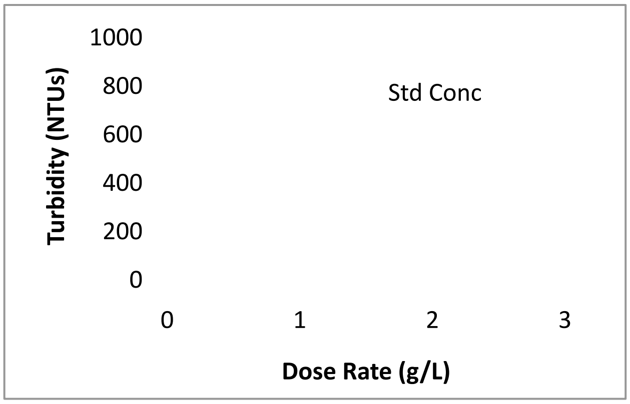




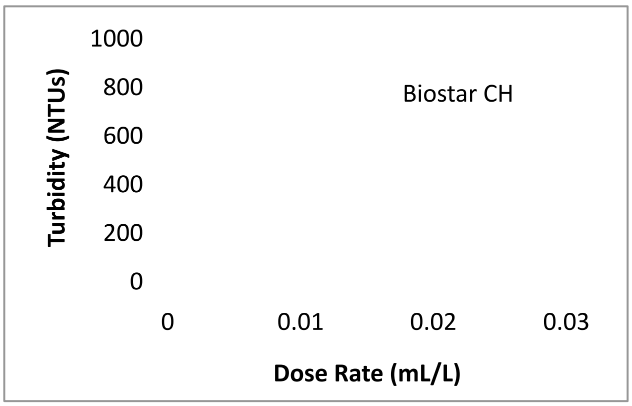


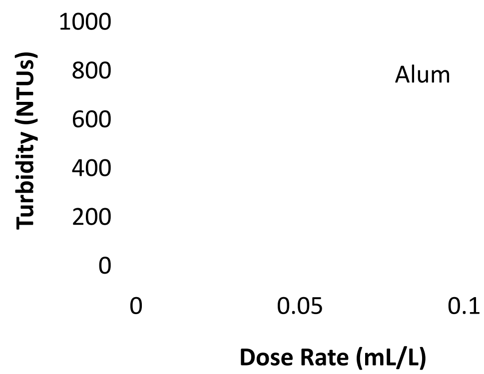


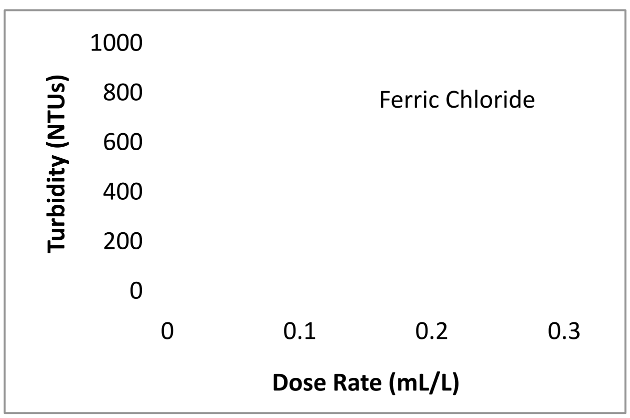


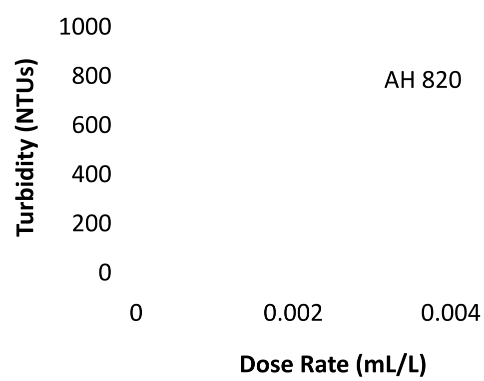


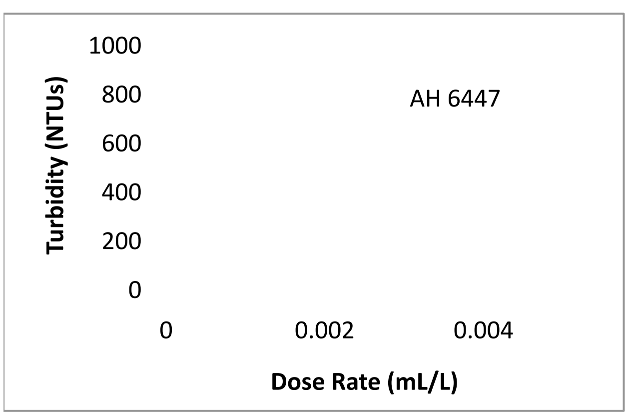
Material	Ada Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

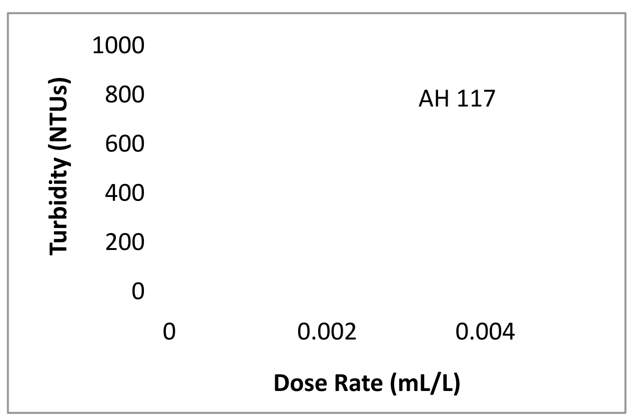


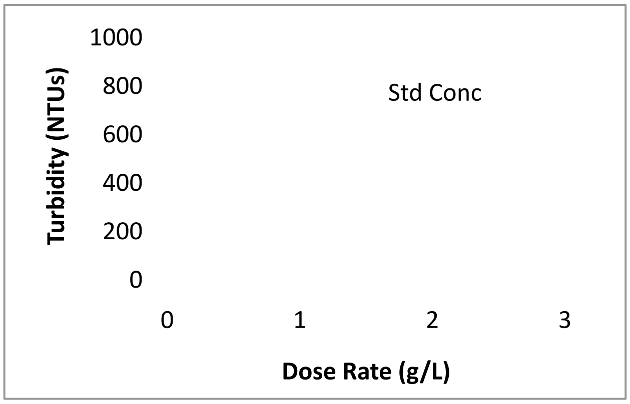




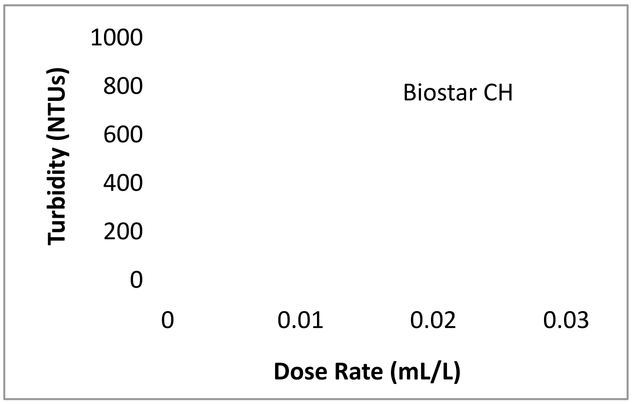


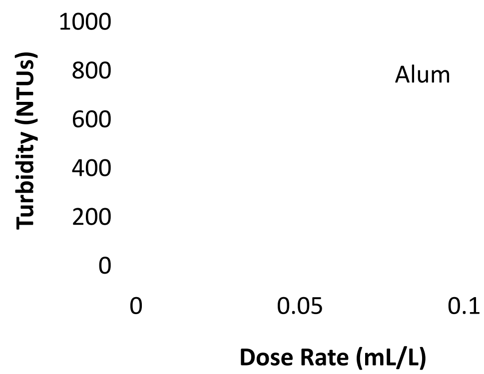


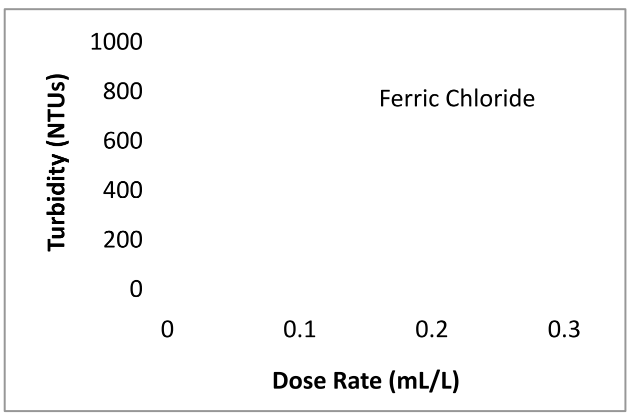


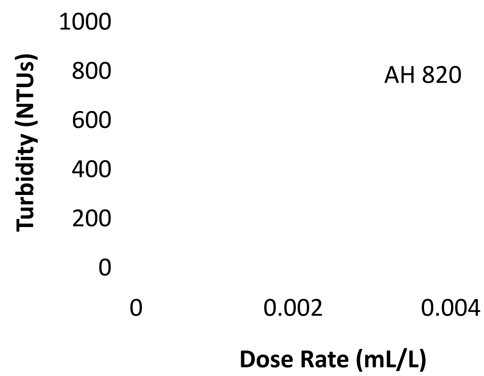


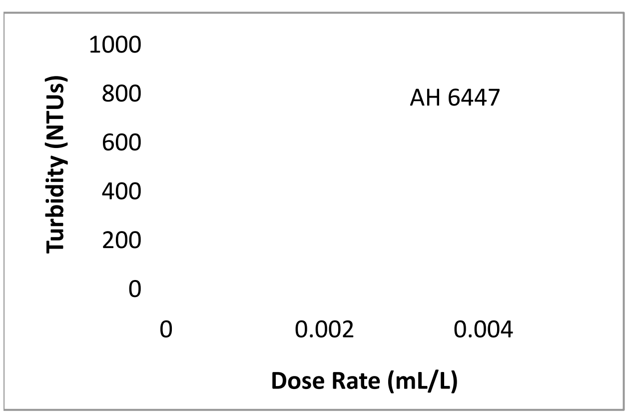
Material	Brandon Subsoil
Classification	Slightly Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Stagnation Moraine
Geomorphology	Wadena Lobe

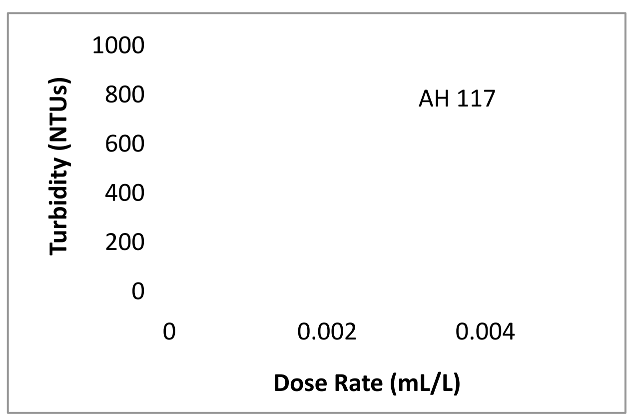


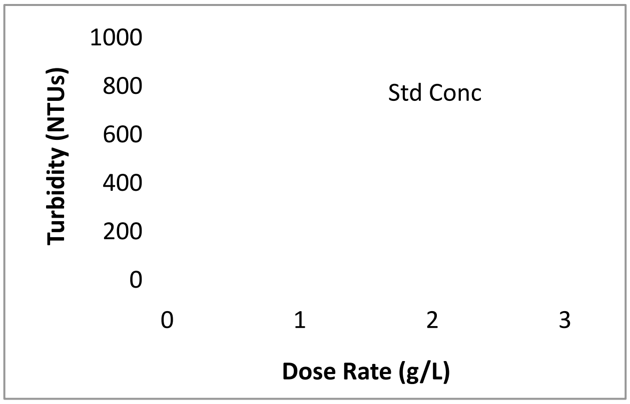




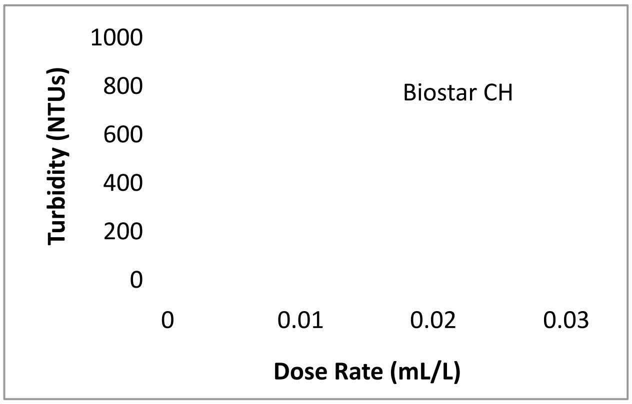


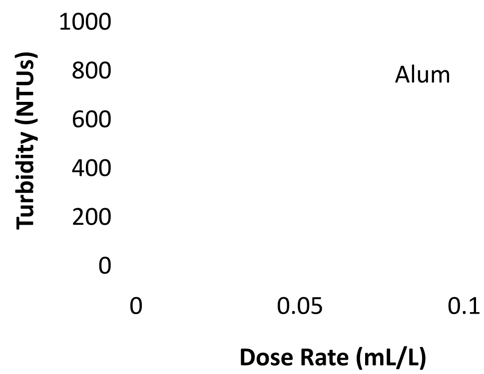


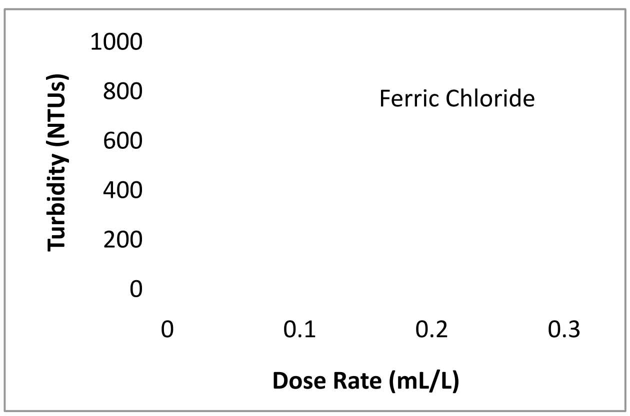


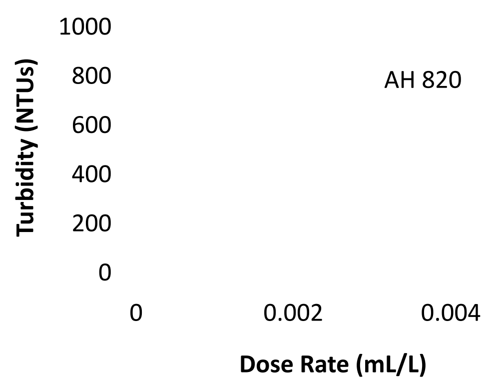


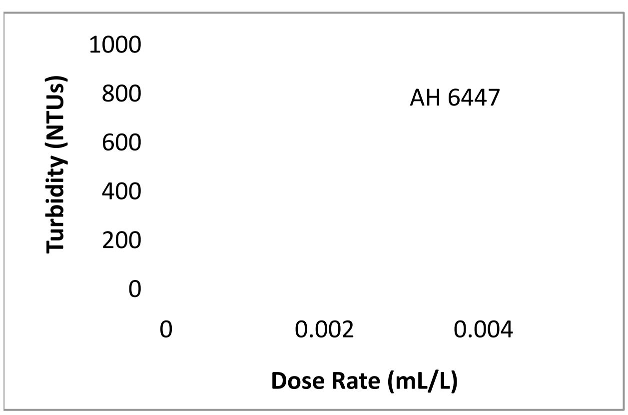
Material	Brandon Topsoil
Classification	Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Stagnation Moraine
Geomorphology	Wadena Lobe

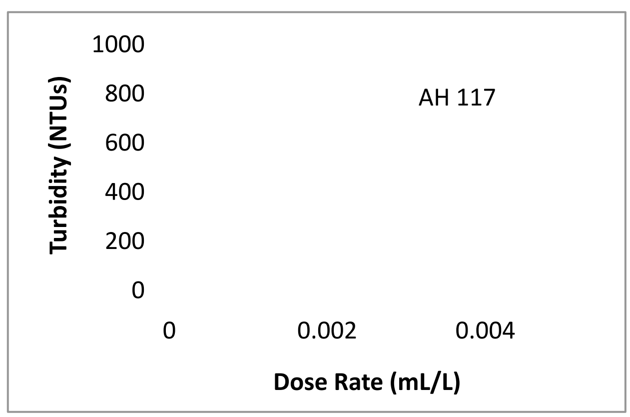


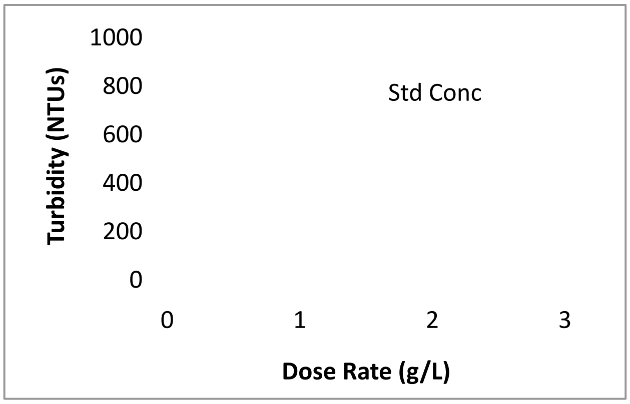




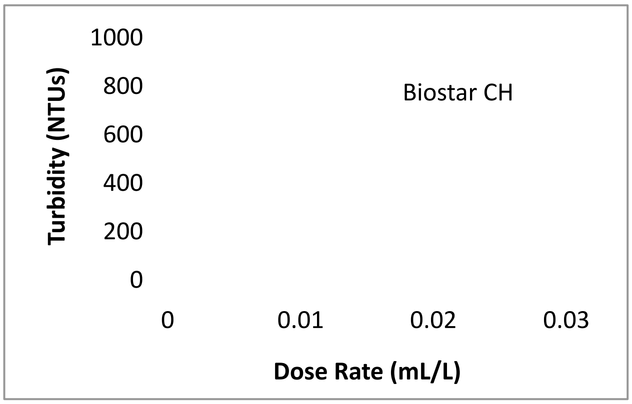


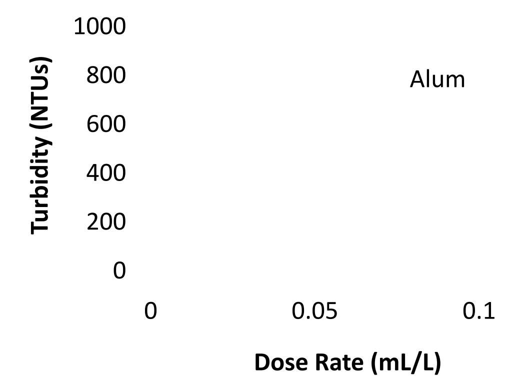


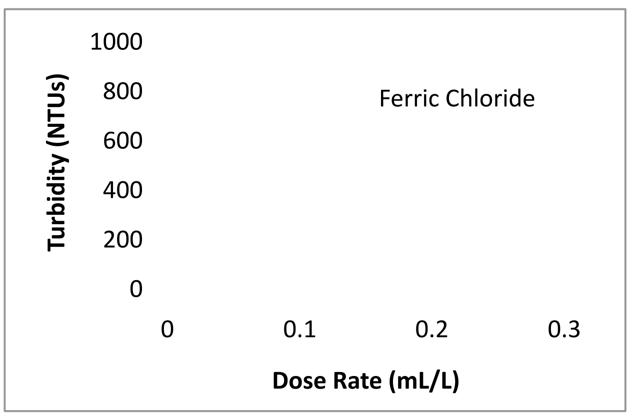


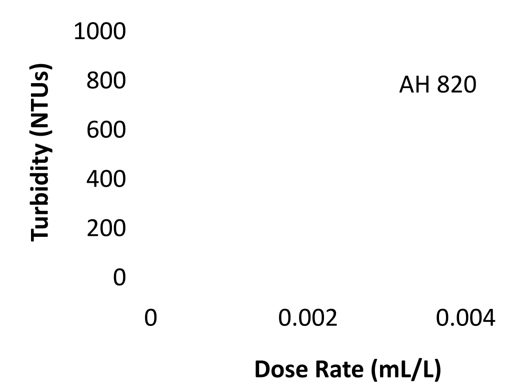


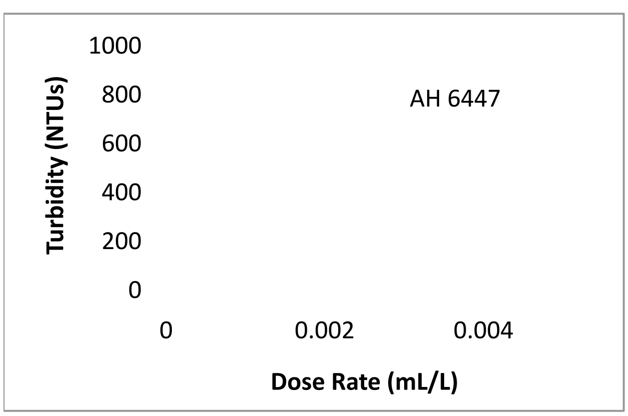
Material	Carlton Subsoil
Classification	Loam
USCS Symbol(s)	ML
Strata	Glacial Lake Sediment
Geomorphology	Superior Lobe

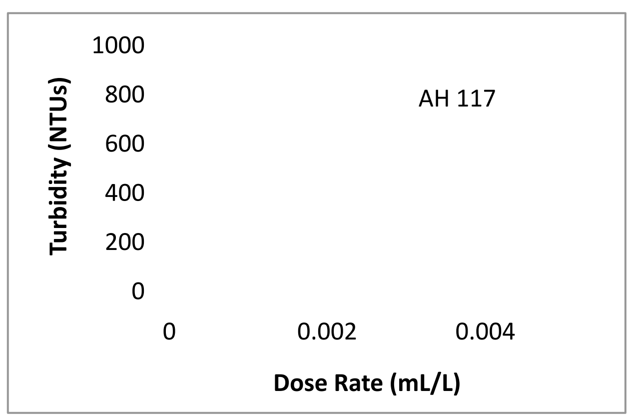


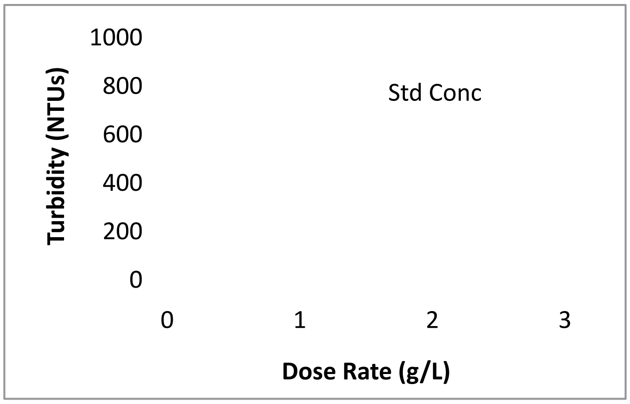




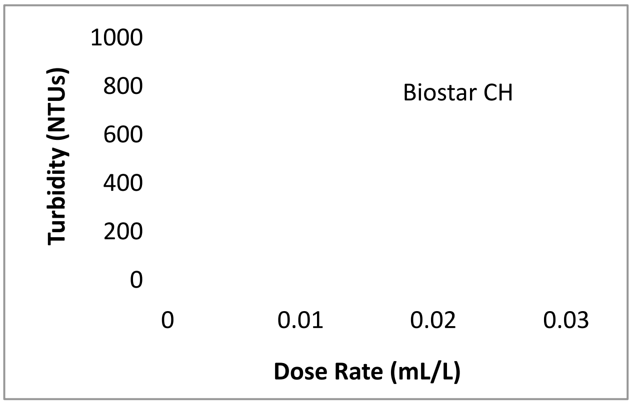


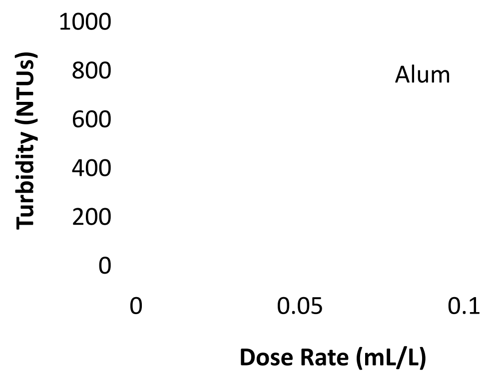


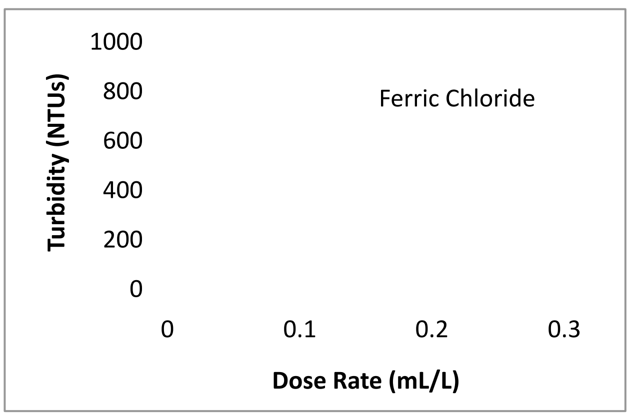


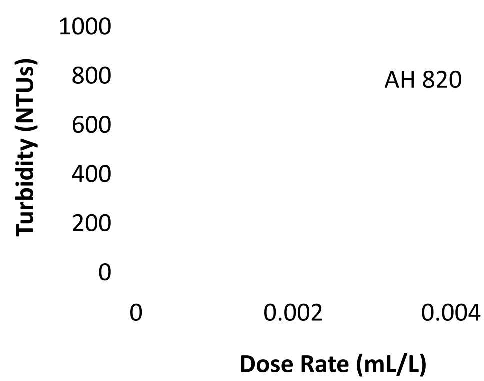


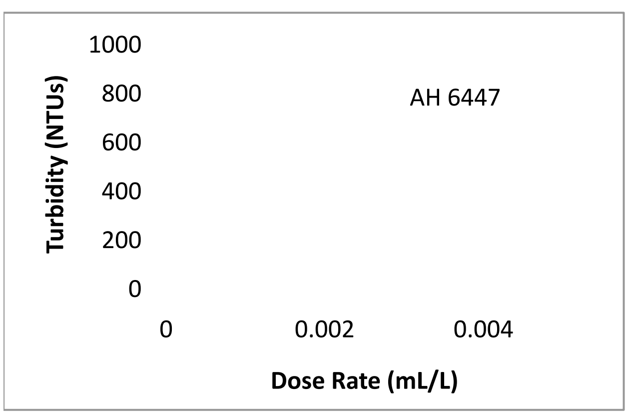
Material	Carlton Topsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Glacial Lake Sediment
Geomorphology	Superior Lobe

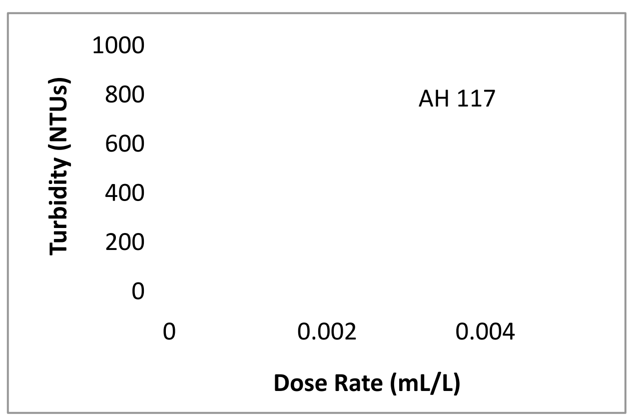


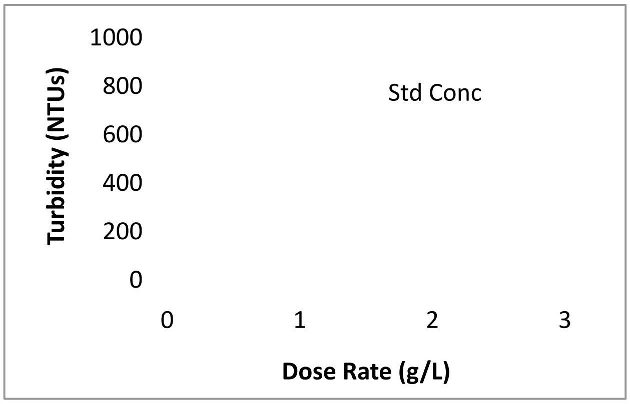




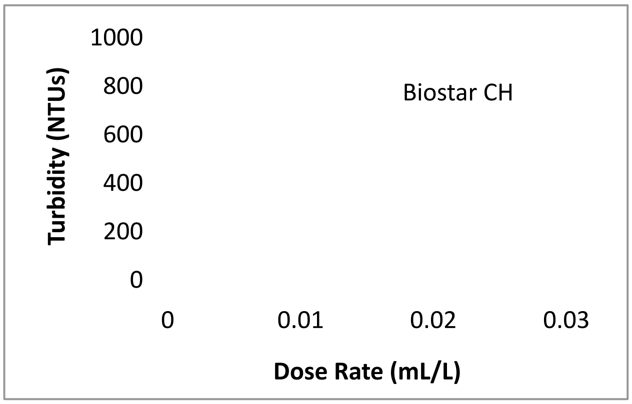


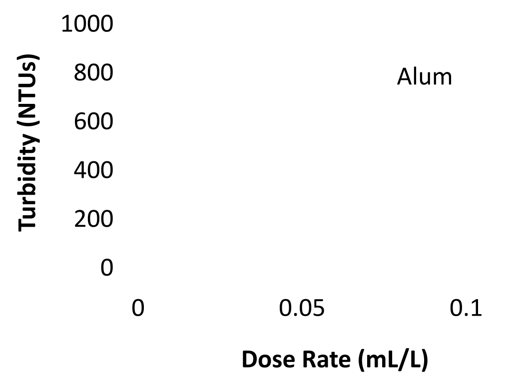


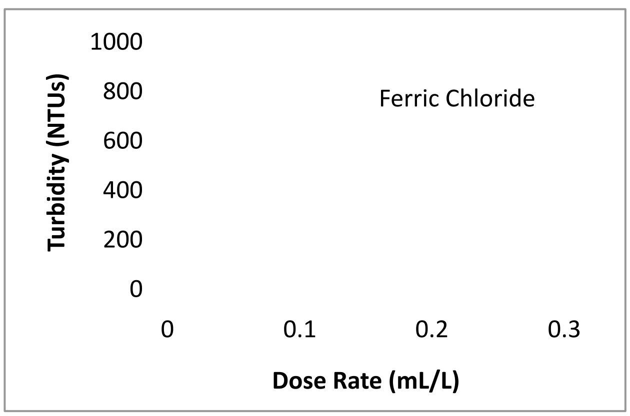


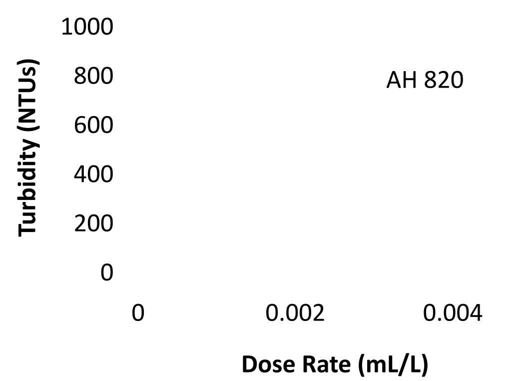


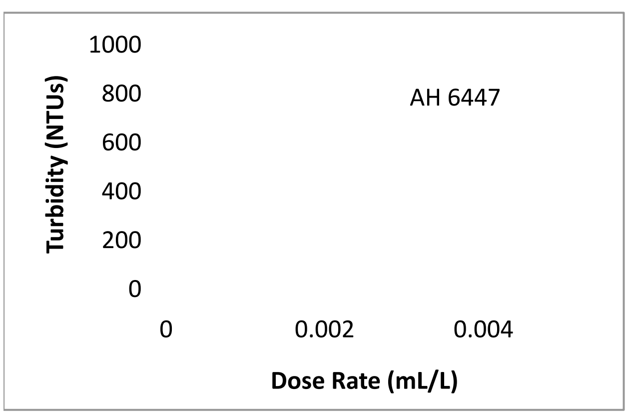
Material	Cook Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Superior Lobe

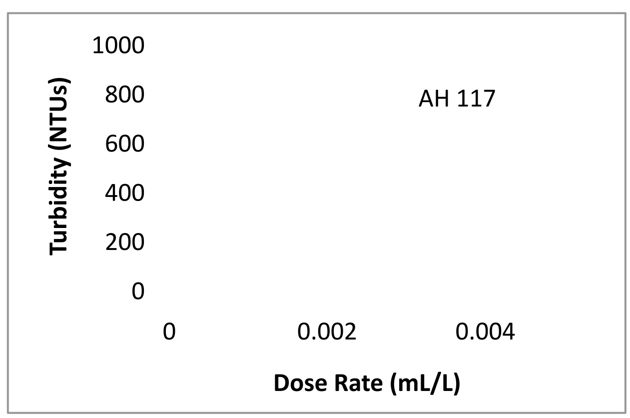


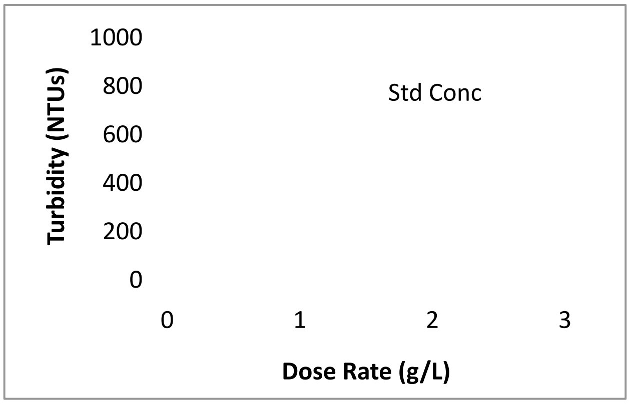




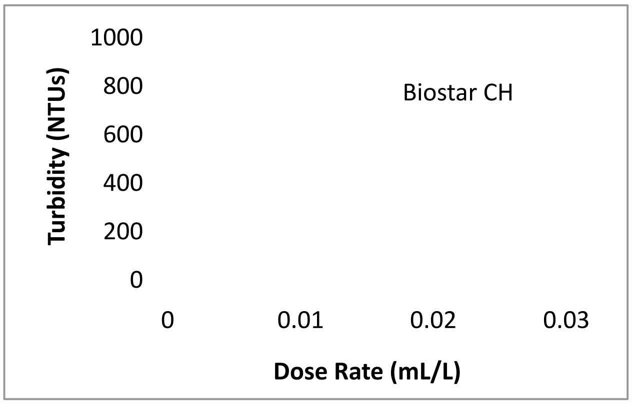


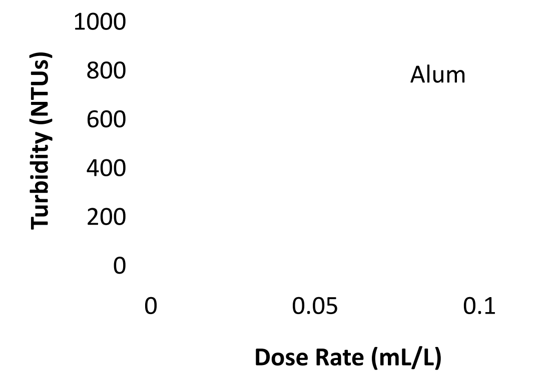


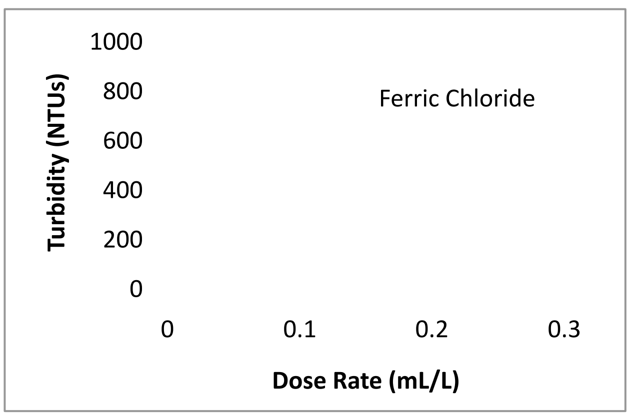


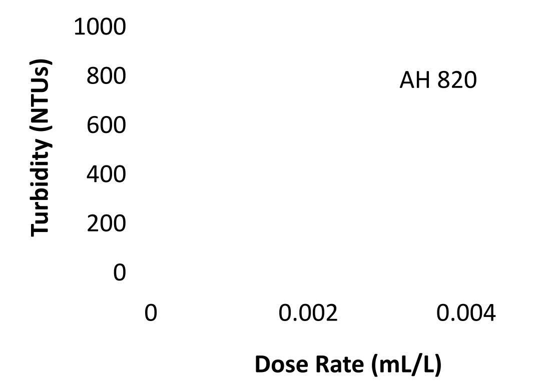


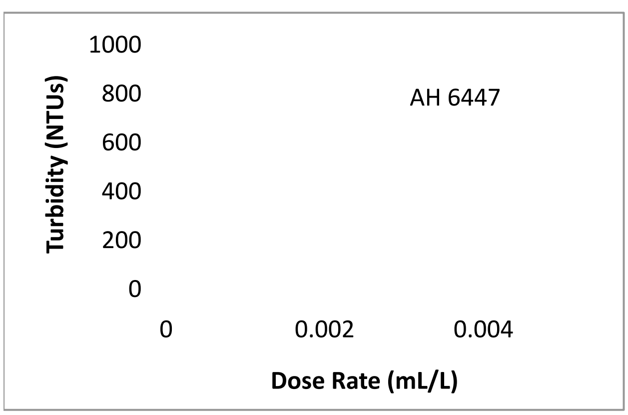
Material	Cook Topsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Superior Lobe

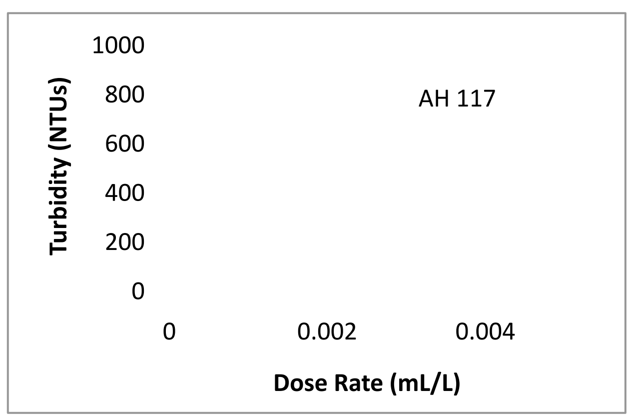


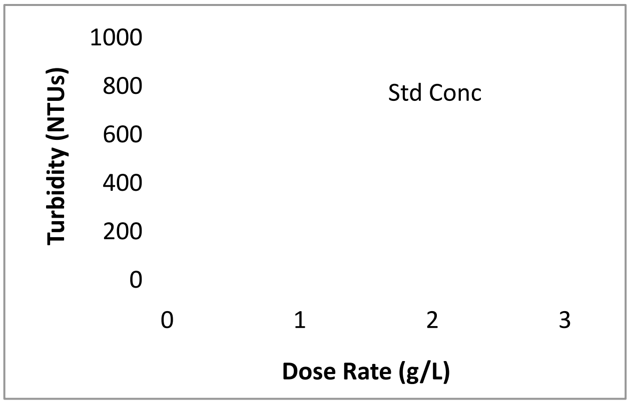




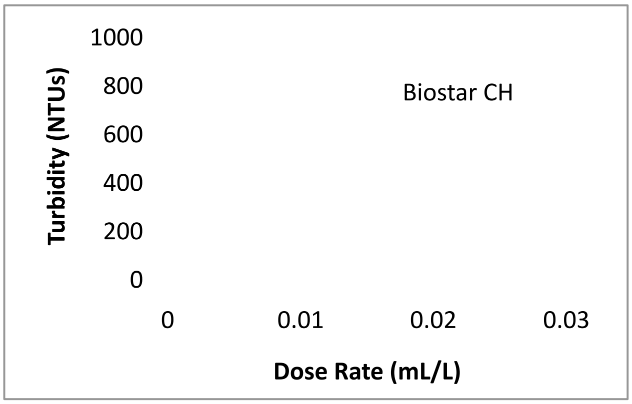


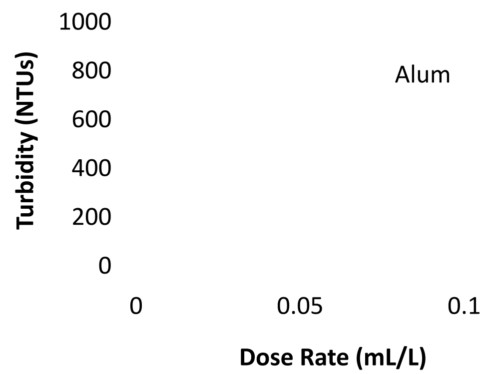


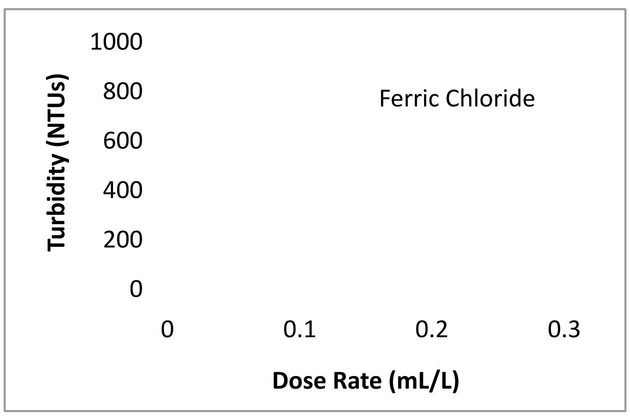


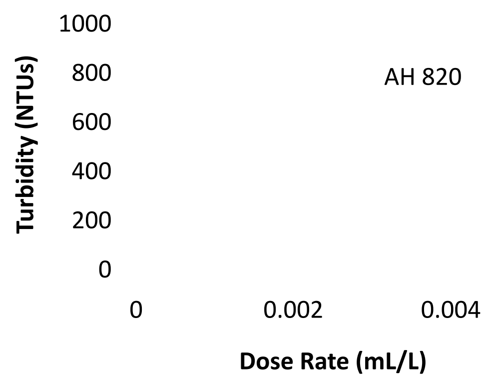


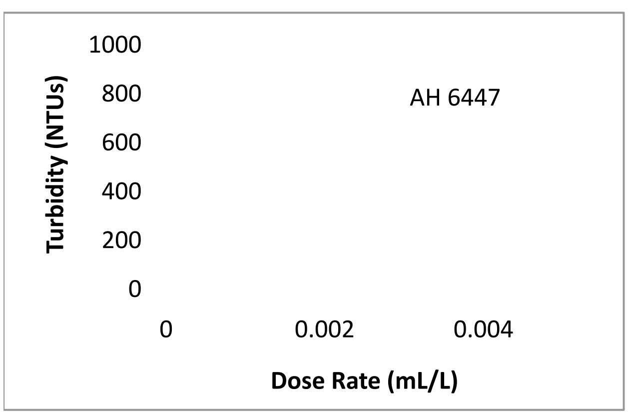
Material	Coon Rapids Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

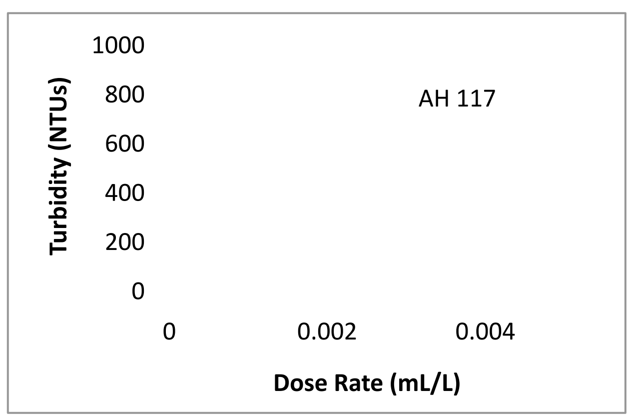


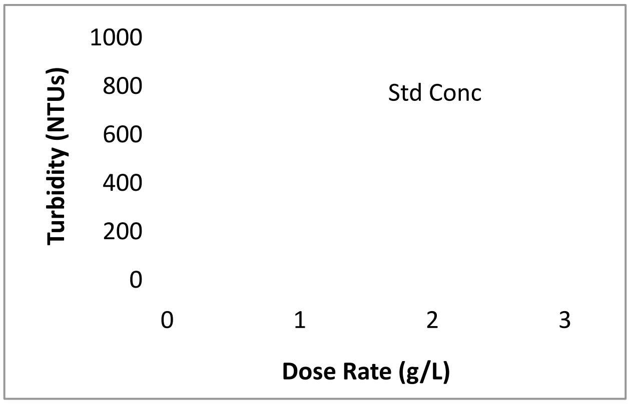




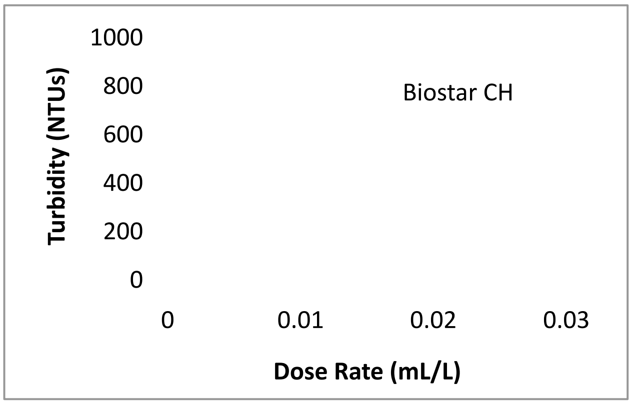


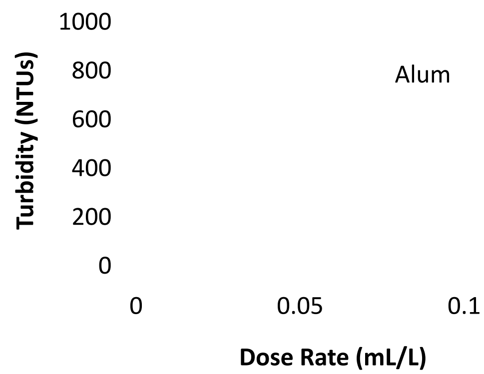


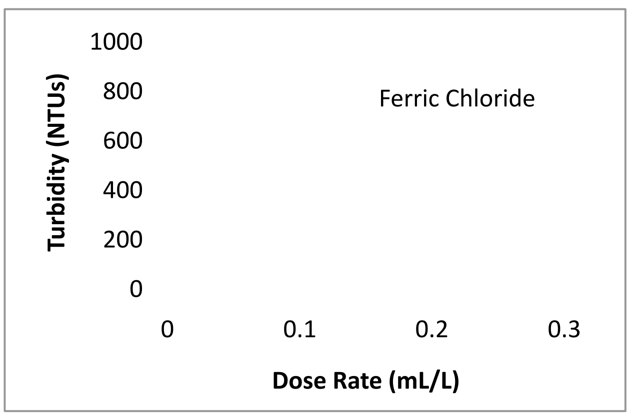


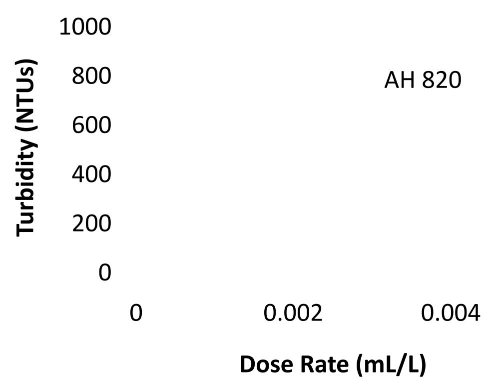


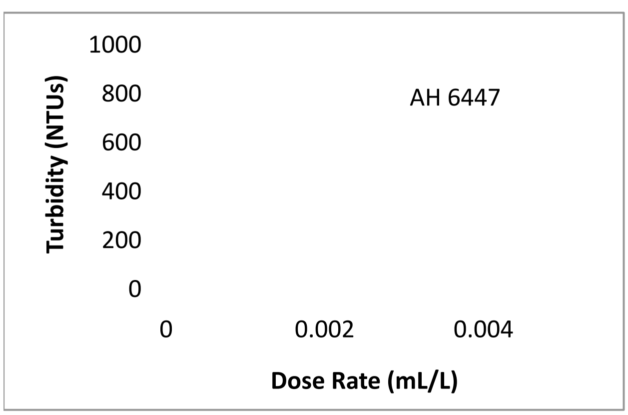
Material	Coon Rapids Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

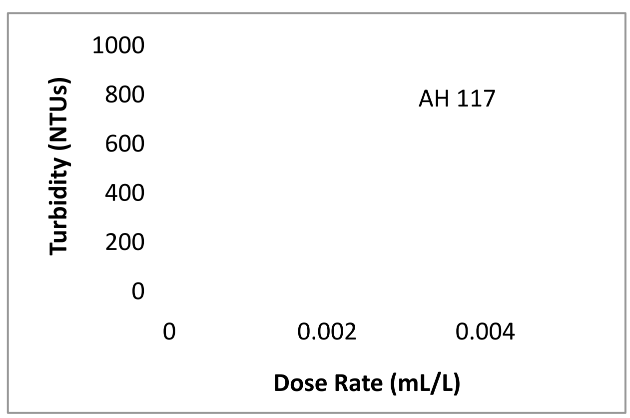


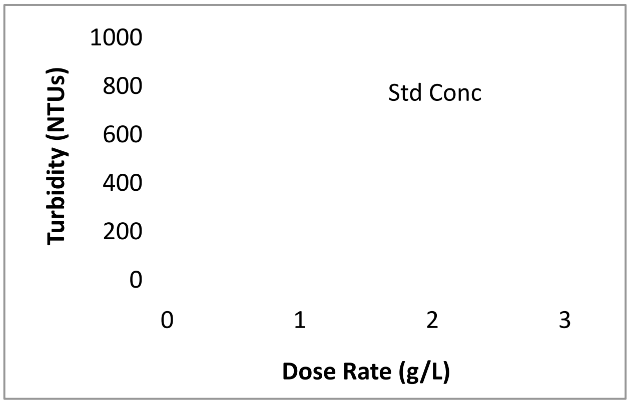




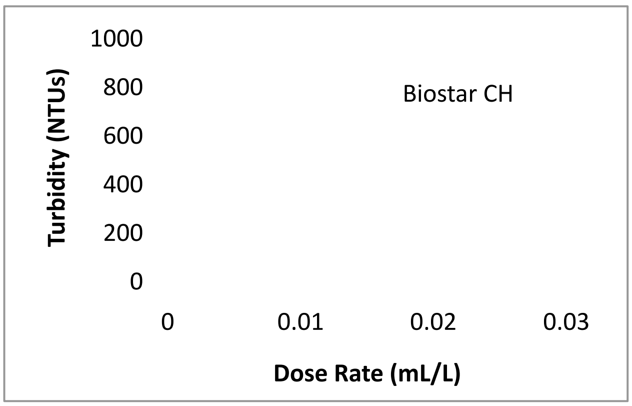


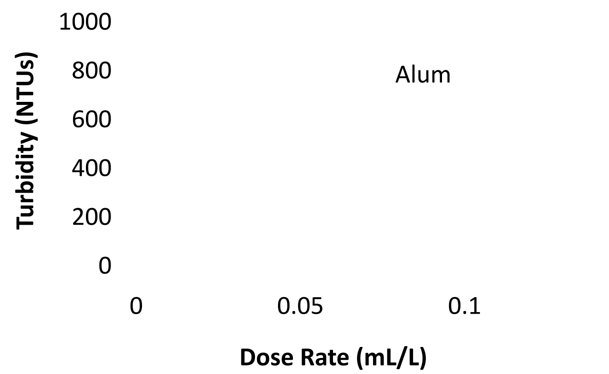


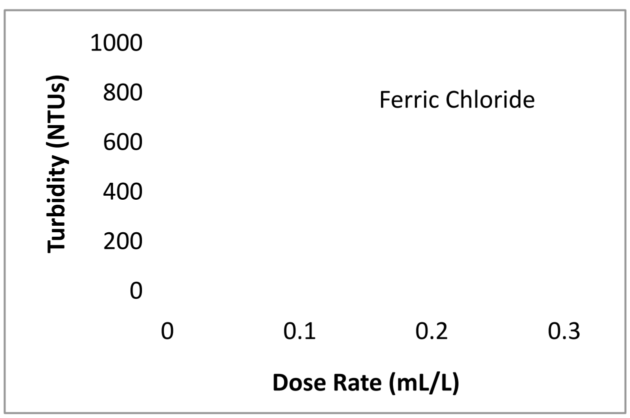


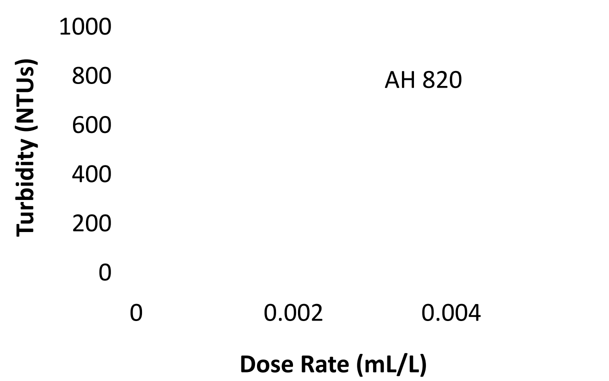


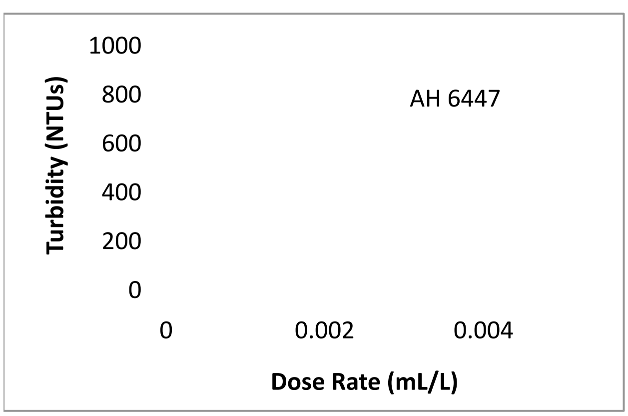
Material	East Grand Forks Subsoil
Classification	Slightly Organic Clay Loam
USCS Symbol(s)	CL-ML-OL
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

