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A CLASSIFICATION OF STREAM TYPES AT REFERENCE
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A CLASSIFICATION OF STREAM TYPES AT REFERENCE REACH USGS GAGE STATIONS IN MICHIGAN

By

Kristine L. Boley-Morse

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ABSTRACT

A CLASSIFICATION OF STREAM TYPES AT REFERENCE REACH USGS GAGE STATIONS IN MICHIGAN

By

Kristine L. Boley-Morse

In order to have a better understanding of the geomorphic characterization and description of Michigan rivers, 43 stable reference reach rivers with established U.S. Geological Survey gage stations were surveyed to determine stream types using the Level II Rosgen Classification System. Geomorphic field measurements of floodprone width, bankfull width, bankfull mean depth, bankfull maximum depth, sinuosity, slope, and median channel material were taken at reference reach locations to determine the Rosgen Classification System stream type. Out of the 43 sites surveyed, 39 were classified as a "C" stream type that are indicative of streams that are slightly entrenched (>2.2), have a moderate to high width to depth ratio (>12), have moderate to high sinuosity (>1.2), and have a slope less than 2% with a well-developed floodplain in narrow to wide valleys. We now have a better understanding of what stream types occur in Michigan at USGS gage locations and have site specific geomorphic information that can be used as a communication, monitoring, and research tool amongst various disciplines that manage, research, monitor, and rehabilitate rivers.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Images in this thesis are presented in color.

Introduction:

Michigan is the home to over 36,000 miles of rivers (MDNR, 2009). These rivers twist and turn across Michigan's various landscapes to reach their destination to one of the four Michigan Great Lakes. The geomorphic characterization of rivers in Michigan is generally understood as a result of the regional geology, parent materials and soil, topography, climate conditions, and vegetation. Theses variables contribute to a river's channel morphology. Collected, site specific geomorphic characterization information of Michigan rivers is not known.

In 2002, members from several federal, state and local agencies who were involved in stream monitoring, management, and rehabilitation in Michigan got together to share their knowledge and experience and recognized the need to increase the application of geomorphology science in physical and biological monitoring, management, education, communication amongst agencies and organizations, and rehabilitation of streams, hence creating the Michigan Stream Team (MST). The MST developed goals to enhance the science of Michigan stream geomorphology and the knowledge of those who study, manage, monitor, rehabilitate, review permits, evaluate grant proposals, make policies and/or legal decisions on Michigan streams.

Goals of the MST are to produce regional reference curves for Michigan, develop and manage a database for the reference reach data including determining the quality control necessary for stream data to be entered, determine stream types at the reference reaches utilizing the Rosgen (1994) Classification System, train the MST and those that manage streams in Michigan on stream morphology, and serve as a technical resource to advance stream morphology science to Michigan agencies and interest groups. To have a better understanding of the physical and dynamic processes of Michigan streams, the development of regional reference curves and classification of stream types became a priority in order to have a baseline assessment of reference reach stream geomorphic characterizations and morphological descriptions.

The overall goal of this research is to better understand site specific fluvial geomorphology characteristics and morphological descriptions of Michigan streams at USGS gage stations at reference reach streams and the application of geomorphic tools in various aspects of river management. This thesis will be comprised of an introduction to fluvial geomorphology and the classification of Michigan river reference reaches located at USGS gage stations. The goal of the introduction is to give an overview of rivers, fluvial geomorphology and its applications. Stream processes are dynamic and are dependent on regional geology, topography, vegetation, landuse, and climate. Land use in Michigan has changed significantly since the turn of the century and has influenced the function of our streams. A basic understanding of fluvial geomorphic processes will help guide individuals that our involved in various aspects of stream management and learn the implication of geomorphology that are fundamental in managing Michigan streams.

The goal of this research is to type streams in Michigan using the Level II river inventory to provide the morphologic description of streams in the Rosgen Classification System (RCS) (1994 and 1996) at United States Geological Survey (USGS) gage stations. The RCS, developed by Dave Rosgen (1994 and 1996) is based on stream geomorphology or channel dimension, pattern and profile. The geomorphic characterization of stream channels can be classified into broad stream types "A" through "G" and to a more defined classification of the morphological description of stream types such as "C5." The RCS (1994 and 1996) can be used as a communication tool amongst various disciplines that are involved in some aspect of stream management. This information can also be used as a tool to cross-reference present, site specific information to other streams that are located in similar physiographic regions and that are of comparable basin sizes. Little is known about the Level II RCS (1994 and 1996) stream types that occur regionally throughout Michigan and has not been applied to Michigan on a large scale basis. Forty-three reference reach streams located at USGS gage stations were classified by the RCS (1994 and 1996) stream types. This research will provide site specific, baseline stream morphological information and associated stream type.

As part of the research to classify Michigan streams using the RCS (1994 and 1996), data was collected concurrently to develop regional hydraulic geometry curves for Michigan streams located at USGS gage stations. This research is currently being reviewed by the USGS for publication and is titled

Regional Hydraulic Geometry Curves for Estimating Bankfull Characteristics of Michigan Rivers (Rachol, 2009). Regional curves relate bankfull stream channel dimensions including cross-sectional area, mean depth and width to watershed drainage area in similar physiographic regions (Dunne and Leopold, 1978). Established Regional Curves are essential to channel assessment and stream rehabilitation efforts. Regional curves support the identification of bankfull stage and channel dimensions in ungaged watersheds in similar physiographic regions and help estimate the appropriate bankfull dimension and discharge for natural channel designs (Glickauf et al. 2007) by making stream rehabilitation efforts more effective. Regional Curves developed for Michigan will assist and support engineers, hydrologists, geomorphologists, drain commissioners, and biologists in designing bridges, culverts, in-stream habitat structures, dam removals, and other projects that may impact or rehabilitate stream stability and function. Regional Curves will also provide regulating agencies critical information needed for evaluating permit applications dealing with Michigan stream rehabilitation and/or management projects that are considering the geomorphic implications of an alluvial system.

There is a lack of knowledge about site specific fluvial geomorphic and physical conditions of Michigan streams. The development of Regional Reference Curves and the designation of Stream Types applying the RCS (1994 and 1996) will increase the knowledge, use, and the value of fluvial geomorphology in the management and rehabilitation of Michigan streams. The

RSC (1994 and 1996) and Regional Reference Curve development has been implemented nationally and internationally. The information provided by this study for Michigan streams will furnish various professionals with the tools essential to streamline a morphological approach for communication amongst various disciplines that manage, monitor, and assess stream condition; provide a baseline Level II RCS (1994 and 1996) inventory of Michigan stream types at reference reach locations located near USGS gage stations; supply regional reference curve information at USGS gage stations that can be used to estimate bankfull channel dimensions and discharge versus drainage area at ungaged stream reaches in similar physiographic regions; and the creation of monitoring stations that can be re-surveyed to evaluate stream condition over time or expand the river inventory to the Level III and IV of the RCS (1994 and 1996).

Brief Overview of Fluvial Geomorphology:

Michigan is the home of over 36,000 miles of rivers (MDNR, 2009). These rivers twist and turn across Michigan's various landscapes to reach their destination to one of the Great Lakes. The nature of a river is a result of the regional composition of the landscape or geology and climatic conditions (Seelbach et al, 1997). The landscape unit of a river, called a watershed or sometimes referred to as the catchment, is the topographic area within which surface water runoff drains to a specific point on a stream or to other waterbodies, such as a lake (Omernik and Bailey, 1997).

As precipitation falls from the sky, it meets the earth's various surfaces ranging anywhere from an ocean, lake, river, field, forest, wetland, lawn, parking lot, or rooftop. The surface to where it falls depends on the journey to its destination. Some of the precipitation will become part of the storage of an ocean, lake or river and eventually evaporate back to the earth's atmosphere. Some precipitation may be intercepted by a forest canopy or leaf litter on the forest floor and evaporate. Impermeable surfaces such as rooftops, roads, and parking lots will capture a portion and the excess will run-off into storm drains and outlet to local wetlands, rivers, lakes, retention and detention ponds.

