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MAPPING TECHNIQUES FOR SOIL EROSION: MODELING STREAM POWER INDEX IN EASTERN NORTH DAKOTA

by

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Submitted to the Graduate Faculty

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for the degree of

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This thesis, submitted by Rick James Thalacker in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

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Wayne Swisher
Dean of the Graduate School

May 8, 2014
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PERMISSION

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Rick James Thalacker
April 14, 2014

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ABSTRACT

Soil erosion is a worldwide problem that can negatively affect surface water through the introduction of sediment, nutrients (eg. nitrogen, phosphorus), pesticides, and other chemicals. Soil erosion is often exacerbated by agricultural and other types of land use. The objective of this study was to identify gully locations in agricultural fields adjacent to the Turtle and Forest rivers in eastern North Dakota that accumulate surface flow resulting in areas of critical surface erosion in a GIS using the Stream Power Index (SPI). A field survey was conducted to verify the accuracy of the terrain analysis at identifying 391 gully and inlet locations. Sediment samples were collected from 44 inlets/gully locations and analyzed for soil texture, pH and conductivity to characterize the material being eroded and transported. The pH levels for the soil samples ranged from neutral to moderately alkaline and the EC values represented soils that were either non-saline or slightly saline. Sand was the dominant separate for both study areas. This study found that SPI signatures at or above critical erosion levels can be used to target precision conservation in individual fields adjacent to the Turtle and Forest rivers.

CHAPTER I

INTRODUCTION

Soil erosion is a worldwide problem that can negatively affect surface water quality through the introduction of sediment, nutrients (e.g. nitrogen, phosphorus), pesticides, and other chemicals (Morgan 2005). Worldwide, approximately 76.2 billion tonnes of fertile topsoil is lost from agricultural fields, in the U.S. that loss is approximately 7.1 million tonnes. Soil losses worldwide or on a local scale are not sustainable and result in the introduction of fertilizers and soil amendments to supplement beneficial quantities that were present (Pimentel 2000). The addition of these supplements can be toxic to aquatic and terrestrial biota, surface water for drinking, agriculture, and industry.

Erosion impacts a soil's productivity by decreasing the efficiency of plant nutrient use, decreasing the rooting depth of plants and reducing the soil's water-holding capacity. Erosion also increases surface runoff, decreases soil permeability and reduces infiltration rates (O'Geen and Schwankl 2006). Off-site erosional problems arise from sedimentation downstream or downwind, which reduces the capacity of rivers and drainage ditches, enhances the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs (Morgan 2005).

Gully erosion, the focus of this study, is an advanced stage of rill erosion. A gully is an open, incised surface channel that has been eroded to the point where it cannot be smoothed over by normal tillage operations (Hilborn and Stone 1988). Land use practices such as agriculture often compound the effects of soil erosion resulting in gully formation. Causes can include factors such as tillage practices, increases in surface or sub-surface water flow, and change of vegetation type resulting in a decrease in erosion resistance and sloughing at the head of the gully (Hilborn and Stone 1988).

In North Dakota, more than 11.3 million surface hectares are in cropland and 4.0 million hectares in rangeland. The North Dakota State Water Commission has identified soil erosion as a concern in contributing to sedimentation in lakes and reservoirs. In particular, soil erosion in the Red River Basin has been identified as problematic because of loss of soil and the pollution of lakes and streams (North Dakota State Water Commission 2005). Local soil conservation districts work with local producers, the Natural Resource Conservation Service (NRCS), and other state and federal agencies to implement best management practices (BMPs) to reduce the amount of soil erosion. Using soil prediction models to identify locations prone to soil erosion can help these agencies to prioritize their efforts for implementing BMPs.

Commonly used empirical and process-based erosion models are the Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), the Soil and Water Assessment Tool (SWAT), and the Water Erosion Prediction Project (WEPP). These models allow for the prediction of sediment runoff and water-quality, but fail to pinpoint locations of potential erosion.

Digital terrain analysis is a landscape modeling technique using Digital Elevation Models (DEM) in a geographic information system (GIS) to describe hydrological processes relating to erosion through the calculations of both primary and secondary attributes. Primary attributes are calculated directly from the DEM and secondary attributes are calculated from both the primary attributes and physically based or empirically derived indices (Wilson and Gallant 2000). The primary attributes of the digital terrain analysis that are included in this study are slope, flow direction (aspect), and flow accumulation (upslope contributing area). The secondary attribute included in this study is the Stream Power Index (SPI), which is computed from two or more primary attributes.

High resolution 1-m LiDAR bare earth data are available for the Red River Basin of North Dakota, Minnesota and South Dakota. This high resolution data, when processed into a DEM, provides provisional accuracy of 1-m root mean squared error (RMSE) on the horizontal and 15-cm RMSE on the vertical (RRBMI 2010). The higher accuracy afforded from the 1-m data over a 30-m DEM has the potential to improve DEM quality in low relief terrain such as the Red River Basin. Hodgson and Bresnahan (2004) found that very few empirical studies existed on the accuracy of DEMs produced from LiDAR data. They state that most aero service companies would quote a 15-cm root mean square error (RMSE). They continue by stating most would now agree that such accuracy can only be attainable under ideal circumstances such as low altitude collection, reduced or no vegetation or flat terrain.

A review of the literature indicates that terrain analysis can provide accurate models of erosion potential for areas of moderate to high topographic relief. The main hypothesis for this study is that terrain analysis from high resolution DEMs for the Red River Basin will produce accurate erosion potential models for the low relief landscape. The goals of this study are to:

- Locate critical areas of surface erosion identified by gullies and inlets from agricultural ditches to the Lower South Branch of the Upper Turtle River and the South Branch of the Forest River watersheds of North Dakota using the SPI; and
- Verify the results of the index models in the field and characterize the physiochemical properties of the sediment.

The identification of these critical areas will allow for the implementation of precision conservation techniques to decrease impacts to surface water quality. The results of this pilot study can be extended to the greater Red River Valley to identify critical areas of erosion.

CHAPTER II

LITERATURE REVIEW

Previous Research

The identification of soil erosion or soil erosion potential has been addressed using many different techniques. Erosion surveys allow for on-the-ground mapping and/or the use of aerial photos (Morgan 2005), but these surveys can be time-consuming and expensive. Many different types of remote sensing and terrain analysis techniques have been developed to assess erosion (e.g. Wilson and Gallant 2000; Van Lynden and Mantel 2001; James, Watson, and Hansen 2007; Galzki, Birr, and Mulla 2011). These methods integrate well with GIS, and have increased in use because of the availability of high resolution DEMs derived from LiDAR technologies.

Erosion Models

Empirical and process-based models such as the Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Water Erosion Prediction Project (WEPP) and Surface and Water Assessment Tool (SWAT) allow for the prediction of sediment runoff as well as changes to runoff and water quality based on different management and cropping scenarios (Gilley and Flanagan 2007). These methods evaluate overall erosion, or loading to local surface water, but do not pinpoint locations of increased erosion potential. The USDA Agricultural Research Service defines the USLE (Eq. 1) as an empirical technology that has been applied worldwide to estimate soil erosion by raindrop impact and surface runoff. The USLE predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices (Stone and Hilborn 2000). The USLE is an empirical model that was designed to predict only the amount of soil loss that results from sheet or rill erosion on a single slope and does not factor in soil losses from gully erosion. The RUSLE is a revised version of the USLE which includes new maps, a new approach for estimating soil erosion factors and new management factors. Both USLE and RUSLE compute the average annual erosion by using a functional relationship of several factors, expressed in an equation:

$$A = R * K * LS * C * P \tag{1}$$

where

A = spatially and temporally average soil loss per unit area

R = rainfall-runoff erosivity factor

K = soil erodibility factor as measured standard unit plot conditions

L = slope length factor

S = slope steepness factor

C = cover-management factor

P = support practice factor

L S factors are usually considered together to combine the effect of slope and slope-length (Renard et al.1997).

The WEPP model is a process-oriented, continuous simulation computer program that can be applied to hillslope profiles or field-sized watersheds (Flanagan and Nearing 1995). The WEPP model is used to estimate temporal and spatial soil erosion. The

WEPP technology consists of three models including a hillslope profile, a watershed version, and a grid version. The hillslope profile computes soil detachment and deposition on a hillslope as well as the total soil delivery from the end of the slope and provides the basis for the other two versions. The watershed and grid versions can estimate net soil loss or gain over a small watershed or field-sized area at all points including channels (Risse and Nearing 1991). Areas subjected to permanent gullies and perennial streams should be excluded from WEPP since these types of erosion features are not simulated in the model. The technology used in the WEPP erosion model is based on infiltration, hydrology, soil physics, plant science, hydraulics and erosion mechanics (Flanagan and Nearing 1995).

The SWAT erosion model is a distributed parameter model designed to simulate water, sediment and chemical fluxes in watersheds and large river basins with varying climatic conditions, soil properties, stream channel characteristics, land use and agricultural management (Arnold et al., 1996, 1998; Srinivasan et al. 1998). The SWAT model works on a basin-scale, designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. Important variables in the SWAT model include property and temperature of soils, climate and weather, local hydrology, plant growth, nutrients, pesticides, bacteria and pathogens and land management (Gassman et al. 2007).

LiDAR Datasets

Only recently has high resolution LiDAR data become available, before now most elevation data came with a spatial resolution of 10-m (32.8 ft) or greater. Now that 1-m LiDAR data are available it is easier to detect landscape features with greater accuracy than elevation data with coarser resolution. LiDAR data are especially useful in low topography landscapes because of their ability to model small topographic features that are difficult to identify from ground surveys (Ogren 2012). Sub-meter (15-cm) elevation (DEMs) can be processed from 1-m LiDAR data, providing a more accurate hydrological representation of the actual terrain through digital terrain analysis in a GIS. Galzki, Birr, and Mulla (2011) compared the results between 30-m (98 ft) and 3-m (9.8 ft) elevation data. They found that the coarser resolution data could not accurately model the individual erosion features that the high resolution data could.

A study by James, Watson and Hanson (2007) used terrestrial LiDAR to map gullies and headwater streams under forest canopy. In addition to improved map precision, their goal was to show that accurate LiDAR-derived DEMs could be used to extract local gully morphologic information for parameterizing runoff, erosion, and sediment transport models. In order to model the topography at the field scale for gully formation and development over time it is necessary to work with higher resolution DEMs with spatial resolution ranging between 5-mm to 15-cm (Momm et al. 2013).

A study on Santa Cruz Island, CA also produced a higher resolution dataset with terrestrial LiDAR, but with orientation and footprint limitations. This comparison study (Perroy et al. 2010) looked at both airborne and terrestrial LiDAR. They found that by using terrestrial LiDAR they could produce a higher density point cloud allowing for higher resolution DEMs of the study area, producing a more detailed dataset at a reduction in cost. They also recorded limitations of the side-looking orientation of the terrestrial LiDAR. These limitations included a restrictive footprint requiring different look angles to reduce blind spots that the laser could not see in deeply incised channels.

These blind spots produced areas of no data. They concluded that the airborne LiDAR produced the most complete dataset even at its lower resolution.

Terrain Analysis

Digital elevation data commonly are used to extract surface flow features. Because elevation is a key factor in extracting surface flow features, high resolution LiDAR-derived DEMs provide the detail needed to consistently integrate hydrography with elevation, land cover, structures, and other geospatial features. The DEMs created from the LiDAR data are typically hydrologically conditioned to remove depressions, spurious artifacts, by filling them (Poppenga, et al. 2010).

Depression in a DEM, also known as a sink or pit, is a single grid cell or a group of cells identified as a minimum elevation point without an outlet or pour point. In the computer model this depression will reflect an area of artificial ponding, a location were water will not flow out of the cell or group of cells. DEMs processed from LiDAR data must be filled to remove theses artifacts, also known as depressions or pits, inherent in point cloud datasets. Identification and removal of surface depressions is a critical step for automated modeling of surface rainfall runoff based on DEMs (Wang and Liu. 2006). Wang and Liu (2006) found that depressions act as sinks for the upstream accumulated overland flow in which water will drain towards the depression located within the interior basin and not the basin perimeter as usually occurs.

Closed depressions can be complex features that might contain flat areas and other smaller nested depressions. Depressions in DEMs can be natural, real landscape features, or spurious artifacts. Spurious depressions represent imperfections in DEMs. They may arise from input-data errors, interpolation defects during DEM generation, truncation or rounding of interpolated values to lower precision, or averaging of elevation values within grid cells (Martz and Garbrecht 1998).

The ability of a stream to perform geomorphic work, such as overcome frictional resistance, transport sediment downstream and generate heat is known as stream power, it is the rate of potential energy of the stream. Stream power is the energy that is expended on the stream channel (Hugget 2002). If the stream channel cross-section remains constant for a defined reach and there is no increase in discharge then the energy lost will act upon the stream bed and embankments.

Stream power is calculated as follows:

$$\Omega = pgQs \qquad [2]$$

Where

Ω = stream power per unit length of stream channel (W/m)

p (rho) = water density (1000 kg/m^3)

g = gravitational acceleration (9.8 m/s^2)

Q = stream discharge (m^3/s)

s = channel slope

An increase in discharge and channel slope will increase the stream power value.

The SPI is a calculated value of upstream catchment area, the erosive power of flowing water, and the slope of each individual cell in the raster and can be used to identify suitable locations for soil conservation measures to reduce the effect of concentrated surface runoff. SPI can be used to describe potential flow erosion and related landscape processes. As specific catchment area and slope steepness increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence SPI and erosion risk increase. SPI measures the erosive power of overland flow as a function of local slope and upstream drainage area.

Galzki, Birr, and Mulla (2011) used 3-m resolution LiDAR data to identify gully and inlets in individual fields in south-central Minnesota. The documentation of these erosional features could then be used to design BMPs to reduce runoff or capture the sediment. Galzki, Birr, and Mulla (2011) calculated a SPI, a measure of the power of water as it flows across the landscape, as a proxy for erosional features. Galzki, Birr, and Mulla (2011) used all of the calculated SPI values above the 85 percentile to identify highly eroded areas. The study found that the SPI method had an 80 percent success rate in identifying gullies that were field verified.

This same SPI methodology was used to identify critical areas of erosion in the upper Devils Lake Basin (Dinger 2012). The Devils Lake Basin study had a 79 percent success rate in correctly identifying the location of gullies intersecting with local waterways. This methodology can now be used to identify critical erosion areas in the upper Devils Lake Basin. Both flow direction and flow accumulation grids were produced from the conditioned DEMs. The flow accumulation algorithm produces a raster of accumulated flow to each cell, determined by accumulating the weight for all cells that flow into each downslope cell. Output cells with a high flow accumulation are areas of concentrated flow and can be used to identify stream channels. Its estimation of drainage patterns makes it a valuable attribute for water resource applications.

Best Management Practices

In 1987, the U.S. established provisions in an amendment to the Clean Water Act to address issues such as non-point pollution (D’Arcy and Frost 2000), which includes sediment and nutrient loading in streambeds because of surface erosion. The development of BMPs was a way of implementing resources to reduce or diffuse pollution from all sources and sectors (D'Arcy and Frost 2000). BMPs are a physical structure, manufactured or organic, that are installed at ground level to assist in reducing or eliminating surface erosion. These structures can be hard structures, such as concrete or logs, or soft structures incorporating vegetation, or a combination of both types.

Hard structures are built from concrete, logs, rock, stone, and other materials such as manufactured geotextiles. These structures are used to protect the areas of high stress such as the toe of an embankment where undercutting from the stream current can occur. In larger streams or areas of increase channel flow are areas where hard structures would be included into the BMP model (D'Arcy and Frost 2000).

The soft structures are used as stream buffers that incorporate a vegetative ground cover in perimeter locations along the stream channel, separating row crops from the stream bed, silt fences and runoff diversions. Benefits of using live vegetation as a stream buffer includes a root structure that induces bank stability, a reduction in flow velocity of overland flow near the stream channel, and a reduction in the abrasive ability of transported soil particles. Also, close-growing vegetation in a stream buffer can induce sediment deposition by reducing overland flow velocity before the sediment can enter the stream channel (Allen and Leech 1997). There are three basic types of vegetation: grasses (including forbs), shrubs, and trees with each type providing certain benefits that are better than the others. Table 1 compares three different vegetation types including grass, shrubs, and trees for the relative level of specific benefits they can provide in an agricultural riparian buffer.

Table 1. Relative effectiveness of BMPs using differing vegetation types (Dosskey, Schultz, and Isenhart 1997)

	Vegetation Type		
Benefit	**Grass**	**Shrub**	**Tree**
Stabilize bank erosion	Low	High	High
Filter sediment	high	Low	Low
Filter nutrients, pesticides, microbes			
sediment-bound	High	Low	Low
soluble	Medium	Low	Medium
Aquatic habitat	Low	Medium	High
Wildlife habitat			
range/pasture/prairie wildlife	High	Medium	Low
forest wildlife	Low	Medium	High
Economic products	Medium	Low	Medium
Visual diversity	Low	Medium	High
Flood protection	Low	Medium	high

By using a combination of the different vegetation types in the model as a stream channel buffer, the introduction of non-point pollution can be reduced as part of a watershed management program.

The use of high resolution LiDAR data in a digital terrain analysis model will allow for the identification of critical SPI signatures in the very low topography of both study areas. These high signatures can then be used to locate gully locations that extend from agricultural fields to an intersection with the stream channel within the terrain model. This identification will reduce the total hours that would normally be spent in the field resulting in a reduction in cost. The results can then be used to help locate areas where the installation of BMPs would be the most beneficial in reducing erosion and limiting sediments and nutrients introduced to the stream.

CHAPTER III

STUDY AREA

Site Locations

The study areas include the upper hydrologic unit code 12 (HUC 12) watershed basins for Larimore and Fordville dams in Grand Forks County, North Dakota. Both watersheds are in the Red River Basin which is part of the former Lake Agassiz basin. Long, narrow beach ridges intersect both watersheds in a northwest-southeast direction rising up to 3-m (10 ft) above the lake plain (Kelly and Poulson 1970). Both watersheds are located along the outer western edge of the Red River Valley in Grand Forks, Nelson, and Walsh counties, at the position of the ancient Lake Agassiz beach ridges. Land distribution for the Larimore Dam and Fordville Dam watersheds is seen in (Table 2).

Table 2. Percentage of land distribution for the Larimore Dam and Fordville Dam watersheds (Hargiss 2011).

Type	Larimore Dam Watershed	Fordville Dam Watershed
Agriculture	56 %	60 %
Pasture / Grassland	-	17 %
Wetland / Water / Woods or Conservation Reserve Program	36 %	12 %
Urban Development	8 %	8 %
Forest / Open Water / Barren or Fallow/Idle	-	3 %

The Larimore Dam watershed (HUC 12 090203070203) covers approximately 4,025 hectares of the Lower South Branch of the Turtle River in western Grand Forks County (Fig. 1). The Fordville Dam watershed (HUC 12 090203080303) covers (Fig. 2)

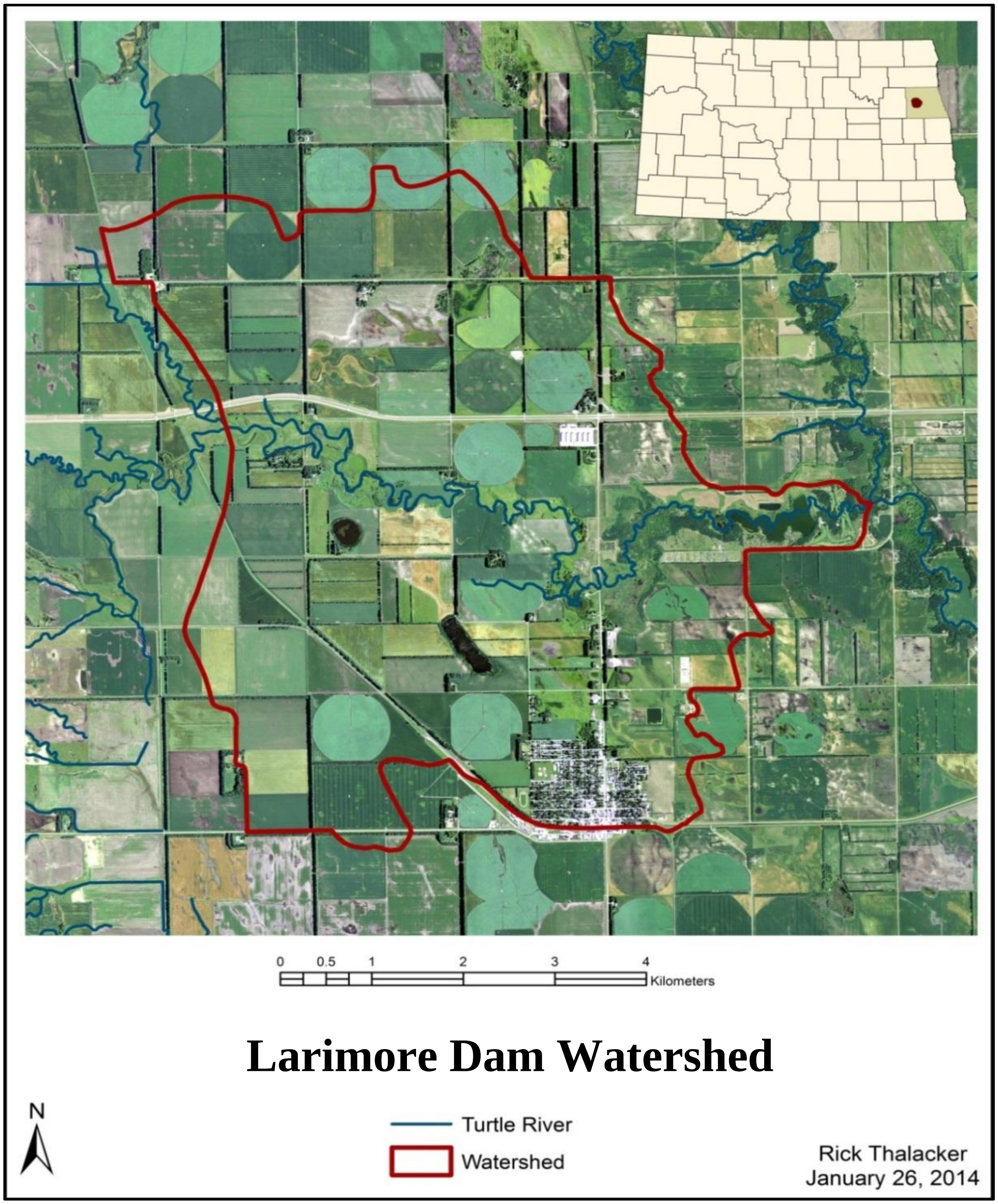


Figure 1. Larimore Dam Watershed of the Lower South Branch of the Turtle River, Grand Forks County, North Dakota.