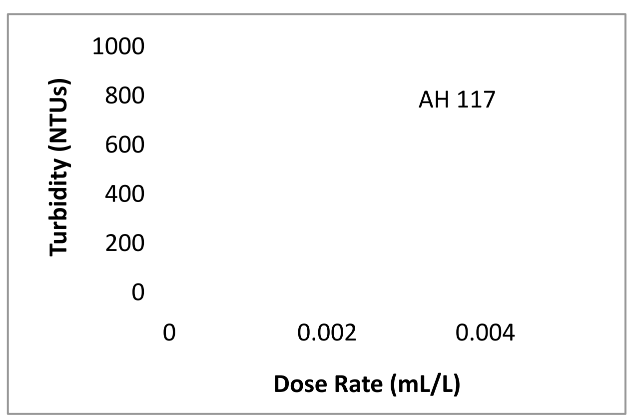


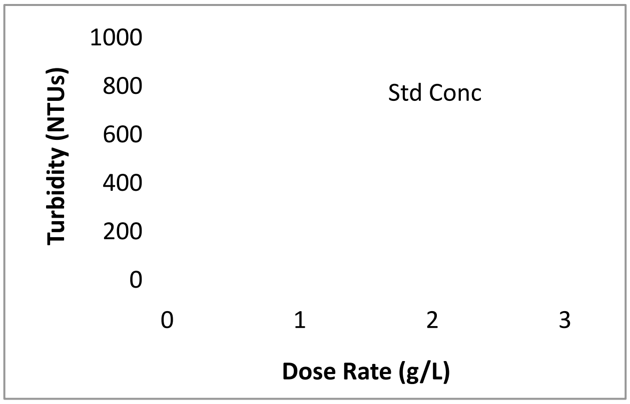




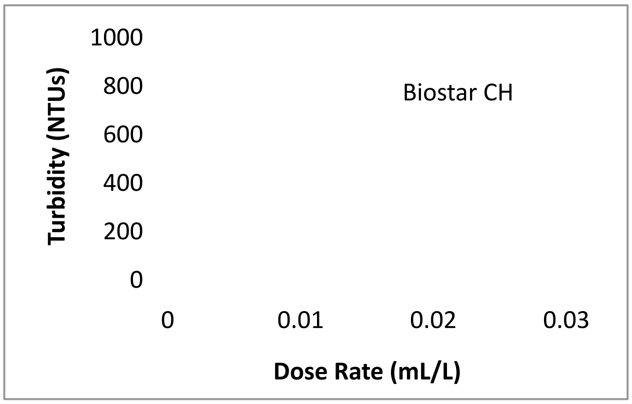


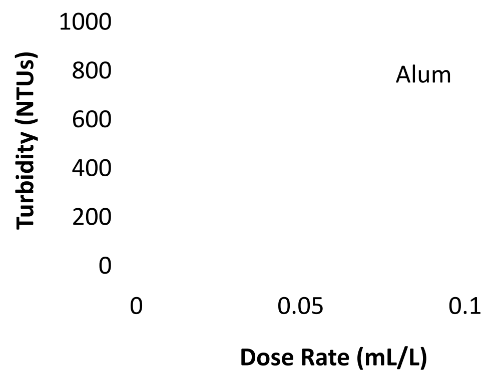


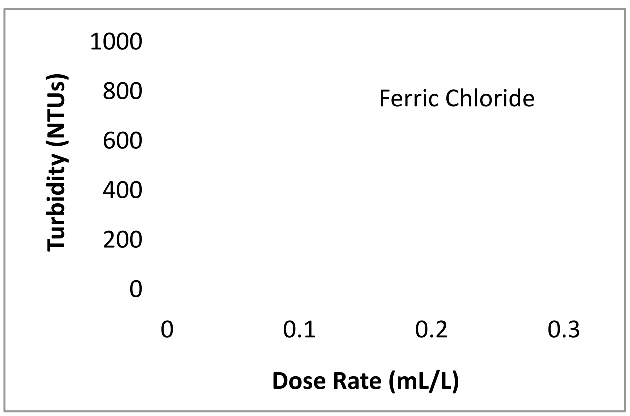


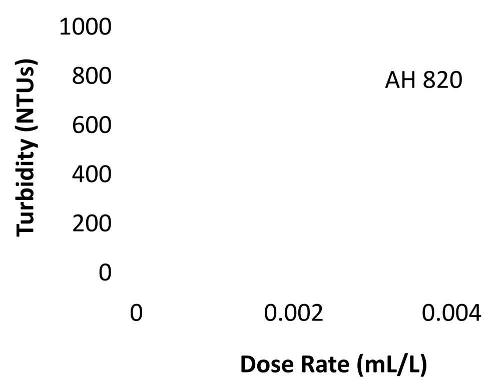


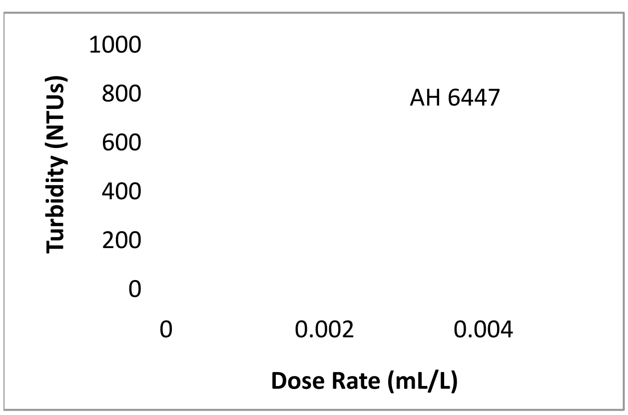
Material	East Grand Forks Topsoil
Classification	Organic Clay Loam
USCS Symbol(s)	OL
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

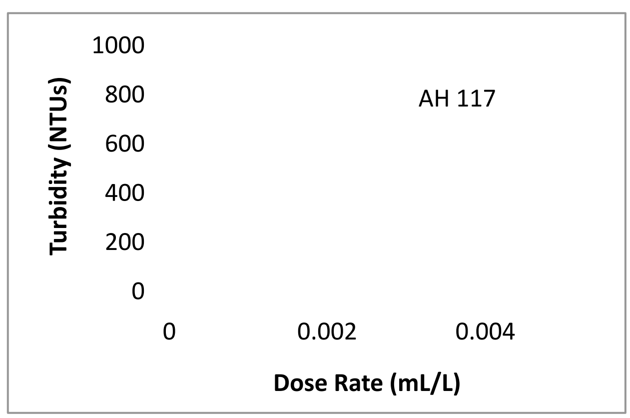


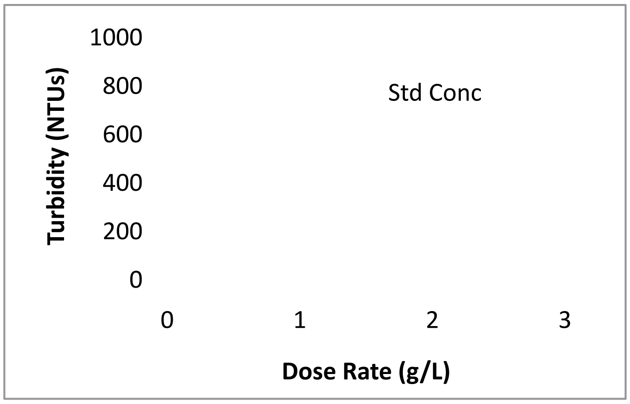




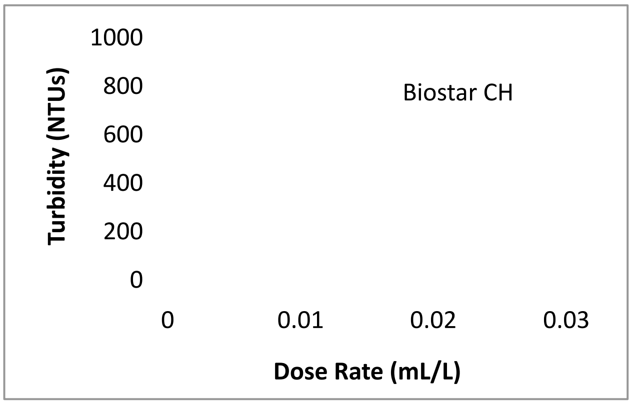


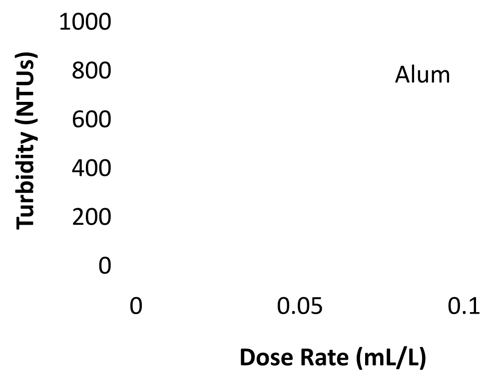


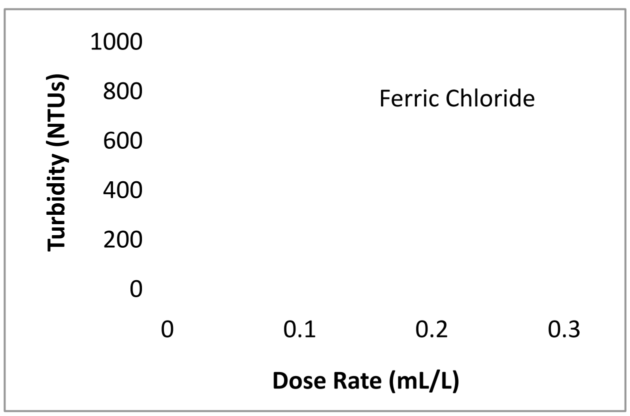


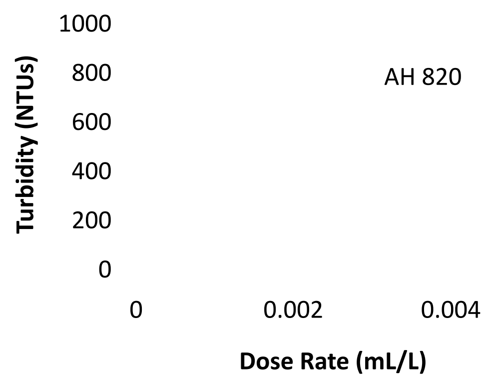


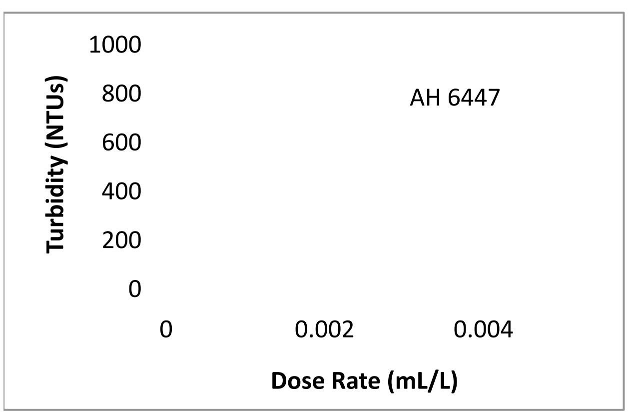
Material	Foley Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Superior Lobe

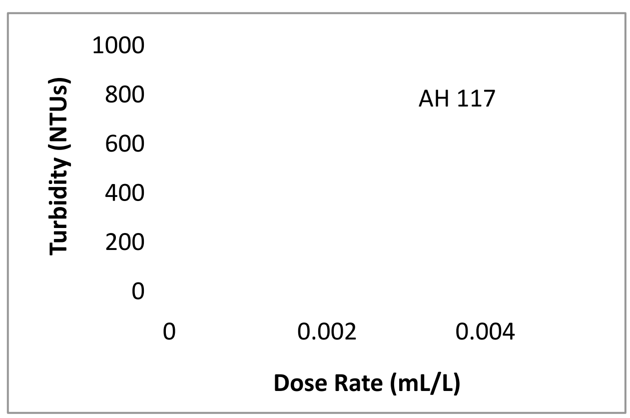


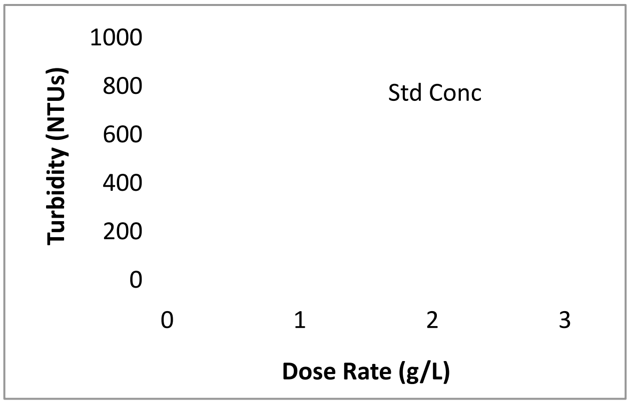




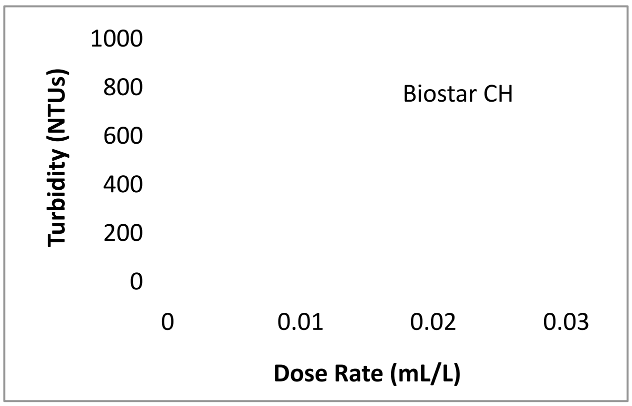


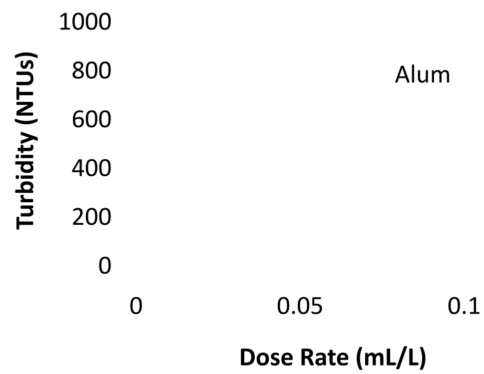


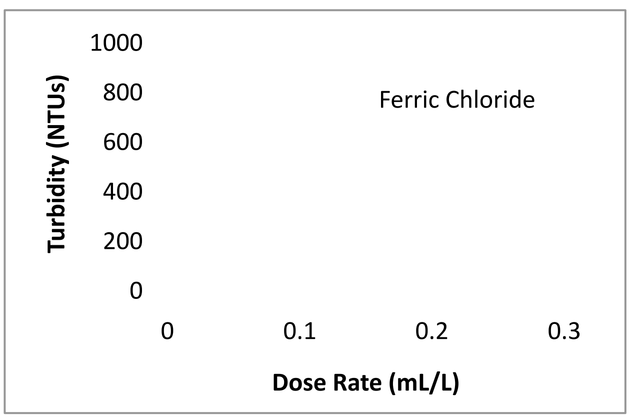


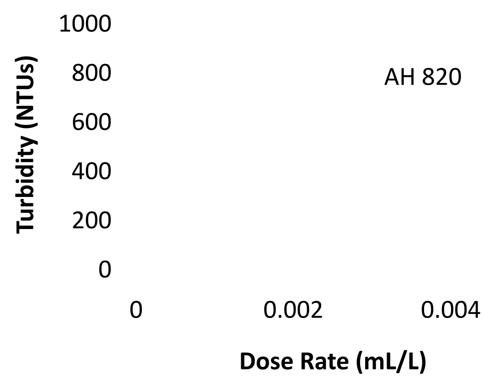


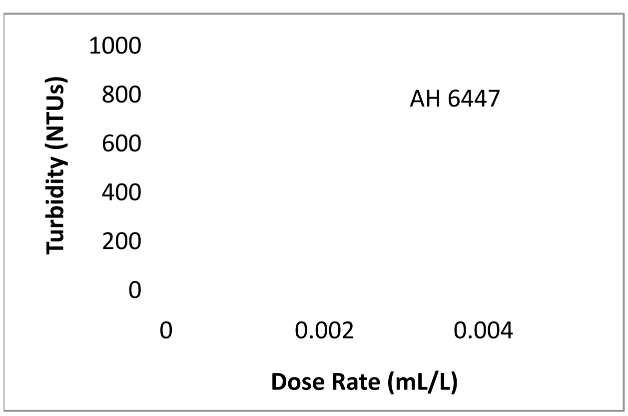
Material	Foley Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Superior Lobe

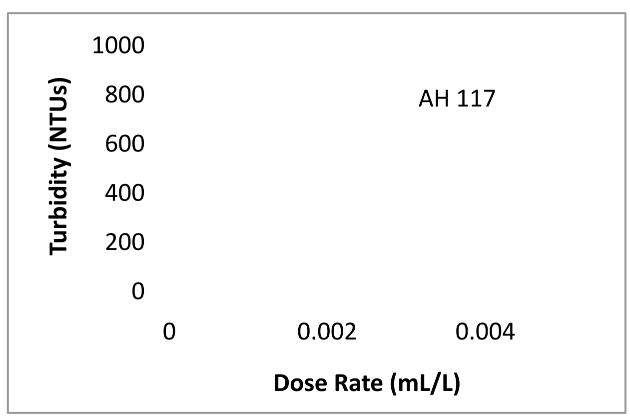


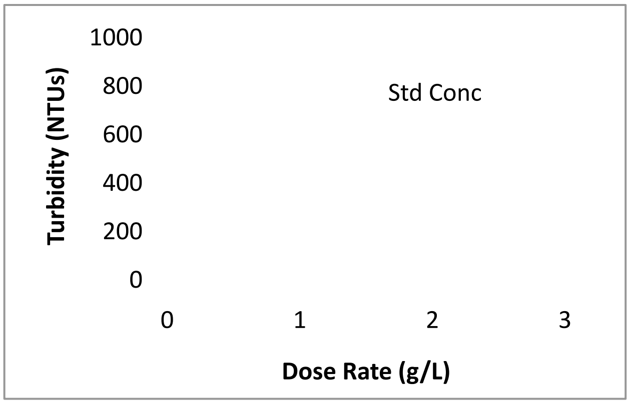




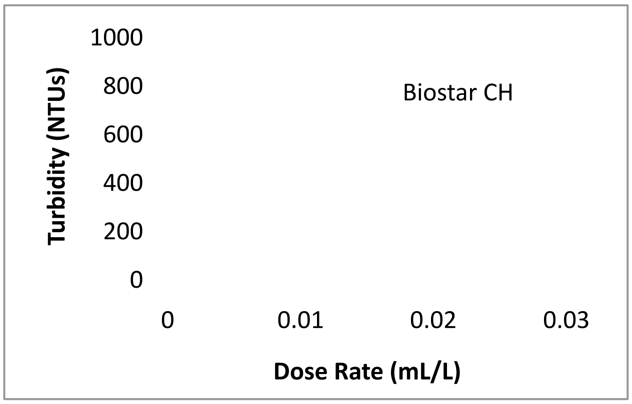


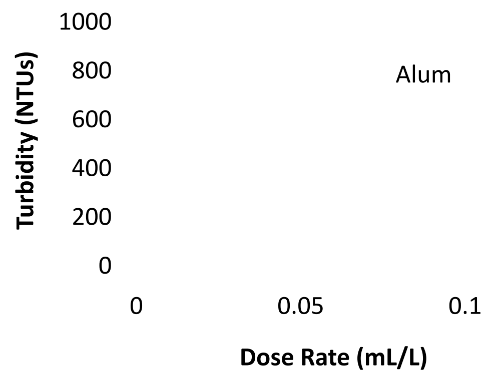


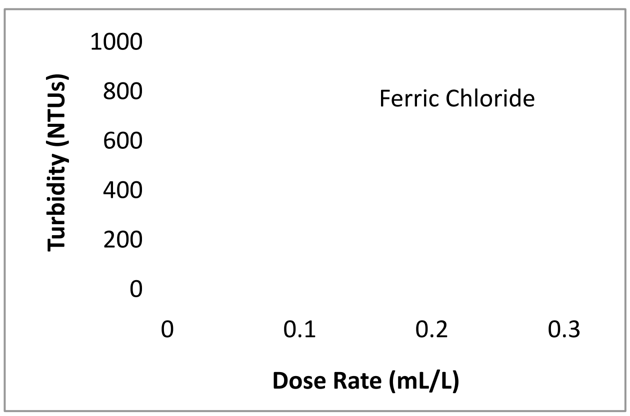


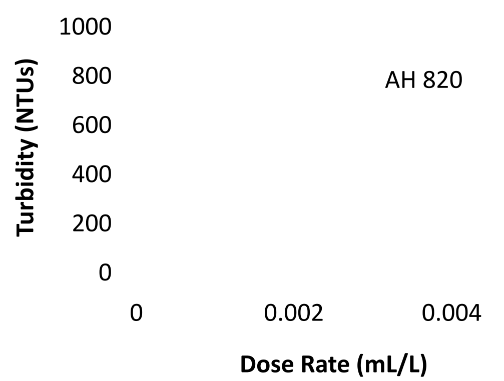


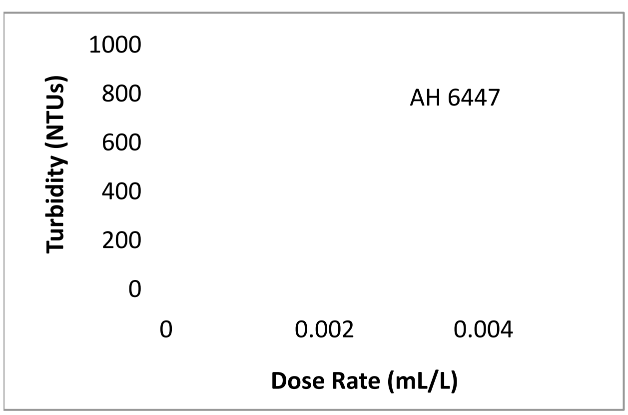
Material	Grand Rapids Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

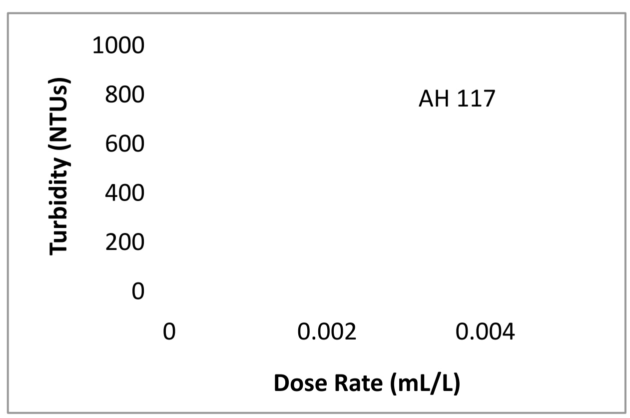


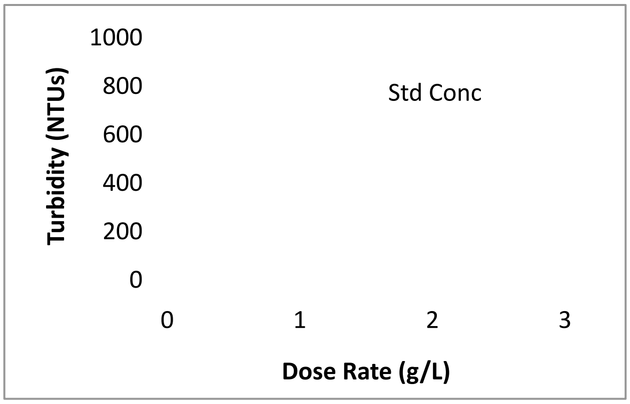




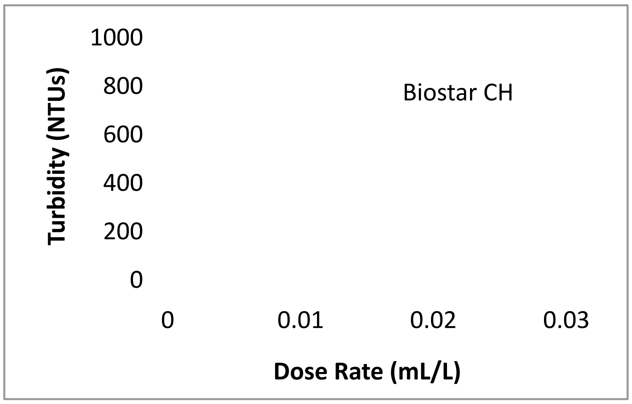


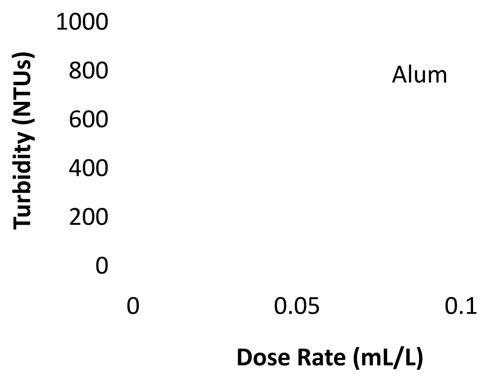


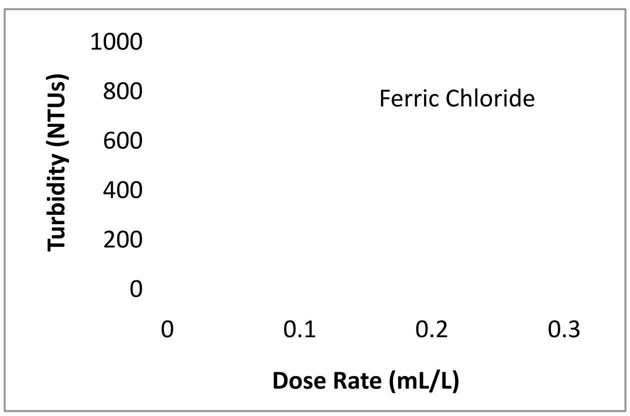


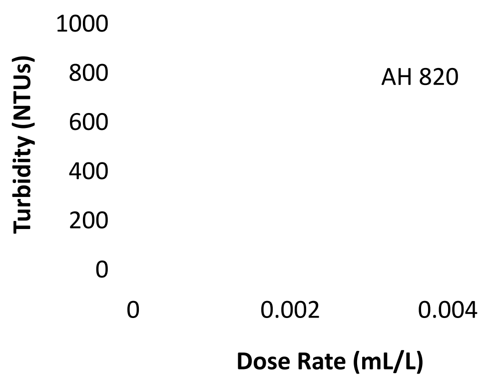


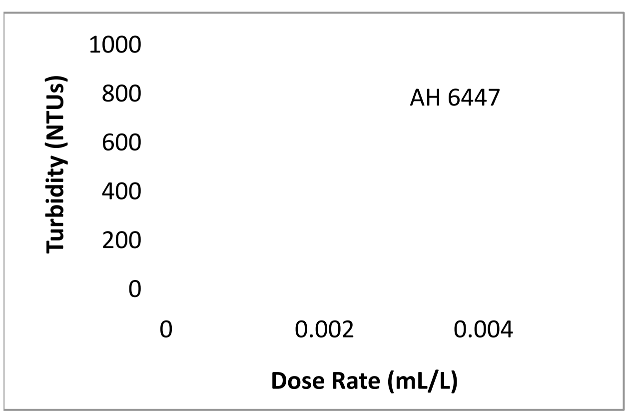
Material	Grand Rapids Topsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

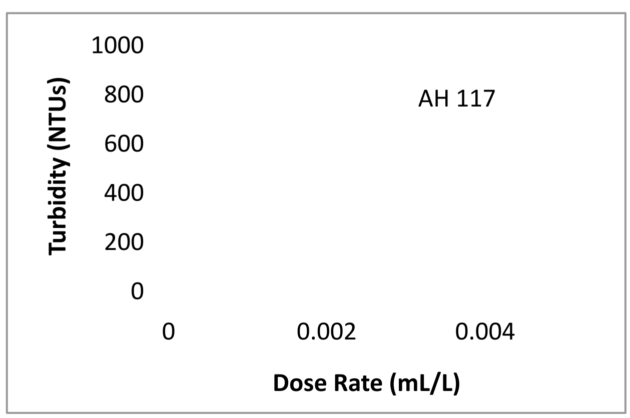


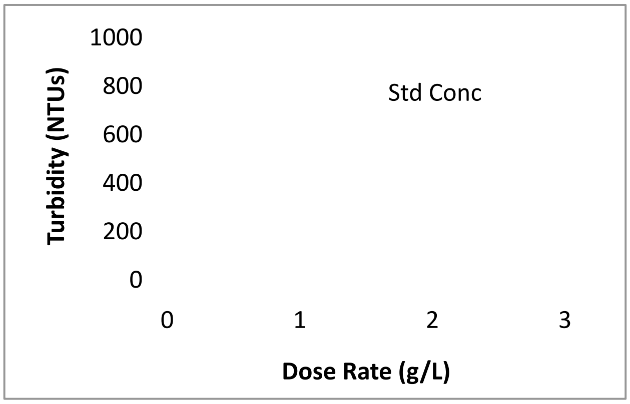




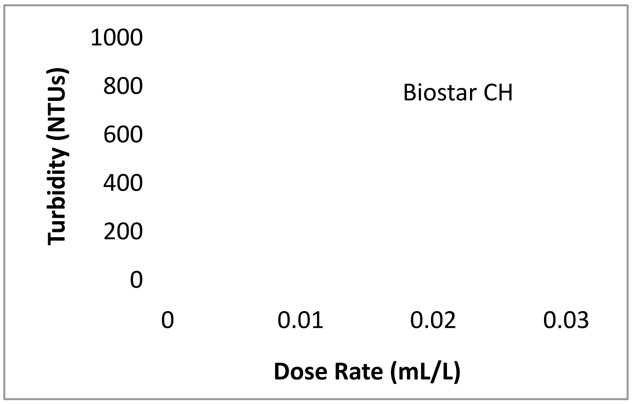


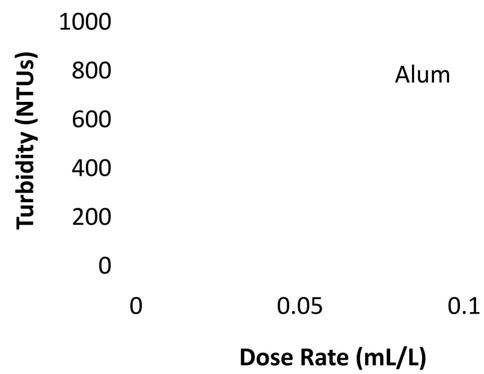


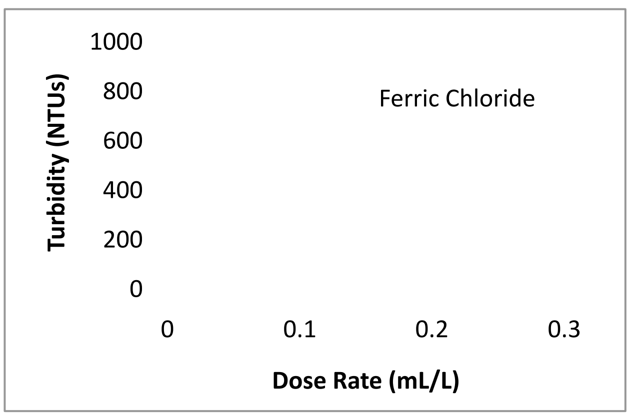


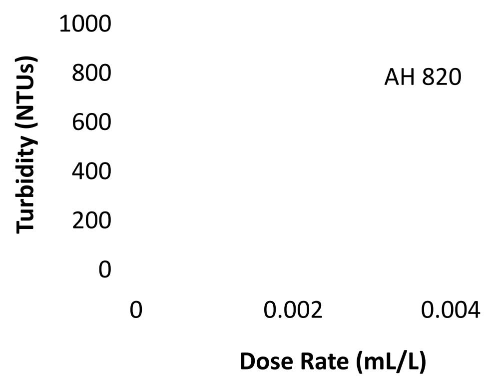


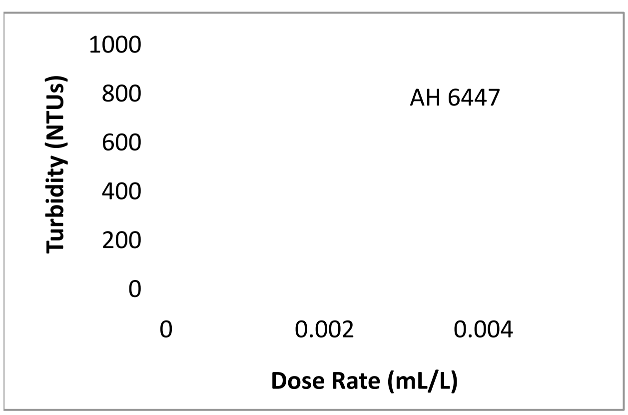
Material	Hampton Subsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Red Drift
Geomorphology	Illinoisian Glaciation

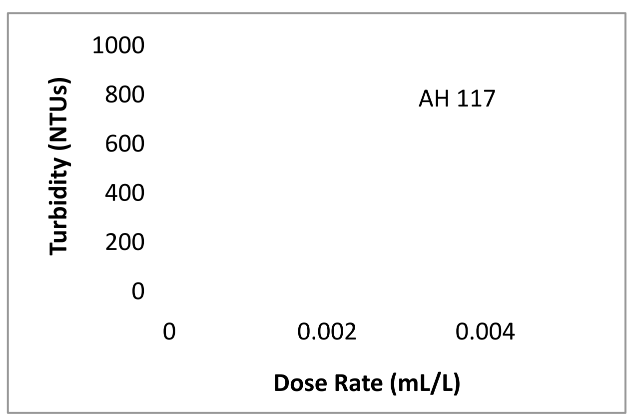


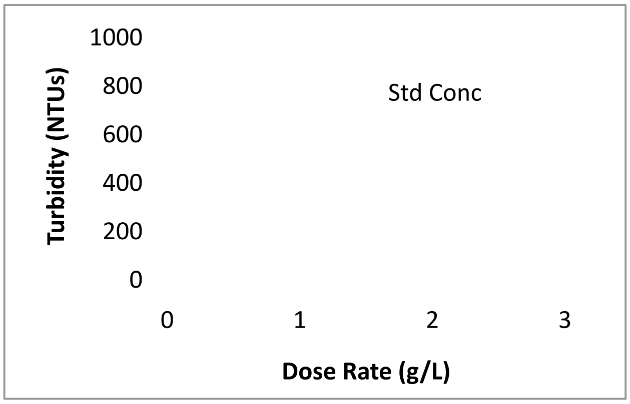




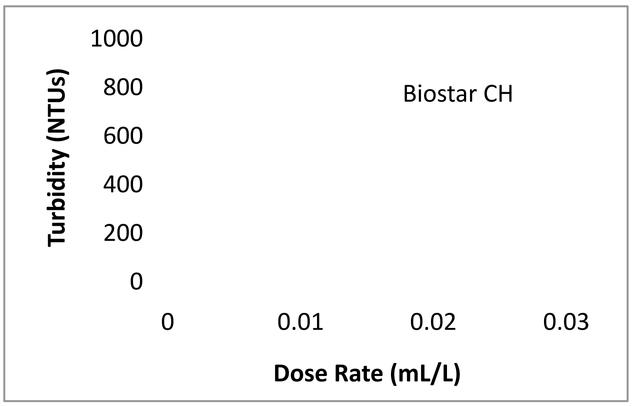


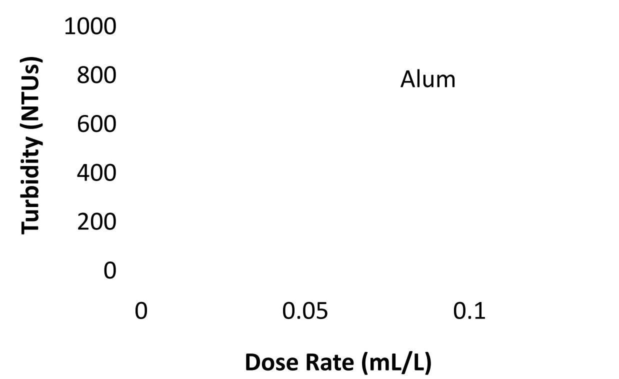


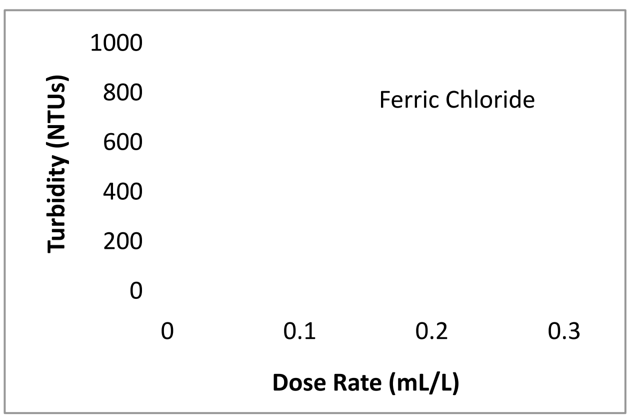


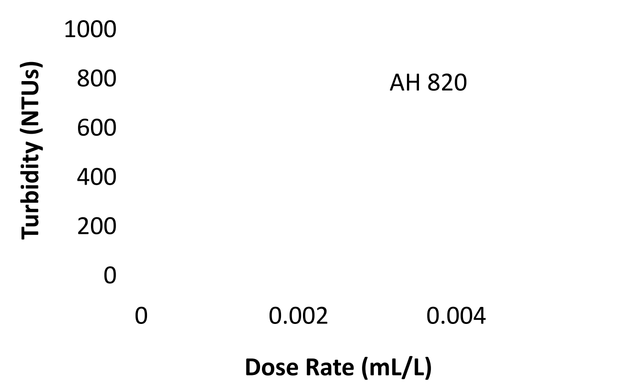


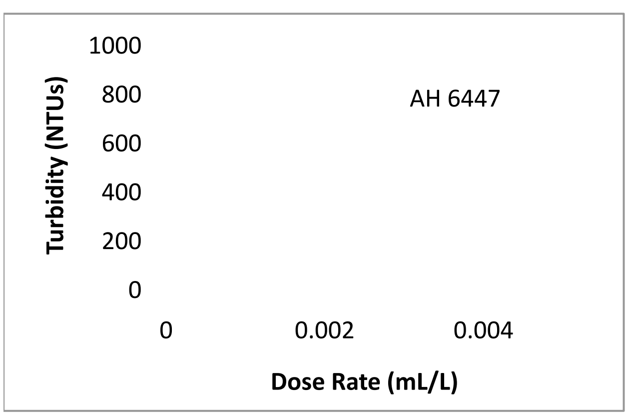
Material	Hampton Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Red Drift
Geomorphology	Illinoisian Glaciation

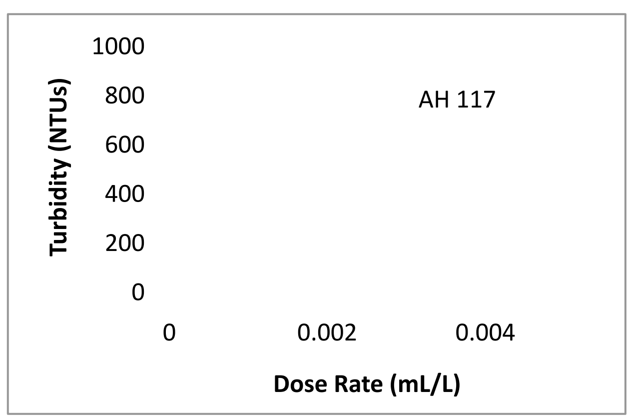


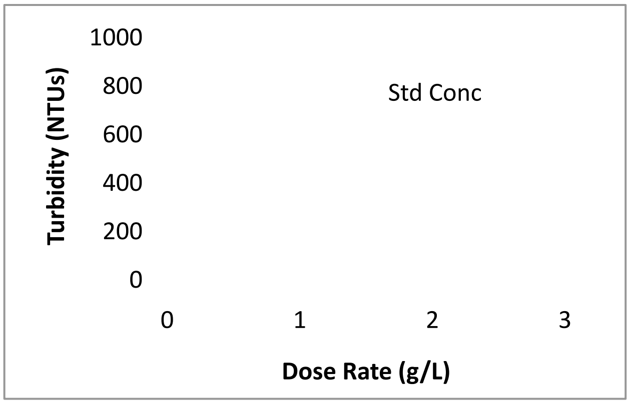




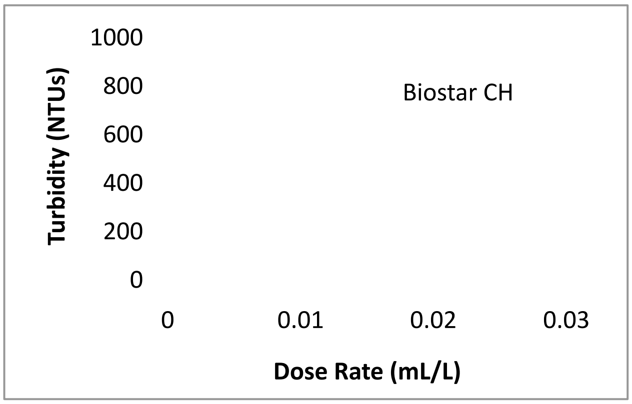


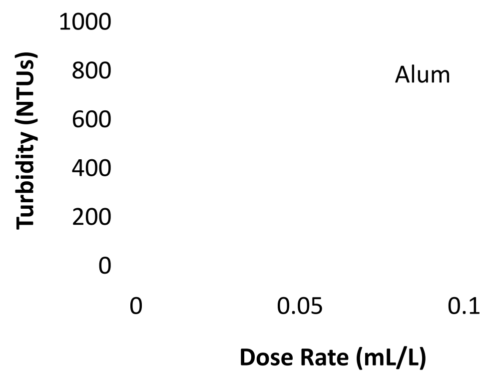


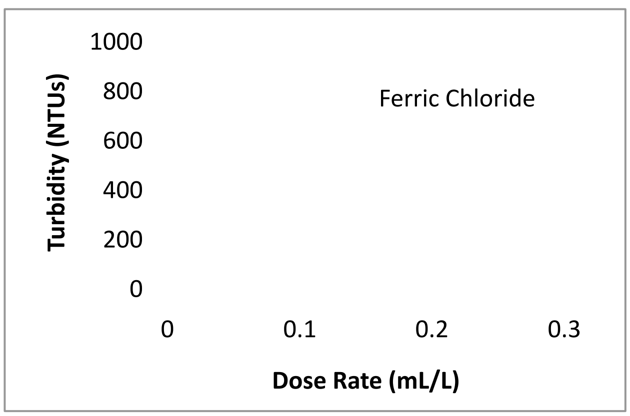


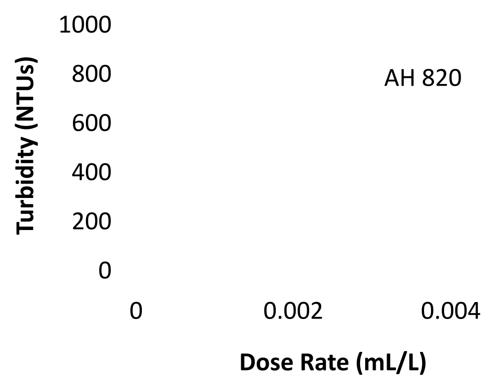


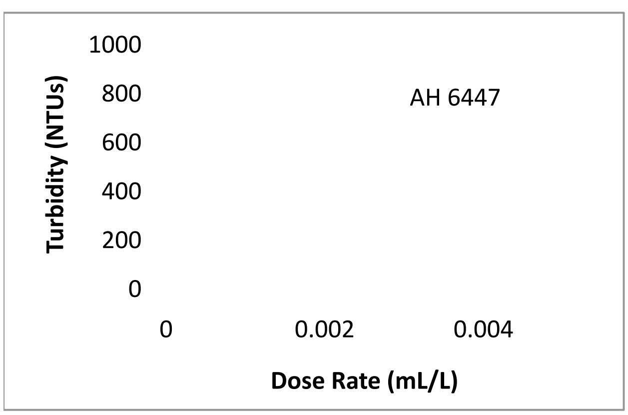
Material	Houston Riverbed
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Colluvuum
Geomorphology	Weathered Residual

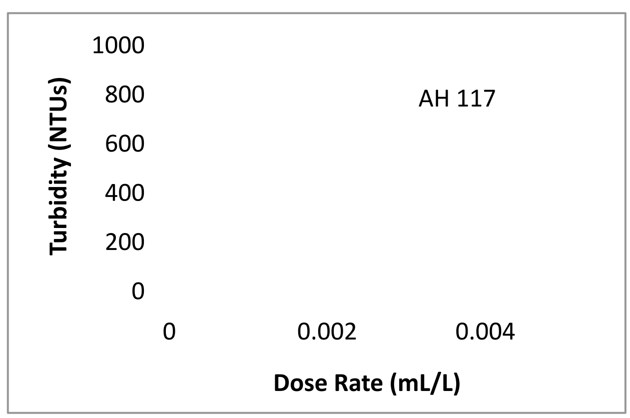


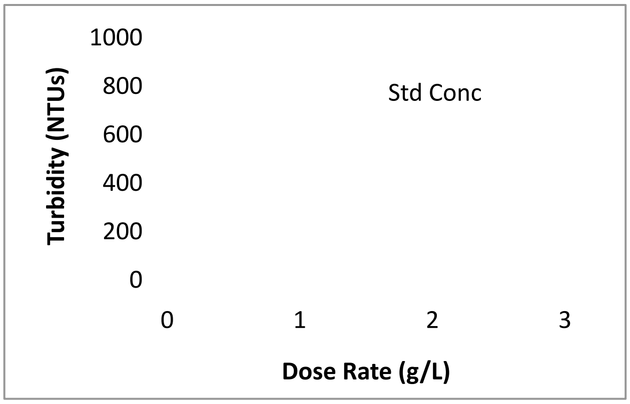




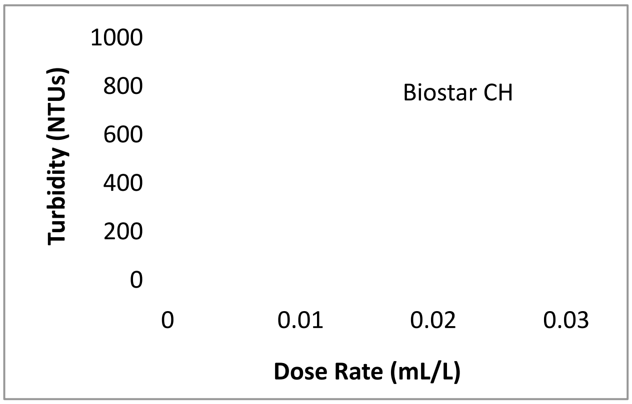


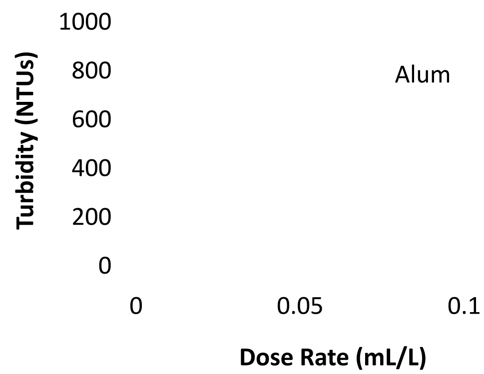


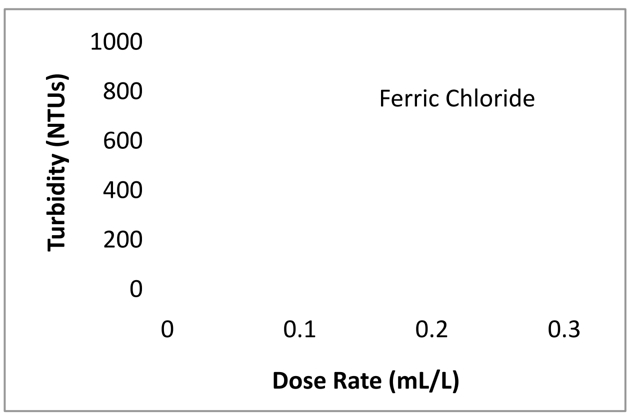


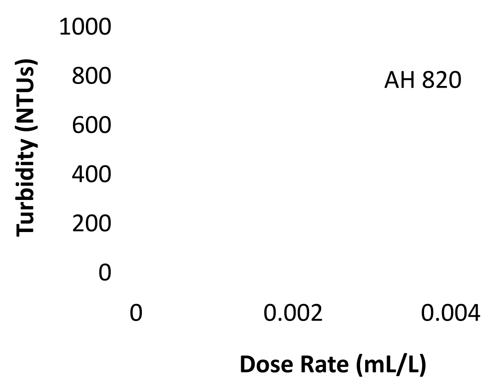


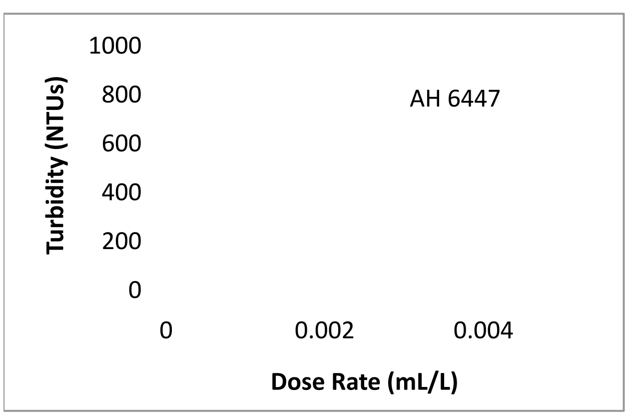
Material	Houston Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Colluvuum
Geomorphology	Weathered Residual

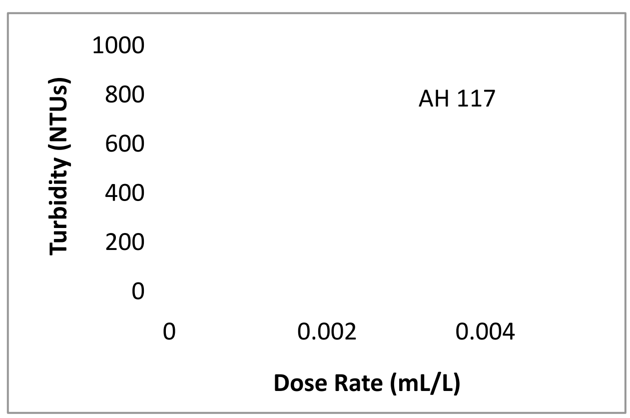


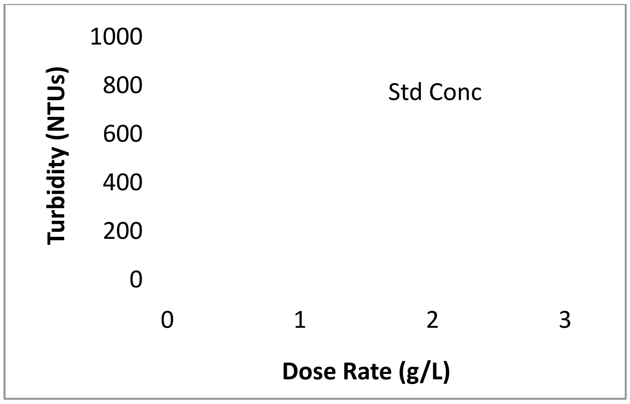




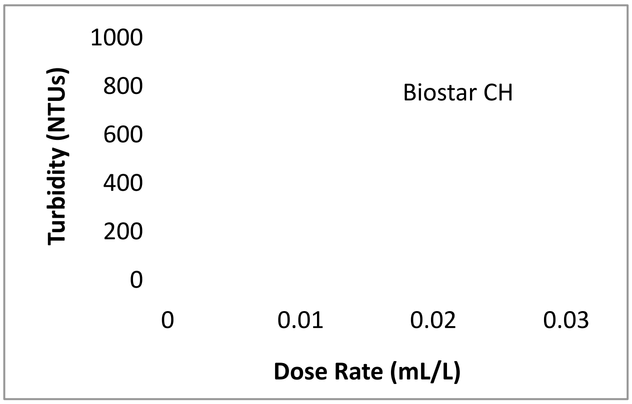


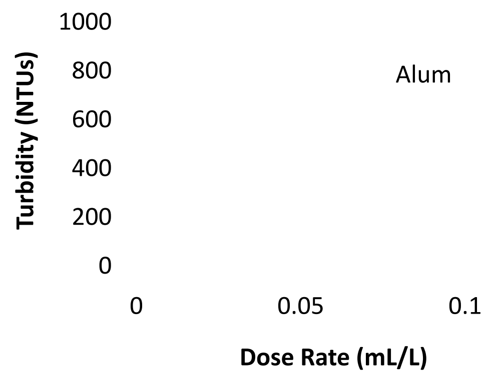


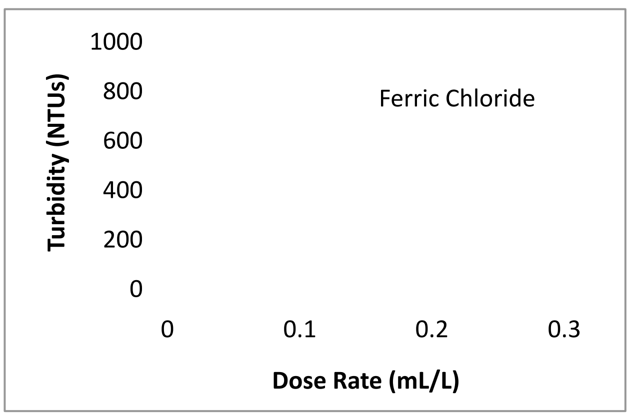


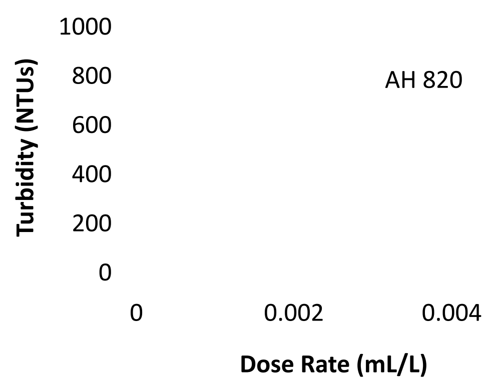


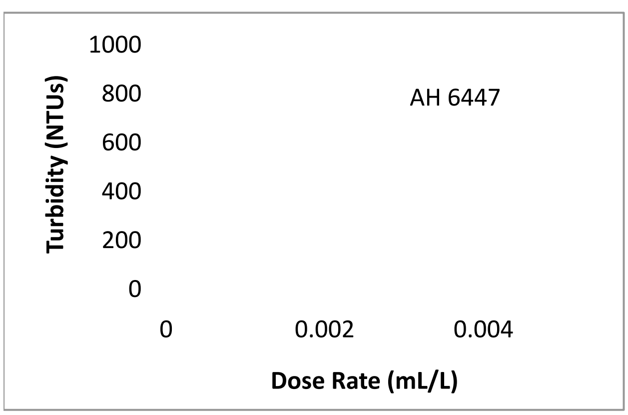
Material	Kandiyohi Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Stagnation Moraine
Geomorphology	Wadena Lobe