A portion of the precipitation will be captured by the stream itself, called channel interception. A percentage of precipitation will actually make it to the ground and infiltrate in-between soil particles and depending on the type of soil, may flow through the subsurface of the soil as throughflow or may percolate further down to the water table and become groundwater flow, where the soil is completely saturated. Water in the soil profile may also be absorbed by tree and plant roots and transported to leaves that release water vapor back to the atmosphere through transpiration. If it is a long and strong storm event, the soil may become saturated and can no longer take up water and results in run-off. The run-off will then travel across the landscape following the down slope gradient by gravitational force reaching channels and becoming stream flow. Stream flow is a representation of stream discharge (Q), a volume per unit time and is expressed as cubic feet per second (cfs). A hydrograph is a plot of discharge over time that can be utilized to determine quantitative characteristics of a watershed and its channels (Leopold, 1994). Streams and rivers form channel banks over time and become established at a height that confines the stream for all but the larger streamflow events in a year (Brooks et al, 2003). The smallest of the channels are called rills; and meet to form creeks, runs, or streams; then, at some undefined size, they are termed rivers (Leopold, 1994). As explained by Leopold, each channel is fed from two sources, overland flow (run-off) to a channel and groundwater emerging at the channel boundary. In dry conditions, all the flow in the channels derives from groundwater output (Leopold, 1994) which is often termed baseflow.

Channel Dimension (cross-sectional view):

River channels not only carry water across the landscape, they also carry sediment and dissolved materials, transforming the landscape by erosion, dissolution, and deposition (Wiley and Seelbach, 1997). The combination of these variables results in the shape or often referred to as the dimension of the cross-section of the river channel. The cross-section of a river channel can be described as a slice of a river from left bank to right bank that describes channel shape. The cross-sectional shape of a river is a function of the flow, the quantity and character of the sediment in motion through the channel, and the character or composition of the materials (including the vegetation) that make up the bed and banks of the channel (Leopold, 1994). Generally, in straight reaches, channel cross-sections are trapezoidal in shape and are more asymmetrical at curves and bends (Leopold, 1994). Natural channels migrate laterally by eroding one bank and maintaining on average, a constant channel cross-section by deposition on the opposite bank creating a point bar, resulting in a balance of erosion and deposition (Leopold, 1994). This lateral migration associated with alluvial channels is the process of floodplain development when point bars areas are abandoned (Rosgen, 1996). Floodplains are level areas adjacent to a river channel, constructed by a river during the present climate, that receives and stores channel overflow during moderate flow events (Leopold, 1994). A floodplain can be abandoned, especially during drier climate conditions, and is referred to as a terrace (Leopold, 1994).

An important aspect of stream morphology is bankfull stage and discharge. Bankfull stage is often termed "the incipient point of flooding." Rosgen further defines it as the flow that fills the channel to the top of its banks and bankfull stage is at an elevation where the water begins to overflow onto a floodplain (1996). Dunne and Leopold (1978) further explain the importance of bankfull stage and the related discharge as "the bankfull stage corresponds to the discharge at which channel maintenance is the most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphological characteristics of channels." The general consensus of the reoccurrence of bankfull discharge is every 1.5 years in the annual flood series (Leopold, 1994).

Channel Pattern (plan form view):

Aerial photos are a resource that can be used to illustrate channel pattern, such as looking down at a river from an airplane (Leopold, 1994). Rivers often wind and bend as it moves back and forth across the floodplain. Natural, straight river channels rarely occur and if they do, it is often for a short distance (Leopold, 1994). According to Leopold, even a river's thalweg (thread of the deepest part of the river) tends to wind between the channel banks in straight reaches of a river (1994). Patterns of rivers are a result of dissipating kinetic energy from flow and the transportation of sediment (Rosgen, 1996). A meander wavelength or bend in the river can be described as the portion of river entering into a bend in the river, following the channel through the bend, and the exit out of that bend as the river enters into a new bend. Stream flow occurrences or regimes can change stream patterns depending on the magnitude and duration of the flow (Rosgen, 1996).

Channel Profile (longitudinal view):

The profile of a river channel is the longitudinal description of the downstream gradient or slope of a river from upstream to downstream. Channel gradient decreases in a downstream direction resulting in an increase in flow, and a decrease in sediment size (Rosgen, 1996). The profile of a river can change from reach to reach depending on the influence of the local channel gradient and resident stream bed materials (Rosgen, 1996). The flow of a river as it meanders along the floodplain often carves and shapes distinct stream bed features. Portions of the channel where there is a steeper gradient result in the formation of riffles that are shallow and exhibit more turbulent flows. Deeper portions of the channel are termed pools which are indicative of tranquil flows and flatter slopes. Bed materials comprised in these features depends on the local geology that the river flows through. The sequences of riffle and pool features along the channel profile are often spaced at a repeating distance of five to seven widths where the pools are often located on the outside of the bend (Leopold, 1994). As a reference, standing in a stream channel looking downstream, the bank on the left is referred to the left bank and the bank to the right is referred to as the right bank, however, this is not standard.

Channel Material:

The amount of sediment transported by a stream depends on the interrelationships between supply of material to the channel, characteristics of the channel, the physical characteristics of the sediment, and the rate and amount of stream flow discharge (Brooks, et al, 2003). Bed and bank materials of an alluvial channel are critical for sediment transport, hydraulic influences of relative roughness and the dimension, pattern, and profile of that channel (Rosgen, 1994). Transport physics, sediment size, sediment load, increases in the magnitude and duration of stream flow, stability of stream banks and bed all influence the contribution of sediment from channel processes (EPA, WARSS Introduction). The surface material of both the bed and banks of a river channel is referred to as pavement and materials just beneath the pavement are called the sub pavement (Rosgen, 1996). Bedload is the portion of the total sediment in transport that is carried by intermittent contact with the streambed by rolling, sliding, and bouncing (EPA, WARSS Introduction). Suspended sediment is that portion of the total sediment load of rivers that is carried in the water column and contains the "wash load" or that portion of the suspended load not represented in the bed material (EPA, WARSS Introduction).

Channel Stability:

A "stable channel balance" relationship developed by Lane (1955) based on extensive field observations expresses the proportion between sediment discharge, stream discharge, particle size, and slope and is expressed as:

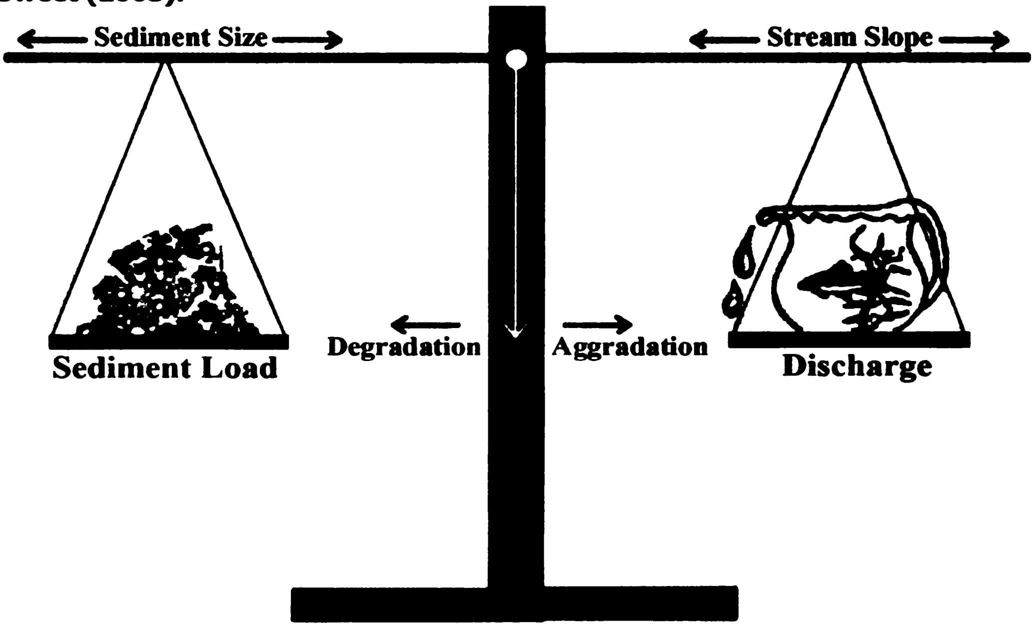
$$(Qs)\ (D50) \sim (Q)\ (S)$$

Where Qs is sediment discharge
D50 is the median particle size
Q is stream discharge
And S is bed slope

When the relationship is balanced (Figure 1), there is no net gain or loss in a river reach, however, a change in any of these variables can result in a series of adjustments resulting in channel aggradation or degradation.

Channel stability is the product of equilibrium conditions of natural alluvial channels that develop as a result of flow regimes that are a function of the regional precipitation regime of the watershed, vegetation, evapotranspiration, and other constant factors that affects the amount of precipitation that runs-off or enters the stream as base flow (Nunnally, 1978). Stream channel stability

Figure 1: Lane's (1955) stable channel balance relationship after Rosgen (1996), by Sweet (2003).