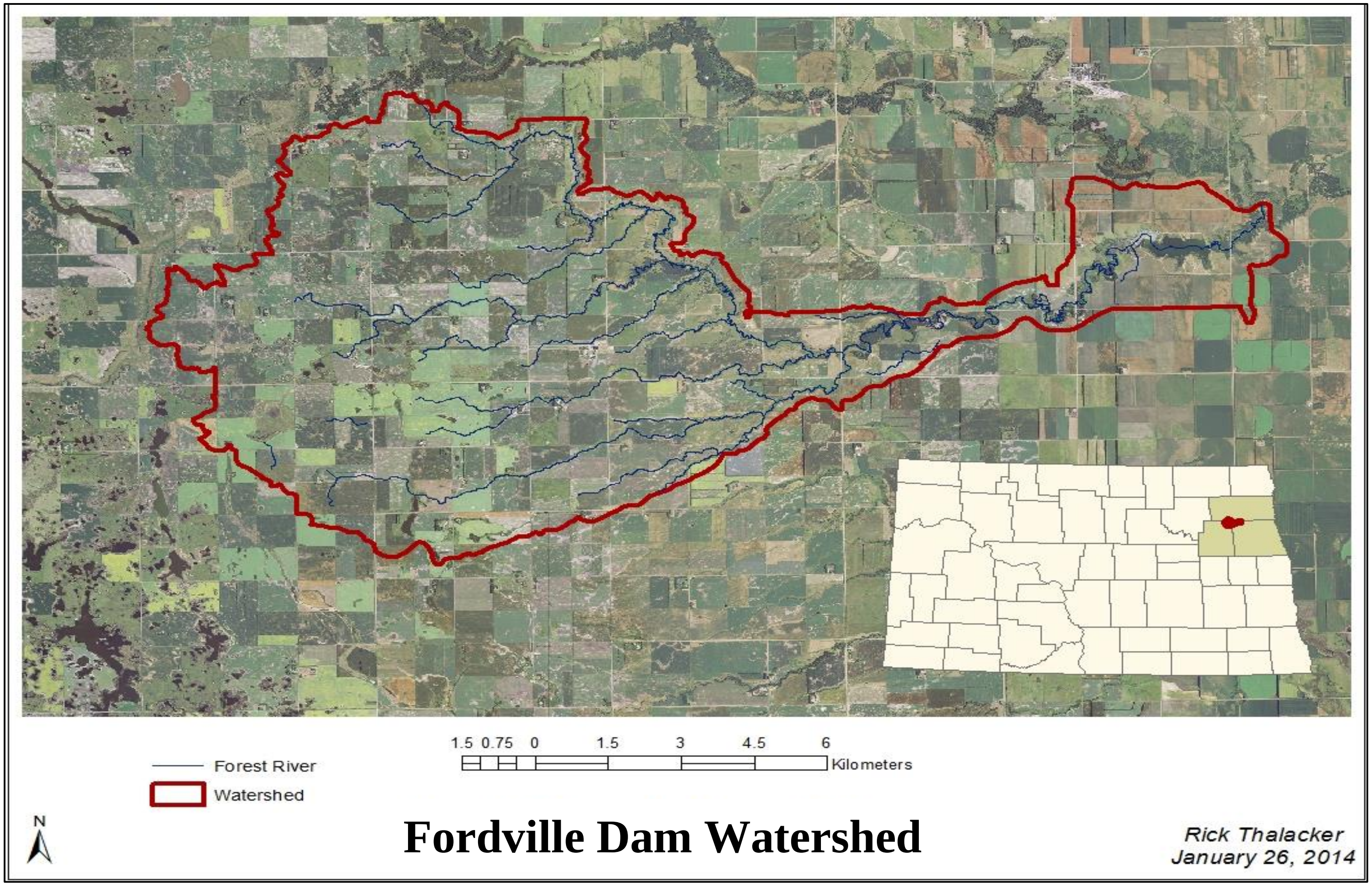


Figure 2. Fordville Dam Watershed of the South Branch of the Forest River in Grand Forks, Nelson, and Walsh counties, North Dakota.

approximately 12,000 hectares of the South Branch Forest River in Grand Forks, Nelson, and Walsh counties.

Climate

Northeastern North Dakota lies in a sub-humid continental climate. Variable weather patterns and large seasonal temperature variance are experienced throughout annually. Summers are often warm and humid with frequent thunderstorms and winters are cold. Average daily temperatures range from -6.6 ºC (20° F) in the winter to 20º C (68° F) in the summer (Hargiss 2011). Precipitation occurs primarily during the warmer months and is normally heavy in late spring and early summer. Grand Forks County has an average annual precipitation of approximately 48.26 cm (19 in) with most of the rain fall, 40.6 cm (16 in), occurring between April and October. Average seasonal snowfall is approximately 104 cm (41 in) (Hargiss 2011). Snowfall is normally not too heavy in the winter months and windblown drifts are common so the ground can be snow free. On average, there is snow cover of at least 2.54 cm (1 in) for 62 days per year, this number varies greatly annually (NRCS 1972).

Geology

The Larimore Dam watershed is located in the western half of Grand Forks County and includes the drift plains and Agassiz Lake Plains. The Fordville Dam watershed is located in the Northwestern portion of Grand Forks County and the watershed extends into Walsh and Nelson counties. This watershed includes the physiographic units of the North-South trending Pembina Escarpment, drift plains and the Agassiz Lake Plain of the Red River Valley (Hansen and Kume 1970). Both the

Larimore Dam and Fordville Dam watersheds lie within three eco-regions (Hargiss 2011):

- the Northern Glaciated Plains eco-region, which is characterized by a flat to gently rolling landscape composed of glacial drift.
- the Glacial Lake Agassiz Basin, which is extremely flat with thick lacustrine sediments underlain by glacial till.
- the Sand Deltas and Beach Ridges, which consists of parallel lines of sand and gravel formed from the wave action of Lake Agassiz's varying shorelines.

Dominant soil types are described in terms of soil associations by the National Resources Conservation Service (NRCS). Each soil association is identified by a distinct soil type, topography and drainage type characterizations. The soils of the Larimore Dam Watershed (Table 3) are dominantly level to gently sloping, medium textured and moderately coarse textured soils formed in glaciofluvial and glaciolacustrine deposits on delta plains and beaches (NRCS 1980).

Table 3. Larimore Dam Watershed soil associations

County	**Association**	**Description**
Grand Forks	Embden – Inkster	Deep, level to gently sloping, moderately well drained, moderately coarse textured soils found on delta plains and beaches
Grand Forks	Arvilla – Hecla	Deep, nearly level and gently sloping, somewhat excessively drained and moderately well drained, moderately textured soils formed in glaciofluvial and glaciolacustrine deposits.
Grand Forks	LaDelle – Cashel	Deep, level to moderately steep, moderately well drained and somewhat poorly drained, medium and moderately fine textured soils found on alluvium slopes.

The soils of the Fordville Dam watershed (Table 4) are dominantly level to undulating or gently sloping, loamy and silty soils on till plains and they are formed in till plains and alluvium.

Table 4. Fordville Dam Watershed Soil Associations

County	**Association**	**Description**
Grand Forks	Svea – Buse – Hamerly	Deep, nearly level to moderately sloping, well drained to somewhat poorly drained, medium textured soils formed in till and glaciolacustrine deposits overlying till
Walsh	Hamerly – Svea – Barnes	Deep, nearly level to rolling, somewhat poorly drained to well-drained loamy soils formed in calcareous glacial till in area where potholes are part of the landscape
Walsh	Svea – Barnes	Deep, nearly level and gently sloping, moderately well drained and well drained loamy soils formed on glacial till plains
Nelson	Hamerly—Svea—Tonka	Deep, level to undulating, moderately well drained to poorly drained medium textured soils
Nelson	Svea—Buse—Parnell	Deep level to undulating moderately well drained, well drained, and very poorly drained medium textured soils
Nelson	Cresbard—Svea	Deep, nearly level and undulating, well drained, medium textured soils
Nelson	Svea—Buse	Deep, nearly level and undulating, well drained, medium textured soils

The Grand Forks County soil association map (Fig. 3) shows the general location of the Larimore Dam and Fordville Dam Watershed relative to the soil association distributions. The Larimore Dam Watershed is inclusive to Grand Forks County and the Fordville Dam Watershed extends from Grand Forks County into both Nelson and Walsh counties.

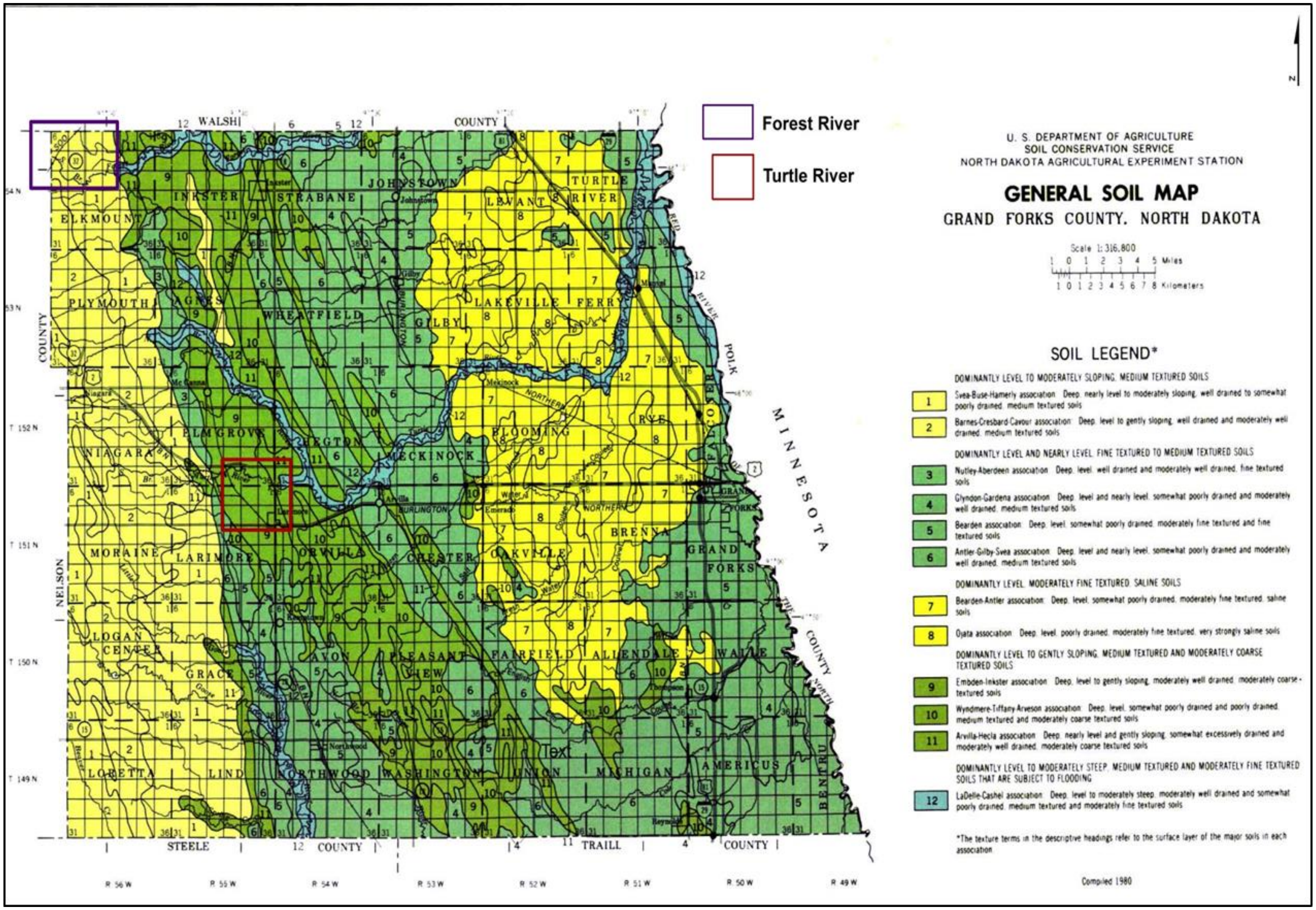


Figure 3. Soil map showing locations of the study areas including the Lower South Branch of the Turtle River and the South Branch of the Forest River (NRCS 1980).

CHAPTER IV

METHODS

Data processing included the use of 1-m resolution bare earth LiDAR data which was converted into a DEM and then hydrologically conditioned. Terrain analysis involved pit filling the DEM to remove processing artifacts, flow direction, flow accumulation and lastly the SPI calculations. A field survey was conducted for this study involving documenting gully locations where they intersect with the stream channel in both watersheds. During the field survey, soil samples were collected with the location of the sample documented for soil analysis. The soil analysis involved testing for pH and electrical conductivity to characterize the material and hydrometer testing to identify the separates size percentage at each sample location.

Data Processing

The 1-m LiDAR datasets were acquired from the Red River Basin Decision Information Network LiDAR Portal (http://gis.rrbdin.org/lidardownload/index.html). The bare earth LiDAR dataset for both study areas have a header error with the projection identified as 14S. To correct for this error, data were imported into ArcGIS 10.1 (Environmental Systems Research Institute, Redlands, CA) and re-projected to NAD_1983_UTM_Zone_14N using the LAS toolset. After the re-projection, the data were converted to a raster using the LASer File Format Exchange (LAS) to Raster function in ArcMap 10.1. The datasets were re-classed to 3 m during the LAS to Raster function in an effort to reduce processing times and the overall point count within the point cloud for easier data management. Galzki, Birr, and Mulla (2011) in their study states that several spatial resolutions were considered; however, a 3-m resolution was chosen because it demands less computing power than finer-scale data, while maintaining a high level of elevation data accuracy.

Hydrological conditioning of the DEM datasets were required because of the very flat topography of the study areas and the high resolution of the LiDAR data. A result of the high resolution dataset is an obstruction referred to as a digital dam. Digital dams are created in the DEM during processing because of manmade structures such as roads, bridges, and railroad tracks. These physical structures typically have culverts or other diversions that allow for stream flow, but the terrain analysis recognizes them as a solid structure creating a “dam” that blocks flow and models ponding instead of continuous flow through the structure (Fig. 4). For culverts and channels to be interpreted as a continuous stream channel, these locations are “burned” into the DEMs (Figs. 5 and 6) to allow for hydrological correctness for accurate modeling.

This method involved creating a new polyline shapefile in ArcMap 10.1 and adding a new field (“DEPTH”) to the attribute table. A polyline was then digitized across each of the “dams” in the DEM using a 1-m National Agriculture Imagery Program (NAIP) image as ground truth to assist in locating culvert and bridge locations. The original DEM was used as an elevation layer to locate the lowest elevation grid cell on each side of the dam and the chosen depth of the line for that feature was entered into the attribute table. The new shapefile was then reclassified and converted from a Polyline to Raster using the polyline to raster tool in ArcMap 10.1. The new raster was subtracted from the original DEM to produce the final difference DEM with the digital dams correctly burned into the raster surface. A high resolution NAIP was underlain for use as ground truth to assist in identifying obstructions such as roads, bridges and culvert locations. If an obstruction was found to be the source of the ponding then a channel was burned into the DEM (Fig. 5 and 6).

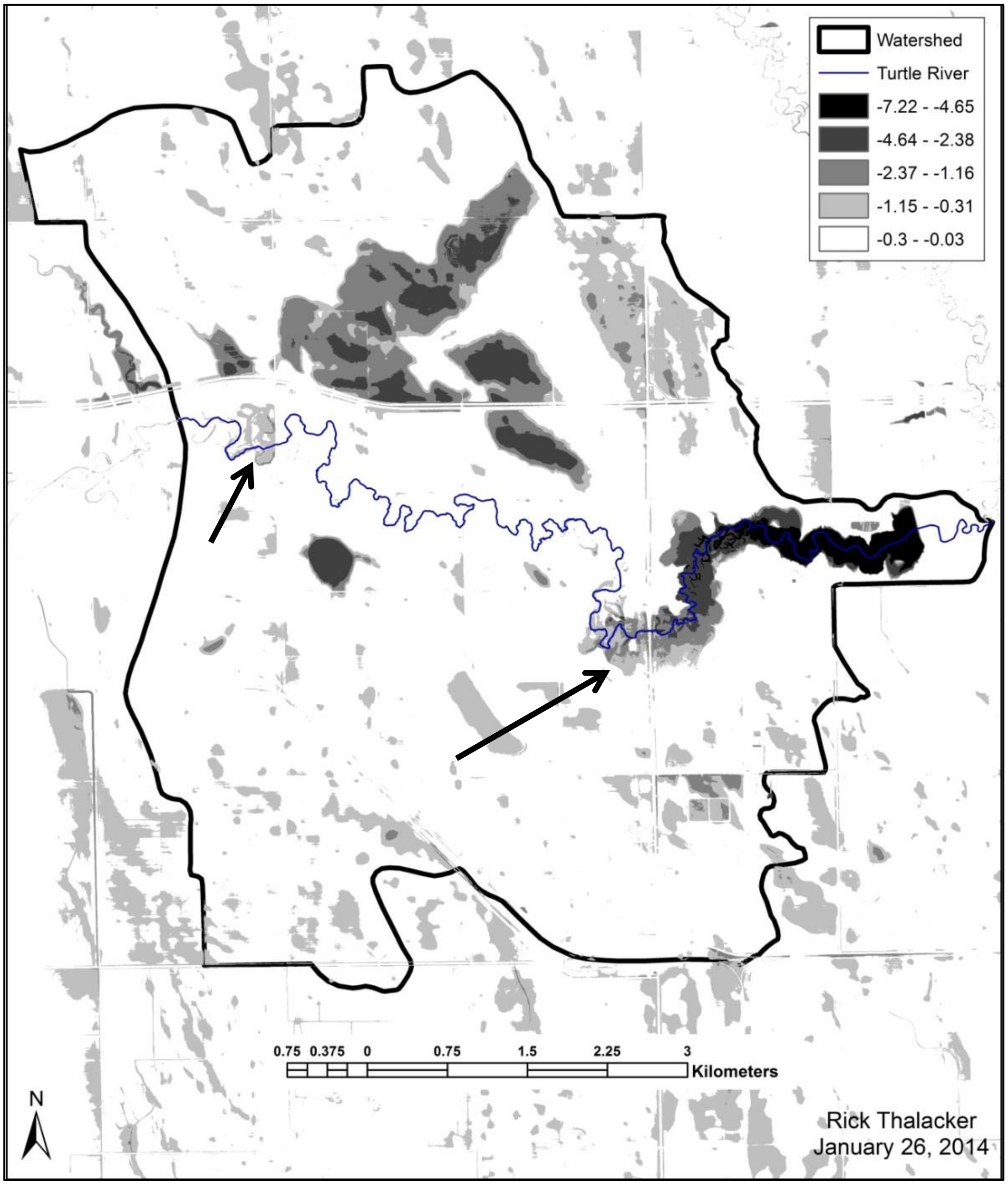


Figure 4. Difference grid showing locations of depressions that induce ponding. The negative values indicate depth of the depression.

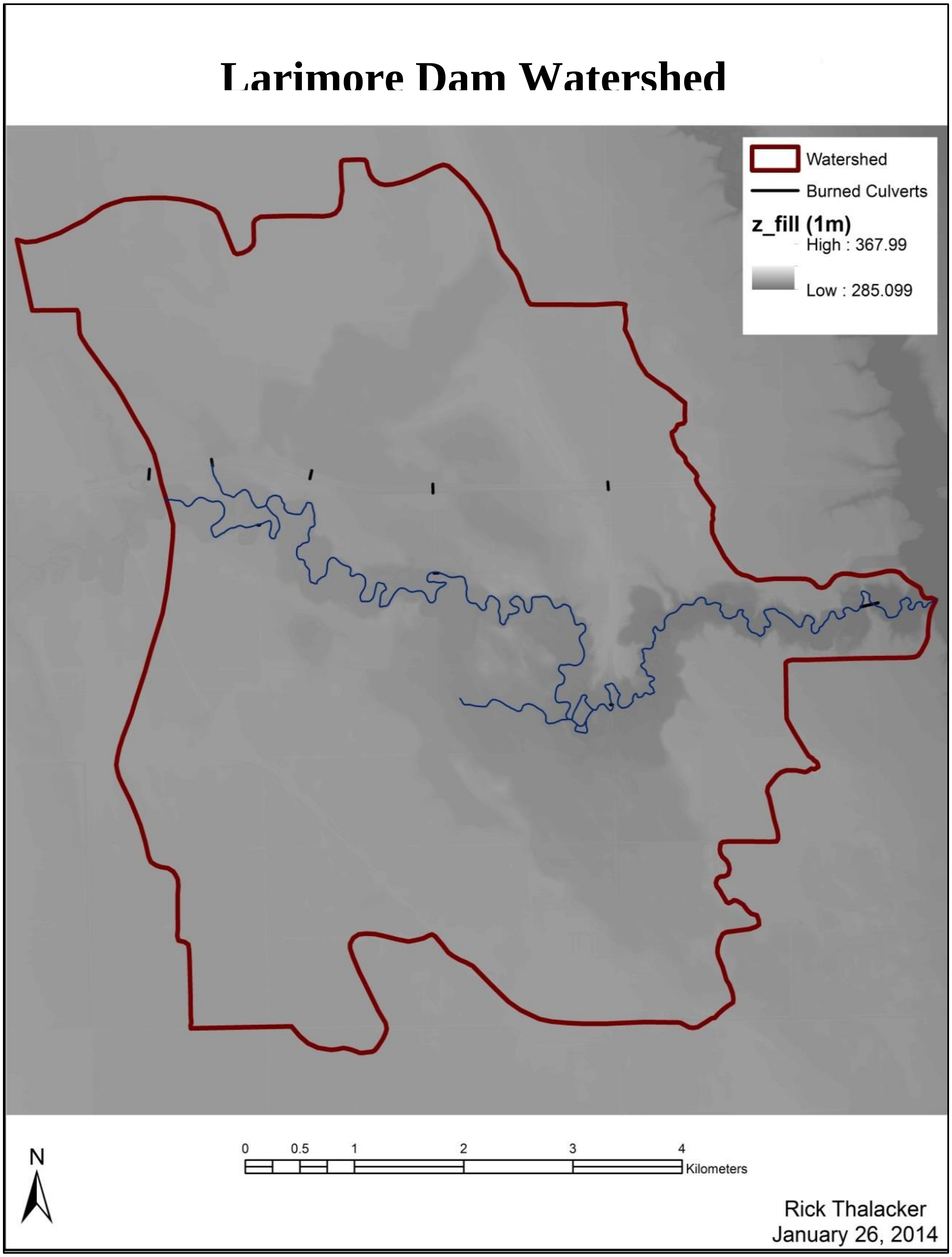


Figure 5. Hydrologically conditioned DEM for the Larimore Dam Watershed. Culvert and bridge locations on the stream channel proper at section roads and U.S. Hwy 2 were burned into the DEM to reduce ponding on the upstream portion of the obstruction.