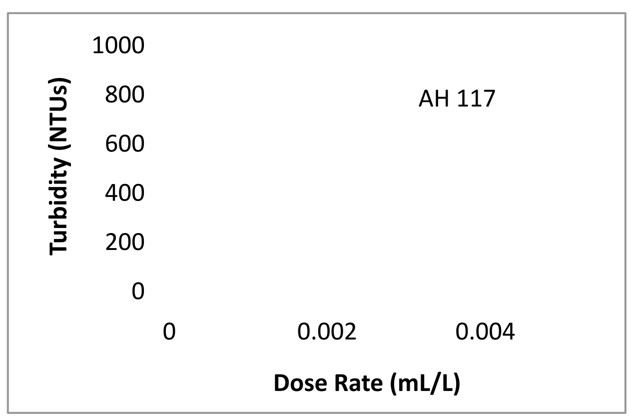


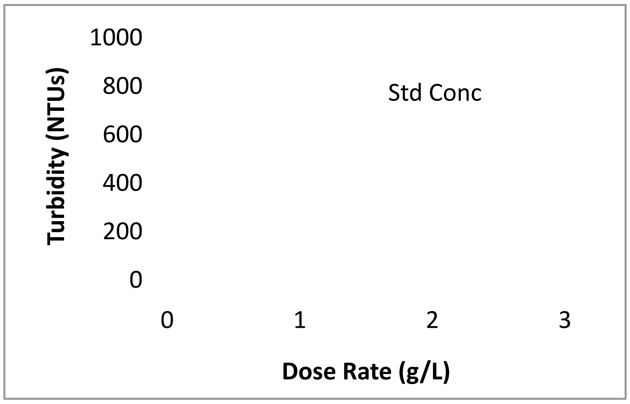




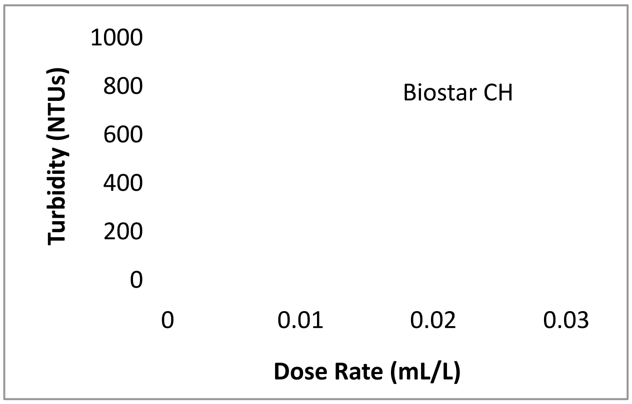


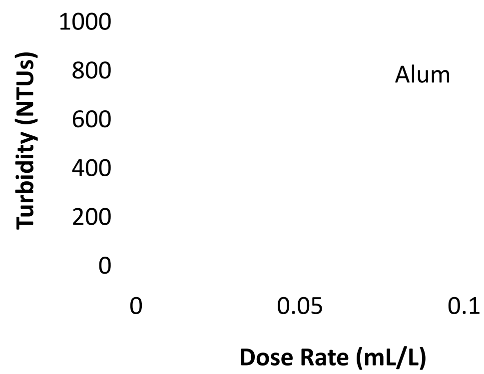


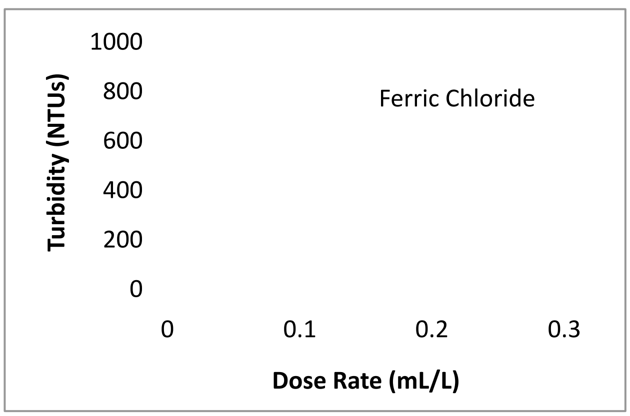


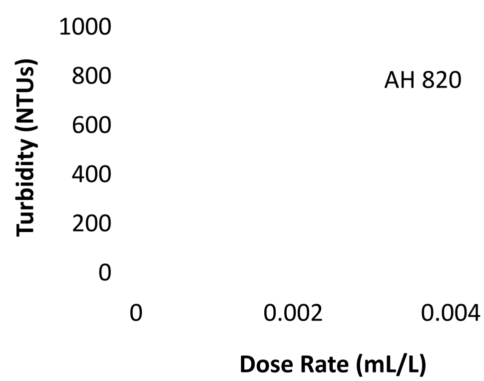


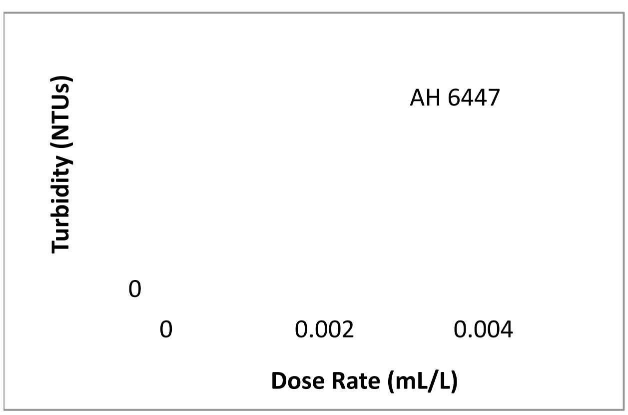
Material	Kandiyohi Topsoil
Classification	Organic Clay Loam
USCS Symbol(s)	OL
Strata	Stagnation Moraine
Geomorphology	Wadena Lobe

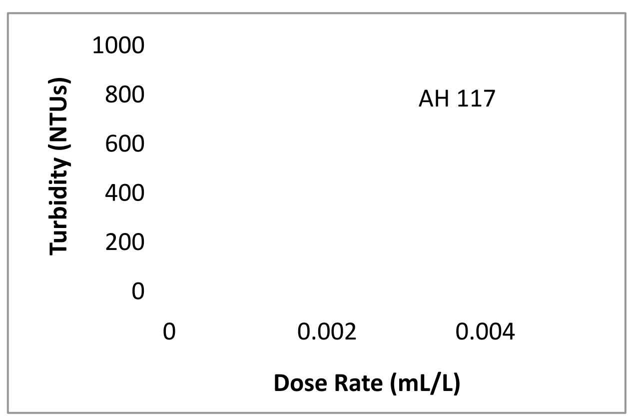


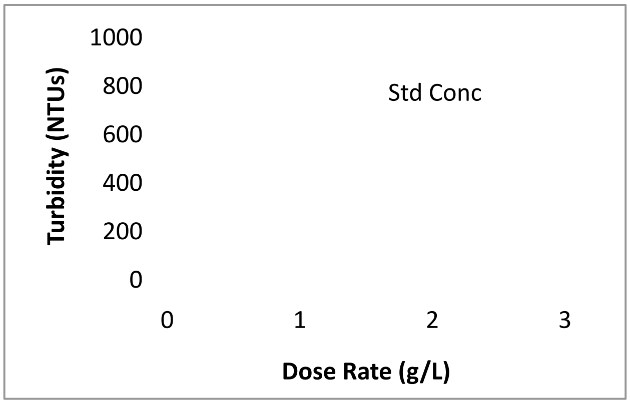




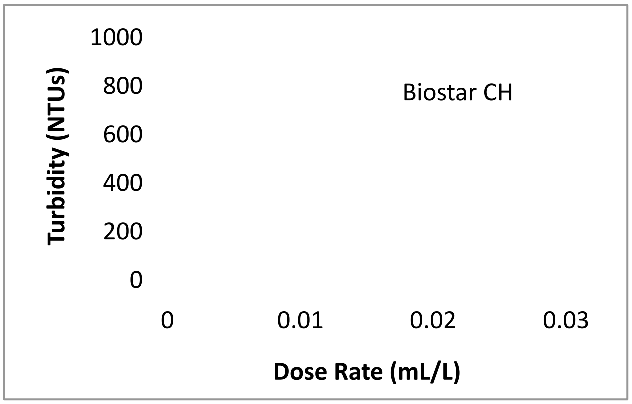


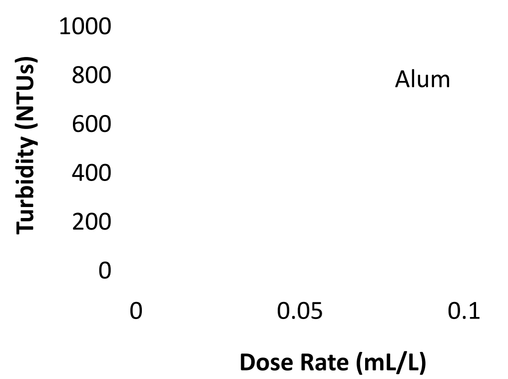


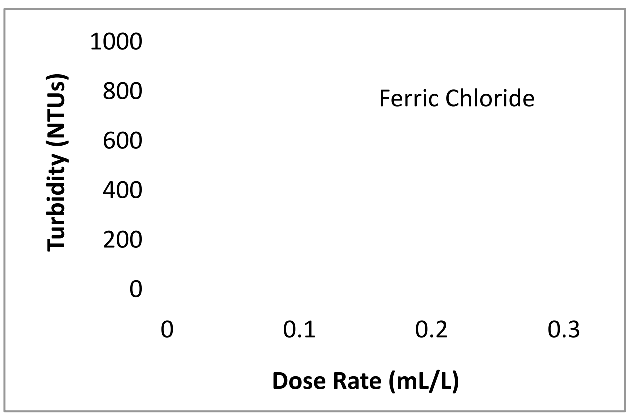


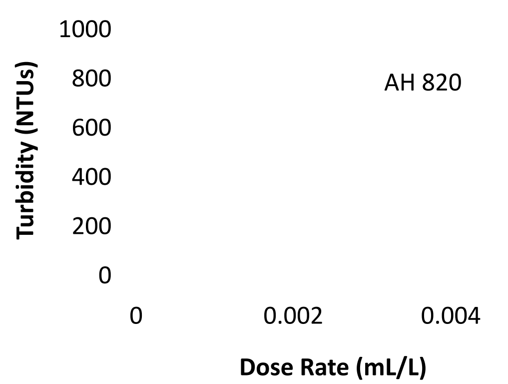


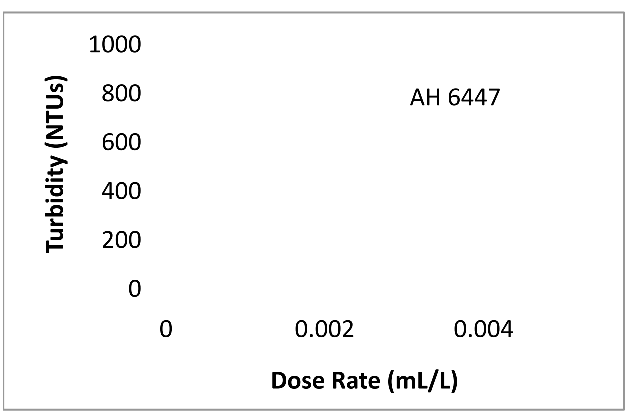
Material	Lakeville Subsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Gray Drift
Geomorphology	Kansan Glaciation

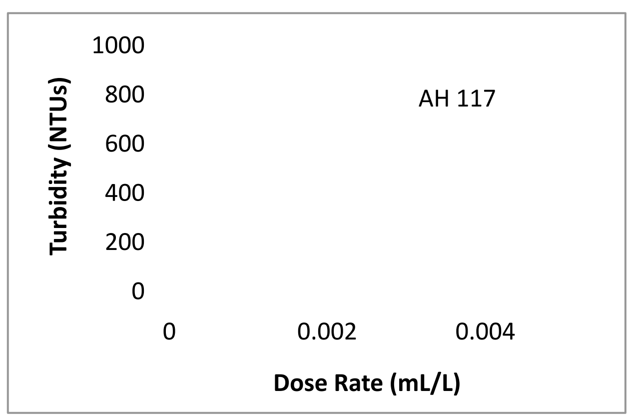


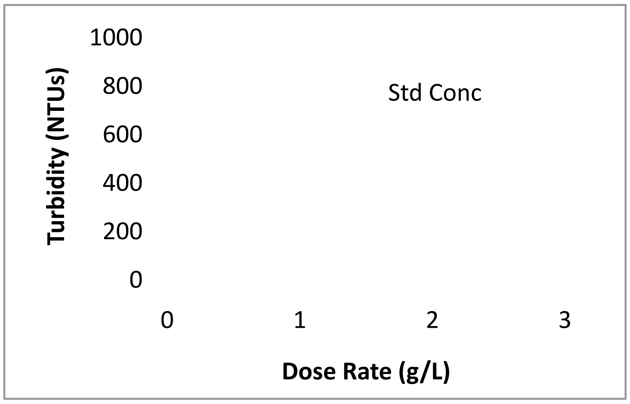




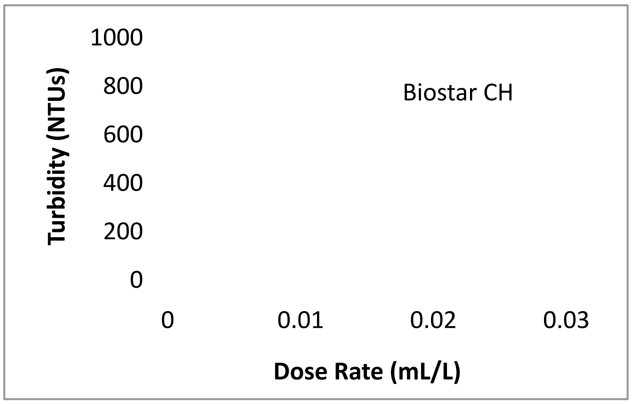


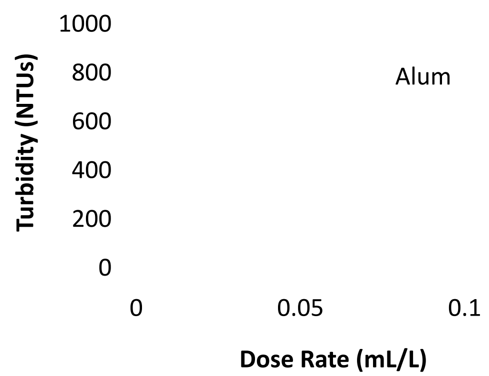


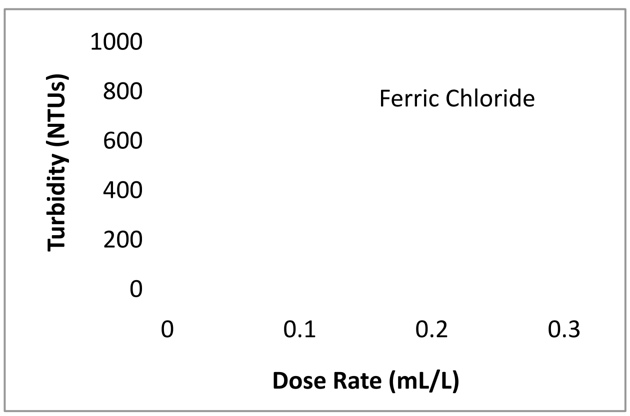


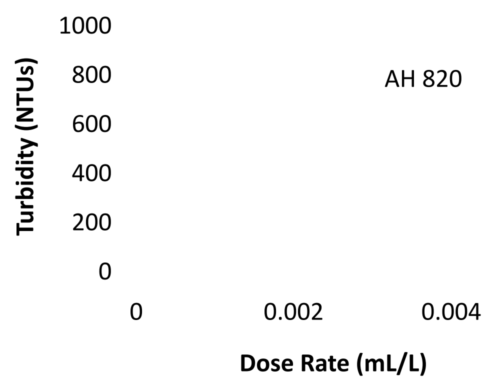


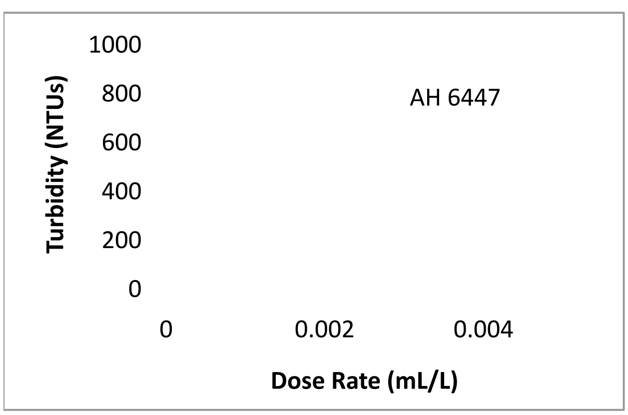
Material	Lakeville Topsoil
Classification	Slightly Organic Clay Loam
USCS Symbol(s)	ML-OL
Strata	Gray Drift
Geomorphology	Kansan Glaciation

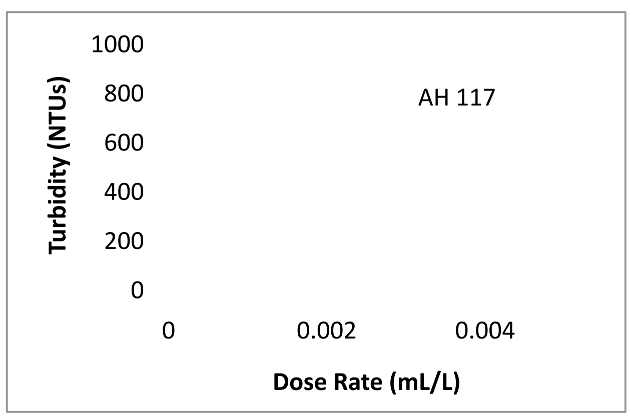


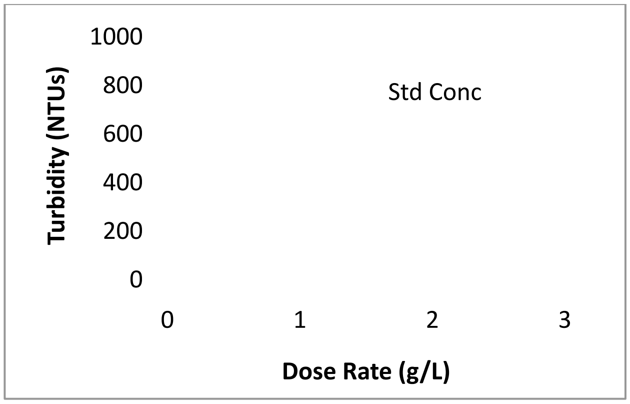




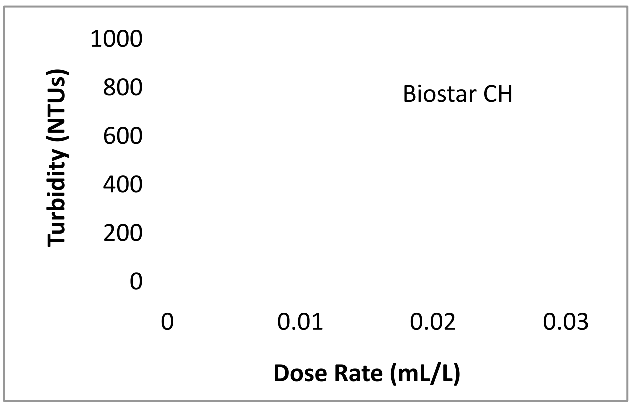


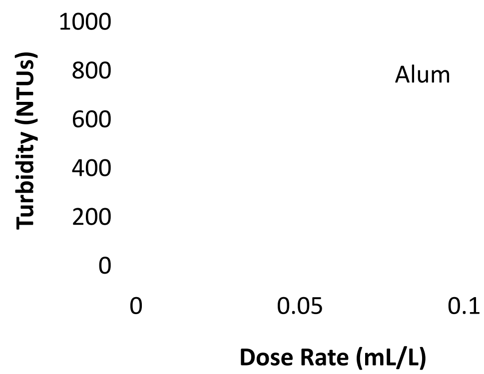


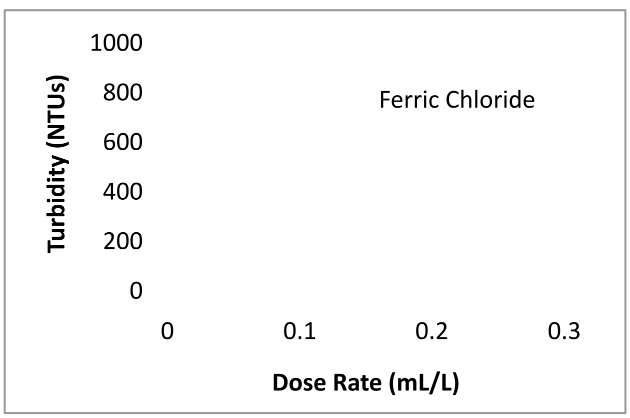


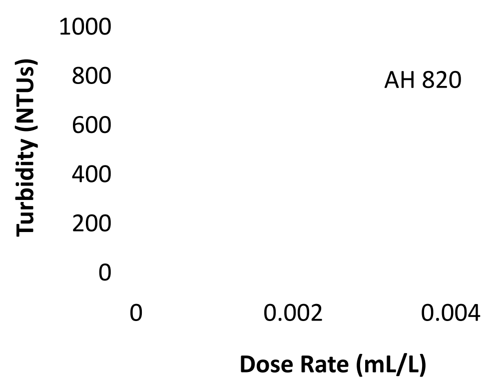


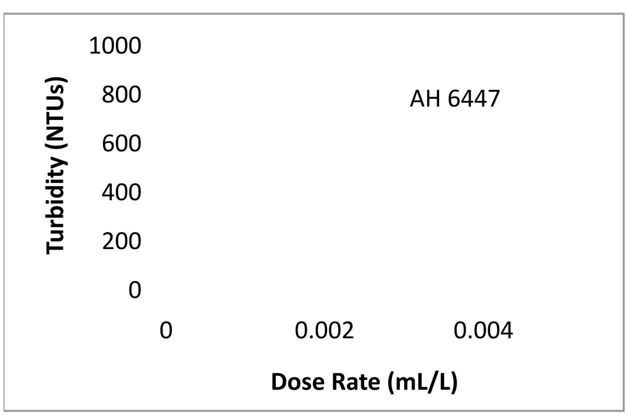
Material	Lindstrom Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

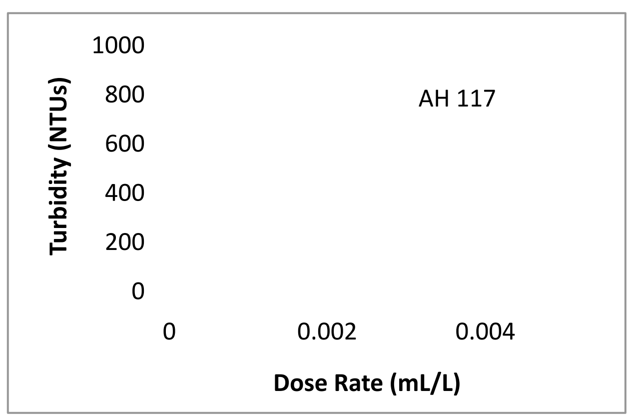


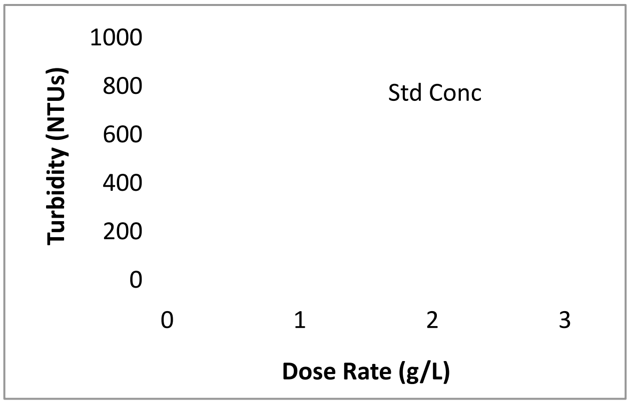




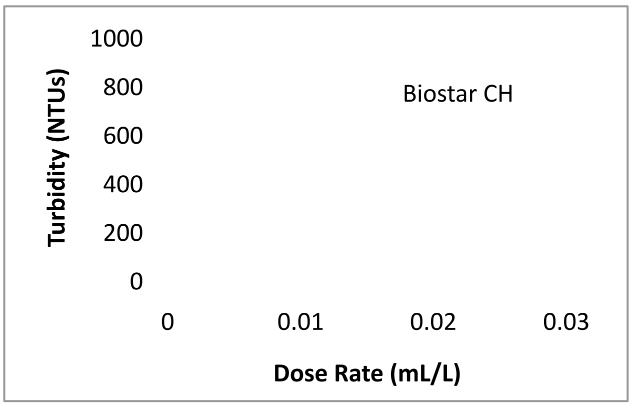


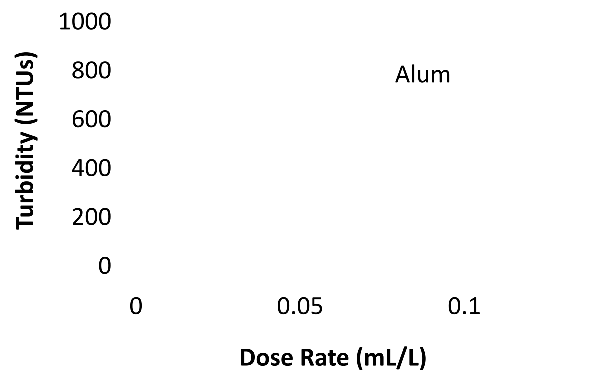


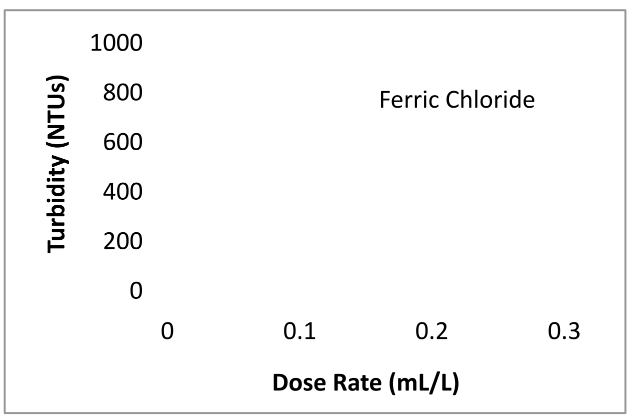


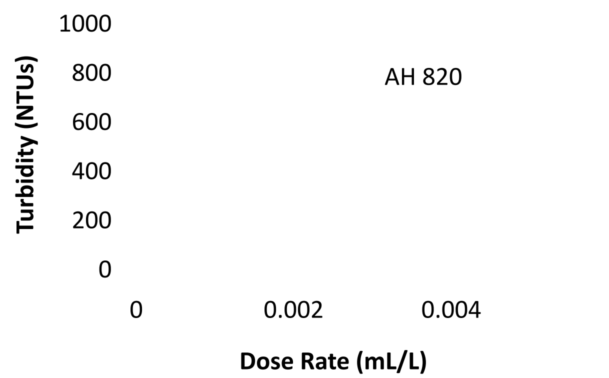


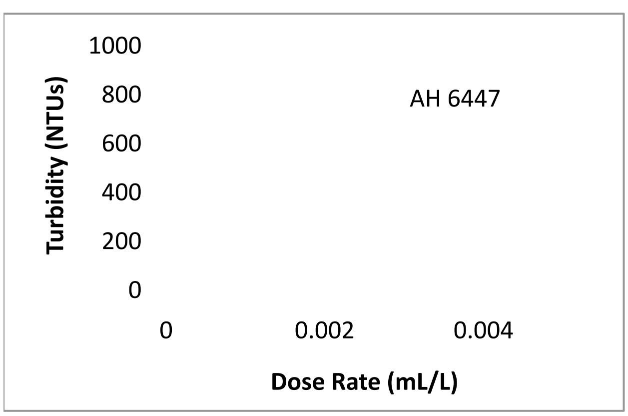
Material	Lindstrom Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

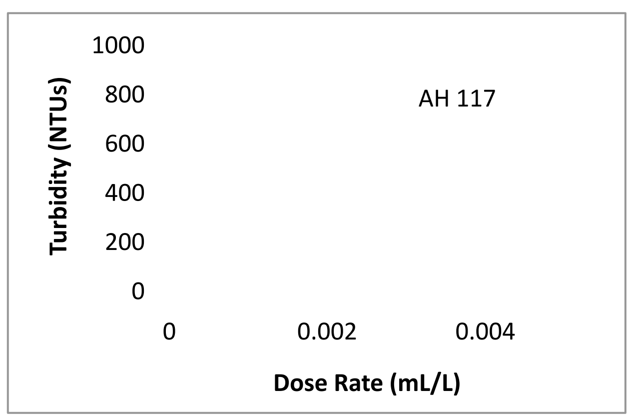


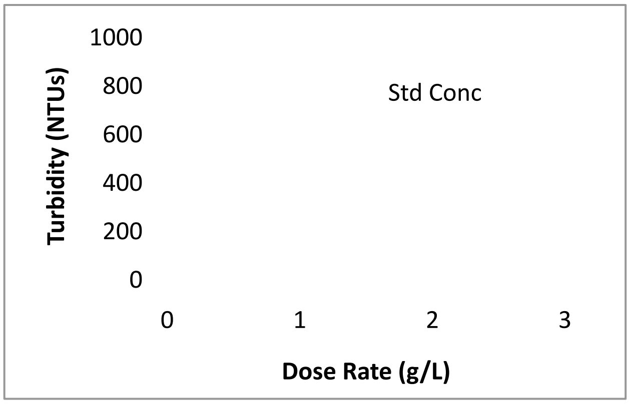




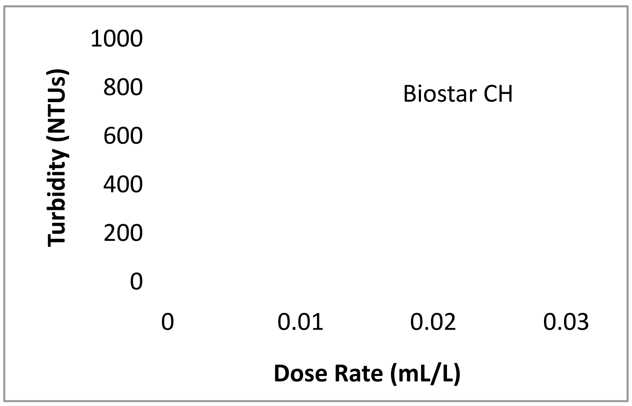


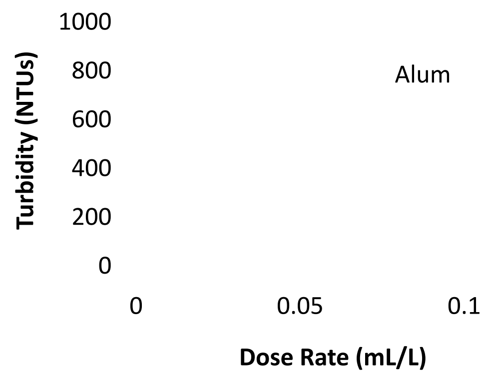


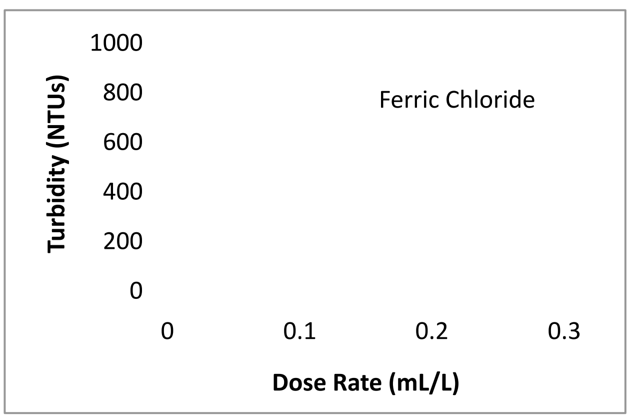


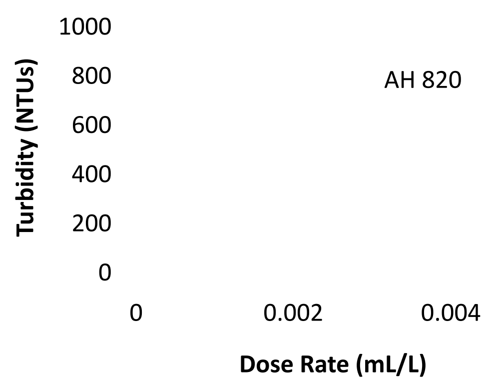


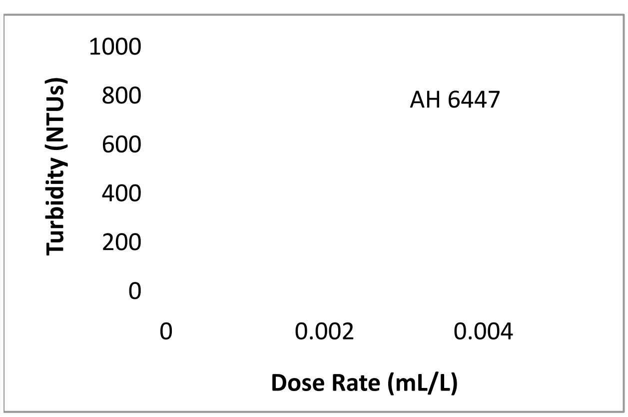
Material	Mankato Topsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Glacial Lake/Alluvium
Geomorphology	Des Moines Lobe

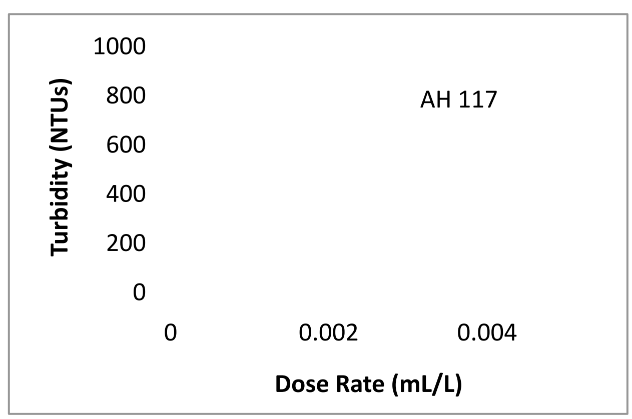


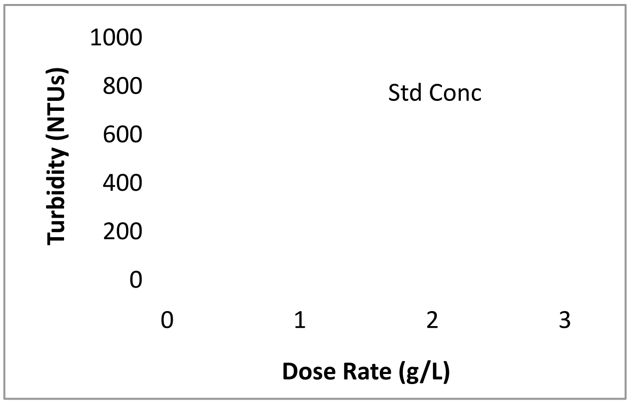




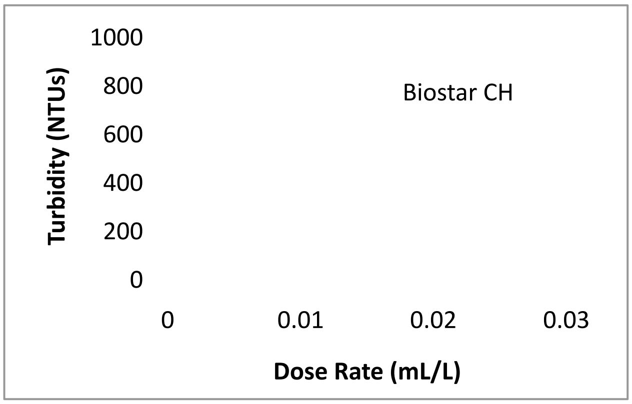


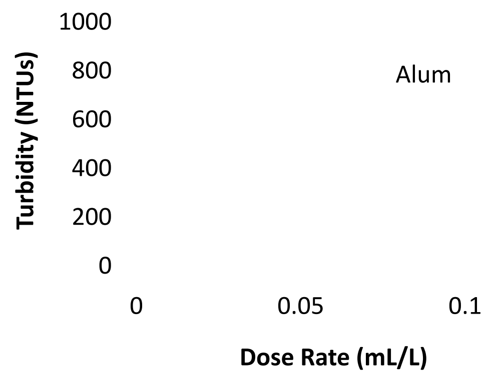


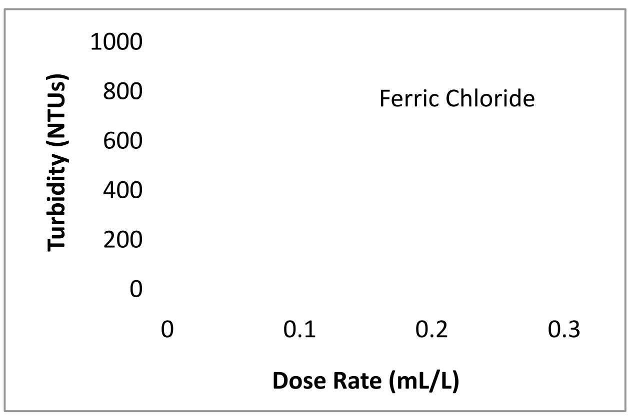


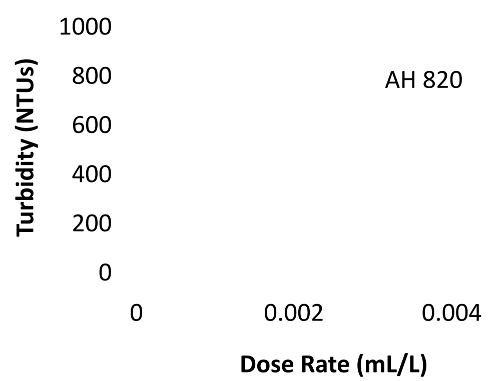


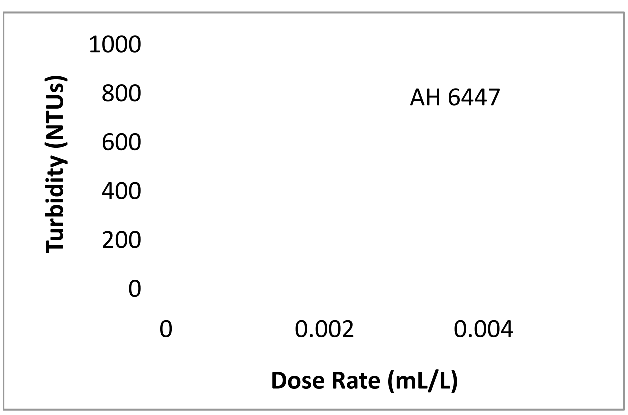
Material	Mapleton Topsoil
Classification	Slightly Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

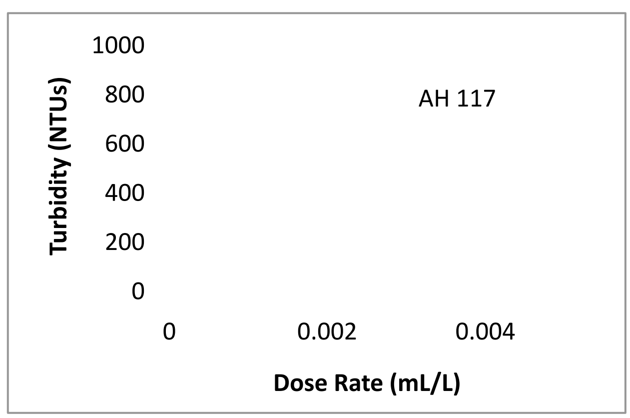


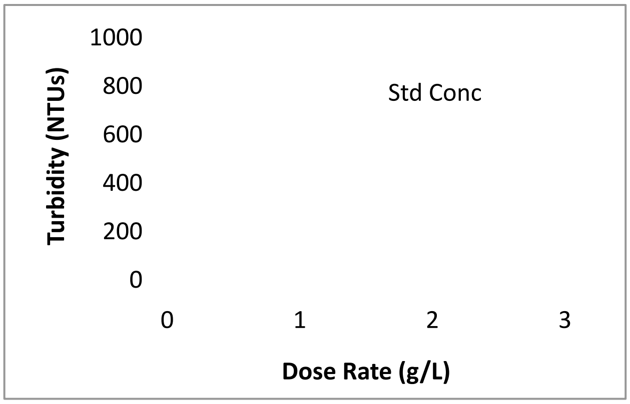




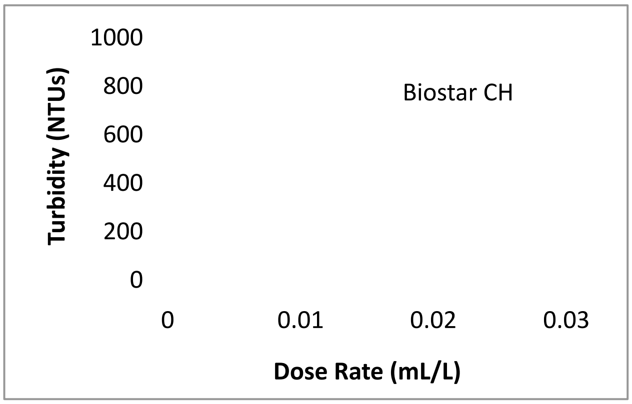


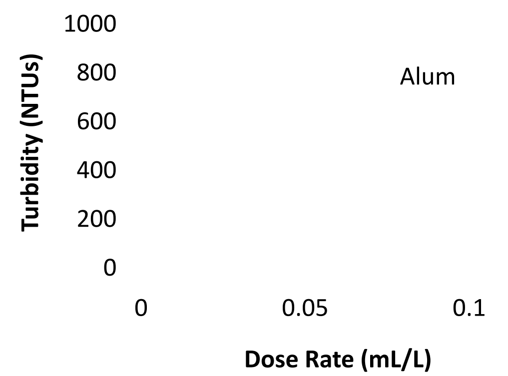


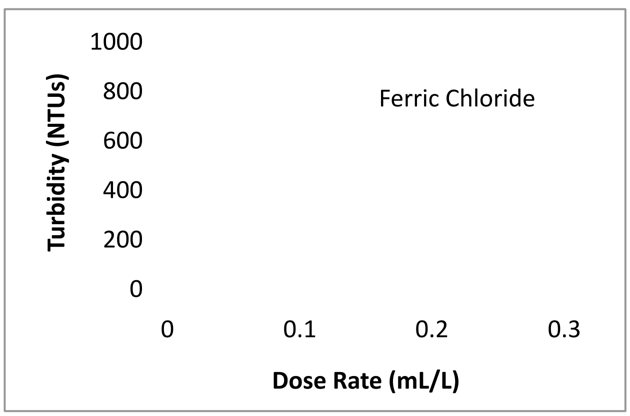


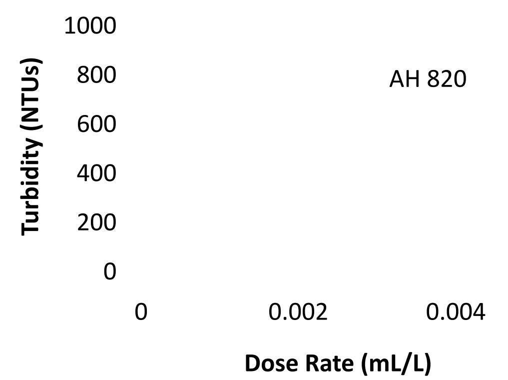


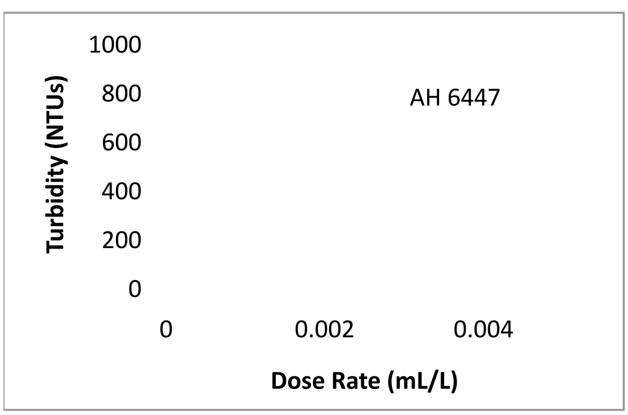
Material	Moorhead Subsoil
Classification	Slightly Organic Clay Loam
USCS Symbol(s)	CL-ML-OL
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

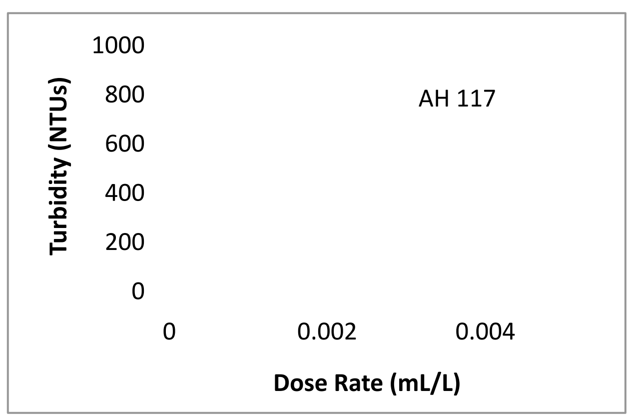


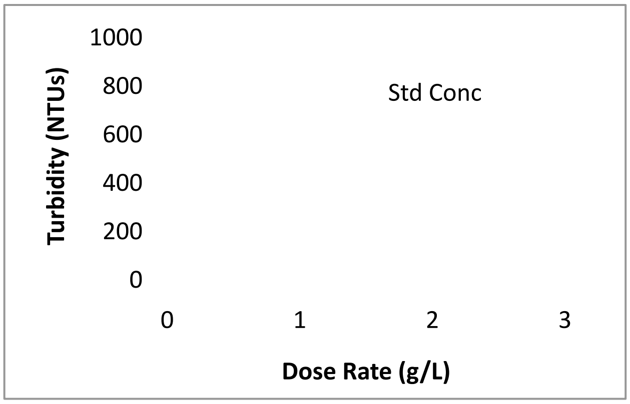




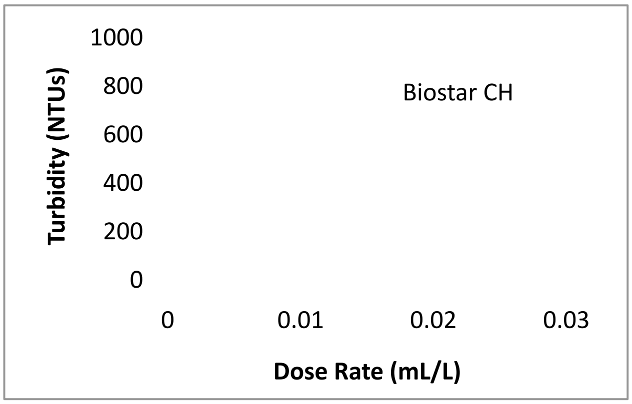


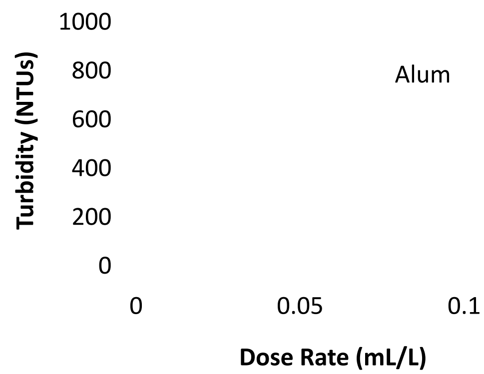


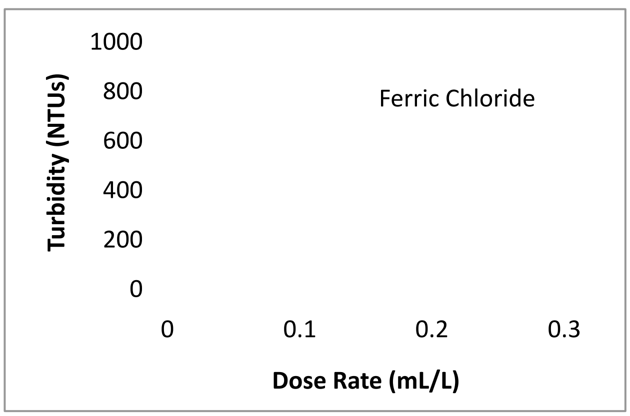


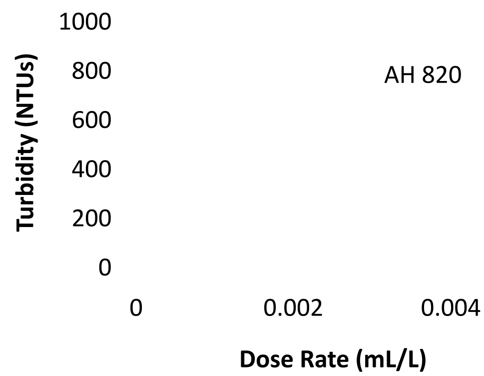


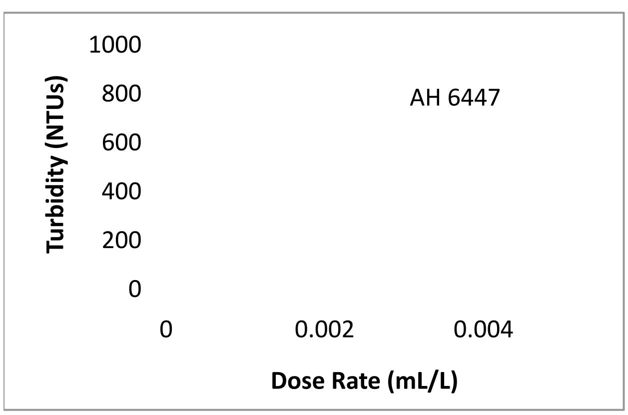
Material	Moorhead Topsoil
Classification	Organic Clay Loam
USCS Symbol(s)	OL
Strata	Glacial Lake Sediment
Geomorphology	Des Moines Lobe