Sediment Load x Sediment Size ~ Stream Slope x Discharge

defined by Rosgen (1996), "is the ability of a stream, over time, in the present climate, to transport the sediment and flows by its watershed in such a manner that the stream maintains dimension, pattern, and profile without either aggrading or degrading." Leopold et al (1964) identified eight major variables that influence stream pattern morphology that include channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size. As a result, Rosgen (1994) points out that "a change in any one of these variables sets up a series of channel adjustments which lead to change in the others in channel pattern alteration."

Hydraulic Geometry:

As explained by Leopold (1994), cross sections of any river have changed their shape and dimension overtime to accept a range of flows and consistently reflect the way that hydraulic parameters change from low flow to high flow. First introduced by Leopold and Maddock (1953), hydraulic geometry is the empirical relationship of width (W), mean depth (D) and mean velocity (U) of a given cross section and a power function of discharge of a river along a river network in a hydraulically similar basin and can be described as:

$$W=aQ^b$$

$$D=cQ^f$$

$$U=kQ^m$$

Where b, f, and m are exponents and a, c, and k are coefficients that indicate a rate of increase in hydraulic variable of width, depth, and velocity with increasing discharge. Since discharge is,

$$Q=WDU$$

Or

$$Q=AV$$

Where A is cross section area and V is velocity, then

$$Q= (aQ^b) (cQ^f) (kQ^m)$$

Or

$$Q= ack (Q)^{b+f+m}$$

Therefore, b + f + m and ack must equal 1. The values of b, f, and m have been determined by plotting collected field data from gaging stations from rivers throughout the world and describe both the geometry of the channel and the resistance to erosion associated with the character of the bed and banks

(Leopold, 1994). Field data collected at USGS gage stations include individual flow measurements recording width, cross-sectional area, gage height, discharge, and mean velocity at a variety discharges.

River Uses:

Rivers have provided Michigan residents and visitors with historical, social, economic, and biological benefits. Early settlers in Michigan often settled their towns and villages near rivers and the current populated areas in the state are often found adjacent to a river. Earlier settlers used rivers by erecting dams for mill power, transporting people, transporting goods (lumber, fur, etc.), water use (drinking, cleaning, etc.), food (fish, small mammals, and plants), and agricultural irrigation. Rivers also have social benefits by providing educational, recreational, environmental aesthetics, and public access uses. Economically, they provide communities and businesses with mill power, hydropower, transportation of goods, watering livestock, irrigation of crops, recreation (fishing and boating), and tourism. Biologically, rivers are an ecosystem that provides a range of habitats for fish, birds, reptiles, and mammals.

As reported by Poff et al (1997), the impacts that humans have had on the natural hydrologic processes has resulted in the disruption of the dynamic equilibrium between the movement of water and the movement of sediment that exists in free-flowing rivers (Dunne and Leopold, 1978). Michigan's rivers have suffered disconnection from dams and diversions, a reduction of functioning floodplains from disconnection and development, increased flows from run-off from impervious surfaces (parking lots, roads, and buildings (stormwater), increased sediment and nutrient loadings from run-off of various land uses and severe stream bank erosion, loss of channel structure from straightening and channeling to increase drainage and reduce flooding, resulting in an overall negative impact to the biological, chemical, hydrological, and physical dynamics of a river.

Rehabilitation of Rivers:

An estimated $10 billion dollars was spent on the restoration of the United States rivers with varying restoration activities including erosion control, hydrologic stability, nutrient and sediment reduction, and the enhancement of habitat diversity (Allan, 2009). According to the National River Science Synthesis, between 1970 and 2006, Michigan had 846 restoration projects ranging from bank stabilization, channel reconfiguration, dam removal/retrofit, fish passage, flow modification, in-stream habitat improvement, in-stream species management, riparian management, stormwater management, aesthetics/recreation/education and water quality management costing over 41 million dollars with only 1% of the projects that were monitored pre and post restoration (2006). These statistics confirm that few restoration projects are evaluated to determine success (Palmer et al., 2006).

Public awareness over the last decade has prompted federal, state, local jurisdictions and environmental groups to direct major efforts at preserving, protecting, enhancing, stabilizing, rehabilitating and restoring rivers throughout the United States (Rosgen, 2006). Various methods have been utilized in river restoration including hard engineering which often uses rigid materials such as rock rip rap (stone) and gabion baskets (a basket or cage filled with earth or stone) to alleviate stream bank erosion. In some cases, such as the management of designated drains, restoration includes channelization, which is a combination of shortening (by abandoning and cutting-off natural channel meandering bends), widening (increasing channel width), deepening (increasing channel depth), straightening (increasing channel slope), and removing vegetation (reducing the effective size of the channel, increasing resistance of banks to erosion, and increasing hydraulic resistance) of a river channel (Nunnally, 1978). Often, entire stream channels (banks and bed) are concreted to reduce localized flooding, increase drainage, and stabilize eroding banks. These techniques have resulted in an increase or decrease in stream morphology variables (width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size) eventually resulting in instability. As a result, the stream will have to adjust into a new state of equilibrium.

Recently, natural channel design has emerged as a popular and preferred restoration technique. Natural channel design often utilizes natural materials that tend to blend in with the natural environment such as native vegetation, root wads, in-stream rock structures, addition of woody debris, and geotextiles to assist in vegetation colonization. These techniques are sometimes referred to as "soft" engineering. More recently, stream geomorphology has come into the forefront as one of the most important variables in designing stream restorations. As defined by Rosgen (1996), "natural channel design is restoring the dimension, pattern and profile of a disturbed river system to emulate the natural, stable river" (Rosgen, 2006).

USGS Gage Stations:

The United States Geological Survey's (USGS) National Streamflow Information Program (NSIP) is a stream flow data warehouse for the United States. The USGS operates and maintains over 7,000 nationwide gage stations in partnership with federal, state, and local agencies and organizations (USGS, 2009). Gage stations are constructed adjacent to rivers to collect stream flow information. The purpose of a gage station is to measure and record the height or stage of the water above a reference point in a river channel termed gage height (USGS, 2009). Throughout the life of the gage station, USGS technicians conduct cross sectional area and velocity measurements by measuring width and depth with a flow meter to determine discharge at a recorded gage height. As more discharge measurements are made, they can be plotted against gage height and recorded on a rating table. The rating table then provides gage height with a known discharge and vice versa a discharge with a known gage height. Information provided by current and discontinued gage stations in Michigan is essential for the classification of stream type and development of regional curves for Michigan streams.

Stream Classification:

Suggested by Naiman, stream classification implies that sets of observations and characteristics can be organized into meaningful groups based on measures of similarity or difference (1998). As reported by Rosgen (1994), a definition of classification in the strictest sense means ordering or arranging objects into groups or sets on the basis of their similarities or relationships by Platts (1980). However, a classification arrangement can over simplify a particularly complex system (Rosgen, 1994).

A summary of stream classification is reviewed by Wasson (1989), Naiman et al. (1992), Montgomery and Buffington (1993), Seelbach and Wiley (1997) and Rosgen (1994). Throughout this century, various attempts of stream classification schemes have been made based on physical and biological indicators over various spatial scales. Early attempts of whole-river classification were developed by Davis (1890) who classified streams as young, mature, or old on the basis of observed erosion patterns (Naiman, 1998). Shelford (1911) attempted to classify rivers near Chicago based on the arrangement of fish in a stream from mouth to source. Strahler (1957) modified Horton's (1945) classification of stream order by designating headwater perennial streams as order 1, and at the confluence of two first order streams the downstream reach was designated a second order stream. This ordering system continues downstream where the downstream reach of the confluence of two second order streams becomes a third order stream. The largest stream order in the world is the Amazon River that is designated as a twelfth order stream. Leopold, Wolman, and Miller (1957) as well as Schumm (1977) organized and described stream patterns as straight, meandering, and braided patterns while Lane (1955) developed slope-discharge relationships for braided, intermediate, and meandering streams (Rosgen, 1994). Schumm (1977) divided river systems into three zones; zone of production (upper reach), the zone of transfer (intermediate reach), and the zone of deposition (lower reach). Seelbach et al (1997) developed a landscape based ecological classification system for river valley segments in Lower Michigan. Key attributes selected to describe the character of river valley segments (physical channel unit) include catchment size, hydrology, water chemistry, valley character, channel character, and fish assemblages (Seelbach et al, 1997). As noted by Rosgen, for river classification schemes to be useful for extrapolation purposes, restoration designs, and prediction, these schemes should represent the physical characteristics of the river (1994).