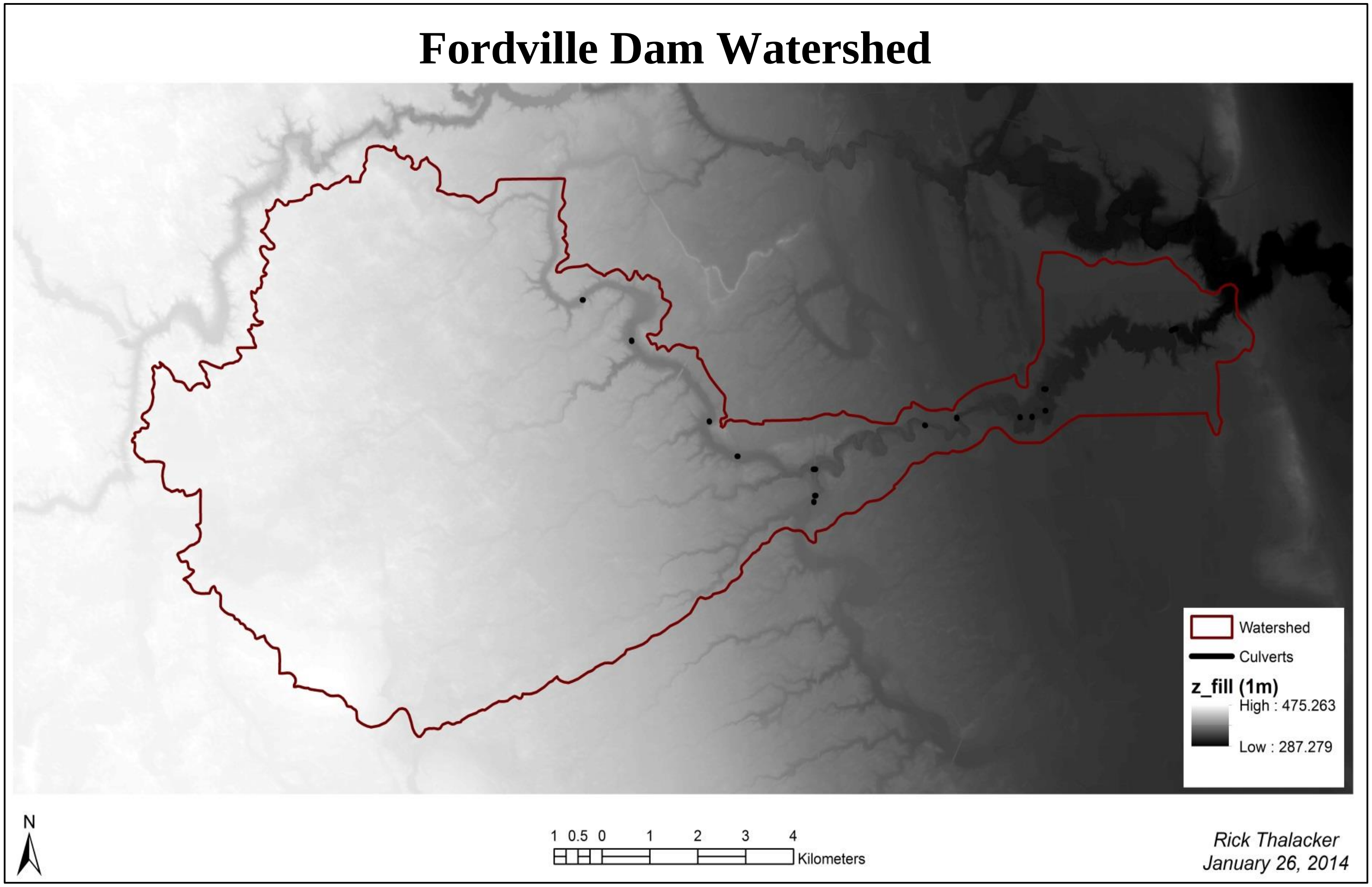


Figure 6. Hydrologically conditioned DEM for the Fordville Dam Watershed. Culvert and bridge locations on the stream channel proper at section roads were burned into the DEM to reduce ponding on the upstream portion of the obstruction.

After the culvert burning process to initiate proper stream flow, the DEMs were filled with 1 m z-limit, to eliminate sinks. This pit-filling process may not be appropriate for all areas, especially in areas of ponding. Galzki (2009), however, found it to be a more conservative approach than using a non-filled DEM because it tends to err on the side of overestimating rather than underestimating flows. Sinks are often errors because of the resolution of the data or rounding of elevations to the nearest integer value (ESRI 2011). This step will fill the depressions, natural or processing artifacts, so that these cells will not hold water and artificially drain to a wrong grid cell (Fig. 7).

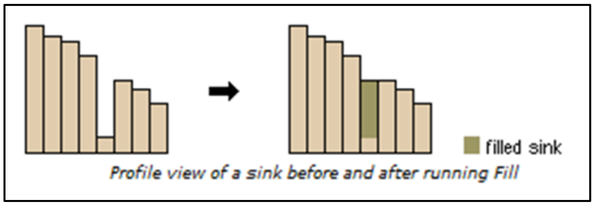


Figure 7. Sink profile (ESRI 2011).

The z-fill command specifies the maximum difference allowed between the depth of a sink and the pour point and determines which sinks will be filled and which will remain untouched. The z-limit is not the maximum depth to which a sink will be filled (ESRI 2011). The 1 m z-fill will fill only the sinks that are less than the specified z-limit in depth such that if the z-limit is greater than the difference of the depth of pit and pour point of cell then the sink will be filled. If the depth exceeds the difference of the z-limit the sink would be considered a valid sink and not be filled. This process will fill the artifacts and rounding errors but will leave the true low lying areas and wetlands to represent proper hydrological conditions.

Terrain Analysis

Following DEM conditioning, the primary terrain attributes of slope, flow direction, flow accumulation and the secondary attribute of SPI were calculated for both the Turtle River and Forest River watersheds. In areas of low topography, accurately identifying slope and flow direction (aspect) becomes very important in identifying upstream accumulation cells. The high resolution LiDAR datasets, vertical RMSE of 15 cm, becomes very beneficial in areas with a subtle change in elevation as we see in the Red River Basin. Slope calculates the rate of maximum change in Z-value from each cell of a raster surface (ESRI 2011).

$$\text{Percent slope} = \text{rise} / \text{run} * 100 \qquad [3]$$

Flow direction determines the flow of water from every cell in a raster creating a grid of flow direction to its steepest downslope neighbor. The D8 algorithm (Eq. 3) was used to calculate flow direction for this study because of its simplicity. The D8 method uses a 3 x 3 moving window, calculating the steepest downslope path from the center cell to its surrounding nearest neighbors (Garbrecht and Mart 2000). The direction of flow (Eq. 4) is determined by the direction of steepest descent, or maximum drop, from each cell. Flow direction is calculated as follows:

$$\text{Flow Direction} = \Delta z / \text{distance} * 100 \qquad [4]$$

The distance calculated between two cells is given a value of 3 when measured orthogonally and the distance on the diagonal is given a value of 3.414.

Cells with a high flow accumulation are areas of concentrated flow from all upstream cells thereby estimating drainage patterns. By incorporating flow direction into the calculation it may be used to identify stream channels (ESRI 2011). Flow accumulation calculates a single cell value that is dependent upon all upslope cells values that flow into it (Poppenga 2010).

SPI describes potential surface flow erosion and landscape processes related to surface flow (Eq. 5). To avoid potential errors in the calculation of SPI for both of the watershed DEMs, all individual cells within the DEM with a slope value of 0.0 were changed to 0.001.

$$\text{SPI} = \text{Ln}((\text{Flow Accumulation} + 0.001) * (\text{Slope} + 0.001)) \tag{5}$$

As values of both Flow Accumulation and Slope increase, the contributing water and flow increases, identifying areas of risk. SPI is a measure of the erosive power of overland flow. Flow Accumulation is identified as the upstream (catchment) area and Slope is the percent change in elevation in a given grid cell. High calculated SPI values are indicative of areas with a high potential for surface runoff erosion.

A threshold cutoff value at the 85th percentile or greater was chosen for mapping the SPI index to identify critical erosion areas. These breakpoint values represent the areas with the highest potential for surface or potential surface erosion and this threshold has been chosen for other SPI studies. The 85th percentile was used in a past study by Galzki, Birr, and Mulla (2011) where they found that the 85th percentile breakpoint was very useful in identifying field gully and inlet erosion locations.

Upon completion of the terrain attributes the SPI grids were converted to an ASCII file using the Raster to ASCII conversion tool in ArcMap 10.1. The ASCII files were imported into Microsoft Excel and percentile intervals were calculated so that the 85th percent and higher SPI values could be screened out. In his study, Galzki (2009) found the 85th percentile to be the average percentile for field surveyed erosion features. The SPI raster for both the Turtle and Forest rivers were reclassified to two classes and the break point set to the 85th percentile value in the layer symbology.

To identify the SPI signatures ≥ 85^{th} percentile, the SPI layer for each study area was overlain on a stream shapefile for each of the study areas. A 2012 1-m resolution NAIP was also included to assist in identifying the SPI signatures that were originating from the fields, having connectivity with the stream, and those SPI signatures that were below the high-water mark relating to stream-bank erosion. Connectivity was determined to be the point location where the SPI signatures intersected the waterway. The stream-bank erosion was determined to be locations of high SPI values that were completely within the area between the low-water mark and the high-water mark.

Field Survey

The field survey was completed by documenting 299 gully locations in the Larimore Dam Watershed and 92 gully locations in the Fordville Dam Watershed were they intersect the stream channel at or near the low-water mark (Fig 8).

Figure 8. Documenting a gully location with Trimble Juno GPS unit.

Documentation was done using a Trimble Juno SB handheld Global Positioning System (GPS) unit, horizontal accuracy 2 m to 5 m after differential correction.

After data collection in the field the GPS points were converted to a shapefile in Trimble Pathfinder Office software and then imported into ArcGIS 10.1. A small river kayak (Fig. 9) was used for the survey to overcome the limitations of foot travel because of the incised nature of the streambed in many locations.

Figure 9. River kayak used for field survey.

The western most upstream section of the Larimore Dam Watershed was not surveyed because of land access issues involving no trespassing signage and wire fence, including fencing strung perpendicular to the stream channel at the low-water mark. Also, the perimeter of the reservoir was surveyed but not used in the SPI signature identification because of the recreational designation of the area. The dam is located on the eastern portion of the reservoir and the southern shoreline is picnic grounds, campground and public beach. Only one section of the stream channel of the Fordville Dam Watershed was included in the field survey. Land access issues were more prevalent in this watershed with signage in some locations and wire fencing perpendicular to the stream channel at every section road. Also, the perimeter of the reservoir was surveyed but not used in the SPI signature identification because of the recreational designation of the area. The dam is located on the eastern portion of the reservoir with a road running along the top of the dam. The northern shoreline of the reservoir includes picnic areas and public beach and the southern shoreline includes a campground.

Sediment samples were collected for soil analysis at 29 gully locations in the Larimore Dam Watershed and 16 gully locations in the Fordville Dam Watershed. The samples were collected within 1 m of the low-water mark using a hand trowel and collecting the soil from approximately the top 3 to 5 cm at each location where the gully just started to fan out. The sediment samples from each of the study areas were analyzed for pH, electrical conductivity (EC) and soil texture, closely following the methods of Gee and Or (2002).

Soil Analysis

The samples were stored in open containers to air dry for 4 months before test analysis. Each sample was then spread out on a table to further air dry away from the container for 3-4 days and then sieved. A 2-mm sieve (Fig. 10) was used to separate the sand, silt, and clay separates for the original sample and placed into new containers. Ten grams of each sample was weighed and then oven dried for 24 hours at 105° C and then reweighed with the wet weight, dry weight and difference weight recorded. This recorded mass difference was subtracted from the sample mass in the hydrometer testing to correct for the bulk sample mass. The initial calibration verification for pH was 10.01

using a 10.00 standard and 7.01 using a 7.01 standard. The EC initial calibration verification was 1.413. The calibration was repeated at the start of each soil sample testing session. A duplicate sample was recorded for every 10th sample tested with the relative percent difference recorded for the duplicate samples.

Sample preparation included adding 10 grams of air dried soil to 10 mL of distilled water, stirred and tested with each probe. A third test tube filled with distilled water was included for temperature verification for each sample with a range between 21° and 23° C. An Oakton PC 2700 instrument was used with required probes for both the pH and EC analysis with each probe being rinsed with distilled water between each test. Texture analysis was used to determine soil separate size using the hydrometer method and Stokes Law. Concentration of soil particles in suspension at a given time were calculated using the formula from Gee and Or (2002):

$$C = R - R_L \qquad [6]$$

where

- C = corrected concentration of soil in suspension in g/L
- R = uncorrected hydrometer reading
- R_L = blank solution hydrometer reading

Summation percentage:

$$C/C_o \qquad [7]$$

where

- C_o = corrected mass of the soil in 1 L [40.0 g – (40.0 g)(θ_d)]

Moisture content of soil θ_d:

$$\text{(wet soil + tare)} - \text{(dry soil + tare)} / \text{dry soil + tare)} - \text{(tare)} \qquad [8]$$

Sample preparation for the soil texture analysis required mixing 40 grams of soil to 100 mL of a NA-Hexametaphosphate (HMP) solution, mixed to a ratio of 25 grams HMP to 500 mL distilled water. The mixture was hand stirred and allowed to rest for 24 hours with a light covering over each beaker to reduce evaporation. The sample was then vigorously mixed in a blender for 5 minutes. Next the soil sample was added to a 1,000 mL sedimentation cylinder and distilled water was added up to the 1,000 mL level (Fig. 11). Soil texture analysis of five soil samples per day were completed with the starting intervals staggered to allow for the measurements of each sample at the proper time. A blank standard was also prepared from 100 mL of HMP solution and added to a 1,000 mL sedimentation cylinder. The standard was stirred using the plunger method and then an ASTM 152 H-type hydrometer was lowered into the solution to determine the blank hydrometer reading (R_L). R_L was recorded periodically throughout all soil particle analysis along with the temperature of both the standard and the soil sample. Hydrometer testing of the soil samples included stirring with a plunger at the start of the analysis and lowering the hydrometer into the soil solution with the first readings recorded at 30 seconds, 1 minute, 3 minutes and then following the timed intervals.

At each timed interval R (g/L) and R (C°) were measured and recorded into an Excel spreadsheet (Appendix B). After the soil analysis was completed the data were entered into the USDA’s Hydrometer Particle Size Calculator ASTM No. 1 152H-Type with Bouyoucos scale in gL-1 developed by the Stillwater, OK Soil Survey Office. The soil separates data were also plotted on a soil texture triangle and separate size designation nomenclature was assigned along with a particle size summation curve (Figs. 12 and 13).

Figure 10. Soil sieve to ≤ 2 mm.

Figure 11. Separates analysis using the hydrometer method.

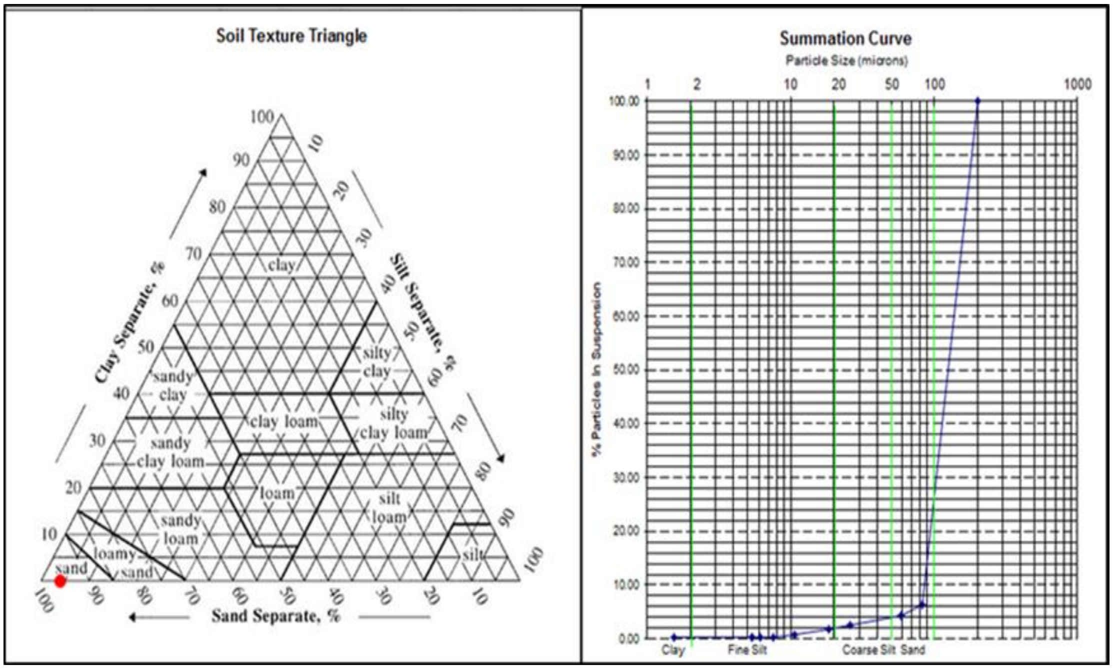


Figure 12. Sand soil texture triangle and summation curve.

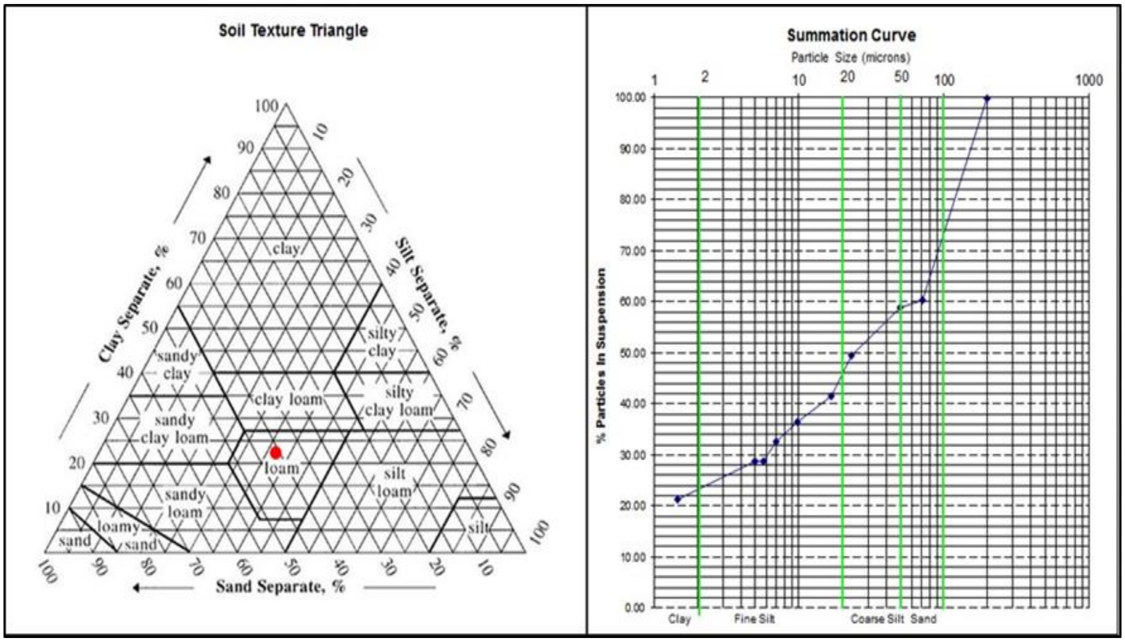


Figure 13. Loam soil texture triangle and summation curve.

CHAPTER V

RESULTS

Terrain Analysis

The SPI signatures values in the Larimore Dam watershed had a range from areas of no predicted erosion at -13.825 to areas of extremely high erosion at 12.114. The Fordville Dam watershed values were at -13.815 for areas with no erosion to 13.448 for areas of high erosion. The SPI signatures that fell at or above the threshold value for the Larimore Dam watershed represents an area of 6.80 km^2 (2.63 mi^2) or 17.6 percent of the total surface area of the study area. The SPI signatures that fell at or above the threshold value for the Fordville Dam watershed represents an area of 24.05 km^2 (9.29 mi^2) or 20 percent of the total surface area of the study area (Table 5).

Table 5. Percent SPI signatures per surface area.

Larimore Dam Watershed		
SPI Threshold of 85th percentile	Area (km^2)	Percentage
Threshold ($\geq$ -0.94812)	6.80	17.60
Threshold (< -0.94812)	31.83	82.40
Watershed Total	38.63	100
Fordville Dam Watershed		
Threshold ($\geq$ -0.70932)	24.05	19.90
Threshold (< -0.70932)	96.85	80.12
Watershed Total	120.91	100

The 85th percentile threshold value for the Larimore Dam was -0.973 and -0.709 for the Fordville Dam watershed. The cumulative distribution plots of the SPI signature for both watersheds in (Fig. 14) isolate the field verified erosion features from the total

SPI signatures. The majority of the measured gullies were found in the upper end of the distribution plots. Galzki (2009) found that the signature values that show up at the lower end of the distribution were found to be anomalies and could indicate areas where topography fails to portray surface flow because of subsurface influences such as soil factors or artificial watershed drainage. The inflections in the total SPI values (Fig. 14) represents a lack of SPI values for this data range because the fill reduced the SPI signatures of these cells (Galzki et al. 2011).

Visual interpretation of the SPI signatures before the 85th percentile threshold was applied to the SPI layer in ArcMap 10.1 is difficult as seen in (Fig. 15a). After the SPI values were reclassified to the 85th percentile threshold and only values at or above that threshold were displayed it becomes very easy to pinpoint locations of high SPI signatures (Fig 15b).

Field Survey

The field survey identified 299 gully and inlet locations in the Larimore Dam watershed and 92 locations in the Fordville Dam watershed. Within the Larimore Dam watershed the terrain analysis model identified 239 gully and inlet locations that had connectivity from the field to the stream channel. Of these 239 locations (Table 6) 186 (78%) were correctly identified during the field survey with the remaining 53 (22%) locations resulting in a false positive (Type I Error). The 66 gully locations not identified in the model and identified in the field survey, but did not show connectivity from the field to the stream were omission errors (Type II Errors). These gully locations were identified in the model as being within confines of the high-water mark and defined as stream-bank erosion with a high concentration of these locations in the deeply entrenched portions of the river channel. In the Fordville Dam watershed the terrain analysis model identified

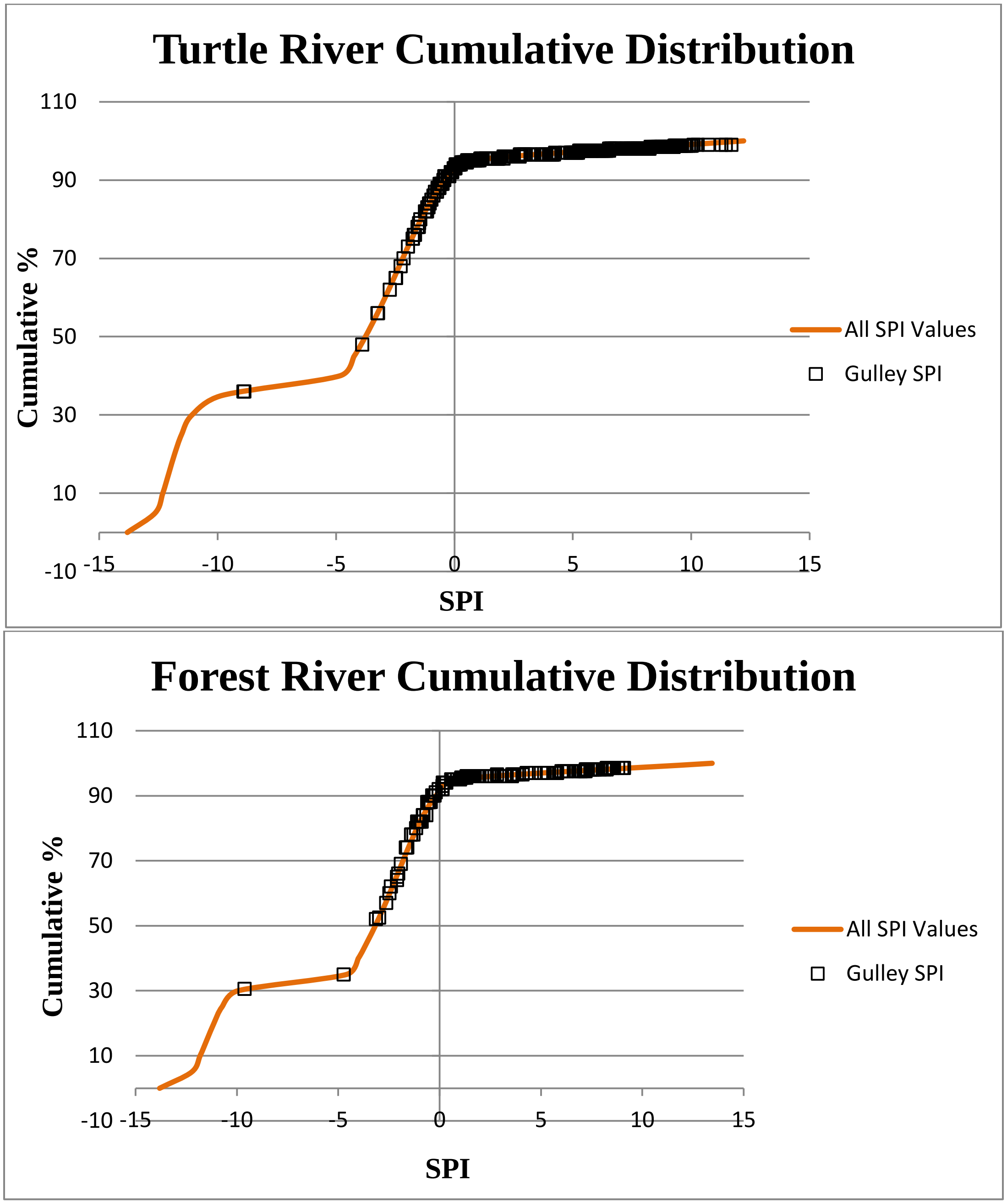


Figure 14. Cumulative distribution plots of SPI signatures of field verified erosion features for the Larimore Dam Watershed (Turtle River) and the Fordville Dam Watershed (Forest River). Galzki, Birr, and Mulla (2011) found that the inflection in the cumulative SPI percentages is representative of a lack of SPI signatures for this range because the pit filling lowered these data values.