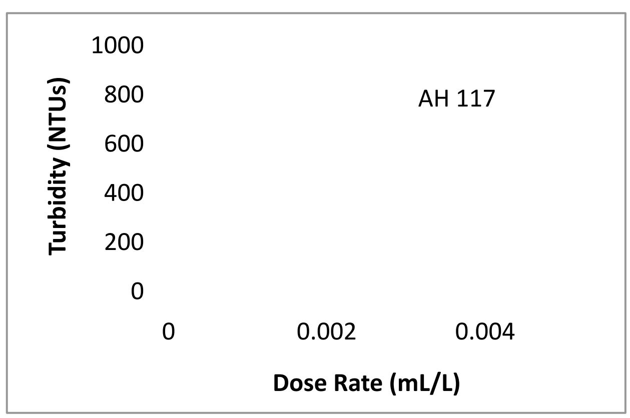


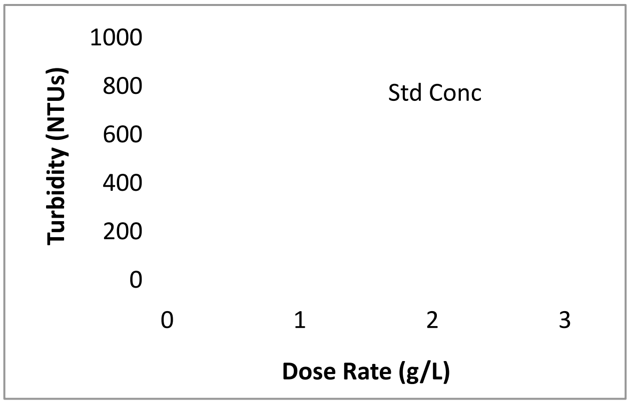




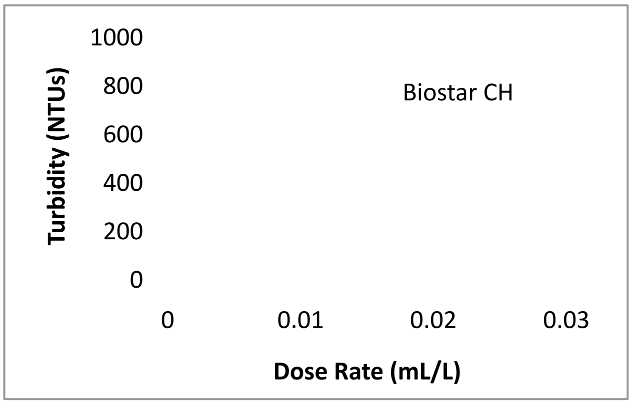


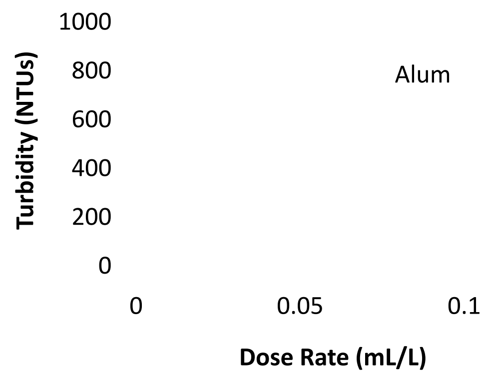


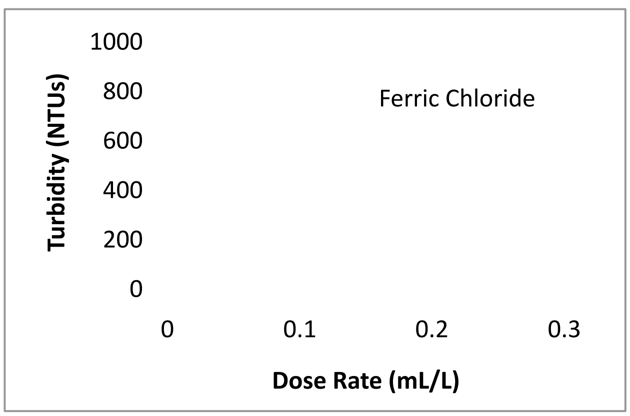


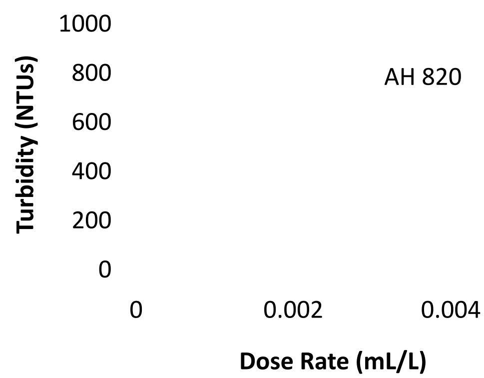


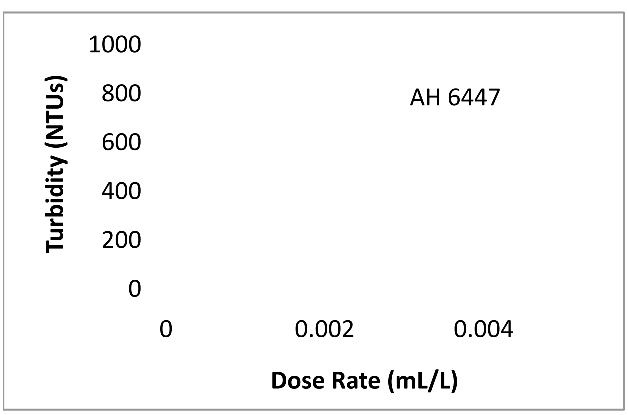
Material	New Sweden Topsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Stagnation Moraine
Geomorphology	Des Moines Lobe

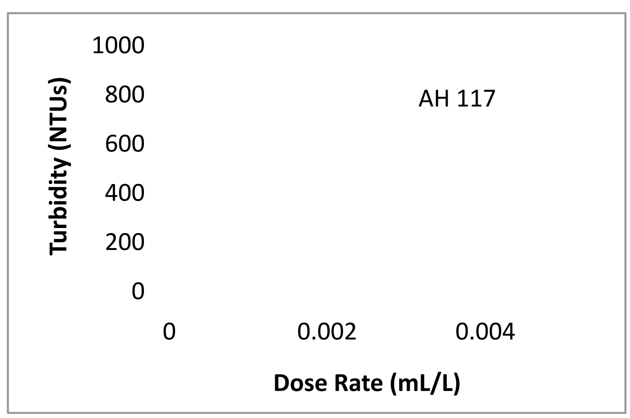


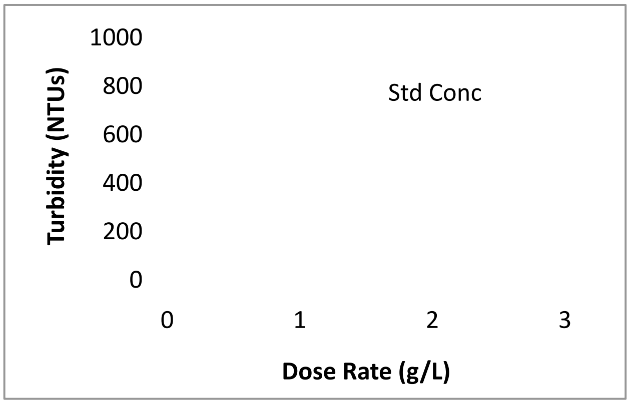




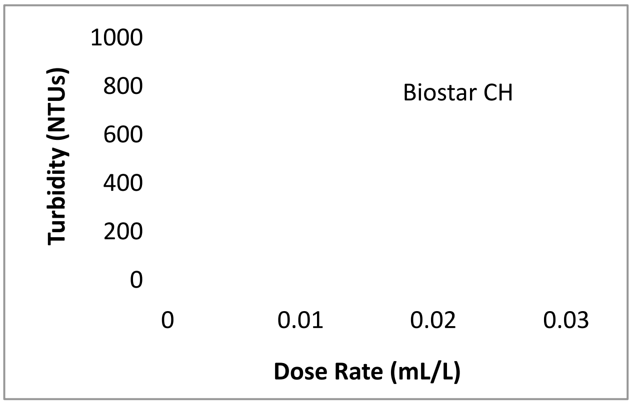


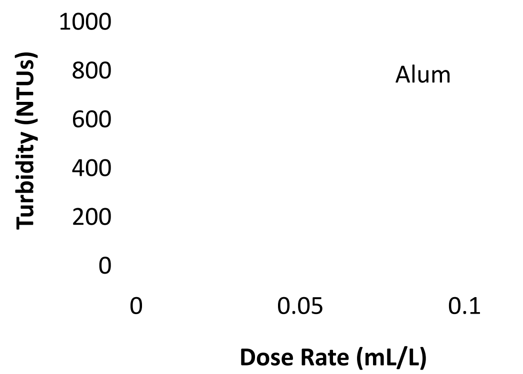


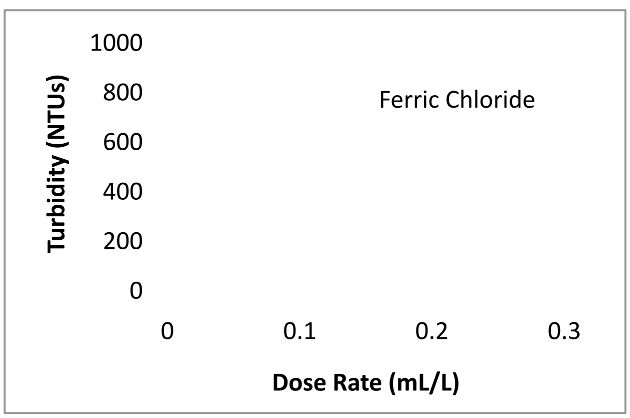


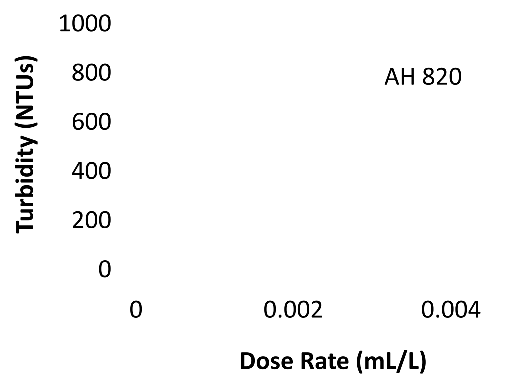


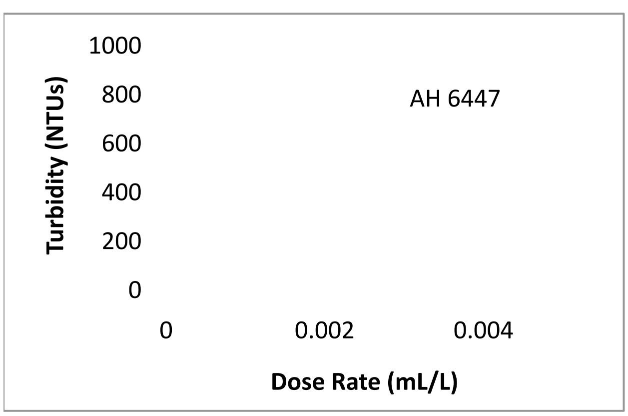
Material	North Mankato Subsoil
Classification	Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

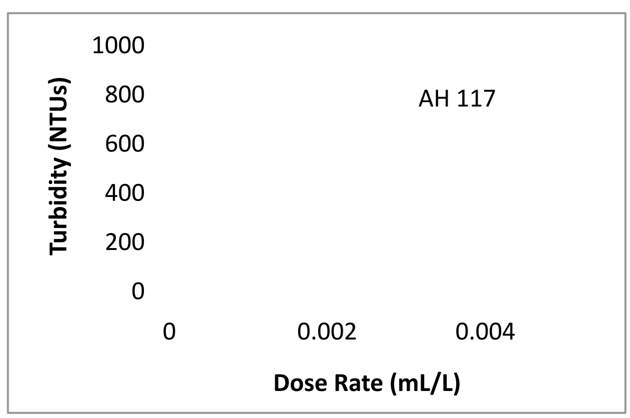


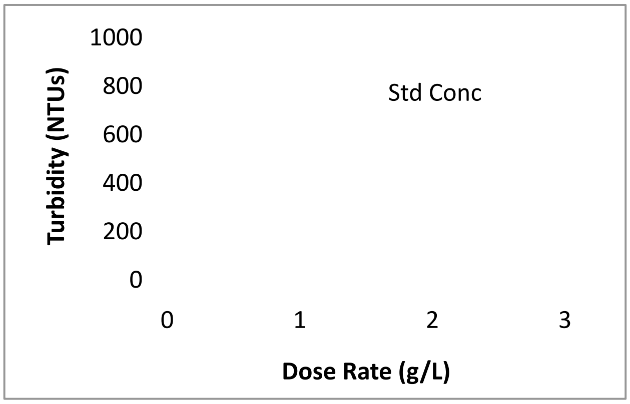




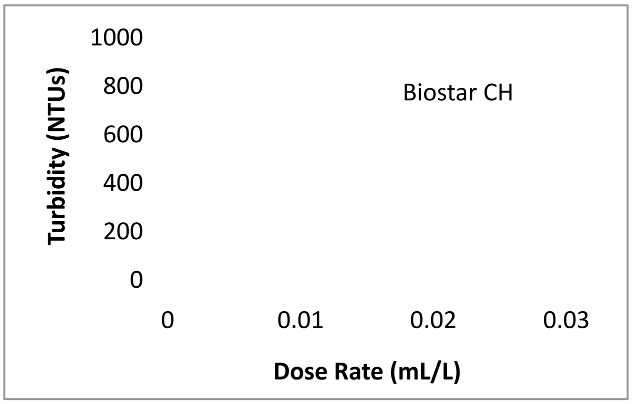


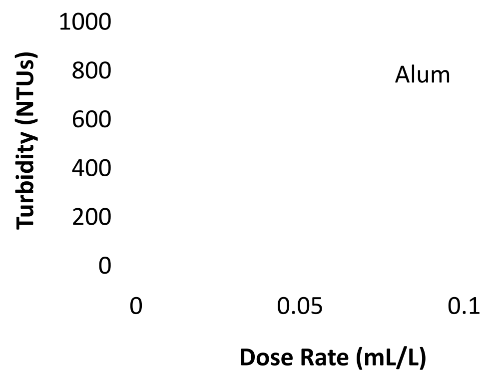


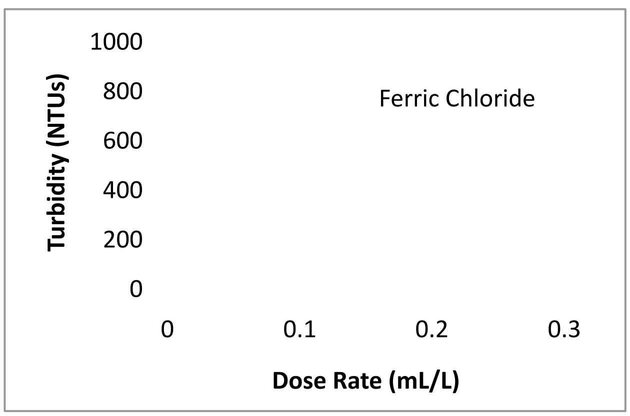


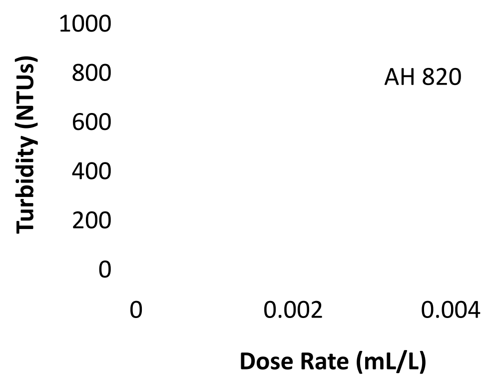


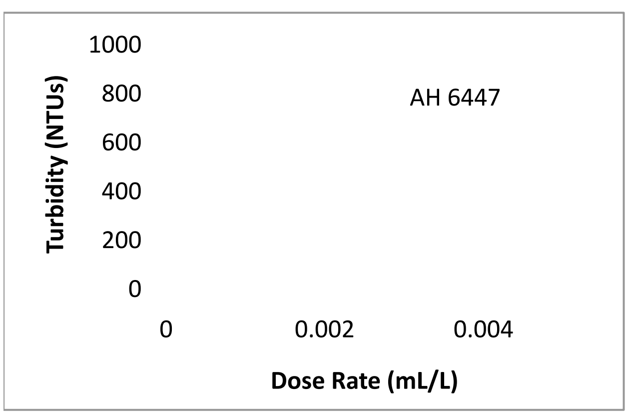
Material	North Mankato Topsoil
Classification	Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

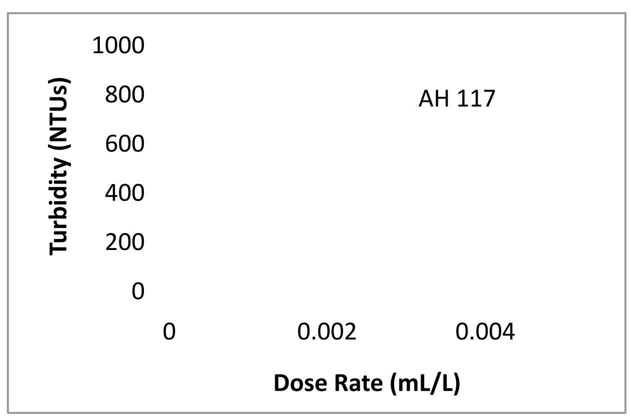


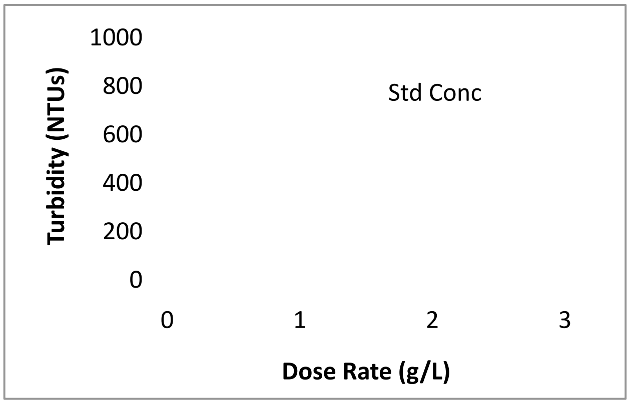




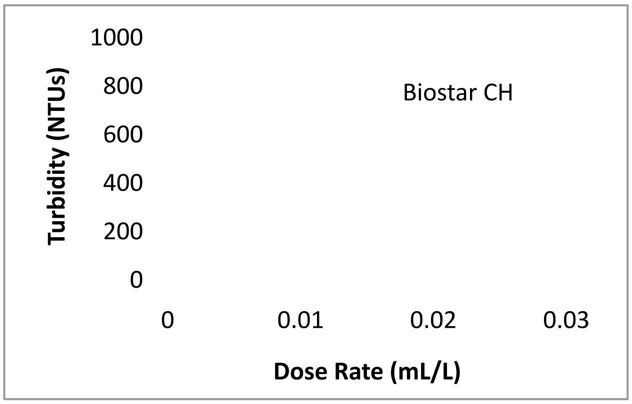


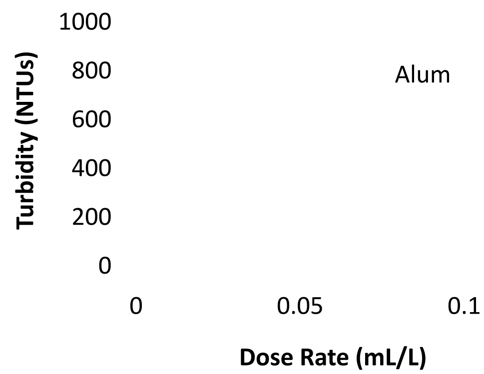


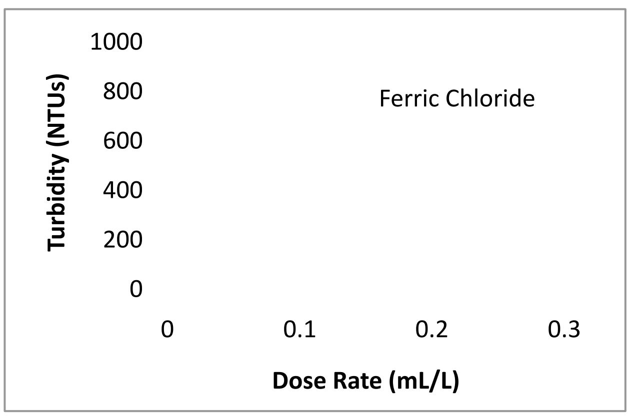


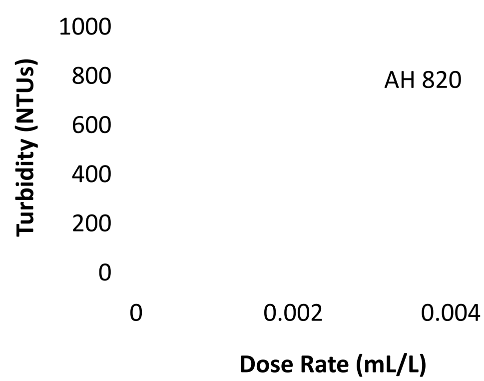


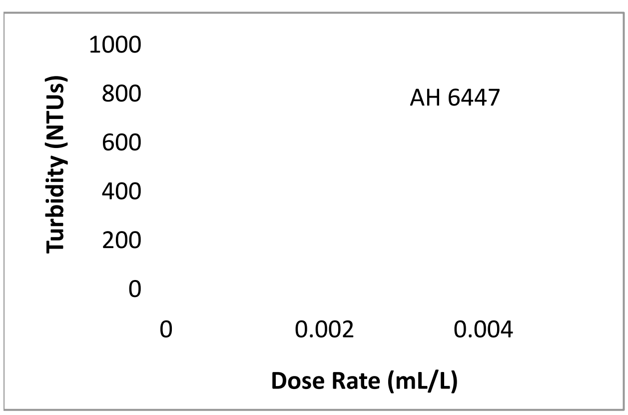
Material	Olivia A Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

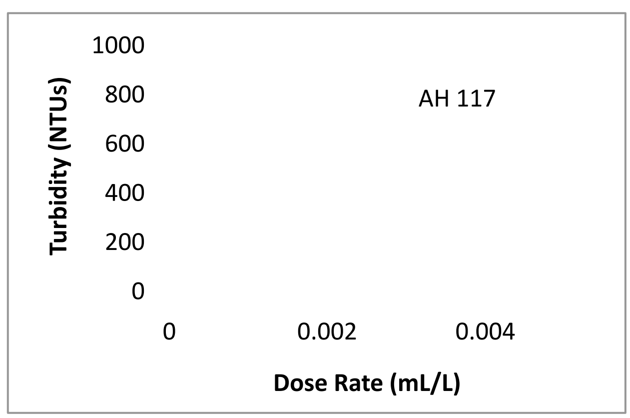


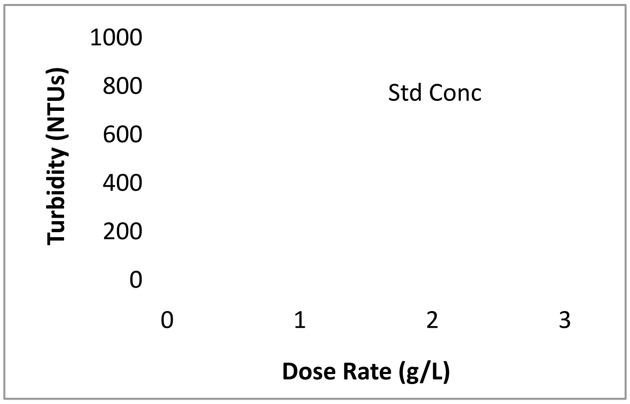




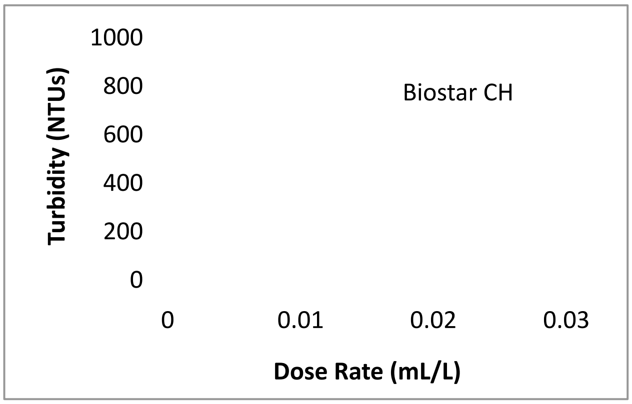


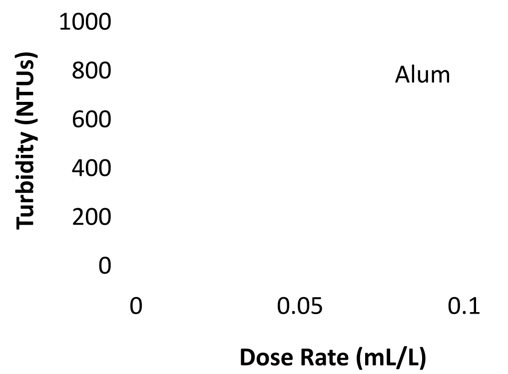


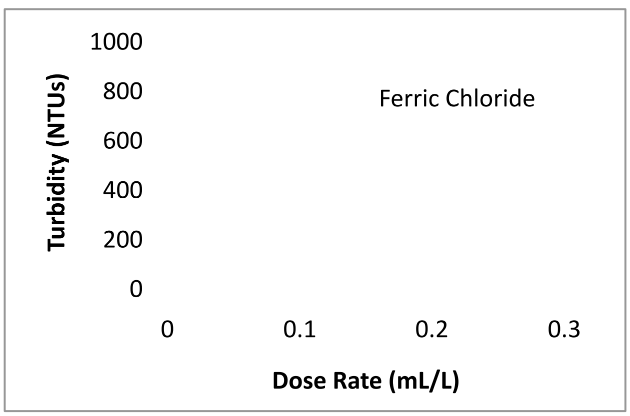


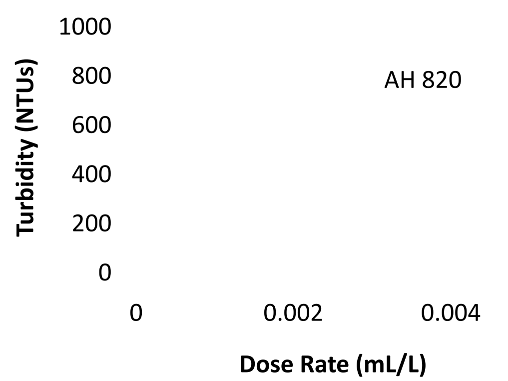


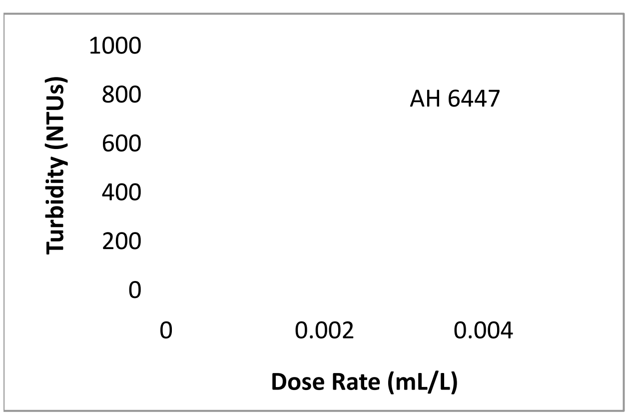
Material	Olivia A Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

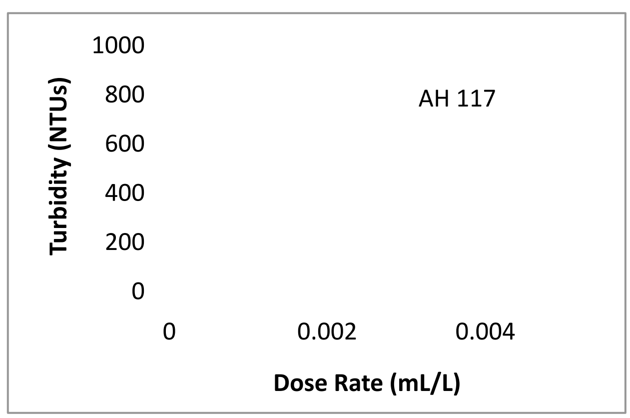


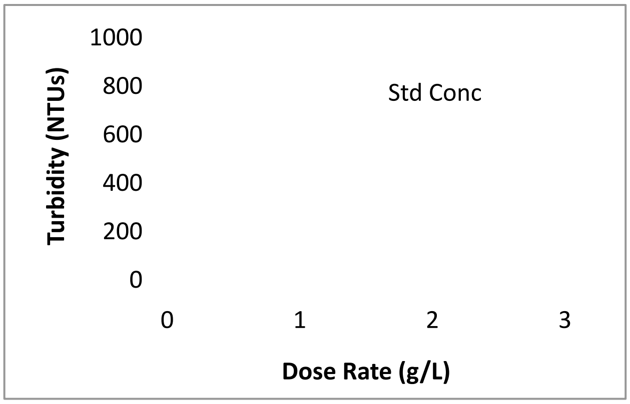




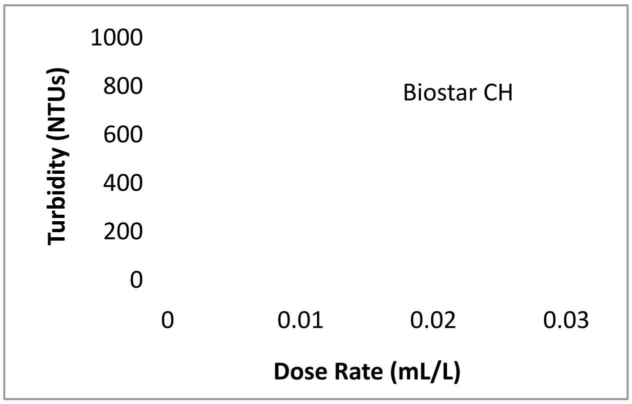


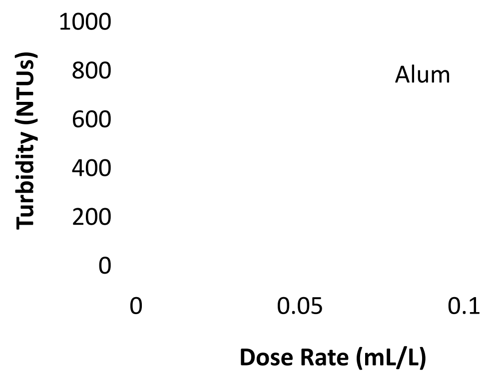


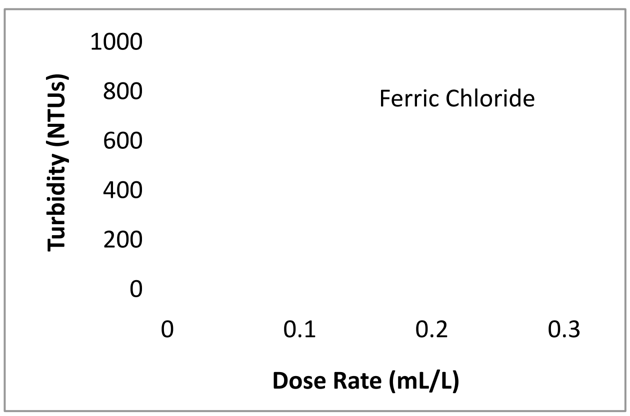


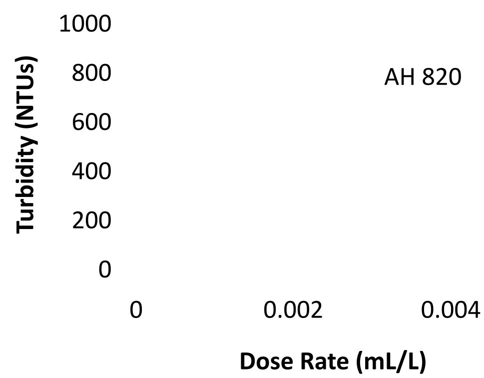


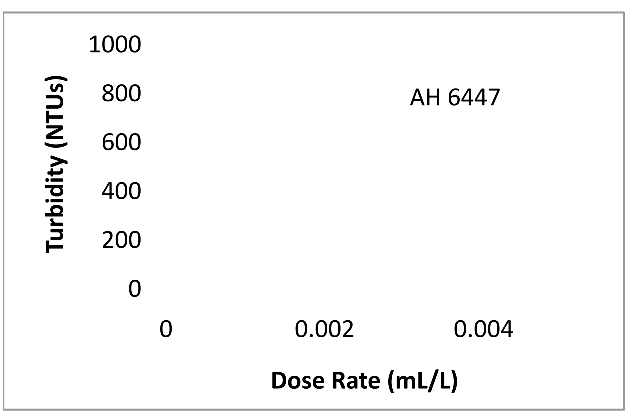
Material	Olivia B Clay
Classification	Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

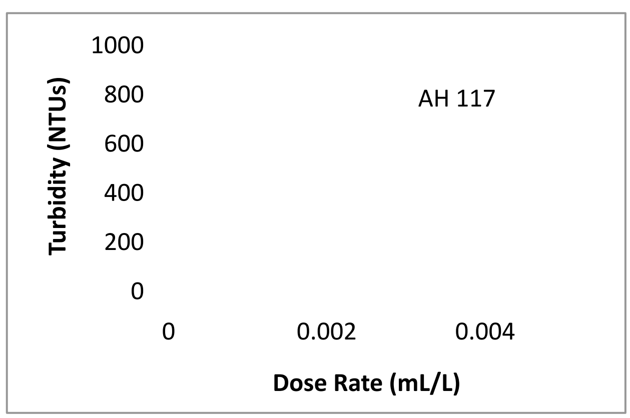


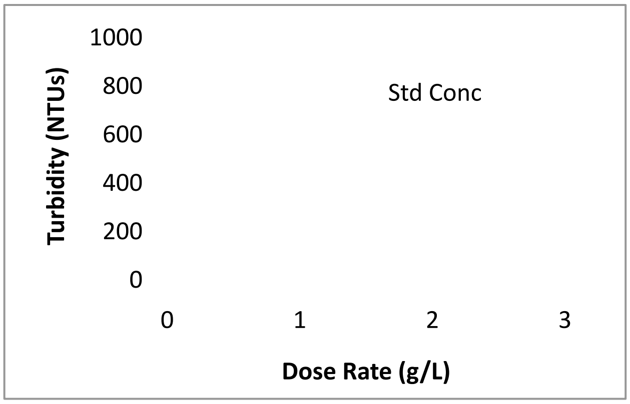




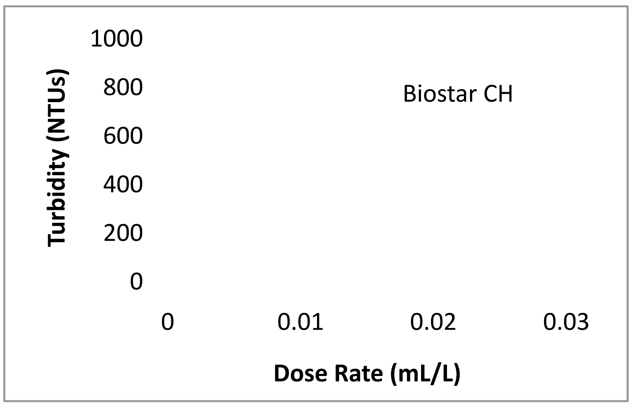


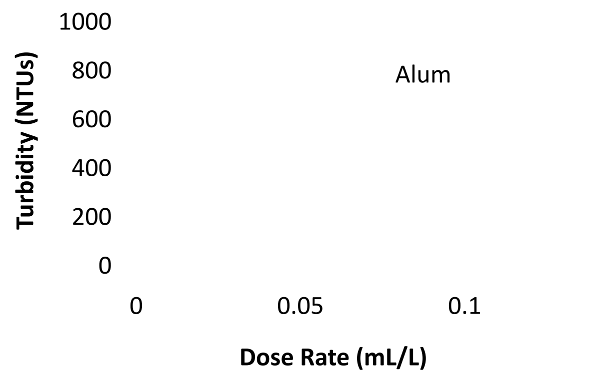


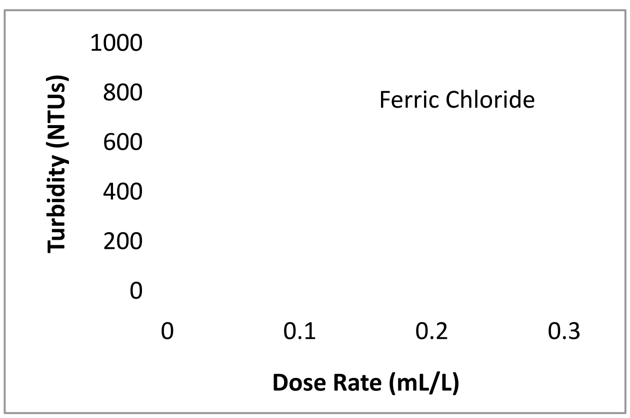


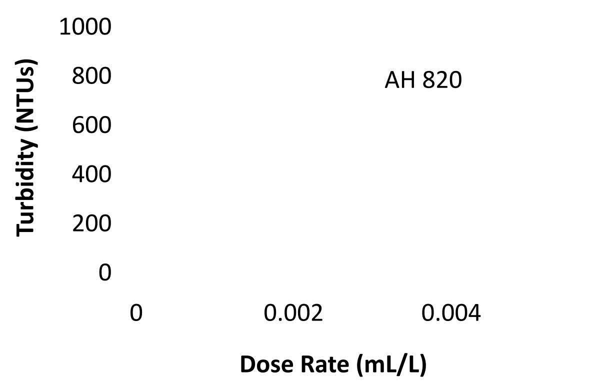


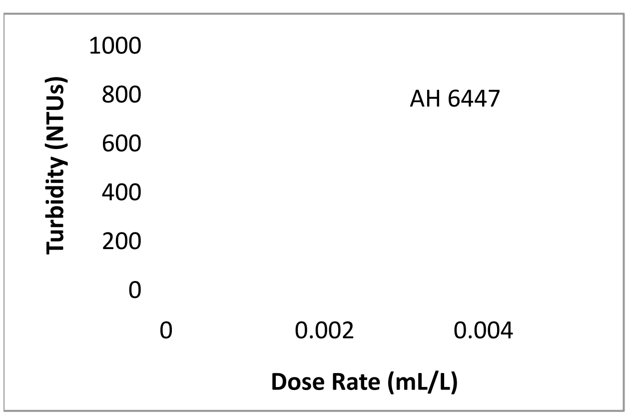
Material	Owatonna Clay
Classification	Slightly Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

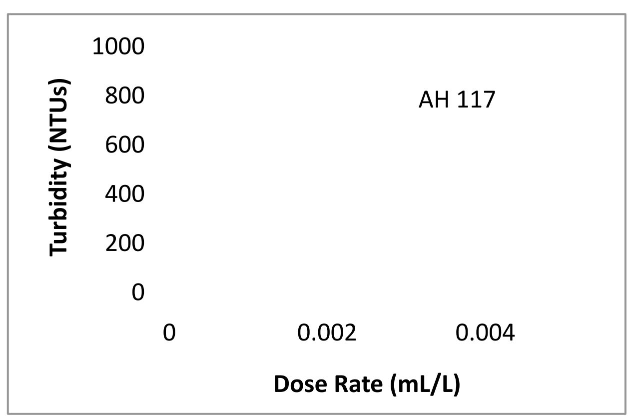


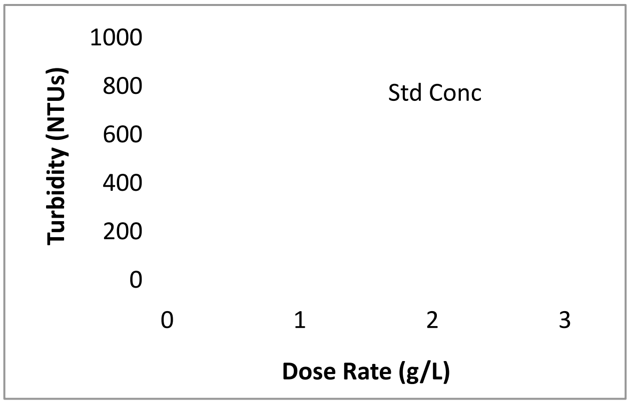




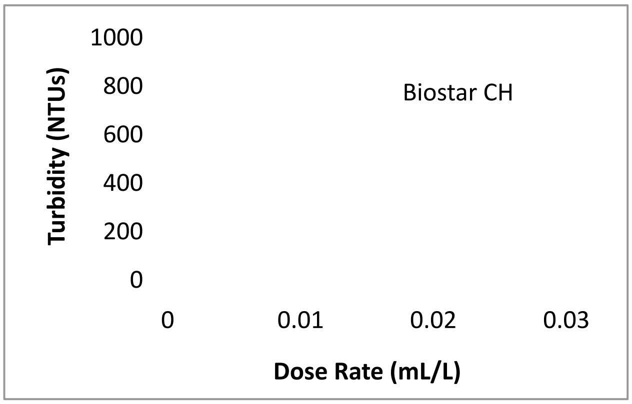


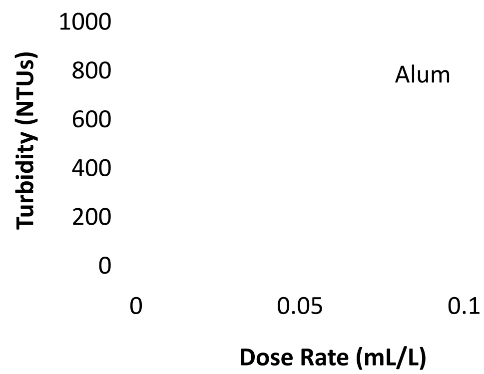


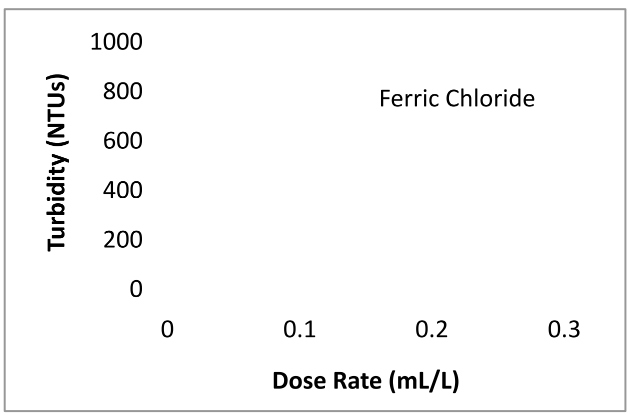


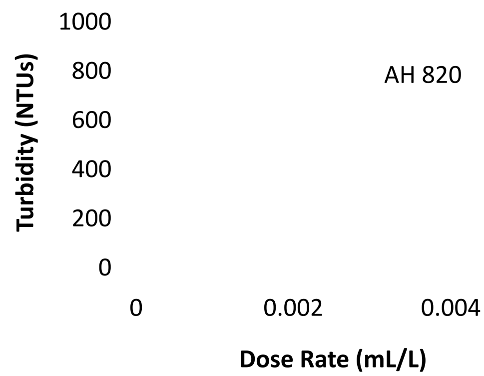


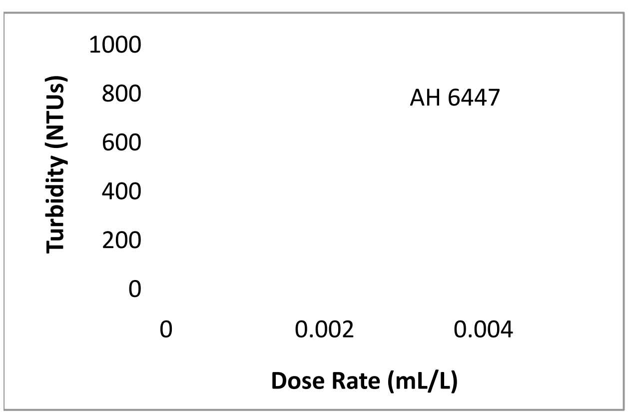
Material	Owatonna Topsoil
Classification	Slightly Organic Sandy Clay Loam
USCS Symbol(s)	SC-SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

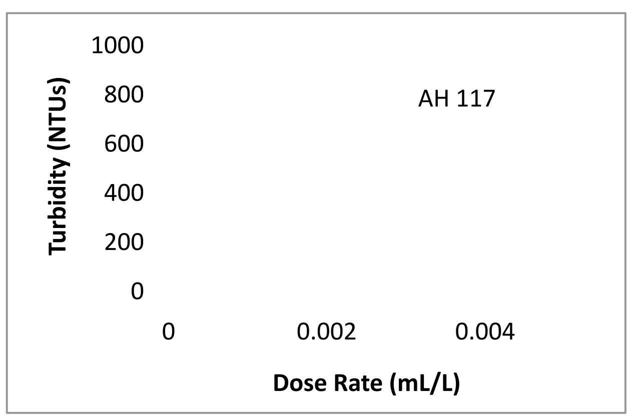


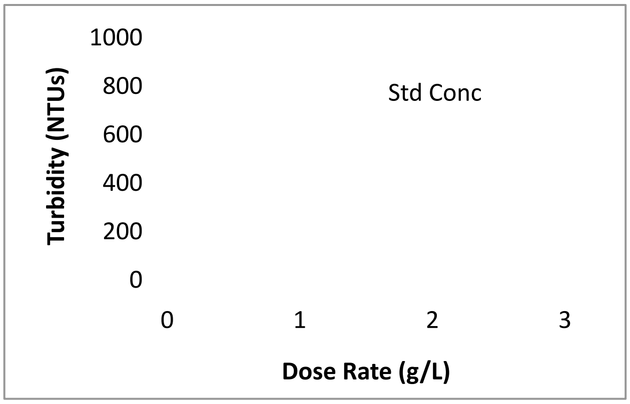




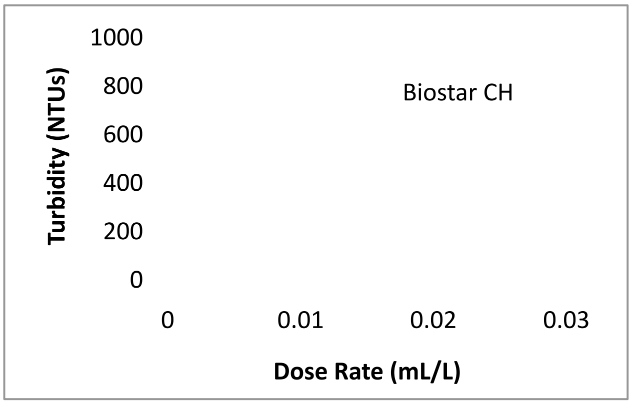


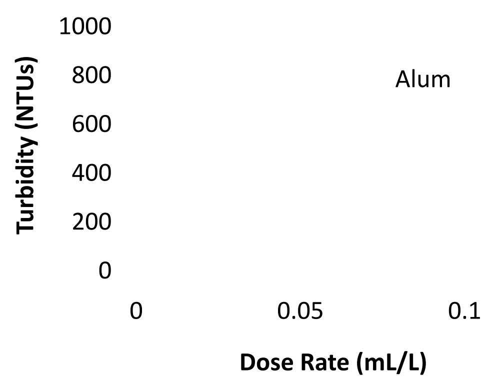


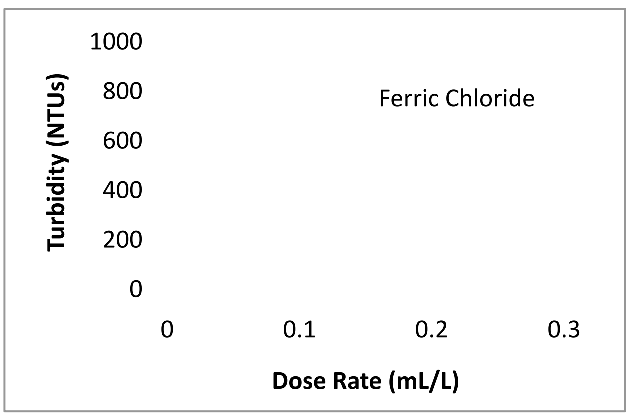


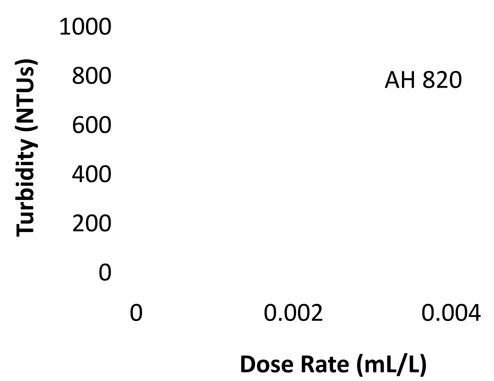


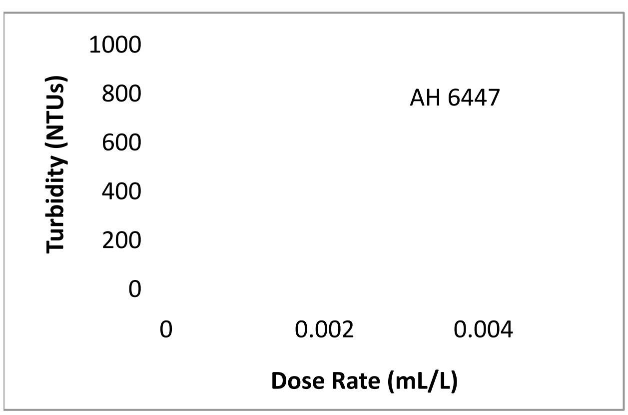
Material	Perham Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

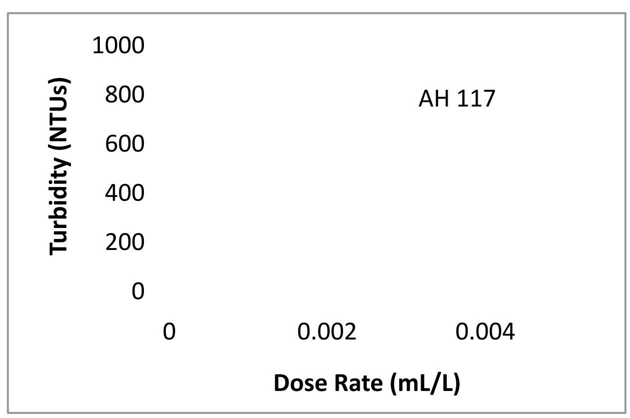


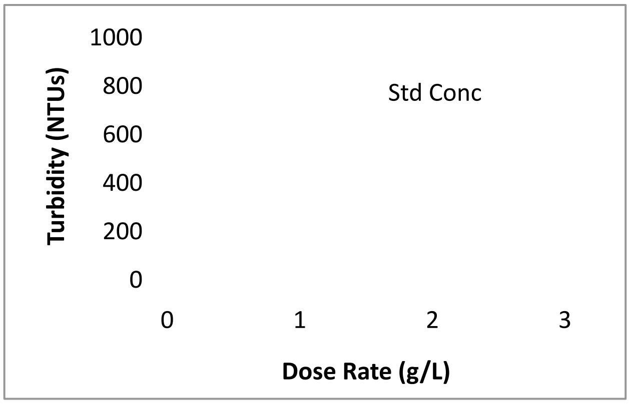




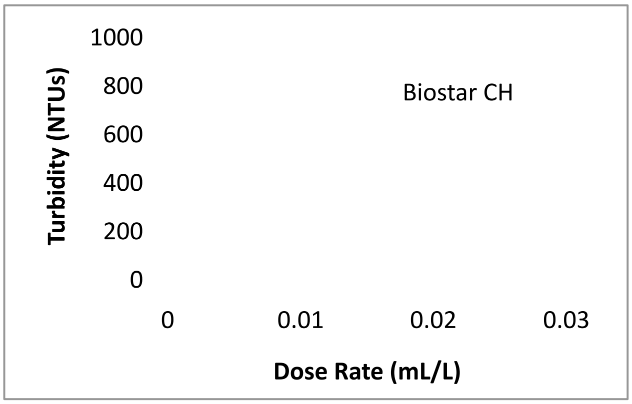


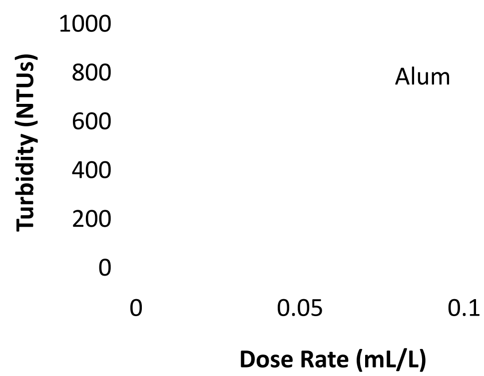


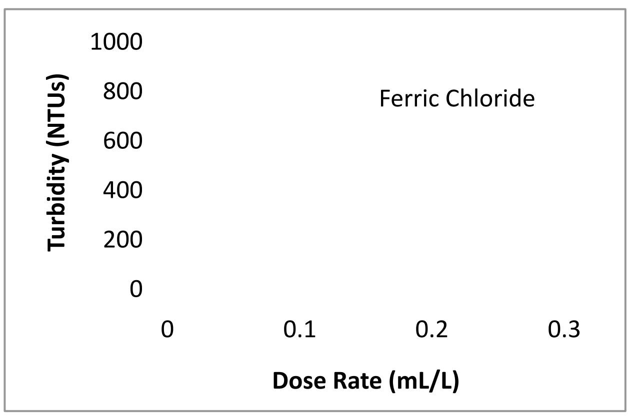


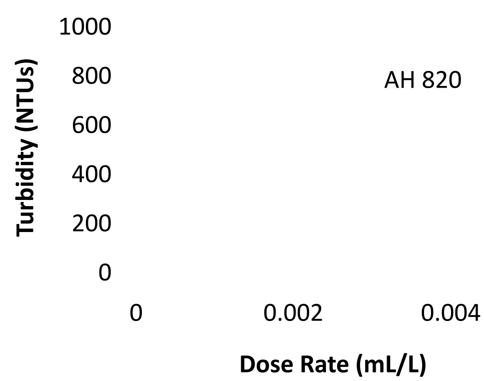


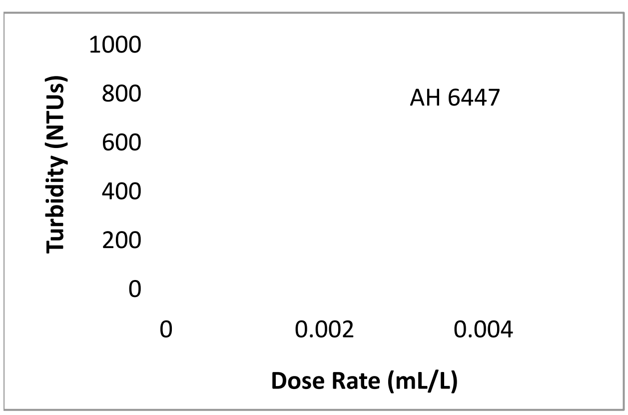
Material	Perham Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Outwash
Geomorphology	Des Moines Lobe