Rosgen Classification System:

The Rosgen (1994) Classification of Natural Rivers is based on eight major variables that influence stream morphology as described by Leopold et al. (1964) as channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size. An increase or decrease in any of the above mentioned variables will result in channel adjustments that will influence the other variables, contributing to a disruption in dimension, pattern, and profile (Rosgen, 1994). As summarized by Ward and Trimble (2004) after

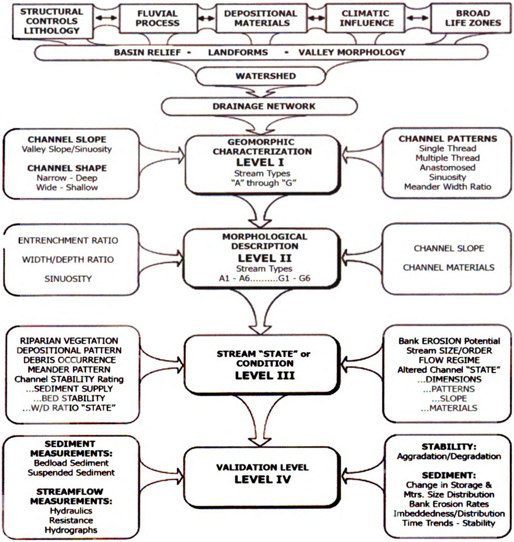
Rosgen (1996), the Rosgen Classification System (RCS) includes the following objectives:

1) Provide a consistent frame of reference for communicating stream morphology and condition among a variety of disciplines and interested parties
2) Predict stream behavior from appearance
3) Develop specific hydraulic and sediment relationships for a given stream type and its state.
4) Provide a mechanism to extrapolate site-specific data to stream reaches with similar attributes
5) Identify if the stream is in dynamic equilibrium and/or in a transitional (stable or unstable) stage
6) Provide a context for evaluating stream condition

The RCS (1994 and 1996) system encompasses four hierarchy inventory levels. Level I describes the geomorphic characterization, Level II provides the morphological description, Level III evaluates the stream "state" or condition, and Level IV is the validation of the analyses of the previous levels (see Figure 2). This study focuses on the Level I and II of the RCS (1994 and 1996) and is used collectively to determine Michigan stream types and provide the physical data necessary for the development of the regional curve.

Level I of the RCS (1994 and 1996) is a broad level geomorphic characterization of a river reach and is based on a river's dimension, pattern and profile. The RCS (1994 and 1996) categorizes stream reaches into nine stream types (Aa+, A, B, C, D, DA, E, F, and G) and eleven Valley Types (I, II, III, IV, V, VI, VII, VIII, VIIII, IX, X, and XI). The Level I classification and delineation process provides a general characterization of valley types and landforms and identifies the corresponding major stream types in watershed areas that can often be

Figure 2: The hierarchy of river inventory and assessment (Rosgen, 1996)



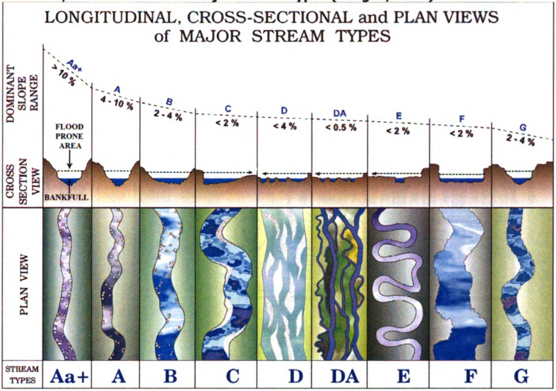
determined from aerial photos and topographic maps (Rosgen, 1996) (See Table 1). A general assessment is made by identifying Valley Type, channel pattern (single thread, multiple thread, sinuous, or straight), valley and channel profile (slope), and a rough estimate of channel dimension (narrow and deep or wide and shallow)(see Figure 3)(Fluvial Geomorphology Training Module, 2009).

Table 1.1: Valley Types, description of valley types, and associated stream types (After Rosgen, 2006)

Valley Type	Description of Valley Types	Associated Stream Types
I	"v" notched canyons, rejuventated sideslopes	A & G
II	Moderately steep, gentle sloping side slopes often in colluvial valleys.	B
III	Alluvial fans and debris cones.	A, G, D, & B
IV	Gentle gradient canyons, gorges, and confined alluvial valleys.	F or C
V	Moderately steep valley slopes, "U" shaped glacial trough valleys.	D & C
VI	Moderately steep, fault controlled valleys	B, G, & C
VII	Steep, highly dissected fluvial slopes.	A & G
VIII	Wide, gentle valley slope with a well-developed floodplain adjacent to river terraces.	C or E Occasional D, F & G
IX	Broad, moderate to gentle slopes, associated with glacial outwash and/or eolian sand dunes	D & some C
X	Very broad and gentle slopes, associated with extensive floodplains - Great Plains, semi-desert and desert provinces: coastal plains and tundra: Lacustrine valleys.	C, E & DA Occasional F & G
XI	Elongate or lobate configuration of highly constructive deltas with a distributary channel system.	DA & D Occasional C & E

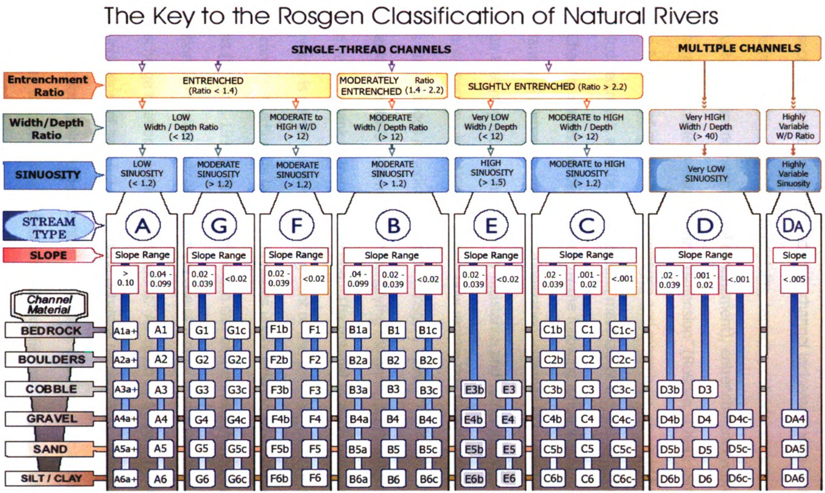
Level II of the RCS (1994 and 1996) requires a detailed assessment and survey of the morphological characteristics of dimension, pattern, profile, and channel material of a river and is conducted in the field. Level II of the RCS (1994 and 1996) determines the morphological description of the stream and expands stream typing into 94 types by further categorizing by slope and channel material (see Figure 4). The morphological variables determined in Level II in a stream should not be used to describe an entire basin area. These characteristics may change over short and/or long distances and over time. Level II criteria is used to assign a stream type by utilizing data collected in the field of a stream cross section, longitudinal profile, and planform features at stream reaches.

Figure 3: Broad level stream classification delineation showing Longitudinal, Cross-sectional, and Plan Views of Major Stream Types (Rosgen, 1996).



The precise identification of bankfull elevation in the field is crucial to correctly classify streams in Level II classification. The geomorphologic information that is needed to classify stream types at Level II include mean bankfull depth, maximum bankfull depth, bankfull width, floodprone area width, channel sinuosity, water surface slope, and mean channel material size (D_{50}) (Rosgen, 1994 and 1996). This information is collected by surveying and measuring a river longitudinal profile, channel cross section, determining sinuosity and median channel material in the field at reference reach locations. "A reference reach is a geomorphic blueprint of a stable river and information from these sites can be extrapolated to other areas that have similar valley and

Figure 4: Key to the Rosgen Classification of Natural Rivers (Rosgen, 1996).



Key to the ROSGEN CLASSIFICATION of NATURAL RIVERS. As a function of the "continuum of physical variables" within stream reaches, values of **Entrenchment** and **Sinuosity** ratios can vary by +/- 0.2 units: while values for **Width/Depth** ratios can vary by +/- 2.0 units.

lithological types for stream classification and restoration" (Rosgen, 1996).
A cross-section of a river is used to "identify channel incisement with in its valley, as well as information concerning floodplains, terraces, colluvial slopes, structural control features, confinement (lateral confinement), entrenchment (vertical containment), and valley versus channel dimension" (Rosgen, 1994). Stream width is a function of stream flow occurrence and magnitude, size and type of transported sediment, and the bed and bank materials of the channel (Rosgen, 1996). Channel widths can be impacted by the following influences:
direct channel disturbances such as channelization; changes in riparian vegetation that may modify the boundary resistance and vulnerability to streambank erosion; alterations in stream flow regime due to watershed changes; and changes in sediment regime (Rosgen, 1996).

