ESTIMATING BEDLOAD SEDIMENT DELIVERY TO THE GREAT LAKES FROM SIXTY MICHIGAN RIVERS

by

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DISSERTATION

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DEDICATION

This dissertation is dedicated to my amazing wife Cynthia, and to my wonderful children Timothy, Catherine, and Anna for supporting and motivating me, as well as my parents Mary Ann and John William Barkach who instilled in me the value of hard work and academic achievement. This research required long hours and many weekends to complete, and through it all, Cynthia, Timothy, Catherine and Anna provided tremendous support and patience to help me complete this academic journey. Thank you!

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I would like to express my gratitude and thanks to my advisor Dr. Carol Miller for supporting this research, and providing guidance and encouragement to complete this work. Dr. Miller's knowledge of open channel hydraulics and reservoir sedimentation were instrumental in this research. In addition, I would like to acknowledge Dr. James Selegean, U.S. Army Corps of Engineers for his guidance, knowledge of sediment transport, and facilitating access to the extensive dredging data and other resources at the USACE Detroit District. Emily Bradley, USACE completed the Geographic Information System analysis of the 60 Michigan watersheds and five sub-watersheds that are summarized in the Appendices. Dr. James Syvitski, University of Colorado was especially helpful in providing data and answering questions regarding estimation of watershed sediment delivery using the BQART equation and other methods. Dr. Mark Baskaran, WSU was instrumental in the re-evaluation of the ^{137}Cs and ^{210}Pb radiometric data to select the sediment cores that were used to estimate sediment deposition rates within the associated reservoirs of the five sub-watersheds. Luke Trumble, EGLE Dam Safety Unit answered questions and provided an updated inventory of dams located in Michigan. In addition, I acknowledge the extensive support provided by Susan Greiner, PE, Michigan Department of Environment, Great Lakes, and Energy, and Dr. Marlio Lesmez, PE, EGLE of Hydrologic Studies and Dam Safety Unit who completed the mean annual river flow and exceedance flow calculations for all 60 watersheds and five sub-watersheds, and the contributing watershed areas for 45 of the 60 watersheds.

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CHAPTER 1 INTRODUCTION

1.1 Watershed Sediment Delivery to the River Outlet

Watershed sediment delivery is the total amount of sediment generated within a watershed and delivered to the river outlet over a particular timeframe. Estimation of watershed sediment delivery involves an understanding of the complex processes of soil erosion, sediment transport, and sediment deposition (Borah et al, 2008; Creech C et al, 2010; Garcia, 2008; Gray and Simoes, 2008; MacArthur et al, 2008; Milliman and Farnsworth, 2011; Sommerlot et al, 2013; Alighalehbabakhani et al, 2017a; and, USACE, 1995 and 2008).

Soil erosion at the watershed scale involves transport of sediment entrained in overland surface water flow to the river system as well as erosion of the bed and banks of the river (formation of gullies, river bank failure, and mass wasting). As water and sediment move from higher elevations to a lower elevations, energy is released and a river dissipates this energy by performing work on the channel (erosion and deposition; see Figure 1) and by movement of sediment entrained in water (Bagnold RA, 1977; Morisawa 1968; Brooks et al., 2013; UNESCO, 2013). The transport of sediment by water forms the bed and banks of the river, and changes the slope of the river through aggradation (raising of the river bed) and degradation (deepening of the river bed). Sediment depositional areas (e.g. sinks) within the watershed include sediment deposited onto floodplains and in the bed and banks of the river, upland and aquatic wetlands, as well as sediment deposited in natural lakes and manmade reservoirs that trap sediment before it reaches the river outlet (Biedenharn et al., 2008; Cohen et al., 2014; FISRWG, 1998: Foster et al., 1981; Gray and Simoes, 2008; USACE, 2008).

Figure 1. Examples of Deposition and Erosion Within a Fluvial System, Two Hearted River (61) (Google Earth Pro, 2021)

Estimation of watershed sediment delivery integrates the effects of river flow, topography, surficial geology, and land use. Excessive sedimentation has significant economic impacts and is a leading stressor of biological communities that inhabit these waterways (Charlton R, 2008; MacArthur et al, 2008; Smith et al., 2015). The effects of excessive sedimentation include habitat degradation and corresponding changes to the biological communities and spawning habitats (Yang CT, 2006; MDEQ, 2008). An example of sediment discharge from Grand River (14) to Lake Michigan following a large storm event is shown in Figure 2.

Figure 2. Aerial Photograph of the Outlet of the Grand River (14) at Lake Michigan Following a Large Storm Event, April 22nd, 2013 (Beaver M, 2013)

With respect to economic impact, damage to infrastructure due to excessive erosion and sedimentation is well documented (MacArthur et al, 2008; USACE, 1995; USACE, 2015). Excessive erosion along river banks and downcutting of the river bed can damage roads, sewers, bridges, buildings, and other infrastructure. Aside from the effects on biological communities, excessive sedimentation can significantly reduce reservoir capacity and affect the water quality of rivers and impoundments (USACE, 1995; Yang CT, 2006; Alighalehbabakhani et al., 2017b). Another economic impact of watershed sediment delivery includes the physical loss of top soil due to erosion which can adversely affect soil fertility and lead to an increase in fertilizer use (and increased agricultural expense), potentially degrading the water quality of nearby streams and rivers (Montgomery DR, 2012; Ritter J, 2015; Trimble and Lund, 1982).

From 1986 to 2013, USACE Great Lakes maintenance dredging of federal navigation channels averaged approximately 2.4 million cubic meters of sediment each year; however, sediment is accumulating in the navigational channels and harbors faster than the sediment is removed resulting in a growing dredging backlog (USACE, 2014; see Figure 3). The estimated Fiscal Year 2021 navigational dredging costs in the Great Lakes are $48,620,000 for maintenance dredging of 2,821,000 cubic meters (3,690,000 cubic yards) of sediment (USACE, 2021). In addition, the Fiscal Year 2021 USACE Great Lakes appropriation includes $9,930,000 to perform condition assessments (bathymetric surveys) to determine the amount of sediment that has accumulated in the navigation channel and harbor that requires maintenance dredging to maintain the project depth (USACE, 2021). As of October 2020, the dredging backlog for these 30 USACE-Detroit District maintained harbors and navigational channels totals 2,514,341 cubic meters (3,288,634 cubic yards) of sediment.

The USACE-Detroit District maintains 94 harbors and navigation channels within the Great Lakes watershed. Of the 60 Michigan rivers included in this research, 30 of these rivers discharge to USACE-Detroit District maintained harbors or navigation channels (see Figure 4). Estimation of bedload sediment delivery to the river outlet of these 60 Michigan watersheds and five sub-watersheds is the subject of this research.

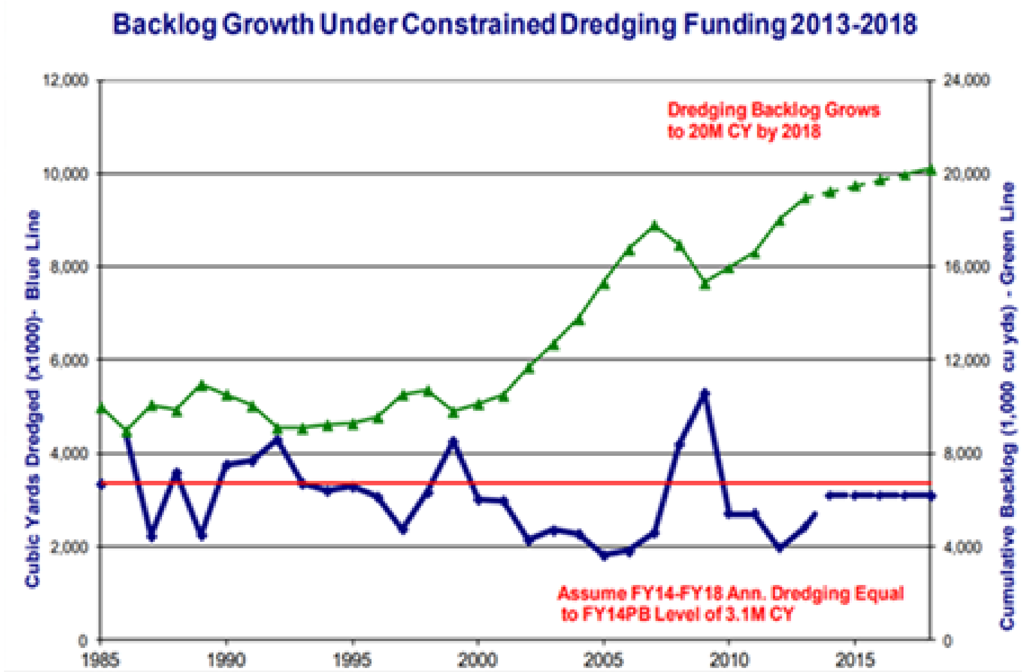
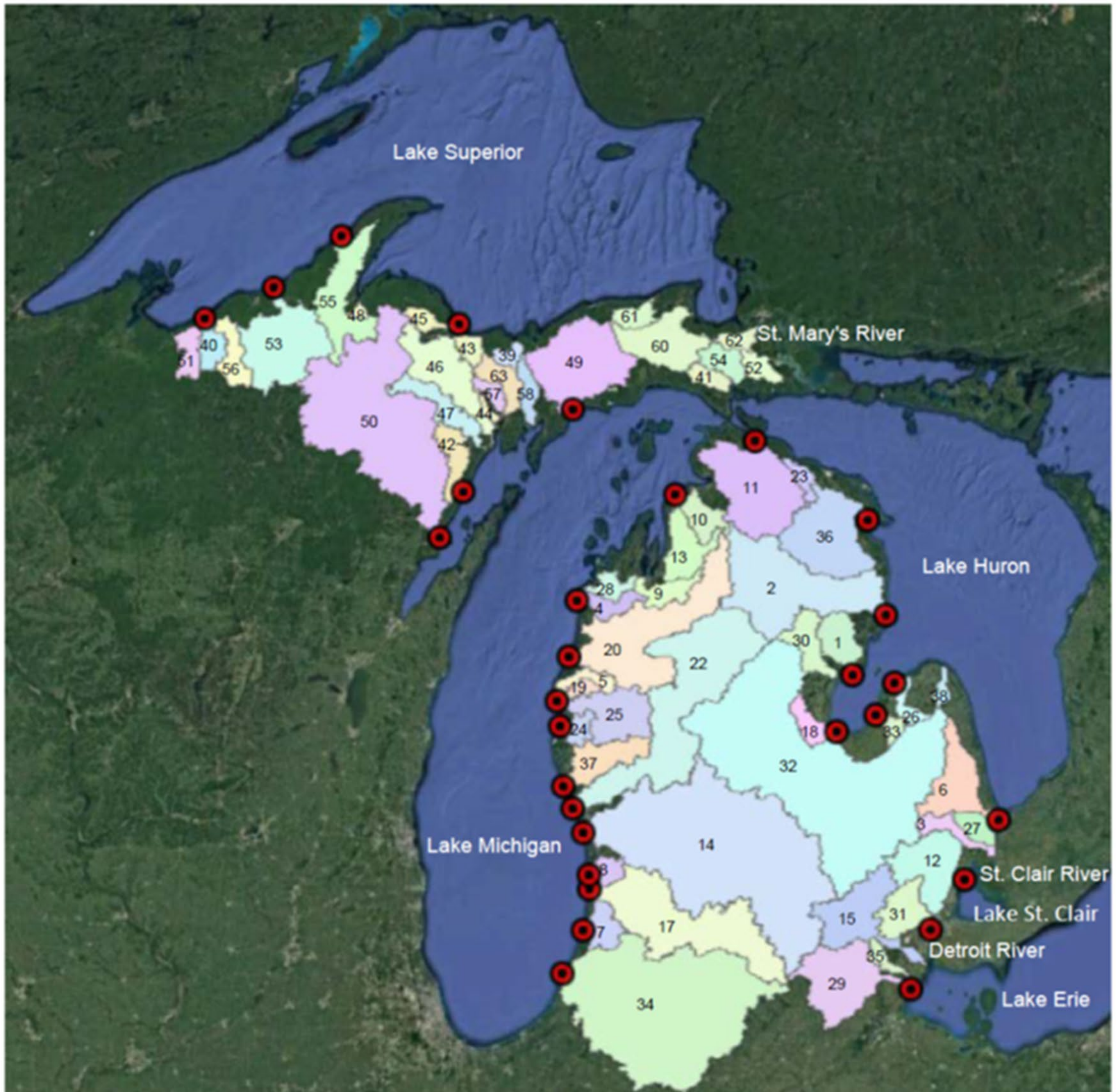


Figure 3. Sediment Dredging Backlog Under Constrained Dredging Funding 2013-2018 (USACE, 2014)

1.2 Hypothesis

If an empirical equation can be developed as a statistical model to describe the relationship between bedload watershed sediment delivery to the river outlet and significant watershed characteristics, then bedload watershed sediment delivery can be reliably predicted as a function of the characteristics of the watershed. Characteristics of the watershed include: watershed area; the mean annual flow and/or recurrence interval flows of the river draining the watershed at the river outlet; characteristics of the watershed such as land use as expressed by the watershed Runoff Curve Number and the average and maximum elevation of the watershed relative to the receiving water elevation; and the percentage of the watershed covered in depositional areas such as natural surface water bodies, aquatic and upland wetlands, and manmade dams and associated reservoirs located within the watershed.



Watershed Reference Number	River	U.S. Army Corps of Engineers Harbor or Navigation Channel
1	Au Gres River	Point Lookout Harbor
2	Au Sable River	Au Sable Harbor
3	Belle River	NA
4	Betsie River	Frankfort Harbor
5	Big Sable	NA
6	Black River (East)	Black River
7	Black River (West)	South Haven Harbor
8	Macatawa River	Holland Harbor
9	Boardman	NA
10	Pine River	Charlevoix Harbor
11	Cheboygan River	Cheboygan Harbor
12	Clinton River	Clinton River
13	Elk River	NA
14	Grand River	Grand Haven Harbor
15	Huron River	NA
17	Kalamazoo River	Saugatuch Harbor
18	Kawkawlin River	NA
19	Lincoln River	NA
20	Manistee River	Manistee Harbor
22	Muskegon River	Muskegon Harbor
23	Oqueoc River	NA
24	Pentwater River	Pentwater Harbor
25	Pere Marquette River	Ludington Harbor
26	Pigeon River	Caseville Harbor
27	Pine River	NA
28	Platte River	NA
29	River Raisin	Monroe Harbor
30	Rifle River	NA
31	Rouge River	Rouge River
32	Saginaw River	Saginaw River
33	Sebewaing River	Sebewaing River
34	St. Joseph River	St. Joseph Harbor
35	Stoney Creek	NA
36	Thunder Bay River	Alpena Harbor
37	White River	White Lake Harbor
38	Willow Creek	NA
39	Au Train	NA
40	Black River (Gogebic)	Black River Harbor
41	Carp River	NA
42	Cedar River	Cedar River Harbor
43	Chocolay River	NA
44	Days River	NA
45	Dead River	Presque Isle Harbor
46	Escanaba River	NA
47	Ford River	NA
48	Falls River	NA
49	Manistique River	Manistique Harbor
50	Menominee River	Menominee Harbor
51	Montreal River	NA
52	Munuscong River	NA
53	Ontonagon River	Ontonagon Harbor
54	Pine River	NA
55	Portage River	Keweenaw Waterway
56	Presque Isle River	NA
57	Rapid River	NA
58	Sturgeon River	NA
60	Tahquamenon River	NA
61	Two Hearted River	NA
62	Waiska River	NA
63	Whitefish River	NA

Notes: [icon] - USACE Maintained Harbor or Navigation Channel; NA – not applicable. Google Earth Image: Data SIO/NOAA/US Navy; NOAA 2018, Image Landsat/Copernicus.

Figure 4. Location of 60 Michigan Watersheds and Associated USACE Harbors

CHAPTER 2 LITERATURE REVIEW

2.1 Overview of Sediment Transport, Dissolved Load, Wash Load, and Bed Material Load

The field of sediment transport might just as well be called “transport of granular particles by fluids,” and embodies a type of two-phase flow, in which one phase is fluid (river water) and the other phase is a solid, e.g. sediment (Garcia MH, 2008). The rivers that drain each watershed transport sediment. River discharge (Q; cubic meters/second) is calculated using the Continuity Equation as follows:

$$Q = U \times A \tag{1}$$

where,

U = water velocity (meter/second)

A = cross-sectional area of the river perpendicular to flow (square meter)

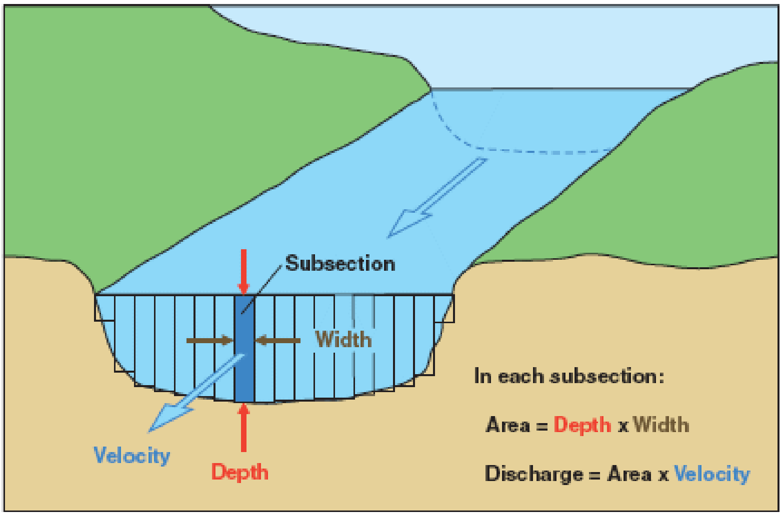


Figure 5. Diagram of Channel Cross-Section (USGS, 2016)

As shown in Figure 5, total river discharge (Q) is calculated by measuring current velocity (U) in each channel subsection and integrating over the subsection areas (Area, A) to obtain total discharge (Q). In steady, turbulent, uniform, open-channel flow, a river is characterized using the following measurements (Garcia MH, 2008; USDA, 2007): mean flow depth (H; meters), mean flow velocity (U; meters/second), river width (B; meters), water surface slope (S; meter/meter), and a river bottom surface roughness that has an effective height of k_s (meter). For very wide river channels (B/H >> 1), the hydraulic radius of the river (R_h; cross-sectional area/wetted perimeter) approximates the mean flow depth (H).

The river channel is covered with sediment having a mean size or diameter (D; meter) and the roughness height (k_s) will be proportional to this diameter. Due to the weight of the water and the slope of the channel, the river flow exerts on the river bottom a tangential force per unit bed area known as the bed shear stress (T_b), which in the case of steady, uniform flow can be expressed as:

Bed Shear Stress, $T_b = (\Upsilon)(R_h)(S)$ (2)

where,

Υ = specific weight of water (998 kilograms/cubic meters)

R_h = hydraulic radius (meter)

S = slope of energy grade line or water surface (meter/meter)

Υ = specific weight of water = $(\rho)(g)$

ρ = water density

g = acceleration due to gravity

Bed shear stress has units of force (kilograms/square meter) and is used to evaluate sediment movement (incipient motion) and the particle size of the sediment that can be moved by a river at a certain stage (water depth). When breaking this force into components, the component in the downstream direction is the force that moves sediment (bed shear stress); the deeper the water (e.g. the larger the hydraulic radius, R), the greater the bed shear stress (see Figure 6).

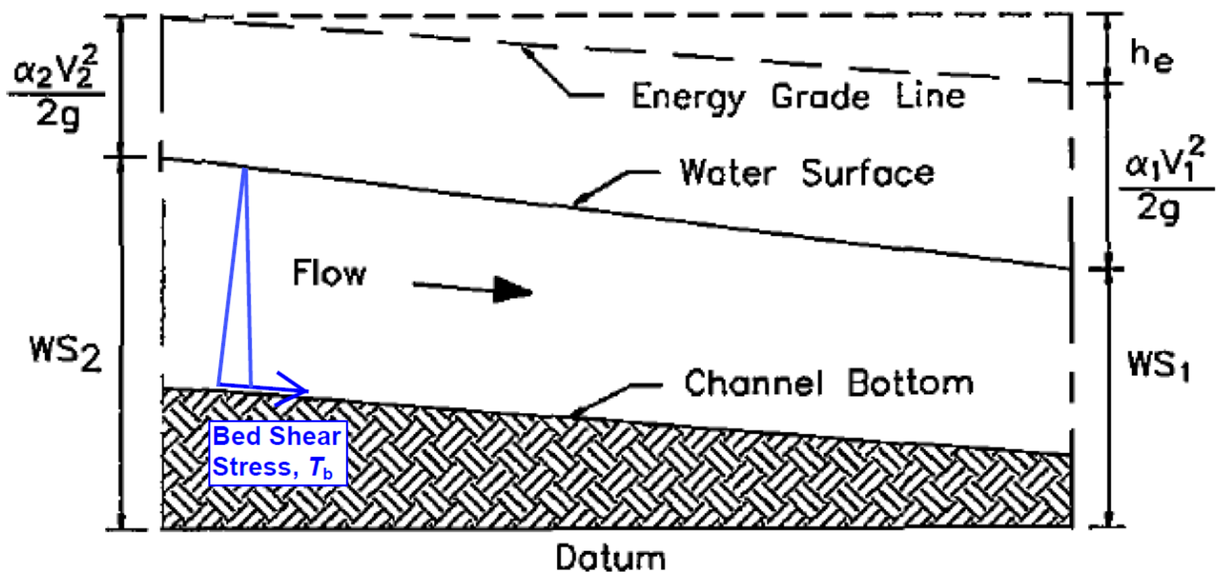


Figure 6. Bed Shear Stress (Figure 2.1, USACE, 1993)

In the case of steady, uniform flow, shear stress (T) varies with depth of water above the river bottom (z), and is given as follows:

$$T = T_b (1 - z/H) \quad (3)$$

As shown in Figure 6, shear stress (T) is greatest near the river bottom and decreases toward the surface of the river. The depth-wise variation in shear stress and shear velocity help explain the vertical distribution of suspended sediment in open channel flow. Bed shear stress is used to determine if sediment of a certain particle size can be set in motion by a river with a given slope and depth (USDA, 2007; McCuen, 2004; Garcia MH, 2008). Shear velocity (V_s) helps lift sediment particles as the water velocity increases as the water accelerates over the top of the particle.

$$V_S = \sqrt{gR_hS} \qquad (4)$$

g = acceleration due to gravity (9.81 meters/second squared)

R_h = hydraulic radius (meter)

S = slope of energy grade line/water surface (meter/meter)

Shear velocity (V_s) provides a direct measure of the flow intensity, and a river's ability to entrain and transport sediment particles (USDA, 2007; Garcia MH, 2008). The size of the sediment particles on the river bottom determines the surface roughness (k_s), which in turn affects the flow velocity distribution and sediment transport rate. Shear velocity creates turbulence on the downstream side of the sediment particle; depending on sediment particle size and shape, this mechanism can cause sediment particles to roll, slide, saltate (bed load), or become suspended in the water column (suspended load).