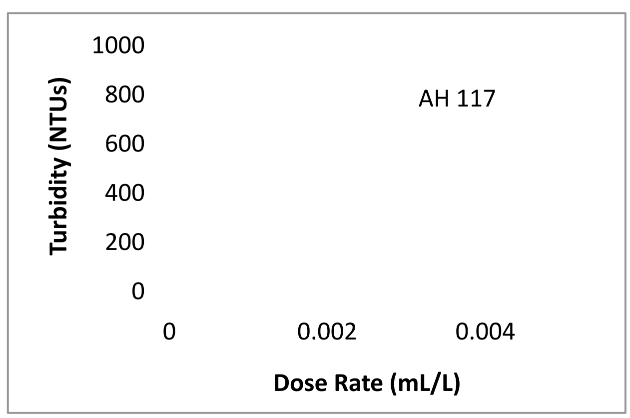


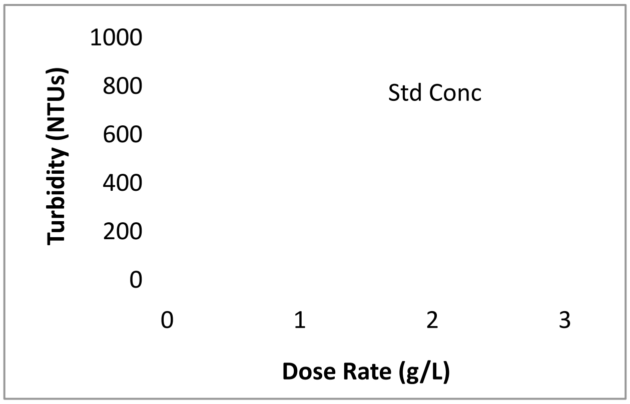




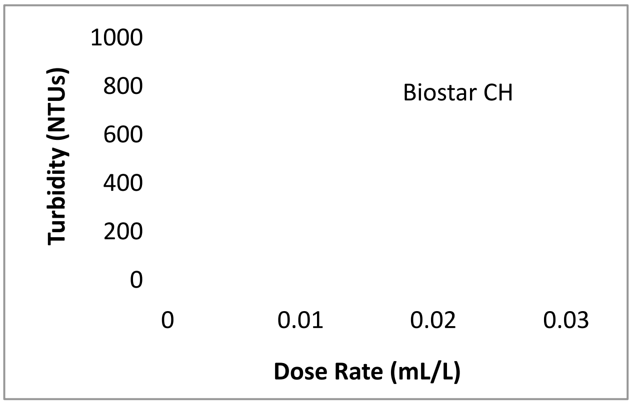


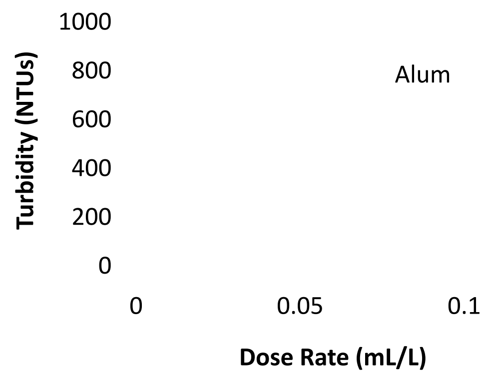


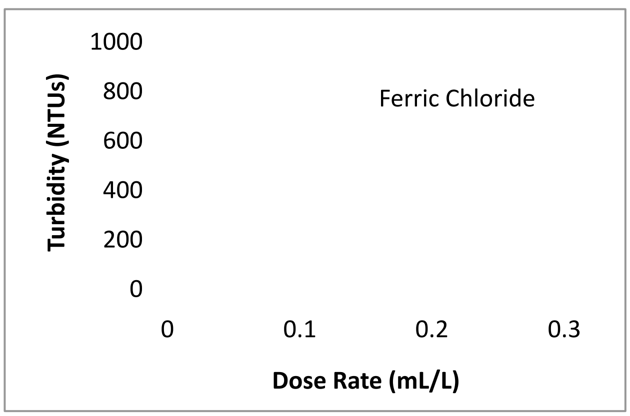


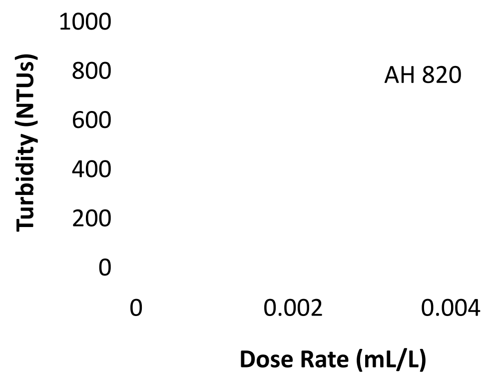


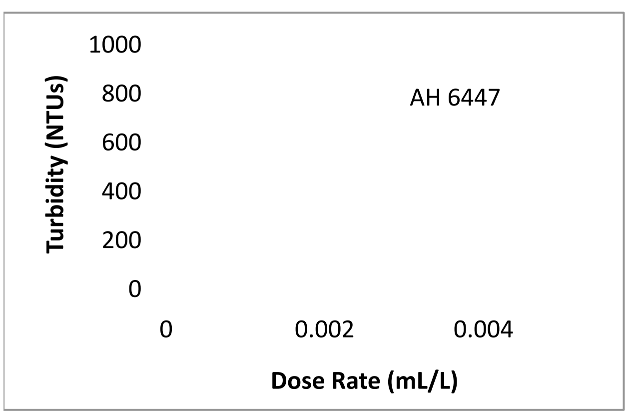
Material	Pipestone Subsoil
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Gray Drift
Geomorphology	Kansan Glaciation

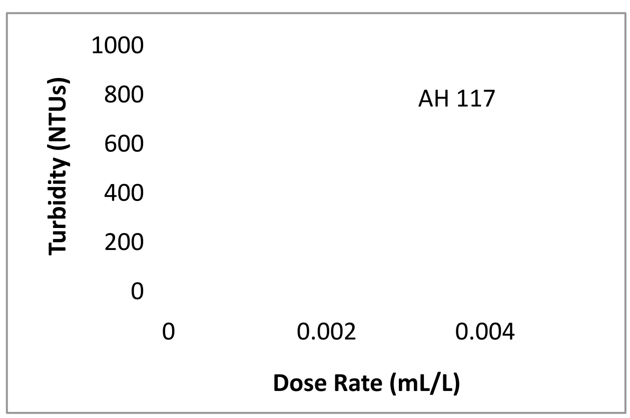


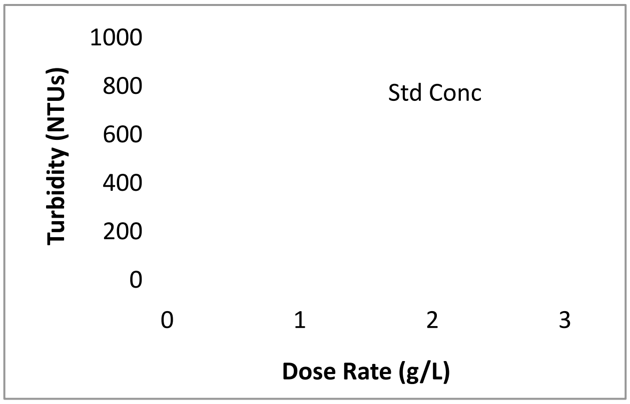




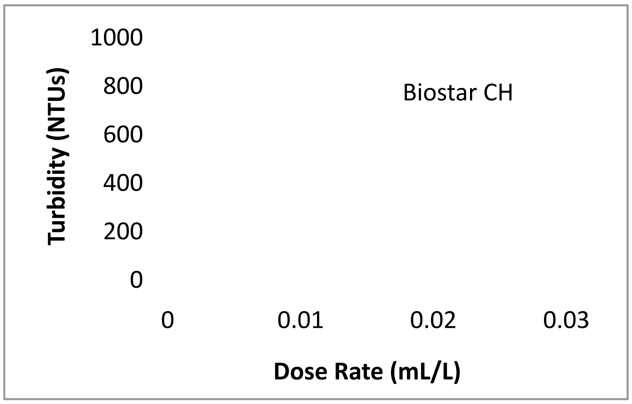


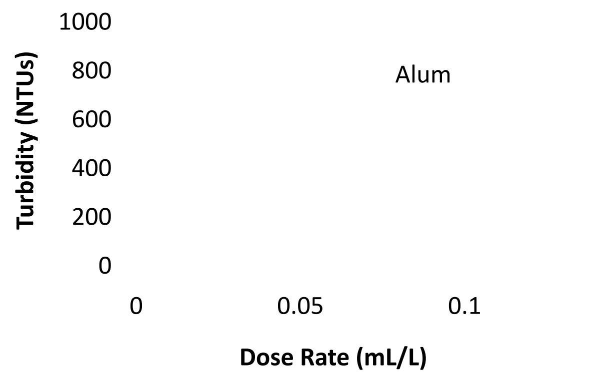


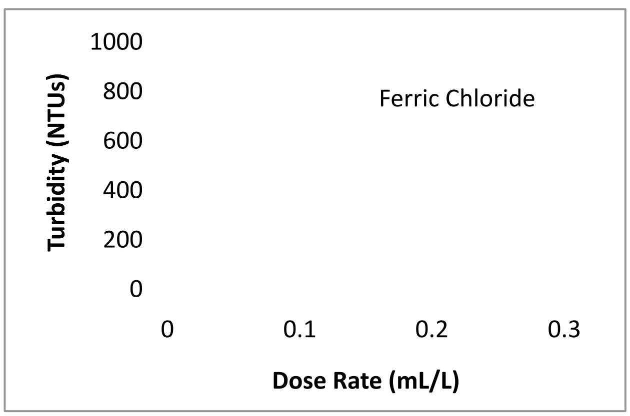


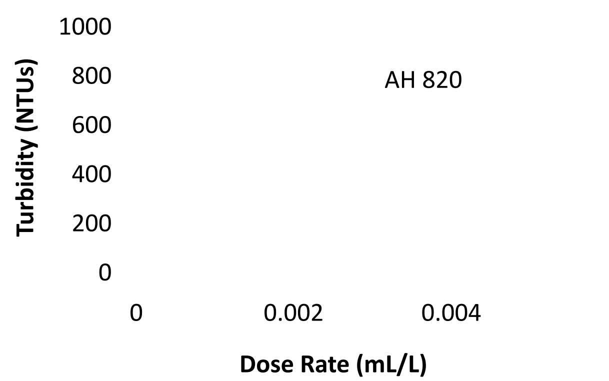


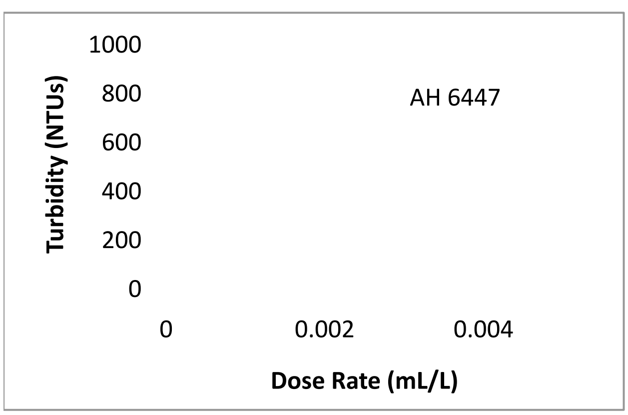
Material	Pipestone Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Gray Drift
Geomorphology	Kansan Glaciation

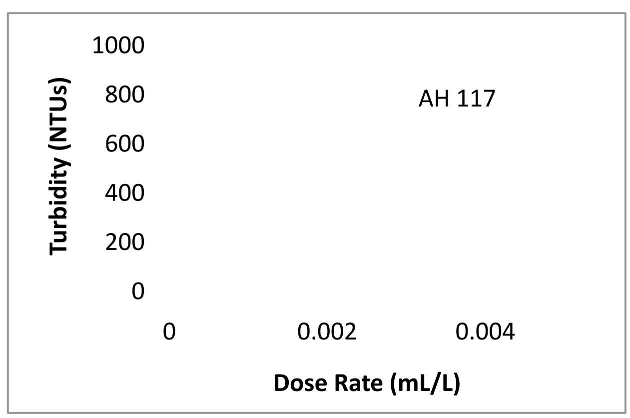


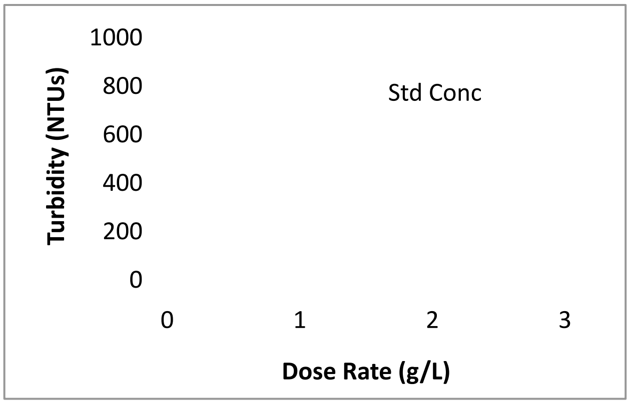




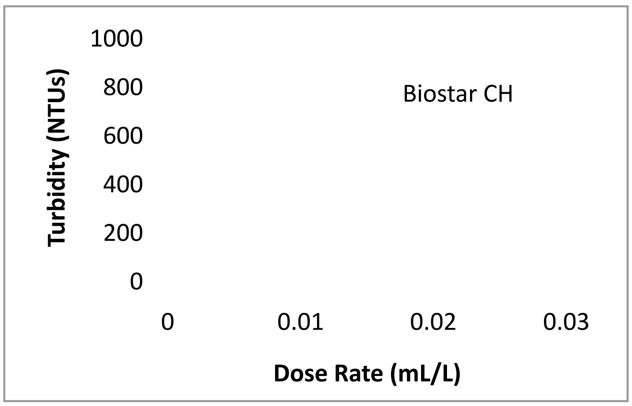


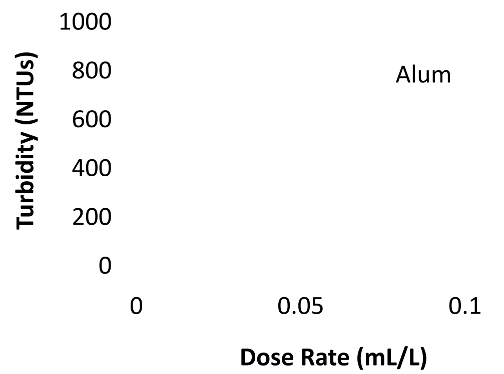


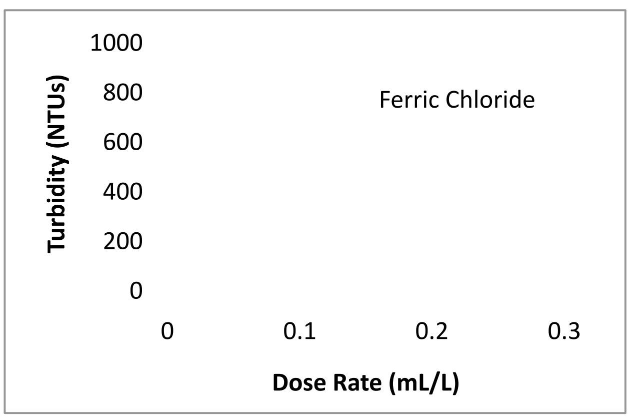


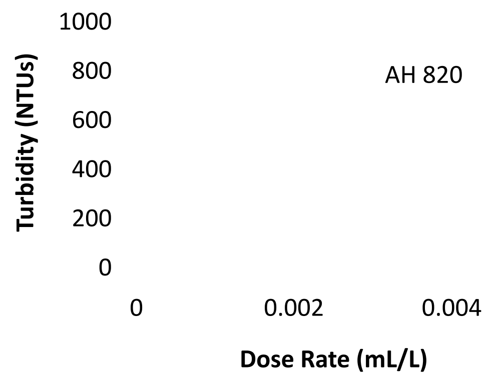


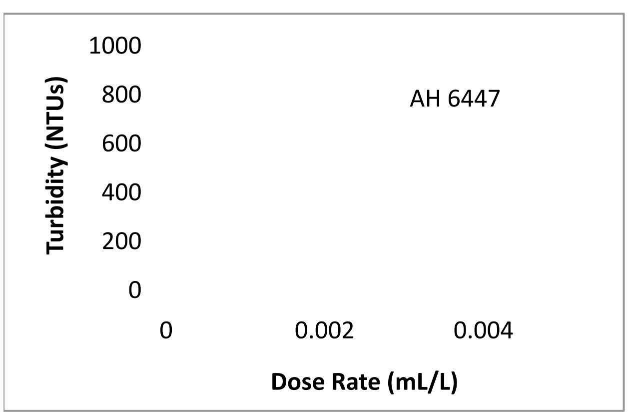
Material	Ramsey Peat
Classification	Highly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	End Moraine
Geomorphology	Des Moines Lobe

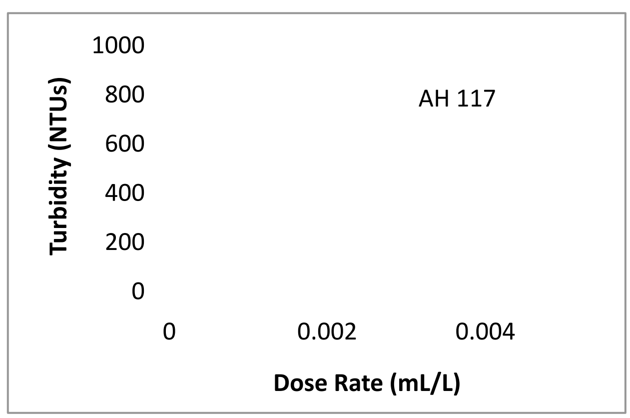


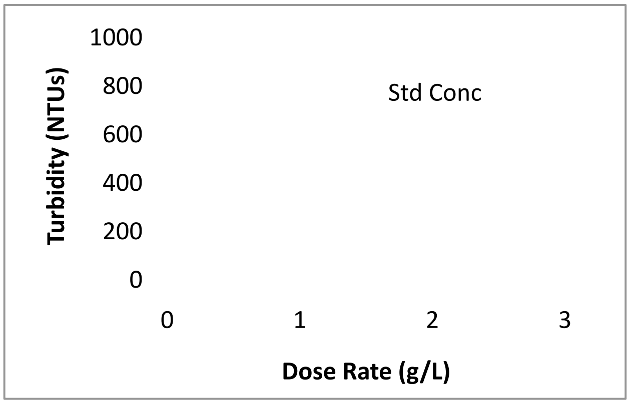




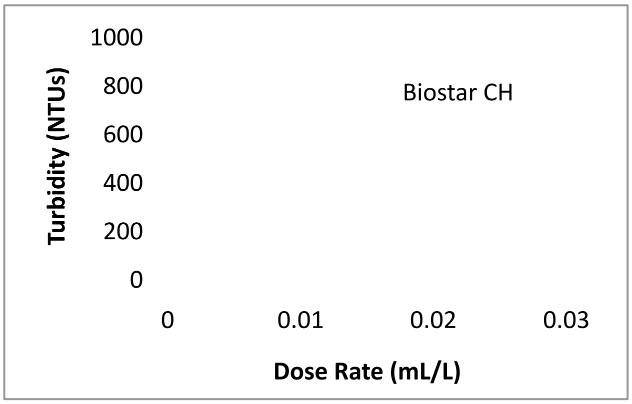


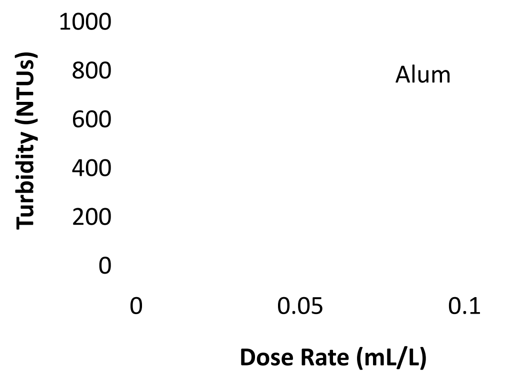


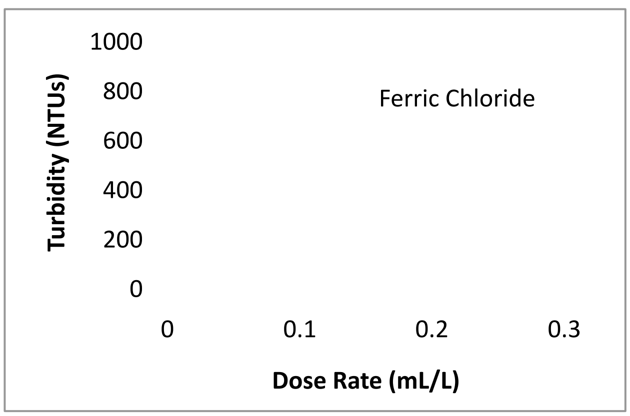


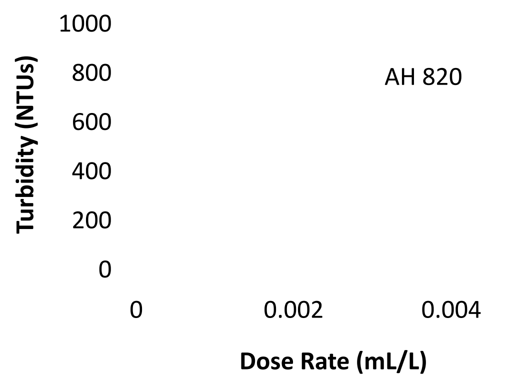


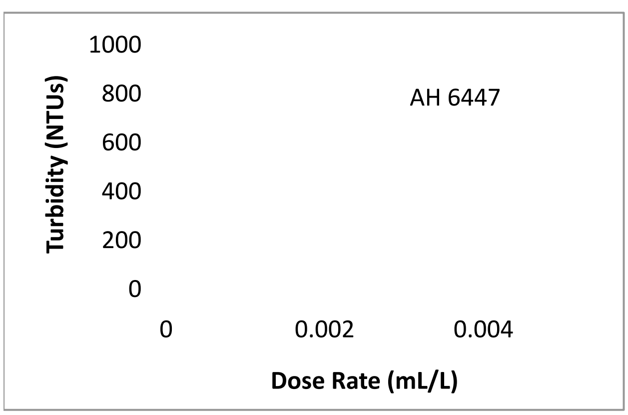
Material	Rockford Cornfield
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	End Moraine
Geomorphology	Des Moines Lobe

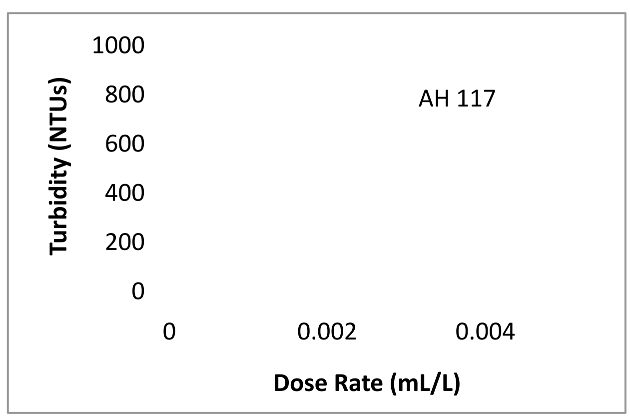


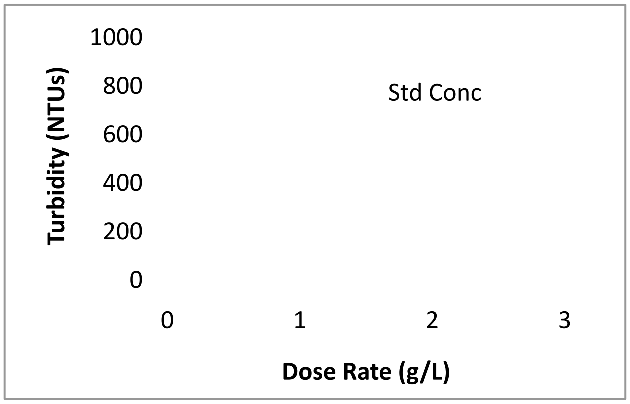




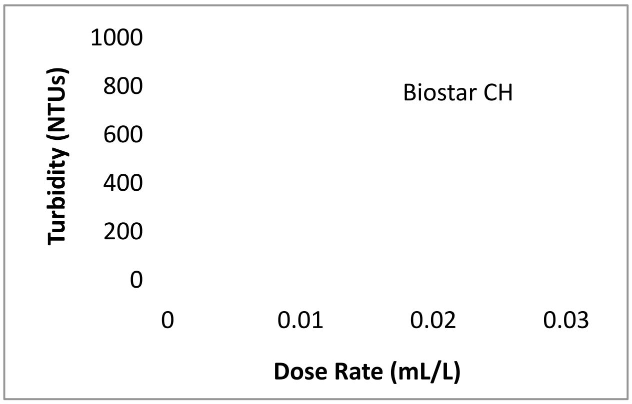


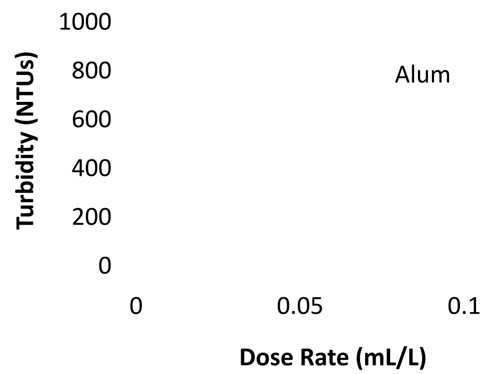


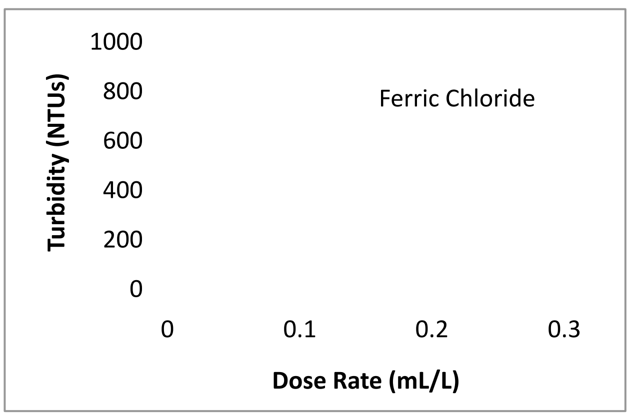


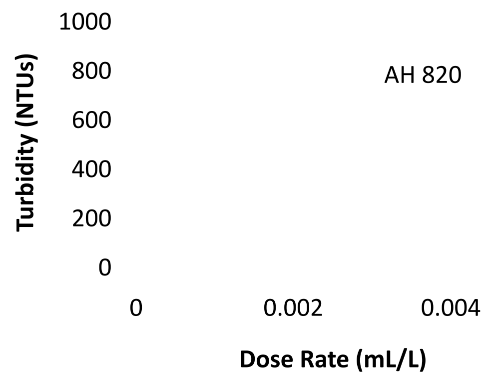


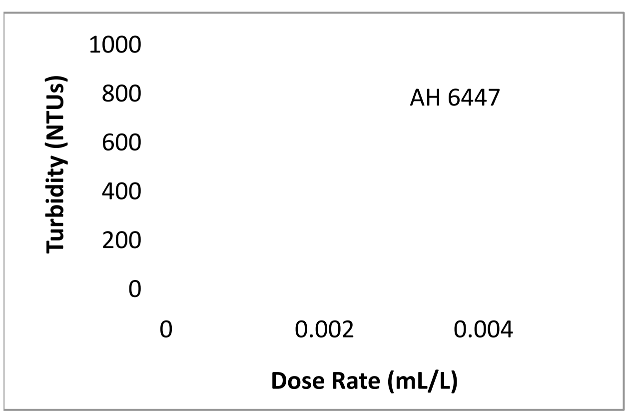
Material	Rockford Subsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	End Moraine
Geomorphology	Des Moines Lobe

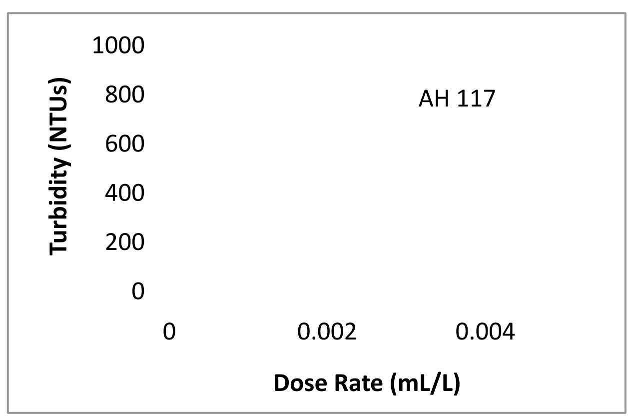


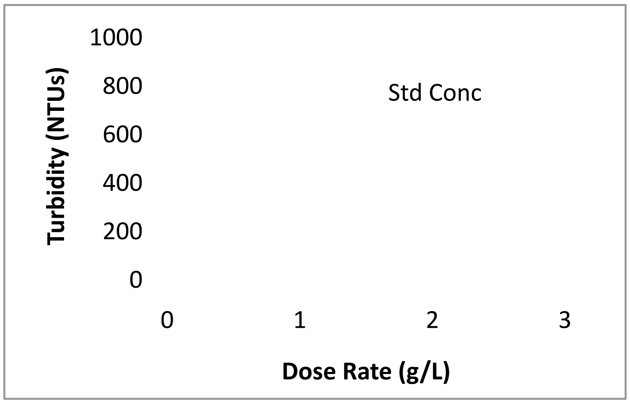




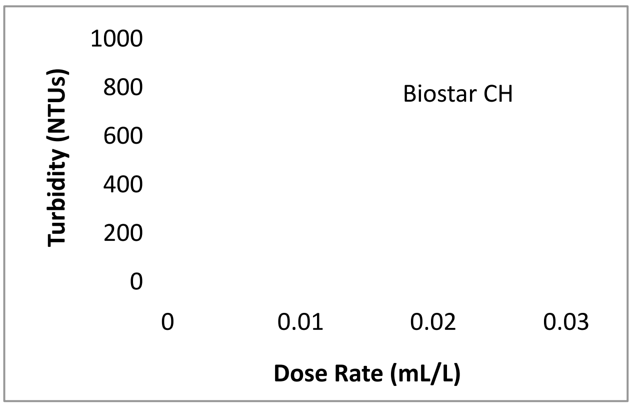


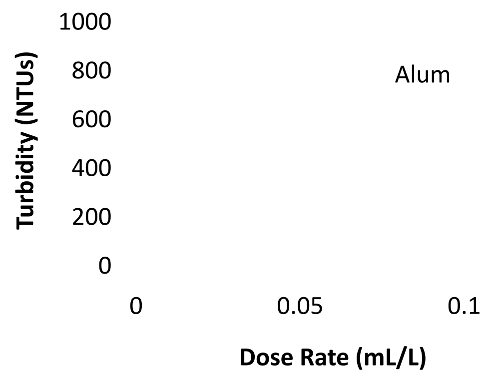


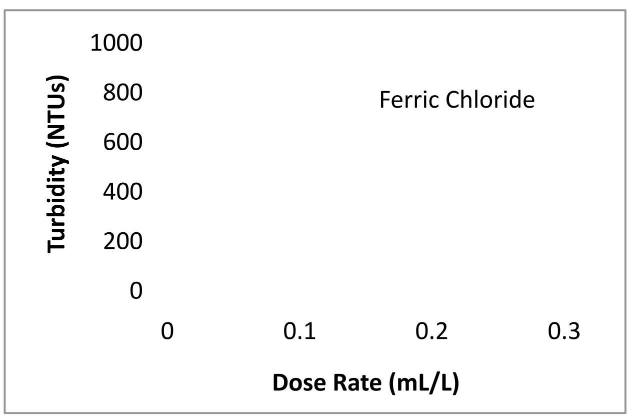


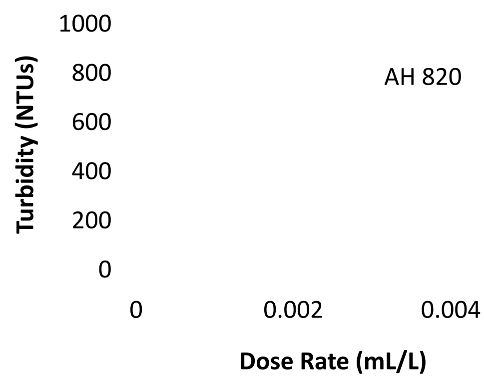


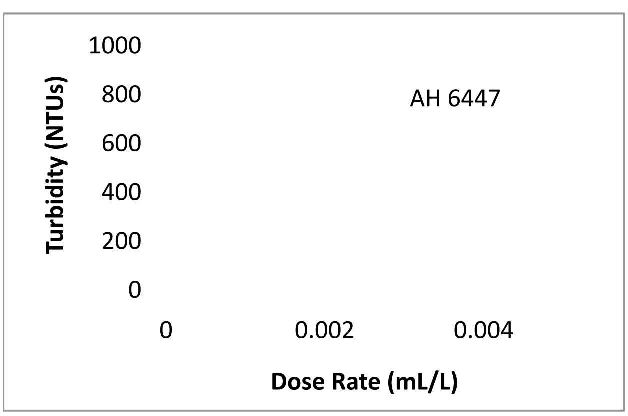
Material	Rockford Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	End Moraine
Geomorphology	Des Moines Lobe

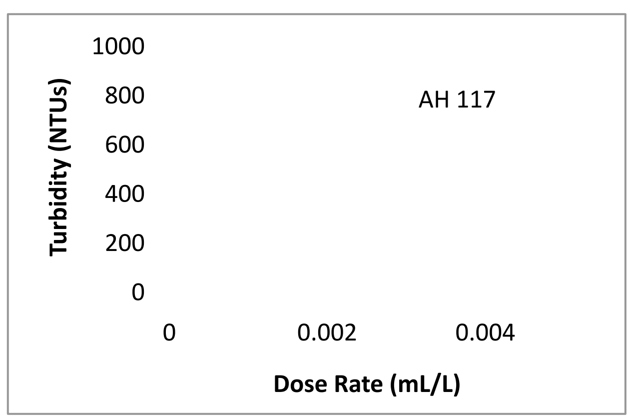


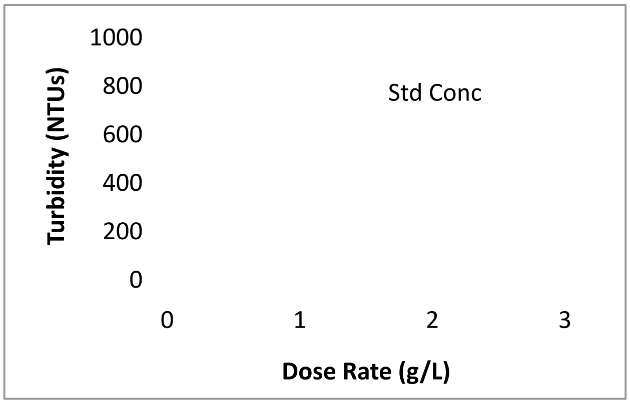




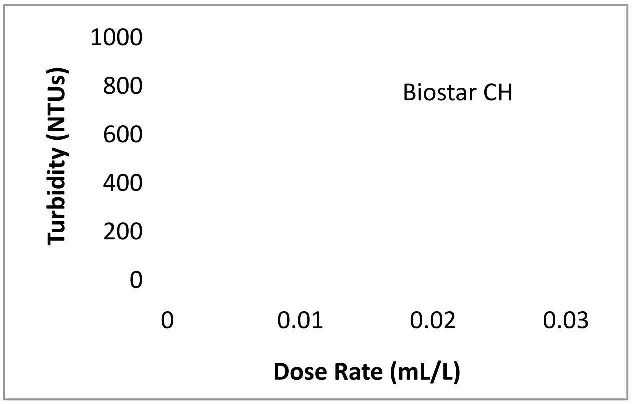


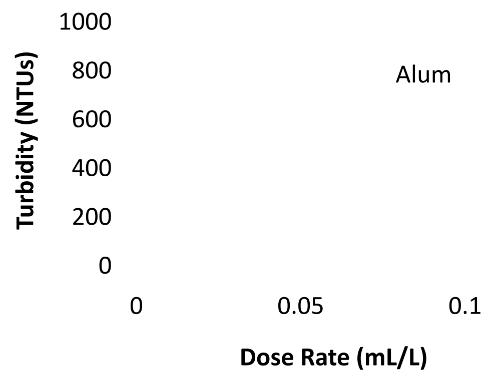


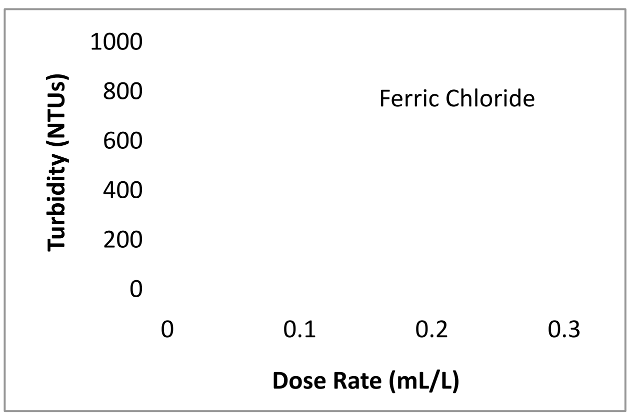


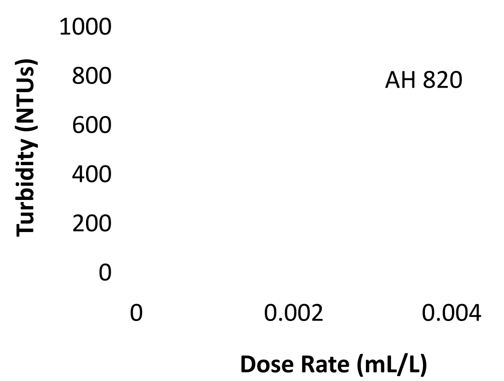


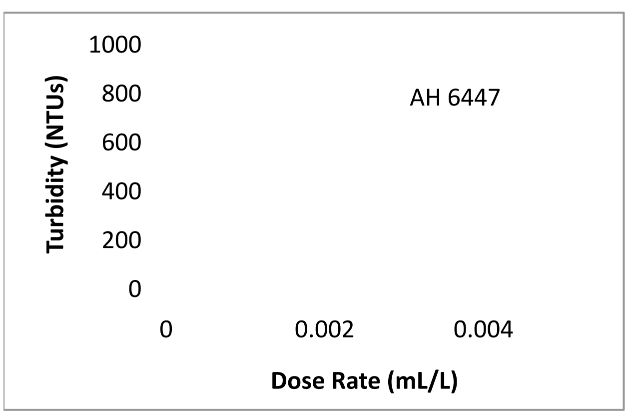
Material	Sandstone Subsoil
Classification	Slightly Organic Clay Loam
USCS Symbol(s)	CL-ML-OL
Strata	Ground Moraine
Geomorphology	Superior Lobe

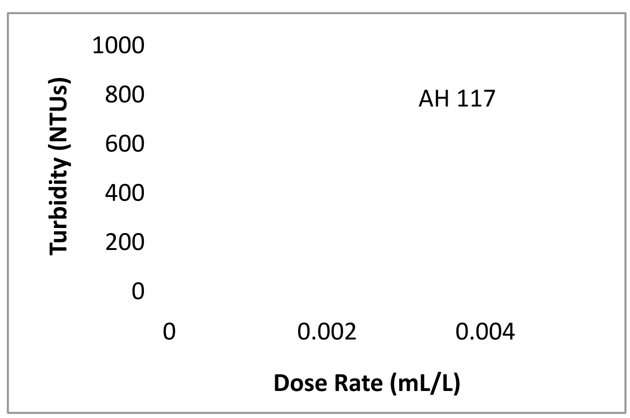


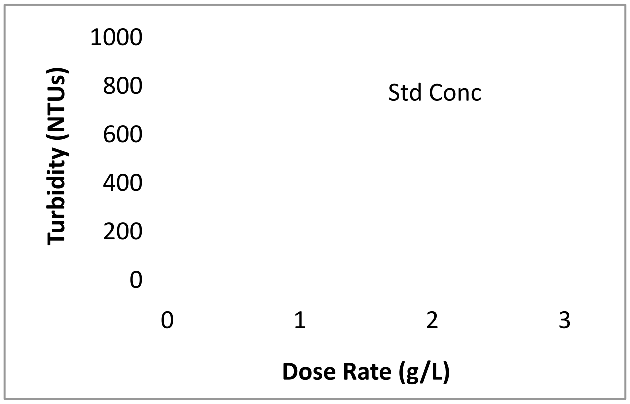




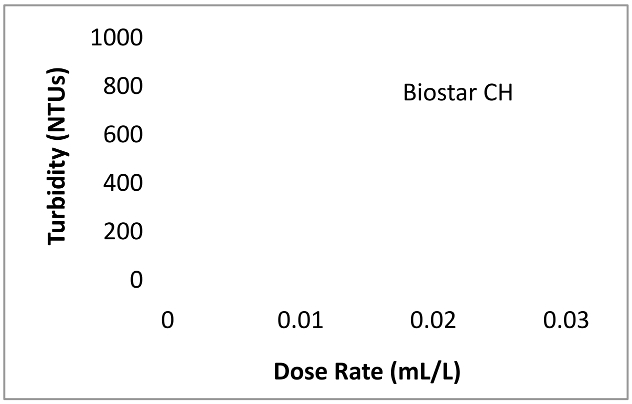


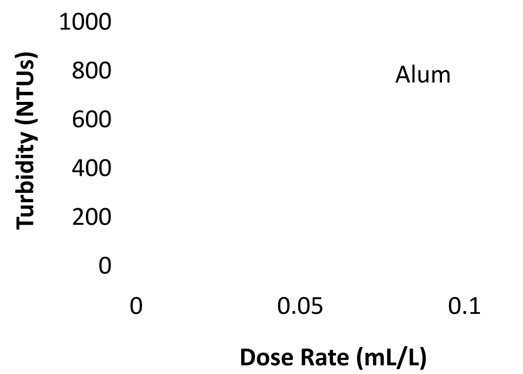


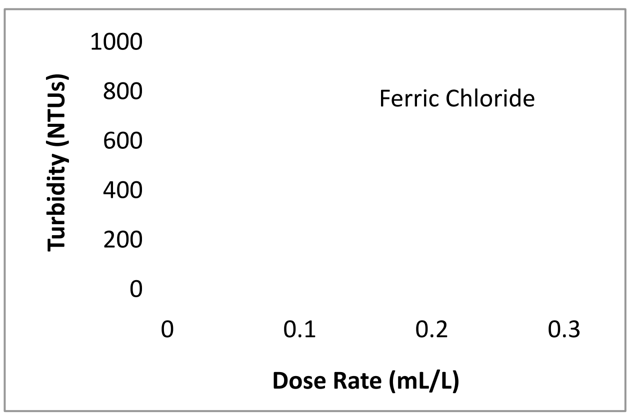


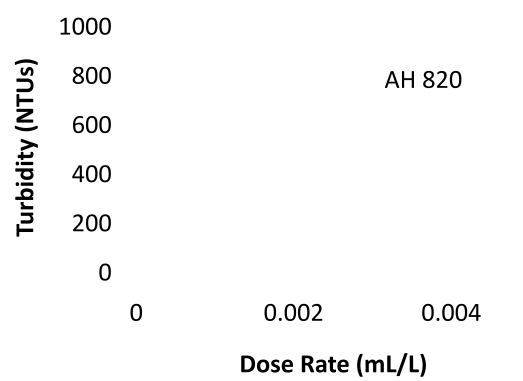


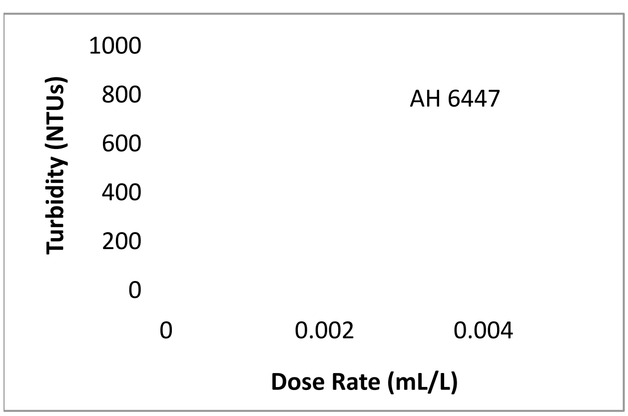
Material	Sandstone Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Superior Lobe

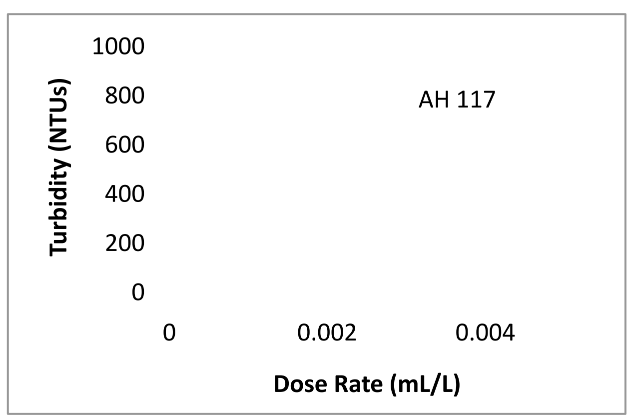


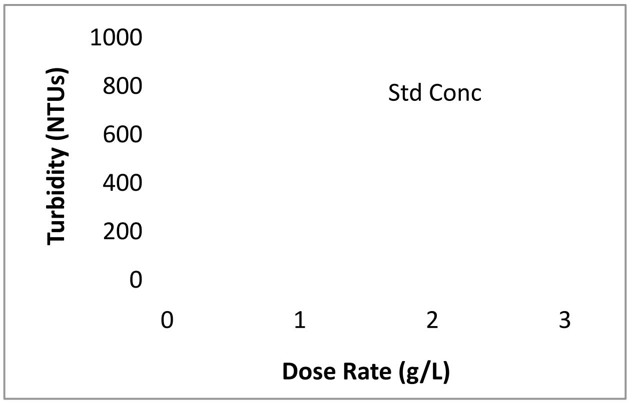




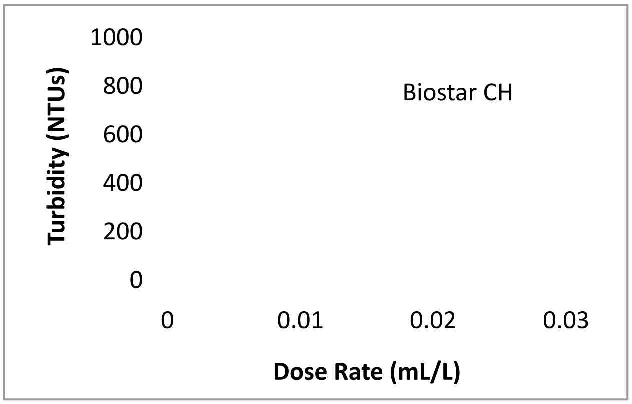


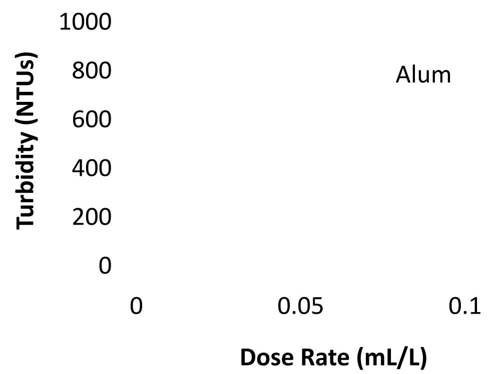


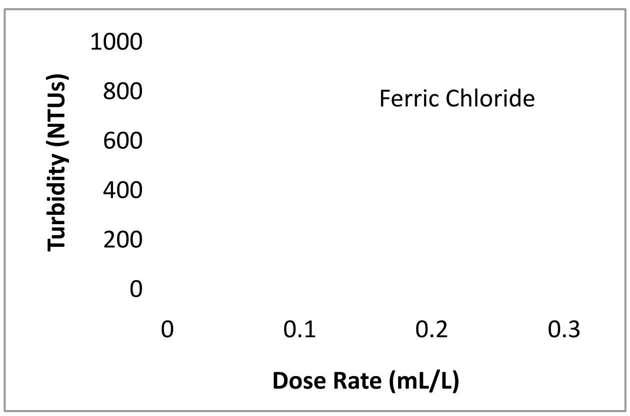


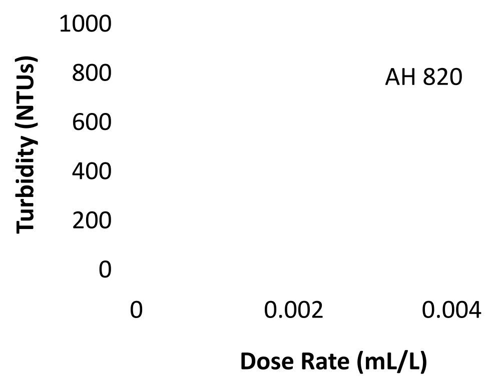


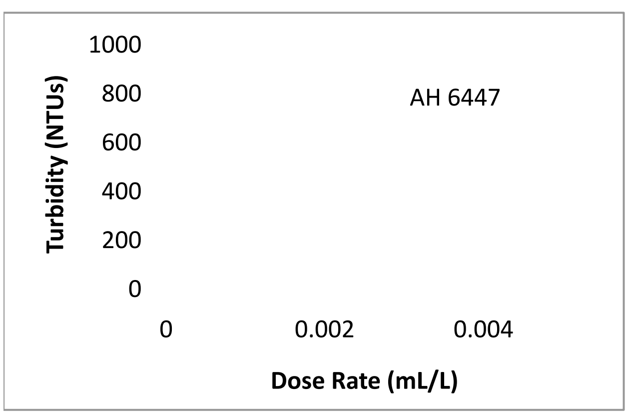
Material	Stillwater Sediment
Classification	Organic Loam
USCS Symbol(s)	OL
Strata	End Moraine
Geomorphology	Superior Lobe

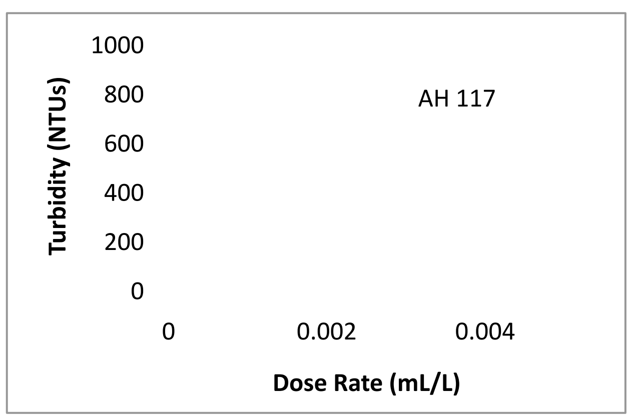


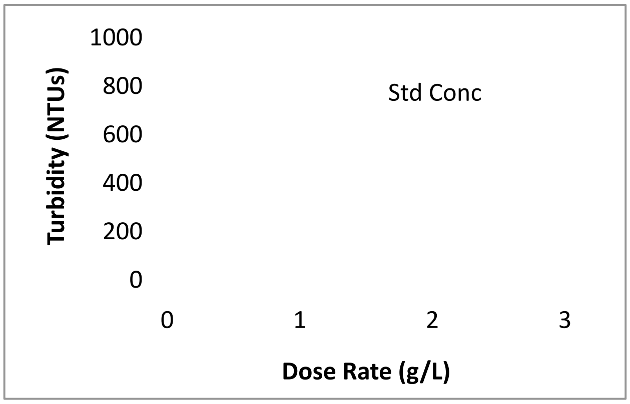




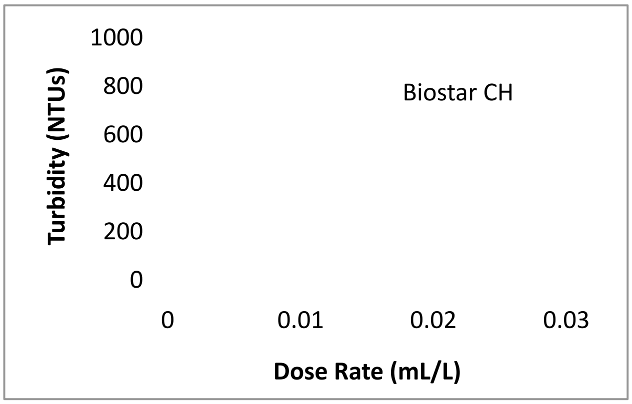


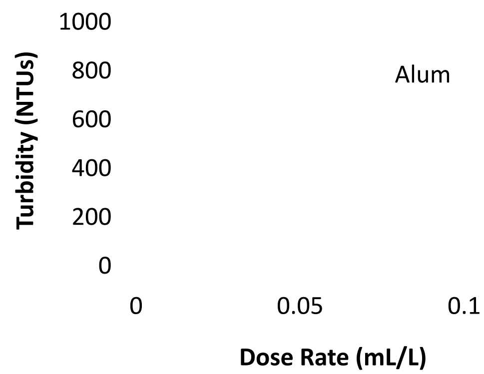


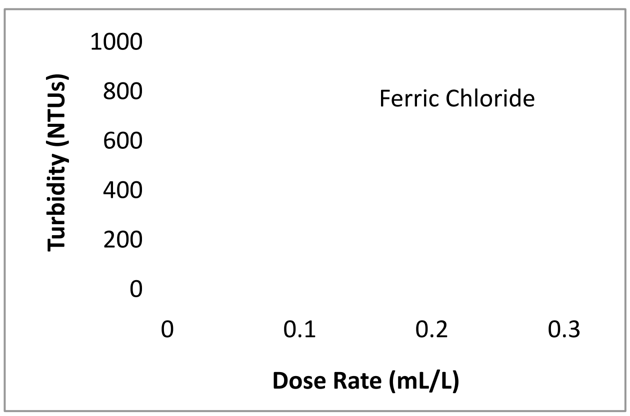


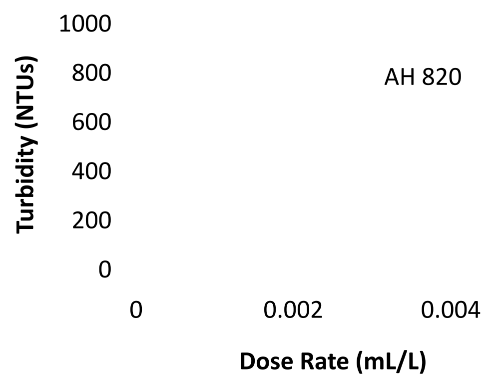


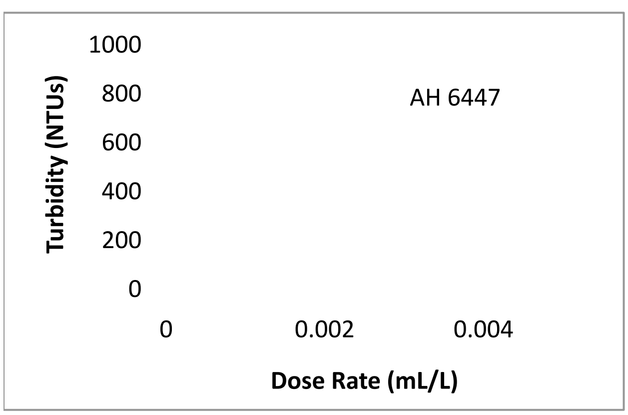
Material	Tamarack Clay
Classification	Slightly Organic Clay
USCS Symbol(s)	CL-OL
Strata	End Moraine
Geomorphology	Des Moines Lobe