Bankfull width is determined by identifying the bankfull elevation on at least one or each bank of the cross section. The optimal location to measure bankfull width is within the narrowest segment of the selected reach where the channel can freely adjust its lateral boundaries under existing streamflow conditions (Rosgen, 1996). Bankfull elevation can best be determined by a combination of physical indicators and the use of a peak flow analysis of stage/discharge relationships at gage stations. As noted by Rosgen (1996), physical indicators of bankfull where gage datum is not available include the presence of a floodplain at the elevation of incipient flooding, the elevation associated with the top of the highest depositional features, a break in slope of the banks and/or a change in the particle size distribution, evidence of an inundation feature such as a small benches, staining of rocks, exposed root hairs below an intact soil layer indicating exposure to erosive flow, and lichens or certain riparian vegetation species. Bankfull width is the measurement of a channel cross section from bankfull elevation of the left bank to bankfull elevation of the right bank. Bankfull depth is a measurement of the average depth of a channel cross section at bankfull elevation. Floodprone width is the measurement of stream width at the elevation that corresponds to twice the maximum depth (thalweg of the channel) of the bankfull elevation and is associated with less than a 50 year return period flood (Rosgen, 1996)(See Figure 5). The cross-section information is then utilized to determine the entrenchment ratio and width to depth ratio (see Figure 5).

The entrenchment ratio is the ratio of the width of the flood-prone area to the surface width of the bankfull channel to describe the vertical containment of a river (Rosgen, 1994 and 1996).

$$Er = WFP/W_{bkf}$$

Where Er is entrenchment ratio
WFP is floodprone width
and W_{bkf} is bankfull width

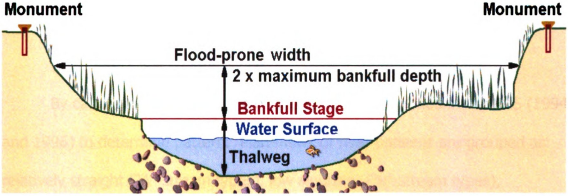
The width to depth ratio is defined as the ratio of the bankfull surface width to the mean depth of the bankfull channel (Rosgen, 1996). According to Rosgen, the width to depth ratio is essential to understanding the distribution of available energy within a channel, the ability of various discharges occurring within the channel to move sediment, and provides a rapid assessment of stream stability (1996).

Width/Depth Ratio = W/d

Where W is width
and d is depth

By calculating these variables, a stream type can be designated by dimension. Measured mean values and ranges by stream type by the RCS (1994 and 1996) are shown in Figure 4.

Figure 5: Parameters determined from surveyed cross-section by Fongers (MST, 2005).



Pattern is also used in determining stream type of the Level II RCS by the measured and mean values of sinuosity. As noted by Rosgen, the planimetric view of various stream patterns may be qualitatively described as straight, meandering, or braided (1996). Meander geometry is a function of bankfull width (Rosgen, 1996). Patterns in rivers are a result of its primary functions to perform work such as transporting sediment and dissipating the energy of moving water. When channels are straightened, the end result is the negative impact on the natural morphology of the channel and its stability. Sinuosity can be expressed in either of the following equations:

1) Using an aerial photograph, measure stream length and related valley length for at least two meander wavelengths to determine sinuosity (See Figure 6).

$$K = SL/VL$$

Where K is sinuosity
SL is stream length
VL is valley length

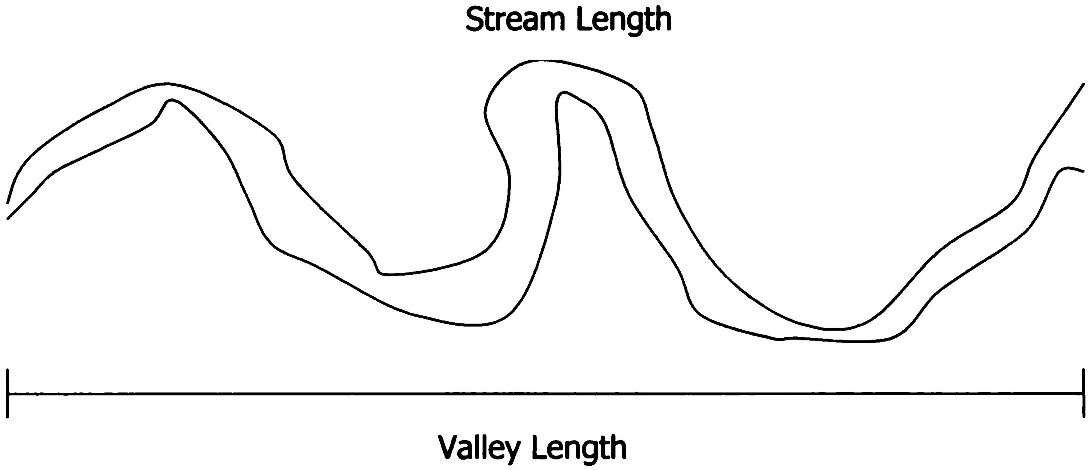
2) Use measured slope ratios to determine sinuosity.

$$K = VS/CS$$

Where K is sinuosity
VS is valley slope
and CS is channel slope

By calculating sinuosity, a stream type can be identified in the RCS (1994 and 1996) to determine pattern. Plan-views of river patterns are grouped as: relatively straight ("A" stream types), low sinuosity ("B" stream types), meandering ("C" and "F" stream types), tortuously meandering ("E" stream types), and complex stream patterns that are associated with multiple channels and braided ("D" type) and anastomosed ("DA" stream type). Ranges of sinuosity to determine stream type is depicted in Figure 4.

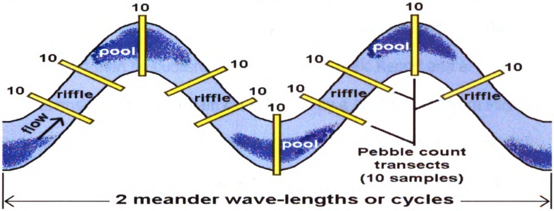
Figure 6: Measuring stream sinuosity (k) is Stream Length/Valley Length



Another Level II attribute used in the Rosgen classification system is profile. Rosgen noted that channel gradient decreases in a downstream direction with increases in stream flow and a corresponding general decrease in sediment size (1996). The longitudinal profile of a stream reach reflects profile morphology based on the work of Grant et al. (1990) utilized in RCS (1994 and 1996). Slope is calculated from the top of profile to the bottom of the profile on similar stream bed characteristics (i.e. begin riffle to end riffle) of the channel reach that is at least two meander wavelengths or twenty bankfull widths long and is expressed in feet/feet (Rosgen, 1996).

The final attribute used in the Rosgen Level II Classification (1994) is mean channel material referred to as the D_{50}. A modified version of the "pebble count" developed by Wolman (1954) is used to determine the mean channel material in the field including the bank material and for sand and smaller sizes (Rosgen, 1994). The D_{50} is the representation of bed and bank material that is the size of material that is 50% of the population that is sampled is of the same size or finer (Rosgen, 1994). In the RCS (1994 and 1996), channel material is categorized by six channel material types and correlated by number: 1) bedrock (>2048 mm), 2) boulders (256mm to 2048mm), 3) cobble (64 to 256), 4)gravel (2mm to 64mm), 5) sand (.062mm to 2mm), and 6) silt/clay (<.062) as shown in Figure 4. A total of 100 pebbles are sampled and counted according to the percentage of stream bed characteristics (pools, riffles, glides, and runs) of the surveyed stream profile as shown in Figure 7. For instance, if a surveyed stream profile of a length of 1,500 feet and consists of three runs, three riffles, and four pools, the sample size for a pebble count would be 30% runs (10 samples taken at each run), 30% riffles (10 samples taken at each riffle), and 40% pools (10 samples taken at each pool) to equal 100% (100 samples taken) of the entire reach. A series of ten blind samples of bank and bed material are taken at cross section locations from bankfull to bankfull at each bed feature. For a more in-depth explanation of the pebble count procedure, please see "Protocol for Field Surveys of Stream Morphology at Gaging Stations in Michigan" (2009).

Figure 7: Reach Average Pebble Count Diagram by Fongers (MST, 2005).



Methods:

Protocol Development for Regional Reference Curves and Stream Classification:

To increase the knowledge and information of the fluvial geomorphic attributes of Michigan streams, Regional Reference Curves at USGS gage stations and a classification of stream types designated by the RCS (1994 and 1996) were developed. To corroborate the development of the curves and stream classification, the MST composed the Protocol for Field Surveys of Stream Morphology at Gaging Stations in Michigan (2006) to streamline Regional Curve and RCS (1994 and 1996) stream typing data collection. The protocol is divided into two sections: 1) reconnaissance survey and 2) full field survey. The purpose of the reconnaissance survey is to evaluate and select gage station reaches for the full field survey. The purpose of full field survey is to collect all the field data necessary to develop the regional curves and classify the channel using the Level II RCS system (1994 and 1996). In order to complete needed field work to develop the curves, a partnership was developed with the Calhoun

Conservation District and the United States Geological Survey (USGS) to conduct field reconnaissance surveys, full field surveys, and analyze collected data. The results would then be published in an USGS Scientific Report and a comprehensive thesis of stream classification by a grad student from Michigan State University funded through the Michigan Department of Environmental Quality (MDEQ), the Michigan Department of Transportation (MDOT), and the USGS.