The total sediment load transported by a river to the river outlet consists of dissolved load, wash load, and bed material load (USACE, 1995; Garcia MH, 2008, Gray JR and Simoes JM, 2008; USDA, 2007):

Dissolved Load: Material dissolved in a river may constitute a large portion of the total load, but it is of no geomorphic significance but may be biologically significant.

Wash Load: Material not found in the river bed in any appreciable significance; diameter d_5 (5% of the bed material is finer) and usually consists of clays and fine silts. Wash load can remain suspended for long periods of time even at very low flow rates. Wash load is kept in suspension by Brownian motion.

Bed Material Load: Bed material load is all of the material found in appreciable quantities in the bed and banks of a river (d_5 to d_{100}). Bed material load consists of bed load and suspended load and is the only material of geomorphic significance. Bed material load is typically assumed to be approximately 10% bed load and 90% suspended load, however these percentages can vary widely (USGS, 2011).

Suspended Load: The portion of the bed material load that is lifted by turbulence to travel within the water column at elevations above the bed greater than a few sediment grain diameters.

Bed Load: The portion of the bed material load that travels within a few grain diameters of the bed and moving slower than the flow of the river. Bed load moves by rolling, sliding, and saltating along the bed of the river. Typically, bedload represents 5–20 percent of the total load carried by a river (USGS, 2011).

In a truly alluvial river, the bed and banks of the river consist of bed material load. However, in the Great Lakes watershed, alluvial rivers are nearly non-existent because they are geologically very young. The most recent glacial event, the Wisconsin glaciation, ended between 11,000 to 14,000 years ago (Flint RF, 1971). There has not been enough time for the rivers of the Great Lakes watersheds to meander back and forth, to create truly alluvial rivers where the bed and banks consist of bed material load. Many sediment transport equations assume that the river is alluvial (Garcia MH, 2008; Mehta AJ and McAnally WH, 2008; Parker G, 2008; USDA, 2007).

2.2 Bankfull River Flow

Bankfull stage is a very important concept in the assessment of watershed sediment transport. Bankfull stage is the elevation where the river spills into the flood plain and is a relief valve for the river (USACE, 1995; USDA, 2007). At bankfull stage, the bed shear force is greatest, and the river performs the most work (e.g. moves the most sediment; see Figure 7). If the river cannot spread out onto the flood plain to release energy, the river may incise (downcut erosion) and de-stabilize banks (bank failure or mass wasting). The frequency of bankfull within a river system varies, but the recurrence interval typically ranges from 1.5 to 2.0 years (Biedenharn et al, 2008).

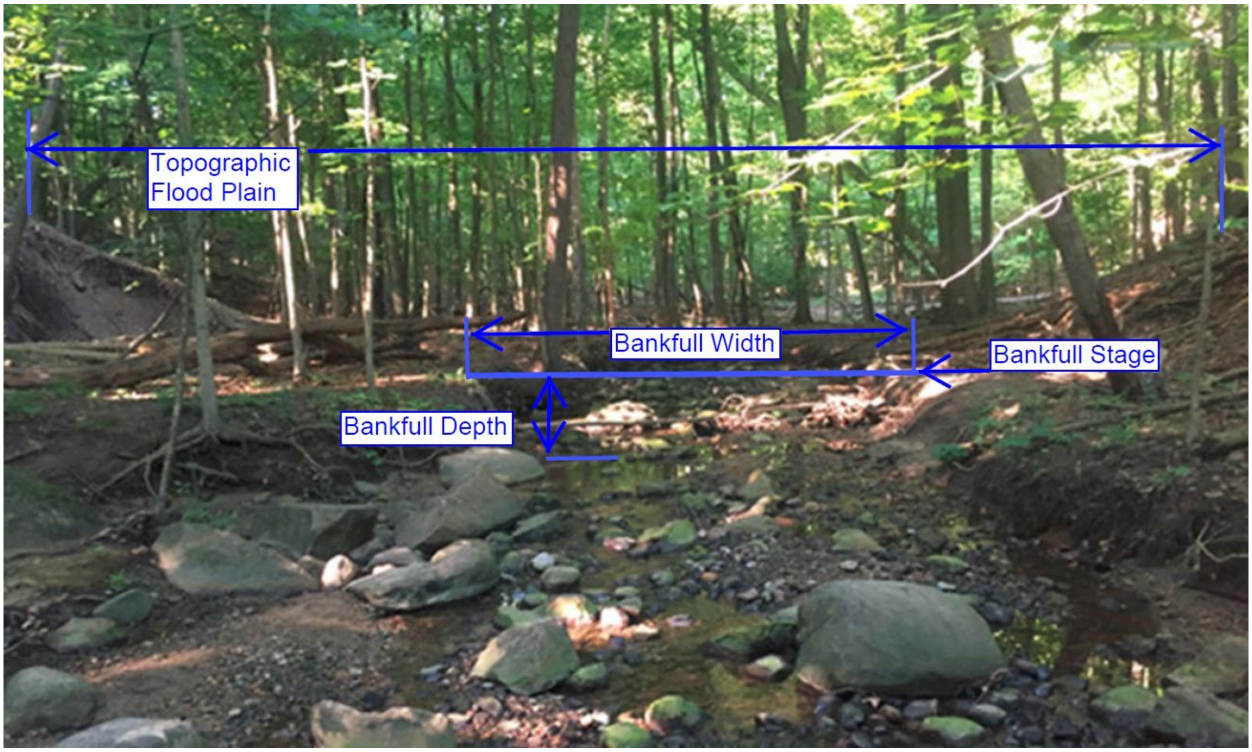


Figure 7. Example of Bankfull Stage, Upper Rouge River

2.3 Watershed Sediment Delivery Equations

Initial research was conducted to compare empirical watershed sediment delivery estimates using two fundamentally different approaches (Barkach JH et al, 2020): the 2010 Great Lakes regional trend line that was developed by the USACE (USACE, 2010a; Creech et al, 2010) and the global BQART sediment delivery equation that was developed Syvitski and Milliman (2007; see Section 2.6). Note that Sections 2.3 to 2.7 discuss the application and comparison of the Syvitski and Milliman Global BQART equation to the USACE (2010a) Great Lakes regional trend line for 60 Michigan Rivers as presented in Barkach JH et al (2020). Insights regarding the river and basin characteristics that primarily affect watershed sediment delivery to the river outlet were developed by comparing the watershed sediment delivery estimates using the global BQART equation and USACE (2010) Great Lakes regional trend line (Barkach JH et al, 2020).

The USACE (2010) Great Lakes regional trend line is based on 61 watershed sediment delivery estimates that are located within Great Lakes basin and served as the basis of comparison with respect to the global BQART watershed sediment delivery estimates. In addition, for six of these 60 watersheds, the global BQART equation and the USACE Great Lakes regional trend line were compared to watershed sediment delivery estimates that were prepared by the USACE using complex, calibrated hydrodynamic and sediment delivery models.

Watershed sediment delivery equations have often been developed for application at much larger watershed scales than those represented by these 60 Michigan watersheds (Syvitski, 2002; Syvitski and Milliman, 2007; Cohen et al., 2011; and, Cohen et al., 2014). For example, the Syvitski and Milliman (2007) BQART equation was developed from a database of 488 global rivers whose watersheds cover 63% of the earth's surface. The global BQART equation was validated for rivers that have mean annual flows greater than 30 cubic meters/second (Cohen et al, 2011; Syvitski JPM, 2019). The average annual flow rate of the Michigan rivers included in this research is 22 cubic meters/second, and range in size from 1.0 cubic meters/second (Days River; 44) to 132.5 cubic meters/second (St. Joseph River; 34).

2.4 USACE Watershed Models to Estimate Sediment Delivery

Calibrated hydrologic and watershed sediment delivery models were developed by the USACE under the Great Lakes Tributary Model (GLTM) program that was established through Section 516(e) of the Water Resources Development Act of 1996. These comprehensive USACE 516(e) studies were completed on six of the 60 Michigan watersheds included in this research. These watershed sediment delivery estimates were prepared in conjunction with the Great Lakes Tributary Modeling Program (516(e); USACE, 2008) and include:

- Saginaw River watershed (USACE, 1999 and 2000)
- Clinton River watershed (USACE, 2005)
- St. Joseph River watershed (USACE, 2007a)
- Grand River watershed (USACE, 2007b)
- Sebewaing River watershed (USACE, 2007c)
- Ontonagon River watershed (USACE, 2010a)

Watershed models were used by the USACE to simulate short-term (individual storm events) and long-term (historical) changes in a watershed by estimating upland soil and stream erosion, hydrologic conditions, and transport and deposition of sediment. These models are comprehensive and data intensive tools some of which can also be used simulate chemical mixing in water; these models are also called nonpoint source pollution models because they simulate surface water pollutants, including sediment, nutrients, pesticides, and other chemicals, originating from nonpoint or diffused sources (Borah DK et al, 2008; USACE, 2008).

The watershed models that have been used by the USACE and others to predict sediment delivery are complex and require extensive data regarding the hydrologic conditions of the watershed, as well as detailed data regarding soil erosion, sediment transport, and sediment deposition processes. As with all models, the reliability and accuracy of the input data directly affect the reliability and accuracy of the watershed sediment delivery (output) estimated using models. For this reason, model calibration of the hydrologic conditions was completed by the USACE for each of these six watersheds (USACE, 2008; Riedel et al., 2010).

2.5 Estimates of Watershed Sediment Delivery Using the USACE 2010 Great Lakes Regional Trend Line

The USACE 2010 Great Lakes regional trend line (USACE, 2010; Creech et al, 2010) is based on sediment delivery estimates from 61 watersheds located throughout the Great Lakes basin, these include 13 USACE 516(e) models and 48 Great Lakes reservoirs from the Subcommittee on Sedimentation Reservoir Sedimentation (RESSED) database (USGS, 2014). Using these data, the USACE (2010) developed an area-based watershed sediment delivery regression equation for the Great Lakes watershed where:

$$Q_s = 177.6A^{0.77} \qquad (5)$$

where,

Q_s = Watershed Sediment Delivery (metric tonnes/year)

A = Watershed Area (square kilometers)

The USACE (2010) Great Lakes regional trend line is an empirical equation, and as such, is most applicable to estimating watershed sediment delivery within the Great Lakes basin (see Figure 8). Note that Equation 5 is presented as a function of watershed area (square kilometers) and watershed sediment delivery (metric tonnes/year).

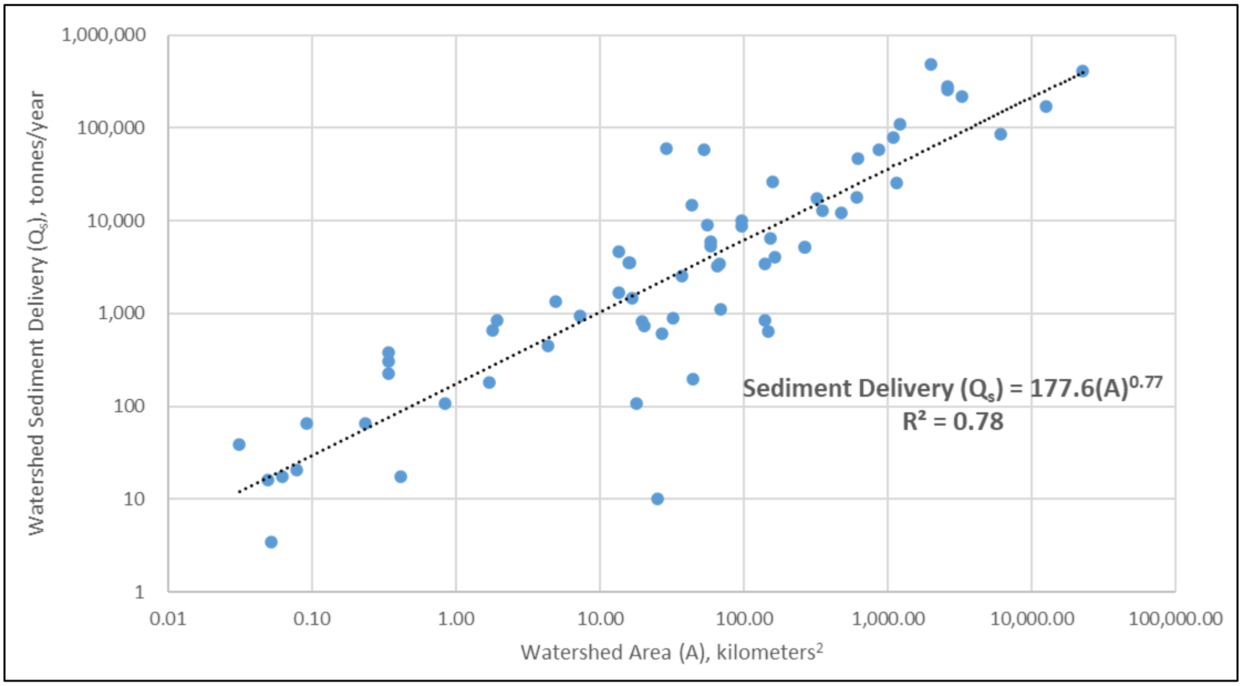


Figure 8. Annual Watershed Sediment Delivery to River Outlet, USACE (2010) Great Lakes Regional Trend Line (Barkach JH, 2020)

With respect to the USACE (2010) Great Lakes regional trend line, the high correlation between watershed area and watershed sediment delivery (R^2=0.78) appears to be reflected in the high correlation (R^2=0.95) between watershed area and mean annual river flow for the 60 watersheds included in this research (Barkach JH et al, 2020).

2.6 Estimates of Watershed Sediment Delivery Using the Syvitski and Milliman (2007) BQART Equation

Given the extensive data and computational requirements of calibrated hydrodynamic and watershed sediment delivery models (USACE, 2010; Riedel et al., 2010), a number of empirical models have been developed based on observations of watershed sediment delivery and watershed characteristics (Schumm and Hadley, 1961:

Wilson, 1973; Milliman 1980, Milliman and Meade, 1983; Milliman and Syvitski, 1992; Mulder and Syvitski, 1996).

Milliman and Syvitski (1992) demonstrated a strong correlation (R^2 ranging from 0.70 to 0.82) between watershed sediment delivery (Q_s; millions of metric tonnes of sediment/year; MT/yr) and basin area (A; square kilometers) using a global database of 275 rivers. Mulder and Syvitski (1996) observed that when watersheds with significant human impacts were removed, the correlation coefficient improved. Further, Mulder and Syvitski (1996) noted the importance of surficial geology on watershed sediment delivery where watersheds comprised of softer sedimentary rocks and unconsolidated soils demonstrated much larger sediment delivery than those underlain by metamorphic and igneous rocks. The importance of surficial geology on watershed sediment delivery at the river outlet has been studied by many authors (Striffler, 1963; Bent, 1970; Bent, 1971, Thomas and Beson, 1975; USGS, 1984a; Pinet and Souriau, 1988; Probst and Suchet, 1992; Hicks et al., 1996; Ludwig and Probst, 1998; Inman and Jenkins, 1999; Kapsimalis et al. 2005).

One of Milliman and Syvitski's (1992) contributions was evaluating rivers regardless of size based on relief classes (Syvitski and Milliman, 2007). Relief (R) represents the maximum watershed elevation minus the elevation of the receiving water. Mulder and Syvitski's (1996) multi-regression analysis established a relationship between watershed sediment delivery, watershed area, and maximum watershed relief. Syvitski and Milliman (2007) developed the BQART equation using a database of 488 global rivers whose watersheds encompass 63% of the earth's land surface. The BQART equation estimates annual suspended sediment load that will discharge to a receiving water body at mean annual river flow. Syvitski and Milliman (2007) developed two equations, one equation for watersheds where the annual mean basin temperature is greater than 2 degrees Centigrade (C) and a second equation for watersheds with an annual mean basin temperature <2°C. The 60 rivers and five sub-watersheds evaluated in this research have mean basin temperatures >2°C, the Syvitski and Milliman (2007) BQART equation for watersheds with annual mean basin temperatures >2°C follows:

$$Q_s = wBQ^{0.31}A^{0.5}RT \qquad (6)$$

where,

Q_s = watershed sediment delivery, millions of metric tonnes (MT) per year

w = 0.0006 for units of million metric tonnes/year (MT/yr)

B = geologic and human influence factor, calculated value

Q = mean annual river flow, cubic kilometers/year

A = watershed area, square kilometers

R = relief, kilometers

T = mean basin temperature, °C

The variable B of the BQART equation accounts for characteristics of the watershed and human influence. Characteristics of the watershed include the glacial erosion factor (I), an average basin-wide lithology factor (L), and the sediment trapping efficiency (T_e) of lakes and man-made reservoirs (Syvitski and Milliman, 2007). The human-influenced soil erosion factor (E_h) addresses anthropogenic factors that affect sediment delivery to rivers draining watersheds such as agricultural practices, urbanization, and deforestation among others (Syvitski and Milliman, 2007). The variable B is calculated as follows (Syvitski and Milliman, 2007):

$$B = IL\,(1-T_e)E_h \qquad (7)$$

where:

L = basin-wide lithology factor (see Figure 5 of Syvitski and Milliman, 2007)

T_e = sediment trapping efficiency of dams and lakes within the watershed

E_h = human influence soil erosion factor (see Figure 7 of Syvitski and Milliman, 2007)

I = glacial erosion factor, where

$I = (1 + 0.09\ A_g)$,

A_g = area of the drainage watershed with ice cover as a percentage of the total drainage area of the watershed

Syvitski and Milliman (2007) found that watershed sediment delivery to the world's oceans was most affected by geological parameters (65%: watershed area, maximum relief, surficial geology, and ice cover), climatic factors (14%: precipitation and temperature), and anthropogenic factors (16%: reservoir sedimentation and population density).

The basin-wide lithology factor (L) addresses surficial geology and the impact on watershed sediment delivery. Watersheds composed of soft rock and unconsolidated sediments deliver more sediment to rivers then watersheds underlain by igneous and metamorphic rocks. Syvitski and Milliman (2007) utilized six basin-wide lithology classes ranging from basins composed of hard igneous or high-grade metamorphic rocks (L=0.5) to basins underlain by exceptionally erodible materials such as loess (L=3). A basin-wide lithology factor L=2 is reserved for basins draining a significant proportion of sedimentary rocks, unconsolidated sedimentary cover, and alluvial deposits (Syvitski and Milliman, 2007). The 60 watersheds addressed in this research are underlain by unconsolidated glacial deposits including glacial outwash plains, glacial till, ice contact and lacustrine deposits; for this reason, a basin-wide lithology factor L=2 was utilized (Barkach JH, 2020).

Natural lakes and manmade reservoirs trap sediment before the sediment can reach the river outlet. The effect of an individual dam on watershed sediment yield is a function of the amount of water entering the lake or reservoir, the hydraulic capacity of the lake or reservoir and the resulting hydraulic retention time, the geometry of the surface water body, and the size of the suspended sediment and bedload among other factors (USACE, 1995; Morris et al, 2008; Alighalehbabakhani et al, 2017a). With respect to Michigan, the 60 watersheds included in this research contain 2,345 dams located within these 60 watersheds. In the Great Lakes region, the small dams are often located in the edges of the watershed where relief is greatest (near glacial moraines and outwash deposits) in contrast to the large dams that are typically located in series along the main stems of the larger rivers. Vorosmarty et al. (2003) developed equations to predict basin-wide sediment trapping efficiency, however the effect of multiple manmade reservoirs and natural lakes on watershed sediment delivery is difficult to predict. Due to the inherent challenge of calculating a basin specific trapping efficiency (T_e), the average ($1-T_e$) value in Syvitski and Milliman's (2007) global database of 488 rivers (0.8) was used for this research (Barkach JH et al, 2020).