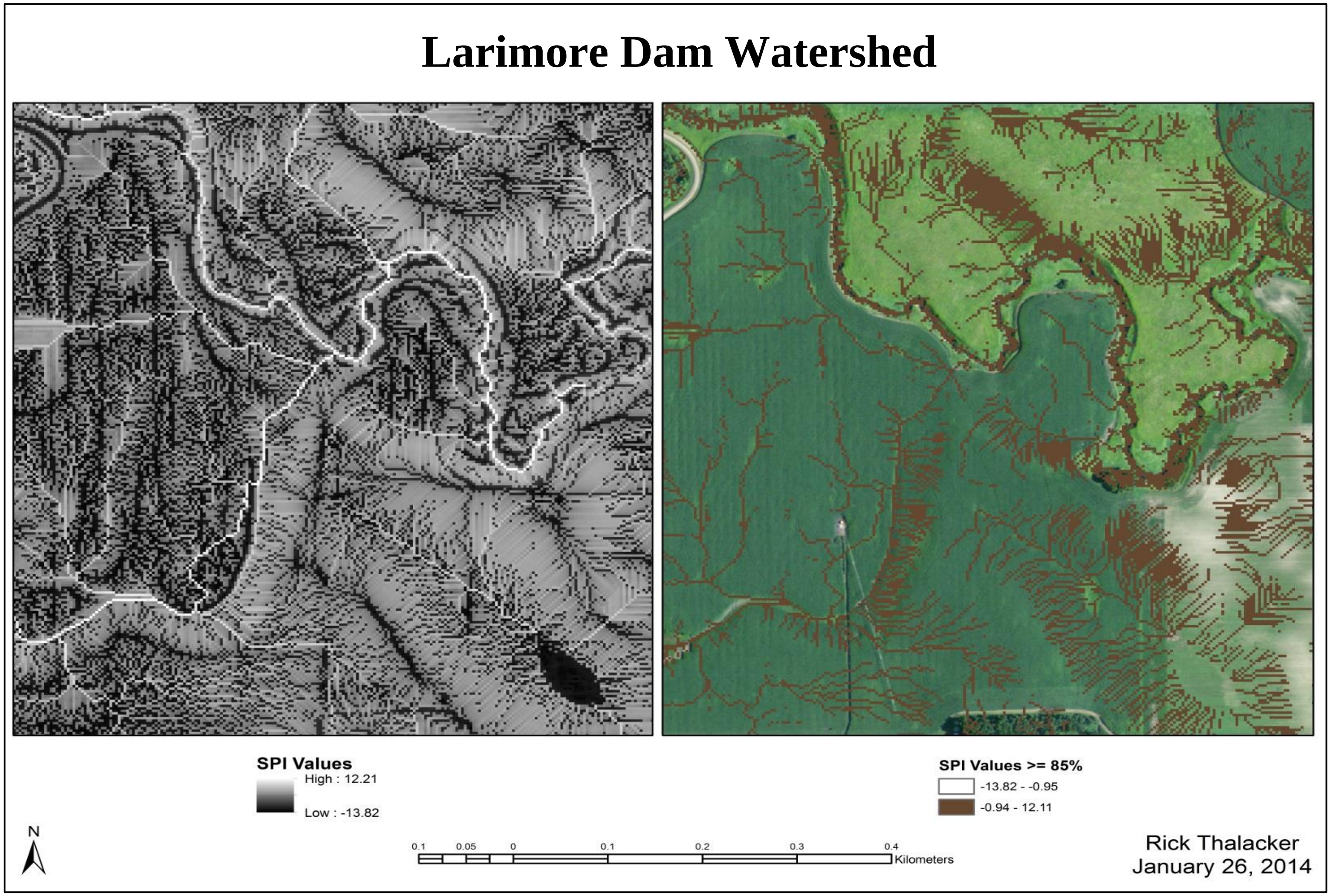


Figure15. SPI distributions at the field scale. Left side (a) represent all SPI values and right side (b) are all SPI values ≥ 85%.

84 gully and inlet locations that had connectivity from the field to the stream channel. Of the 84 identified locations, 68 (81%) were correctly identified during the field survey with the remaining 16 (19%) locations being a false positive (Type I Error). The eight gully locations identified in the field survey that did not show connectivity from the field to the stream in the model were omission errors (Type II Errors). The omission errors for these gully locations were also identified as stream bank erosion (Table 7). Gully widths were measured at the location where the gully began to fan out above the low-water line.

Table 6. Larimore Dam watershed error assessment table.

Correctly Identified	False Positive (Type 1 Error)	Omission by Model (Type II Error)
186/239 (78%)	47/239 (20%)	66/299 (22%)

Table 7. Fordville Dam watershed error assessment table.

Correctly Identified	False Positive (Type 1 Error)	Omission by Model (Type II Error)
68/84 (81%)	16/84 (19%)	92-84 (8%)

The smallest identified gullies measured 20-30 cm in width and were as shallow as 15-20 cm in depth. The larger gullies exceed widths over 100-cm and depths up to 90-cm. Correctly identified gulley locations for both watersheds (Figs. 16 and 17). A gully extends from a flat area with agricultural fields on both sides in the Larimore Dam Watershed as seen in (Fig. 18). A gully in a steep, loose, embankment can be seen in (Fig. 19). A small erosion feature (Fig. 20) is identifiable extending from the edge of the corn field where it then increases into a medium sized gulley as it nears the stream bank. A gully location of extreme erosion can be seen (Fig. 21) where the first three rows of crops have fallen into the gully at this location in the Larimore Dam watershed.

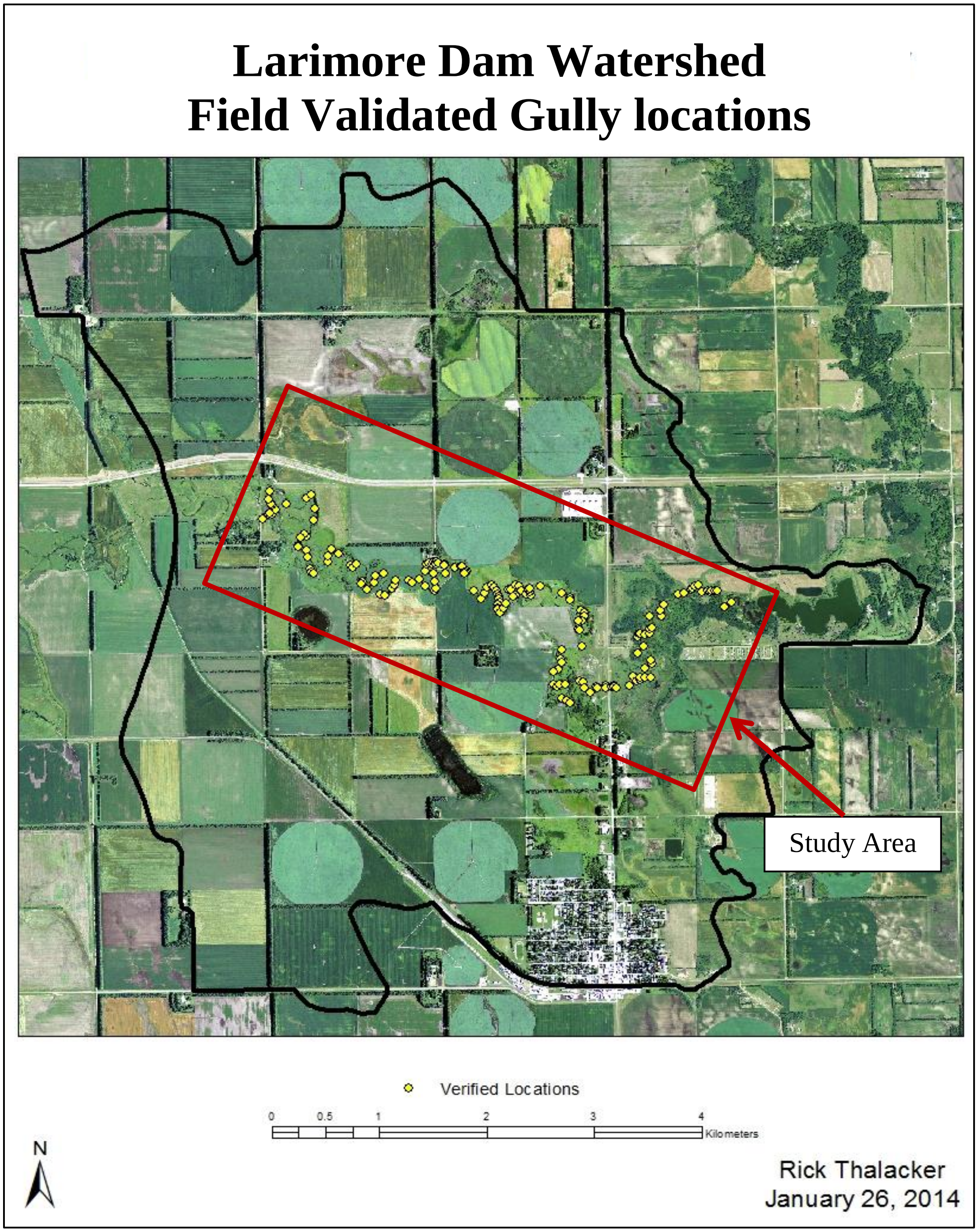


Figure 16. Larimore Dam Watershed gully locations that have connectivity to the stream channel. These locations were identified by the computer model and field verified during the field survey. The far western section of the stream channel was not included in the model because of land access issues.

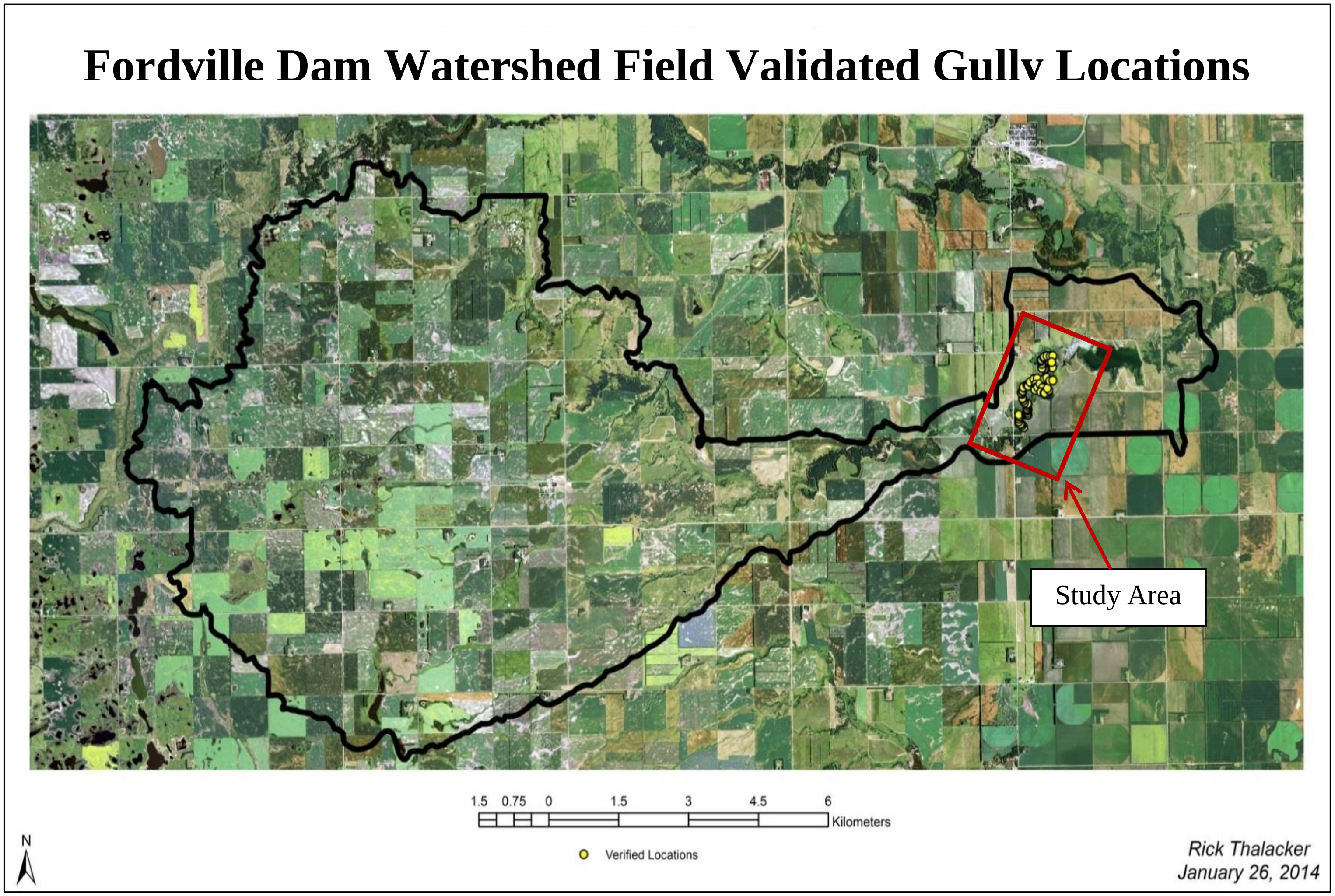


Figure 17. Fordville Dam Watershed gully locations that have connectivity to the stream channel. These locations were identified by the computer model and field verified during the field survey. Only the section of stream nearest to the reservoir was included in the study because of land access issues.

Figure 18. Gully location in relatively flat terrain.

Figure 19. Gully location located on steep stream bank.

Figure 20. Small erosion feature leading into a gully system.

Figure 21. Severe erosion feature on the Turtle River.

Soil Analysis

The Larimore Dam Watershed soil texture from the collected samples was predominately sand. Ten samples were predominantly sand characteristic, seven samples were sandy loam, eight samples were loamy sand, and four samples were loam. The Fordville Dam Watershed had six collected samples designated sand, five samples were sandy loam, two samples were loamy sand, one sample was loam, and one sample was sandy clay. The percentage distributions of soil texture for the gully location samples for each watershed (Fig. 22) show the dominance of the sand.

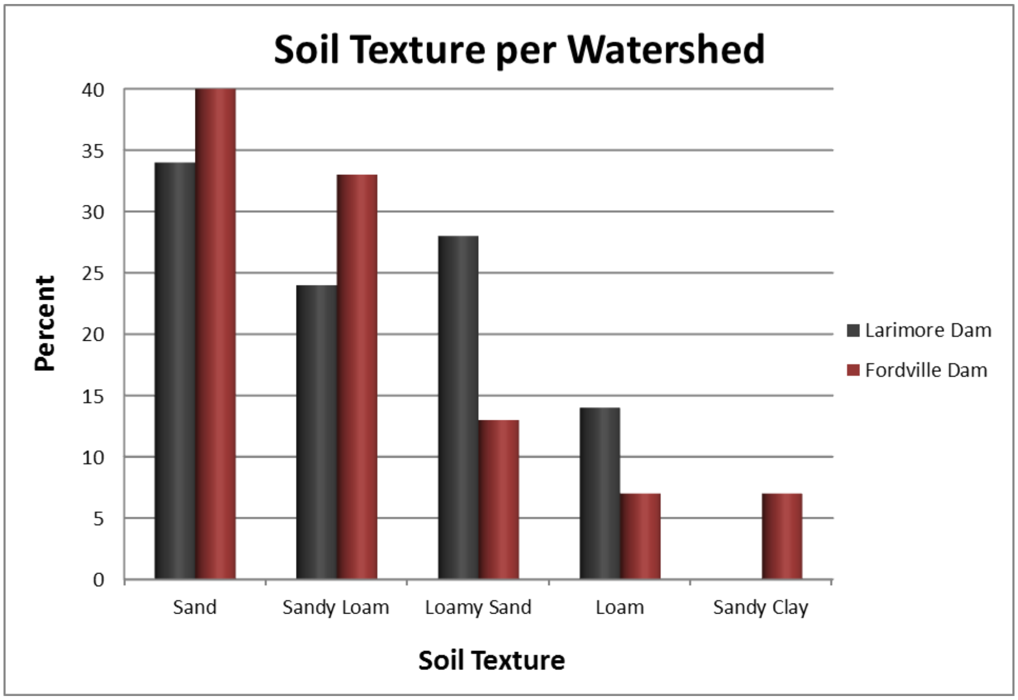


Figure 22. Soil texture distribution of the field samples for each watershed.

The soil texture analysis shows sand at approximately 34 percent, as the highest percentage separate size of the collected samples from the field survey. The high sand content was expected with the watershed being aligned within the beach ridges of the Lake Agassiz Basin. The soil texture analysis for the Fordville Dam watershed shows sand at approximately 40 percent as the highest separate size which again was to be expected being in the beach ridge area of the Red River Valley.

The pH tests for the soil analysis of the Larimore Dam watershed suggest a neutral to basic soil distribution from the samples collected along the stream channel. The pH values range from 6.93 to 8.38. Of the 29 samples collected, one sample was characterized as slightly acidic, 11 were neutral, nine were mildly basic, and the remaining eight were moderately basic. The pH tests for the soil texture analysis of the Fordville Dam watershed suggest a neutral to basic soil distribution across the watershed. Of the 15 samples collected, two samples were characterized as slightly acidic, seven were neutral, four were mildly basic, and the remaining two were moderately basic (Fig. 23).

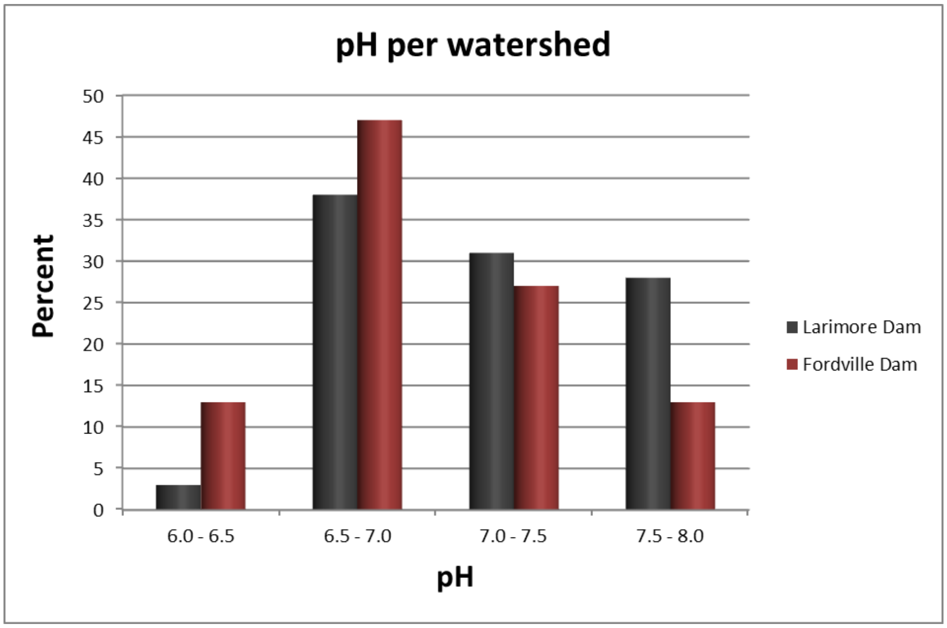


Figure 23. pH analysis per watershed

The EC for soil samples for the Larimore Dam Watershed had values that ranged from a low of 0.081 mS/cm to a high of 2.281 mS/cm. Of the 29 soil samples from the Larimore Dam Watershed 25 samples were between 0-2 mS/cm indicating non-saline and four samples were between 2-4 mS/cm indicating a very slightly saline soil. The EC for the soil samples for the Fordville Dam Watershed range from a low EC value of 0.3440 mS/cm to a high EC value of 1.976 mS/cm. All the soil samples from the Fordville Dam Watershed indicate non-saline type soils (Fig. 24).

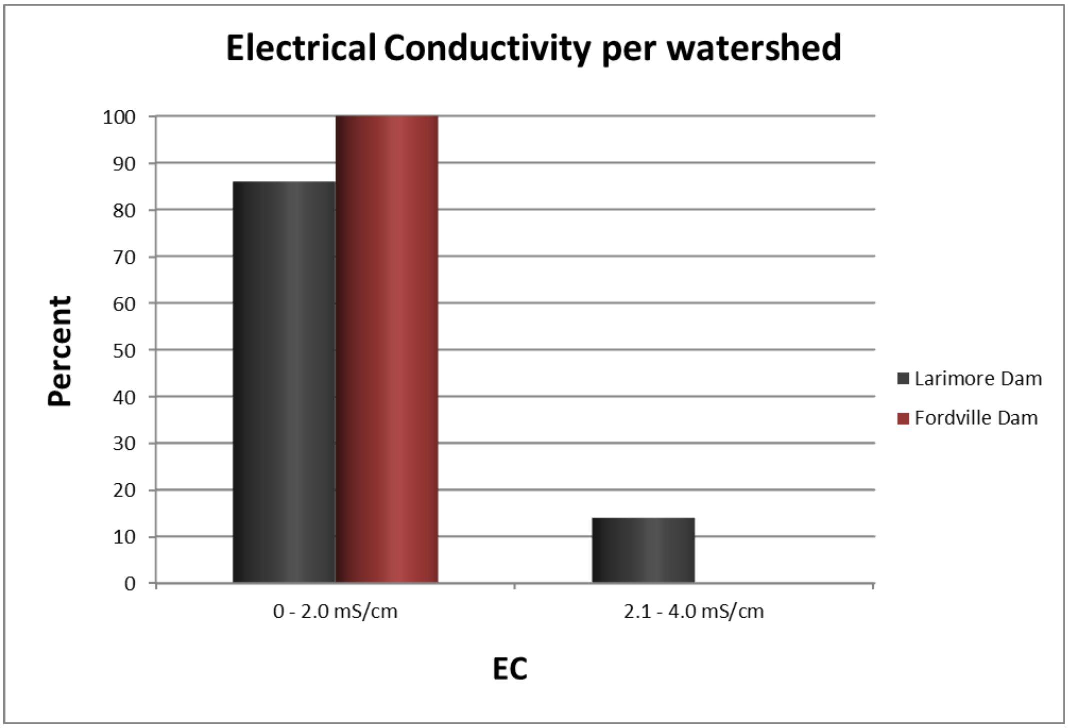


Figure 24. Electrical Conductivity per watershed

The soil analysis results for the Larimore Dam Watershed are listed categorically in Table 8 and for the Fordville Dam Watershed in Table 9.