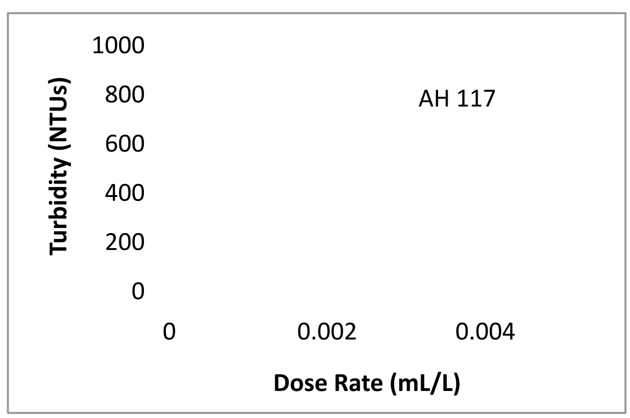


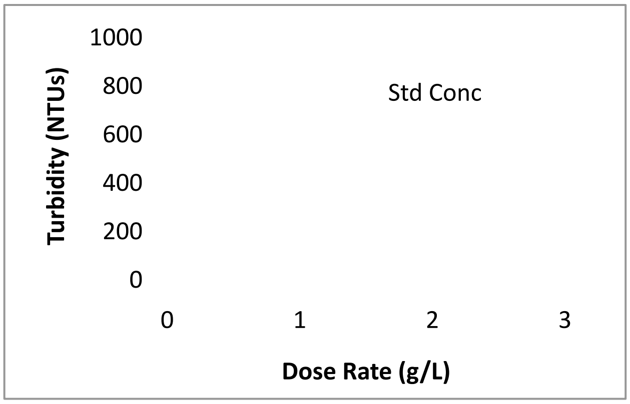




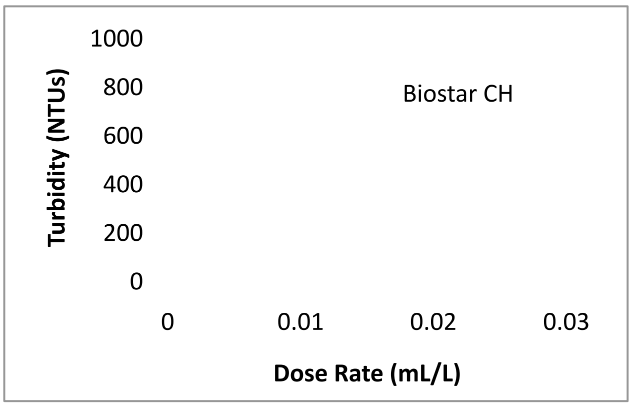


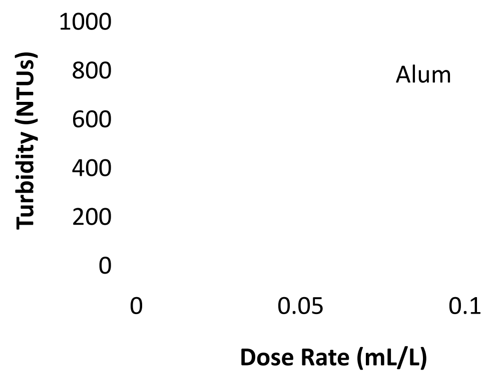


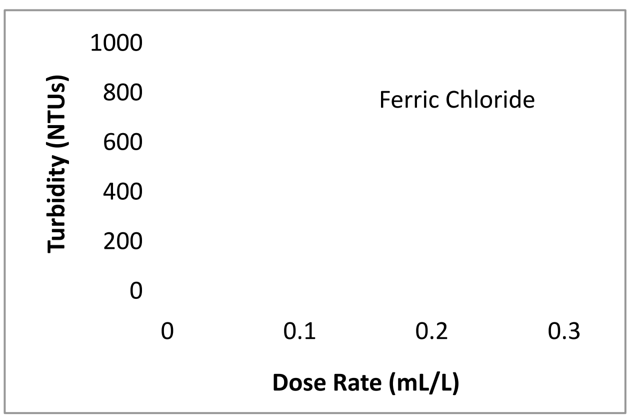


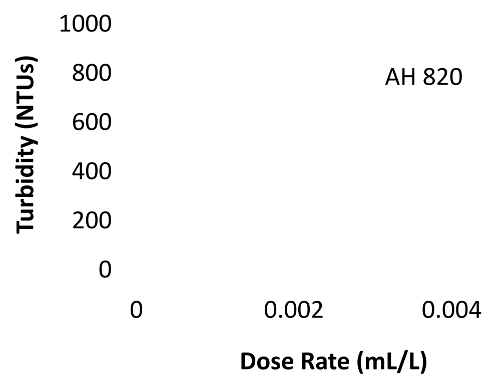


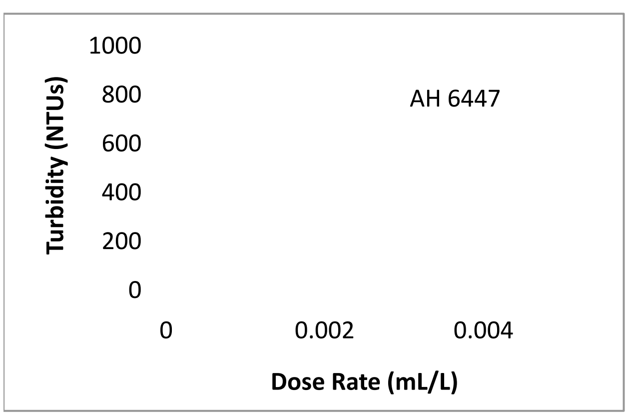
Material	Tamarack Peat
Classification	Peat
USCS Symbol(s)	PT
Strata	Peat
Geomorphology	Des Moines Lobe

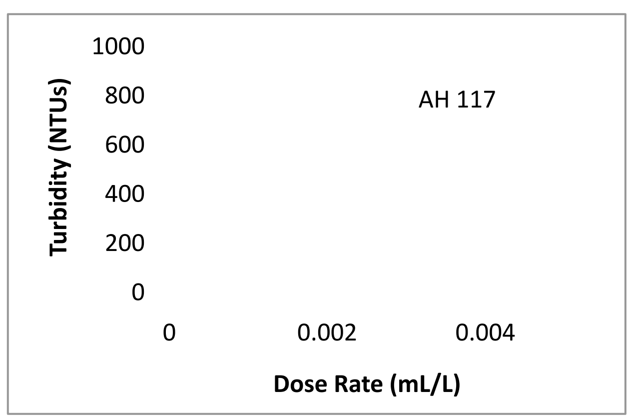


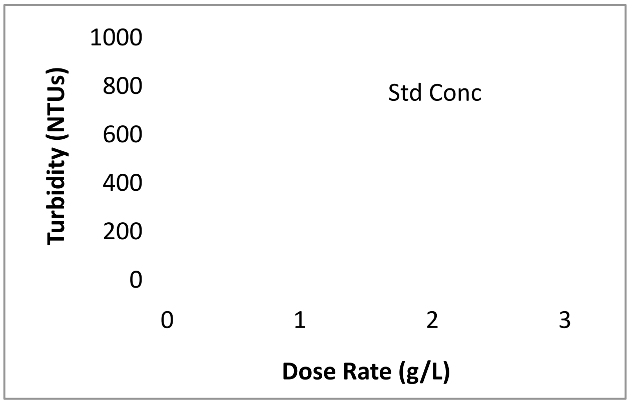




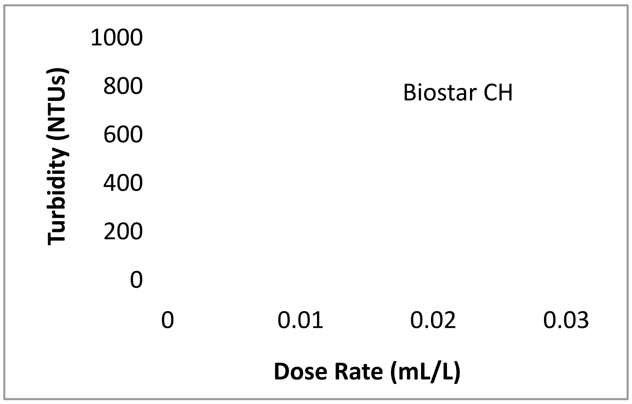


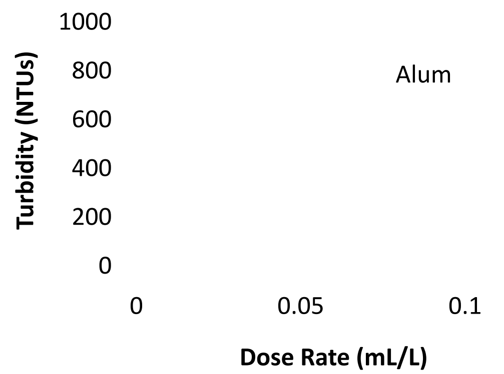


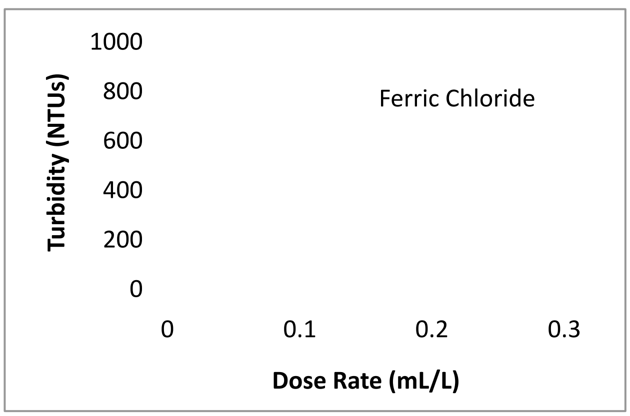


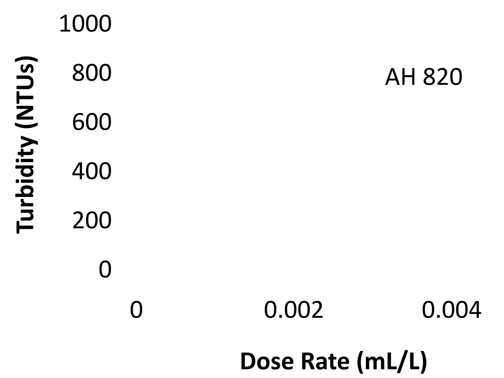


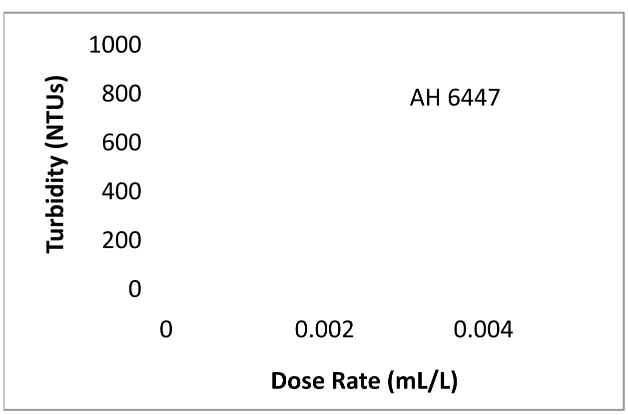
Material	Tamarack Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	End Moraine
Geomorphology	Des Moines Lobe

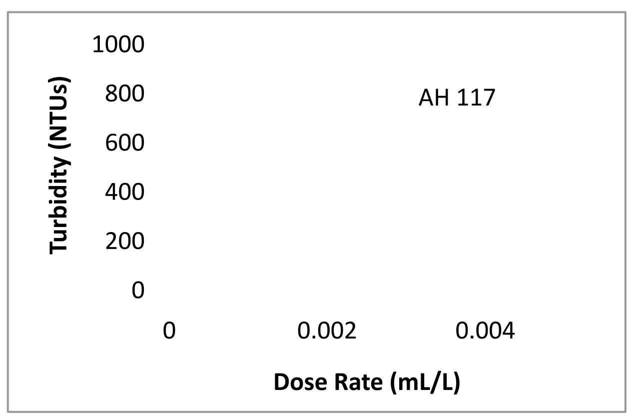


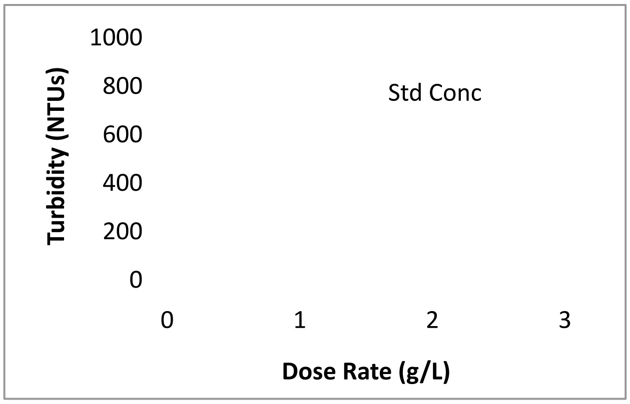




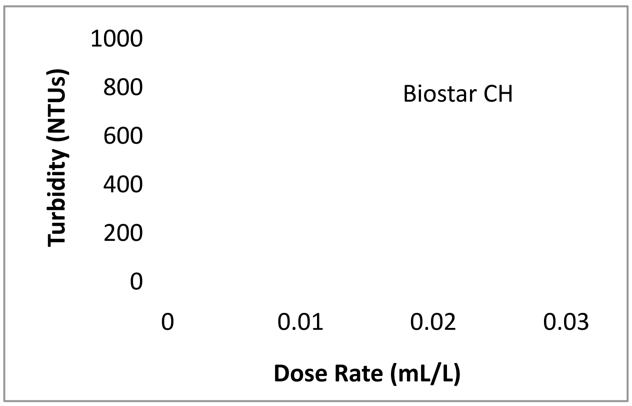


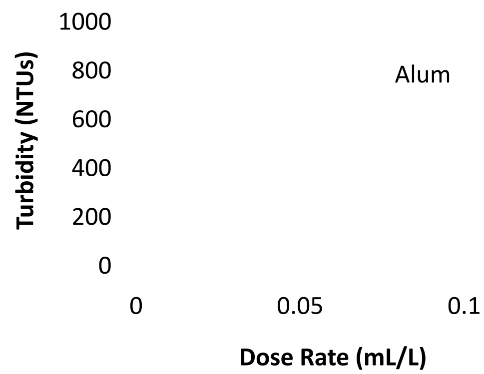


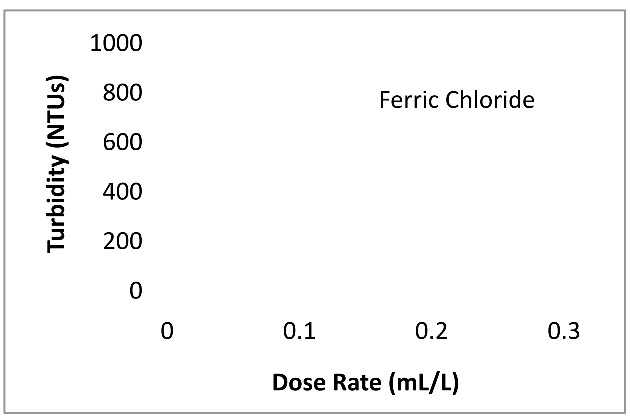


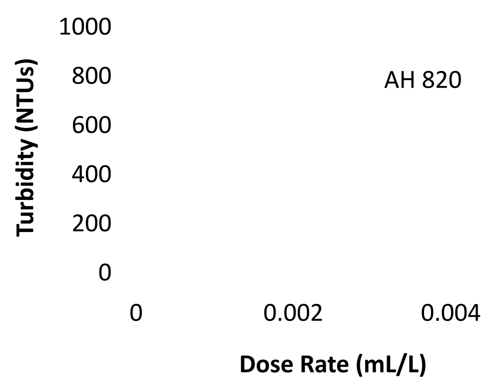


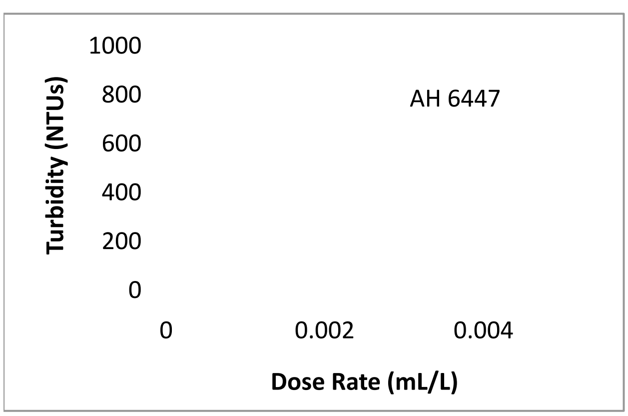
Material	Wabasha Subsoil (Box)
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Colluvuum
Geomorphology	Weathered Residual

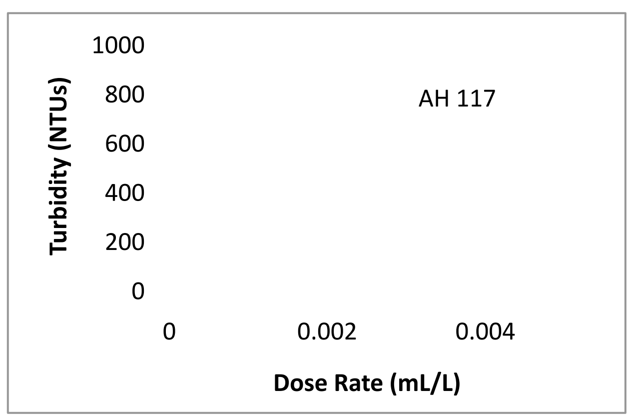


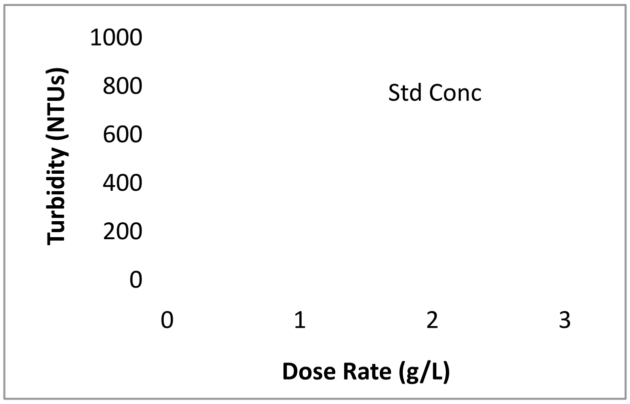




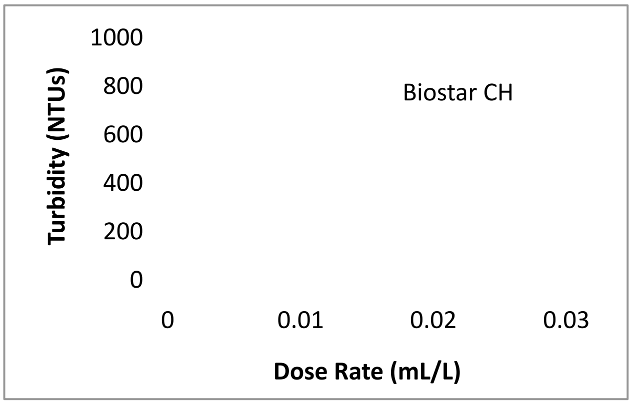


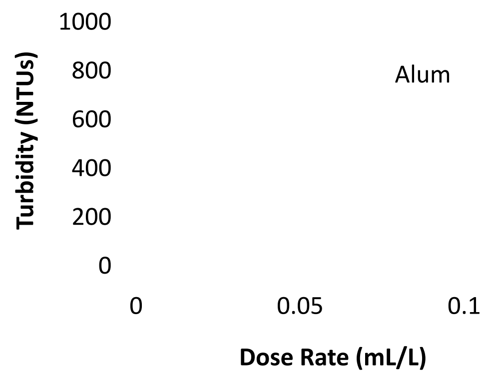


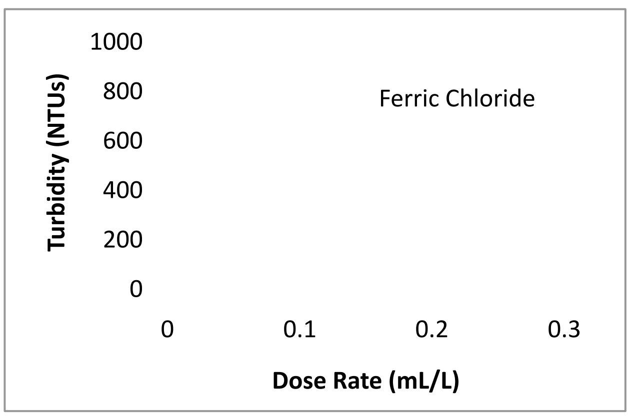


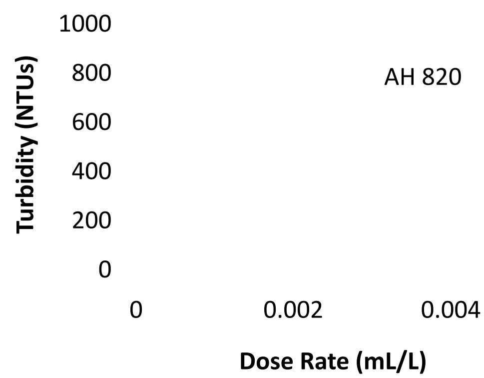


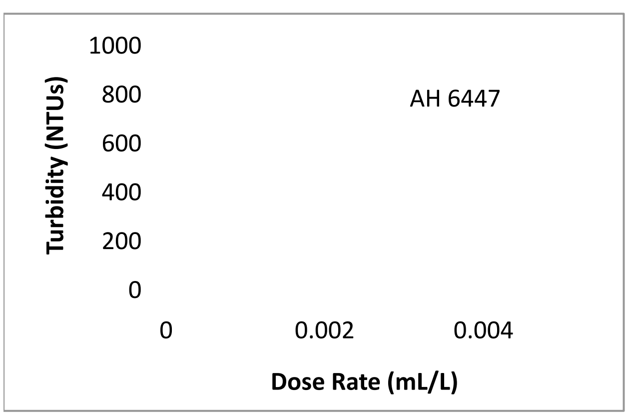
Material	Wabasha Subsoil (Rock)
Classification	Sandy Loam
USCS Symbol(s)	SM
Strata	Colluvuum
Geomorphology	Weathered Residual

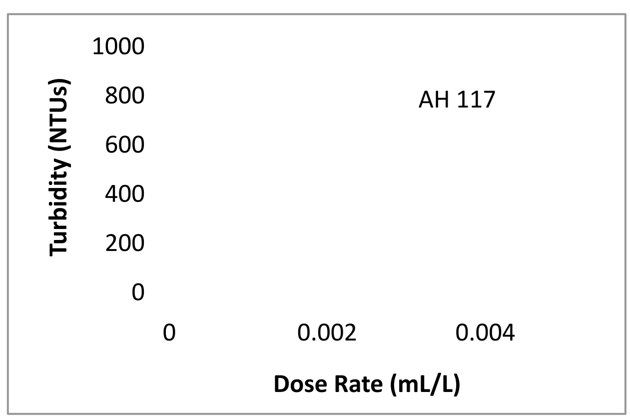


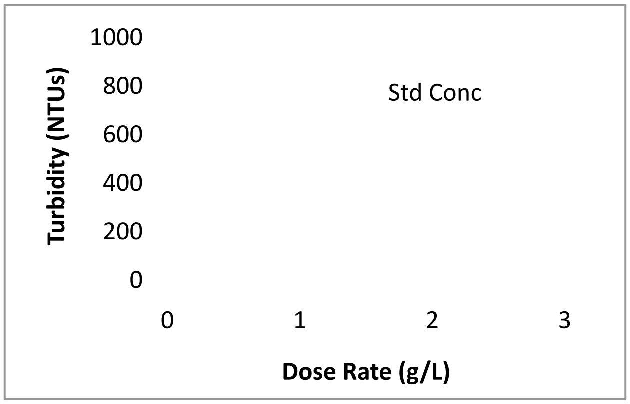




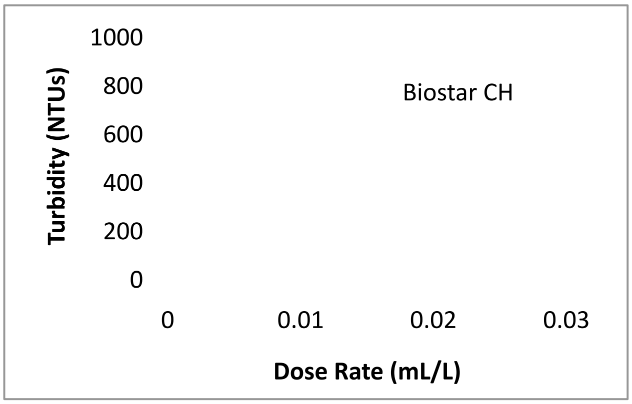


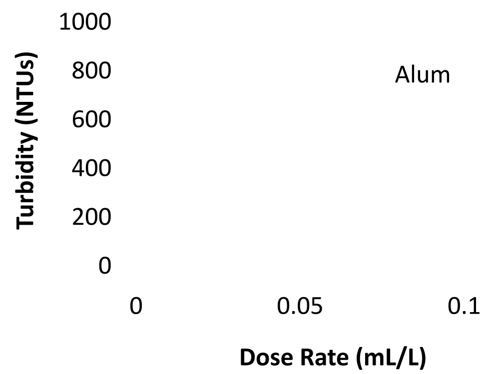


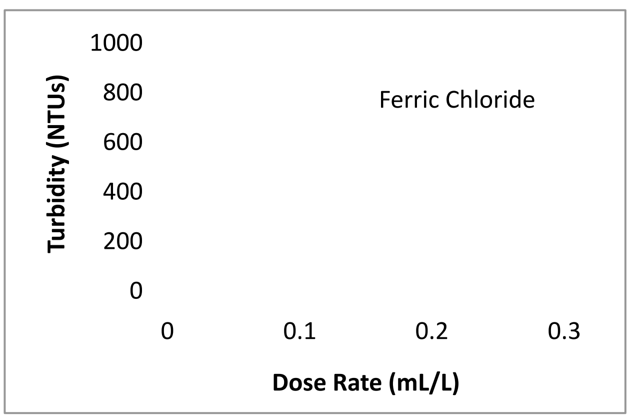


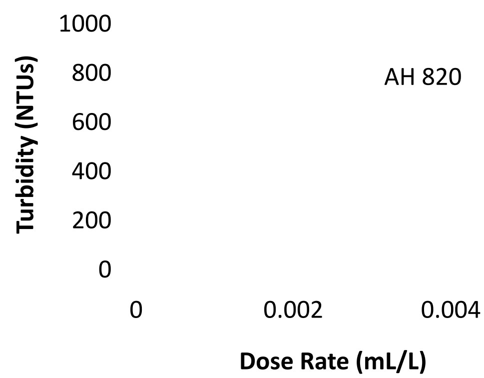


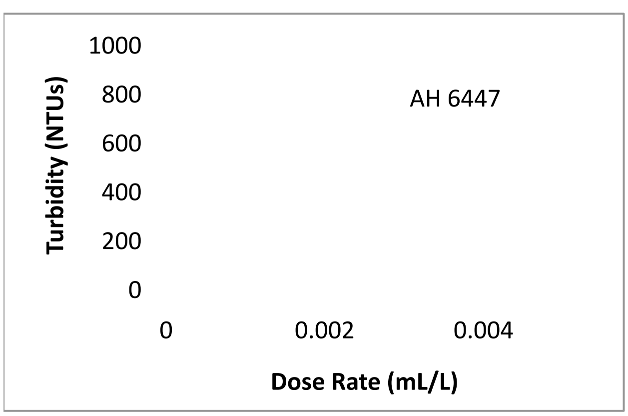
Material	Wabasha Topsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Colluvuum
Geomorphology	Weathered Residual

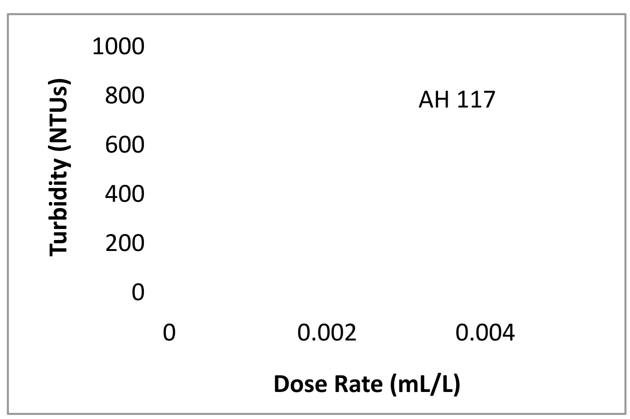


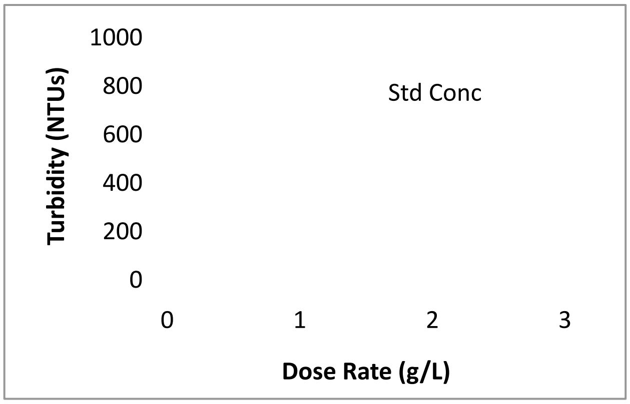




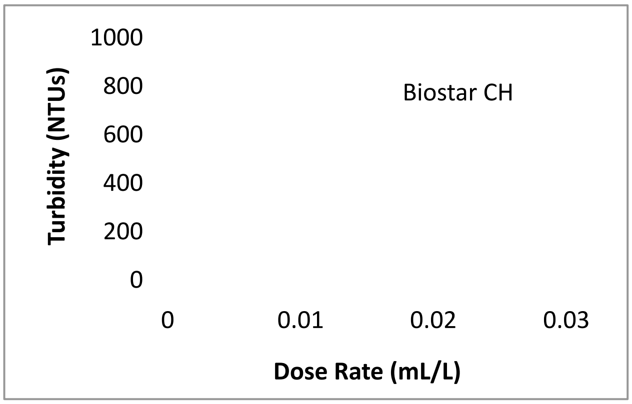


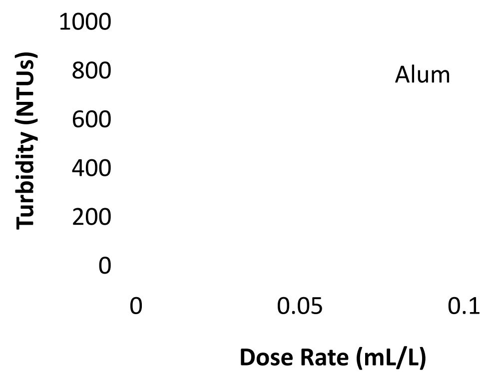


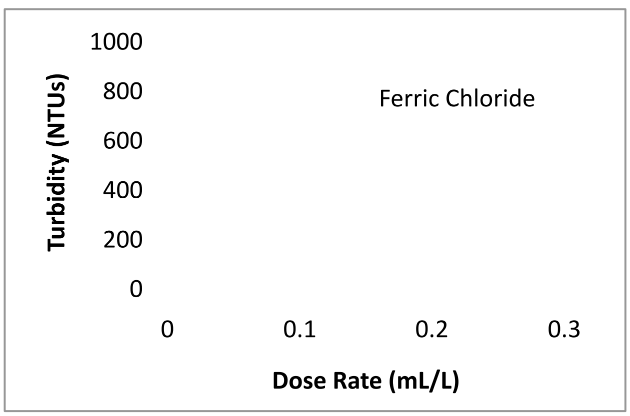


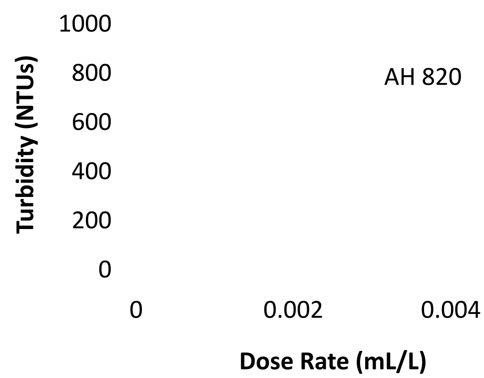


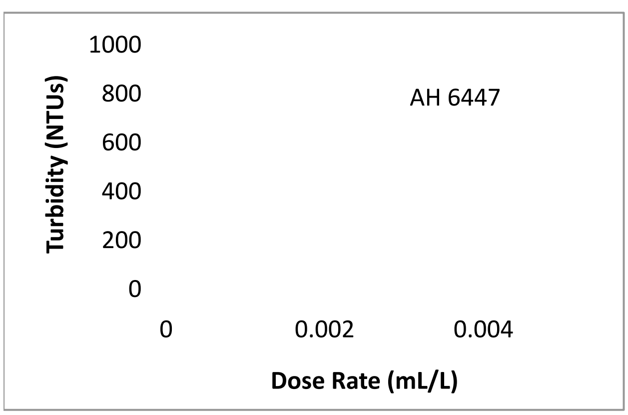
Material	Worthington Subsoil
Classification	Slightly Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

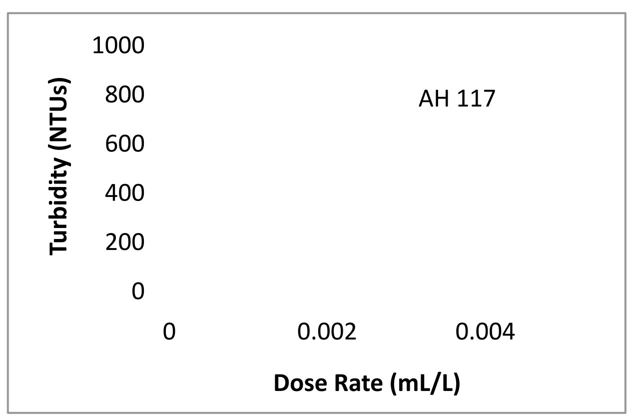


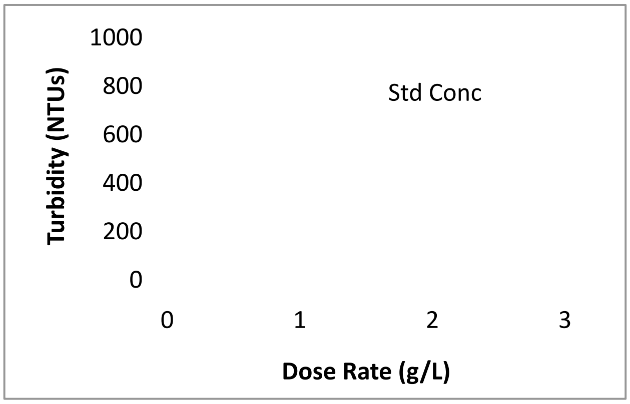




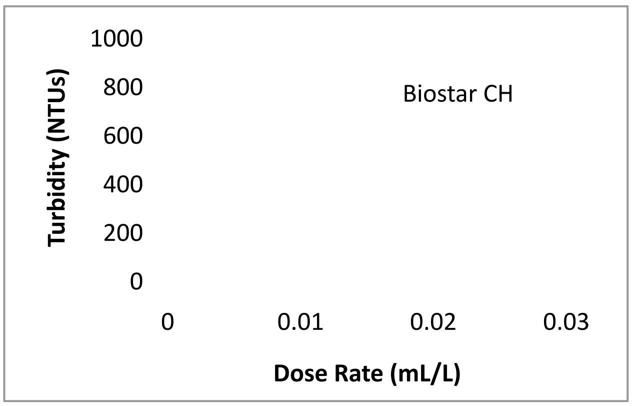


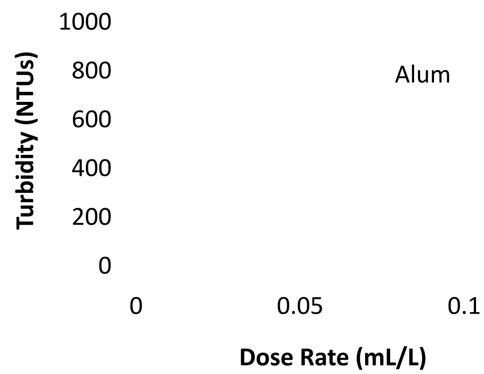


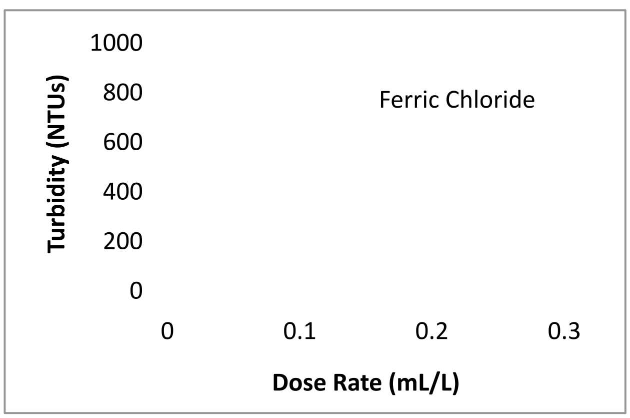


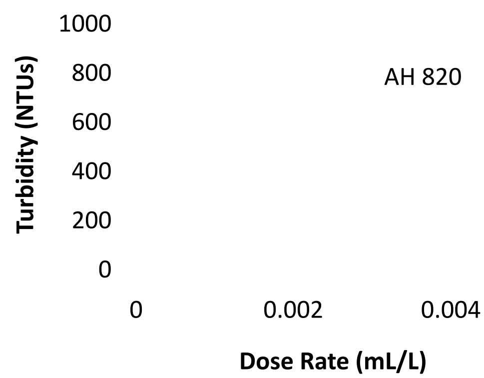


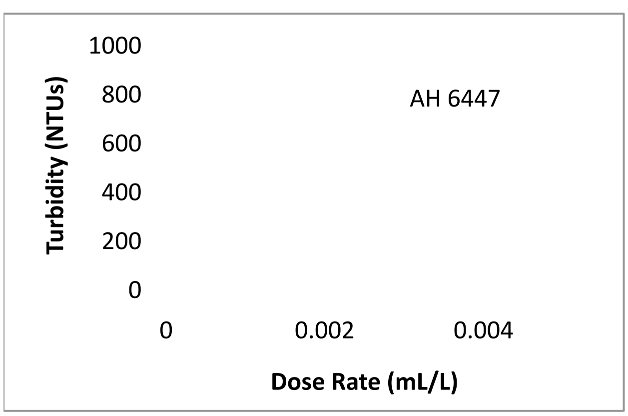
Material	Worthington Topsoil
Classification	Organic Sandy Loam
USCS Symbol(s)	SM
Strata	Ground Moraine
Geomorphology	Des Moines Lobe

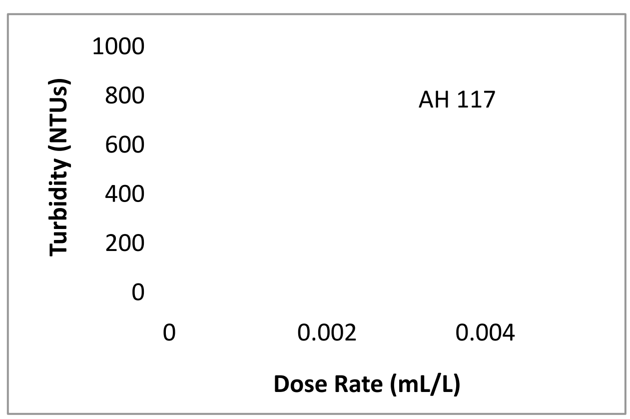












Appendix D – Mixing Technique Analysis

Appendix D

Mixing Technique Analysis

Mixing Technique Analysis

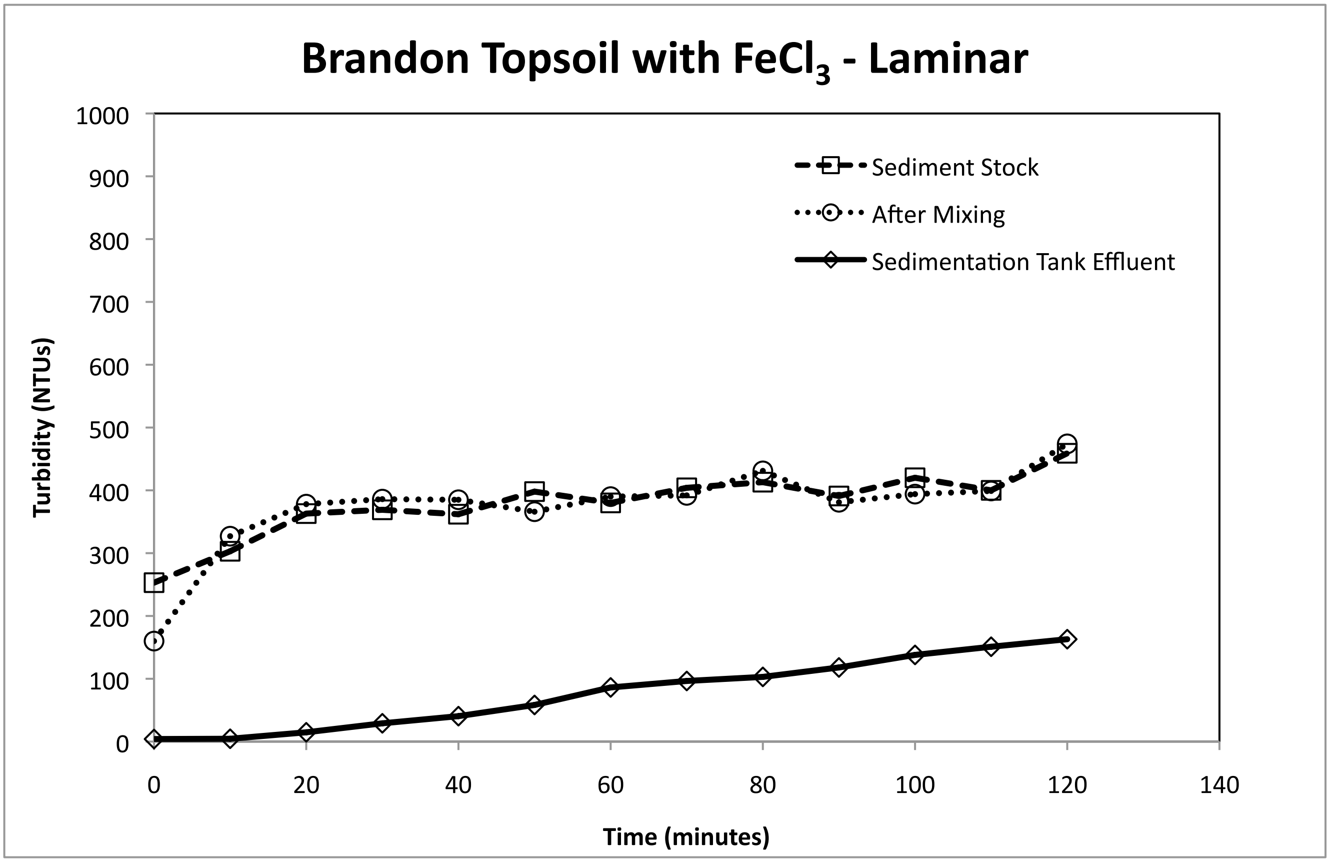
Mixing Technique	Soil	Average Sediment Stock Turbity (NTUs)	Average Post Mixing Turbidity (NTUs)	Average Settlement Tank Effluent Turbidity (NTUs)	Average Removal	2-Hour Settlment Tank Effluent Turbidity (NTU)	2-Hour Removal
Laminar	Brandon Topsoil	378	374	77	79.6%	163	56.9%
2 ft Gravel	Perham Topsoil	725	713	212	70.8%	462	36.3%
6 ft Gravel	Perham Topsoil	302	257	19	93.7%	28	90.7%
2 ft Corregated Pipe	Perham Topsoil	487	434	61	87.5%	106	78.2%
8 ft Corregated Pipe	Perham Topsoil	324	288	34	89.5%	47.3	85.4%
Baffle Mixing	Brandon Topsoil	290	258	43	85.2%	104	64.1%
Floc Log	Perham Topsoil	306	181	67	78.1%	55.5	81.9%
Floc Pillow	Perham Topsoil	589	571	97	83.5%	202	65.7%
Drip Line Mixing	Mankato Topsoil	403	364	59	85.4%	108	73.2%
Sump Mixing	Mankato Topsoil	350	317	56	84.0%	143	59.1%
Turbulant Air Mixing	Mankato Topsoil	644	595	30	95.3%	32.8	94.9%
Double Bladed Mixer	Mankato Topsoil	834	807	141	83.1%	203	75.7%
Single Bladed Mixer	Mankato Topsoil	298	250	15	95.0%	15.7	94.7%
No Flocculant	Mankato Topsoil	830	816	378	54.5%	538	35.2%
No Flocculant	Brandon Topsoil	314	297	57	81.8%	114	63.7%
No Flocculant	Perham Topsoil	203	207	22	89.2%	57.5	71.7%

Environmental Engineering Lab
MSU Manakato

Flocculent Mixing Analysis

Analyst: Anthony Adderley
Date: March 14, 2013

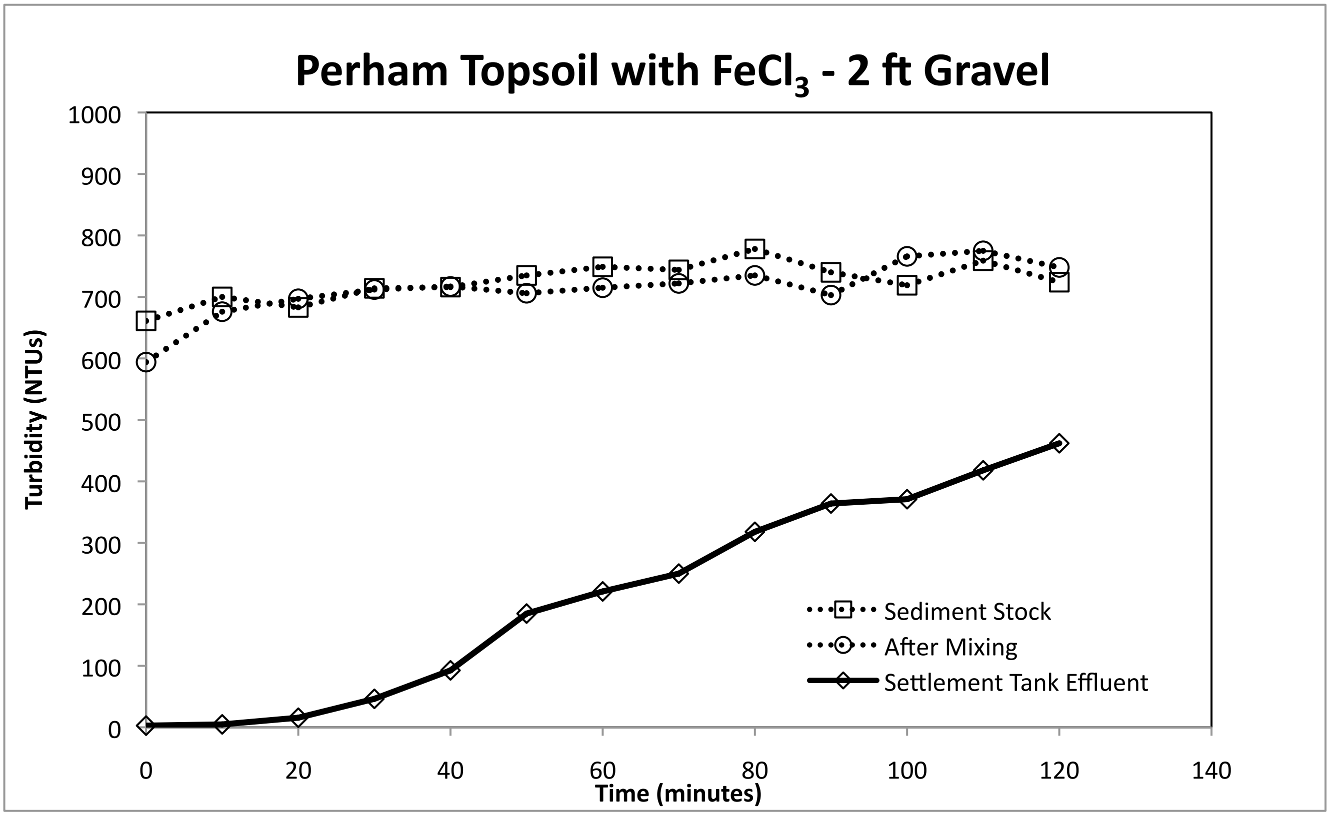
	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	253	160	4.07	
Brandon Topsoil	10	303	327	4.5	
Soil Mass (g)	20	363	378	14.79	
Water (gal)	30	369	386	29.1	
Sediment Stock Conc.	40	362	385	40.5	
100 g/gal	50	398	366	58.3	
	60	380	390	86.2	
Flocculant	70	404	392	96.5	
35% Ferric Chloride	80	413	431	103	
Floc Vol (mL) 2	90	391	381	118	
Water (L) 1	100	420	394	138	
Floc Stock Conc.	110	400	399	151	
2 mL/L	120	459	474	163	
Sediment Stock Flow	Averages	378	374	77	57%
500 mL/min				80%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Laminar -					
straight channel					
no obstructions					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Brandon Topsoil with $FeCl_3$ - Laminar
Sediment Stock
After Mixing
Sedimentation Tank Effluent
Turbidity (NTUs)
Time (minutes)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140

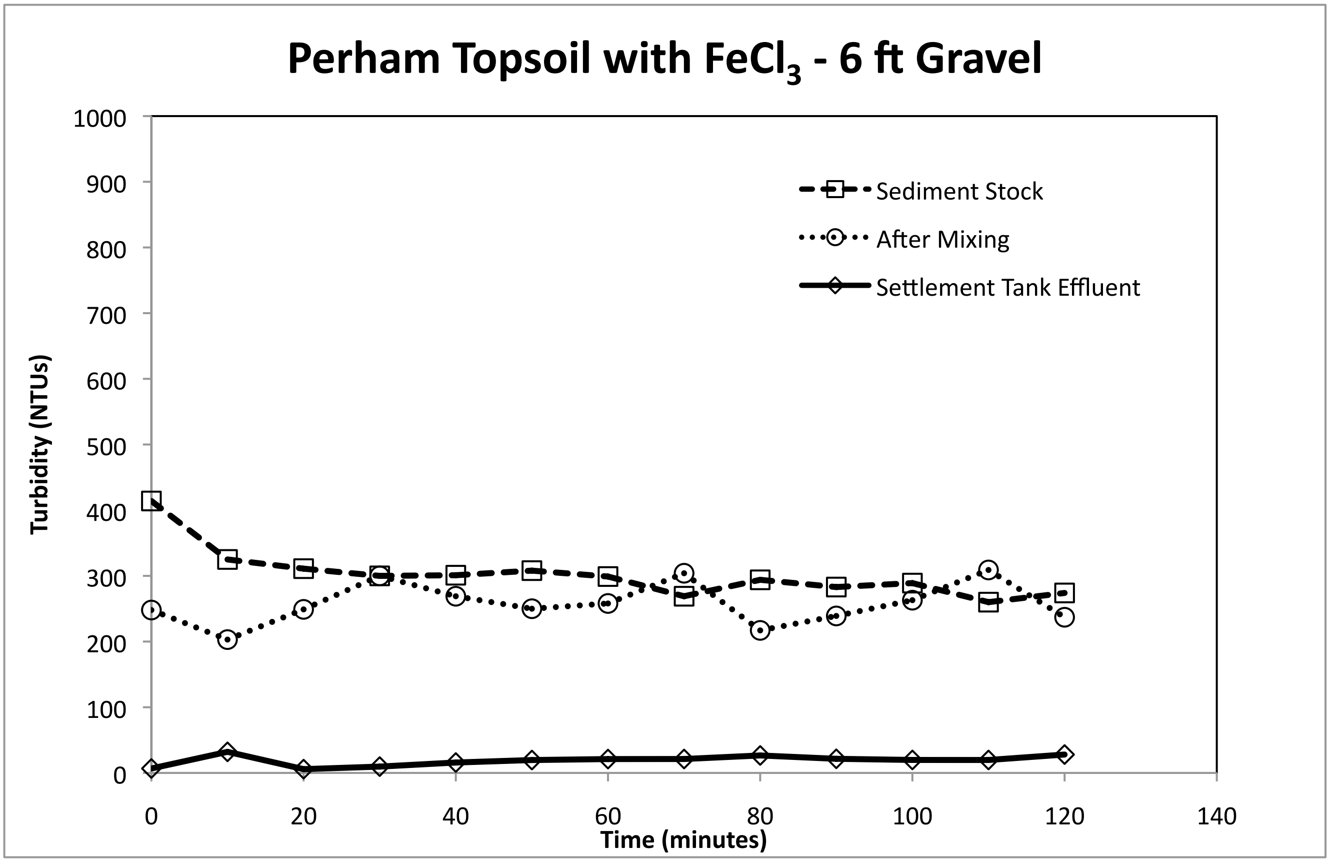
Flocculent Mixing Analysis

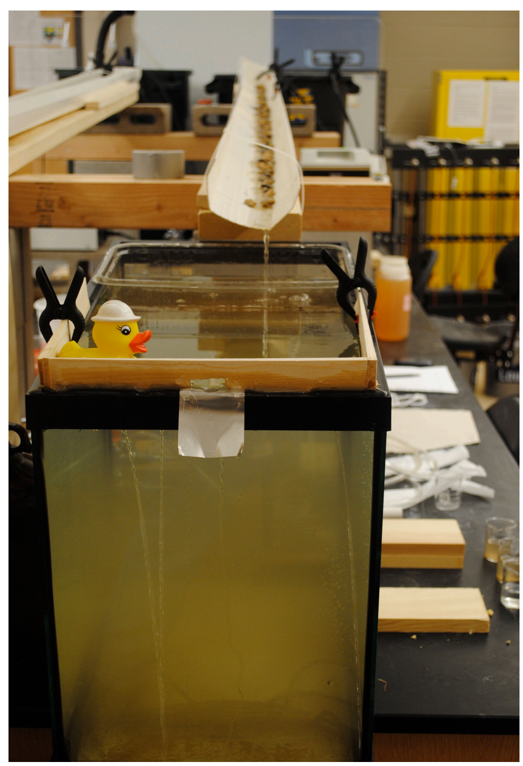
Analyst: Anthony Adderley
Date: March 14, 2013