The human influenced soil erosion factor (E_h) addresses anthropogenic factors such as urbanization, deforestation, agricultural practices, and mining activities which can increase watershed sediment delivery to a river outlet (Syvitski and Milliman, 2007). According to Syvitski and Milliman (2007), an E_h of 0.3 is used for high-density populations of greater than 200 people/square kiolometer and a per capita income of >$15,000/year. An E_h of 1 is used for basins with a low human footprint (population <50/square kilometer). An E_h of 2.0 was used for watersheds with population density (PD) >200/square kilometer but per capita income is low <$1,000/year. With respect to Michigan, all 83 counties have a per capita income greater than >$15,000/year based on the 2010 United States Census Data. Population densities were calculated for each of the 60 watersheds and the human influenced soil erosion factor was varied by population density using the Syvitski and Milliman (2007) values described previously. With respect to the 60 watersheds, the human influence soil erosion factor (E_h) was set to 1 for all watersheds with exception of watersheds with high population densities (>200/square kilometer) where E_h was set to 0.3 including the Macatawa River (PD 256/ square kilometer), the Rouge River (PD 1,087/square kilometer), the Clinton River (PD 696/ square kilometer), and the Huron River (PD 260/square kilometer).

With respect to the BQART equation, the glacial erosion factor (I) ranges from 1 (0% ice cover) to 10 (100% ice cover). Since there are no glaciers in Michigan, the glacial erosion factor was set to I=1 representing 0% ice cover (Syvitski and Milliman, 2007).

2.7 Comparison of the Watershed Sediment Delivery Estimates Using the USACE (2010) Great Lakes Regional Trendline and the Syvitski and Milliman (2007) BQART Equation

Of the 60 rivers evaluated, the global BQART equation predicts on average 19% less sediment delivery to the river outlet in comparison to the USACE (2010) Great Lakes regional trend line (Barkach JH et al, 2020). In Figure 9, watershed sediment delivery estimates using the global BQART equation are compared graphically to the USACE (2010) Great Lakes regional trend line. Both a regression line and a 1:1 line is shown in Figure 9 . The equation of the regression line is:

$$y = 1.1909x - 8855.8 \qquad R^2 = 0.87 \qquad (8)$$

where,

y = watershed sediment delivery, global BQART equation, metric tonnes/year

x = watershed sediment delivery, USACE Great Lakes regional trend line, metric tonnes/year

. The slope of the regression equation of 1.1909 is reflected in the average difference (-19%) between the global BQART equation and the USACE (2010) Great Lakes regional trend line and is also apparent in comparison to the 1:1 line that is shown in Figure 9. The noted R^2 value of 0.87 of the regression line demonstrates the strong correlation between these two methods of estimating watershed sediment delivery to the river outlet. Overall, the global BQART sediment delivery estimates are within 25% of the

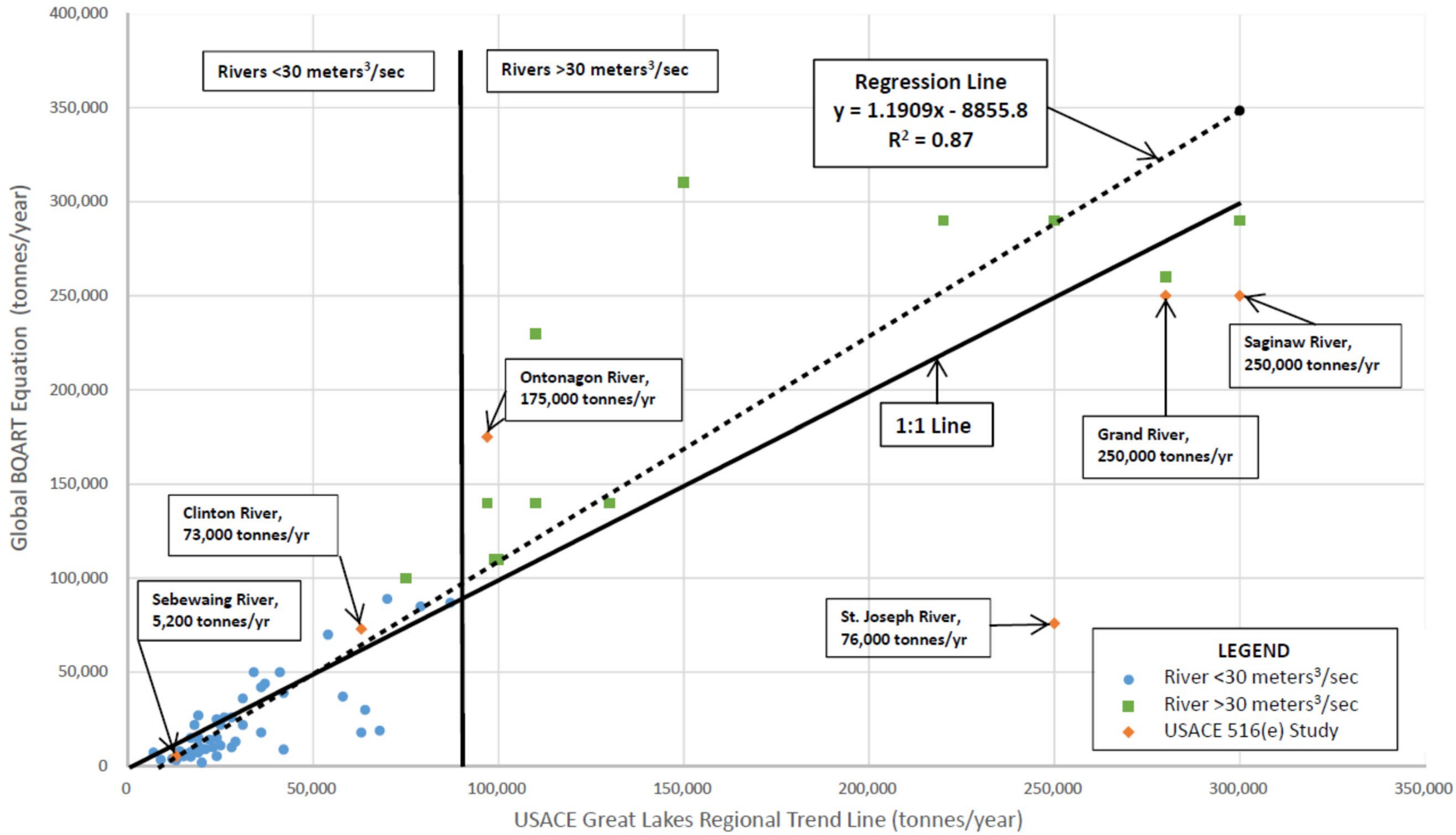


Figure 9. Comparison of Watershed Sediment Delivery Estimates to the Great Lakes: the Global BQART Equation and the USACE (2010) Great Lakes Regional Trend Line

USACE (2010) Great Lakes regional trend line estimates for 21 out of the 60 Michigan rivers (35%). Of these 21 rivers, 15 of these rivers have mean annual flows of less than 30 cubic meters/second which is the validated minimum water discharge that was used to establish the BQART equation (Cohn et al., 2011; Syvitski JPM, 2019).

Of the 60 rivers included in this research, 48 rivers have mean annual flows of less than 30 cubic meters/second. With respect to the Michigan rivers with mean annual flows of less than 30 cubic meters/second, 31% of the rivers have BQART sediment delivery estimates that are within 25% of the USACE (2010) Great Lakes regional trend line (Barkach JH et al, 2020). Of these 48 rivers, the BQART sediment delivery estimates were on average 31% smaller than the USACE (2010) Great Lakes regional trend line. The global BQART equation provides lower estimates of the watershed sediment delivery in comparison to the USACE (2010) Great Lakes regional trend line for rivers with mean annual flow rates of <30 cubic meters/second (Barkach JH et al, 2020).

Of the 12 Michigan rivers with mean annual flows greater than 30 cubic meters/second, 50% of the rivers have BQART sediment delivery estimates that are within 25% of the USACE (2010) Great Lakes regional trend line. Further, these 12 rivers have global BQART sediment delivery estimates that were on average 32% larger than the corresponding USACE (2010) Great Lakes regional trend line estimate. Of these 12 rivers, two stand out. The BQART watershed sediment delivery estimates for the Manistee River and Muskegon River were 109% and 107% larger than the corresponding USACE (2010) Great Lakes regional trend line estimate. The percent differences between the BQART model estimate and the USACE (2010) Great Lakes regional trend line estimate of greater than 30% were noted in three other rivers with mean annual river flows >30 cubic meters/second including the Portage River (33%), Ontonagon River (44%), and Menominee River (32%). With respect to the Manistee River, Muskegon River, Portage River, Ontonagon River, and Menominee River, the relief term (R) is greater than 0.34 kilometers for all five rivers. The relief term (R) for the remaining seven rivers averages 0.23 kilometers reflecting the low gradient streams common in Michigan. The differences in watershed sediment delivery between these two methods appears to be due, at least in part, to the value used for the relief term (R) of the global BQART equation (Barkach JH et al, 2020).

In addition to comparison of the global BQART watershed sediment delivery estimates to the USACE (2010) Great Lakes regional trend line, both methods were compared to calibrated hydrodynamic and sediment transport models that were completed by the USACE (Barkach JH et al, 2020). The USACE 516(e) studies were completed on six of the 60 rivers included in this research: the Saginaw River watershed (USACE, 1999 and 2000), the Clinton River watershed (USACE, 2005), the St. Joseph River watershed (USACE, 2007a), the Grand River watershed (USACE, 2007b), the Sebewaing River watershed (USACE, 2007c), and the Ontonagon River watershed (USACE, 2010a).

The Saginaw River is the largest watershed in Michigan (15,882 square kilometers) and due to the river's high watershed sediment delivery to Saginaw Bay (Lake Huron), is arguably the most studied. With respect to the Saginaw River watershed, the mean annual flow rate is 124.9 cubic meters/second. The watershed sediment delivery predicted using the global BQART equation is estimated to be 290,000 tonnes/year to Saginaw Bay (Lake Huron). The global BQART estimate is very similar to the watershed sediment delivery estimate of 250,000 tonnes/year that was prepared in conjunction with the USACE's (1999, 2000) 516(e) program. The USACE (2010) Great Lakes regional trend line predicts a watershed sediment delivery of 300,000 tonnes/year which is nearly identical to the global BQART watershed sediment delivery estimate of 290,000 tonnes/year.

The most recent USACE 516(e) study was completed on the Ontonagon River (USACE, 2010). The Ontonagon River covers 3,585 square kilometers and has a mean annual flow rate of 39.4 cubic meters/second. Using calibrated hydrodynamic and sediment delivery models, the USACE estimated watershed sediment delivery of 180,000 tonnes/year to Lake Superior. The USACE (2010) Great Lakes regional trend line and the global BQART equation predict watershed sediment delivery of 97,000 and 140,000 tonnes/year, respectively. U.S. Geological Survey sediment gages with long-term records are rare in Michigan; however, a USGS gage with over 20 years of measurements is located on the Ontonagon River. Using the USGS sediment gage data, the USACE (2010a) estimated that the average annual watershed sediment delivery to Lake Superior is approximately 140,000 tonnes/year (Barkach JH et al, 2020). In this case, the global BQART watershed sediment delivery estimate was similar to the USACE 516(e) study and the watershed sediment delivery estimate completed using the USGS Ontonagon River sediment gage, and less similar to the USACE (2010a) Great Lakes regional trend line.

Four other USACE 516(e) studies were completed by the USACE, two on rivers that have mean annual flow rates of less than 30 cubic meters/second (Sebewaing River and the Clinton River) and two on rivers with mean annual flow rates greater than 30 cubic meters/second (St. Joseph River and the Grand River). The Sebewaing River and Clinton River discharge to Lake Huron and Lake St. Clair, and have mean annual flow rates of 1.6 cubic meters/second and 17.6 cubic meters/second, respectively. With respect to the Sebewaing River, the watershed delivery estimates are 5,200 tonnes/year (USACE 516(e) study), 13,000 tonnes/year (USACE Great Lakes regional trend line), and 3,200 tonnes/year (global BQART equation). With respect to the Clinton River, the watershed sediment delivery estimates are 73,000 tonnes/year (USACE 516(e) study), 27,000 tonnes/year (USGS sediment gage), 63,000 tonnes/year (USACE Great Lakes regional trend line), and 18,000 tonnes/year (global BQART equation). In the case of the rivers with mean annual river flows smaller than 30 cubic meters/second, the variability of the watershed sediment delivery estimates is high and the BQART watershed sediment delivery equation typically predicts less sediment delivery than the USACE (2010) Great Lakes regional trend line (see Figure 9).

The St. Joseph River and the Grand River discharge to Lake Michigan and are two of the largest rivers included in this research with mean annual flow rates of 132.5 cubic meters/second and 127.1 cubic meters/second. With respect to the Grand River, the three watershed sediment delivery estimates were very similar, with 250,000 tonnes/year (USACE 516(e) study), 280,000 tonnes/year (USACE Great Lakes regional trend line), and 260,000 tonnes/year (global BQART equation). With respect to the St. Joseph River, the watershed sediment delivery estimates are 76,000 tonnes/year (USACE 516(e) study), 250,000 tonnes/year (USACE Great Lakes regional trend line), and 290,000 tonnes/year (global BQART equation). The variability of the watershed sediment delivery estimates may be due to the large number of dams located on this river. As discussed in the USACE (2007b) 516(e) study, 190 dams are located within the St. Joseph River watershed of which 95 are considered large dams. USACE (2007b) estimates that only 13% of the watershed can drain directly to the river outlet and that up to 80% of the suspended sediment is trapped by the large network of dams located within this watershed.

Given the differences in the data sets used to develop the global BQART equation and the USACE (2010) Great Lakes regional trend line, the BQART equation can provide remarkably close estimates of watershed sediment delivery especially for rivers with mean annual flows greater than 30 cubic meters/second. The watershed sediment delivery estimates calculated using the global BQART equation are comparable to the USACE (2010a) Great Lakes regional trend line for many Michigan watersheds and implies that the global and Great Lakes regional processes of soil erosion, sediment transport, and sediment deposition are similar. With respect to rivers with mean annual flows greater than 30 cubic meters/second, the BQART equation appears to overestimate watershed sediment delivery in comparison the USACE (2010a) Great Lakes regional trend line; these higher estimates of watershed sediment delivery may be due in part to the value used for the relief (R) term of the BQART equation. Examples include the Muskegon River and Manistee River and, to a lesser extent, Portage River, Ontonagon River, and Menominee River. For the St. Joseph River, the importance of the sediment trapping efficiency of dams and natural lakes located within the watershed is evident based on the USACE 516(e) estimate of watershed sediment delivery in comparison to the global BQART equation and the USACE (2020) Great Lakes regional trend line.

2.8 Bedload Sediment Delivery Equations

Many equations have been developed to estimate bed material load and bedload (USACE, 1995; Garcia MH, 2008, Gray JR and Simoes JM, 2008; USDA, 2007). The Syvitski and Milliman (2007) BQART and USACE (2010) Great Lakes Regional Trend Line are examples of empirical watershed sediment delivery equations (see Sections 2.5 to 2.7). Excellent summaries of bedload load transport and sediment transport equations are contained in Armijos et al (2021); Einstein HA (1950); Garcia MH (2008); Gomez B and Church M (1989); Gray JR and Simoes JM (2008); USACE (1995), and USDA (2007).

Two approaches to bedload sediment delivery equations are used, one is based on direct measurement and the second is based on hydraulic parameters and sediment transport potential. Because bed load travels within a few grain diameters of the river bed by rolling, sliding, and saltating along the bed of the river, this creates significant difficulties in measuring bedload in natural streams and for this reason, a significant majority of the bedload equations were developed from laboratory flume experiments (Armijos et al, 2021; Gomez B and Church M, 1989; Gray JR and Simoes JM, 2008; USDA, 2007).

ASCE (1982) ranked bedload material transport equations using 40 sets of field data and 165 sets of laboratory flume data; with respect to bedload equations, Bagnold RA (1956), Meyer-Peter and Muller (1948), and Yalin MS (1963) were ranked highest. Similar recommendations regarding bedload sediment transport equations were included in the USDA (2007) National Engineering Handbook 654, the three bedload sediment transport equations provided in STREAMTools Sediment Transport Module 4.0 include: Ackers P and White WR (1973), Meyer-Peter and Muller (1948), and Einstein HA (1950). Ackers P and White WR (1973) bedload equation is a function of river depth, slope, the D_{35} of the river bed material (35% of the bed material is finer), and the roughness of the river bed (Manning's n). The Einstein HA (1950) bedload equation is a function of river depth, river slope, and the D_{50} of the river bed material. Meyer-Peter and Muller (1948) bedload equation is based on the energy slope of the river and is a function of river depth, river slope, and the D_{50} of the river bed material. The Meyer-Peter and Muller (1948) equation is a good example of a bedload sediment delivery equation and is presented as follows (Meyer-Peter and Muller, 1948; Armijos E et al, 2021):

$$\gamma\left(\frac{Kst}{Kr}\right)^{3/2} S = 0.47(\gamma S - \gamma)d + 0.25pw^{1/3}qbw^{2/3} \qquad (9)$$

where,

q_{bw} = submerged weight of transported sediment [tonnes/sec)/m]

S = slope (meter/meter)

γ = specific weight of water (tonnes/cubic meters)

γ_s= specific weight of water (tonnes/cubic meters)

p_w = specific weight of water (tonnes per second^2/meter^4)

K_{st} = bed roughness (dimensionless)

K_r = particle roughness (dimensionless)

d = d_{50} grainsize (meter)

With respect to the USDA (2007) NEH 654 STREAMTools bedload equations, all three equations are based on either laboratory flume studies (Ackers P and White WR, 1973; Einstein HA, 1950) or bedload measurements in small structures (Meyer-Peter and Muller, 1948), a summary of the test conditions that served as the basis of these three common bedload sediment delivery equations are presented on Table 1. As shown in Table 1, the data used to develop these bedload equations are based laboratory flume experiments and field data collected from small structures (water depths of less than four feet deep and structure widths of less than seven feet wide). Leopold LB and Emmett WW (1997) summarized the problem as follows: “it would be highly desirable to have direct measurements of the bed-load transport in a natural river and of the concomitant hydraulic characteristics of the flow. The problem has been particularly intractable, because no sampling device has been available that would provide reliable and repeatable measurements of the debris load moving along the bed of the river.”

Due to these limitations in collection of field data to calibrate bedload sediment equations, most bed-load and bed-material-load equations were derived from a comparatively restricted database, and their utility has been established on the basis of relatively few field data (Gomez and Church 1989). Further, although the measurements of sediment-transport rates in the laboratory can be quite accurate, they do not represent natural river conditions well (Gray JR and

Table 1. Summary of Laboratory Test Conditions, Three Bedload Sediment Transport Equations (Thomas WA, Copeland RR, McComas DN, 2002: USDA, 2007)

Ackers P and White WR (1973)	**Laboratory Flume Data**
Particle Size (mm)	0.4 - 7
Specific Gravity	1.0 – 2.7
Multiple Size Classes	No
Water Velocity (ft/sec)	0.7 - 7.1
Depth (feet)	0.01 - 1.4
Slope (ft/ft)	0.00006 – 0.037
Width (feet)	0.23 - 4
Water Temperature (°F)	46 -89
Meyer-Peter and Muller (1948)	**Data Range**
Particle Size (mm)	0.4 - 29
Specific Gravity	1.25 - 4
Multiple Size Classes	Yes
Water Velocity (ft/sec)	1.2 – 9.4
Depth (feet)	0.03 – 3.9
Slope (ft/ft)	0.0004 – 0.02
Width (feet)	0.5 – 6.6
Water Temperature (°F)	Not reported
Einstein HA (1950)	**Laboratory Flume Data**
Particle Size (mm)	0.78 - 29
Multiple Size Classes	Yes
Water Velocity (ft/sec)	0.9 – 9.4
Depth (feet)	0.03 – 3.6
Slope (ft/ft)	0.00037 – 0.018
Width (feet)	0.66 – 6.6
Water Temperature (°F)	Not reported

Simoes FJM). Leopold and Emmett (1997) observed that a river's ability to adjust its cross section to a variety of flows is a characteristic not shared by a fixed-wall laboratory flume. For these reasons, this research focused on the development of an empirical bedload watershed sediment delivery equation based on the characteristics of the fluvial system and watershed.

CHAPTER 3 METHODS

This research utilized a series of geospatial data sets including digital terrain models, watershed boundaries, soil type, surficial geology, and land use that are readily available through the State of Michigan (2020) Geographic Information System (GIS) Open Data Portal. In addition, the Michigan Department of Environment, Great Lakes, and Energy (EGLE), Hydrologic Studies and Dam Safety Unit completed mean annual river flow and recurrence interval flow calculations for all 60 watersheds and five sub-watersheds, and provided contributing watershed areas for 45 of the 60 watersheds. The USACE-Detroit District provided extensive dredging data extending back to the early- to mid-1960's for 30 watersheds that were incorporated into this research as well as guidance regarding current estimates of future dredging and dredging backlog data for each harbor and navigation channel.