Table 8. Larimore Dam Watershed soil analysis.

Sample #	**pH**	**EC (mS/cm)**	**SPI**	**% Sand**	**% Silt**	**% Clay**	**Texture**
Turtle River # 01 07/30/2013	7.35	1.514	5.621298	70	19	11	Sandy Loam
Turtle River # 02 07/22/2013	8.38	0.2796	-2.326847	73	18	9	Sandy Loam
Turtle River # 03 07/31/2013	7.87	1.006	2.335297	96	4	0	Sand
Turtle River # 04 07/03/2013	7.12	0.8967	1.155164	96	4	0	Sand
Turtle River # 05 07/30/2013	7.17	1.075	0.745148	97	3	0	Sand

Table 8. Larimore Dam Watershed soil analysis (Cont).

Sample #	pH	EC (mS/cm)	SPI	% Sand	% Silt	% Clay	Texture
Turtle River # 06 07/30/2013	7.72	0.7114	-10.338384	89	11	0	Sand
Turtle River # 07 07/30/2013	7.62	1.109	7.42525	94	2	4	Sand
Turtle River # 08 07/26/2013	7.19	1.607	-2.447439	41	37	22	Loam
Turtle River # 09 07/26/2013	7.77	1.639	-0.293825	84	13	3	Loamy Sand
Turtle River # 10 07/28/2013	7.17	2.170	-8.945934	87	7	6	Loamy Sand
Turtle River # 11 07/26/2013	8.01	0.081	-0.418013	72	26	2	Loamy Sand
Turtle River # 12 07/26/2013	7.45	1.481	-0.810668	73	15	12	Sandy Loam
Turtle River # 13 07/31/2013	6.93	1.447	1.393871	50	38	12	Loam
Turtle River # 14 07/26/2013	7.50	2.281	-2.265615	38	42	20	Loam
Turtle River # 15 07/26/2013	7.59	1.565	0.392245	35	40	25	Loam
Turtle River # 16 07/17/2013	7.24	1.694	-4.065121	93	4	3	Sand
Turtle River # 17 07/17/2013	7.68	1.580	7.236764	86	10	4	Loamy Sand
Turtle River # 18 07/??/2013	7.08	1.051	-9.48075	97	2	1	Sand
Turtle River # 19 07/??/2013	7.19	1.086	-9.720047	73	20	7	Sandy Loam
Turtle River # 20 07/04/2013	7.91	0.3261	5.127947	84	9	7	Loamy Sand
Turtle River # 21 07/04/2013	7.17	1.788	8.427243	78	16	6	Loamy Sand
Turtle River # 22 07/30/2013	7.61	1.104	1.497384	86	14	0	Sand
Turtle River # 23 07/04/2013	7.86	1.609	2.934914	75	17	8	Sandy Loam
Turtle River # 24 07/07/2013	7.63	1.676	4.162928	63	23	14	Sandy Loam
Turtle River # 25 07/04/2013	7.28	1.080	1.58768	89	6	5	Sand
Turtle River # 26 07/09/2013	7.22	0.8621	-11.777555	96	4	0	Sand
Turtle River # 27 07/09/2013	7.75	1.214	-2.467624	84	7	9	Loamy Sand
Turtle River # 28 07/09/2013	7.57	2.063	-0.861154	63	25	12	Sandy Loam
Turtle River # 29 07/09/2013	7.76	2.017	-2.120443	87	8	5	Loamy Sand

Table 9. Fordville Dam Watershed soil analysis.

Sample #	pH	EC (mS/cm)	SPI	% Sand	% Silt	% Clay	Texture
Forest River # 01 07/29/2013	6.68	0.5730	-8.65694	70	23	7	Sandy Loam
Forest River # 02 07/30/2013	8.11	0.3440	0.411944	95	2	3	Sand
Forest River # 03 07/23/2013	6.83	1.482	-0.911269	70	23	7	Sandy Loam
Forest River # 04 07/22/2013	7.62	0.8617	3.832469	57	27	16	Sandy Loam
Forest River # 05 07/27/2013	7.07	1.387	0.872469	87	10	3	Sand
Forest River # 06 07/27/2013	7.83	0.8431	10.538981	80	8	12	Sandy Loam
Forest River # 07 07/27/2013	7.25	1.269	-2.232587	59	19	22	Sandy Clay
Forest River # 08 07/27/2013	7.02	1.976	-1.520202	87	7	6	Loamy Sand
Forest River # 10 07/22/2013	7.23	0.6987	-2.959735	89	6	5	Sand
Forest River # 11 07/22/2013	7.62	0.4088	8.326159	84	16	0	Sand
Forest River # 12 07/22/2013	7.81	1.609	-1.638009	38	45	17	Loam
Forest River # 13 07/27/2013	7.51	1.976	7.128326	69	20	11	Sand
Forest River # 14 07/20/2013	7.88	1.345	-9.725096	98	2	0	Sand
Forest River # 15 07/20/2013	7.41	0.9910	-10.91385	73	21	6	Sandy Loam
Forest River # 16 0/20/2013	7.41	0.7124	0.580496	76	19	5	Loamy Sand

CHAPTER VI

DISCUSSION

Terrain Analysis

Terrain attributes derived from the 3-m LiDAR DEMs for this study were effective in modeling SPI signatures that could identify gully and inlet locations in the low relief topography of the study area. The importance of mapping the SPI signatures is in documenting these small areas of the landscape that contribute high levels of contaminants and in the conservation value, the ability to identify areas of erosion or potential erosion from overland surface flow (Wilson and Gallant 2000). A critical SPI threshold of 85th percentile was chosen so that only the top 15th percentile of the SPI signatures were displayed. This allowed for the easy identification of SPI signature connectivity with the stream channel. By isolating these locations it was then possible to identify critical erosion areas. Once identified, these vulnerable, critical erosion areas can be addressed with the implementation of BMPs resulting in potential improvement to the water quality in the local stream channel, and to the watershed overall.

The field survey was successful in validating the terrain analysis model for both watersheds. The Larimore Dam study area validation was 78 percent for the correctly identified gully locations and the Fordville Dam was at 81 percent. The false positives (Type I Error), locations identified by the model but were not field verified was 19 and 20 percent respectively. These values are higher than the values calculated by Galzki

(2009) and Dinger (2012) and could be directly related to the entrenched nature of the stream channel and the difficulty of accessing the high-water line in many locations. The omission errors, areas of high SPI signatures that connected to the stream channel but did not connect to the field was considered to be stream-bank erosion.

Soil Analysis

The proximity of the beach ridges for both watersheds can explain the results of the high dominance of sand in the sediment samples collected. The beach ridges intersect the Larimore Dam Watershed through the middle section resulting in samples collected on the East and West sides of the ridges.

The sediment samples for the Fordville Dam Watershed were collected only in the far eastern section of the watershed nearest to the beach ridges, hence, also having an influence on the texture distribution. Two main reasons for the areas of high erosion and gully formation within the watersheds are too much water over a surface area that is affected by a reduction of vegetative cover (Morgan 2005) and the sandy loam and loamy sand textures found in both watersheds. These medium-textured soils are more susceptible to higher erosion rates because of the higher percentage of silts and fine sands (O’Geen 2006). The introduction of these sediments to the stream channel has direct affects downstream in the reduction of water quality and reducing stream and reservoir capacities (Morgan 2005).

The pH levels, ranging from 6.0 – 8.5, for the Larimore Dam and the Fordville Dam Watersheds varied between slightly acidic to moderately basic with the highest percentage of the samples being at or near a pH of 7.0. The low EC values, a measure of the amount of salts that are present in the soil ranged from 0.0 – 2.4 mS/cm. These values correlate directly to non-saline to very slightly saline condition with a sand to silt texture.

A Spearman’s Rho statistical analysis was calculated to determine if there is a correlation between the critical SPI signatures and each of sand, silt and clay percentages for the soil samples collected during the field survey. The Spearman’s Rho for both the Larimore Dam Watershed (Table 10) and (Fig. 25) showed little correlation in the soil sample data.

Table 10. Spearman’s rho test for the Larimore Dam watershed.

Larimore Dam Watershed			**SPI**	**Sand**	**Silt**	**Clay**
Spearman's rho	SPI	Correlation Coefficient	1.000	-.092	.040	.075
		Sig. (2-tailed)	.	.637	.838	.700
		N	29	29	29	29

**. Correlation is significant at the 0.01 level (2-tailed).

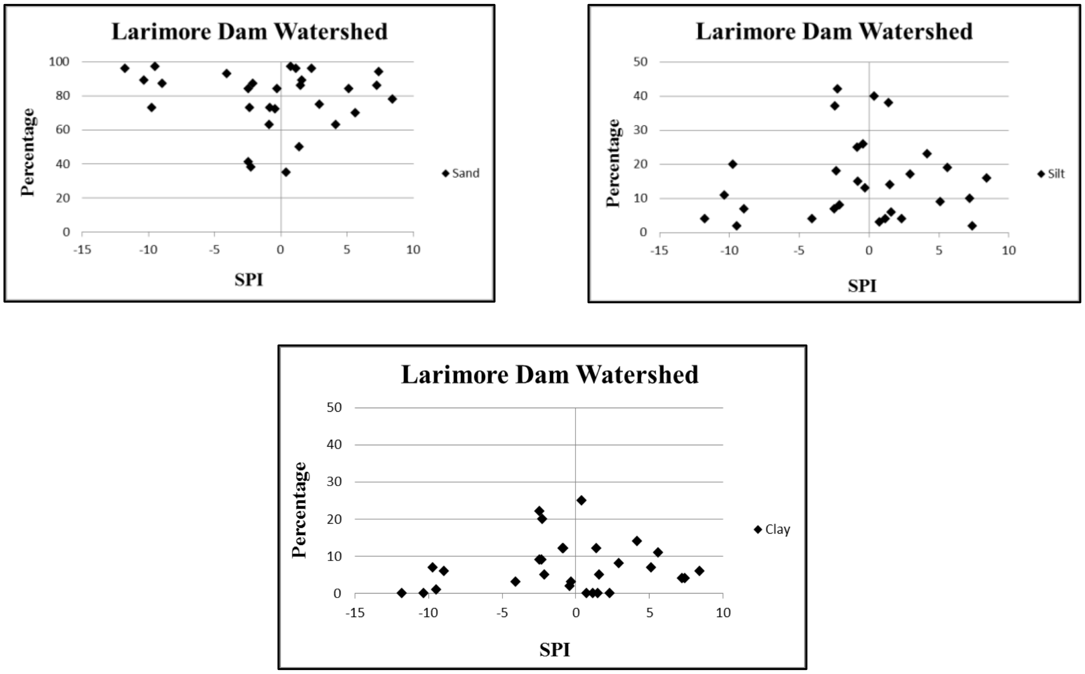


Figure 25. Larimore Dam Watershed SPI signatures to texture correlation.

The Spearman’s Rho for both the Fordville Dam Watershed (Table 11) and (Fig. 26) showed similar results with little correlation in the soil sample data.

Table 11. Spearman’s rho test for the Fordville Dam Watershed.

Fordville Dam Watershed			**SPI**	**Sand**	**Silt**	**Clay**
Spearman's rho	SPI	Correlation Coefficient	1.000	-.144	.075	-.188
		Sig. (2-tailed)	.	.594	.782	.486
		N	15	15	15	15

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

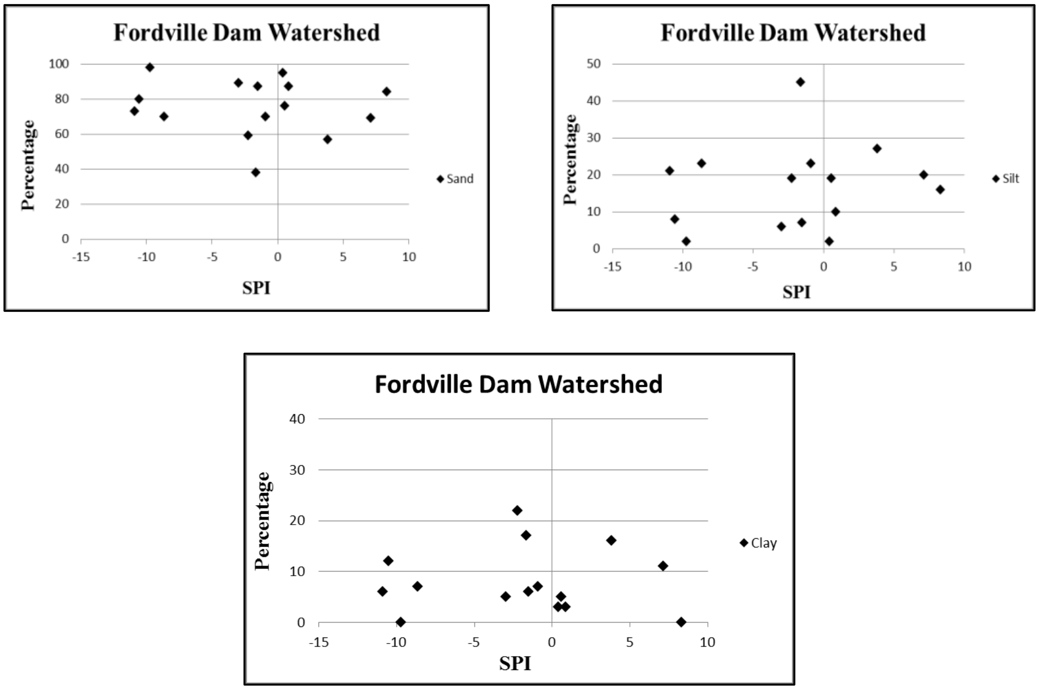


Figure 26. Fordville Dam Watershed SPI signatures to texture correlation.

CHAPTER VII

CONCLUSIONS

This study proved to be highly accurate in using terrain analysis for identifying critical areas of erosion in both watersheds. The model correctly identified 186 out of 239 (78 percent) field-identified erosion features in the Larimore Dam watershed, and 64 out of 84 (81 percent) field-identified erosion features in the Fordville Dam watershed. The 78 percent accuracy rate for the Larimore Dam watershed and 81percent for the Fordville Dam watershed are very similar to the results obtained in both Galzki (2009) 80 percent and Dinger (2012) 79 percent. The similarity of these results to other studies validates the effectiveness of the terrain analysis model in low relief topography. The physiochemical properties of the sediment samples collected are reflective of a high sand content in each watershed with non-saline to very low saline soil conditions. The pH levels ranged from 6.93 to 8.38 for both watersheds.

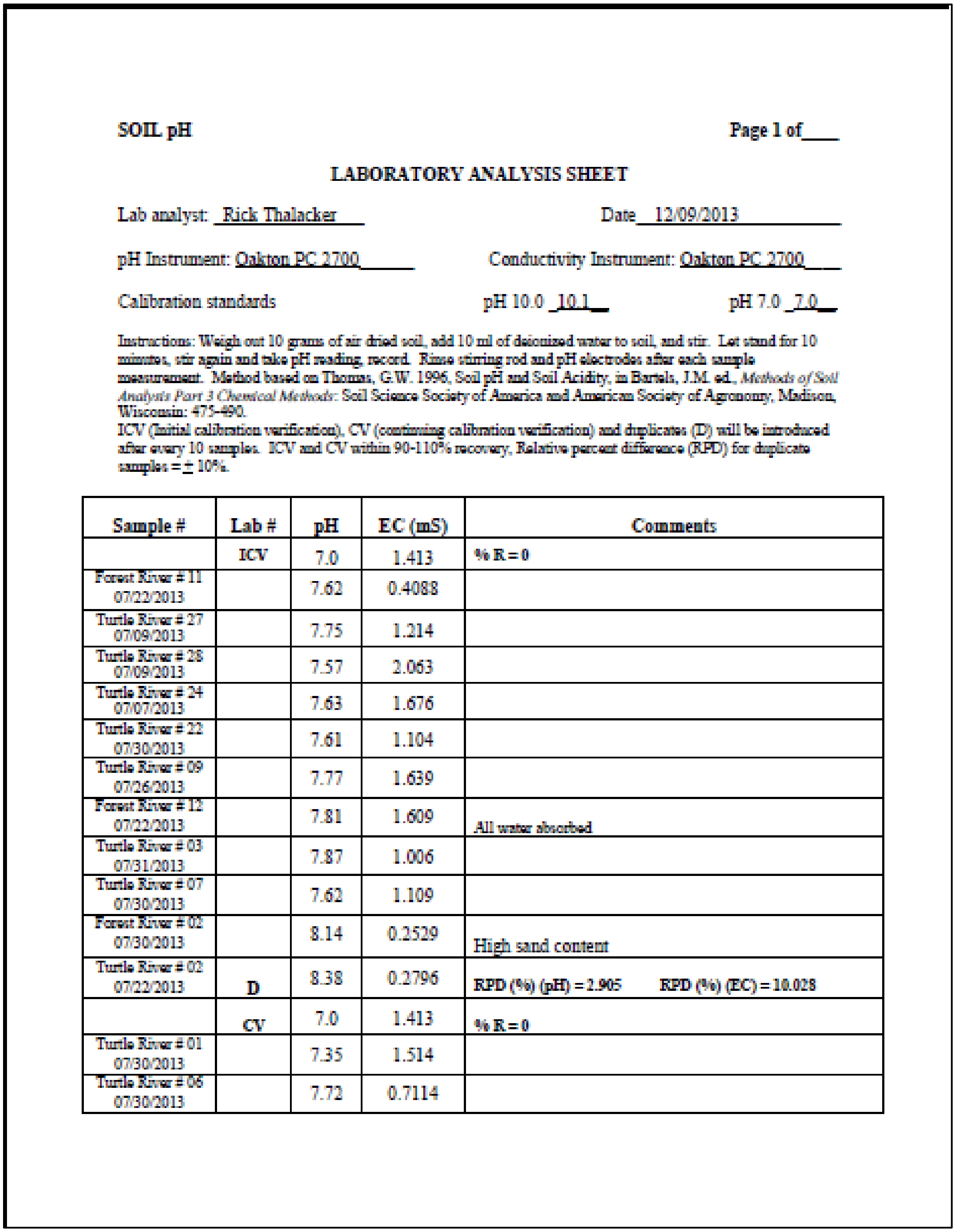
The SPI method allows for the identification of critical areas of erosion for the implementation of precision conservation techniques in the Turtle River and Forest River watersheds. These conservation techniques can be installed at the field scale at the location of the identified critical erosion features to decrease potential negative affects to surface water quality through the introduction of sediments, nutrients, pesticides and chemicals and these gully locations.

To better improve the results for future studies in both of these watersheds it is recommended to do the field work in late spring and early summer, May and June. The dense vegetation later in the year makes for difficult identification of small erosional features on the steep embankments in the stream channel. It is also extremely difficult to access the high-water line in many parts of the watershed from the low water line for the same reason. To increase the accuracy of the field survey it would be more effective if conducted not only from kayak at low-water line, but also foot travel down each side of the stream channel. From the low-waterline it is problematic to identify erosional connectivity from the field to the stream channel. This technique would require a minimum of three people for each day of the field survey, dramatically increasing the field hours.

APPENDICES

Appendix A

Laboratory Analysis Data



SOIL pH **Page 1 of____**

LABORATORY ANALYSIS SHEET

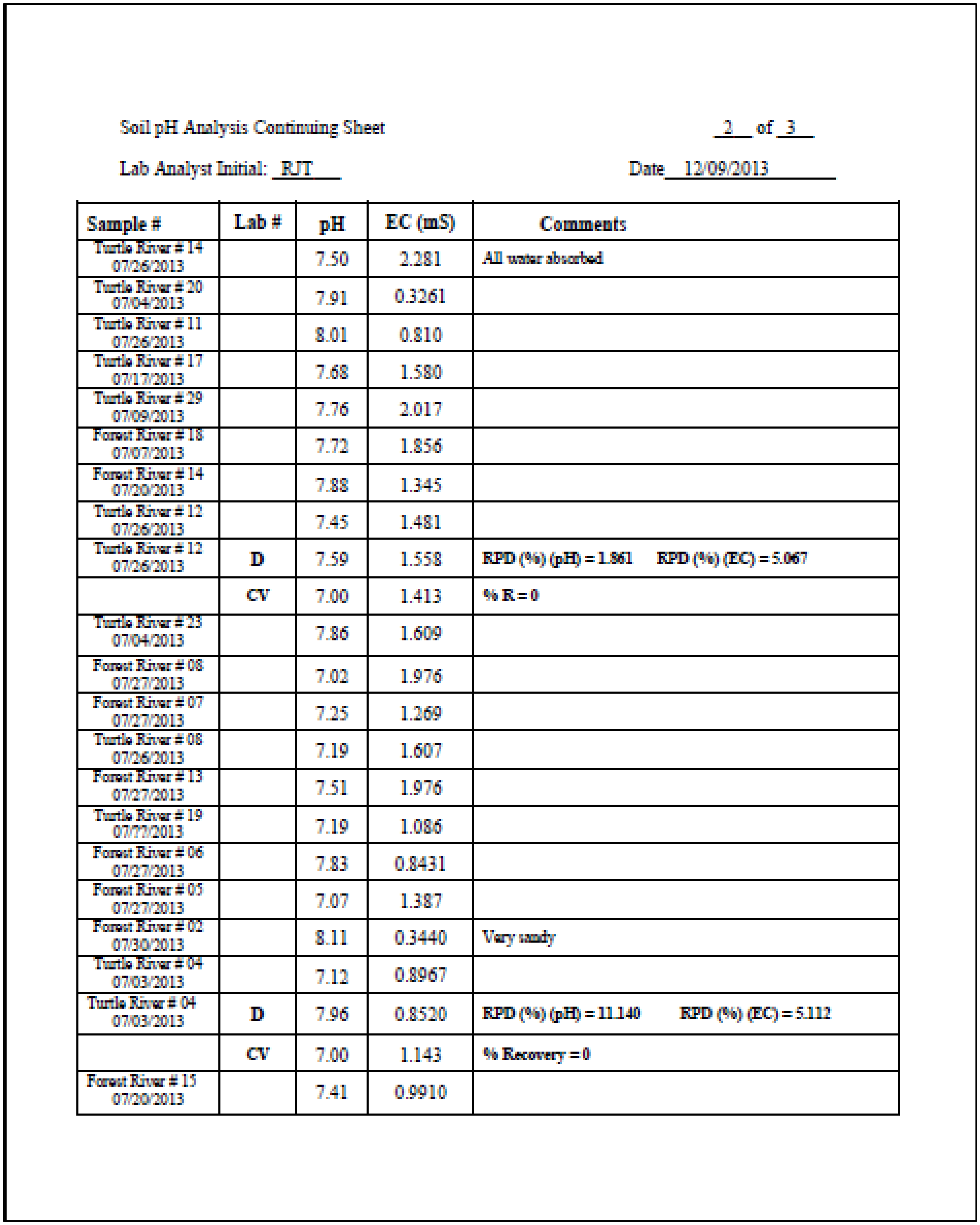
Lab analyst: Rick Thalacker Date 12/09/2013

pH Instrument: Oakton PC 2700 Conductivity Instrument: Oakton PC 2700

Calibration standards pH 10.0 10.1 pH 7.0 7.0

Instructions: Weigh out 10 grams of air dried soil, add 10 ml of deionized water to soil, and stir. Let stand for 10 minutes, stir again and take pH reading, record. Rinse stirring rod and pH electrodes after each sample measurement. Method based on Thomas, G.W. 1996, Soil pH and Soil Acidity, in Bartels, J.M. ed., *Methods of Soil Analysis Part 3 Chemical Methods*: Soil Science Society of America and American Society of Agronomy, Madison, Wisconsin: 475-490.
ICV (Initial calibration verification), CV (continuing calibration verification) and duplicates (D) will be introduced after every 10 samples. ICV and CV within 90-110% recovery, Relative percent difference (RPD) for duplicate samples = ± 10%.