USGS Gage Selection:

To determine the number of gages available to include in the study, the USGS conducted an initial in-house evaluation and screening of 341 discontinued and current gage stations that fit the following criteria: the USGS gage station had at least 10 years of record, no artificial controls (dams and/or lake level control structures) that could influence the flow record, obstruct sediment transport or impacted from impoundment; the site is not indicative of stream instability such as excessive channel degradation, bank erosion, or bed aggradation; the stream channel is able to adjust its dimension, pattern, and profile thereby eliminating sites with bedrock influenced channels; and for discontinued sites, the reference marks are intact to tie the survey reach into gage datum. This resulted in the removal of 238 gage stations from the study and left 103 that would be available for stream reconnaissance (See Figure 8).

Peak Flow Analysis:

Fongers of the Michigan Department of Environmental Quality (MDEQ) developed a Peak Flow Analysis of Michigan USGS Gages (2007) for gages with at least 10 years of record to assist in the Regional Curve development and stream typing using the RCS (1994 and 1996). The peak flow analysis for Michigan Gage stations analyzed gage stations with a minimum of 10 years of record using PKFQWin 5.2.0 software to produce sufficiently accurate estimates of the 80% (1¼ -year), 67% (1½ -year), and 50% (2-year) chance floods (Fongers, 2007). Program PeakFQ provides estimates of instantaneous annual-maximum peak flows for a range of recurrence intervals, including 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years (annual-Exceedance probabilities of 0.6667, 0.50, 0.4292 0.20, 0.10, 0.04, 0.02, 0.01, 0.005, and 0.002, respectively). The Pearson Type III frequency distribution is fit to the logarithms of instantaneous annual peak flows following Bulletin 17B guidelines of the Interagency Advisory Committee on Water Data. The parameters of the Pearson Type III frequency curve are estimated by the logarithmic sample moments (mean, standard deviation, and coefficient of skewness) with adjustments for low outliers, high outliers, historic peaks, and generalized skew (USGS, 2009).

The Peak Flow Analysis of Michigan USGS Gages (2007) was used in the field to help support the identification of bankfull at reference reach sites by comparing gage height of the field reconnaissance and survey field day to the 1.25, 1.5, and 2-year discharge reoccurrence intervals gage heights from the gage station rating table. The difference between the return floods gage height and the field day gage height is the approximate feet above water surface where bankfull may be located. This comparison was also supplemented with physical and visual indications of bankfull elevation in the field.

Stream Reconnaissance:

A stream reconnaissance was conducted at 103 USGS gage sites consistent with the Protocol for Field Surveys of Stream Morphology at Gaging Stations in Michigan (MST, 2005). Prior to reconnaissance, a copy of the gage station description, gage station rating table, a most recent aerial photograph, and topographic map were collected for each site. The field reconnaissance at gage stations included: the identification of at least two, intact USGS reference marks to tie the field survey with gage datum; the site was considered wadeable; the reference reach length was at least two meander wavelengths or 20 times bankfull widths and located in the vicinity of the gage; the reach is located where there is no contributing flow from tributaries that the gage is not accounting for; sites that were not indicative of channel instability such as excessive stream bank erosion, channel aggradation or degradation, a high width to depth ratio, and the presence of channel bars; bankfull elevation was identifiable visually, physically, or cross-referenced from the Peak Flow Analysis (Fongers, 2007) and gage datum; the stream channel was not constrained by bedrock; and there was no evidence of reach impact from undersized culverts and bridges, riparian land uses, dams or lake level control structures. Each site was waded and notes were recorded summarizing the field reconnaissance. As a result of the site reconnaissance, 60 sites were eliminated from the study and a total of 43 sites were surveyed.

Data Collection:

The field data collection survey consisted of the reference reach longitudinal profile, a representative riffle cross-section, a representative pool cross-section, and cross-section and reach pebble counts. The pool cross-section is not used in stream classification or the regional curve development; however, the MST deemed pool information important for geomorphic data collection for future use in stream restoration design parameters. Surveys were conducted using the MST protocol (MST, 2005) by staff from the USGS, Calhoun Conservation District-Michigan State University Graduate Student (CCD), Michigan Department of Natural Resources-Habitat Management Unit (MDNR), MDEQ, MDOT, U.S. Army Corp of Engineers-Detroit District (USACE), and the U.S. Fish and Wildlife Service. A Regional Curve and stream classifications were developed for five locations in the Menominee River Basin in Michigan's Upper Peninsula by Mistak and Stille (2008) and are included in this stream classification study.

Once on location of the site to be surveyed, gage height and discharge were recorded if the gage station was current or there was an existing wire weight gage from a discontinued site often located on bridges to measure surface water elevation that correlates to gage height. From the Peak Flow Analysis (Fongers, 2007), the difference in the day of the survey gage height and the 1.25, 1.5, and 2 year return's gage heights were used to estimate bankfull elevation. Using a laser level, two USGS reference marks were used to tie survey data with gage datum. Several tapes were stretched out along the left bank at a length of two meander wavelengths or 20 times bankfull width. A longitudinal profile survey was conducted from the top (upstream) to the bottom (downstream) reach from riffle to riffle to collect stream bed elevations and notes on dominant channel material, water depth, and bankfull elevations. Bankfull elevations were rated in three tiers: 1) excellent indication of bankfull, 2) moderate indication of bankfull, and 3) poor indication of bankfull from the visual, physical, and peak flow analysis information of each site. The longitudinal profile survey was then closed within .02 (two hundredths) of the reference mark datum. A site sketch of the longitudinal profile was conducted to illustrate reach location, cross-section location, temporary benchmark locations, prominent terraces, woody debris, floodplain and bank vegetation, channel vegetation, riparian uses or buildings, stream bed characteristics (riffles, pools, and runs), direction of flow, and any other information needed to identify the stream reach.

Next, a riffle and pool cross section were surveyed and tied into the longitudinal profile. The riffle cross-section was chosen at a representative riffle in the longitudinal reach. The cross section was then monumented with rerod on each bank at an elevation just above estimated bankfull. A tag line was stretched from the left bank to right bank from each monument. The survey was conducted from left bank to right bank capturing any changes in elevation including left and right bankfull elevations, left and right edge of water (surface water elevations), and channel bed elevations with notes on dominant bed material and a rating of bankfull elevation. Photographs were taken from the center of the cross section channel looking at the left bank, downstream, right bank, and upstream.

Lastly, a cross section and average reach pebble count was conducted and recorded. The cross section pebble count consists of taking 100 first "blind touch" samples between the index finger and thumb of bank and bed material from bankfull to bankfull at increment measurements of bankfull width. If material sampled was larger than 2 millimeters (coarse sand), a ruler was used to measure the intermediate axis of the material. Pebble count data collected from the riffle cross section is used to determine the D_{84} (84^{th} percentile particle size) to use in discharge calculations for regional curve development. The average reach pebble count collected from the longitudinal profile is used to determine the D_{50} (50^{th} percentile particle size) for use in stream type classification.

Data Analysis, Results and Discussion:

Gage station ID number, gage station name, drainage area, state, county, latitude and longitude, and field data collected from the longitudinal profile, riffle and pool cross section, and pebble counts at each site was entered into

Rivermorph software (2002) and analyzed to determine stream type for stream classification. Flood-prone width and stream sinuosity were measured from topographic maps and were also entered into Rivermorph. Parameters used to determine stream type in Rivermorph (2002) include the riffle cross-section width (ft), mean depth (ft), maximum depth (ft), cross-sectional area (ft), entrenchment ratio (ft), and width to depth ratio (ft). Slope (ft/ft) was determined from the longitudinal profile and the D_{50} of channel material was determined from the average reach pebble count. The calculations produced by Rivermorph were re-calculated manually to validate results.