The 60 Michigan rivers included in this research encompass a total watershed area of 128,043 square kilometers; 119,622 square kilometers are located within in the State of Michigan and 8,421 square kilometers extend into adjoining States. Land use data was obtained from the 2011 version of the National Land Cover Database (USDA, 2011). The GIS and watershed data are provided for the total watershed area and are summarized in an Appendix for each watershed included in this research. Each watershed Appendix includes (see Appendices A through PPP):

- A summary of watershed hydrology including:
    - A map index showing the location of the watershed within the State of Michigan
    - The location of the river and tributaries (USGS, 2020)

  - The location of dams within the watershed that are listed in the National Inventory of Dams database (USACE, 2018)
  - The location and identification number of USGS gages with 20 or more years of daily discharge records (USGS, 2020)
  - An aerial photograph and coordinates of either the river outlet or USACE navigation channel outlet
- A digital elevation map of the watershed (State of Michigan, 2020)
- A land use map of the watershed (NLCD, 2011)
- Surficial geology map of the watershed (Farrand WR and Bell DL, 1982)

With respect to watersheds that extend outside of the State of Michigan, GIS data from the U.S. Department of Agriculture Geospatial Data Gateway (USDA, 2019) and the U.S. Geological Survey (USGS, 2019a) National Map Viewer were used.

3.1 Watershed Area

The 60 Michigan watersheds that were included in this research range in size from the Falls River (48) with a contributing watershed area covering 117 square kilometers to the Saginaw River watershed (32) covering 15,882 square kilometers (see Figure 4; EGLE, 2021). Together, the area of these 60 watersheds covers 128,043 square kilometers of which 119,622 square kilometers are located within in the State of Michigan and 8,421 square kilometers extend into adjoining States. These 60 watersheds drain toward four Great Lakes and their corresponding connecting channels (Figure 4). Of the 60 rivers included in this research, the percentage of watershed area discharging to Lake

Michigan, Lake Huron, Lake Superior, and Lake Erie is 56%, 25.1%, 9.9%, and 9.0% of the total watershed area of 128,043 square kilometers.

The Michigan Department of Environment, Great Lakes and Energy provided contributing watershed areas for 45 of the 60 watersheds, and four of five sub-watersheds. If a contributing watershed area was not available, then the total watershed area is listed in Table 2, Table 3, Table 4, Table 5, and Table 6. With respect to Table 2, Table 3, Table 4, and Table 5, total watershed area is presented for the following rivers (and watershed reference numbers): Clinton River (12), Kalamazoo River (17), Pine River (27), River Raisin (29), Rifle River (30), Rouge River (31), St. Joseph River (34), Manistique River (49), Menominee River (50), Ontonagon River (53), Portage River (55), Sturgeon River (58), Tahquamenon River (60), Two Hearted River (61), and Waiska River (62).

3.2 Mean Annual River Flow and Recurrence Interval Flows at the River Outlet

A key enabler of this research is the extensive data set that was provided by EGLE's Hydrologic Studies and Dam Safety Unit. EGLE provided the mean annual river flow and recurrence interval flows (1.5 year, 2.0 year, 5 year, 10 year, 25-year, 50 year, and 100-year) for all 60 watersheds (and five sub-watersheds) at the point where the river discharges into a Great Lake, Great Lake connecting channel, or reservoir. The average value of the mean annual flow rates of the 60 Michigan rivers included in this research is 22 cubic meters/second, and range in value from 1.0 cubic meters/second (Days River; 44) to 132.5 cubic meters/second (St. Joseph River; 34). The exceedance flows provide by EGLE's Hydrologic Studies and Dam Safety Unit were developed from one of following three sources:

- Calculation of exceedance flows using the Drainage Area Ratio to a USGS gage using log-Pearson III statistical analysis incorporating USGS Bulletin 17C methodology (IACWD, 1982; USGS, 2019b).
- Exceedance flows contained in an existing Federal Emergency Management Agency (FEMA) Flood Insurance Study; virtually all FEMA Flood Insurance Studies utilized log-Pearson III statistical analysis.
- If a USGS gage was not present in the watershed, the USGS (1984a and 1994) Regression Method was utilized.

For 28 of the 60 watersheds and three of five sub-watersheds, the recurrence interval flows were calculated using annual peak flow data from a USGS gage located on the river, closest to the river outlet. EGLE typically only used USGS gages that have at least 20 years of daily discharge records (USGS, 2020). EGLE utilized USGS Bulletin 17C methodology (IACWD, 1982; USGS, 2019b) to calculate recurrence interval flows. A log-Pearson Type III statistical analysis was conducted by EGLE on annual peak flow data from the most downstream USGS gage located within the watershed, and adjusted using the Drainage Area Ratio (DAR) to estimate the recurrence interval flows at the river outlet to the Great Lake or connecting channel (USDA, 1972; USGS, 2005; Ries III KG, 2007; MDOT, 2018).

Table 2. Characteristics of 12 Michigan Rivers Located Within the Lake Superior Watershed

Watershed Reference Number	River	Watershed Area (kilometers^2)	Watershed Area Basis	Maximum Watershed Relief (meters)	Average Watershed Relief (meters)	Mean Annual River Flow (m^3/sec)	Reccurence Interval Flow at the River Outlet: 1.5 year (m^3/sec)	2.0 year (m^3/sec)	5 year (m^3/sec)	10 year (m^3/sec)	25 year (m^3/sec)	50 year (m^3/sec)	100 year (m^3/sec)	EGLE Basis
48	Falls River[3]	117	Contributing	392.6	212.7	1.2	15.6	18.4	25.5	31.1	36.8	42.5	48.1	Regression
39	Au Train	285	Contributing	151.6	88.3	4.0	11.3	14.2	24.1	31.1	39.6	45.3	51.0	DAR to Gage #04044724
62	Waiska River[2,3]	383	Total	104.6	36.8	5.9	48.1	56.6	76.5	87.8	104.8	116.1	127.4	Regression
43	Chocolay River	399	Contributing	257.6	108.5	10.8	36.8	45.3	68.0	82.1	101.9	116.1	130.3	FIS (Marquette County, 2016)
45	Dead River[3]	422	Contributing	381.6	269.3	5.7	34.0	39.6	51.0	56.6	68.0	73.6	82.1	Regression
61	Two Hearted River[2]	536	Total	166.6	60.7	9.1	34.0	39.6	56.6	70.8	87.8	101.9	118.9	DAR to Gage #04044813
40	Black River (Gogebic)	660	Contributing	366.0	263.4	8.5	99.1	127.4	201.0	260.5	339.8	424.8	509.7	DAR to Gage #04031000
51	Montreal River	699	Contributing	387.2	256.0	9.3	73.6	90.6	138.8	172.7	220.9	254.9	283.2	DAR to Gage #04029990
56	Presque Isle River	935	Contributing	386.9	284.7	10.8	76.5	90.6	121.8	141.6	164.2	181.2	198.2	DAR to Gage #04032000
60	Tahquamenon River[2]	2,095	Total	170.6	61.0	26.9	113.3	127.4	158.6	178.4	198.2	215.2	229.4	DAR to Gage #04045500
55	Portage River[1,2]	2,572	Contributing	359.6	155.8	40.5	175.6	201.0	266.2	311.5	339.8	396.4	424.8	DAR to Gage #04042300 ext. #04041500
53	Ontonagon River[2]	3,585	Total	382.6	235.7	39.4	249.2	311.5	509.7	623.0	792.9	934.5	1076.0	FIS (Village of Ontonagon, 1983)
	Minimum:	**117**		**104.6**	**104.6**	**1.2**	**11.3**	**14.2**	**24.1**	**31.1**	**36.8**	**42.5**	**48.1**	
	Average:	**1,057**		**292.3**	**292.3**	**14.3**	**80.6**	**96.9**	**141.5**	**170.6**	**207.9**	**241.9**	**273.3**	
	Maximum:	**3,585**		**392.6**	**392.6**	**40.5**	**249.2**	**311.5**	**509.7**	**623.0**	**792.9**	**934.5**	**1076.0**	
	Total Area:	**12,688**												

EGLE - Hydrologic Studies Unit, Michigan Department of Environment, Great Lakes, and Energy

Footnote 1. Sub-basin, area-weighted maximum watershed elevations were calculated using the individual sub-basins; these include watersheds 1, 2, 10, 14, 32, 34, 50, and 55.

Footnote 2. Total Watershed Area.

Footnote 3. Recurrence interval flows were calculated using the USGS (1984) Regression Method.

Table 3. Characteristics of 26 Michigan Rivers Located Within the Lake Michigan Watershed

Watershed Reference Number	River	Watershed Area (kilometers²)	Watershed Area Basis	Maximum Watershed Relief (meters)	Average Watershed Relief (meters)	Mean Annual River Flow (m³/sec)	Reccurence Interval Flow at the River Outlet: 1.5 year (m³/sec)	2.0 year (m³/sec)	5 year (m³/sec)	10 year (m³/sec)	25 year (m³/sec)	50 year (m³/sec)	100 year (m³/sec)	EGLE Basis
44	Days River[3]	161	Contributing	145.6	76.1	1.0	12.5	15.6	22.7	28.3	34.0	39.6	45.3	Regression
19	Lincoln River	256	Contributing	81.6	33.1	2.8	21.2	24.1	31.1	36.8	42.5	48.1	53.8	Previous DAR to Regression
57	Rapid River	357	Contributing	173.6	93.3	1.2	34.0	39.6	53.8	62.3	73.6	82.1	93.4	FIS (Delta County, 1998)
28	Platte River	360	Contributing	188.6	74.7	5.4	13.6	15.6	19.8	22.7	25.5	28.3	31.1	DAR to Gage #04126740 ext. #04127800
5	Big Sable	427	Contributing	158.6	40.9	5.7	13.0	15.6	21.2	25.5	31.1	34.0	39.6	DAR to Gage #04123000
24	Pentwater River[3]	430	Contributing	128.6	47.1	5.1	39.6	48.1	65.1	76.5	90.6	104.8	116.1	Regression Gage #04127800
8	Macatawa River	451	Contributing	57.6	23.1	5.4	107.6	144.4	235.0	311.5	396.4	481.4	566.3	DAR to Gage #04108800
58	Sturgeon River[2]	567	Total	127.6	58.1	6.2	31.1	36.8	45.3	53.8	59.5	65.1	70.8	DAR to Gage #04057510
9	Boardman	572	Contributing	219.6	122.9	8.8	18.4	21.2	28.3	34.0	42.5	48.1	51.0	FIS (City of Traverse City, 1982)
4	Betsie River	603	Contributing	186.6	73.6	8.2	25.5	26.9	31.1	36.8	39.6	41.1	43.9	DAR to Gage #04126600
7	Black River (West)	738	Contributing	69.6	28.2	10.2	17.0	24.1	45.3	65.1	93.4	116.1	147.2	FIS (Van Buren County, 2009)
10	Pine River[1,3]	808	Contributing	208.6	83.6	13.0	53.8	65.1	85.0	96.3	113.3	121.8	133.1	Regression Gage #04127800
63	Whitefish River[3]	811	Contributing	202.6	93.2	8.8	65.1	79.3	107.6	127.4	152.9	172.7	192.6	Regression
42	Cedar River	976	Contributing	173.6	66.2	7.6	48.1	59.5	85.0	101.9	124.6	141.6	161.4	DAR to Regression
13	Elk River[3]	1,035	Contributing	275.6	89.9	20.1	28.3	34.0	42.5	48.1	53.8	59.5	62.3	Regression
37	White River	1,178	Contributing	204.6	68.7	16.7	45.3	56.6	85.0	107.6	135.9	158.6	184.1	DAR to Gage #04122200
47	Ford River	1,197	Contributing	295.6	150.2	10.5	70.8	82.1	110.4	127.4	150.1	164.2	181.2	DAR to Gage #04059500
25	Pere Marquette River	1,673	Contributing	249.6	92.7	22.4	51.0	59.5	82.1	96.3	113.3	124.6	138.8	DAR to Gage #04122500
46	Escanaba River	2,341	Contributing	372.6	196.9	24.6	144.4	169.9	229.4	266.2	311.5	339.8	368.1	DAR to Gage #04059000
49	Manistique River[2]	3,792	Total	295.6	150.2	51.5	198.2	235.0	311.5	368.1	453.1	509.7	566.3	DAR to Gage #04056500
20	Manistee River	4,349	Contributing	342.6	147.8	65.7	155.7	172.7	203.9	223.7	246.4	263.3	277.5	DAR to Gage #04126000
17	Kalamazoo River[2]	5,260	Total	204.6	87.2	51.5	127.4	152.9	212.4	254.9	311.5	368.1	424.8	DAR to Gage #04108500
22	Muskegon River	6,550	Contributing	345.6	149.4	66.0	175.6	203.9	277.5	339.8	396.4	453.1	509.7	DAR to Gage #04122000
50	Menominee River[1,2]	10,500	Total	371.6	223.4	101.4	339.8	396.4	538.0	651.3	792.9	906.1	1019.4	DAR to Gage #04067500
34	St. Joseph River[1,2]	12,196	Total	195.6	89.9	132.5	311.5	368.1	453.1	509.7	566.3	623.0	651.3	FIS (Berrien County, 2006)
14	Grand River[1]	14,100	Contributing	169.6	77.4	127.1	481.4	594.7	849.5	1047.7	1302.6	1500.8	1727.3	FIS (Ottawa County, 2013)
	Minimum:	**161**		**57.6**	**23.1**	**1.0**	**12.5**	**15.6**	**19.8**	**22.7**	**25.5**	**28.3**	**31.1**	
	Average:	**2,757**		**209.4**	**93.8**	**30.0**	**101.2**	**120.8**	**164.3**	**196.9**	**236.7**	**269.1**	**302.2**	
	Maximum:	**14,100**		**372.6**	**223.4**	**132.5**	**481.4**	**594.7**	**849.5**	**1047.7**	**1302.6**	**1500.8**	**1727.3**	
	Total Area:	**71,690**												

EGLE - Hydrologic Studies Unit, Michigan Department of Environment, Great Lakes, and Energy

Footnote 1. Sub-basin, area-weighted maximum watershed elevations were calculated using the individual sub-basins; these include watersheds 1, 2, 10, 14, 32, 34, 50, and 55.

Footnote 2. Total Watershed Area.

Footnote 3. Recurrence interval flows were calculated using the USGS (1984) Regression Method.

Table 4. Characteristics of 14 Michigan Rivers Located Within the Lake Huron Watershed

Watershed Reference Number	River	Watershed Area (kilometers^2)	Watershed Area Basis	Maximum Watershed Relief (meters)	Average Watershed Relief (meters)	Mean Annual River Flow (m^3/sec)	Reccurence Interval Flow at the River Outlet: 1.5 year (m^3/sec)	2.0 year (m^3/sec)	5 year (m^3/sec)	10 year (m^3/sec)	25 year (m^3/sec)	50 year (m^3/sec)	100 year (m^3/sec)	EGLE Basis
38	Willow Creek[3]	246	Contributing	82.6	44.9	1.8	31.1	39.6	56.6	70.8	90.6	101.9	116.1	Regression
33	Sebewaing River	269	Contributing	67.6	20.6	1.6	53.8	65.1	93.4	113.3	138.8	158.6	175.6	FIS (Huron County, 2008)
23	Oqueoc River[3]	370	Contributing	112.6	63.4	3.4	12.2	13.6	17.0	19.8	21.2	24.1	25.5	Regression
26	Pigeon River	378	Contributing	74.6	29.2	2.5	34.0	48.1	85.0	107.6	141.6	167.1	192.6	Gage analysis, Gage #04158500.
41	Carp River[3]	440	Contributing	127.6	65.6	4.0	70.8	76.5	85.0	93.4	101.9	107.6	110.4	Regression
52	Munuscong River[3]	464	Contributing	135.6	33.2	5.7	73.6	82.1	101.9	118.9	135.9	147.2	158.6	Regression
18	Kawkawlin River	585	Contributing	60.6	22.1	3.7	51.0	62.3	87.8	107.6	130.3	150.1	169.9	FIS (Bay County, 2010)
1	Au Gres River[1]	629	Contributing	112.6	50.9	4.6	42.5	51.0	65.1	76.5	90.6	99.1	107.6	FIS (Arenac County, 2015)
54	Pine River	710	Contributing	127.6	55.8	8.5	82.1	93.4	124.6	144.4	169.9	186.9	203.9	DAR to Gage #04127918
30	Rifle River[2]	984	Total	279.6	101.2	10.2	62.3	70.8	96.3	110.4	130.3	141.6	155.7	DAR to Gage #04142000
36	Thunder Bay River	3,116	Contributing	256.6	86.7	24.1	107.6	138.8	218.0	274.7	339.8	396.4	453.1	DAR to Gage #04135000
11	Cheboygan River	3,691	Contributing	295.6	85.9	37.7	76.5	82.1	99.1	107.6	118.9	127.4	133.1	FIS (Cheboygan County, 2012)
2	Au Sable River[1]	4,351	Contributing	278.6	164.6	42.2	96.3	104.8	130.3	144.4	164.2	172.7	186.9	FIS (Iosco County, 2012)
32	Saginaw River[1,2]	15,882	Contributing	197.6	66.6	124.9	764.6	877.8	1161.0	1330.9	1557.4	1699.0	1868.9	FIS (Bay County, 2010)
	Minimum:	**246**		**60.6**	**20.6**	**1.6**	**12.2**	**13.6**	**17.0**	**19.8**	**21.2**	**24.1**	**25.5**	
	Average:	**2,294**		**157.8**	**63.6**	**19.6**	**111.3**	**129.0**	**172.9**	**201.5**	**238.0**	**262.8**	**289.8**	
	Maximum:	**15,882**		**295.6**	**164.6**	**124.9**	**764.6**	**877.8**	**1161.0**	**1330.9**	**1557.4**	**1699.0**	**1868.9**	
	Total Area:	**32,116**												

EGLE - Hydrologic Studies Unit, Michigan Department of Environment, Great Lakes, and Energy

Footnote 1. Sub-basin, area-weighted maximum watershed elevations were calculated using the individual sub-basins; these include watersheds 1, 2, 10, 14, 32, 34, 50, and 55.

Footnote 2. Total Watershed Area.

Footnote 3. Recurrence interval flows were calculated using the USGS (1984) Regression Method.

Table 5. Characteristics of Eight Michigan Rivers Located Within the Lake Erie Watershed

Watershed Reference Number	River	Watershed Area (kilometers[2])	Watershed Area Basis	Maximum Watershed Relief (meters)	Average Watershed Relief (meters)	Mean Annual River Flow (m^3/sec)	Reccurence Interval Flow at the River Outlet: 1.5 year (m^3/sec)	2.0 year (m^3/sec)	5 year (m^3/sec)	10 year (m^3/sec)	25 year (m^3/sec)	50 year (m^3/sec)	100 year (m^3/sec)	EGLE Basis	Receiving Water
35	Stoney Creek	319	Contributing	72.8	45.2	2.4	19.8	25.5	42.5	53.8	70.8	82.1	104.8	FIS (Monroe County, 2014)	Lake Erie
27	Pine River[2]	505	Total	80.3	33.8	8.5	53.8	68.0	107.6	135.9	169.9	201.0	232.2	FIS (Saint Clair County, 2010)	St. Clair River
3	Belle River	588	Contributing	151.3	61.2	4.2	59.5	73.6	107.6	130.3	161.4	184.1	209.5	FIS (Saint Clair County, 2010)	St. Clair River
31	Rouge River[2]	1,204	Total	131.3	49.4	8.8	85.0	116.1	206.7	283.2	396.4	481.4	594.7	DAR to USGS Gage #04166500	Detroit River
6	Black River (East)	1,839	Contributing	131.7	58.9	12.5	186.9	220.9	311.5	356.5	424.8	476.0	522.4	FIS (Saint Clair County, 2010)	St. Clair River
12	Clinton River[2]	2,064	Total	190.0	68.8	17.6	28.3	45.3	76.5	101.9	135.9	167.1	192.6	FIS (Macomb County, 2013)	Lake St. Clair
15	Huron River	2,258	Contributing	188.8	101.3	16.7	76.5	99.1	150.1	203.9	260.5	311.5	339.8	FIS (Wayne County, 2013)	Lake Erie
29	River Raisin[2]	2,771	Total	199.3	75.6	22.5	135.9	164.2	240.7	283.2	339.8	396.4	481.4	FIS (Monroe County, 2014)	Lake Erie
	Minimum:	**319**		**72.8**	**33.8**	**2.4**	**19.8**	**25.5**	**42.5**	**53.8**	**70.8**	**82.1**	**104.8**		
	Average:	**1,444**		**143.2**	**61.8**	**11.6**	**80.7**	**101.6**	**155.4**	**193.6**	**244.9**	**287.5**	**334.7**		
	Maximum:	**2,771**		**199.3**	**101.3**	**22.5**	**186.9**	**220.9**	**311.5**	**356.5**	**424.8**	**481.4**	**594.7**		
	Total Area:	**11,549**													

EGLE - Hydrologic Studies Unit, Michigan Department of Environment, Great Lakes, and Energy

Footnote 1. Sub-basin, area-weighted maximum watershed elevations were calculated using the individual sub-basins; these include watersheds 1, 2, 10, 14, 32, 34, 50, and 55.

Footnote 2. Total Watershed Area.

Footnote 3. Recurrence interval flows were calculated using the USGS (1984) Regression Method.