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	661	594	2.73	
Perham Topsoil	10	700	676	4.71	
Soil Mass (g)	20	683	697	15.58	
Water (gal)	30	714	712	46.3	
Sediment Stock Conc.	40	716	717	92.6	
100 g/gal	50	735	706	185	
	60	749	715	221	
Flocculant	70	744	722	250	
35% Ferric Chloride	80	778	735	318	
Floc Vol (mL) 2	90	740	703	364	
Water (L) 1	100	719	766	371	
Floc Stock Conc.	110	759	775	418	
2 mL/L	120	724	748	462	
Sediment Stock Flow	Averages	725	713	212	36%
500 mL/min				71%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Gravel 2 ft bed					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Perham Topsoil with FeCl3 - 2 ft Gravel
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	414	248	6.77	
Perham Topsoil	10	325	203	32.1	
Soil Mass (g)	20	311	249	5.77	
Water (gal)	30	300	300	9.64	
Sediment Stock Conc.	40	301	269	15.84	
100 g/gal	50	308	250	19.63	
	60	299	258	21.1	
Flocculant	70	269	304	21.2	
35% Ferric Chloride	80	294	217	26.6	
Floc Vol (mL) 2	90	283	239	21.5	
Water (L) 1	100	289	263	19.77	
Floc Stock Conc.	110	260	309	19.7	
2 mL/L	120	274	237	28	
Sediment Stock Flow	Averages	302	257	19	91%
500 mL/min				94%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Gravel 6 ft bed					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					

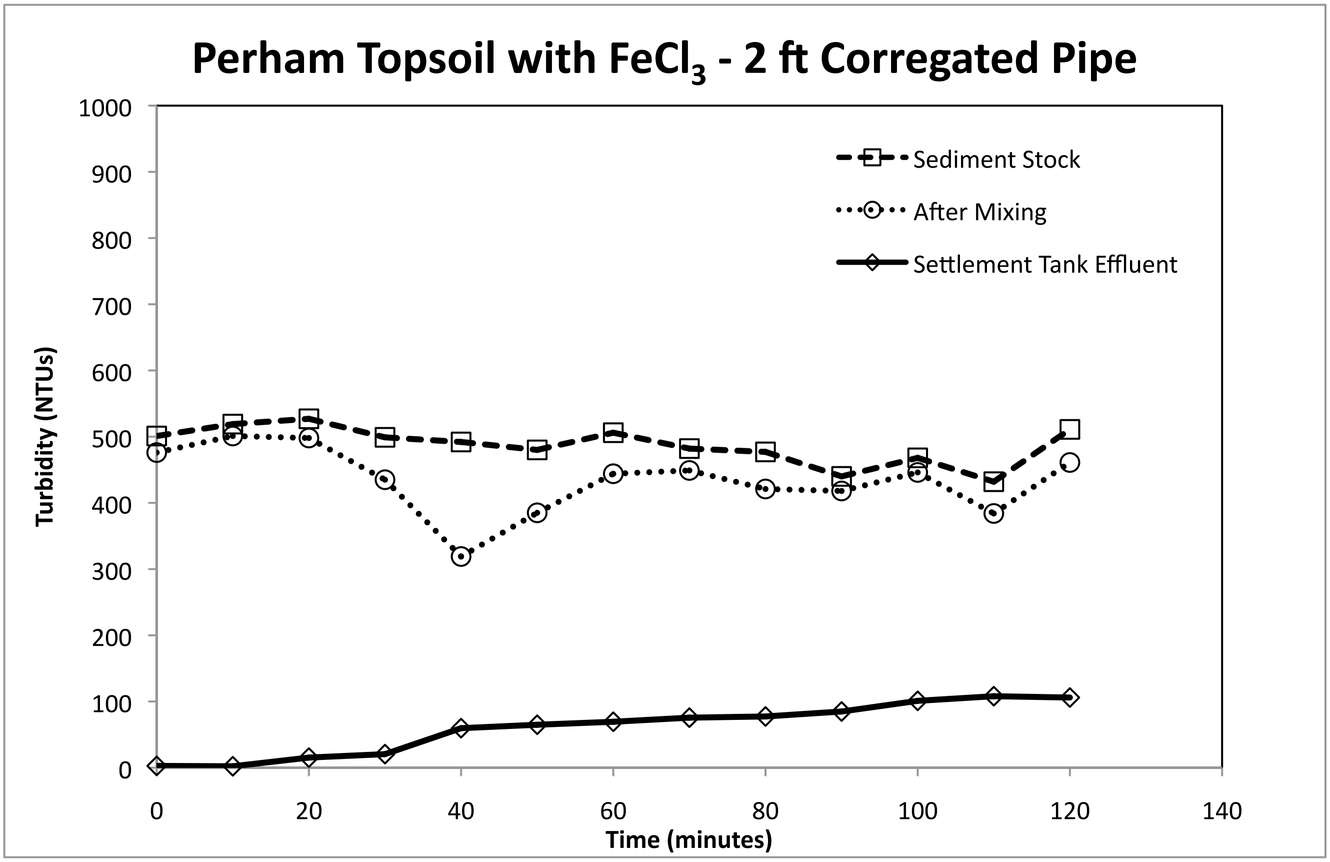

Perham Topsoil with $FeCl_3$ - 6 ft Gravel
Sediment Stock
After Mixing
Settlement Tank Effluent
Turbidity (NTUs)
Time (minutes)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140

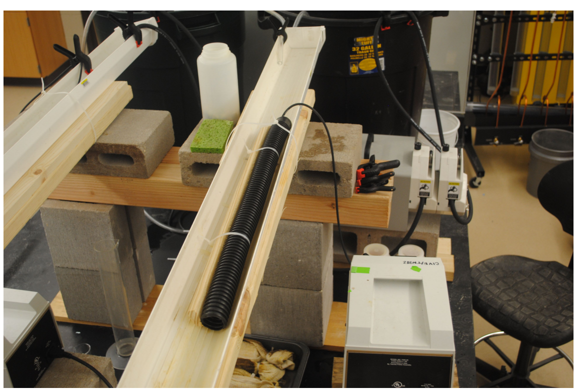


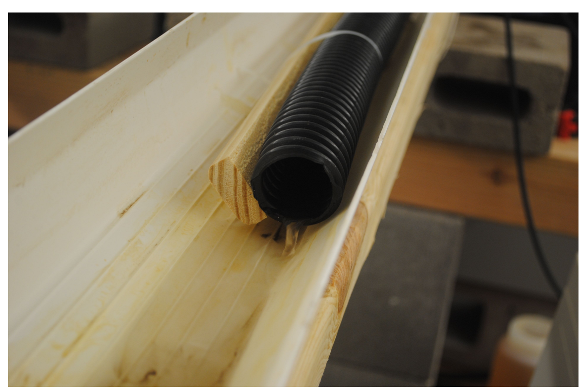
Flocculent Mixing Analysis

Analyst: Isabelle Race
Date: March 14, 2013

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	501	476	2.74	
Perham Topsoil	10	519	501	2.16	
Soil Mass (g)	20	527	498	15.29	
Water (gal)	30	499	435	20.5	
Sediment Stock Conc.	40	492	319	59.7	
100 g/gal	50	480	385	64.9	
	60	506	444	69.4	
Flocculant	70	482	449	75.6	
35% Ferric Chloride	80	477	421	77.4	
Floc Vol (mL) 2	90	440	418	84.9	
Water (L) 1	100	468	446	101	
Floc Stock Conc.	110	432	384	108	
2 mL/L	120	511	461	106	
Sediment Stock Flow	Averages	487	434	61	78%
500 mL/min				88%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Corregated Pipe 2 ft					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Perham Topsoil with $FeCl_3$ - 2 ft Corregated Pipe
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140

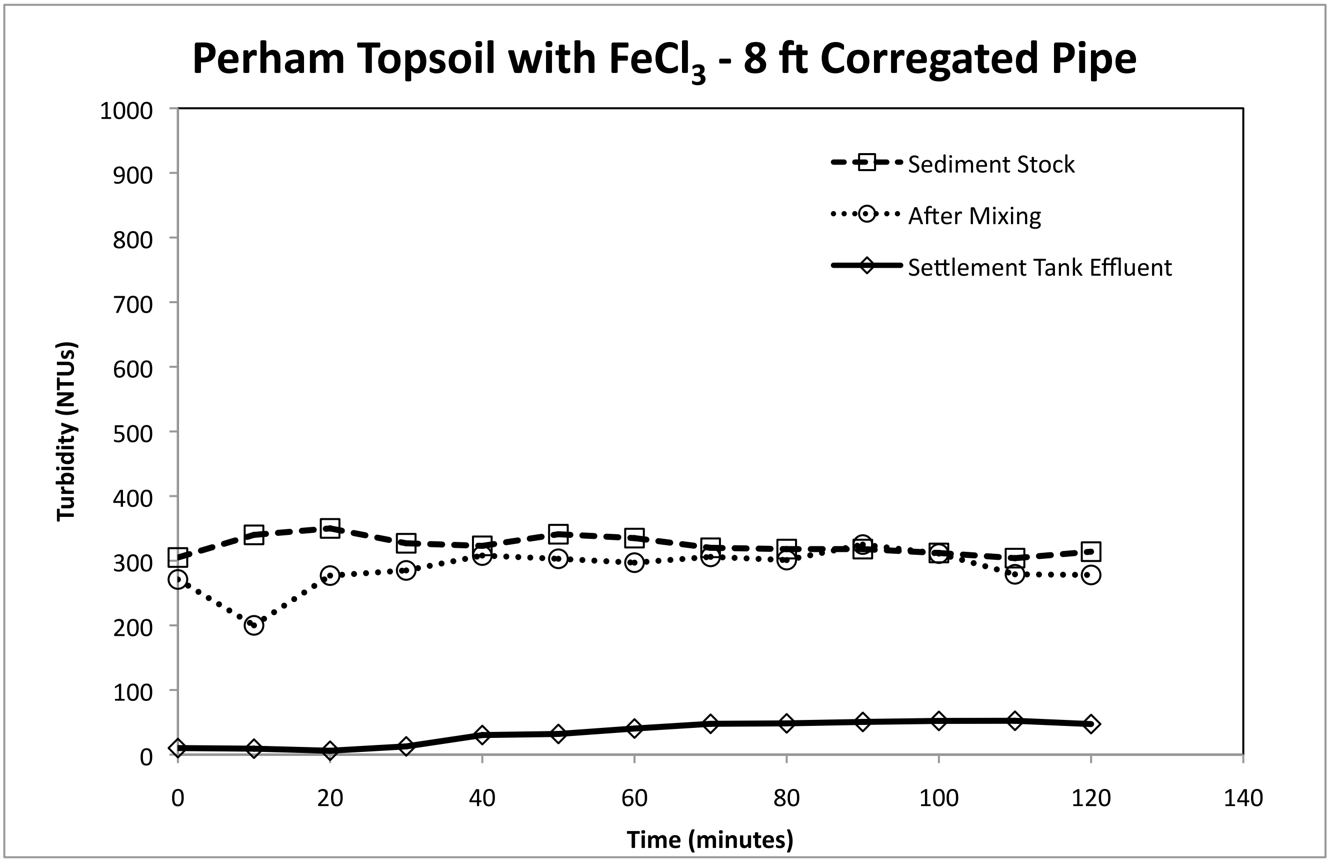


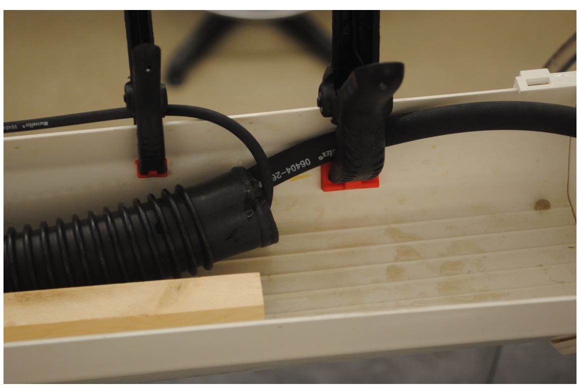


Flocculent Mixing Analysis

Analyst: Ryan Johnson
Date: March 12, 2013

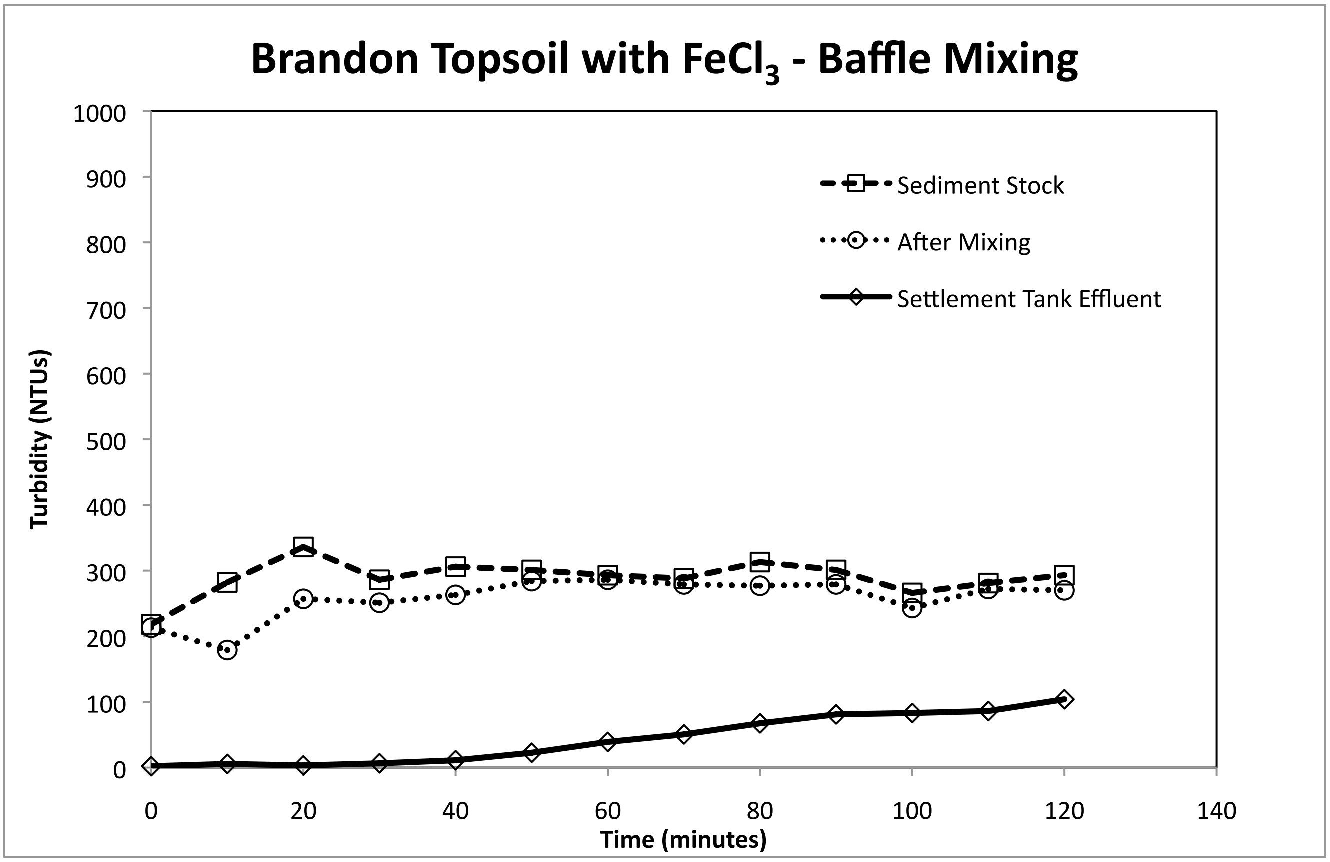
	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	305	271	10.17	
Perham Topsoil	10	340	200	9.23	
Soil Mass (g)	20	350	277	6.04	
Water (gal)	30	327	285	12.77	
Sediment Stock Conc.	40	323	308	30.3	
100 g/gal	50	341	303	32	
	60	335	297	40.4	
Flocculant	70	320	306	47.7	
35% Ferric Chloride	80	318	301	48.4	
Floc Vol (mL) 2	90	318	325	50.6	
Water (L) 1	100	312	311	52.2	
Floc Stock Conc.	110	304	279	52.4	
2 mL/L	120	314	278	47.3	
Sediment Stock Flow	Averages	324	288	34	85%
500 mL/min				90%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Corregated Pipe 8 ft					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					

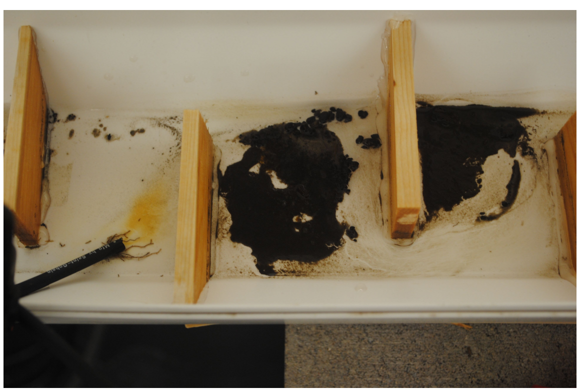

Perham Topsoil with FeCl3 - 8 ft Corregated Pipe
Sediment Stock
After Mixing
Settlement Tank Effluent
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)

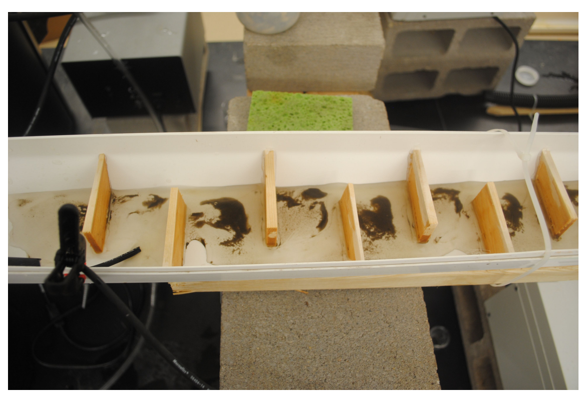


Soil Sample & Strata	
Brandon Topsoil	
Soil Mass (g)	
Water (gal)	
Sediment Stock Conc.	
100	g/gal
Flocculant	
35% Ferric Chloride	
Floc Vol (mL)	2
Water (L)	1
Floc Stock Conc.	
2	mL/L
Sediment Stock Flow	
500	mL/min
Floc Stock Flow Rate	
25	mL/min
Total Flow Rate	
525	mL/min
Floc Final Conc.	
0.10	mL/L
Sediment Mixing Method	
Air	
Water Temp	22 deg C
Flash Mixing Method	
Hydraulic Baffles	
Slow Mixing Method	
Baffle	
Sedimentation Method	
20 gal Aquarium	

Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
0	218	213	2.07	
10	282	179	5.52	
20	336	257	3.29	
30	286	251	6.45	
40	306	263	11.07	
50	301	284	22.6	
60	293	286	39.1	
70	288	279	50.5	
80	313	277	67.4	
90	301	279	81	
100	266	243	83.1	
110	281	272	86.1	
120	293	270	104	
Averages	290	258	43	64%
			85%	2-Hour Removal


Brandon Topsoil with $FeCl_3$ - Baffle Mixing
Sediment Stock
After Mixing
Settlement Tank Effluent
Turbidity (NTUs)
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
20
40
60
80
120
140

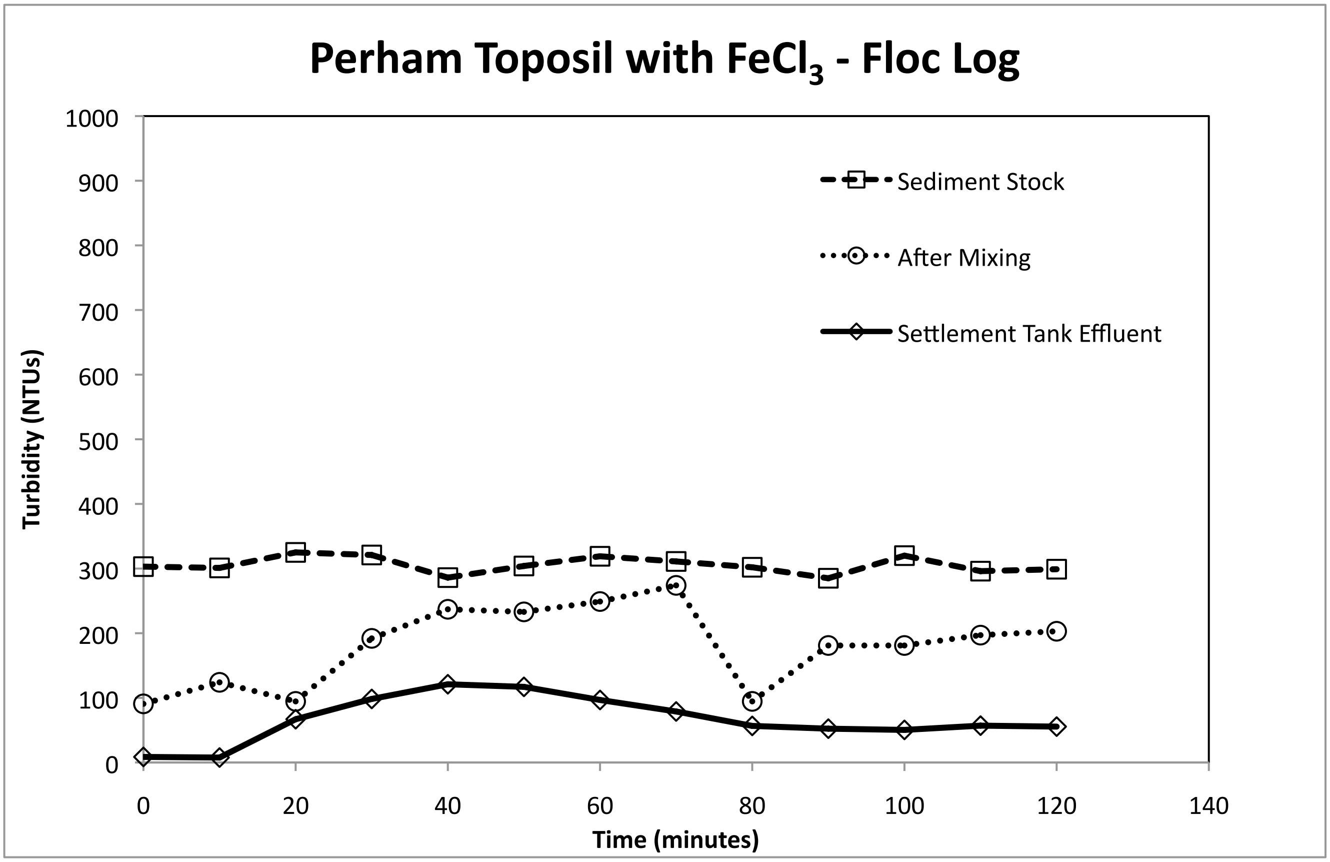




Flocculent Mixing Analysis

Analyst: Isabelle Race
Date: March 12, 2013

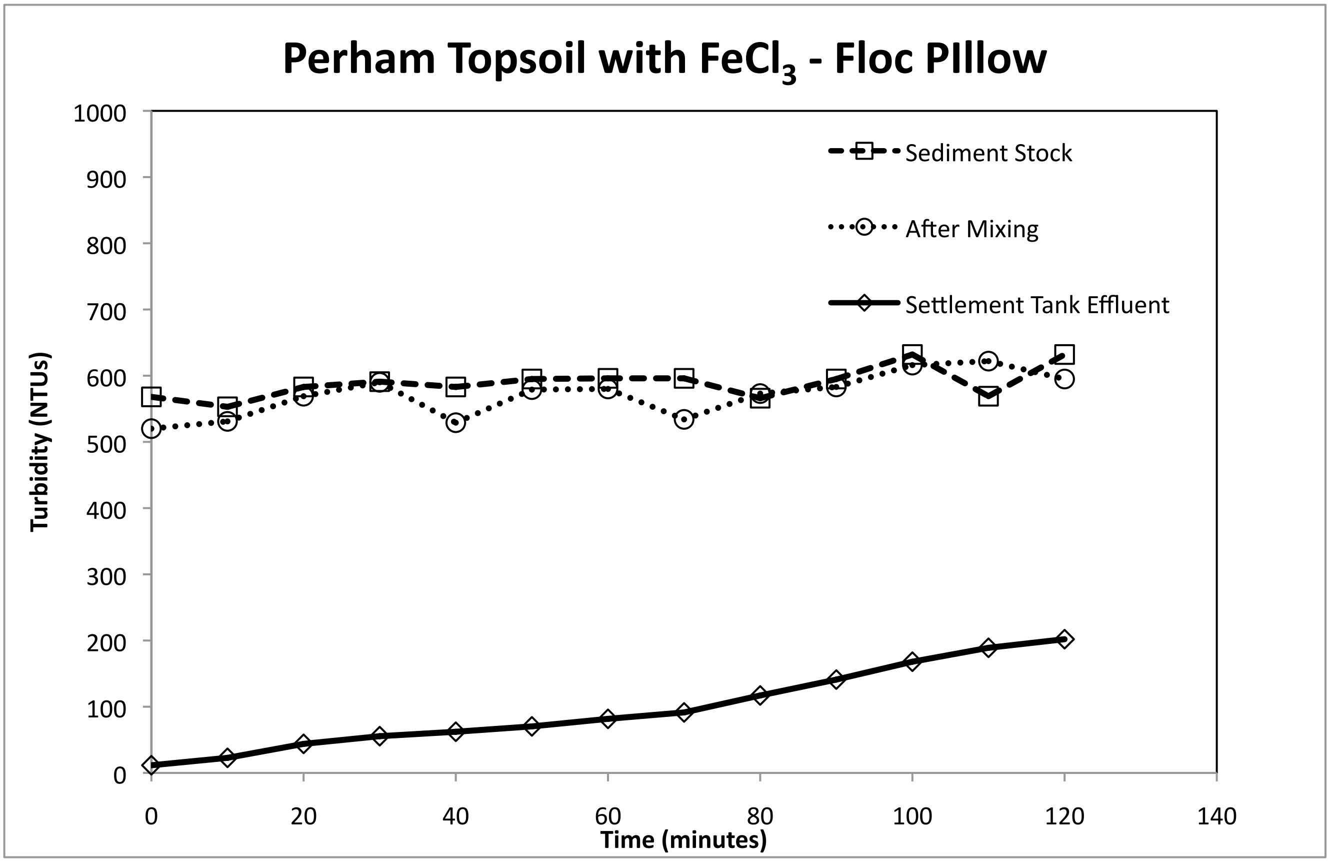
	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	303	90.7	8.6	
Perham Topsoil	10	301	124	7.63	
Soil Mass (g)	20	325	94.5	66.9	
Water (gal)	30	321	192	98.3	
Sediment Stock Conc.	40	286	237	121	
100 g/gal	50	304	233	117	
	60	319	249	96.7	
Flocculant	70	311	274	78.9	
35% Ferric Chloride	80	302	94.5	56.6	
Floc Vol (mL) 2	90	285	181	52.3	
Water (L) 1	100	320	181	50.4	
Floc Stock Conc.	110	296	197	57	
2 mL/L	120	299	203	55.5	
Sediment Stock Flow	Averages	306	181	67	82%
500 mL/min				78%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Floc Log					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					

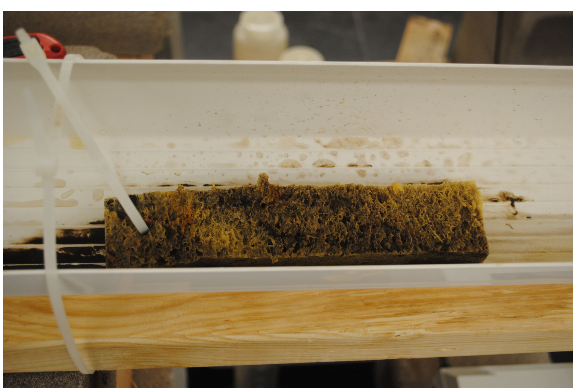

Perham Toposil with FeCl3 - Floc Log
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140

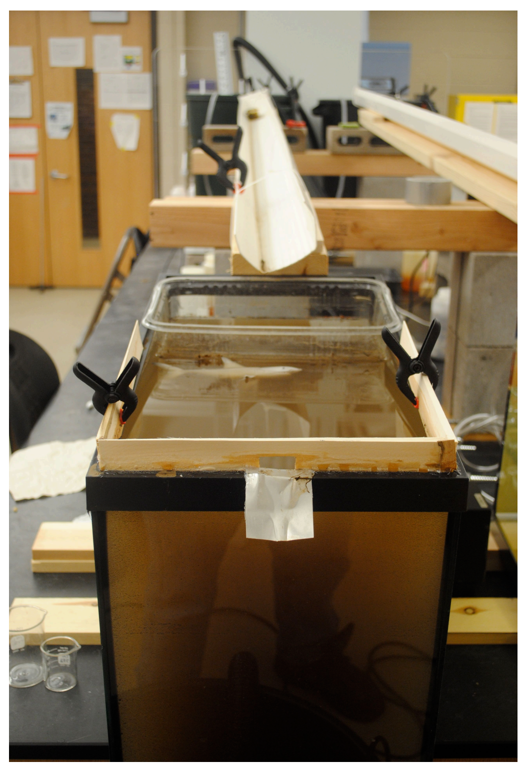
Flocculent Mixing Analysis

Analyst: Anthony Adderley
Date: March 12, 2013

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	568	520	11.57	
Perham Topsoil	10	553	531	22.8	
Soil Mass (g)	20	583	569	43.9	
Water (gal)	30	591	590	55.5	
Sediment Stock Conc.	40	583	529	62.2	
100 g/gal	50	595	579	70.3	
	60	596	580	81.7	
Flocculant	70	596	534	91.4	
35% Ferric Chloride	80	566	573	117	
Floc Vol (mL) 2	90	595	583	141	
Water (L) 1	100	632	616	168	
Floc Stock Conc.	110	569	622	189	
2 mL/L	120	632	595	202	
Sediment Stock Flow	Averages	589	571	97	66%
500 mL/min				84%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
525 mL/min					
Floc Final Conc.					
0.10 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Floc Pillow					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Perham Topsoil with $FeCl_3$ - Floc PIllow
Sediment Stock
After Mixing
Settlement Tank Effluent
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)

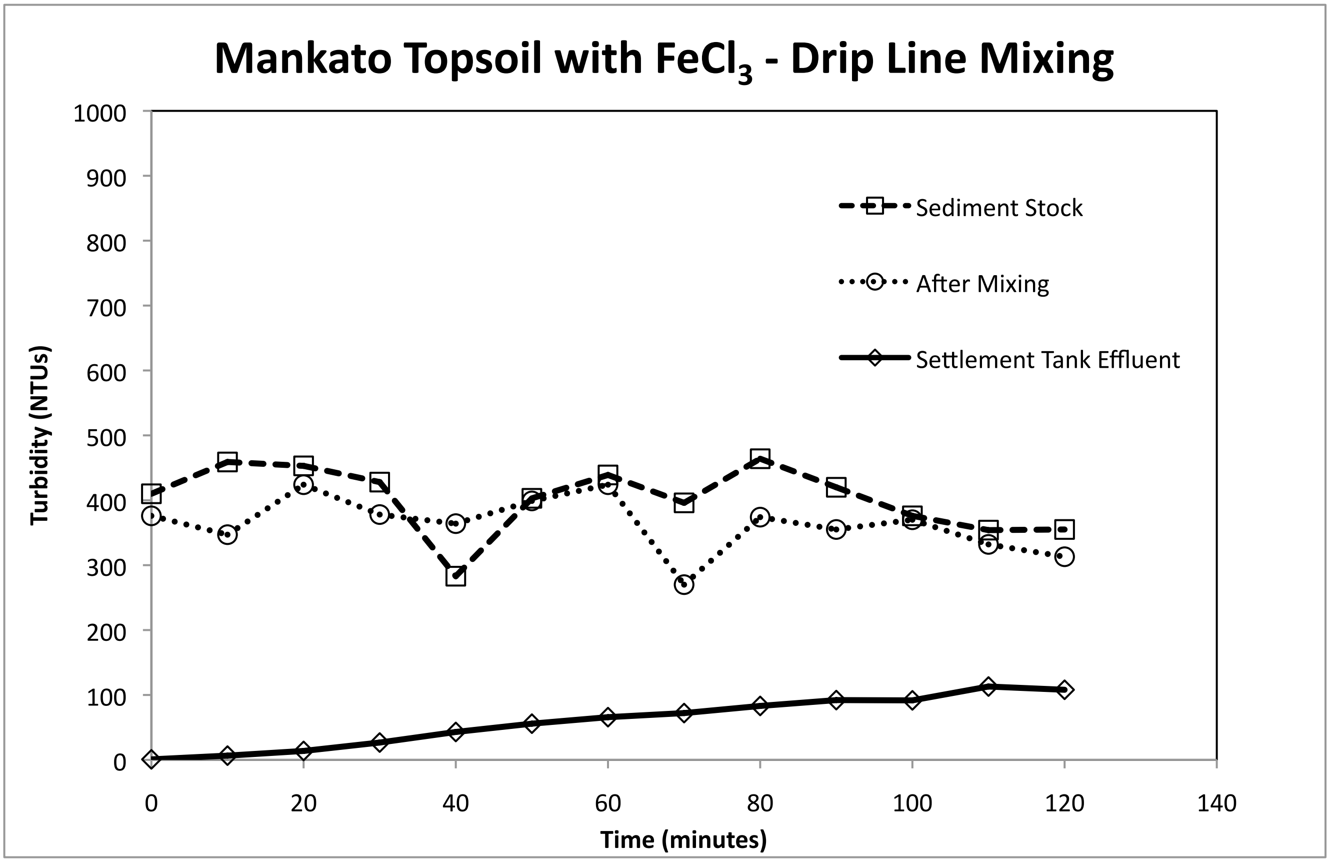




Flocculent Mixing Analysis

Analyst: Anthony Adderley
Date: March 15, 2013

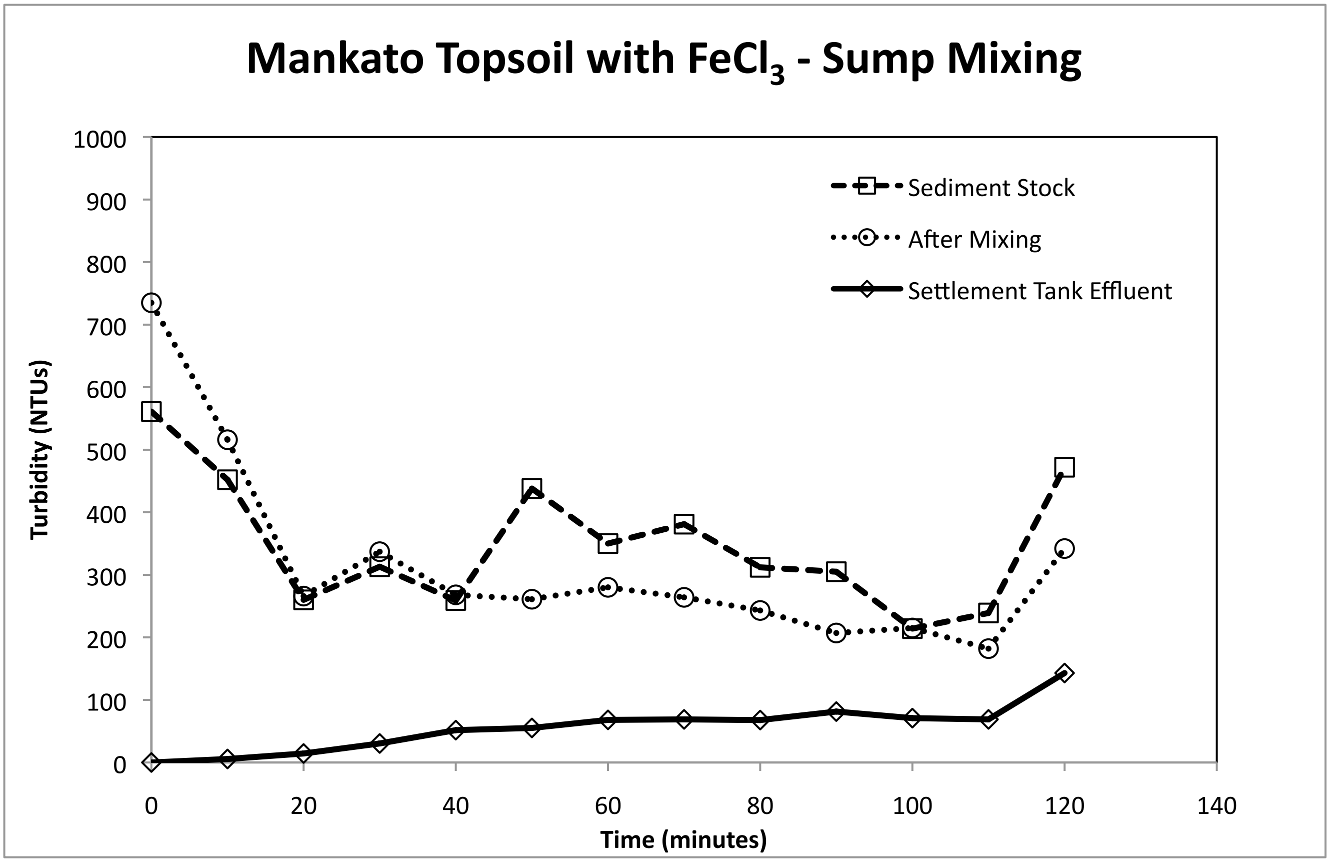
	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	410	376	0.78	
Mankato Topsoil	10	459	347	6.53	
Soil Mass (g)	20	453	424	13.76	
Water (gal)	30	428	378	26.7	
Sediment Stock Conc.	40	283	364	43	
100 g/gal	50	403	399	55.8	
	60	439	424	65.8	
Flocculant	70	396	270	72.1	
35% Ferric Chloride	80	464	374	83.1	
Floc Vol (mL) 1	90	420	355	92.1	
Water (L) 1	100	376	370	91.7	
Floc Stock Conc.	110	354	332	113	
1 mL/L	120	355	313	108	
Sediment Stock Flow	Averages	403	364	59	73%
500 mL/min				85%	2-Hour Removal
Floc Stock Flow Rate					
50 mL/min					
Total Flow Rate					
550 mL/min					
Floc Final Conc.					
0.09 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Drip Line					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					

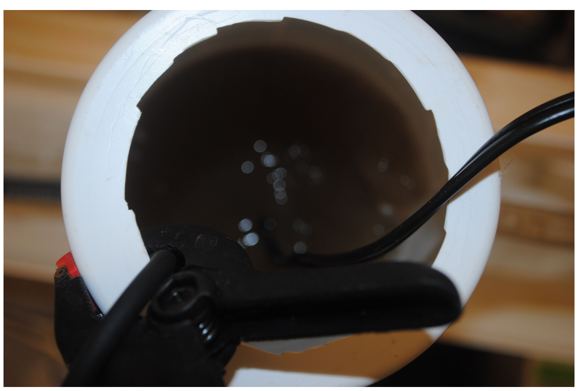

Mankato Topsoil with FeCl3 - Drip Line Mixing
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140

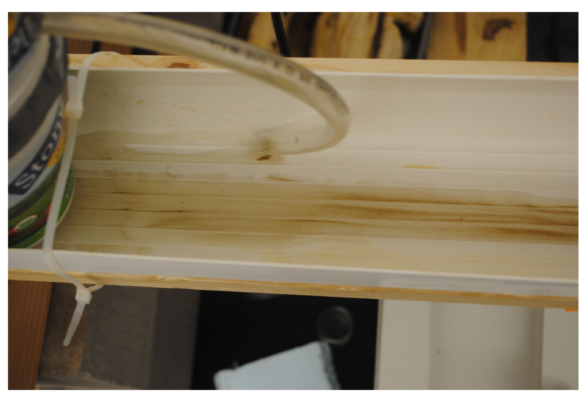
Flocculent Mixing Analysis

Analyst: Alex Raymond
Date: March 15, 2013

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	561	735	0	
Mankato Topsoil	10	452	516	5.59	
Soil Mass (g)	20	260	266	14.38	
Water (gal)	30	313	337	30.4	
Sediment Stock Conc.	40	259	268	51.7	
100 g/gal	50	438	261	55.2	
	60	350	280	68.1	
Flocculant	70	381	264	68.9	
35% Ferric Chloride	80	312	243	67.8	
Floc Vol (mL) 2	90	305	207	81.4	
Water (L) 1	100	214	215	70.9	
Floc Stock Conc.	110	239	182	68.9	
2 mL/L	120	472	342	143	
Sediment Stock Flow	Averages	350	317	56	59%
500 mL/min				84%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
550 mL/min					
Floc Final Conc.					
0.09 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Sump Mixing					
w/20 gal/hr					
centrifugal pump					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Mankato Topsoil with $FeCl_3$ - Sump Mixing
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140





Flocculent Mixing Analysis

Analyst: Alex Raymond
Date: March 23, 2013

Soil Sample & Strata
Mankato Topsoil
Soil Mass (g)
Water (gal)
Sediment Stock Conc.
100 g/gal

Flocculant
35% Ferric Chloride
Floc Vol (mL) 2
Water (L) 1
Floc Stock Conc.
2 mL/L

Sediment Stock Flow
500 mL/min
Floc Stock Flow Rate
25 mL/min
Total Flow Rate
550 mL/min

Floc Final Conc.
0.09 mL/L

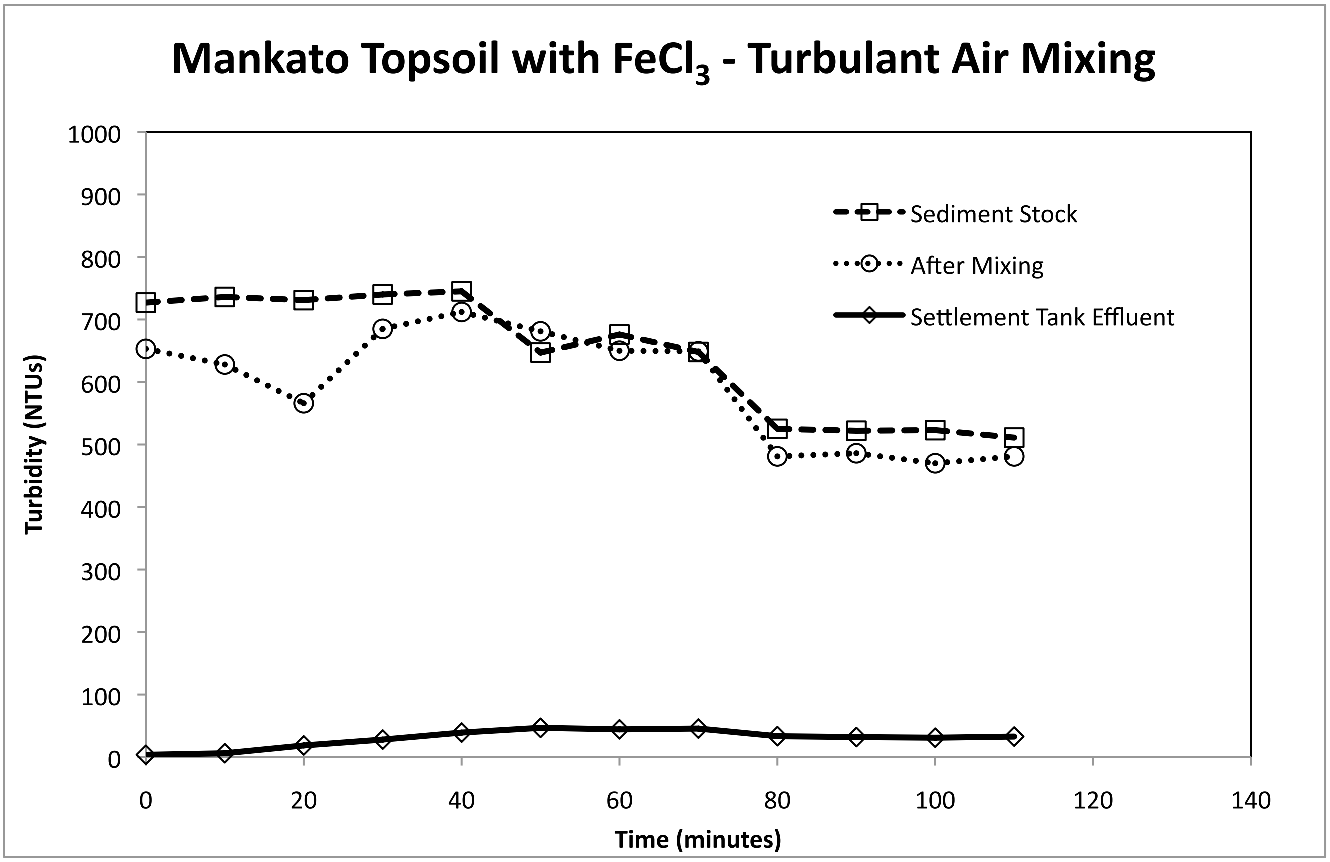
Sediment Mixing Method
Air
Water Temp 22 deg C

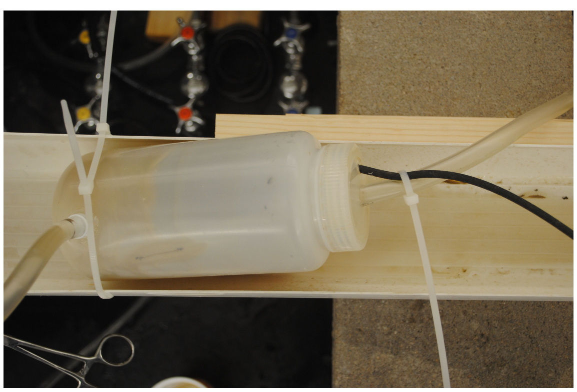
Flash Mixing Method
Turbulant air injection

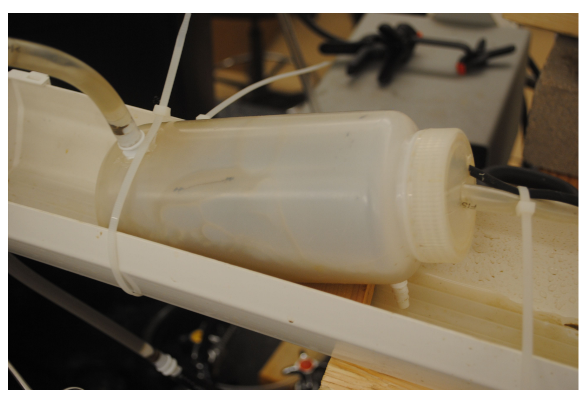
Slow Mixing Method
Baffle

Sedimentation Method
20 gal Aquarium

Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
0	727	653	3.65	
10	736	628	6.12	
20	731	566	18.59	
30	740	685	28	
40	745	712	39.2	
50	647	681	46.8	
60	676	650	44.3	
70	648	649	45.6	
80	525	481	33.4	
90	522	486	32	
100	523	470	31	
110	511	481	32.8	
Averages	644	595	30	95%
			95%	2-Hour Removal


Mankato Topsoil with $FeCl_3$ - Turbulant Air Mixing
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent



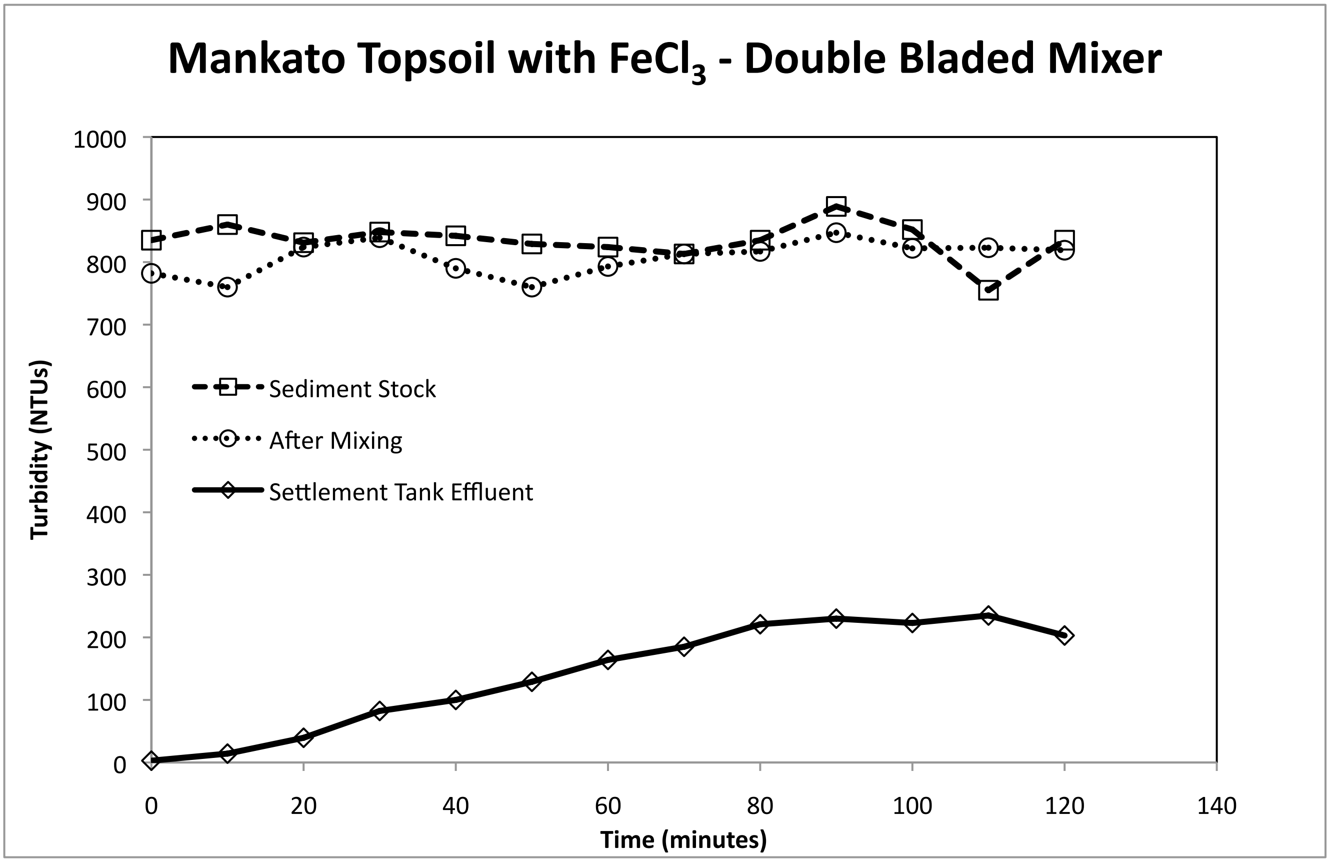


Environmental Engineering Lab
MSU Manakato

Flocculent Mixing Analysis

Analyst: Alex Raymond
Date: March 23, 2013

	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	835	782	2.89	
Mankato Topsoil	10	860	760	14.17	
Soil Mass (g)	20	831	824	39.5	
Water (gal)	30	848	839	82.4	
Sediment Stock Conc.	40	842	790	100	Floc stock nozzle
100 g/gal	50	829	760	129	noted as clogged
	60	824	793	164	
Flocculant	70	813	813	185	
35% Ferric Chloride	80	835	817	221	insufficient floc stock
Floc Vol (mL) 2	90	889	847	230	noted. Not enough
Water (L) 1	100	852	822	223	has been injected.
Floc Stock Conc.	110	755	823	235	(approx half dose)
2 mL/L	120	835	819	203	
Sediment Stock Flow	Averages	834	807	141	76%
500 mL/min				83%	2-Hour Removal
Floc Stock Flow Rate					
25 mL/min					
Total Flow Rate					
550 mL/min					
Floc Final Conc.					
0.09 mL/L					
Sediment Mixing Method					
Air					
Water Temp 22 deg C					
Flash Mixing Method					
Double Blade Mixer					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Mankato Topsoil with $FeCl_3$ - Double Bladed Mixer
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140

Flocculent Mixing Analysis

Analyst: Sam Stoffels
Date: March 23, 2013

Soil Sample & Strata
Mankato Topsoil
Soil Mass (g)
Water (gal)
Sediment Stock Conc.
100 g/gal

Flocculant
35% Ferric Chloride
Floc Vol (mL) 2
Water (L) 1
Floc Stock Conc.
2 mL/L

Sediment Stock Flow
500 mL/min
Floc Stock Flow Rate
25 mL/min
Total Flow Rate
550 mL/min