Out of the 43 streams surveyed, 39 classified as a "C" stream type (See Table 1.2 & 1.3). "C" streams are indicative of slightly entrenched (>2.2), moderate to high width to depth ratio (>12), moderate to high sinuosity (>1.2), and a slope less than 2% with a well-developed floodplain in narrow to wide valleys (Rosgen, 1996). The average riffle and pool sequencing is on average one-half a meander wavelength or approximately 5 to 7 bankfull channel widths representing the channel geometry of the reach (Rosgen, 1996). The channel aggradation/degradation and lateral migration processes are dependent on the natural stability of the stream banks, the present watershed conditions, flow and sediment regimes in C type streams (Rosgen, 1996). Channels of "C" type streams are also vulnerable to alteration and de-stabilization when there are significant changes to bank stability, watershed condition, and flow regime are combined and result in an acceleration of channel instability (Rosgen, 1996). "C" streams classified down to channel material and slope resulted in fourteen "C5c-," thirteen "C4," seven "C4c-," two "C5," two "C3," and one "C3c-."

Out of the remaining four streams surveyed, two classified as a "B" stream type and the final two classified as an "E" stream type (See Table 1.2 & 1.3). "B" streams are indicative of a moderately entrenched (1.44 to 2.2), a moderate width to depth ratio (>12), moderate sinuosity (>1.2), and a slope less than 4% with a limited floodplain due to narrow valley constraints. The average pool to pool sequencing is 4 to 5 bankfull channel widths and decreases with an increasing slope (Rosgen, 1996). "B" type streams have low streambank erosion and channel aggradation/degradation rates (Rosgen, 1996). "B' type streams classified down to channel material and slope resulted in one "B4c" and one "B5c.

"E" streams are "considered *evolutionary* in terms of fluvial process and morphology" (Rosgen, 1996) and are indicative of a slightly entrenched (>2.2), a very low width to depth ratio (<12), very high sinuosity (>1.5), and a slope of less than 4%. "E" type streams are the most sinuous compared to all other stream types and have a consistent riffle and pool sequence and generate the highest number of pools per unit distance of channel distance (Rosgen, 1996). "E" type streams "often develops inside of the wide, entrenched, and meandering channels of the "F" type streams following floodplain development and vegetation recovery of former "F" channel beds" (Rosgen, 1996). They can be quite stable if the floodplain and the low width to depth ratio are maintained, however, they are sensitive to disturbances and can rapidly adjust and convert to other stream types in a short period of time (Rosgen, 1996). "E" type streams classified down to channel material and slope resulted in one "E4" and one "E5."

Table 1.2: Surveyed USGS Gage Station ID, Station Name, channel geometry, water surface slope, mean channel material, and stream type.

Station ID	Name	Single Thread Channel	Entrenchment Ratio (W_{fpa}/W_{bkf}) ft/ft	Width/Depth Ratio (W_{bkf}/d_{bkf}) ft/ft	Channel Sinuosity (k)	Water Surface Slope (S) ft/ft	Channel Material (D_{50}) mm	Stream Type
04096015	Galien River near Sawyer	x	16.62	13.99	1.19	0.0004	0.2	C5c-
04096340	St. Joseph River at Clarendon	x	2.8	34.25	1.46	0.00033	1	C5c-
04096400	St. Joseph River near Burlington	x	3.28	29.69	1.43	0.0004	0.84	C5c-
04096405	St. Joseph River at Burlington	x	4.46	37.59	1.19	0.0008	21.5	C4c-
04096515	South Branch Hog Creek near Allen	x	7.47	49.65	1.12	0.00025	10.75	C4c-
04096600	Coldwater River near Hodunk	x	3.61	37.1	1.41	0.00219	30.12	C4
04097170	Portage River near Vicksburg	x	3.17	71.65	1.27	0.00046	1.42	C5c-
04097370	Flowerfield Creek at Flowerfield	x	6.95	25.7	1.05	0.00244	0.3	C5
04097540	Prairie River near Nottawa	x	8.44	59.23	1.64	0.00049	0.36	C5c-
04102776	Middle Branch Black River near South Haven	x	8.07	15.59	1.58	0.00065	0.11	C5c-
04103010	Kalamazoo River near Marengo	x	2.82	57.26	1.03	0.00079	1.25	C5c-
04104945	Wanadoga Creek near Battle Creek	x	18.03	46.22	1.28	0.00008	0.1	C5c-
04105700	Augusta Creek near Augusta	x	34.57	16.84	1.38	0.00245	11.77	C4

Table 1.2: (Cont'd)

Station ID	Name	Single Thread Channel	Entrenchment Ratio (W_{fpa}/W_{bkf}) ft/ft	Width/Depth Ratio (W_{bkf}/d_{bkf}) ft/ft	Channel Sinuosity (k)	Water Surface Slope (S) ft/ft	Channel Material (D_{50}) mm	Stream Type
04108600	Rabbit River near Hopkins	x	4.35	15.34	1.86	0.00056	0.33	C5c-
04111379	Red Cedar River near Williamston	x	12.2	17.63	1.23	0.00035	0.38	C5c-
04111500	Deer Creek near Dansville	x	9.19	8.98	1.02	0.00061	0.42	E5
04114498	Looking Glass River near Eagle	x	3.32	28.8	1.21	0.00073	22.12	C4c-
04117500	Thornapple River near Hastings	x	2.41	42.22	1.1	0.00173	34.84	C4
04146063	South Branch Flint River near Columbiaville	x	3.91	29.94	1.61	0.00032	7.08	C4c-
04150500	Cass River at Cass City	x	2.89	27.42	1.09	0.00055	90.77	C3C-
04159900	Mill Creek near Avoca	x	3.57	13.73	1.4	0.00053	21.28	C4c-
04160600	Belle River at Memphis	x	3.34	17.43	1.05	0.00234	12.47	C4
04160800	Sashabaw Creek near Drayton Plains	x	6.26	13.78	1.36	0.00085	5.53	C4c-
04161580	Stony Creek near Romeo	x	13.62	29.27	1.09	0.00482	19.55	C4
04161760	West Branch Stony Creek near Washington	x	11.69	22.31	1.72	0.00503	14.43	C4

Table 1.2: (Cont'd)

Station ID	Name	Single Thread Channel	Entrenchment Ratio (W_{fpa}/W_{bkf}) ft/ft	Width/Depth Ratio (W_{bkf}/d_{bkf}) ft/ft	Channel Sinuosity (k)	Water Surface Slope (S) ft/ft	Channel Material (D_{50}) mm	Stream Type
04164050	North Branch Clinton River near Romeo	x	5.22	38.29	1.3	0.00195	22.6	C4
04164150	North Branch Clinton River near Meade	x	3.31	11.73	1.11	0.00162	11.73	E4
04172500	Portage Creek near Pinckney	x	12.73	13.41	1.27	0.0005	0.5	C5c-
04033000	Middle Branch Ontonagon near Paulding	x	1.48	25.84	1.56	0.00302	25.29	B4c
04040500	Sturgeon River near Sidnaw	x	4.34	37.11	1.46	0.00507	177.64	C3
04046000	Black River near Garnet	x	8.36	18.88	1.4	0.01619	111.53	C3
04060993	Brule River near Florence	x	3.22	35.29	1.02	0.00096	35.9	C4c-
04062200	Peshekee River near Champion	x	3.78	24.08	1.04	0.00182	54.91	C4
04065500	Sturgeon River near Foster City	x	5.47	28.04	1.02	0.00023	0.38	C5c-
04065600	Pine Creek near Iron Mountain	x	6.94	24.76	1.04	0.00116	0.08	C5
04122230	North Branch Pentwater River near Pentwater	x	13.65	27.01	1.3	0.0008	0.1	C5c-
04060500	Iron River at Caspian	x	1.91	15.65	1.04	0.00277	0.78	B5c

Table 1.2: (Cont'd)

Station ID	Name	Single Thread Channel	Entrenchment Ratio (W_{fpa}/W_{bkf}) ft/ft	Width/Depth Ratio (W_{bkf}/d_{bkf}) ft/ft	Channel Sinuosity (k)	Water Surface Slope (S) ft/ft	Channel Material (D_{50}) mm	Stream Type
04123000	Big Sable River near Freesoil	x	8.21	27.19	1.88	0.00088	0.34	C5c-
04124500	East Branch Pine River near Tustin	x	3.27	13.03	1.51	0.00678	36.73	C4
04125460	Pine River near Hoxeyville	x	3.88	19.27	1.37	0.00259	3.5	C4
04128000	Sturgeon River near Wolverine	x	7.4	23.18	1.81	0.00249	33.18	C4
04129500	Pigeon River at Afton	x	2.91	16.84	1.22	0.00318	30.43	C4
04135700	South Branch Au Sable River near Luzerne	x	6.64	39	1.51	0.00155	24.56	C4

Table 1.3: Surveyed USGS Gage Station ID, Station Name, Stream Type, and Valley Type.