Table 6. Sub-Watersheds, Mio Dam (2A), Brown Bridge Dam (9A), Webber Dam (14A), Ford Dam (15A), and Riley Dam (34A)

Dam and Corresponding River	Watershed Area (kilometers[2])	Watershed Area Basis	Maximum Watershed Relief (meters)	Average Watershed Relief (meters)	Mean Annual River Flow (m^3/sec)	Reccurence Interval Flow at the River Outlet: 1.5 year (m^3/sec)	2.0 year (m^3/sec)	5 year (m^3/sec)	10 year (m^3/sec)	25 year (m^3/sec)	50 year (m^3/sec)	100 year (m^3/sec)	EGLE Basis
2A. Mio Dam, Au Sable River	2,735	Contributing	177.4	78.9	28.0	73.6	82.1	96.3	104.8	116.1	124.6	133.1	Gage #04136500
9A. Brown Bridge Dam, Boardman	311	Contributing	153.3	73.3	4.5	12.7	14.2	18.4	21.2	24.1	26.9	28.3	DAR to Gage #04127000
14A. Weber Dam, Grand River	4,501	Contributing	172.4	51.5	36.0	135.9	181.2	311.5	396.4	509.7	623.0	707.9	DAR to City of Portland FIS, Gage #04114000
15A. Ford Dam, Huron River	2,018	Contributing	154.4	76.2	17.8	73.6	90.6	135.9	167.1	212.4	246.4	283.2	FIS (Washtenaw Countywide 2012)
34A. Riley Dam, St. Joseph River	1,357	Total	114.2	45.2	13.3	36.8	42.5	59.5	73.6	87.8	99.1	110.4	FIS (Berrien County, 2006)
Minimum:	**311**		**114.2**	**114.2**	**4.5**	**12.7**	**14.2**	**18.4**	**21.2**	**24.1**	**26.9**	**28.3**	
Average:	**2,184**		**154.3**	**154.3**	**19.9**	**66.5**	**82.1**	**124.3**	**152.6**	**190.0**	**224.0**	**252.6**	
Maximum:	**4,501**		**177.4**	**177.4**	**36.0**	**135.9**	**181.2**	**311.5**	**396.4**	**509.7**	**623.0**	**707.9**	
Total Area:	**10,922**												

EGLE - Hydrologic Studies Unit, Michigan Department of Environment, Great Lakes, and Energy

Footnote 1. Sub-basin, area-weighted maximum watershed elevations were calculated using the individual sub-basins; these include watersheds 1, 2, 10, 14, 32, 34, 50, and 55.

Footnote 2. Total Watershed Area.

Footnote 3. Recurrence interval flows were calculated using the USGS (1984) Regression Method.

For 20 of the 60 watersheds and two sub-watersheds, EGLE used the flood discharge values reported in an existing FEMA Flood Insurance Study. FEMA's Flood Insurance Rate Maps (FIRMs) are used for regulatory purposes, so EGLE confirmed that the FEMA Flood Insurance Study was consistent with the FEMA Flood Insurance Rate Maps. The Flood Insurance Studies and Flood Insurance Rate Maps can be found at FEMA's online Map Service Center (FEMA, 2020). With respect to the exceedance flows developed in FEMA Flood Insurance Studies, virtually all were calculated using the Drainage Area Ratio (USDA, 1972; USGS, 2005; Ries III DK, 2007; MDOT, 2018) to a log-Pearson III statistical analysis of a USGS gage located at or near the river outlet.

For 12 of 60 watersheds, the USGS (1984a and 1994) Regression Analysis method was used to determine recurrence interval flows for watersheds that do not contain a USGS gage. These rivers (and watershed reference number) include: Pine River (10), Elk River (13), Oqueoc River (23), Pentwater River (24), Willow Creek (38), Carp River (41), Days River (44), Dead River (45), Falls River (48), Munuscong River (52), Waiska River (62), and Whitefish River (63). The Regression Analysis method was developed by USGS (1984a and 1994) and is based on Michigan streamflow data (Bent PC, 1970); these regression equations were developed for Michigan watersheds of up to 2,590 square kilometers and are based on USGS peak-discharge records available through 1982 and from 185 gaging stations with 10 or more years of record (USGS, 1984b and 1994).

There are 12 predictive variables used in the USGS (1984a, 1984b and 1994) Regression Analysis method to determine recurrence interval flows. These include:

contributing watershed drainage area; main-channel slope; the percentage of main-channel length that passes through swamp, lake, or pond; the slenderness ratio which is the square of river channel length divided by the drainage area; the 100-year, 24-hour rainfall event (centimeters); and the percentage of the contributing watershed covered by seven surficial geologic soil classifications (Farrand WR and Bell DL, 1982). The recurrence intervals for the USGS (1984b and 1994) Regression Analysis equations range up to 100 years.

3.3 Watershed Relief

The maximum and average watershed relief for each river and sub-watershed are shown in Table 2, Table 3, Table 4, Table 5, and Table 6 and represent the maximum and average topographic elevation subtracted from the receiving water elevation at the point where the river discharges to the Great Lake, Great Lake connecting channel, or reservoir (five sub-watersheds). With respect to the Great Lake elevations used in this research, the receiving water elevation represents the long-term average elevation from 1918 to 2018 (USACE, 2021d). The following receiving water elevations were utilized: Lake Superior (183.4 meters), Lake Huron and Lake Michigan (176.4 meters), Lake St. Clair (175.0 meters), and Lake Erie (174.2 meters). The Lake Erie watershed includes two Great Lakes connecting channels (the St. Clair River and the Detroit River) as well as Lake St. Clair (see Figure 4).

With respect to the five sub-watershed basins, the receiving water elevation of the corresponding reservoir was provided by the EGLE Hydrologic Studies and Dam Safety Unit. The following receiving water elevations were utilized: Mio Dam (2A), Au Sable

River (293.6 meters); Brown Bridge Dam (9A), Boardman River (242.7 meters); Webber Dam (14A), Grand River (208.6 meters); Ford Dam (15A), Huron River (208.6 meters); Riley Dam (34A), St. Joseph River (265.8 meters).

With respect to rivers that discharge to Great Lakes connecting channels such as the St. Clair River (Pine River, 27; Belle River, 3; and Black River-East, 6) and the Detroit River (Rouge River, 31), the receiving water elevation at the river outlet was calculated using the water surface slope of the connecting channel between the adjacent Great Lakes.

Of the 60 watersheds evaluated, eight watersheds are divided into major sub-basins typically defined by glacial moraines (EGLE, 2019; Farrand WR and Bell DL, 1982). These rivers (and watershed reference number) include: Au Gres River (1), Au Sable River (2), Pine River (10), Grand River (14), Saginaw River (32), St. Joseph River (34), Menominee River (50), and Portage River (55). For these eight rivers, the maximum elevation of the watershed was calculated from the area-weighted maximum elevations of the individual sub-basins (Barkach JH et al, 2020). For example, with respect to the Saginaw River, the maximum elevation of the watershed (470.0 meters) occurs in the Tittabawassee sub-basin which accounts for 23% of the total watershed area. However, the area-weighted maximum elevation for the Saginaw River is 374.0 meters (see Table 7). Maximum relief (R) for the Saginaw River is 197.6 meters which is the difference between the area-weighted maximum relief (374.0 meters) and the receiving water elevation of Lake Huron (176.4 meters).

Table 7. Area Weighted Maximum Relief, Eight Watersheds

Au Gres Watershed (1)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Au Gres Basin	632	62%	289
East Branch Au Gres Sub-basin	380	38%	289
Total (kilometers^2):	**1,012**	**100%**	**289**

Au Sable River Watershed (2)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Au Sable River Sub-basin	4,574	86%	471
Pine River Sub-basin	731	14%	352
Total (kilometers^2):	**5,305**	**100%**	**455**

Pine River Watershed (10)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Boyne Sub-basin	186	22%	397
Jordan Sub-basin	333	39%	445
Pine Sub-basin	341	40%	319
Total (kilometers^2):	**860**	**100%**	**385**

Grand River Watershed (14)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Grand Sub-basin	5,650	39%	381
Red Cedar Sub-basin	1,192	8%	320
Looking Glass Sub-basin	807	6%	289
Maple Sub-basin	2,448	17%	320
Thornapple Sub-basin	2,197	15%	320
Flat Sub-basin	1,461	10%	351
Rogue Sub-basin	678	5%	335
Total (kilometers^2):	**14,433**	**100%**	**346**

St. Joseph River Watershed (34)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
St. Joseph Sub-basin	8,210	67%	390
Paw Paw Sub-basin	1,156	9%	324
Pigeon Sub-basin	1,024	8%	357
Elkhart Sub-basin	1,811	15%	328
Total (kilometers^2):	**12,202**	**100%**	**372**

Saginaw River Watershed (32)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Cass Sub-basin	2,251	14%	305
Flint Sub-basin	3,446	21%	365
Shiawassee Sub-basin	3,278	20%	359
Chippewa Sub-basin	2,656	17%	366
Tittabawassee Sub-basin	3,749	23%	470
Saginaw Sub-basin	651	4%	224
Total (kilometers^2):	**16,031**	**100%**	**374**

Menominee River Watershed (50)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Menominee Sub-basin	3,357	32%	509
Paint Sub-basin	1,695	16%	571
Brule Sub-basin	1,029	10%	578
Michigamme Sub-basin	1,874	18%	601
Pine (Wisconsin) Sub-basin	1,465	14%	562
Sturgeon (Dickinson) Sub-basin	1,115	11%	491
Total (kilometers^2):	**10,535**	**100%**	**548**

Portage River Watershed (55)	Area (km)	Sub-basin Percentage	Maximum Relief (meters)
Portage Sub-basin	679	26%	442
Sturgeon (Houghton) Sub-basin	1,890	74%	579
Total (kilometers^2):	**2,569**	**100%**	**543**

3.4 River Slope

The river slopes presented in Table 8, Table 9, Table 10, Table 11, and Table 12 were calculated one of two ways. River slopes identified as either USGS or EGLE on were calculated using USGS (1984b) methodology. Using the USGS (1984b) methodology, the slope of the main river channel is calculated from the difference in the streambed elevations between points 10 and 85 percent of the distance along the main river channel from the river outlet to the watershed basin divide, divided by 0.75 times the channel length. Using the USGS (1984b) method, the stream bed elevations were estimated from USGS topographic maps by extrapolating the streambed elevation data between topographic contour lines that cross the main river channel. With respect to Tables 5-8, river slopes calculated by EGLE utilized the USGS (1984b) method and those designated USGS were published previously (USGS, 1984b).

River slopes identified as WSU were calculated in a two-step process. First, the difference between the surface water elevation of the most upstream USGS gage within the watershed and the receiving water elevation (or reservoir surface water elevation for five sub-watersheds) was determined. This difference in elevation was then divided by the channel length between the USGS gage and the river outlet to arrive at the calculated river slope. The water surface elevation at the USGS gage was calculated by adding the average USGS (2020) gage depth to the elevation of the USGS gage. If the average river gage depth was not available, then the elevation of the USGS gage was utilized. The river slopes presented on Table 8, Table 9, Table 10, Table 11, and Table 12 represent the river slope of the longest river channel reach using either the USGS (1984b) stream bed elevation method or the WSU water surface elevation method.

The slopes of the 60 Michigan rivers and five sub-watersheds that were evaluated in this research are relatively small and reflect Michigan's glacial heritage. Low gradient rivers are common in Michigan and throughout the Great Lakes basin. The multiple glacial advances within the Great Lakes basin resulted in watersheds underlain by a complex sequence of glacial moraines, ice contact deposits, glacial outwash plains, and glacial lake bed deposits (Bent PC, 1971; Flint RF, 1971; Farrand WR and Bell DL, 1982). Michigan's extensive glacial heritage has resulted in relatively small differences in topography at the watershed scale in comparison to the elevation of the receiving water (the corresponding Great Lake or Great Lakes connecting channel, or reservoir).

3.5 Watershed Curve Number

During the late 1990's, Geographical Information Systems (GIS) began to be used by the State of Michigan in conjunction with automated processing of many mapping functions, including the calculation of watershed runoff curve numbers (MDEQ, 2016; MDEQ, 2010; MDEQ, 1999). The Hydrologic Studies Program of the Michigan Department of Environment, Great Lakes, and Energy (EGLE) developed a system to automate runoff CN calculations by creating a set of GIS lookup tables used to identify each soil-land use combination and its associated watershed runoff CN. Each individual soil-land use combination has a runoff CN that was determined using NRCS (1986) methodology.

The NRCS publishes spatial and tabular data online through its Web Soil Survey (NRCS, 2020). Michigan is divided into 83 Counties; each County soil classification table is unique, and each Michigan County has a table identifying the hydrologic soils group associated with each NRCS (1986) soil classification. To calculate the watershed runoff CNs, Michigan Resource Information System (MIRIS) land use data is utilized (MDNR, 1978). This set of shapefiles was used because its tables contain land use classification information set up for automated runoff CN processing. GIS processing of the watershed runoff CNs involves joining the soil and land use shapefiles (MDEQ, 2010; MDEQ, 2016). The two shapefiles are intersected to produce a shapefile where each polygon is associated with a single soil-land use combination. In this manner, one GIS shape file exists for each Michigan County that contains a runoff CN for each land use/soil type polygon.

To calculate the composite runoff CN for a watershed, the County shapefile is clipped to the watershed boundary. In many instances, the watershed in question covers more than one Michigan County. In this case, the GIS shape file for each County is clipped and the polygons for that particular watershed are combined into a single shapefile used to calculate the composite watershed CNs that are presented in Tables 7-11. The composite watershed CN is calculated by multiplying the area of each polygon by the unique CN for that particular land use/soil type combination. To calculate the watershed CN, the values of Area times Runoff CN are summed and divided by the watershed area (MDEQ, 2010; MDEQ, 2016; McCuen RH, 2004).

Table 8. Watershed Curve Numbers, Annual Runoff and Slopes of 12 Michigan Rivers Located in the Lake Superior Watershed

			Lake Superior Watershed Rivers: Curve Number Basis					River Slope Calculation		
Watershed Reference Number	**River**	**Annual Watershed Runoff (mm/year)**	**Watershed Curve Number (CN)**	**CN Watershed Area (kilometers^2)**	**Number of CN Polygons**	**Average Area of CN Polygons (kilometers^2)**	**Polygon Area_CN**	**River Slope (m/m)**	**Slope: River Length Evaluated (meters)**	**Slope Method Basis**
48	Falls River	337	60.9	118	2,795	0.042	7,166	0.0053	10,794	EGLE
39	Au Train	439	67.4	284	4,472	0.064	19,162	0.0006	26,354	WSU
62	Waiska River	489	72.6	384	5,999	0.064	27,916	0.0013	40,023	EGLE
43	Chocolay River	851	63.5	398	8,098	0.049	25,258	0.0032	59,953	EGLE
45	Dead River	423	65.6	421	8,764	0.048	27,666	0.0045	72,735	EGLE
61	Two Hearted River	533	66.8	536	6,292	0.085	35,837	0.0010	65,561	EGLE
40	Black River (Gogebic)	406	77.6	632	21,092	0.030	48,999	0.0037	40,234	USGS
51	Montreal River	421	76.8	253	8,182	0.031	19,458	0.0042	72,023	WSU
56	Presque Isle River	363	76.0	770	30,739	0.025	58,536	0.0020	69,363	USGS
60	Tahquamenon River	405	68.3	2096	27,980	0.075	143,189	0.0002	107,826	USGS
55	Portage River[1]	497	72.8	2569	65,300	0.039	186,894	0.0015	122,445	WSU
53	Ontonagon River	346	71.4	3492	103,805	0.034	249,396	0.0032	160,423	WSU
	Minimum Value:	**337**	**60.9**	**118**	**2,795**	**0.025**	**7,166**	**0.0002**		
	Average Value:	**459**	**70.0**	**996**	**24,460**	**0.049**	**70,790**	**0.0026**		
	Maximum Value:	**851**	**77.6**	**3,492**	**103,805**	**0.085**	**249,396**	**0.0053**		
	Area Weighted:	**427**	**71.1**	**11,953**	**293,518**	**Totals: Lake Superior Watershed CN**		**0.0022**		

1. Mean basin precipitation for the Lake Superior watershed is 759.1 millimeters; Basis: Hunter et al. (2015), mean precipitation 1900 to 2014.
2. Mean basin temperature for the Lake Superior watershed is 3.11 °C; Basis: Hunter et al. (2015), period of record 1948 to 2014.

Table 9. Watershed Curve Numbers, Annual Runoff and Slopes of 26 Michigan Rivers Located in the Lake Michigan Watershed

			Lake Michigan Watershed Rivers: Curve Number Basis					River Slope Calculation		
Watershed Reference Number	River	Annual Watershed Runoff (mm/year)	Watershed Curve Number (CN)	CN Watershed Area (kilometers^2)	Number of CN Polygons	Average Area of CN Polygons (kilometers^2)	Polygon Area_CN	River Slope (m/m)	Slope: River Length Evaluated (meters)	Slope Method Basis
44	Days River	195	69.8	159	3,007	0.053	11,100	0.0025	55,327	EGLE
19	Lincoln River	341	67.4	257	11,494	0.022	17,340	0.0008	55,784	EGLE
57	Rapid River	102	71.7	358	10,132	0.035	25,684	0.0027	67,771	EGLE
28	Platte River	471	54.1	361	9,567	0.038	19,515	0.0002	16,237	WSU
5	Big Sable	418	61.8	427	13,737	0.031	26,348	0.0004	27,412	WSU
24	Pentwater River	374	60.7	430	16,448	0.026	26,129	0.0015	44,053	EGLE
8	Macatawa River	376	75.9	451	14,334	0.031	34,220	0.0001	20,847	WSU
58	Sturgeon River	346	63.4	568	9,940	0.057	36,021	0.0012	68,236	USGS
9	Boardman	484	56.1	573	17,761	0.032	32,144	0.0020	38,968	WSU
4	Betsie River	429	57.0	603	14,997	0.040	34,364	0.0003	20,376	WSU
7	Black River (West)	436	69.1	738	28,779	0.026	50,985	0.0007	39,107	USGS
10	Pine River[1]	508	61.5	808	30,854	0.026	49,734	0.0020	65,045	USGS
63	Whitefish River	341	69.9	811	16,841	0.048	56,688	0.0024	74,796	EGLE
42	Cedar River	247	76.8	977	33,277	0.029	75,035	0.0013	90,284	EGLE
13	Elk River	612	60.3	1299	28,262	0.046	78,363	0.0001	101,023	EGLE
37	White River	447	60.6	1179	33,739	0.035	71,516	0.0012	104,768	USGS
47	Ford River	276	70.2	1195	31,622	0.038	83,852	0.0013	148,221	USGS
25	Pere Marquette River	422	58.7	1672	49,930	0.033	98,167	0.0011	109,757	USGS
46	Escanaba River	332	65.1	2340	57,034	0.041	152,349	0.0019	152,853	WSU
49	Manistique River	429	67.7	3806	55,070	0.069	257,863	0.0005	137,438	USGS
20	Manistee River	476	54.1	4347	110,636	0.039	235,048	0.0007	280,026	USGS
17	Kalamazoo River	309	70.8	5258	205,179	0.026	372,303	0.0006	236,574	USGS
22	Muskegon River	318	63.9	7055	267,852	0.026	450,597	0.0005	332,011	WSU
50	Menominee River[1]	304	68.7	6563	176,674	0.037	451,050	0.0016	302,337	WSU
34	St. Joseph River[1]	343	72.4	7795	230,821	0.034	564,219	0.0011	290,828	WSU
14	Grand River[1]	284	75.2	14097	618,266	0.023	1,060,329	0.0003	345,590	WSU
	Minimum:	**102**	**54.1**	**159**	**3,007**	**0.022**	**11,100**	**0.0001**		
	Average:	**370**	**65.5**	**2,466**	**80,625**	**0.036**	**168,114**	**0.0011**		
	Maximum:	**612**	**76.8**	**14,097**	**618,266**	**0.069**	**1,060,329**	**0.0027**		
	Area Weighted:	**343**	**68.2**	**64,128**	**2,096,253**	**Totals: Lake Michigan Watershed CN**		**0.0008**		

1. Mean basin precipitation for the Lake Michigan watershed is 806.6 millimeters; Basis: Hunter et al. (2015), mean precipitation 1900 to 2014.
2. Mean basin temperature for the Lake Michigan watershed is 6.60 °C; Basis: Hunter et al. (2015), period of record 1948 to 2014.

Table 10. Watershed Curve Numbers, Annual Runoff and Slopes of 14 Michigan Rivers Located in the Lake Huron Watershed

			Lake Huron Watershed Rivers: Curve Number Basis					River Slope Calculation		
Watershed Reference Number	River	Annual Watershed Runoff (mm/year)	Watershed Curve Number (CN)	CN Watershed Area ($kilometers^2$)	Number of CN Polygons	Average Area of CN Polygons ($kilometers^2$)	Polygon Area_CN	River Slope (m/m)	Slope: River Length Evaluated (meters)	Slope Method Basis
38	Willow Creek	232	79.0	247	3,291	0.075	19,486	0.0014	41,263	EGLE
33	Sebewaing River	186	78.9	269	1,914	0.141	21,245	0.0015	29,773	USGS
23	Oqueoc River	289	64.6	370	13,154	0.028	23,890	0.0012	68,875	EGLE
26	Pigeon River	208	80.6	378	3,686	0.102	30,439	0.0005	36,721	WSU
41	Carp River	284	72.8	440	9,415	0.047	32,027	0.0012	73,091	EGLE
52	Munuscong River	385	75.7	463	7,725	0.060	35,077	0.0006	56,270	EGLE
18	Kawkawlin River	198	79.2	585	13,961	0.042	46,344	0.0005	65,178	USGS
1	Au Gres River[1]	228	75.0	630	23,995	0.026	47,242	0.0013	65,661	USGS
54	Pine River	378	71.1	709	8,984	0.079	50,426	0.0003	20,019	WSU
30	Rifle River	327	67.0	987	45,997	0.021	66,107	0.0009	96,619	WSU
36	Thunder Bay River	244	66.8	3114	95,533	0.033	208,126	0.0007	80,752	WSU
11	Cheboygan River	322	61.5	3689	144,499	0.026	226,984	0.0035	78,413	WSU
2	Au Sable River[1]	306	55.9	4349	161,893	0.027	242,998	0.0008	196,019	WSU
32	Saginaw River[1]	248	75.5	15878	572,377	0.028	1,198,520	0.0004	187,162	WSU
	Minimum Value:	**186**	**55.9**	**247**	**1,914**	**0.021**	**19,486**	**0.0003**		
	Average Value:	**274**	**71.7**	**2,293**	**79,030**	**0.052**	**160,636**	**0.0011**		
	Maximum Value:	**385**	**80.6**	**15,878**	**572,377**	**0.141**	**1,198,520**	**0.0035**		
	Area Weighted:	**270**	**70.0**	**32,107**	**1,106,424**	**Totals: Lake Huron Watershed CN**		**0.0009**		

1. Mean basin precipitation for the Lake Huron watershed is 809.7 millimeters; Basis: Hunter et al. (2015), mean precipitation 1900 to 2014.
2. Mean basin temperature for the Lake Huron watershed is 6.99 °C; Basis: Hunter et al. (2015), period of record 1948 to 2014.