Floc Final Conc.
0.09 mL/L

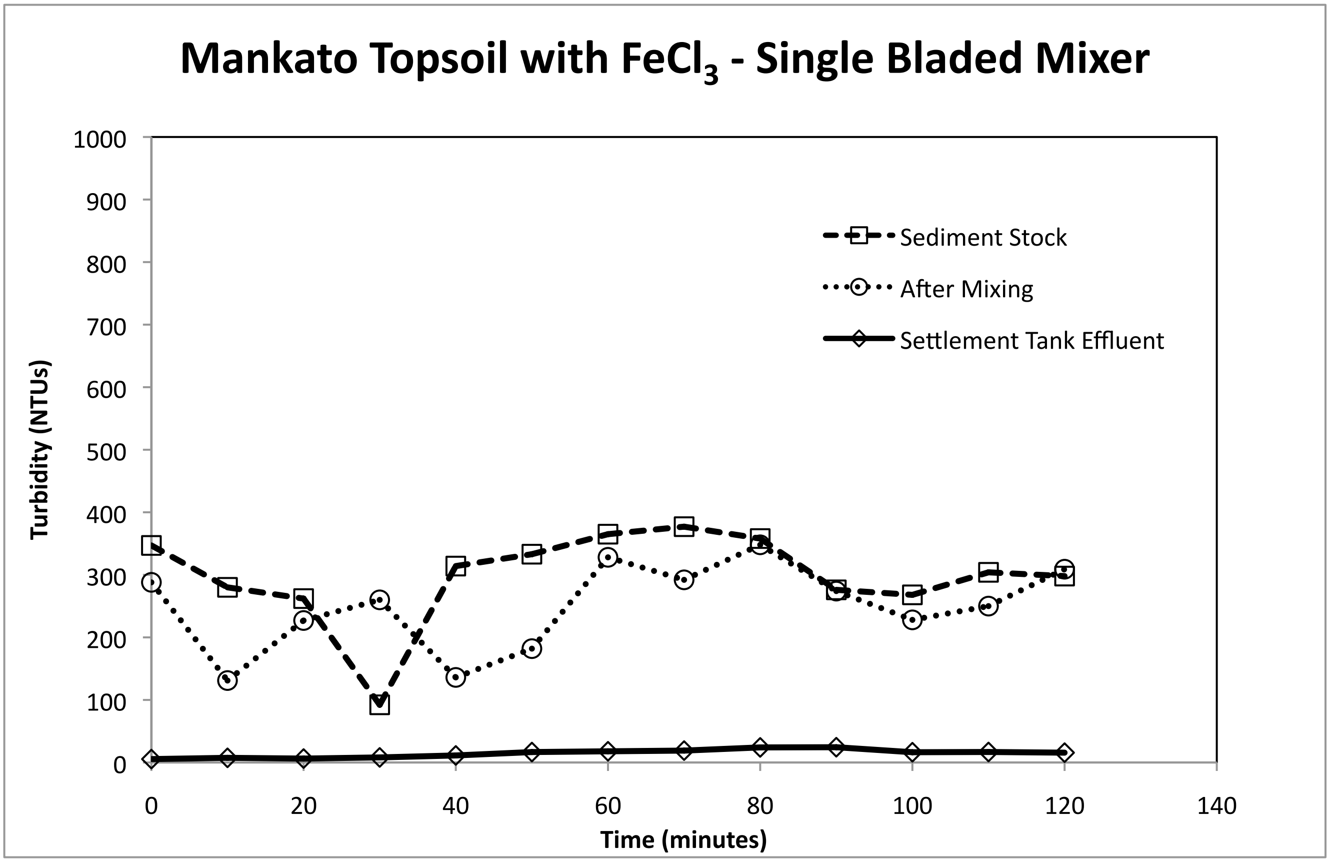
Sediment Mixing Method
Air
Water Temp 22 deg C

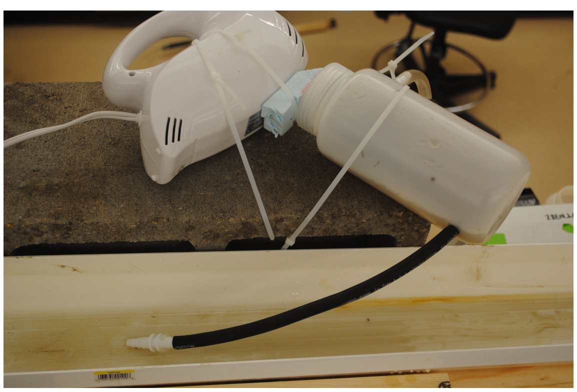
Flash Mixing Method
Single Blade Mixer

Slow Mixing Method
Baffle

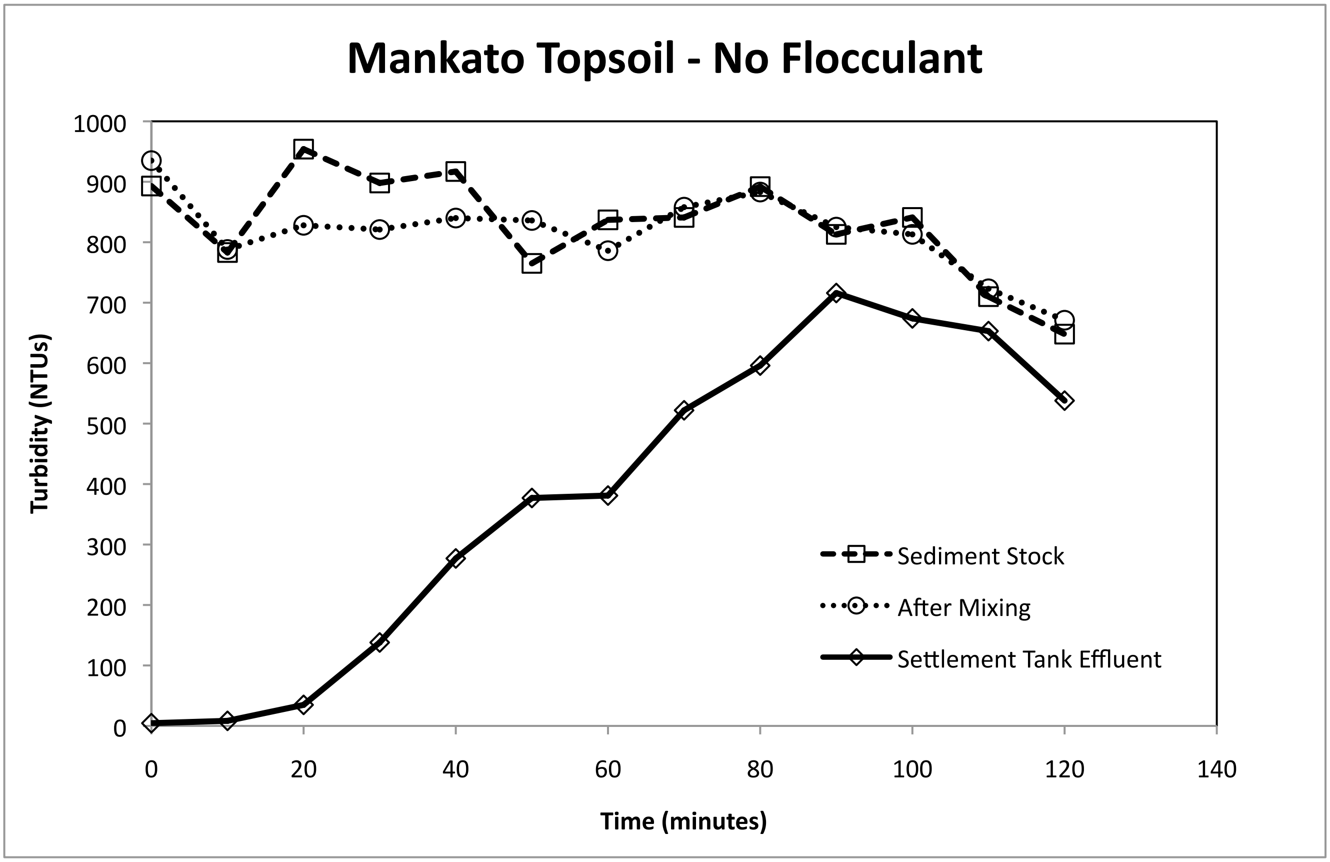
Sedimentation Method
20 gal Aquarium

Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
0	347	288	5.43	
10	280	131	7.43	
20	262	227	6.26	
30	92.2	260	8.09	
40	314	136	11.25	
50	333	182	16.67	
60	365	328	17.88	
70	377	292	19	
80	358	348	24.1	
90	276	274	24.4	
100	268	228	16.39	
110	304	250	16.78	
120	298	309	15.7	
Averages	298	250	15	95%
			95%	2-Hour Removal


Mankato Topsoil with FeCl3 - Single Bladed Mixer
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent



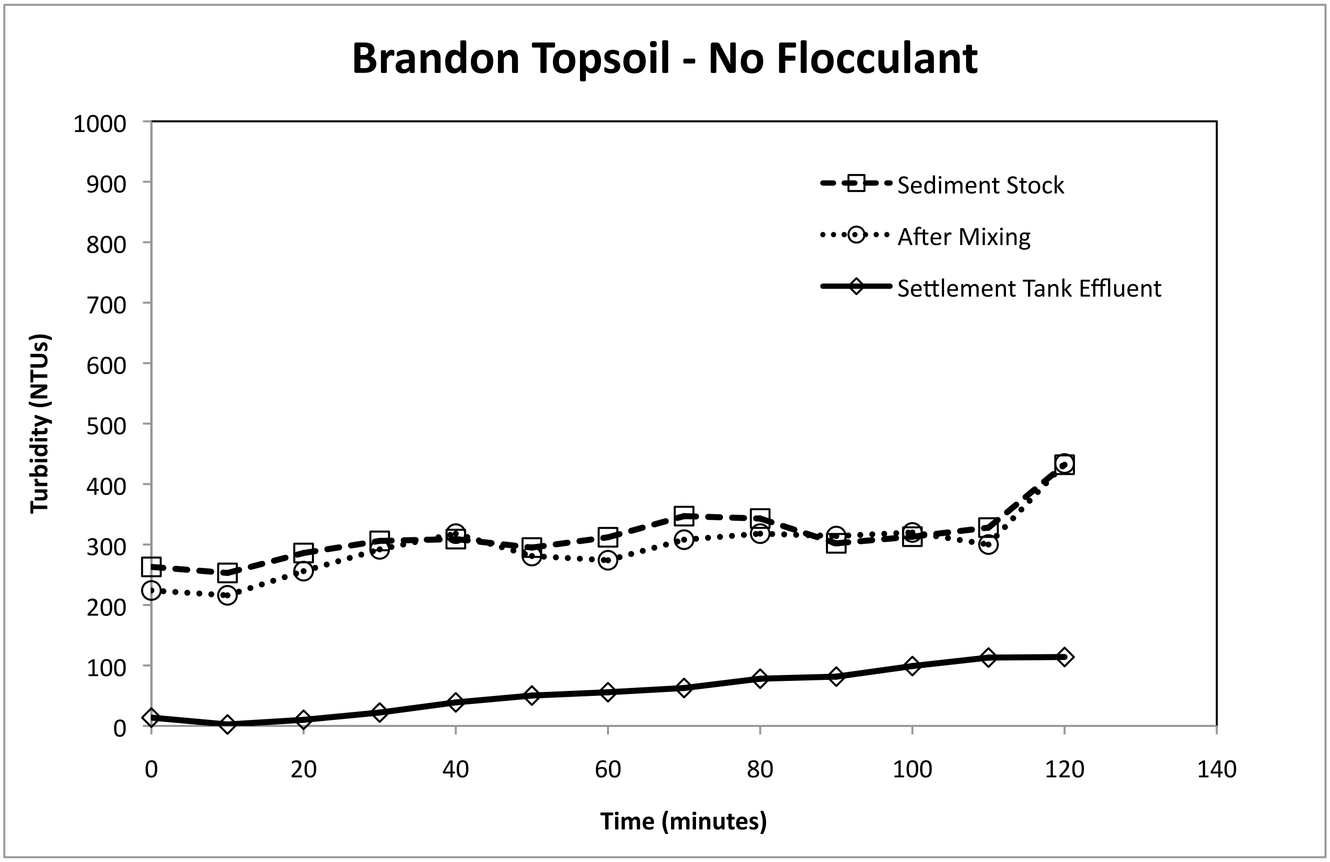
		Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata		0	893	935	4.49	
Mankato Topsoil		10	783	788	8.38	
Soil Mass (g)		20	954	828	34.8	
Water (gal)		30	898	821	138	
Sediment Stock Conc.		40	917	840	277	
100	g/gal	50	765	836	377	
		60	837	786	381	
Flocculant		70	841	858	522	
none		80	892	883	596	
Floc Vol (mL)	0	90	813	825	716	
Water (L)	0	100	841	813	674	
Floc Stock Conc.		110	710	723	653	
0	mL/L	120	648	671	538	
Sediment Stock Flow		Averages	830	816	378	35%
500	mL/min				54%	2-Hour Removal
Floc Stock Flow Rate						
0	mL/min					
Total Flow Rate						
500	mL/min					
Floc Final Conc.						
0.00	mL/L					
Sediment Mixing Method						
Air						
Water Temp	22 deg C					
Flash Mixing Method						
None						
Slow Mixing Method						
Baffle						
Sedimentation Method						
20 gal Aquarium						


Mankato Topsoil - No Flocculant
Turbidity (NTUs)
1000
900
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent

Flocculent Mixing Analysis

Analyst: Sam Stoffels
Date: March 23, 2013

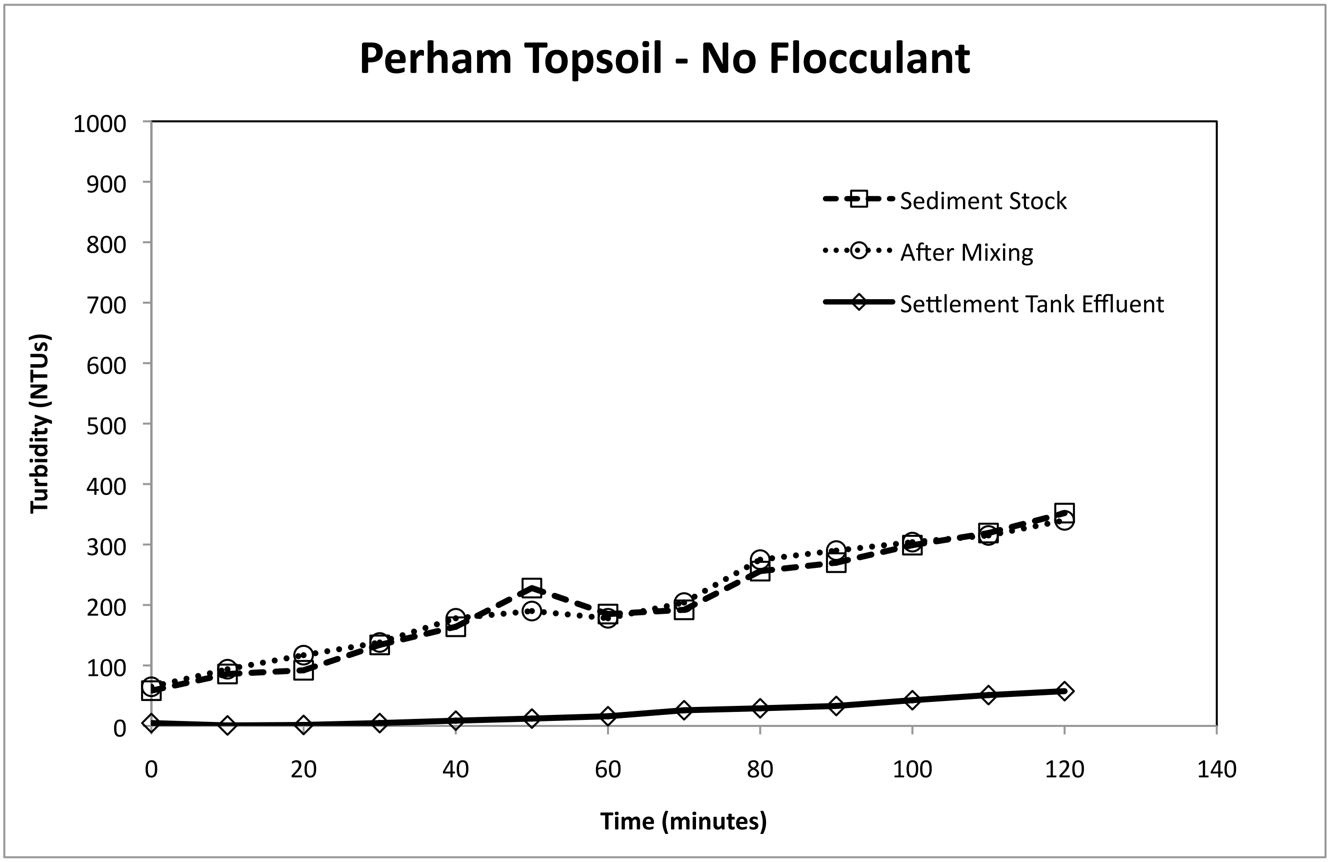
		Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata		0	263	224	13.73	
Brandon Topsoil		10	253	216	2.4	
Soil Mass (g)	2880	20	286	256	10.08	
Water (gal)	28.86	30	306	292	22.1	
Sediment Stock Conc.		40	309	318	38.9	
100	g/gal	50	295	281	50.2	
		60	312	274	55.7	
Flocculant		70	347	308	62.7	
none		80	343	318	78.1	
Floc Vol (mL)	0	90	302	314	81.5	
Water (L)	0	100	313	320	99	
Floc Stock Conc.		110	328	300	113	
0	mL/L	120	432	434	114	
Sediment Stock Flow		Averages	315	297	57	64%
500	mL/min				82%	2-Hour Removal
Floc Stock Flow Rate						
0	mL/min					
Total Flow Rate						
500	mL/min					
Floc Final Conc.						
0.00	mL/L					
Sediment Mixing Method						
Air						
Water Temp	22 deg C					
Flash Mixing Method						
None						
Slow Mixing Method						
Baffle						
Sedimentation Method						
20 gal Aquarium						


Brandon Topsoil - No Flocculant
Turbidity (NTUs)
Time (minutes)
Sediment Stock
After Mixing
Settlement Tank Effluent
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140

Flocculent Mixing Analysis

Analyst: Sam Stoffels
Date: March 23, 2013

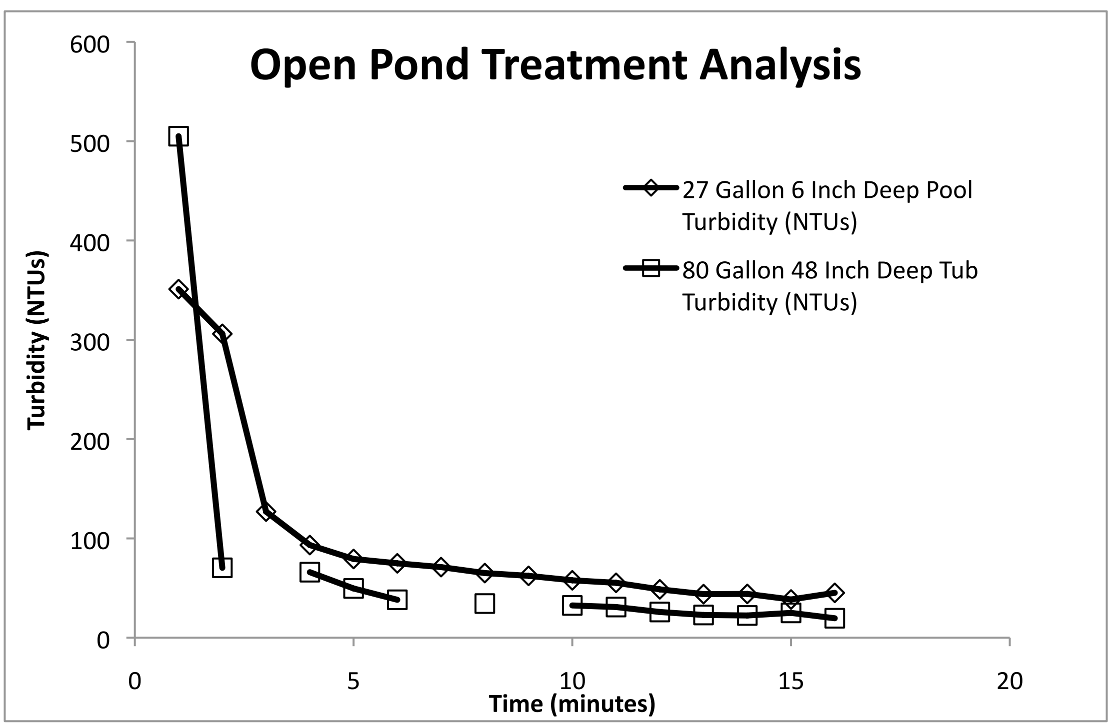
	Elapsed Time (min)	Sediment Stock (NTUs)	After Mixing (NTUs)	Settlement Tank Effluent (NTUs)	Notes
Soil Sample & Strata	0	58.3	64.7	4.72	
Perham Topsoil	10	85.9	93.8	0.82	
Soil Mass (g): 1150	20	92	117	1.59	
Water (gal): 28.86	30	134	138	4.72	
Sediment Stock Conc.	40	164	178	8.69	
39.8 g/gal	50	228	190	12.13	
	60	185	178	15.99	
Flocculant	70	192	204	25.9	
none	80	256	275	29.1	
Floc Vol (mL): 0	90	270	290	33.0	
Water (L): 0	100	299	304	42.5	
Floc Stock Conc.	110	319	315	51.0	
0 mL/L	120	352	340	57.5	
Sediment Stock Flow	Averages	203	207	22	72%
500 mL/min				89%	2-Hour Removal
Floc Stock Flow Rate					
0 mL/min					
Total Flow Rate					
500 mL/min					
Floc Final Conc.					
0.00 mL/L					
Sediment Mixing Method					
Air					
Water Temp: 22 deg C					
Flash Mixing Method					
None					
Slow Mixing Method					
Baffle					
Sedimentation Method					
20 gal Aquarium					


Perham Topsoil - No Flocculant
Sediment Stock
After Mixing
Settlement Tank Effluent
Turbidity (NTUs)
Time (minutes)
0
100
200
300
400
500
600
700
800
900
1000
0
20
40
60
80
100
120
140

Appendix E – Open Pond Treatment Model Analysis

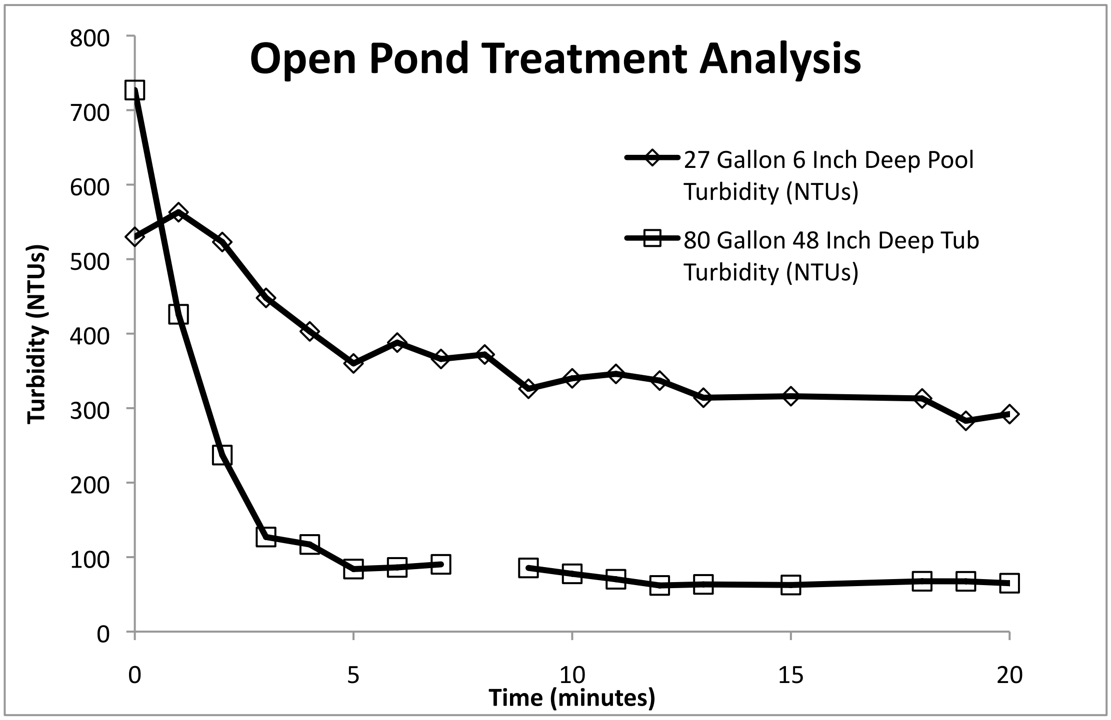
25 g/L Mankato Topsoil 2 minute rapid mix
0.2 mL/L Ferric Chloride 35% Pool: Turbine Mixer Tub: Air Mix
Direct apply Turbidity measured 3 inches below surface

Time (minutes)	27 Gallon 6 Inch Deep Pool Turbidity (NTUs)	80 Gallon 48 Inch Deep Tub Turbidity (NTUs)
1.0	351	505
2.0	306	70.4
3.0	127	
4.0	93.3	66
5.0	79.3	49.6
6.0	74.9	38.2
7.0	71.1	
8.0	65.1	34.4
9.0	62.3	
10.0	57.8	32.5
11.0	55.3	30.9
12.0	48.7	25.9
13.0	43.9	22.9
14.0	44.1	22.4
15.0	38.5	25
16.0	45.2	19.6



25 g/L Mankato Topsoil 2 minute rapid mix
0.2 mL/L Ferric Chloride 35% Pool: Air Mix Tub: Air Mix
Direct apply Turbidity measured 3 inches below surface

Time (minutes)	27 Gallon 6 Inch Deep Pool Turbidity (NTUs)	80 Gallon 48 Inch Deep Tub Turbidity (NTUs)	
0.0	530	727	
1.0	563	426	
2.0	523	237	
3.0	448	127	
4.0	403	117	
5.0	360	84	
6.0	388	86.2	
7.0	366	90.3	
8.0	372		
9.0	326	85.5	
10.0	340	77.6	
11.0	346	70.3	
12.0	337	62	
13.0	314	63.4	
15.0	316	62.6	
18.0	313	67.6	air mix
19.0	283	67.5	
20.0	292	65	
21.0	292	55.1	
22.0	281	56.1	
24.0	277	56.8	
25.0	283	51.7	
26.0	278		


Open Pond Treatment Analysis
27 Gallon 6 Inch Deep Pool Turbidity (NTUs)
80 Gallon 48 Inch Deep Tub Turbidity (NTUs)
Turbidity (NTUs)
Time (minutes)
0
100
200
300
400
500
600
700
800
0
5
10
15
20

Appendix F – Column Study Analysis

Column Study Test: 25 g/L Mankato Topsoil, Ferric Chloride 35% at 0.2 ml/L, 2 min Rapid Mix, 0 Slow Mix

Turbidity [NTU]								
		Time [min]						
Group	Depth[ft]	0	10	20	30	40	50	60
J Burns and D West	0	330	72					
		276	81.3					
		285						
	2	252	146	22.1	17.04	17.17	17.54	15.43
		243	151	22.7	18.57	17.24	21.7	16.86
		236						
	4	248	192	45.1	16.5	14.41	16.73	12.87
		216	201	39.7	16.35	15.47	17.19	16.19
		231						
	6	339	305	69.8	12.71	12.04	13.49	12.15
		318	322	90	15.72	13.01	16.07	11.96
		313						
C Jacobsen and E Jaiteh	0	232	88					
		376	107					
	2	488	280	24.4	39.6	24.3	21.8	17
		620	249	34.9	23.5	20.2	21.2	15.93
	4	620	160	220	55	25.1	37.1	41.7
		612	469	187	32.9	21	31.2	34.4
	6	560	586	296	99	15.01	14.14	12.73
		586	588	209	154	23.5	12.1	12.69
Z Lingl and A Engel	0	551						
		456						
	2	492	275	109	188	36.8	25.5	16.34
		428	218	73.4	137	33.5	25.6	15.85
	4	369	623	233	203	32.2	22.9	23.9
		382	622	354	160	34.9	21.4	23.4
	6	410	512	189	212	70.1	20.4	15.45
		535	596	110	164	46.8	16.87	13.67

Turbidity [NTU]								
		Time [min]						
Group	Depth[ft]	0	10	20	30	40	50	60
K Fischer and A Stanek	0							
	2	276	85.3	43.2	46.4	26.9	21.4	16.2
		309	87.2	42.7	34.6	35.6	21.5	18.94
		284	82.2	47.1	39.0	32.8	22.6	12.24
	4	587	213	71.2	90.4	20.9	17.72	19.18
		571	226	64.4	42.1	32.6	20.9	14.97
		579	218	68.4		18.7	17.95	16.8
	6	362	328	38.3	64	33.3	26.6	20.5
		429	345	64.1	55.9	28.8	21.8	24.4
		462	339	60.4	66.1	19.77	23.3	24.9
S Bulfer and R Johnson	0	650	330					
		635	340					
		625	338					
	2	640	492	159	82.5	39.4	57.8	36.4
		633	443	210	48.6	70	64.3	39.6
		650	622	168	80.3	90	54.5	35
	4	497	529	605	106	33.3	39.8	22.4
		550	478	605	66.7	36	38.2	32.2
		311	466	558	112	33.3	37.6	33.2
	6	680	644	666	43.9	37.1	28.5	21.1
		578	621	790	57.4	49.6	33.5	25.1
		578	639	765	47	54	32.1	20.9
G Gomez and D Draper	0	329	84.1					
		337						
		349						
	2	386	156	47	33.9	28.8	21.8	20.5
		391	150	45.1	33.8	28.7	22.7	20.5
		393						
	4	372	171	47.2	37.1	28.9	25.4	22.2
		379	167	49.5	35.6	29	26.4	22.9
		389						
	6	309	331	62.8	26.2	23.9	20.5	20.6
		350	297	58.7	28.2	23.1	20.3	22
		369						

Turbidity [NTU]								
		Time [min]						
Group	Depth[ft]	0	10	20	30	40	50	60
T Elbert and S Huneke	0	388	180	99.5	86.7	71.9	78.6	
		425	185	86.1	91.2	81	117	
		383	183	77.5	94.2	62.8	58.2	
	2	371	285	87.2	179	46	27.8	24.1
		371	426	96	315	44.1	26.6	24.8
		351	287	64.4	308	40.7	31.3	23
	4	376	716	221	66.5	44.7	22.2	25
		307	579	193	55.1	32.9	22.8	28.3
		396	561	265	63.5	31.1	14.84	25.6
	6	251	621	277	155	41	15.4	16.53
		275	546	293	124	23.4	15.89	13.21
		240	671	278	96.7	22.8	15.63	13.69
D Tipp and A Raymond	0	505	176					
		497	209					
		468	217					
	2	604	310	156	119	185	61.2	52.1
		427	403	182	134	202	50.9	40.6
		662	297	175	146	144	48.7	58.3
	4	497	731	302	212	160	51.8	57.5
		495	659	342	201	192	54.5	48.1
		521	765	311	164	154	54	44.9
	6	608	776	386	108	58.1	37.1	29.2
		549	655	327	75.3	40.3	43.5	38.6
		587	771	286	73.1	48	33.4	28.3
S Muir and M Origer	0	539						
		681						
		734						
	2	494	214	150	53.2	38.2	58.2	41.2
		508	202	129	60.5	42.3	45.9	41.2
		429	280	105	55.6	46	63.5	40.7
	4	294	326	49.4	23.6	18.2	14.7	13.2
		278	338	43.2	22.8	17.1	14.8	12.1
		290	366	43.2	21.7	18.1	16	12.9
	6	557	348	103	48.4	19.6	22.4	14.3
		449	332	109	33	24	22.6	16.5
		610	270	117	38.1	22	21.3	15.8

Column Study Test: 25 g/L Mankato Topsoil, Ferric Chloride 35% at 0.2 ml/L, 2 min Rapid Mix, 0 Slow Mix

		Starting Turbidity	Removals (% based on average starting turbidity reading at depth)					
			Time [min]					
Group	Depth[ft]		10	20	30	40	50	60
J Burns and D West	0	330	76%					
		276	73%					
		285						
	2	252	40%	91%	93%	93%	93%	94%
		243	38%	91%	92%	93%	91%	93%
		236						
	4	248	17%	81%	93%	94%	93%	94%
		216	13%	83%	93%	93%	93%	93%
		231						
	6	339	6%	78%	96%	96%	96%	96%
		318	0%	72%	95%	96%	95%	96%
		313						
C Jacobsen and E Jaiteh	0	232	71%					
		376	65%					
	2	488	49%	96%	93%	96%	96%	97%
		620	55%	94%	96%	96%	96%	97%
	4	620	74%	64%	91%	96%	94%	93%
		612	24%	70%	95%	97%	95%	94%
	6	560	-2%	48%	83%	97%	98%	98%
		586	-3%	64%	73%	96%	98%	98%
Z Lingl and A Engel	0	551						
		456						
	2	492	40%	76%	59%	92%	94%	96%
		428	53%	84%	70%	93%	94%	97%
	4	369	-66%	38%	46%	91%	94%	94%
		382	-66%	6%	57%	91%	94%	94%
	6	410	-8%	60%	55%	85%	96%	97%
		535	-26%	77%	65%	90%	96%	97%

		Starting Turbidity	Removals (% based on average starting turbidity reading at depth)					
			Time [min]					
Group	Depth[ft]		10	20	30	40	50	60
K Fischer and A Stanek	0							
	2	276	71%	85%	84%	91%	93%	94%
		309	70%	85%	88%	88%	93%	93%
		284	72%	84%	87%	89%	92%	96%
	4	587	63%	88%	84%	96%	97%	97%
		571	61%	89%	93%	94%	96%	97%
		579	62%	88%	100%	97%	97%	97%
	6	362	21%	91%	85%	92%	94%	95%
		429	17%	85%	87%	93%	95%	94%
		462	19%	86%	84%	95%	94%	94%
S Bulfer and R Johnson	0	650	48%					
		635	47%					
		625	47%					
	2	640	23%	75%	87%	94%	91%	94%
		633	31%	67%	92%	89%	90%	94%
		650	3%	74%	87%	86%	91%	95%
	4	497	-17%	-34%	77%	93%	91%	95%
		550	-6%	-34%	85%	92%	92%	93%
		311	-3%	-23%	75%	93%	92%	93%
	6	680	-5%	-9%	93%	94%	95%	97%
		578	-1%	-29%	91%	92%	95%	96%
		578	-4%	-25%	92%	91%	95%	97%
G Gomez and D Draper	0	329	75%					
		337						
		349						
	2	386	60%	88%	91%	93%	94%	95%
		391	62%	88%	91%	93%	94%	95%
		393						
	4	372	55%	88%	90%	92%	93%	94%
		379	56%	87%	91%	92%	93%	94%
		389						
	6	309	3%	82%	92%	93%	94%	94%
		350	13%	83%	92%	93%	94%	94%
		369						

		Starting Turbidity	Removals (% based on average starting turbidity reading at depth)					
			Time [min]					
Group	Depth[ft]		10	20	30	40	50	60
T Elbert and S Huneke	0	388	55%	75%	78%	82%	80%	
		425	54%	78%	77%	80%	71%	
		383	54%	81%	76%	84%	85%	
	2	371	22%	76%	51%	87%	92%	93%
		371	-17%	74%	14%	88%	93%	93%
		351	21%	82%	15%	89%	91%	94%
	4	376	-99%	39%	82%	88%	94%	93%
		307	-61%	46%	85%	91%	94%	92%
		396	-56%	26%	82%	91%	96%	93%
	6	251	-143%	-8%	39%	84%	94%	94%
		275	-114%	-15%	51%	91%	94%	95%
		240	-163%	-9%	62%	91%	94%	95%
D Tipp and A Raymond	0	505	64%					
		497	57%					
		468	56%					
	2	604	45%	72%	79%	67%	89%	91%
		427	29%	68%	76%	64%	91%	93%
		662	47%	69%	74%	74%	91%	90%
	4	497	-45%	40%	58%	68%	90%	89%
		495	-31%	32%	60%	62%	89%	90%
		521	-52%	38%	67%	69%	89%	91%
	6	608	-33%	34%	81%	90%	94%	95%
		549	-13%	44%	87%	93%	93%	93%
		587	-33%	51%	87%	92%	94%	95%
S Muir and M Origer	0	539						
		681						
		734						
	2	494	55%	69%	89%	92%	88%	91%
		508	58%	73%	87%	91%	90%	91%
		429	41%	78%	88%	90%	87%	91%
	4	294	-13%	83%	92%	94%	95%	95%
		278	-18%	85%	92%	94%	95%	96%
		290	-27%	85%	92%	94%	94%	96%
	6	557	35%	81%	91%	96%	96%	97%
		449	38%	80%	94%	96%	96%	97%
		610	50%	78%	93%	96%	96%	97%

Average Starting Turbidity (NTUs)	438					
	10 min	20 min	30 min	40 min	50 min	60 min
Average Removal All Tests & Depths	16%	60%	80%	90%	93%	94%
Average Turbidity All Tests & Depths (NTUs)	361	181	85	46	31	25

Minnesota State University, Mankato
Department of Mechanical and Civil Engineering

Spring 2013

CIVE 436 – Civil Engineering Experimentation

Experiment 10
Sedimentation Lab

Objective: Evaluate water quality for the design of primary sedimentation basin.

Method: Perform evaluations of water quality during sedimentation performed after flocculation

Evaluations:

- Turbidity

Note: perform all analyses <u>in triplicate</u> and report all results as MEAN ± STANDARD DEVIATION units (%RSD), where % RSD = relative standard deviation = standard deviation/mean (expressed as %).

<u>Materials Available:</u>
8 gallons water (obtain from eye wash station)
0.8 kg soil (divide in two)
6 mL of Ferric Chloride

<u>Equipment Available:</u>
Two 5-gal buckets
Turbidity meter
Drill & mixer paddle
Column testing apparatus
Four 250 mL Erlenmeyer flasks

Experiment 10
Sedimentation Lab

LAB METHOD & MINIMUM REQUIREMENTS:

1. Plan out whole lab and set up a table of measurements and observations for before and after all planned actions. Label the four Erlenmeyer flasks with the depth of measurement (dedicate one flask to each measurement level).

2. TURBIDITY: Calibrate turbidity meter using provided standards, and note meter manufacture and model. Mix sample. Place ~20 mL sample water into turbidity vial and cap. Place vial into turbidity meter, cap with shroud and press read. Record value. Dump out sample and rinse vial with DI water.

3. Take two buckets of water and the soil onto the testing platform. Homogenize the two buckets of sample water (4 gal) and 0.4 kg of soil using the drill and mixer paddle. Add 3 mL of Ferric Chloride to each bucket and mix well for one minute alternating between buckets. Lift the buckets one by one and pour into the column set for your test. Begin the time measurement.

4. Take turbidity samples (about 100 mL is plenty) from each sampling port and test for turbidity in triplicate. Sample at 0, 10, 20, 30, 40, 50 and 60 minutes.

5. After the 60 minute sampling, place a bucket over the clean out to redirect the water flow and raise the pool to its' full water holding level. Blocking behind the bucket firmly, CAREFULLY remove the lower cleanout cap and drain the column. Assist the instructor in pumping off the water and scraping up the sludge (sediment) from the pool until the pool is emptied.

6. Prepare a report of all methods and observations. Make use of tables as needed, particularly for the evaluation of the triplicate turbidity results. Include photographs. Prepare a graph of turbidity level by depth and time (use average of turbidity but do not include standard deviation information on graph). Interpret results and make conclusions. Assess potential for error.

Appendix G – Flocculant Aided Filtration Analysis

Run	Sediment Dose	Sediment	Sediment Mixing	Coagulant & Strength	Final Dose of Coagulant	Rapid Mix	Slow Mix	Settle
1	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	20 min
2	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	no
3	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	no	no
4	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	20 min
5	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	no
6	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	no	no
7	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	20 min
8	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	no
9	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	no	no
10	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	20 min
11	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	no
12	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	no	no

	Filter #1: #4 GAC					Filter #2: 4-10 Sand				
Run	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	16.00	34.7	14.15	10.39	1.05	5.09	34.3	7.26	3.17	1.06
2	7.47	261	7.12	6.56	1.04	3.19	23.5	10.97	3.03	1.05
3	305	136	206	19.04	1.42	262	255	136	11.8	1.19
4	13.74	69.7	19.02	10.43	1.06	8.38	17.96	10.98	16.45	1.02
5	103	104	74.1	30.0	1.04	25.8	66.3	24.5	23.6	1.56
6	372	193	206	17.14	1.32	225	275	133	8.24	1.32
7	7.00	19.09	12.86	3.88	1.02	8.58	24.1	8.68	5.28	1.00
8	166	134	117	48.9	1.03	84.8	98.6	82.5	33.2	1.06
9	350	398	195	23.8	1.17	256	188	139	30.5	N/A
10	143	142	104	53.0	1.02	85.6	76.5	71.9	37.8	0.59
11	188	211	141	44.4	1.03	126	169	162	36.1	1.03
12	422	209	198	58.4	1.40	199	189	189	28.3	1.05

	Filter #3: 10-20 Sand					Filter #4: 54 Garnet				
Run	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	4.82	34.6	7.45	2.74	1.06	8.77	22.4	5.39	3.27	1.06
2	5.05	42.2	12.72	4.00	1.05	2.99	29.8	5.13	3.17	1.06
3	197	215	128	10.6	1.12	299	301	159	18.15	1.14
4	10.8	61.9	14.97	8.72	1.03	18.44	74.9	19.3	13.57	1.01
5	55.0	105	42.9	27.9	1.01	94.8	92.9	79.6	42.3	1.06
6	210	205	78.6	10.91	N/A	313	303	135	15.82	N/A
7	6.63	21.5	6.61	3.53	1.00	9.79	16.85	10.12	3.95	1.02
8	88.3	106	68.7	40.4	1.01	108	99.8	89.3	47.1	1.03
9	296	307	142	22.0	1.01	320	338	318	16.55	1.15
10	98.0	94.0	67.7	56.8	1.01	86.7	70.0	67.1	36.5	0.59
11	114	215	83.7	33.50	1.07	141	121	104	45.6	1.16
12	241	289	246	48.4	1.17	286	315	256	50.3	0.58

	Filter #5: #4 GAC + 10-20 Sand					Filter #6: #4 GAC + 54 Garnet				
Run	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	7.90	26.0	5.42	2.93	1.04	6.36	23.7	5.64	4.70	1.07
2	5.75	85.4	19.94	4.40	1.10	8.44	25.7	6.16	3.62	1.10
3	350	217	141	13.76	1.29	268	229	155	9.55	1.16
4	9.77	65.2	25.0	9.91	1.02	27.0	78.3	26.3	18.13	0.59
5	83.3	91.0	75.6	32.5	1.05	87.9	73.8	78.9	32.7	1.01
6	341	382	149	12.98	1.06	237	181	126	11.11	2.39
7	8.03	39.7	10.72	4.05	1.04	7.56	22.5	6.71	3.92	1.00
8	174	162	157	64.8	1.05	124	102	94.4	37.6	1.02
9	312	478	208	20.1	1.04	319	179	112	22.6	1.06
10	187	122	110	74.1	1.03	95.8	96.1	72.7	38.3	0.59
11	159	139	108	39.40	1.00	204	211	124	41.3	1.05
12	349	318	276	54.0	2.11	332	254	202	46.2	1.04

Environmental Engineering Lab
MSU Manakato

Flocculant Filtration Analysis

Analyst: Ryan Johnson
Date: May 15, 2013

									Filter #1: #4 GAC			Filter #2: 4-10 Sand			Filter #3: 10-20 Sand			Filter #4: 54 Garnet			Filter #5: #4 GAC + 10-20 Sand			Filter #6: #4 GAC + 54 Garnet		
Run	Sediment Dose	Sediment	Sediment Mixing	Coagulant & Strength	Final Dose of Coagulant	Rapid Mix	Slow Mix	Settle	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Average Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	20 min	16.00	19.7	1.05	5.09	13.5	1.06	4.82	13.5	1.06	8.77	10.7	1.06	7.90	11.7	1.04	6.36	10.4	1.07
2	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	no	7.47	91.6	1.04	3.19	9.2	1.05	5.05	16.1	1.05	2.99	11.3	1.06	5.75	30.7	1.10	8.44	11.7	1.10
3	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	no	no	305	120.3	1.42	262	172.8	1.19	197	137.7	1.12	299	200.4	1.14	350	189.4	1.29	268	166.1	1.16
4	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	20 min	13.74	33.1	1.06	8.38	9.1	1.02	10.8	24.6	1.03	18.44	31.5	1.01	9.77	25.3	1.02	27.0	35.4	0.59
5	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	no	103	69.4	1.04	25.8	31.0	1.56	55.0	53.9	1.01	94.8	62.9	1.06	83.3	58.5	1.05	87.9	54.3	1.01
6	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	no	no	372	138.7	1.32	225	167.1	1.32	210	138.8	N/A	313	308.0	N/A	341	361.5	1.06	237	139.7	2.39
7	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	20 min	7.00	11.9	1.02	8.58	11.2	1.00	6.63	9.7	1.00	9.79	9.2	1.02	8.03	16.3	1.04	7.56	10.4	1.00
8	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	no	166	100.0	1.03	84.8	61.5	1.06	88.3	65.1	1.01	108	69.6	1.03	174	112.3	1.05	124	75.7	1.02
9	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	no	no	350	205.6	1.17	256	148.4	N/A	296	301.5	1.01	320	219.7	1.15	312	263.7	1.04	319	166.3	1.06
10	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	20 min	143	99.7	1.02	85.6	54.4	0.59	98.0	64.2	1.01	86.7	52.6	0.59	187	103.2	1.03	95.8	64.3	0.59
11	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	no	188	132.1	1.03	126	98.7	1.03	114	110.0	1.07	141	87.7	1.16	159	99.7	1.00	204	138.7	1.05
12	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	no	no	422	155.1	1.40	199	129.8	1.05	241	177.0	1.17	286	200.7	0.58	349	222.5	2.11	332	196.0	1.04

Environmental Engineering Lab
MSU Manakato

Flocculant Filtration Analysis

Analyst: Ryan Johnson
Date: May 15, 2013

			Average Turbidity of Filtrate (NTUs)			Reduction Due to Flocculant Addition		
Filter Column	Filtration Technique	Turbidity of Blank (NTUs)	1.25 mL/L	2.5 mL/L	5 mL/L	1.25 mL/L	2.5 mL/L	5 mL/L
1	conv	99.7	11.9	33.1	19.7	88.1%	66.8%	80.2%
1	direct	132.1	100	69.4	91.6	24.3%	47.5%	30.7%
1	inline	155.1	205.6	138.7	120.3	-32.6%	10.6%	22.4%
2	conv	54.4	11.2	9.1	13.5	79.4%	83.3%	75.2%
2	direct	98.7	61.5	31	9.2	37.7%	68.6%	90.7%
2	inline	129.8	148.4	167.1	172.8	-14.3%	-28.7%	-33.1%
3	conv	64.2	9.7	24.6	13.5	84.9%	61.7%	79.0%
3	direct	110	65.1	53.9	16.1	40.8%	51.0%	85.4%
3	inline	177	301.5	138.8	137.7	-70.3%	21.6%	22.2%
4	conv	52.6	9.2	31.5	10.7	82.5%	40.1%	79.7%
4	direct	87.7	69.6	62.9	11.3	20.6%	28.3%	87.1%
4	inline	200.7	219.7	308	200.4	-9.5%	-53.5%	0.1%
5	conv	103.2	16.3	25.3	11.7	84.2%	75.5%	88.7%
5	direct	99.7	112.3	58.5	30.7	-12.6%	41.3%	69.2%
5	inline	222.5	263.7	361.5	189.4	-18.5%	-62.5%	14.9%
6	conv	64.3	10.4	35.4	10.4	83.8%	44.9%	83.8%
6	direct	138.7	75.7	54.3	11.7	45.4%	60.9%	91.6%
6	inline	196	166.3	139.7	166.1	15.2%	28.7%	15.3%

Run	Sediment Dose	Sediment	Sediment Mixing	Coagulant & Strength	Final Dose of Coagulant	Rapid Mix	Slow Mix	Settle
1	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	20 min
2	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	no
3	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	no	no
4	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	20 min
5	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	no
6	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	no	no
7	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	20 min
8	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	no
9	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	no	no
10	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	20 min
11	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	no
12	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	no	no

Run	Beaker 1					Beaker 2					Beaker 3				
	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	16.00	34.7	14.15	10.39	1.05	5.09	34.3	7.26	3.17	1.06	4.82	34.6	7.45	2.74	1.06
2	7.47	261	7.12	6.56	1.04	3.19	235	10.97	3.03	1.05	5.05	42.2	12.72	4.00	1.05
3	305	136	206	19.04	1.42	262	255	136	11.8	1.19	197	215	128	10.6	1.12
4	13.74	69.7	19.02	10.43	1.06	8.38	17.96	10.98	16.45	1.02	10.8	61.9	14.97	8.72	1.03
5	103	104	74.1	30.0	1.04	25.8	66.3	24.5	23.6	1.56	55.0	105	42.9	27.9	1.01
6	372	193	206	17.14	1.32	225	275	133	8.24	1.32	210	205	78.6	10.91	N/A
7	7.00	19.09	12.86	3.88	1.02	8.58	24.1	8.68	5.28	1.00	6.63	21.5	6.61	3.53	1.00
8	166	134	117	48.9	1.03	84.8	98.6	82.5	33.2	1.06	88.3	106	68.7	40.4	1.01
9	350	398	195	23.8	1.17	256	188	139	30.5	N/A	296	307	142	22.0	1.01
10	143	142	104	53.0	1.02	85.6	76.5	71.9	37.8	0.59	98.0	94.0	67.7	56.8	1.01
11	188	211	141	44.4	1.03	126	169	162	36.1	1.03	114	215	83.7	33.50	1.07
12	422	209	198	58.4	1.40	199	189	189	28.3	1.05	241	280	246	48.4	1.17

Run	Beaker 4					Beaker 5					Beaker 6				
	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)	Turbidity in Beaker Tank (NTU)	Nonwoven Filter Filtrate Tubidity (NTU)	Woven Filter Filtrate Tubidity (NTU)	Paper Filter Filtrate Tubidity (NTU)	Filter Rate (vol/time)
1	8.77	22.4	5.39	3.27	1.06	7.90	26.0	5.42	2.93	1.04	6.36	23.7	5.64	4.70	1.07
2	2.99	29.8	5.13	3.17	1.06	5.75	85.4	19.94	4.40	1.10	8.44	25.7	6.16	3.62	1.10
3	299	301	159	18.15	1.14	350	217	141	13.76	1.29	268	229	155	9.55	1.16
4	18.44	74.9	19.3	13.57	1.01	9.77	65.2	25.0	9.91	1.02	27.0	78.3	26.3	18.13	0.59
5	94.8	92.9	79.6	42.3	1.06	83.3	91.0	75.6	32.5	1.05	87.9	73.8	78.9	32.7	1.01
6	313	303	135	15.82	N/A	341	182	149	12.98	1.06	237	181	126	11.11	2.39
7	9.79	16.85	10.12	3.95	1.02	8.03	39.7	10.72	4.05	1.04	7.56	22.5	6.71	3.92	1.00
8	108	99.8	89.3	47.1	1.03	174	162	157	64.8	1.05	124	102	94.4	37.6	1.02
9	320	338	318	16.55	1.15	312	478	208	20.1	1.04	319	179	112	22.6	1.06
10	86.7	70.0	67.1	36.5	0.59	187	122	110	74.1	1.03	95.8	96.1	72.7	38.3	0.59
11	141	121	104	45.6	1.16	159	139	108	39.40	1.00	204	211	124	41.3	1.05
12	286	315	256	50.3	0.58	349	318	276	54.0	2.11	332	254	202	46.2	1.04

Run	Sediment Dose	Sediment	Sediment Mixing	Coagulant & Strength	Final Dose of Coagulant	Rapid Mix	Slow Mix	Settle	Average Turbidity in Beaker Tank (NTU)	Average Nonwoven Filter Filtrate Tubidity (NTU)	Average Woven Filter Filtrate Tubidity (NTU)	Average Paper Filter Filtrate Tubidity (NTU)	Average Nonwoven Filter Rate (vol/time)
1	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	20 min	8.2	29.3	7.6	4.5	1.1
2	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	20 min	no	5.5	113.2	10.3	4.1	1.1
3	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	10 mL /2 L	1 min	no	no	280.2	225.5	154.2	13.8	1.2
4	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	20 min	14.7	61.3	19.3	12.9	1.0
5	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	20 min	no	75.0	88.8	62.6	31.5	1.1
6	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	5 mL /2 L	1 min	no	no	283.0	223.2	137.9	12.7	#VALUE!
7	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	20 min	7.9	24.0	9.3	4.1	1.0
8	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	20 min	no	124.2	117.1	101.5	45.3	1.0
9	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	2.5 mL /2 L	1 min	no	no	308.8	314.7	185.7	22.6	#VALUE!
10	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	20 min	116.0	100.1	82.2	49.4	0.8
11	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	20 min	no	155.3	177.7	120.5	40.1	1.1
12	50 g /2L	Mankato Topsoil	2 min	FeCl3 @ 20mL/L	NONE	1 min	no	no	304.8	260.8	227.8	47.6	1.2

Environmental Engineering Lab
MSU Manakato

Flocculant Filtration Analysis

Analyst: FA HM
Date: May 28, 2013

Nonwoven Membrane Filtration

	Turbidity of Blank as Filtered (NTUs)	Average Turbidity of Filtrate (NTUs)			Reduction Due to Flocculant Addition		
		1.25 mL/L	2.5 mL/L	5 mL/L	1.25 mL/L	2.5 mL/L	5 mL/L
Conv	100	24.0	61.3	29.3	76.1%	38.7%	70.7%
Direct	178	117.1	88.8	113.2	34.1%	50.0%	36.3%
Indirect	261	314.7	223.2	225.5	-20.6%	14.4%	13.5%

Woven Membrane Filtration

	Turbidity of Blank as Filtered (NTUs)	Average Turbidity of Filtrate (NTUs)			Reduction Due to Flocculant Addition		
		1.25 mL/L	2.5 mL/L	5 mL/L	1.25 mL/L	2.5 mL/L	5 mL/L
Conv	82	9.3	19.3	7.6	88.7%	76.6%	90.8%
Direct	121	101.5	62.6	10.3	15.8%	48.0%	91.4%
Indirect	228	185.7	137.9	154.2	18.5%	39.4%	32.3%

Paper Membrane Filtration

	Turbidity of Blank as Filtered (NTUs)	Average Turbidity of Filtrate (NTUs)			Reduction Due to Flocculant Addition		
		1.25 mL/L	2.5 mL/L	5 mL/L	1.25 mL/L	2.5 mL/L	5 mL/L
Conv	49	4.1	12.9	4.5	91.7%	74.0%	90.8%
Direct	40	45.3	31.5	4.1	-13.1%	21.4%	89.7%
Indirect	48	22.6	12.7	13.8	52.5%	73.3%	71.0%