Station ID	Name	Stream Type	Valley Type
4033000	Middle Branch Ontonagon near Paulding	B4c	II
4060500	Iron River at Caspian	B5c	II
4040500	Sturgeon River near Sidnaw	C3	V
4046000	Black River near Garnet	C3	V
4150500	Cass River at Cass City	C3c-	VIII
4062200	Peshekee River near Champion	C4	V
4096600	Coldwater River near Hodunk	C4	VIII
4105700	Augusta Creek near Augusta	C4	VIII
4117500	Thornapple River near Hastings	C4	VIII
4124500	East Branch Pine River near Tustin	C4	VIII
4125460	Pine River near Hoxeyville	C4	V
4128000	Sturgeon River near Wolverine	C4	VIII
4129500	Pigeon River at Afton	C4	VIII
4135700	South Branch Au Sable River near Luzerne	C4	VIII
4160600	Belle River at Memphis	C4	VIII
4161580	Stony Creek near Romeo	C4	VIII
4161760	West Branch Stony Creek near Washington	C4	VIII
4164050	North Branch Clinton River near Romeo	C4	VIII
4060993	Brule River near Florence	C4c-	VIII
4096405	St. Joseph River at Burlington	C4c-	VIII
4096515	South Branch Hog Creek near Allen	C4c-	VIII
4114498	Looking Glass River near Eagle	C4c-	VIII
4146063	South Branch Flint River near Columbiaville	C4c-	VIII
4159900	Mill Creek near Avoca	C4c-	VIII
4160800	Sashabaw Creek near Drayton Plains	C4c-	VIII

Table 1.3: (Cont'd)

Station ID	Name	Stream Type	Valley Type
4065600	Pine Creek near Iron Mountain	C5	VIII
4097370	Flowerfield Creek at Flowerfield	C5	VIII
4065500	Sturgeon River near Foster City	C5c-	VIII
4096015	Galien River near Sawyer	C5c-	VIII
4096340	St. Joseph River at Clarendon	C5c-	VIII
4096400	St. Joseph River near Burlington	C5c-	VIII
4097170	Portage River near Vicksburg	C5c-	VIII
4097540	Prairie River near Nottawa	C5c-	VIII
4102776	Middle Branch Black River near South Haven	C5c-	VIII
4103010	Kalamazoo River near Marengo	C5c-	VIII
4104945	Wanadoga Creek near Battle Creek	C5c-	VIII
4108600	Rabbit River near Hopkins	C5c-	VIII
4111379	Red Cedar River near Williamston	C5c-	VIII
4122230	North Branch Pentwater River near Pentwater	C5c-	VIII
4123000	Big Sable River near Freesoil	C5c-	VIII
4172500	Portage Creek near Pinckney	C5c-	VIII
4164150	North Branch Clinton River near Meade	E4	VIII
4111500	Deer Creek near Dansville	E5	VIII

Conclusion and Future Needs:

Classifying Michigan streams utilizing the RCS (1994 and 1996) resulted with the majority (39 out of 43) of the stream reaches surveyed as a "C" stream type with the remaining four as two "B" stream types and two "E" stream types. By classifying Michigan streams on the basis of channel morphology by the RCS

(1994 and 1996) facilitates the ability to understand the present morphologic characterization of the stream. We now have a better indication of what stream types are found in Michigan at reference reach locations at USGS gage stations. The morphological information collected for the RCS (1994 and 1996) stream typing can also be used to estimate the geomorphic characterization of similar stream types located in comparable physiographic regions. The RCS (1994 and 1996) is also based on in-depth analysis of stream morphology that is measurable and quantifiable. This classification can also be used as a consistent frame of reference of stream morphology among a variety of disciplines that manage rivers in Michigan. Communicating by stream types will allow individuals that are familiar with the RCS (1994 and 1996) and that are involved in river management to have a picture of the geomorphic characterization of rivers of particular interest. For instance, when describing a stream as a "C5," in a valley type VIII, it would be recognized that this particular stream was located in a wide, gentle valley slope with a well-developed floodplain that is adjacent to river terraces, channel materials are predominantly sand bed and banks, the slope is less than 2%, the entrenchment ratio or vertical containment of the river is less than 2.2, the width to depth ratio is less than 12, and the pattern or sinuosity of the river is greater than 1.2.

Caution should be used when extrapolating stream type data results from this study to similar stream types in comparable physiographic areas and applied to stream restoration design. It is imperative that stream restoration design is based on field verification of stream geomorphology, the present condition or state of the stream, an assessment of the causes of stream instability, and the use of supporting information to comparable stream types in similar physiographic regions and regional curve data. Stream classification can provide individuals with baseline information about the geomorphology of a stream reach and can be used as an estimate of stream type to equivalent stream reaches in similar physiographic regions.

This study classified Michigan streams to the Rosgen (1996) Level II morphological description classification. In order to have a better understanding of a stream's "state" or condition and to validate field data collected to determine stream condition, this study should be expanded to Level III and IV Rosgen (1996) river inventory. Baseline morphological information has been collected at each site through this study and these sites can be easily transformed into monitoring stations and continually re-surveyed to evaluate morphological conditions/changes over time. These stations can be used to expand river inventory to the RCS (1994 and 1996) Level III and Level IV.

Level III assess' stream condition as it relates to stream stability, potential and behavior beyond the Level II morphological template using 10 additional parameters of; 1) riparian vegetation, 2) streamflow regime, 3) stream size and stream order, 4) organic debris and/or channel blockage, 5) depositional patterns, 6) meander patterns, 7) streambank erosion potential, 8) aggradation/degradation potential, 9) channel stability rating, 10) altered channel materials and dimensions (Rosgen, 1996). The Level III inventory would provide additional information about the current morphological condition of Michigan streams. As stated by Rosgen (1996) the following objectives are met:

1) The development of a quantitative basis for comparing streams having similar morphologies, but which are in different states and conditions.
2) Description of the potential natural stability of a stream, as contrasted with its existing condition.
3) Determination of the departure of a stream's existing condition from a reference baseline.
4) Provision of guidelines for documenting and evaluating additional field parameters that influence stream state (e.g. flow regime, stream size, sediment supply, channel stability, bank stability, bank erodibility, and direct channel disturbances).
5) Provision of framework for integrating companion studies (e.g. fish habitat indices and composition and density of riparian vegetation).
6) Development and refinement of channel stability prediction methods.
7) Provision of the basis for efficient Level IV validation sampling and data analyses.

Level IV of the Rosgen (1996) river inventory is conducted to verify the predicted stream condition, potential, and stability from the Level III inventory (Rosgen, 1996). Parameters based on Level IV are; (1 streamflow measurements, 2) sediment analysis, and 3) verification of stream stability (Rosgen, 1996). Sediment analysis includes determining the ratio of bedload to total load, the bedload size distribution at or near the bankfull discharge, and the development of sediment rating curve relations (Rosgen, 1996). In the field, stream channel monitoring can verify current stream stability by evaluating if the stream is: 1) aggrading, 2) degrading, 3) shifting particle sizes of stream bed materials, 4) changing the rate of lateral extension through accelerated bank erosion, and 5) changing morphological types through evolutionary sequences (Rosgen, 1996). As stated by Rosgen (1996) a comprehensive data collection effort can provide insight into:

1) Causes, rates, magnitude and direction of river adjustment.
2) Effectiveness of mitigation measures.
3) Accuracy of prediction methodologies.
4) Development of effective mitigation/restoration.
5) Validation of prediction models.
6) Development of empirical relations.
7) Consequence of change.
8) An approach to set limits for channel change and corresponding sediment loads.

The information that could be provided by the Rosgen (1996) Level III and IV river inventory would provide valuable information on the condition and the verification of the condition of Michigan streams. This data could also be referenced for similar stream types in comparable physiographical regions in order to predict channel behavior due to the impact of various human induced and natural watershed changes.

The classification of stream types at USGS gage stations through this study is lacking geographically and only has a minor representation of small drainage sizes. A majority of USGS gage stations in Michigan are located at the lower reaches of drainage basins. If this study was expanded to ungaged locations, there is a strong possibility that other stream types could occur, especially, headwater streams located in steeper valleys found in the Upper Peninsula. Geographically, representation in the northeastern part of the Lower

Peninsula and the northwestern part of the Upper Peninsula is minimal. The expansion of stream typing using the RCS (1994 and 1996) to stable ungaged stream reaches would broaden the representation of Michigan stream types in areas that were not surveyed in this study. Smaller drainage areas were also not represented in this study since it was limited to available USGS gage stations for the regional curve development. The smallest drainage area represented in this study was 16.3 square miles. The expansion of stream typing using the RCS (1994 and 1996) to smaller drainage basins would broaden representation of stream type information in smaller and/or headwater Michigan streams.

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