Table 11. Watershed Curve Numbers, Annual Runoff, and Slopes of Eight Rivers Located Within the Lake Erie Watershed

			Lake Erie Watershed Rivers: Curve Number Basis					River Slope Calculation			
Watershed Reference Number	River	Annual Watershed Runoff (mm/year)	Watershed Curve Number (CN)	CN Watershed Area (kilometers^2)	Number of CN Polygons	Average Area of CN Polygons (kilometers^2)	Polygon Area_CN	River Slope (m/m)	Slope: River Length Evaluated (meters)	Slope Method Basis	Receiving Water Elevation (meters)
35	Stoney Creek	233	75.7	319.5	8,810	0.036	24,179	0.0006	37,580	WSU	174.2
27	Pine River	530	77.6	504.1	8,883	0.057	39,126	0.0009	76,476	EGLE	175.7
3	Belle River	228	79.1	587.4	18,578	0.032	46,439	0.0007	60,796	WSU	175.7
31	Rouge River	230	81.5	1,180.5	39,365	0.030	96,163	0.0007	60,711	WSU	174.7
6	Black River (East)	214	76.8	1,839.5	42,213	0.044	141,248	0.0006	90,606	USGS	176.3
12	Clinton River	268	77.5	2,062.8	78,113	0.026	159,880	0.0011	100,214	WSU	175.0
15	Huron River	233	73.9	2,257.4	110,454	0.020	166,740	0.0006	176,650	WSU	174.2
29	River Raisin	256	79.2	2,682.0	77,161	0.035	212,523	0.0006	223,699	USGS	174.2
	Minimum Value:	**214**	**73.9**	**320**	**8,810**	**0.020**	**24,179**	**0.0006**			
	Average Value:	**274**	**77.7**	**1,429**	**47,947**	**0.035**	**110,787**	**0.0007**			
	Maximum Value:	**530**	**81.5**	**2,682**	**110,454**	**0.057**	**212,523**	**0.0011**			
	Area Weighted:	**254**	**77.5**	**11,433**	**383,577**	**Totals: Lake Erie Watershed CN**		**0.0007**			

1. Mean basin precipitation for the Lake St. Clair watershed is 855.3 millimeters; Basis: Hunter et al. (2015), period of record 1900 to 2014.
2. Mean precipitation data from the Lake St. Clair watershed incorporates the Belle River (3), Black River-East (6), Clinton River (12), and Pine River (27).
3. Mean basin precipitation for the Lake Erie watershed is 890.4 millimeters; Basis: Hunter et al. (2015), period of record 1900 to 2014.
4. Mean basin temperature for the Lake St. Clair watershed is 8.53 °C; Basis: Hunter et al. (2015), period of record 1948 to 2014.
5. Mean basin temperature for the Lake Erie watershed is 9.30 °C; Basis: Hunter et al. (2015), period of record 1948 to 2014.

Table 12. Watershed Curve Numbers, Annual Runoff, and Slopes for Five Sub-Watersheds of the Au Sable River (2), Boardman River (9), Grand River (14A), Huron River (15), and S. Joseph River (34A)

		Lake Erie Watershed Rivers: Curve Number Basis					River Slope Calculation			
Dam and Corresponding River	Annual Watershed Runoff (mm/year)	Watershed Curve Number (CN)	CN Watershed Area (kilometers^2)	Number of CN Polygons	Average Area of CN Polygons (kilometers^2)	Polygon Area_CN	River Slope (m/m)	Slope: River Length Evaluated (meters)	Slope Method Basis	Receiving Water Elevation (meters)
2A. Mio Dam, Au Sable River	323	51.7	3,328.1	98,536	0.034	172,127	0.0007	64,236	WSU	293.6
9A. Brown Bridge Dam, Boardman	460	53.3	395.7	7,770	0.051	21,111	0.0015	7,696	WSU	242.7
14A. Weber Dam, Grand River	252	76.0	7,441.3	301,779	0.025	573,304	0.0004	182,121	WSU	208.6
15A. Ford Dam, Huron River	279	73.0	2,085.2	104,723	0.020	152,233	0.0006	116,215	WSU	208.6
34A. Riley Dam, St. Joseph River	309	75.4	1,356.7	33,437	0.041	102,356	0.0008	55,040	WSU	265.8
Minimum Value:	**252**	**51.7**	**396**	**7,770**	**0.020**	**21,111**	**0.0004**			
Average Value:	**325**	**65.9**	**2,921**	**109,249**	**0.034**	**204,226**	**0.0008**			
Maximum Value:	**460**	**76.0**	**7,441**	**301,779**	**0.051**	**573,304**	**0.0015**			

The watershed curve numbers presented in Table 8, Table 9, Table 10, Table 11, and Table 12 represent the portion of the watershed located within the State of Michigan. Fifty four of the 60 watersheds (and all five sub-watersheds) are located entirely within the State of Michigan; exceptions include the River Raisin (29) and the St. Joseph River (34) located in the Lower Peninsula of Michigan, and the Black River (40), Menominee River (50), Montreal River (51), Ontonagon River (53), and Presque Isle River (56) located in the Upper Peninsula of Michigan. With respect to the 60 rivers and five sub-watersheds that were evaluated in this research, the number of polygons in each watershed, the average area of each polygon, and the area weighted watershed curve number are presented in Table 8, Table 9, Table 10, Table 11, and Table 12. In conjunction with the calculation of the watershed CNs, this research utilized the percentage of the watershed covered in upland wetlands, aquatic wetlands, reservoirs, and surface water (rivers and lakes) in the regression analysis discussed in Chapter 4.

3.6 Mean Basin Precipitation and Temperature

Mean basin precipitation and temperature for the watershed of each Great Lake was compiled by the NOAA Great Lakes Environmental Research Laboratory (GLERL, 2020) utilizing the methodology developed by Hunter TS et al. (2015). The mean basin precipitation and temperature for the Lake Superior watershed are 759 millimeters/year (1900-2014) and 3.1°C (1948-2014), respectively. The mean basin precipitation and temperature for the Lake Michigan watershed are 807 millimeters/year (1900-2014) and 6.6°C (1948-2014), respectively. The mean basin precipitation and temperature for the

Lake Huron watershed are 810 millimeters/year (1900-2014) and 7.0°C (1948-2014), respectively.

NOAA GLERL separates the Lake Erie watershed into two sub-watersheds, Lake St. Clair and Lake Erie. The Lake St. Clair watershed includes the discharge of four rivers, Belle River (3), Black River-East (6), Clinton River (12), and Pine River (27) and the four remaining rivers discharge into the Lake Erie watershed (see Tables 5 and 11). With respect to the Lake St. Clair watershed, the mean basin precipitation and temperature are 855 millimeters/year (1900-2014) and 8.53°C (1948-2014), respectively. With respect to the Lake Erie watershed, the mean basin precipitation and temperature are 890 millimeters/year (1900-2014) and 9.3°C (1948-2014), respectively.

3.7 Radiometric Dating of Sediment Cores, Five Reservoirs

This research included re-evaluation of reservoir sediment accumulation rates based on radiometric dating using ^{137}Cs and ^{210}Pb for five reservoirs that are sub-watersheds of the Au Sable River (2), Boardman River (9), Grand River (14), Huron River (15), and St. Joseph River (34). Vibracore sediment cores were collected for radiometric testing using a 345 pound vibracore unit that operates at 14,000 vibrations per minute (see Figure 10).

Figure 10. Photograph of the Vibracore Sampling Equipment Used to Collect 4-inch Sediment Cores for Radiometric Dating (GLEC, 2011)

Radiometric testing of sediment cores to determine reservoir sedimentation rates was completed at the following dams (Wayne State University, 2017):

- Mio Dam (2A), Au Sable River
- Brown Bridge Dam (9A), Boardman River
- Webber Dam (14A), Grand River
- Ford Dam (15A), Huron River
- Riley Dam (34A), St. Joseph River

With respect to this study, the depositional rates of sediment in manmade reservoirs were determined utilizing short-lived radionuclides, ^{210}Pb and ^{137}Cs, derived primarily from natural and anthropogenic (nuclear weapons testing) sources, respectively (Wayne State University, 2017). The presence of ^{137}Cs and ^{210}Pb in sediments is due to atmospheric deposition (Alighalehbabakhani et al, 2017a; Alighalehbabakhani et al, 2017b; Kumar A et al, 2016; Jweda J and Baskaran M, 2011; Baskaran et al, 2015; Mabit et al, 2013; and Mabit et al., 2014).

Naturally occurring atmospheric ^{210}Pb is constantly released from the decay of ^{222}Rn within the ^{238}U decay series ($^{238}U \rightarrow \ldots ^{226}Ra \rightarrow ^{222}Rn \rightarrow \ldots ^{210}Pb$); ^{222}Rn diffuses primarily from terrestrial rocks and is released into the atmosphere where it undergoes radioactive decay to ^{210}Pb (Baskaran M and Naidu AS, 1995; Baskaran M et al, 2015). Precipitation removes atmospheric ^{210}Pb within a time scale of approximately 2-weeks and the ^{210}Pb is subsequently deposited onto lakes and reservoirs where it is removed from the water column via adsorption on to suspended particulate matter (Jweda J and Baskaran M, 2011; Baskaran et al, 2014; Sanchez-Cabeza JA and Ruiz-Fernandez JC, 2012). The half-life of ^{210}Pb is 22.3 years and this radiometric testing method is effective in dating sediments that have been deposited within the past 120 years (approximately five half-lives).

Because a number of factors can influence the vertical profile of ^{210}Pb in a sediment core such as erosion/redeposition and bioturbation of sediments, a second line of evidence is typically used to validate the ^{210}Pb-based radiometric dating such as ^{137}Cs (Baskaran et al. 2014; Mabit et al. 2014). In contrast to ^{210}Pb which is naturally occurring, the presence of ^{137}Cs is anthropogenic and was mainly introduced into the atmosphere beginning in 1952 as a result of global thermonuclear atmospheric testing (Baskaran et al. 2014; Mabit et al. 2014). The depositional process of ^{137}Cs is similar to that of ^{210}Pb; however, there is an important difference. Because the deposition of ^{137}Cs peaked in approximately 1963 in conjunction with the peak in worldwide atmospheric thermonuclear testing, this peak provides a marker in a sediment core where the rate of subsequent sediment deposition can be estimated and is the basis for measuring sediment accumulation rates (Baskaran et al, 2011; Mabit et al, 2013). In addition, a second ^{137}Cs peak is sometimes measured in sediment cores that corresponds to the initiation of atmospheric thermonuclear testing during 1952 (Baskaran et al, 2014; Mabit et al., 2013). Since 1963, atmospheric ^{137}Cs has steadily declined. Although the 1986 Chernobyl nuclear accident resulted in a measurable increase of ^{137}Cs in the atmosphere, this was negligible compared to the ^{137}Cs derived from global fallout resulting from the peak atmospheric thermonuclear testing during 1963 (Jweda J and Baskaran M, 2011).

During 2010 and 2011, vibracore sediment coring was conducted at Mio Dam (2A; May 2011), Brown Bridge Dam (9A; October 2010); Webber Dam (14A; July 2010), Ford Lake Dam (15A; December 2011), and Riley Dam (34A; July 2010). The sediment cores were subsequently frozen and cut into one-centimeter-thick slices for ^{137}Cs and ^{210}Pb radiometric testing (Wayne State University, 2017). Sample processing and radiometric testing procedures as well as the models used to interpret the sediment accumulation rates are described in detail in the following publications: Baskaran et al. (2015); Kumar et al. (2016); Alighalehbabakhani et al (2017a); and, Alighalehbabakhani et al (2017b). The radiometric data and graphs of cumulative mass depth were published in a report that was prepared for the USACE Detroit District and titled *Sediment Yield and Dam Capacity in the Great Lakes Watershed* (Wayne State University, 2017)

In conjunction with this research, Dr. Mark Baskaran, Wayne State University re-evaluated the ^{137}Cs and ^{210}Pb radiometric data for all sediment cores in all five reservoirs utilized in this research. With respect to the ^{137}Cs radiometric data, a sediment core was selected to recalculate annual reservoir sediment delivery to the reservoir if there was good definition of the 1963 ^{137}Cs peak. With respect to the ^{210}Pb cumulative mass depth, a sediment core was selected to recalculate annual sediment delivery to the reservoir if the plotted radiometric data was linear. An example of a sediment core that was selected based on the characteristics listed above is shown in Figure 11 (Sediment Core RD6, Riley Dam, St. Joseph River). Radiometric data selected for re-evaluation of the reservoir sedimentation rate is highlighted in green tables presented in Figure 12, Figure 13, Figure 14, Figure 15, and Figure 16.

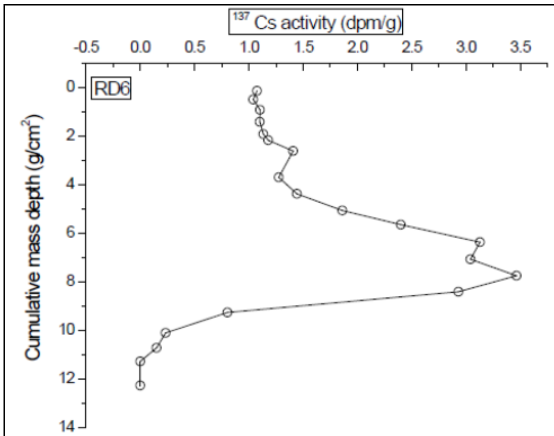
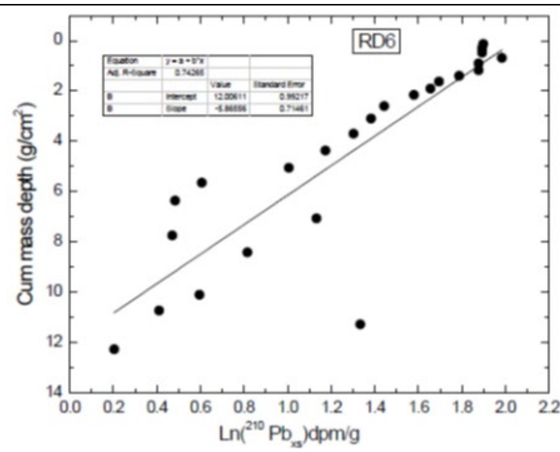
	
Vertical profile of ^{137}Cs activity plotted against cumulative mass depth (Riley Dam RD6, from Figure 3-14; Wayne State University, 2017)	Vertical profile of Ln($^{210}Pbxs$) plotted against cumulative mass depth. (Riley Dam RD6, from Figure 3-78; Wayne State University, 2017)

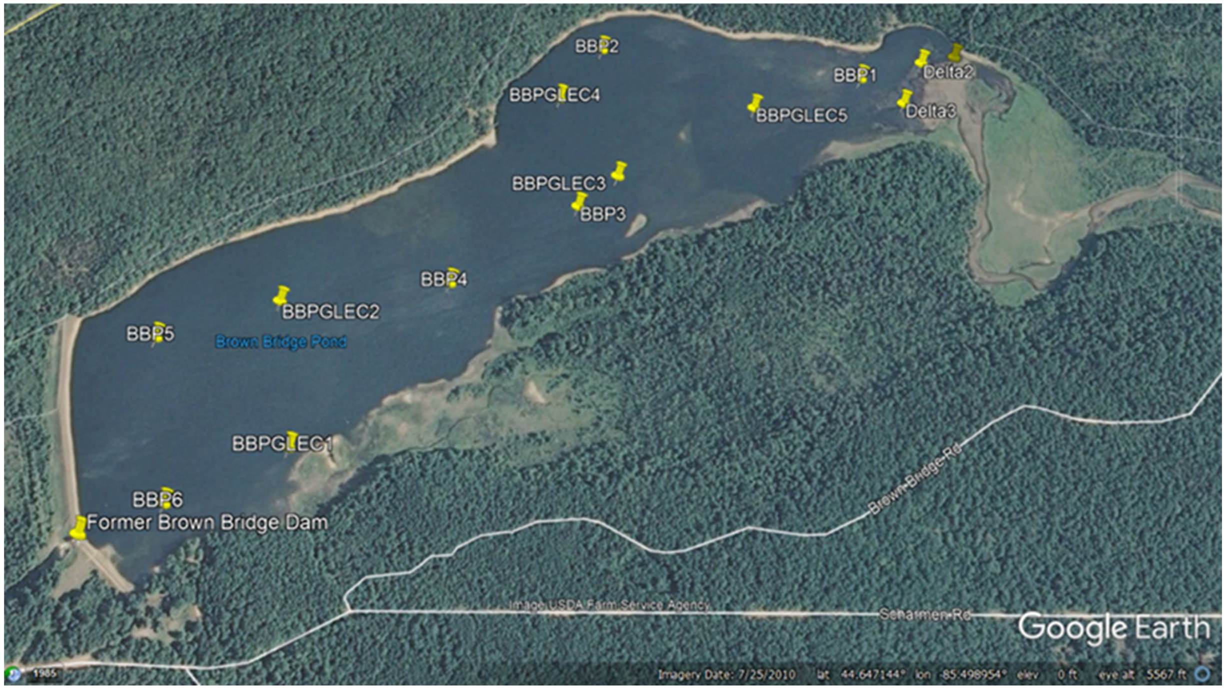
Figure 11. Radiometric Data, Sediment Core RD6, Riley Dam (34A), St. Joseph River

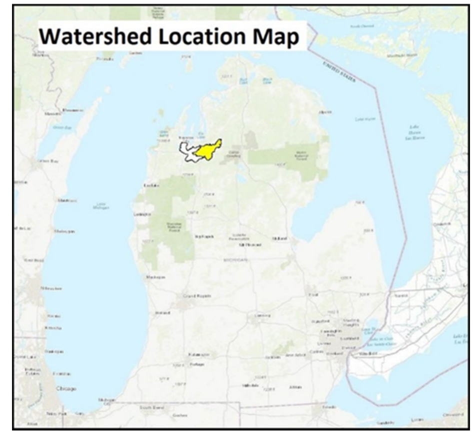
Sample Designation	Latitude	Longitude	Water Depth (meters)	Core Length (cm)
MIO-1	44.65972	-84.13607	7.3	76.2
MIO-2	44.65391	-84.15247	14.7	127.0
MIO-3	44.66897	-84.16369	3.9	45.7
MIO-4	44.66254	-84.17223	6.2	50.8
MIO-5	44.6728	-84.18703	1.5	33.0
MIO-6	44.67221	-84.20005	<1	91.4
MIO-7	44.67086	-84.18803	8.0	25.4
MIO-8	44.67151	-84.19457	<1	68.6
MIO-9	44.66913	-84.19472	1.4	30.5
MIO-10	44.66618	-84.18114	3.1	66.0
MIO-11	44.67358	-84.20537	3.0	132.1

Core Sample Designation	210Pbxs-based Mass accum. rate (g cm-2 yr-1)	137Cs-peak Mass accum. rate (g cm-2 yr-1)
MIO1	0.19	Not datable
MIO2	0.17	0.12
MIO3	Not datable	Not datable
MIO4	Not datable	Not datable
MIO5	Not datable	Not datable
MIO6	**0.35**	**0.36**
MIO7	Not datable	Not datable
MIO8	Not datable	1.47
MIO10	0.2	0.11
MIO11	Not datable	1.85
Average All Values:	**0.23**	**0.78**
	Selected Value, M Baskaran, WSU	

2A, Mio Dam Sediment Accumulation Rate		
Reservoir Pool Area	**661**	acres
Reservoir Pool Area	26,749,720,952	$centimeters^2$
AVG: $^{210}Pb/^{137}Cs$	**0.36**	**(g cm-2 yr-1)**
AVG: $^{210}Pb/^{137}Cs$	9,496,150,938	grams/year
AVG: $^{210}Pb/^{137}Cs$	**9,496**	**metric tonnes/year**