Sample #	Lab #	pH	EC (mS)	Comments
	ICV	7.0	1.413	% R = 0
Forest River # 11 07/22/2013		7.62	0.4088	
Turtle River # 27 07/09/2013		7.75	1.214	
Turtle River # 28 07/09/2013		7.57	2.063	
Turtle River # 24 07/07/2013		7.63	1.676	
Turtle River # 22 07/30/2013		7.61	1.104	
Turtle River # 09 07/26/2013		7.77	1.639	
Forest River # 12 07/22/2013		7.81	1.609	All water absorbed
Turtle River # 03 07/31/2013		7.87	1.006	
Turtle River # 07 07/30/2013		7.62	1.109	
Forest River # 02 07/30/2013		8.14	0.2529	High sand content
Turtle River # 02 07/22/2013	D	8.38	0.2796	RPD (%) (pH) = 2.905 RPD (%) (EC) = 10.028
	CV	7.0	1.413	% R = 0
Turtle River # 01 07/30/2013		7.35	1.514	
Turtle River # 06 07/30/2013		7.72	0.7114	

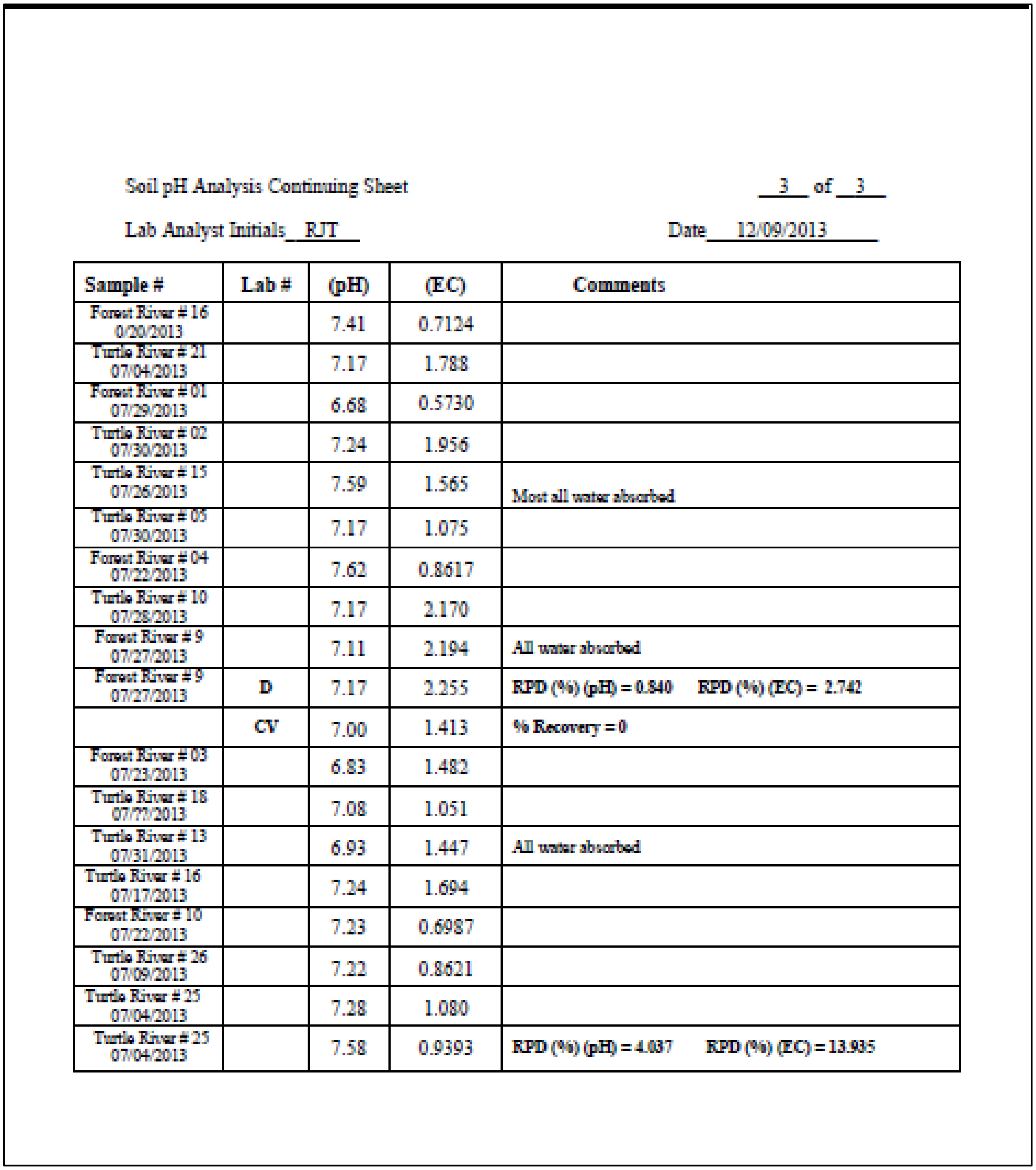


Soil pH Analysis Continuing Sheet 2 of 3

Lab Analyst Initial: RJT

Date 12/09/2013

Sample #	Lab #	pH	EC (mS)	Comments
Turtle River # 14 07/26/2013		7.50	2.281	All water absorbed
Turtle River # 20 07/04/2013		7.91	0.3261	
Turtle River # 11 07/26/2013		8.01	0.810	
Turtle River # 17 07/17/2013		7.68	1.580	
Turtle River # 29 07/09/2013		7.76	2.017	
Forest River # 18 07/07/2013		7.72	1.856	
Forest River # 14 07/20/2013		7.88	1.345	
Turtle River # 12 07/26/2013		7.45	1.481	
Turtle River # 12 07/26/2013	D	7.59	1.558	RPD (%) (pH) = 1.861 RPD (%) (EC) = 5.067
	CV	7.00	1.413	% R = 0
Turtle River # 23 07/04/2013		7.86	1.609	
Forest River # 08 07/27/2013		7.02	1.976	
Forest River # 07 07/27/2013		7.25	1.269	
Turtle River # 08 07/26/2013		7.19	1.607	
Forest River # 13 07/27/2013		7.51	1.976	
Turtle River # 19 07/77/2013		7.19	1.086	
Forest River # 06 07/27/2013		7.83	0.8431	
Forest River # 05 07/27/2013		7.07	1.387	
Forest River # 02 07/30/2013		8.11	0.3440	Very sandy
Turtle River # 04 07/03/2013		7.12	0.8967	
Turtle River # 04 07/03/2013	D	7.96	0.8520	RPD (%) (pH) = 11.140 RPD (%) (EC) = 5.112
	CV	7.00	1.143	% Recovery = 0
Forest River # 15 07/20/2013		7.41	0.9910	



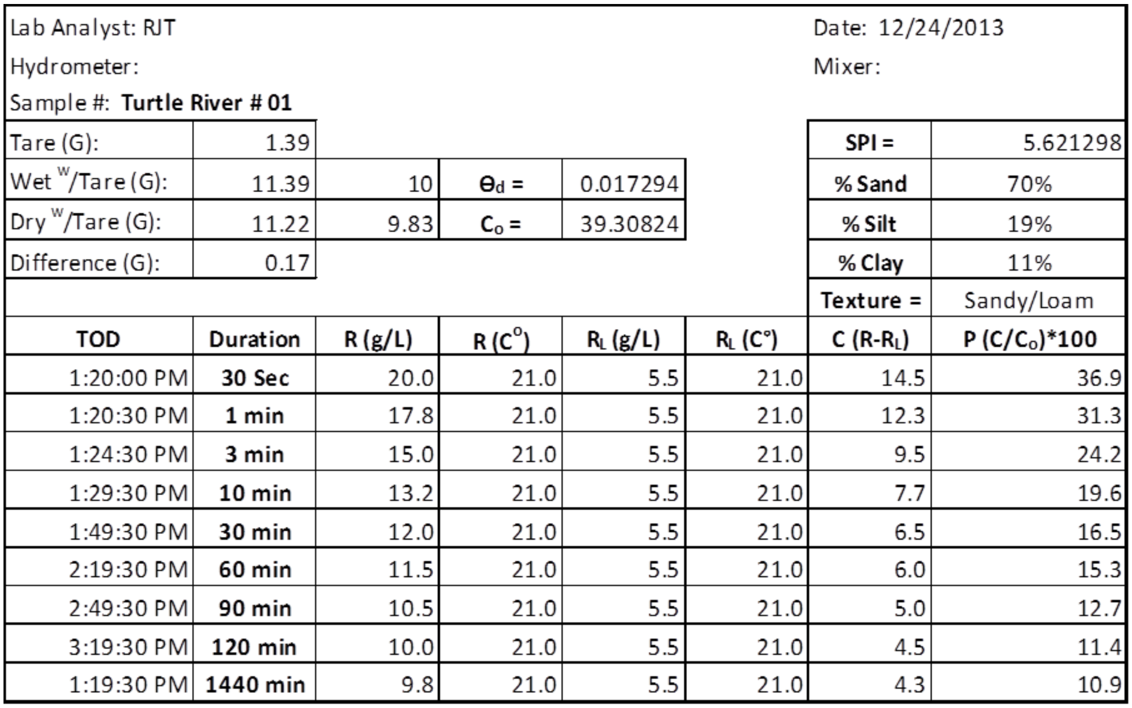
Soil pH Analysis Continuing Sheet __3__ of __3__

Lab Analyst Initials__RJT__ Date__12/09/2013____

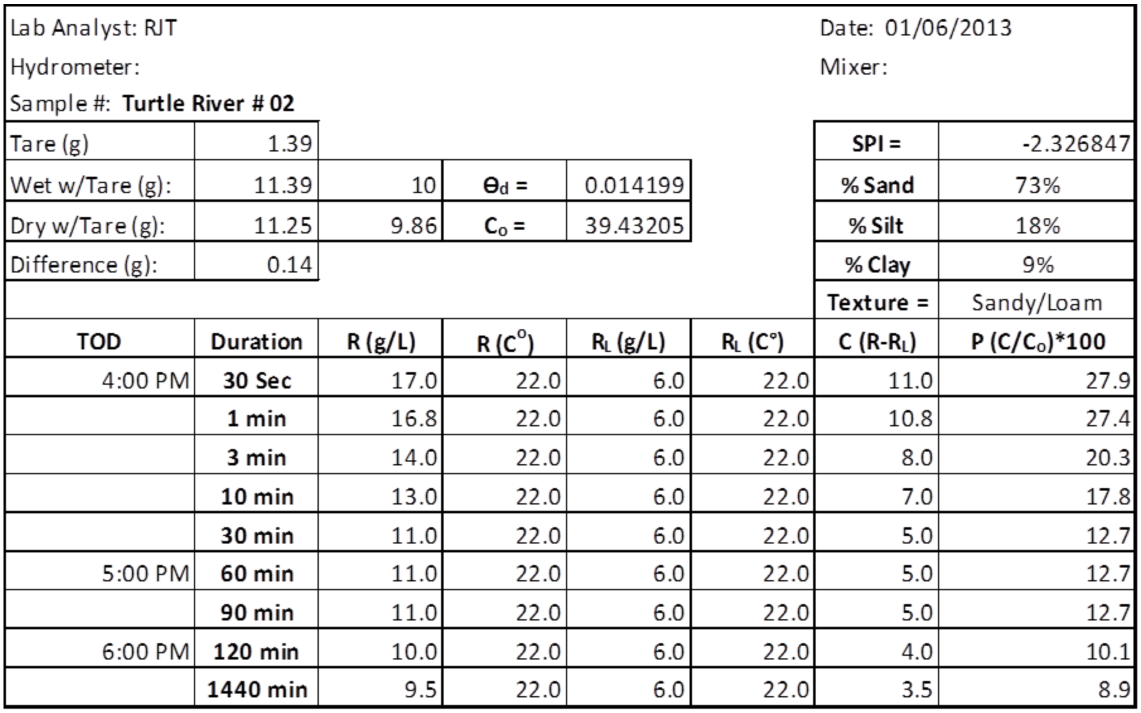
Sample #	Lab #	(pH)	(EC)	Comments
Forest River # 16 0/20/2013		7.41	0.7124	
Turtle River # 21 07/04/2013		7.17	1.788	
Forest River # 01 07/29/2013		6.68	0.5730	
Turtle River # 02 07/30/2013		7.24	1.956	
Turtle River # 15 07/26/2013		7.59	1.565	Most all water absorbed
Turtle River # 05 07/30/2013		7.17	1.075	
Forest River # 04 07/22/2013		7.62	0.8617	
Turtle River # 10 07/28/2013		7.17	2.170	
Forest River # 9 07/27/2013		7.11	2.194	All water absorbed
Forest River # 9 07/27/2013	**D**	7.17	2.255	**RPD (%) (pH) = 0.840 RPD (%) (EC) = 2.742**
	CV	7.00	1.413	**% Recovery = 0**
Forest River # 03 07/23/2013		6.83	1.482	
Turtle River # 18 07/77/2013		7.08	1.051	
Turtle River # 13 07/31/2013		6.93	1.447	All water absorbed
Turtle River # 16 07/17/2013		7.24	1.694	
Forest River # 10 07/22/2013		7.23	0.6987	
Turtle River # 26 07/09/2013		7.22	0.8621	
Turtle River # 25 07/04/2013		7.28	1.080	
Turtle River # 25 07/04/2013		7.58	0.9393	**RPD (%) (pH) = 4.037 RPD (%) (EC) = 13.935**

Appendix B

Soil Separates Analysis



Lab Analyst: RJT						Date: 12/24/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 01**							
Tare (G):	1.39					**SPI =**	5.621298
Wet ^{W}/Tare (G):	11.39	10	**Θ_d =**	0.017294		**% Sand**	70%
Dry ^{W}/Tare (G):	11.22	9.83	**C_o =**	39.30824		**% Silt**	19%
Difference (G):	0.17					**% Clay**	11%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
1:20:00 PM	**30 Sec**	20.0	21.0	5.5	21.0	14.5	36.9
1:20:30 PM	**1 min**	17.8	21.0	5.5	21.0	12.3	31.3
1:24:30 PM	**3 min**	15.0	21.0	5.5	21.0	9.5	24.2
1:29:30 PM	**10 min**	13.2	21.0	5.5	21.0	7.7	19.6
1:49:30 PM	**30 min**	12.0	21.0	5.5	21.0	6.5	16.5
2:19:30 PM	**60 min**	11.5	21.0	5.5	21.0	6.0	15.3
2:49:30 PM	**90 min**	10.5	21.0	5.5	21.0	5.0	12.7
3:19:30 PM	**120 min**	10.0	21.0	5.5	21.0	4.5	11.4
1:19:30 PM	**1440 min**	9.8	21.0	5.5	21.0	4.3	10.9



Lab Analyst: RJT						Date: 01/06/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 02**							
Tare (g)	1.39					**SPI =**	-2.326847
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.014199		**% Sand**	73%
Dry w/Tare (g):	11.25	9.86	**C_o =**	39.43205		**% Silt**	18%
Difference (g):	0.14					**% Clay**	9%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
4:00 PM	**30 Sec**	17.0	22.0	6.0	22.0	11.0	27.9
	1 min	16.8	22.0	6.0	22.0	10.8	27.4
	3 min	14.0	22.0	6.0	22.0	8.0	20.3
	10 min	13.0	22.0	6.0	22.0	7.0	17.8
	30 min	11.0	22.0	6.0	22.0	5.0	12.7
5:00 PM	**60 min**	11.0	22.0	6.0	22.0	5.0	12.7
	90 min	11.0	22.0	6.0	22.0	5.0	12.7
6:00 PM	**120 min**	10.0	22.0	6.0	22.0	4.0	10.1
	1440 min	9.5	22.0	6.0	22.0	3.5	8.9

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Date: 12/24/2013

Hydrometer:

Mixer:

Sample #: **Turtle River # 03**

Tare (g):	1.39					**SPI =**	2.335279
Wet ^{W}/Tare (g):	11.39	10	**Θ_d =**	0.004016		**% Sand**	96%
Dry ^{W}/Tare (g):	11.35	9.96	**C_o =**	39.83936		**% Silt**	4%
Difference (g):	0.04					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:53 PM	**30 Sec**	7.2	21.0	5.5	21.0	1.7	4.3
	1 min	7.0	21.0	5.5	21.0	1.5	3.8
	3 min	7.0	21.0	5.5	21.0	1.5	3.8
	10 min	7.0	21.0	5.5	21.0	1.5	3.8
3:23 PM	**30 min**	6.0	21.0	5.5	21.0	0.5	1.3
3:53 PM	**60 min**	6.0	21.0	5.5	21.0	0.5	1.3
	90 min	5.6	21.0	5.5	21.0	0.1	0.3
4:53 PM	**120 min**	5.6	21.0	5.5	21.0	0.1	0.3
	1440 min	5.6	21.0	5.5	21.0	0.1	0.3

Lab Analyst: RJT

Date: 01/07/2013

Hydrometer:

Mixer:

Sample #: **Turtle River # 04**

Tare (g)	1.39					**SPI =**	1.155164
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.011122		**% Sand**	96%
Dry w/Tare (g):	11.28	9.89	**C_o =**	39.55511		**% Silt**	4%
Difference (g):	0.11					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:27 PM	**30 Sec**	8.0	21.0	6.0	21.0	2.0	5.1
	1 min	7.6	21.0	6.0	21.0	1.6	4.0
	3 min	7.0	21.0	6.0	21.0	1.0	2.5
	10 min	7.0	21.0	6.0	21.0	1.0	2.5
	30 min	6.6	21.0	6.0	21.0	0.6	1.5
4:27 PM	**60 min**	6.4	21.0	6.0	21.0	0.4	1.0
	90 min	6.1	21.0	6.0	21.0	0.1	0.3
5:27 PM	**120 min**	6.1	21.0	6.0	21.0	0.1	0.3
	1440 min	6.1	21.0	6.0	21.0	0.1	0.3

Lab Analyst: RJT						Date: 12/24/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 05**							
Tare (g):	1.39					**SPI =**	0.872469
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	87%
Dry ^{w}/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	10%
Difference (g):	0.13					**% Clay**	3%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:21 PM	**30 Sec**	10.5	21.0	5.5	21.0	5.0	12.7
	1 min	10.5	21.0	5.5	21.0	5.0	12.7
	3 min	9.0	21.0	5.5	21.0	3.5	8.9
	10 min	9.0	21.0	5.5	21.0	3.5	8.9
	30 min	8.5	21.0	5.5	21.0	3.0	7.6
3:21 PM	**60 min**	7.2	21.0	5.5	21.0	1.7	4.3
	90 min	7.2	21.0	5.5	21.0	1.7	4.3
4:21 PM	**120 min**	7.0	21.0	5.5	21.0	1.5	3.8
	1440 min	6.8	21.0	5.5	21.0	1.3	3.3

Lab Analyst: RJT						Date: 12/23/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 06**							
Tare (g)	1.39					**SPI =**	-10.538981
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	80%
Dry ^{w}/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	8%
Difference (g):	0.13					**% Clay**	12%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
4:42 PM	**30 Sec**	14.0	21.0	5.5	21.0	8.5	21.5
	1 min	13.6	21.0	5.5	21.0	8.1	20.5
	3 min	12.6	21.0	5.5	21.0	7.1	18.0
	10 min	12.0	21.0	5.5	21.0	6.5	16.5
	30 min	12.0	21.0	5.5	21.0	6.5	16.5
5:42 PM	**60 min**	11.0	21.0	5.5	21.0	5.5	13.9
	90 min	11.0	21.0	5.5	21.0	5.5	13.9
6:42 PM	**120 min**	10.5	21.0	5.5	21.0	5.0	12.7
	1440 min	10.0	21.0	5.5	21.0	4.5	11.4

Lab Analyst: RJT
Date: 12/26/2013
Hydrometer:
Mixer:
Sample #: **Turtle River # 06**

Tare (G):	1.39					**SPI =**	-10.338384
Wet w/Tare (G):	11.39	10	**Θ_d =**	0.010101		**% Sand**	89%
Dry w/Tare (G):	11.29	9.9	**C_o =**	39.59596		**% Silt**	11%
Difference (G):	0.1					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:41 PM	**30 Sec**	10.0	22.0	5.5	22.0	4.5	11.4
	1 min	9.8	22.0	5.5	22.0	4.3	10.9
	3 min	8.5	22.0	5.5	22.0	3.0	7.6
	10 min	8.0	22.0	5.5	22.0	2.5	6.3
	30 min	7.0	22.0	5.5	22.0	1.5	3.8
3:41 PM	**60 min**	7.0	22.0	5.5	22.0	1.5	3.8
	90 min	6.6	22.0	5.5	22.0	1.1	2.8
4:41 PM	**120 min**	6.0	22.0	5.5	22.0	0.5	1.3
	1440 min	5.6	22.0	5.5	22.0	0.1	0.3

Lab Analyst: RJT
Date: 12/24/2013
Hydrometer:
Mixer:
Sample #: **Turtle River # 07**

Tare (g):	1.39					**SPI =**	7.42525
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.005025		**% Sand**	94%
Dry ^{w}/Tare (g):	11.34	9.95	**C_o =**	39.79899		**% Silt**	2%
Difference (g):	0.05					**% Clay**	4%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:42 PM	**30 Sec**	8.5	21.0	5.5	21.0	3.0	7.5
	1 min	8.0	21.0	5.5	21.0	2.5	6.3
	3 min	8.0	21.0	5.5	21.0	2.5	6.3
	10 min	8.0	21.0	5.5	21.0	2.5	6.3
	30 min	8.0	21.0	5.5	21.0	2.5	6.3
3:42 PM	**60 min**	8.0	21.0	5.5	21.0	2.5	6.3
	90 min	8.0	21.0	5.5	21.0	2.5	6.3
4:42 PM	**120 min**	7.8	21.0	5.5	21.0	2.3	5.8
	1440 min	7.0	21.0	5.5	21.0	1.5	3.8

Lab Analyst: RJT						Date: 12/26/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 08**							
Tare (G):	1.39					**SPI =**	-2.447439
Wet w/Tare (G):	11.39	10	**Θ_d =**	0.264223		**% Sand**	41%
Dry w/Tare (G):	9.3	7.91	**C_o =**	29.4311		**% Silt**	37%
Difference (G):	2.09					**% Clay**	22%
						Texture =	Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:33 PM	**30 Sec**	29.5	22.0	5.5	22.0	24.0	81.5
	1 min	29.0	22.0	5.5	22.0	23.5	79.8
	3 min	25.2	22.0	5.5	22.0	19.7	66.9
	10 min	22.0	22.0	5.5	22.0	16.5	56.1
	30 min	20.0	22.0	5.5	22.0	14.5	49.3
3:33 PM	**60 min**	18.5	22.0	5.5	22.0	13.0	44.2
	90 min	17.0	22.0	5.5	22.0	11.5	39.1
4:33 PM	**120 min**	17.0	22.0	5.5	22.0	11.5	39.1
	1440 min	14.0	22.0	5.5	22.0	8.5	28.9