Figure 12. Mio Dam (2A) Estimated Sediment Accumulation Rate, Au Sable River



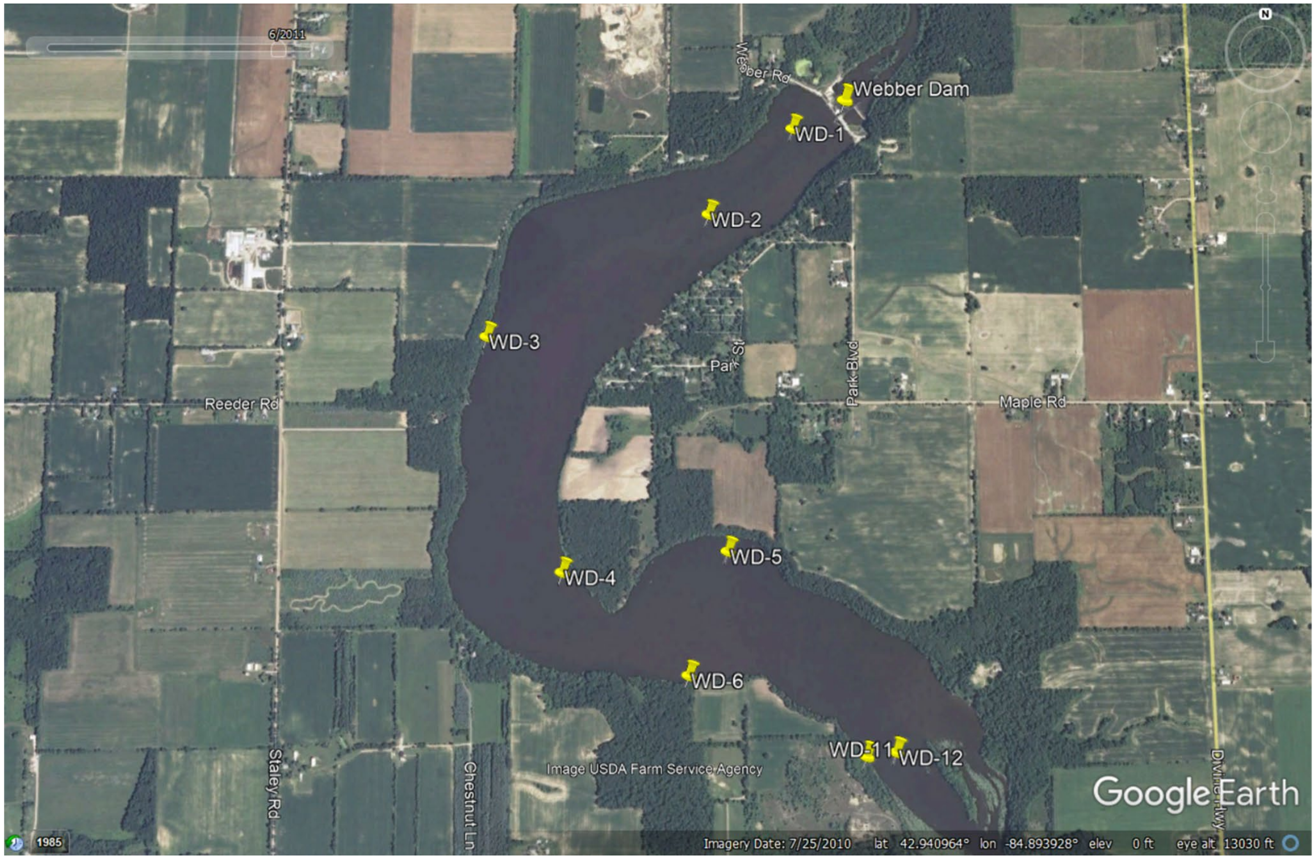


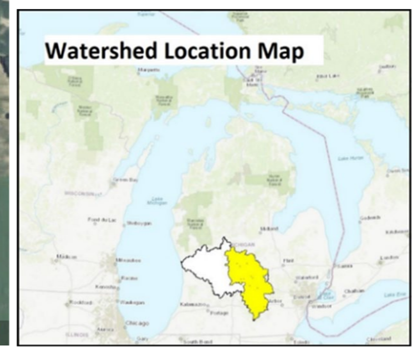
Sample Designation	Latitude	Longitude	Water Depth (meters)	Core Length (cm)
BBPGLEC5	44.65014	-85.49564	1.5	25
BBP1	44.65068	-85.49317	2.6	76
BBP2	44.65122	-85.49909	4.5	72
BBP3	44.64842	-85.4996	4.8	56
BBP4	44.64716	-85.50233	4.4	33
BBP5	44.6463	-85.50844	7.8	51
BBP6	44.64385	-85.50781	4.4	44
BBPGLEC1	44.64465	-85.50542	3.1	36
BBPGLEC2	44.64687	-85.50591	5.9	56
BBPGLEC3	44.64894	-85.49873	2.1	53
BBPGLEC4	44.65032	-85.50004	3.8	45
Delta1	44.65107	-85.49097	0.9	107
Delta2	44.65096	-85.49174	0.7	117
Delta3	44.65022	-85.49224	0.4	59

Core Sample Designation	210Pbxs-based Mass accum. rate (g cm-2 yr-1)	137Cs-peak Mass accum. rate (g cm-2 yr-1)
BBP-1	**0.11**	**0.13**
BBP-2	**0.12**	**0.09**
BBP-3	**0.08**	**0.04**
BBP-4	0.045	Not datable
BBP-5	**0.11**	0.06
BBP-6	0.05	0.02
BBPGLEC1	0.09	0.03
BBPGLEC2	0.16	0.01
BBPGLEC3	0.09	0.05
BBPGLEC4	1.56	0.01
BBPGLEC5	0.05	0.02
DELTA1	0.11	0.78
DELTA2	Not datable	**0.46**
DELTA3	0.23	0.23
Average All Values:	**0.22**	**0.15**
	Selected Value, M Baskaran, WSU	

9A, Brown Bridge Dam Sediment Accumulation Rate		
Reservoir Pool Area	**191**	acres
Reservoir Pool Area	7,729,495,767	$centimeters^2$
AVG: $^{210}Pb/^{137}Cs$	**0.14**	**(g cm-2 yr-1)**
AVG: $^{210}Pb/^{137}Cs$	1,101,453,147	grams/year
AVG: $^{210}Pb/^{137}Cs$	**1,101**	**metric tonnes/year**

Figure 13. Brown Bridge Dam (9A) Estimated Sediment Accumulation Rate, Boardman River



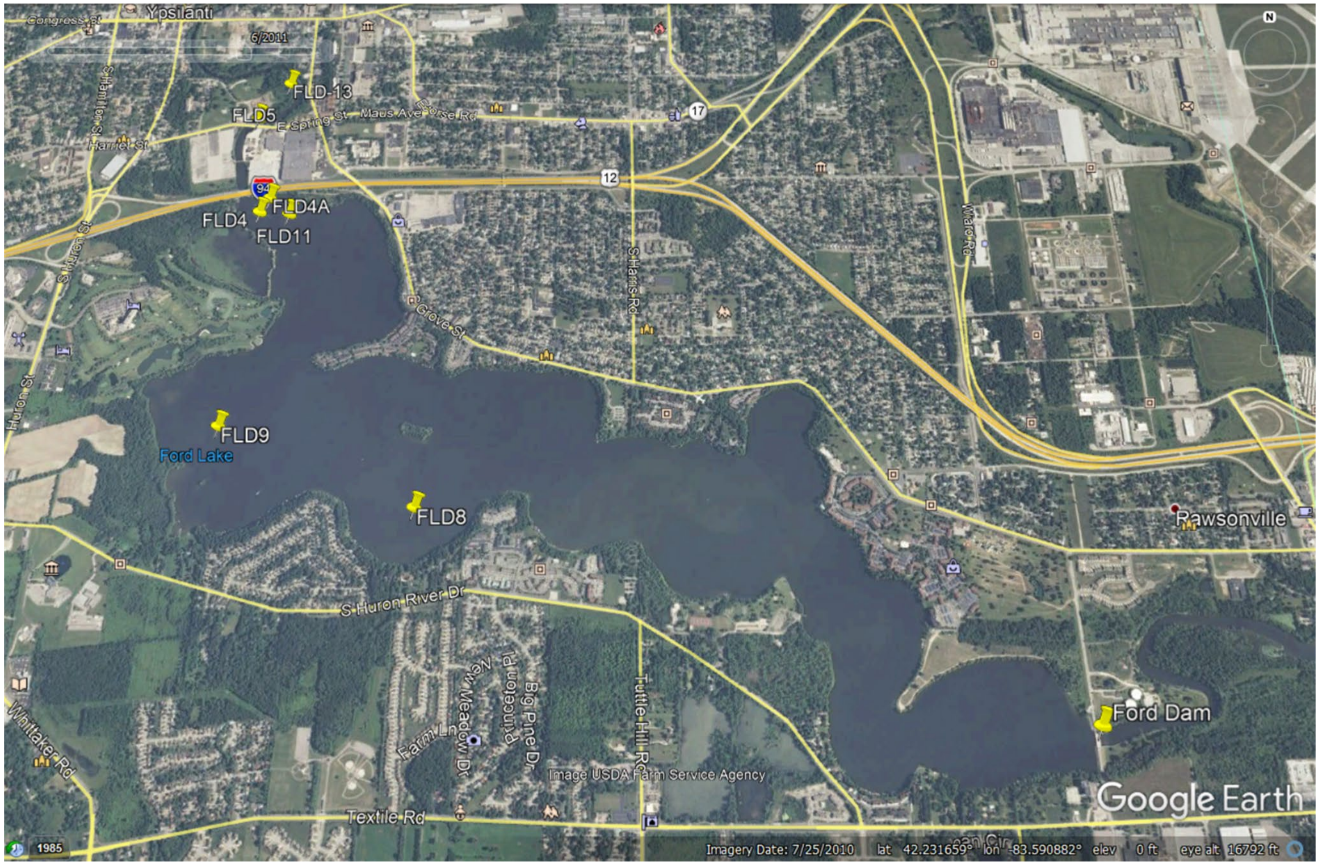


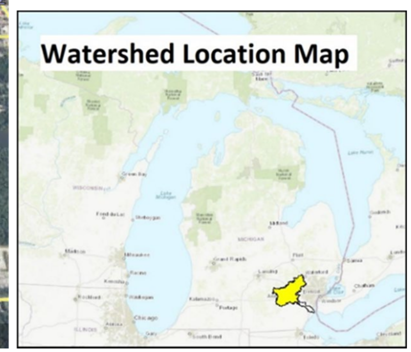
Sample Designation	Latitude	Longitude	Water Depth (meters)	Core Length (cm)
WD-1	42.95261	-84.90424	4.4	106.7
WD-2	42.94979	-84.90795	4.1	180.3
WD-3	42.94584	-84.91759	2.5	77.5
WD-4	42.93842	-84.91425	1.0	34.3
WD-5	42.93907	-84.90719	2.8	114.3
WD-6	42.93526	-84.90887	0.9	91.4
WD-11	42.93281	-84.90141	1.3	63.5
WD-12	42.93294	-84.90017	3.0	59.7

Core Sample Designation	210Pbxs-based Mass accum. rate (g cm-2 yr-1)	137Cs-peak Mass accum. rate (g cm-2 yr-1)
WD-1	**0.64**	**0.65**
WD-2	**0.70**	**0.93**
WD-3	0.4	Not datable
WD-4	0.12	Not datable
WD-5	0.86	Not datable
WD-6	0.37	0.63
WD-11	0.11	0.54
WD-12	Not datable	0.3
Average All Values:	**0.46**	**0.61**
	Selected Value, M Baskaran, WSU	

14A, Weber Dam Estimated Sediment Accumulation Rate		
Reservoir Pool Area	**660**	acres
Reservoir Pool Area	26,709,252,388	centimeters^2
AVG: ^{210}Pb/^{137}Cs	**0.73**	**(g cm-2 yr-1)**
AVG: ^{210}Pb/^{137}Cs	19,497,754,243	grams/year
AVG: ^{210}Pb/^{137}Cs	**19,498**	**metric tonnes/year**

Figure 14. Webber Dam (14A) Estimated Sediment Accumulation Rate, Grand River



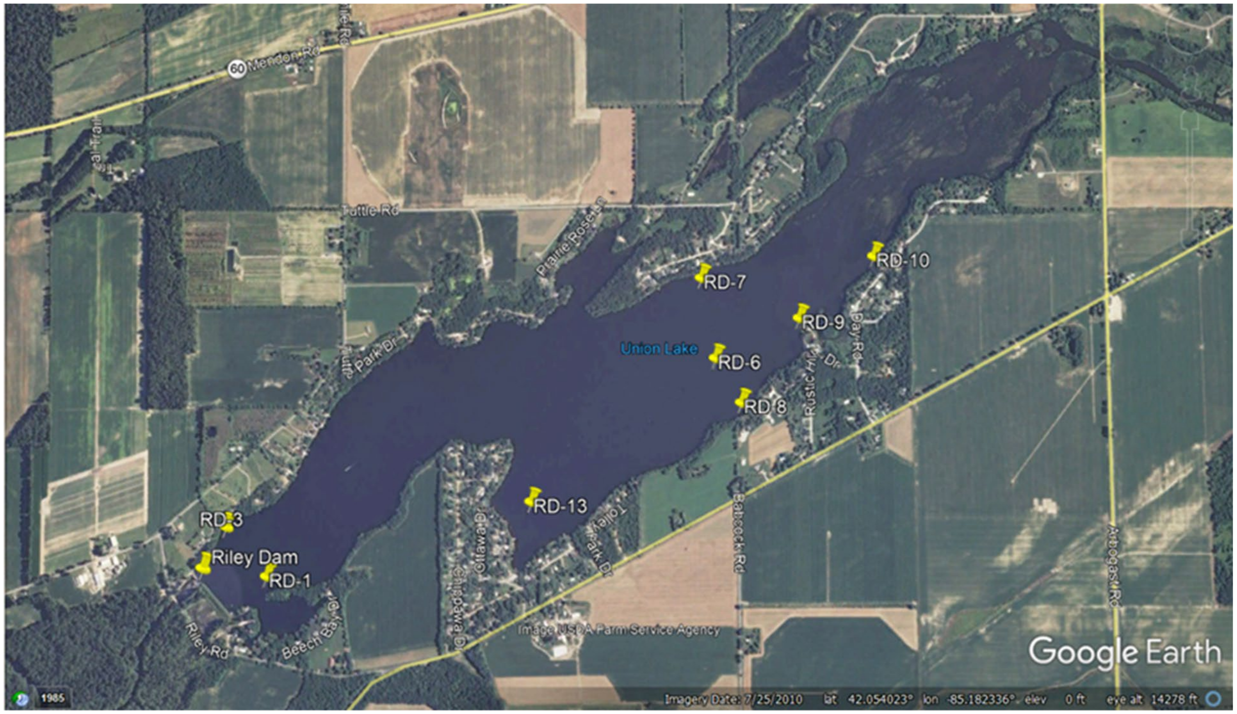


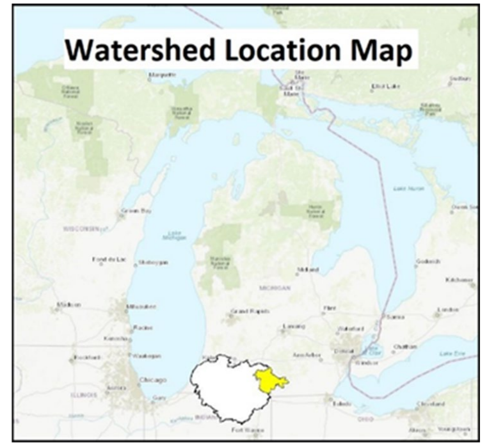
Sample Designation	Latitude	Longitude	Water Depth (meters)	Core Length (cm)
FLD4	42.22976	-83.60585	1.1	20
FLD4A	42.23050	-83.60531	1.1	85
FLD5	42.23498	-83.60678	0.6	53
FLD8	42.21539	-83.59466	4.8	90
FLD9	42.21906	-83.60646	3.3	90
FLD11	42.22965	-83.60397	1.4	64
FLD-13	42.23698	-83.60499	0.8	43

Core Sample Designation	210Pbxs-based Mass accum. rate (g cm-2 yr-1)	137Cs-peak Mass accum. rate (g cm-2 yr-1)
FLD4	Not datable	Not datable
FLD4A	Not datable	Not datable
FLD5	Not datable	Not datable
FLD8	1.08	**0.38**
FLD9	0.39	**0.22**
FLD11	0.32	**0.27**
FLD13	Not datable	Not datable
Average All Values:	**0.60**	**0.29**
	Selected Value, M Baskaran	

15A, Ford Dam Sediment Accumulation Rate		
Reservoir Pool Area	**987**	acres
Reservoir Pool Area	39,942,472,889	centimeters^2
AVG: $^{210}Pb/^{137}Cs$	**0.29**	**(g cm-2 yr-1)**
AVG: $^{210}Pb/^{137}Cs$	11,583,317,138	grams/year
AVG: $^{210}Pb/^{137}Cs$	**11,583**	**metric tonnes/year**

Figure 15. Ford Dam (15A) Estimated Sediment Accumulation Rate, Huron River





Sample Designation	Latitude	Longitude	Water Depth (meters)	Core Length (cm)
RD-1	42.04436	-85.19953	4.0	51
RD-3	42.04616	-85.20154	3.2	99
RD-6	42.05231	-85.17745	2.1	64
RD-7	42.05526	-85.17814	1.2	27
RD-8	42.05069	-85.17617	1.7	41
RD-9	42.05378	-85.17329	2.1	46
RD-10	42.05606	-85.16958	1.6	76
RD-13	42.04707	-85.18655	2.4	71

Core Sample Designation	210Pbxs-based Mass accum. rate (g cm-2 yr-1)	137Cs-peak Mass accum. rate (g cm-2 yr-1)
RD-1	0.2	0.17
RD-3	**0.28**	**0.29**
RD-6	**0.18**	**0.17**
RD-7	0.19	0.06
RD-8	0.16	0.13
RD-9	0.12	0.16
RD-10	**0.20**	**0.16**
RD-13	0.18	0.22
Average All Values:	**0.19**	**0.17**
	Selected Value, M Baskaran, WSU	

34A, Riley Dam Estimated Sediment Accumulation Rate		
Reservoir Pool Area	**518**	acres
Reservoir Pool Area	20,962,716,268	centimeters^2
AVG: $^{210}Pb/^{137}Cs$	**0.21**	**(g cm-2 yr-1)**
AVG: $^{210}Pb/^{137}Cs$	4,472,046,137	grams/year
AVG: $^{210}Pb/^{137}Cs$	**4,472**	**metric tonnes/year**

Figure 16. Riley Dam (34A) Estimated Sediment Accumulation Rate, St. Joseph River

The ^{210}Pbxs-based mass accumulation rate (grams centimeter^{-2} per year^{-1}) and ^{137}Cs-peak mass accumulation rate (grams centimeter^{-2} year^{1}) were averaged and utilized to recalculate the sediment accumulation rate for each of the five reservoirs (see Figures 12-16). The annual reservoir sedimentation accumulation rate is calculated by multiplying the average ^{137}Cs and ^{210}Pb mass accumulation rate (grams centimeter^{-2} year^{1}) times the reservoir pool surface area (square centimmeters) as reported by Michigan Department of Environment, Great Lakes, and Energy (EGLE) reservoir database (EGLE, 2020). The recalculated annual sediment accumulation rate for each reservoir is summarized on Table 13.

Table 13. Comparison of Reservoir Sedimentation Rates of Five Sub-Watersheds Using ^{137}Cs and ^{210}Pb Radiometric Dating

	Wayne State University (2017)	**Alighalehbabakhani et al (2017a)**	**Annual Sediment Accumulation Rate, Revised**
Dam	**metric tonnes/yr**	**metric tonnes/yr**	**metric tonnes/yr**
2A, Mio Dam, Au Sable River	20,000	5,000	9,500
9A, Brown Bridge Dam: Boardman River	2,000	2,000	1,100
15A, Ford Lake Dam, Huron River	13,000	7,000	12,000
14A, Webber Dam: Grand River	18,000	16,000	19,000
34A, Riley Dam: St. Joseph River	4,000	4,000	4,500

Comparison of the re-calculated reservoir sedimentation accumulation rates for these five reservoirs to prior published results (Alighalehbabakhani et al, 2017a; Wayne State University, 2017) reveals that all three rates are very similar with respect to Webber Dam (14A, Grand River) and Riley Dam (34A, St. Joseph River), and within a factor of two with respect to Mio Dam (2A, Au Sable River), Brown Bridge Dam (9A, Boardman River), and Ford Lake Dam (15A, Huron River). With respect to this research, the average annual rate of sediment accumulation within these five reservoirs served as the dependent variable in the subsequent regression analysis discussed in Chapter 4.

3.8 USACE-Detroit District Maintenance Dredging of Federal Navigation Channels and Harbors

In conjunction with this research, the USACE-Detroit District provided extensive harbor and navigation channel maintenance dredging data for 30 harbors located in Michigan. Of the 60 rivers included in this research, USACE maintained navigation channels and harbors are located at the outlets of 30 of these rivers (see Figure 4). The USACE-Detroit District maintains the navigation channels subject to the Rivers & Harbors Act of 1899 (USACE, 2010b). The horizontal and vertical boundaries of these navigation channels are defined and changes are approved by Congress via periodic amendments to the Rivers & Harbors Act of 1899 (USACE, 2010b). These federal navigation channels represent defined boundaries both laterally and vertically (USACE, 2010b).

The USACE-Detroit District performs annual Condition Assessments for each navigation channel and Harbor. The USACE Condition Assessments involve bathymetric surveys to estimate the amount of sediment that has accumulated in the navigation channel in comparison to the prior year, and that requires maintenance dredging. In addition, the USACE-Detroit District updates Harbor Fact Sheets each year. The Harbor Fact Sheets (USACE, 2020a) provide data regarding the history of the navigation channel, a summary of Rivers and Harbors Authorizations, river and navigation channel features, stakeholders, transportation importance and consequences of not maintaining the navigation channel, as well as the maintenance dredging project requirements and a dredging forecast (USACE, 2020a).