Lab Analyst: RJT						Date: 12/24/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 09**							
Tare (g):	1.39					**SPI =**	-0.293825
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.019368		**% Sand**	84%
Dry ^{w}/Tare (g):	11.2	9.81	**C_o =**	39.22528		**% Silt**	13%
Difference (g):	0.19					**% Clay**	3%
						Texture =	Loamy/Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:13 PM	**30 Sec**	12.5	22.0	5.5	22.0	7.0	17.8
	1 min	12.0	22.0	5.5	22.0	6.5	16.6
	3 min	11.0	22.0	5.5	22.0	5.5	14.0
	10 min	10.5	22.0	5.5	22.0	5.0	12.7
	30 min	9.0	22.0	5.5	22.0	3.5	8.9
4:13 PM	**60 min**	8.0	22.0	5.5	22.0	2.5	6.4
	90 min	7.6	22.0	5.5	22.0	2.1	5.4
5:13 PM	**120 min**	7.0	22.0	5.5	22.0	1.5	3.8
	1440 min	6.8	22.0	5.5	22.0	1.3	3.3

Lab Analyst: RJT
Date: 12/28/2013
Hydrometer:
Mixer:
Sample #: **Turtle River # 10**

Tare (g)	1.39					**SPI =**	-8.945934
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.236094		**% Sand**	87%
Dry w/Tare (g):	9.48	8.09	**C_o =**	30.55624		**% Silt**	7%
Difference (g):	1.91					**% Clay**	6%
						Texture =	Loamy/Sand

TOD	Duration	R (g/L)	R (C°)	R_L (g/L)	R_L (C°)	C (R-R_L)	P (C/C_o)*100
1:53 PM	**30 Sec**	11.0	22.0	5.5	22.0	5.5	18.0
	1 min	10.8	22.0	5.5	22.0	5.3	17.3
	3 min	10.0	22.0	5.5	22.0	4.5	14.7
	10 min	9.5	22.0	5.5	22.0	4.0	13.1
	30 min	8.5	22.0	5.5	22.0	3.0	9.8
2:53 PM	**60 min**	8.5	22.0	5.5	22.0	3.0	9.8
	90 min	8.5	22.0	5.5	22.0	3.0	9.8
3:53 PM	**120 min**	8.5	22.0	5.5	22.0	3.0	9.8
	1440 min	8.0	22.0	5.5	22.0	2.5	8.2

Lab Analyst: RJT
Date: 12/22/2013
Hydrometer:
Mixer:
Sample #: **Turtle River # 11**

Tare (g):	1.39					**SPI =**	-0.418013
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.010101		**% Sand**	72%
Dry ^{w}/Tare (g):	11.29	9.9	**C_o =**	39.59596		**% Silt**	26%
Difference (g):	0.1					**% Clay**	2%
						Texture =	Loamy/Sand

TOD	Duration	R (g/L)	R (C°)	R_L (g/L)	R_L (C°)	C (R-R_L)	P (C/C_o)*100
1:42 PM	**30 Sec**	17.0	21.0	5.5	21.0	11.5	29.0
	1 min	16.5	21.0	5.5	21.0	11.0	27.8
	3 min	15.0	21.0	5.5	21.0	9.5	24.0
	10 min	12.5	21.0	5.5	21.0	7.0	17.7
	30 min	10.0	21.0	5.5	21.0	4.5	11.4
2:42 PM	**60 min**	10.0	21.0	5.5	21.0	4.5	11.4
	490 min	8.5	21.0	5.5	21.0	3.0	7.6
3:42 PM	**120 min**	8.0	21.0	5.5	21.0	2.5	6.3
	1440 min	6.0	21.0	5.5	21.0	0.5	1.3

Lab Analyst: RJT						Date: 01/05/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 12**							
Tare (g)	1.39					**SPI =**	-0.810668
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	73%
Dry w/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	15%
Difference (g):	0.13					**% Clay**	12%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:20 PM	**30 Sec**	17.0	22.0	6.0	22.0	11.0	27.9
	1 min	16.2	22.0	6.0	22.0	10.2	25.8
	3 min	15.5	22.0	6.0	22.0	9.5	24.1
	10 min	14.0	22.0	6.0	22.0	8.0	20.3
	30 min	12.0	22.0	6.0	22.0	6.0	15.2
3:20 PM	**60 min**	11.5	22.0	6.0	22.0	5.5	13.9
	90 min	11.5	22.0	6.0	22.0	5.5	13.9
4:20 PM	**120 min**	11.0	22.0	6.0	22.0	5.0	12.7
	1440 min	10.0	22.0	6.0	22.0	4.0	10.1

Lab Analyst: RJT						Date: 01/07/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 13**							
Tare (g)	1.39					**SPI =**	1.393871
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.026694		**% Sand**	50%
Dry w/Tare (g):	11.13	9.74	**C_o =**	38.93224		**% Silt**	38%
Difference (g):	0.26					**% Clay**	12%
						Texture =	Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:12 PM	**30 Sec**	26.0	22.0	6.0	22.0	20.0	51.4
	1 min	25.5	22.0	6.0	22.0	19.5	50.1
	3 min	22.0	22.0	6.0	22.0	16.0	41.1
	10 min	19.5	22.0	6.0	22.0	13.5	34.7
	30 min	17.0	22.0	6.0	22.0	11.0	28.3
4:12 PM	**60 min**	14.6	22.0	6.0	22.0	8.6	22.1
	90 min	14.0	22.0	6.0	22.0	8.0	20.5
5:12 PM	**120 min**	14.0	22.0	6.0	22.0	8.0	20.5
	1440 min	10.2	22.0	6.0	22.0	4.2	10.8

Lab Analyst: RJT Date: 12/23/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 14**

Tare (g):	1.39					**SPI =**	-2.265615
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.029866		**% Sand**	38%
Dry ^{w}/Tare (g):	11.1	9.71	**C_o =**	38.80536		**% Silt**	42%
Difference (g):	0.29					**% Clay**	20%
						Texture =	Loam

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
4:35 PM	**30 Sec**	34.0	21.0	5.5	21.0	28.5	73.4
	1 min	30.0	21.0	5.5	21.0	24.5	63.1
	3 min	28.0	21.0	5.5	21.0	22.5	58.0
	10 min	21.5	21.0	5.5	21.0	16.0	41.2
	30 min	20.0	21.0	5.5	21.0	14.5	37.4
5:34 PM	**60 min**	17.6	21.0	5.5	21.0	12.1	31.2
	90 min	16.5	21.0	5.5	21.0	11.0	28.3
6:34 PM	**120 min**	16.0	21.0	5.5	21.0	10.5	27.1
	1440 min	13.2	21.0	5.5	21.0	7.7	19.8

Lab Analyst: RJT Date: 01/07/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 15**

Tare (g)	1.39					**SPI =**	0.392245
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.071811		**% Sand**	35%
Dry w/Tare (g):	10.72	9.33	**C_o =**	37.12755		**% Silt**	40%
Difference (g):	0.67					**% Clay**	25%
						Texture =	Loam

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:19 PM	**30 Sec**	32.0	22.0	6.0	22.0	26.0	70.0
	1 min	31.5	22.0	6.0	22.0	25.5	68.7
	3 min	27.0	22.0	6.0	22.0	21.0	56.6
	10 min	24.0	22.0	6.0	22.0	18.0	48.5
	30 min	21.0	22.0	6.0	22.0	15.0	40.4
4:19 PM	**60 min**	19.0	22.0	6.0	22.0	13.0	35.0
	90 min	18.0	22.0	6.0	22.0	12.0	32.3
5:19 PM	**120 min**	17.0	22.0	6.0	22.0	11.0	29.6
	1440 min	15.4	22.0	6.0	22.0	9.4	25.3

Lab Analyst: RJT						Date: 12/22/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 16**							
Tare (g):	1.39					**SPI =**	-4.065121
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.004016		**% Sand**	93%
Dry ^{w}/Tare (g):	11.35	9.96	**C_o =**	39.83936		**% Silt**	4%
Difference (g):	0.04					**% Clay**	3%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
1:20 PM	**30 Sec**	9.0	21.0	5.5	21.0	3.5	8.8
	1 min	8.5	21.0	5.5	21.0	3.0	7.5
	3 min	8.5	21.0	5.5	21.0	3.0	7.5
	10 min	8.0	21.0	5.5	21.0	2.5	6.3
	30 min	8.0	21.0	5.5	21.0	2.5	6.3
2:20 PM	**60 min**	7.0	21.0	5.5	21.0	1.5	3.8
	90 min	7.0	21.0	5.5	21.0	1.5	3.8
3:20 PM	**120 min**	7.0	21.0	5.5	21.0	1.5	3.8
	1440 min	6.8	21.0	5.5	21.0	1.3	3.3

Lab Analyst: RJT						1/5/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 17**							
Tare (g)	1.39					**SPI =**	7.236764
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.017294		**% Sand**	86%
Dry w/Tare (g):	11.22	9.83	**C_o =**	39.30824		**% Silt**	10%
Difference (g):	0.17					**% Clay**	4%
						Texture =	Loamy/Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
2:28 PM	**30 Sec**	12.0	22.0	6.0	22.0	6.0	15.3
	1 min	11.5	22.0	6.0	22.0	5.5	14.0
	3 min	10.5	22.0	6.0	22.0	4.5	11.4
	10 min	10.0	22.0	6.0	22.0	4.0	10.2
	30 min	9.6	22.0	6.0	22.0	3.6	9.2
3:28 PM	**60 min**	9.0	22.0	6.0	22.0	3.0	7.6
	90 min	9.0	22.0	6.0	22.0	3.0	7.6
4:28 PM	**120 min**	8.5	22.0	6.0	22.0	2.5	6.4
	1440 min	7.2	22.0	6.0	22.0	1.2	3.1

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 18**

Tare (G):	1.39					**SPI =**	-9.48075
Wet w/Tare (G):	11.39	10	**Θ_d =**	0.184834		**% Sand**	97%
Dry w/Tare (G):	9.83	8.44	**C_o =**	32.60664		**% Silt**	2%
Difference (G):	1.56					**% Clay**	1%
						Texture =	Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:37 PM	**30 Sec**	7.6	22.0	5.5	22.0	2.1	6.4
	1 min	7.0	22.0	5.5	22.0	1.5	4.6
	3 min	7.0	22.0	5.5	22.0	1.5	4.6
	10 min	7.0	22.0	5.5	22.0	1.5	4.6
	30 min	6.6	22.0	5.5	22.0	1.1	3.4
3:37 PM	**60 min**	6.6	22.0	5.5	22.0	1.1	3.4
	90 min	6.6	22.0	5.5	22.0	1.1	3.4
4:37 PM	**120 min**	6.2	22.0	5.5	22.0	0.7	2.1
	1440 min	6.0	22.0	5.5	22.0	0.5	1.5

Lab Analyst: RJT Date: 12/23/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 19**

Tare (g):	1.39					**SPI =**	-9.720047
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.062699		**% Sand**	73%
Dry ^{w}/Tare (g):	10.8	9.41	**C_o =**	37.49203		**% Silt**	20%
Difference (g):	0.59					**% Clay**	7%
						Texture =	Sandy/Loam

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
4:19 PM	**30 Sec**	16	21	5.5	21	10.5	28.0
	1 min	16	21	5.5	21	10.5	28.0
	3 min	14.5	21	5.5	21	9	24.0
	10 min	13	21	5.5	21	7.5	20.0
	30 min	12	21	5.5	21	6.5	17.3
5:19 PM	**60 min**	10.5	21	5.5	21	5	13.3
	90 min	10	21	5.5	21	4.5	12.0
6:19 PM	**120 min**	9.6	21	5.5	21	4.1	10.9
	1440 min	8	21	5.5	21	2.5	6.7

Lab Analyst: RJT Date: 12/24/2013

Hydrometer: Mixer:

Sample #: **Turtle River # 20**

Tare (g):	1.39					**SPI =**	5.127947
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.010101		**% Sand**	84%
Dry ^{w}/Tare (g):	11.29	9.9	**C_o =**	39.59596		**% Silt**	9%
Difference (g):	0.1					**% Clay**	7%
						Texture =	Loamy/Sand

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:09 PM	**30 Sec**	13.0	21.0	5.5	21.0	7.5	18.9
	1 min	12.2	21.0	5.5	21.0	6.7	16.9
	3 min	11.0	21.0	5.5	21.0	5.5	13.9
	10 min	10.5	21.0	5.5	21.0	5.0	12.6
	30 min	10.0	21.0	5.5	21.0	4.5	11.4
2:39 PM	**60 min**	9.0	21.0	5.5	21.0	3.5	8.8
	90 min	9.0	21.0	5.5	21.0	3.5	8.8
3:09 PM	**120 min**	9.0	21.0	5.5	21.0	3.5	8.8
	1440 min	8.0	21.0	5.5	21.0	2.5	6.3

Lab Analyst: RJT Date: 01/07/2013

Hydrometer: Mixer:

Sample #: Turtle River # 21

Tare (g)	1.39					**SPI =**	8.427243
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.023541		**% Sand**	78%
Dry w/Tare (g):	11.16	9.77	**C_o =**	39.05834		**% Silt**	16%
Difference (g):	0.23					**% Clay**	6%
						Texture =	Loamy/Sand

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:23 PM	**30 Sec**	15.0	22.0	6.0	22.0	9.0	23.0
	1 min	14.6	22.0	6.0	22.0	8.6	22.0
	3 min	12.0	22.0	6.0	22.0	6.0	15.4
	10 min	11.0	22.0	6.0	22.0	5.0	12.8
	30 min	10.0	22.0	6.0	22.0	4.0	10.2
4:23 PM	**60 min**	9.0	22.0	6.0	22.0	3.0	7.7
	90 min	9.0	22.0	6.0	22.0	3.0	7.7
5:23 PM	**120 min**	9.0	22.0	6.0	22.0	3.0	7.7
	1440 min	8.2	22.0	6.0	22.0	2.2	5.6

Lab Analyst: RJT						Date: 12/28/2013	
Hydrometer:						Mixer:	
Sample #: Turtle **River # 22**							
Tare (g)	1.39					**SPI =**	1.497384
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.011122		**% Sand**	86%
Dry w/Tare (g):	11.28	9.89	**C_o =**	39.55511		**% Silt**	14%
Difference (g):	0.11					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
2:01 PM	**30 Sec**	11.5	22.0	5.5	22.0	6.0	15.2
	1 min	11.0	22.0	5.5	22.0	5.5	13.9
	3 min	9.0	22.0	5.5	22.0	3.5	8.8
	10 min	8.5	22.0	5.5	22.0	3.0	7.6
	30 min	7.0	22.0	5.5	22.0	1.5	3.8
3:01 PM	**60 min**	7.0	22.0	5.5	22.0	1.5	3.8
	90 min	7.0	22.0	5.5	22.0	1.5	3.8
4:01 PM	**120 min**	6.0	22.0	5.5	22.0	0.5	1.3
	1440 min	5.6	22.0	5.5	22.0	0.1	0.3

Lab Analyst: RJT						Date: 01/06/2013	
Hydrometer:						Mixer:	
Sample #: Turtle River # 23							
Tare (g)	1.39					**SPI =**	2.934914
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.17096		**% Sand**	75%
Dry w/Tare (g):	9.93	8.54	**C_o =**	33.16159		**% Silt**	17%
Difference (g):	1.46					**% Clay**	8%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C ($R-R_L$)**	**P (C/C_o)*100**
3:54 PM	**30 Sec**	17.0	22.0	6.0	22.0	11.0	33.2
	1 min	16.0	22.0	6.0	22.0	10.0	30.2
	3 min	12.0	22.0	6.0	22.0	6.0	18.1
	10 min	11.5	22.0	6.0	22.0	5.5	16.6
	30 min	11.0	22.0	6.0	22.0	5.0	15.1
4:54 PM	**60 min**	9.5	22.0	6.0	22.0	3.5	10.6
	90 min	9.5	22.0	6.0	22.0	3.5	10.6
5:54 PM	**120 min**	9.5	22.0	6.0	22.0	3.5	10.6
	1440 min	9.0	22.0	6.0	22.0	3.0	9.0

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 24**

Tare (G):	1.39					**SPI =**	4.162928
Wet w/Tare (G):	11.39	10	**Θ_d =**	0.191895		**% Sand**	63%
Dry w/Tare (G):	9.78	8.39	**C_o =**	32.3242		**% Silt**	23%
Difference (G):	1.61					**% Clay**	14%
						Texture =	Sandy/Loam

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:09 PM	**30 Sec**	21.0	22.0	5.5	22.0	15.5	48.0
	1 min	20.5	22.0	5.5	22.0	15.0	46.4
	3 min	16.6	22.0	5.5	22.0	11.1	34.3
	10 min	15.0	22.0	5.5	22.0	9.5	29.4
	30 min	14.0	22.0	5.5	22.0	8.5	26.3
4:09 PM	**60 min**	12.6	22.0	5.5	22.0	7.1	22.0
	90 min	12.5	22.0	5.5	22.0	7.0	21.7
5:09 PM	**120 min**	12.0	22.0	5.5	22.0	6.5	20.1
	1440 min	11.0	22.0	5.5	22.0	5.5	17.0

Lab Analyst: RJT Date: 12/22/2013
Hydrometer: Mixer:
Sample #: **Turtle River # 25**

Tare (g):	1.39					**SPI =**	1.58768
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	89%
Dry ^{w}/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	6%
Difference (g):	0.13					**% Clay**	5%
						Texture =	Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:20 PM	**30 Sec**	10.0	21.0	5.5	21.0	4.5	11.4
	1 min	9.8	21.0	5.5	21.0	4.3	10.9
	3 min	9.6	21.0	5.5	21.0	4.1	10.4
	10 min	9.0	21.0	5.5	21.0	3.5	8.9
	30 min	8.2	21.0	5.5	21.0	2.7	6.8
2:20 PM	**60 min**	8.0	21.0	5.5	21.0	2.5	6.3
	90 min	8.0	21.0	5.5	21.0	2.5	6.3
3:20 PM	**120 min**	7.8	21.0	5.5	21.0	2.3	5.8
	1440 min	7.5	21.0	5.5	21.0	2.0	5.1

Lab Analyst: RJT			10.0			Date: 12/22/2013	
Hydrometer:			9.8			Mixer:	
Sample #: **Turtle River # 26**			9.6				
Tare (g):	1.39		9.0			**SPI =**	-11.777555
Wet ^{w}/Tare (g):	11.39	10	**8.2**	0.049318		**% Sand**	96%
Dry ^{w}/Tare (g):	10.92	9.53	**8**	38.02728		**% Silt**	4%
Difference (g):	0.47					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:20 PM	**30 Sec**	8.0	21.0	5.5	21.0	2.5	6.6
	1 min	7.2	21.0	5.5	21.0	1.7	4.5
	3 min	6.5	21.0	5.5	21.0	1.0	2.6
	10 min	6.2	21.0	5.5	21.0	0.7	1.8
	30 min	5.8	21.0	5.5	21.0	0.3	0.8
2:20 PM	**60 min**	5.6	21.0	5.5	21.0	0.1	0.3
	90 min	5.6	21.0	5.5	21.0	0.1	0.3
3:20 PM	**120 min**	5.6	21.0	5.5	21.0	0.1	0.3
	1440 min	5.6	21.0	5.5	21.0	0.1	0.3

Lab Analyst: RJT						Date: 12/28/2013	
Hydrometer:						Mixer:	
Sample #: **Turtle River # 27**							
Tare (g)	1.4					**SPI =**	-2.467624
Wet w/Tare (g):	11.4	10	**Θ_d =**	0.006036		**% Sand**	84%
Dry w/Tare (g):	11.34	9.94	**C_o =**	39.75855		**% Silt**	7%
Difference (g):	0.06					**% Clay**	9%
						Texture =	Loamy/Sand
TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:46 PM	**30 Sec**	12.8	22.0	5.5	22.0	7.3	18.4
	1 min	12.2	22.0	5.5	22.0	6.7	16.9
	3 min	11.0	22.0	5.5	22.0	5.5	13.8
	10 min	10.0	22.0	5.5	22.0	4.5	11.3
	30 min	9.5	22.0	5.5	22.0	4.0	10.1
2:46 PM	**60 min**	9.5	22.0	5.5	22.0	4.0	10.1
	90 min	9.5	22.0	5.5	22.0	4.0	10.1
3:46 AM	**120 min**	9.0	22.0	5.5	22.0	3.5	8.8
	1440 min	9.0	22.0	5.5	22.0	3.5	8.8

Lab Analyst: RJT
Date: 12/28/2013
Hydrometer:
Mixer:
Sample #: **Turtle River # 28**

Tare (g)	1.39					**SPI =**	-0.861154
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.017294		**% Sand**	63%
Dry w/Tare (g):	11.22	9.83	**C_o =**	39.30824		**% Silt**	25%
Difference (g):	0.17					**% Clay**	12%
						Texture =	Sandy/Loam

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:49 PM	**30 Sec**	20.2	22.0	5.5	22.0	14.7	37.4
	1 min	20.0	22.0	5.5	22.0	14.5	36.9
	3 min	16.0	22.0	5.5	22.0	10.5	26.7
	10 min	15.0	22.0	5.5	22.0	9.5	24.2
	30 min	13.0	22.0	5.5	22.0	7.5	19.1
2:49 PM	**60 min**	12.8	22.0	5.5	22.0	7.3	18.6
	90 min	12.0	22.0	5.5	22.0	6.5	16.5
3:49 PM	**120 min**	12.0	22.0	5.5	22.0	6.5	16.5
	1440 min	10.2	22.0	5.5	22.0	4.7	12.0

Lab Analyst: RJT
Date: 01/05/2013
Hydrometer:
Mixer:
Sample #: Turtle **River # 29**

Tare (g)	1.39					**SPI =**	-2.120443
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.176471		**% Sand**	87%
Dry w/Tare (g):	9.89	8.5	**C_o =**	32.94118		**% Silt**	8%
Difference (g):	1.5					**% Clay**	5%
						Texture =	Loamy/Sand

TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:23 PM	**30 Sec**	11.0	22.0	6.0	22.0	5.0	15.2
	1 min	11.0	22.0	6.0	22.0	5.0	15.2
	3 min	10.0	22.0	6.0	22.0	4.0	12.1
	10 min	10.0	22.0	6.0	22.0	4.0	12.1
	30 min	9.0	22.0	6.0	22.0	3.0	9.1
3:23 PM	**60 min**	8.8	22.0	6.0	22.0	2.8	8.5
	90 min	8.8	22.0	6.0	22.0	2.8	8.5
4:23 PM	**120 min**	8.6	22.0	6.0	22.0	2.6	7.9
	1440 min	8.0	22.0	6.0	22.0	2.0	6.1

Appendix B
Soil Separates Analysis for Fordville Dam Watershed

Lab Analyst: RJT						Date: 01/06/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 01**							
Tare (g)	1.39					**SPI =**	-8.65694
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.191895		**% Sand**	70%
Dry w/Tare (g):	9.78	8.39	**C_o =**	32.3242		**% Silt**	23%
Difference (g):	1.61					**% Clay**	7%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:55 PM	**30 Sec**	18.2	22.0	6.0	22.0	12.2	37.7
	1 min	18.0	22.0	6.0	22.0	12.0	37.1
	3 min	16.0	22.0	6.0	22.0	10.0	30.9
	10 min	14.5	22.0	6.0	22.0	8.5	26.3
	30 min	13.0	22.0	6.0	22.0	7.0	21.7
4:55 PM	**60 min**	11.0	22.0	6.0	22.0	5.0	15.5
	90 min	11.0	22.0	6.0	22.0	5.0	15.5
5:55 PM	**120 min**	10.0	22.0	6.0	22.0	4.0	12.4
	1440 min	8.5	22.0	6.0	22.0	2.5	7.7

Lab Analyst: RJT						Date: 01/05/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 02**							
Tare (g)	1.39					**SPI =**	0.411944
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.168224		**% Sand**	95%
Dry w/Tare (g):	9.95	8.56	**C_o =**	33.27103		**% Silt**	2%
Difference (g):	1.44					**% Clay**	3%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:17 PM	**30 Sec**	8.6	22.0	6.0	22.0	2.6	7.8
	1 min	8.0	22.0	6.0	22.0	2.0	6.0
	3 min	8.0	22.0	6.0	22.0	2.0	6.0
	10 min	8.0	22.0	6.0	22.0	2.0	6.0
	30 min	7.6	22.0	6.0	22.0	1.6	4.8
3:17 PM	**60 min**	7.0	22.0	6.0	22.0	1.0	3.0
	90 min	7.0	22.0	6.0	22.0	1.0	3.0
4:17 PM	**120 min**	7.0	22.0	6.0	22.0	1.0	3.0
	1440 min	7.0	22.0	6.0	22.0	1.0	3.0

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: **Forest River # 03**

Tare (g)	1.39					**SPI =**	-0.911269
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.18624		**% Sand**	70%
Dry w/Tare (g):	9.82	8.43	**C_o =**	32.55042		**% Silt**	23%
Difference (g):	1.57					**% Clay**	7%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:45 PM	**30 Sec**	18.0	22.0	5.5	22.0	12.5	38.4
	1 min	17.6	22.0	5.5	22.0	12.1	37.2
	3 min	15.0	22.0	5.5	22.0	9.5	29.2
	10 min	15.0	22.0	5.5	22.0	9.5	29.2
	30 min	13.0	22.0	5.5	22.0	7.5	23.0
3:45 PM	**60 min**	12.0	22.0	5.5	22.0	6.5	20.0
	90 min	11.2	22.0	5.5	22.0	5.7	17.5
4:45 PM	**120 min**	11.0	22.0	5.5	22.0	5.5	16.9
	1440 min	8.0	22.0	5.5	22.0	2.5	7.7

Lab Analyst: RJT Date: 01/06/2013
Hydrometer: Mixer:
Sample #: **Forest River # 04**

Tare (g)	1.39					**SPI =**	3.832469
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.035197		**% Sand**	57%
Dry w/Tare (g):	11.05	9.66	**C_o =**	38.59213		**% Silt**	27%
Difference (g):	0.34					**% Clay**	16%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
4:03 PM	**30 Sec**	23.5	22.0	6.0	22.0	17.5	45.3
	1 min	23.0	22.0	6.0	22.0	17.0	44.1
	3 min	20.0	22.0	6.0	22.0	14.0	36.3
	10 min	18.5	22.0	6.0	22.0	12.5	32.4
	30 min	16.0	22.0	6.0	22.0	10.0	25.9
5:03 PM	**60 min**	14.2	22.0	6.0	22.0	8.2	21.2
	90 min	14.0	22.0	6.0	22.0	8.0	20.7
6:03 PM	**120 min**	13.0	22.0	6.0	22.0	7.0	18.1
	1440 min	12.0	22.0	6.0	22.0	6.0	15.5

Lab Analyst: RJT						Date: 12/24/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 05**							
Tare (g):	1.39					**SPI =**	0.872469
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	87%
Dry ^{w}/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	10%
Difference (g):	0.13					**% Clay**	3%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C^o)**	**C (R-R_L)**	**P (C/C_o)*100**
2:21 PM	**30 Sec**	10.5	21.0	5.5	21.0	5.0	12.7
	1 min	10.5	21.0	5.5	21.0	5.0	12.7
	3 min	9.0	21.0	5.5	21.0	3.5	8.9
	10 min	9.0	21.0	5.5	21.0	3.5	8.9
	30 min	8.5	21.0	5.5	21.0	3.0	7.6
3:21 PM	**60 min**	7.2	21.0	5.5	21.0	1.7	4.3
	90 min	7.2	21.0	5.5	21.0	1.7	4.3
4:21 PM	**120 min**	7.0	21.0	5.5	21.0	1.5	3.8
	1440 min	6.8	21.0	5.5	21.0	1.3	3.3

Lab Analyst: RJT						Date: 12/23/2013	
Hydrometer:						Mixer:	
Sample #: **Forest River # 06**							
Tare (g)	1.39					**SPI =**	-10.538981
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.013171		**% Sand**	80%
Dry ^{w}/Tare (g):	11.26	9.87	**C_o =**	39.47315		**% Silt**	8%
Difference (g):	0.13					**% Clay**	12%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C^o)**	**C (R-R_L)**	**P (C/C_o)*100**
4:42 PM	**30 Sec**	14.0	21.0	5.5	21.0	8.5	21.5
	1 min	13.6	21.0	5.5	21.0	8.1	20.5
	3 min	12.6	21.0	5.5	21.0	7.1	18.0
	10 min	12.0	21.0	5.5	21.0	6.5	16.5
	30 min	12.0	21.0	5.5	21.0	6.5	16.5
5:42 PM	**60 min**	11.0	21.0	5.5	21.0	5.5	13.9
	90 min	11.0	21.0	5.5	21.0	5.5	13.9
6:42 PM	**120 min**	10.5	21.0	5.5	21.0	5.0	12.7
	1440 min	10.0	21.0	5.5	21.0	4.5	11.4

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: **Forest River # 07**

Tare (g)	1.39					**SPI =**	-2.232587
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.196172		**% Sand**	59%
Dry w/Tare (g):	9.75	8.36	**C_o =**	32.15311		**% Silt**	19%
Difference (g):	1.64					**% Clay**	22%
						Texture =	Sandy/Clay

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:30 PM	**30 Sec**	23.0	22.0	5.5	21.0	17.5	54.4
	1 min	22.0	22.0	5.5	21.0	16.5	51.3
	3 min	21.5	22.0	5.5	21.0	16.0	49.8
	10 min	20.0	22.0	5.5	21.0	14.5	45.1
	30 min	18.0	22.0	5.5	21.0	12.5	38.9
3:30 PM	**60 min**	17.0	22.0	5.5	21.0	11.5	35.8
	90 min	16.2	22.0	5.5	21.0	10.7	33.3
4:30 PM	**120 min**	16.0	22.0	5.5	21.0	10.5	32.7
	1440 min	14.0	22.0	5.5	21.0	8.5	26.4

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: Forest River # 08

Tare (g)	1.39					**SPI =**	-1.520202
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.015228		**% Sand**	87%
Dry w/Tare (g):	11.24	9.85	**C_o =**	39.39086		**% Silt**	7%
Difference (g):	0.15					**% Clay**	6%
						Texture =	Loamy/Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:04 PM	**30 Sec**	12.6	22.0	5.5	22.0	7.1	18.0
	1 min	11.0	22.0	5.5	22.0	5.5	14.0
	3 min	11.0	22.0	5.5	22.0	5.5	14.0
	10 min	11.0	22.0	5.5	22.0	5.5	14.0
	30 min	10.0	22.0	5.5	22.0	4.5	11.4
4:04 PM	**60 min**	9.6	22.0	5.5	22.0	4.1	10.4
	90 min	9.0	22.0	5.5	22.0	3.5	8.9
5:04 PM	**120 min**	8.6	22.0	5.5	22.0	3.1	7.9
	1440 min	8.0	22.0	5.5	22.0	2.5	6.3

Lab Analyst: RJT Date: 12/22/2013
Hydrometer: Mixer:
Sample #: **Forest River # 10**

Tare (g):	1.39					**SPI =**	-2.959735
Wet ^{w}/Tare (g):	11.39	10	**Θ_d =**	0.010101		**% Sand**	89%
Dry ^{w}/Tare (g):	11.29	9.9	**C_o =**	39.59596		**% Silt**	6%
Difference (g):	0.1					**% Clay**	5%
						Texture =	Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:04 PM	**30 Sec**	10.1	21.0	5.5	21.0	4.6	11.6
	1 min	10.0	21.0	5.5	21.0	4.5	11.4
	3 min	9.8	21.0	5.5	21.0	4.3	10.9
	10 min	9.6	21.0	5.5	21.0	4.1	10.4
	30 min	9.0	21.0	5.5	21.0	3.5	8.8
2:04 PM	**60 min**	8.2	21.0	5.5	21.0	2.7	6.8
	90 min	7.8	21.0	5.5	21.0	2.3	5.8
3:04 PM	**120 min**	7.5	21.0	5.5	21.0	2.0	5.1
	1440 min	7.3	21.0	5.5	21.0	1.8	4.5

Lab Analyst: RJT Date: 12/28/2013
Hydrometer: Mixer:
Sample #: **Forest River # 11**

Tare (g)	1.39					**SPI =**	8.326159
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.01626		**% Sand**	84%
Dry w/Tare (g):	11.23	9.84	**C_o =**	39.34959		**% Silt**	16%
Difference (g):	0.16					**% Clay**	0%
						Texture =	Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
1:57 PM	**30 Sec**	12.0	22.0	5.5	22.0	6.5	16.5
	1 min	12.0	22.0	5.5	22.0	6.5	16.5
	3 min	10.0	22.0	5.5	22.0	4.5	11.4
	10 min	9.0	22.0	5.5	22.0	3.5	8.9
	30 min	8.0	22.0	5.5	22.0	2.5	6.4
2:57 PM	**60 min**	7.6	22.0	5.5	22.0	2.1	5.3
	90 min	7.0	22.0	5.5	22.0	1.5	3.8
3:57 PM	**120 min**	6.6	22.0	5.5	22.0	1.1	2.8
	1440 min	5.6	22.0	5.5	22.0	0.1	0.3

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: Forest River # 12

Tare (g)	1.39					**SPI =**	-1.638009
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.012146		**% Sand**	38%
Dry w/Tare (g):	11.27	9.88	**C_o =**	39.51417		**% Silt**	45%
Difference (g):	0.12					**% Clay**	17%
						Texture =	Loam

TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:16 PM	**30 Sec**	30.0	22.0	5.5	22.0	24.5	62.0
	1 min	30.0	22.0	5.5	22.0	24.5	62.0
	3 min	26.0	22.0	5.5	22.0	20.5	51.9
	10 min	23.5	22.0	5.5	22.0	18.0	45.6
	30 min	21.0	22.0	5.5	22.0	15.5	39.2
4:16 PM	**60 min**	18.0	22.0	5.5	22.0	12.5	31.6
	90 min	16.2	22.0	5.5	22.0	10.7	27.1
5:16 PM	**120 min**	15.2	22.0	5.5	22.0	9.7	24.5
	1440 min	12.0	22.0	5.5	22.0	6.5	16.4

Lab Analyst: RJT Date: 12/23/2013
Hydrometer: Mixer:
Sample #: **Forest River # 13**

Tare (g):	1.39					**SPI =**	7.128326
Wet ^{w}/Tare (G):	11.39	10	**Θ_d =**	0.059322		**% Sand**	69%
Dry ^{W}/Tare (G):	10.83	9.44	**C_o =**	37.62712		**% Silt**	20%
Difference (G):	0.56					**% Clay**	11%
						Texture =	Sand

TOD	**Duration**	**R (g/L)**	**R (C^{o})**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
4:48 PM	**30 Sec**	20.0	21.0	5.5	21.0	14.5	38.5
	1 min	18.0	21.0	5.5	21.0	12.5	33.2
	3 min	17.0	21.0	5.5	21.0	11.5	30.6
	10 min	15.0	21.0	5.5	21.0	9.5	25.2
	30 min	13.0	21.0	5.5	21.0	7.5	19.9
5:48 PM	**60 min**	11.0	21.0	5.5	21.0	5.5	14.6
	90 min	10.0	21.0	5.5	21.0	4.5	12.0
6:48 PM	**120 min**	10.0	21.0	5.5	21.0	4.5	12.0
	1440 min	9.8	21.0	5.5	21.0	4.3	11.4

Lab Analyst: RJT Date: 12/26/2013
Hydrometer: Mixer:
Sample #: **Forest River # 14**

Tare (g)	1.39					**SPI =**	-9.725096
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.020408		**% Sand**	98%
Dry w/Tare (g):	11.19	9.8	**C_o =**	39.18367		**% Silt**	2%
Difference (g):	0.2					**% Clay**	0%
						Texture =	Sand
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:20 PM	**30 Sec**	7.0	22.0	5.5	22.0	1.5	3.8
	1 min	6.5	22.0	5.5	22.0	1.0	2.6
	3 min	6.5	22.0	5.5	22.0	1.0	2.6
	10 min	6.0	22.0	5.5	22.0	0.5	1.3
	30 min	6.0	22.0	5.5	22.0	0.5	1.3
4:20 PM	**60 min**	5.8	22.0	5.5	22.0	0.3	0.8
	90 min	5.6	22.0	5.5	22.0	0.1	0.3
5:20 PM	**120 min**	5.6	22.0	5.5	22.0	0.1	0.3
	1440 min	5.6	22.0	5.5	22.0	0.1	0.3

Lab Analyst: RJT Date: 01/05/2013
Hydrometer: Mixer:
Sample #: **Forest River # 15**

Tare (g)	1.39					**SPI =**	-10.91385
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.187648		**% Sand**	73%
Dry w/Tare (g):	9.81	8.42	**C_o =**	32.49406		**% Silt**	21%
Difference (g):	1.58					**% Clay**	6%
						Texture =	Sandy/Loam
TOD	**Duration**	**R (g/L)**	**R (C°)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
2:29 PM	**30 Sec**	18.0	22.0	6.0	22.0	12.0	36.9
	1 min	17.0	22.0	6.0	22.0	11.0	33.9
	3 min	13.5	22.0	6.0	22.0	7.5	23.1
	10 min	12.5	22.0	6.0	22.0	6.5	20.0
	30 min	11.0	22.0	6.0	22.0	5.0	15.4
3:29 PM	**60 min**	10.0	22.0	6.0	22.0	4.0	12.3
	90 min	9.5	22.0	6.0	22.0	3.5	10.8
4:29 PM	**120 min**	9.0	22.0	6.0	22.0	3.0	9.2
	1440 min	8.2	22.0	6.0	22.0	2.2	6.8

Lab Analyst: RJT Date: 01/06/2013
Hydrometer: Mixer:
Sample #: **Forest River # 16**

Tare (g)	1.39					**SPI =**	0.580496
Wet w/Tare (g):	11.39	10	**Θ_d =**	0.019368		**% Sand**	76%
Dry w/Tare (g):	11.2	9.81	**C_o =**	39.22528		**% Silt**	19%
Difference (g):	0.19					**% Clay**	5%
						Texture =	Loamy/Sand

TOD	**Duration**	**R (g/L)**	**R (C^o)**	**R_L (g/L)**	**R_L (C°)**	**C (R-R_L)**	**P (C/C_o)*100**
3:48 PM	**30 Sec**	18.0	22.0	6.0	22.0	12.0	30.6
	1 min	16.0	22.0	6.0	22.0	10.0	25.5
	3 min	14.0	22.0	6.0	22.0	8.0	20.4
	10 min	13.0	22.0	6.0	22.0	7.0	17.8
	30 min	11.5	22.0	6.0	22.0	5.5	14.0
4:48 PM	**60 min**	10.5	22.0	6.0	22.0	4.5	11.5
	90 min	9.8	22.0	6.0	22.0	3.8	9.7
5:48 PM	**120 min**	9.5	22.0	6.0	22.0	3.5	8.9
	1440 min	8.0	22.0	6.0	22.0	2.0	5.1

Appendix C

Structure from Motion

This study originally planned for the introduction of a new technique, in the Earth sciences to produce a very high resolution point cloud, that when processed into a DEM could be used in hydrological processing. This technique is called Structure from Motion (SfM) and involves the acquisition of hundreds of images collected with a digital camera and converted to very dense point cloud. After the point cloud processing and geo-referencing the data could be imported into a GIS and converted to a raster. This studies original intent was to generate a SfM DEM and calculate the same SPI signatures that were calculated using the LiDAR data and then compare and contrast the two datasets. The hypothesis was to show that a comparable SPI could be created using little more than a $100 digital camera and open source software to produce viable results at a very low cost. The study produced a SfM point cloud at the localized gully scale when the point cloud should have been at the field scale. This could have been accomplished if the camera would have been flown mounted to either a kite or tethered balloon. The study also failed to properly format the text file for processing in the final step using the Jag-3D software.

Introduction

In an attempt to improve on the 1-m resolution DEMs for a field level scale, a new technique referred to as SfM was incorporated into this study. SfM is the process of estimating 3D structures from 2D image sequences. SfM is similar to traditional photogrammetry in that it uses multiple images with overlapping views to reconstruct the 3D geometry of an object or surface (Westoby et al. 2012). Digital images were acquired from select gullies and inlets in both watersheds for DEM construction using SFM. DEMs produced from this new technique have the potential to produce a higher resolution dataset at a fraction of the costs for identification of these critical erosion areas and for precision conservation in the Red River Basin. GPS located ground control points (GCP) that are manually placed during image acquisition are used for geo-referencing of the SfM dataset.

Structure from Motion

The high costs of data collection are, for many applications in the Earth sciences are increased by the remoteness and inaccessibility of many study locations. This remoteness renders cheaper, more portable surveying platforms (i.e. terrestrial laser scanning or GPS) impractical (Westoby et al. 2012). This study found the SfM technique to be a major advancement in the field of photogrammetry for geoscience applications. The results and experiences of this study are indicative of an inexpensive, effective and flexible approach to capturing complex topography. SfM uses over-the-counter digital cameras and open source, free-to- the public software in point cloud development. This low-cost, functionally mobile technique produces high resolution, geo-referenced DEMs with minimal equipment. With SfM it is possible to produce 3D point clouds of higher resolution and quality than LiDAR and is based on multiple perspective and scale invariant high resolution imagery. By incorporating images acquired from multiple view poses and elevations with a high percentage of image overlap SfM can reconstruct the 3D geometry of an object (Mathews and Jensen 2012). However, unlike photogrammetry where GCPs are not required to restore or construct object geometry in SfM but can be included for transformation and geo-referencing of the point cloud. If GCPs are used during image acquisition they should be large enough and of contrasting hues so they can be identified during the processing stages. This will result is a 3D point cloud comparable to a LiDAR dataset at a fraction of the cost (Mathews and Jensen 2012).

For SfM to be effective the image acquisition must attempt to achieve a high degree of overlap from image to image, 60 percent overlap is recommended. The program, during processing will seek the same individual point from each overlapping image. If the same individual point can be identified in three or more images then that point is added to the point cloud, if the point is identified in two or less images then the point is deleted. The identified points are tracked enabling initial position and coordinate estimates which are then refined iteratively using non-linear squares minimization (Snavely, 2008).

Scene geometry and camera pose are solved by using a highly redundant bundle adjustment in developing a point cloud. The process matches identical features in images by incorporating multiple overlapping, offset images (Westoby et al. 2012). This is similar to stereo pairs but instead of matching features in two images this process uses multiple images. Willis (2012) outlines step-by-step procedures for creating a Photosynth point cloud using aerial photographs obtained from a kite in his online blog: Markeology. Discussions on the field setup, acquiring photos to the processing of the digital images into a point cloud are detailed. Known pitfalls, and how to avoid them, are discussed following with a list of Internet sources linked to the open source software needed for the processing of the point clouds needed in the creation of the DEM. This method will be used in this study.

Nathan Craig (2012) also provides an online tutorial directed towards producing a point cloud dataset. This tutorial describes one method to convert a SfM point cloud (Photosynth and Bundler) into real-world coordinates using a set of mapped controls (Craig 2012). Unlike in *Markology* where only the x, y, z values are retained in the DEM this method also retains the RGB values for future. This technique hinges upon the use of ground control points that must be included in the image acquisition and each ground control point must be mapped with a high accuracy GPS unit. Using the Helmert transformation, the modeled coordinates are transformed into a geo-referenced point cloud by introducing real world coordinates into the transformation (Craig 2012).

Data Collection

Digital images for the SfM analysis were collected using a Canon Powershot 810 digital camera. Images were collected at three of the largest gulley locations identified within the Turtle River Watershed. Collection included mounting the camera on a telescoping pole to obtain a series 200 – 300 images at differing elevations and look angles. The camera was equipped with an intervalometer script acquired from the Cannon Hackers Development Kit (chdk.wikia.com/), so that shutter speed could be controlled automatically at a predetermined rate depending on the ease of movement relative to the topography. A rate of one image every three seconds was chosen which allowed for movement and steadying of the pole/camera between each image. The images were collected using a 360 degree pattern at changing elevations, either by extending or lowering the pole or by lifting the pole overhead to obtain a complete coverage of the gulley and inlet area with a goal of 60 percent overlap for each image.

Ground control points (GCP) were required for the image collection to provide an identifiable feature within the generation of the point cloud. The GCPs were white disposable plates which provided a contrast in colors from the study area ground cover seen in both of the images below. Each GCP was documented with a Trimble Juno SB GPS handheld and hand sketches were made of the placement patterns to assist in identifying each GCP feature in the point cloud development. These values are then imported into a spreadsheet and the x, y, z values are saved as a .txt file. Use of GCPs in the image collection process provides a means of introducing real world coordinates into the computer generated point cloud during the geo-transformation process. Mid-day hours were chosen for image collection to allow for overhead sun illumination. This reduces the potential shadowing effect introduced from either the telescoping pole or the body location of the person collecting the images relative to the location of the sun.

Data Processing

Processing of the SfM dataset into DEM format involved a very different and unique process as documented below. The SfM processing is multi-step using the following open source and licensed software:

- Microsoft Photosynth: (www.photosynth.net)
- Microsoft Photosynth Exporter: (www.synthexport.codeplex.com)
- MeshLab: (www.meshlab.sourceforge.net)
- ScanView: (www.menci.com)
- JAG3D: (www.JAG3D;javagraticule3D.sourceforge.net)
- ESRI ArcGIS: (www.ESRI.com)
- Microsoft Excel and Notepad

The SfM formatting and processing used in this study follows very closely the procedures supplied by Mark Willis in his blog, *Markology*.

The first step was to cull the images to eliminate those that are blurred, off subject, or have excessive shadowing introduced into the image during collection. Following the culling stage the images were imported into Microsoft Photosynth for point cloud development, including adding and deleting images within the program as needed to create the highest density point cloud possible. The images were saved as an ASCII .ply file and exported using Photosynth Point Cloud Exporter creating a PLY model of the point cloud.

Next the point cloud data was imported into the Meshlab software. The point cloud was edited and cleaned, eliminating any extraneous noise by deleting random outliers and saved as a .ply file. The data was then opened in Notepad and the header was deleted leaving only the xyz attributes and saving the file as a .xyz text file. The corrected file was then imported into the Menci Software, Meshlab, for locating of the ground control points and assigning a computer generated coordinate system associated with the GPS positions. The file was then exported from Meshlab, again as a text file and then imported into Microsoft Excel. The file was edited by adding a numerical series field in the first column and adding the real world ground control point x, y, z values in the top rows. The R-G-B and 255 columns were deleted leaving only x, y, z. The file was then exported as a .txt file

Both the GCP .txt file and the point cloud .txt file were imported into the JAG3D transformation software. This program was to be used for a geo-transformation of the entire point cloud. I could not get the .txt files delimited properly the make this transformation. A projected coordinate system would then calculated and assigned to the entire point cloud. The transformation then would have been exported, opened in notepad and the header file deleted and saved as a .txt. The former steps would have properly formatted the point cloud, allowing for the conversion into a DEM in ArcGIS software allowing for hydrological modeling.

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