Excessive sedimentation within the USACE navigation channels and harbors can limit shipping (e.g. light loading of freighters) and is an ongoing issue requiring periodic condition assessments (bathymetric surveys) and maintenance dredging to maintain the project depths of the harbors, turning basins, and navigation channels. The USACE Detroit District, under the authority of the Rivers and Harbors Act of 1899, exercises jurisdiction over these federal waterways, in this case to maintain the project depths via periodic maintenance dredging of the navigational channels to allow commercial and recreational boat traffic ("navigational servitude").

Examples of sediment accumulation above the project depth of federal navigation channels located at the St. Joseph River (34) navigation channel and at Holland Harbor (Macatawa River, 8) are shown on Figure 17 and Figure 18, respectively. The bathymetric survey measurements shown in Figure 17 and Figure 18 represent depth to sediment relative to Low Water Datum. Low Water Datum (and Ordinary High-Water Mark; OHWM) are USACE jurisdictional benchmarks for administering its regulatory program in navigable waterways under Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act (USACE, 2021b). With respect to Holland Harbor, the project depths are 24 feet and 21 feet in the segments of the navigation channel that are shown Figure 18. Water depths to sediment relative to LWD that are deeper than the project depth are shown in blue, and the water depths to sediment that are shallower than the project depth are shown in red and are subject to future USACE-Detroit District maintenance dredging.

Figure 17. Fluvial Sediment Accumulation, St. Joseph River (34) Navigation Channel; USACE (2019a) Bathymetric Survey; Google Earth Pro (2021)

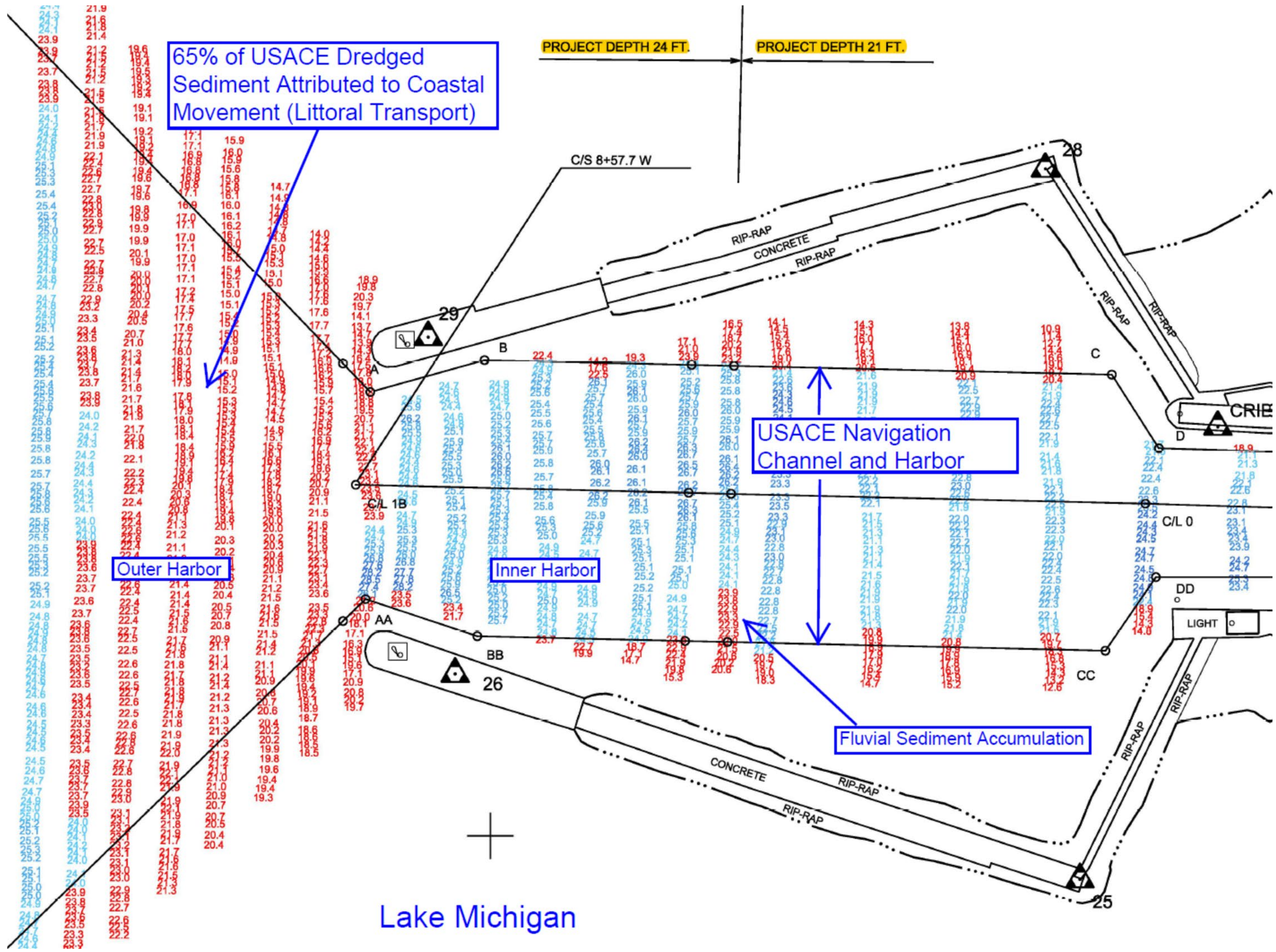


Figure 18. Example of Littoral Sediment Accumulation at the Entrance of Holland Harbor (Outer Harbor), Macatawa River (8), USACE (2019b) Bathymetric Survey (Condition Assessment)

Detailed USACE dredging records of these 30 harbors and navigation channels typically extend back to the early- to mid-1960's and provide important data regarding the rate of sediment accumulation in these federally defined navigation channels over time (USACE, 2021c). Because maintenance dredging can only be conducted within the defined limits of a federal navigation channel (USACE, 2010b), the USACE-Detroit District's dredging data was used in this research to estimate the average annual volume of sediment that has accumulated in the federal navigation channel since federal maintenance dredging commenced.

With respect to USACE maintenance dredging, two types of sediment are removed, littoral sediment originating from coastal movement of sediment outside of the Harbor and navigation channel, and fluvial sediment originating from the river. With respect to USACE dredging data, reference to an Outer Harbor dredging event refers maintenance dredging in front of the Harbor inlet. Inner Harbor maintenance dredging is predominantly fluvial sediment that is transported by the river system (see Figure 17).

Littoral sediment includes sediment transported by longshore currents originating from the lake shoreline and lake bed sediment resuspended by waves. Because most USACE maintenance dredging projects have historically not separated Outer Harbor (littoral sediment) from Inner Harbor (fluvial sediment) sediment, caution is required when evaluating USACE dredging data (USACE, 2010a). An example of littoral sediment accumulation in front of the harbor inlet at Holland Harbor (Macatawa River, 8) is shown in Figure 18; as shown in Figure 19, the effect of longshore current is evident

Figure 19. Littoral Sediment Transport, Holland Harbor, Macatawa River (8) (Google Earth Pro, 2021)

with sediment accumulating on the north side and in front of the Harbor inlet, and is depleted on the southside of the Harbor inlet.

The total number of maintenance dredging events and the volume of sediment dredged by the USACE-Detroit District from each of the 30 Harbors and navigation channels are summarized on Table 14. A total of 867 USACE maintenance dredging events encompassing 65,424,279 $yard^3$ of dredged sediment were compiled in this research. With respect to these 30 Harbors and navigation channels, the number of maintenance dredging varies from four (Black River-East, 6; navigation channel) to 92 (Grand Haven Harbor; Grand River, 14). A number of Harbors and navigation channels are dredged on an annual or near annual basis by the USACE Detroit District, examples include: Holland Harbor, Macatawa River (8); Grand Haven Harbor, Grand River (14); Monroe Harbor, River Raisin (29); Rouge River navigation channel (31); Saginaw River navigation channel (32), and Ontonagon River Harbor (53). Of the 65,424,279 $yard^3$ that have been dredged from these 30 Harbors and navigation channels, 24,285,102 $yard^3$ were dredged from Saginaw River navigation channel. The Saginaw River watershed is the largest in Michigan (15,882 square kilometers), and due to commercial importance and the high cost of maintenance dredging, this watershed is one of the most studied (USACE, 1999, 2000, 2001, and 2012; Ouyang D and Bartholic J, 1997).

Each of the 30 Harbors and associated navigation channels were evaluated by both USACE-Detroit District and Wayne State University to determine if the associated USACE-Detroit District dredging data represents either primarily fluvial or littoral sediment, or a combination of both. Other Harbor and river specific considerations were also evaluated to determine whether or not a particular Harbor was either retained or excluded from this research of fluvial sediment delivery to the river outlet. Of the 30 Harbors evaluated, 12 Harbors were retained and 18 Harbors were excluded, the basis of the decision to retain or exclude a particular Harbor is presented on Table 15. Retained USACE harbors and navigation channels are highlighted in green in Table 15.

The percentage of dredged sediment attributed to fluvial and littoral sediment is shown on Table 15. In most instances, Harbors were retained in this research if 80-90% of the dredged sediment was determined to be fluvial based on the location of USACE maintenance dredging. Exceptions are discussed in the following text.

For three Harbors, the USACE-Detroit District has recently begun to separate maintenance dredging projects into Outer Harbor dredging (primarily littoral sediment) and Inner Harbor dredging (primarily fluvial sediment) and for this reason, these Harbors were retained in this research although the percent of littoral sediment ranged from 65 to 80%. Beginning in approximately 2012, the USACE Detroit District estimated the percentage of sediment attributed to fluvial and littoral processes based on analysis of dredging data for: Holland Harbor (Macatawa River, 8); Grand Haven Harbor (Grand River, 14), and St. Joseph River (34) Navigation Channel. The basis of the separation of Outer Harbor and Inner Harbor dredging volumes are contained in the individual USACE-Detroit District Harbor Fact Sheet dredging forecast, and is based on the past 10 to 20 years of maintenance dredging projects (USACE, 2020a).

Table 14. Summary of USACE Navigation Channel Dredging, 30 Michigan Harbors

MDEQ Watershed Reference Number	River	USACE Harbor	USACE Total Dredged From 1st Recorded Dredge Event to 2016 (yards^3)	USACE Total Dredged 2017 (yard^3)	USACE Total Dredged 2018 (yard^3)	USACE Total Dredged 2019 (yard^3)	Most Recent Authorization, Rivers and Harbors Act of 1899	First USACE Dredge Event	Last USACE Dredge Event	Number of Dredging Events Through 2019
1	Au Gres River	Point Lookout Harbor	552,134				March 2, 1945	1971	2014	10
2	Au Sable River	Au Sable Harbor	434,163		32,100		March 2, 1945	1965	2018	16
4	Betsie River	Frankfort Harbor	809,632		49,956		October 27, 1965	1964	2018	23
6	Black River - East	Black River	232,298				April 3, 1970	1975	2014	4
7	Black River - West	South Haven Harbor	754,961		52,514		August 30, 1935	1963	2018	23
8	Macatawa River	Holland Harbor	3,569,000	34,000	82,751	41,180	September 3, 1954	1962	2019	76
10	Pine River	Charlevoix Harbor	100,507				March 24, 1977	1964	1984	8
11	Cheboygan River	Cheboygan Harbor	177,755				May 17, 1950	1964	2015	7
12	Clinton River	Clinton River	425,515				August 5, 1886	1965	2009	10
14	Grand River	Grand Haven Harbor	4,541,654	75,244	66,500	70,620	June 23, 1886	1963	2019	92
17	Kalamazoo River	Saugatuck Harbor	906,477			34,000	June 25, 1910	1964	2019	30
20	Manistee River	Manistee Harbor	1,713,920		45,263		July 14, 1960	1964	2016	39
22	Muskegon River	Muskegon Harbor	2,438,816				October 23, 1962	1964	2017	36
24	Pentwater River	Pentwater Harbor	975,280			20,000	March 2, 1907	1963	2019	47
25	Pere Marquette River	Ludington Harbor	2,204,349			29,700	December 31, 1970	1964	2019	30
26	Pigeon River	Caseville Harbor	205,122		22,800		October 23, 1962	1964	2018	10
29	River Raisin	Monroe Harbor	7,021,986		49,500		July 3, 1930	1963	2018	48
31	Rouge River	Rouge River	4,582,940		66,500		October 23, 1962	1963	2018	43
32	Saginaw River	Saginaw River	24,285,102	125,000	145,004		10/23/1962, 10/27/1965	1963	2018	86
33	Sebewaing River	Sebewaing River	502,505		-	-	June 3, 1896	1966	2015	9
34	St. Joseph River	St. Joseph River	3,811,635	35,005	28,828	37,000	July 3, 1958	1963	2019	79
36	Thunder Bay River	Alpena Harbor	247,338	27,382			October 27, 1965	1963	2017	10
37	White River	White Lake Harbor	711,179		26,700		March 2, 1907	1964	2018	21
40	Black River (Gogebic)	Black River Harbor	93,287				March 2, 1945	1966	2009	14
42	Cedar River	Cedar River Harbor	106,324				October 27, 1965	1999	2013	3
45	Dead River	Presque Isle Harbor	93,580				July 14, 1960	1971	2016	4
49	Manistique River	Manistique Harbor	177,787				May 17, 1950	1963	2016	6
50	Menominee River	Menominee Harbor	249,688				March 3, 1871	1961	2014	10
53	Ontonagon River	Ontonagon Harbor	2,751,390			142,321	August 26, 1937	1963	2019	51
55	Portage River	Keweenaw Waterway	747,955	31,170	26,189		August 30, 1935	1963	2018	13
		Total:	65,424,279	327,801	716,135	374,821			Total:	867

Table 15. USACE Littoral Sediment Adjustment and Basis to Exclude or Retain a Harbor from Further Analysis

Watershed Reference Number	River	USACE Harbor	Adjust. for Channel Deepening (yard^3)	Adjustment for Channel Deepening: Rivers and Harbors Act of 1899 Authorization	USACE Total Dredged Minus Channel Deepening Adjustment (if any)	December 2019 USACE Estimated Dredging Backlog (10-6-2020)	Dredged Minus Channel Deepening Adjustment Plus 2019 Backlog	Coastal Adjustment, Percent of Sediment Attributed to Littoral Transport	USACE Littoral Dredged Sediment Adjustment, Basis to Exlude or Retain in Analysis	
1	Au Gres River	Point Lookout Harbor	-	no adjustment	611,501	21,558	633,059	10%	90% Fluvial Sediment	Retained
2	Au Sable River	Au Sable Harbor	-	no adjustment	466,263	438	466,701	80%	Excluded, Multiple Large Dams: Foote, Mio, Alcona Dams	Excluded
4	Betsie River	Frankfort Harbor	46,782	1966 Dredge Event	812,806	10,360	823,166	100%	100% Littoral Sediment	Excluded
6	Black River - East	Black River	-	no adjustment	257,148	258,365	515,513	0%	100% Fluvial Sediment	Retained
7	Black River - West	South Haven Harbor	-	no adjustment	807,475	1,403	808,878	90%	90% Littoral Sediment	Excluded
8	Macatawa River	Holland Harbor	-	no adjustment	3,946,830	85,505	4,032,335	65%	65% Littoral Sediment, Basis USACE Dredging Contracts	Retained
10	Pine River	Charlevoix Harbor	-	no adjustment	100,507	4,571	105,078	90%	90% Littoral Sediment	Excluded
11	Cheboygan River	Cheboygan Harbor	-	no adjustment	199,755	9,621	209,376	NA	Excluded Due to Dam and Pocket Beach	Excluded
12	Clinton River	Clinton River	-	no adjustment	425,515	138,767	564,282	10%	10% Littoral Sediment	Retained
14	Grand River	Grand Haven Harbor	-	no adjustment	4,858,430	146,681	5,005,111	80%	77.8% Littoral Sediment, Basis USACE Dredging Contracts	Retained
17	Kalamazoo River	Saugatuck Harbor	-	no adjustment	940,477	3,879	944,356	100%	100% Littoral Sediment	Excluded
20	Manistee River	Manistee Harbor	-	no adjustment	1,835,111	17,558	1,852,669	90%	90% Littoral Sediment	Excluded
22	Muskegon River	Muskegon Harbor	253,899	1965 Dredge Event	2,373,929	36,337	2,410,266	95%	95% Littoral Sediment	Excluded
24	Pentwater River	Pentwater Harbor	-	no adjustment	995,280	5	995,285	95%	95% Littoral Sediment	Excluded
25	Pere Marquette River	Ludington Harbor	36,526	1971 Dredge Event	2,277,353	28,241	2,305,594	95%	95% Littoral Sediment	Excluded
26	Pigeon River	Caseville Harbor	-	no adjustment	227,922	2,095	230,017	NA	Excluded, Ice Relief Channel	Excluded
29	River Raisin	Monroe Harbor	-	no adjustment	7,371,780	154,196	7,525,976	0%	100% Fluvial Sediment, AVG 2003-2007 Dredging Contracts	Retained
31	Rouge River	Rouge River	353,255	1964 Dredge Event	4,387,044	108,437	4,495,481	0%	100% Fluvial Sediment	Retained
32	Saginaw River	Saginaw River	1,610,108	1964, 1966 Dredge Events	24,262,848	695,214	24,958,062	10%	10% Littoral Sediment, USACE 516e Estimate	Retained
33	Sebewaing River	Sebewaing River	-	no adjustment	542,864	123,718	666,582	NA	Excluded, Sediment Removal Ditch	Excluded
34	St. Joseph River	St. Joseph River	-	no adjustment	4,145,392	19,291	4,164,683	75%	75% Littoral Sediment, Basis USACE Dredging Contracts	Retained
36	Thunder Bay River	Alpena Harbor	35,563	1966 Dredge Event	239,157	274,837	513,994	90%	90% Littoral Sediment	Excluded
37	White River	White Lake Harbor	-	no adjustment	737,879	1,318	739,197	100%	100% Littoral Sediment	Excluded
40	Black River (Gogebic)	Black River Harbor	-	no adjustment	93,287	15,436	108,723	NA	Excluded, Bedrock Controlled Channel	Excluded
42	Cedar River	Cedar River Harbor	-	no adjustment	106,324	17,230	123,554	90%	80% to 100% Littoral Sediment	Excluded
45	Dead River	Presque Isle Harbor	-	no adjustment	129,552	65,046	194,598	NA	Excluded, Large Dam Failure	Excluded
49	Manistique River	Manistique Harbor	-	no adjustment	198,487	211,308	409,795	0%	100% Fluvial: AVG 1963 - 1967 Dredging Contracts	Retained
50	Menominee River	Menominee Harbor	-	no adjustment	271,088	12,754	283,842	0%	100% Fluvial, AVG 1968 and 1969 Dredging Contracts	Retained
53	Ontonagon River	Ontonagon Harbor	-	no adjustment	2,958,907	110,770	3,069,677	25%	25% Littoral Sediment USACE 516e, Bathymetric Analysis	Retained
55	Portage River	Keweenaw Waterway	-	no adjustment	805,314	713,280	1,518,594	NA	Excluded, Stamp Sands, Water Movement	Excluded
				Total:	67,507,805	3,288,634	70,796,439			

For example, at Holland Harbor (Macatawa River, 8; USACE, 2021c), the USACE-Detroit District has separated Outer Harbor and Inner Harbor dredging projects since 2012, and the USACE-Detroit District forecasts that the annual Outer Harbor maintenance dredging will average 35,000 $yard^3$ (26,760 cubic meters) and Inner Harbor maintenance dredging within the federal navigation channel will range from 45,000 to 65,000 $yard^3$ (34,400 to 49,700 cubic meters) every 2 to 4 years (USACE, 2021c). The percentage of annual maintenance dredging attributed to littoral sediment transport processes of 65% was calculated by dividing the annual Outer Harbor maintenance dredging forecast of 35,000 $yard^3$ (26,760 cubic meters) by the sum of the geometric mean of the annual Inner Harbor maintenance dredging forecast (19,270 $yard^3$ or 14,730 cubic meters) and the annual Outer Harbor maintenance dredging forecast (35,000 $yard^3$ or 26,760 cubic meters). Using the same method, the percentage of dredged sediment attributed fluvial processes for the Grand Haven Harbor (Grand River, 14), and St. Joseph Harbor (St. Joseph River, 34) are estimated at 80% and 70%, respectively.

With respect to the Saginaw River (32) and Ontonagon River (53), USACE 516e studies were used to estimate the littoral component of dredged sediment (USACE, 2000 and 2010). With respect to the Saginaw River navigation channel, the USACE (1999 and 2000) prepared calibrated hydrodynamic and sediment transport models. The annual sediment volume deposited in the Saginaw River navigation channel was estimated using HEC-6 and MIKE 21 sediment transport models (USACE, 1999 and 2000). By comparing the predicted sediment deposition at the river outlet in Saginaw Bay to the 1982-1999 USACE dredging data from the portion of the USACE navigation channel located in Saginaw Bay (Outer Harbor), the USACE concluded that approximately 10% of the dredged sediment is littoral and 90% of the sediment is fluvial sediment derived from the Saginaw River (USACE, 2000)

For Ontonagon Harbor (Ontonagon River, 53), the USACE-Detroit District completed a bathymetric analysis of several pairs of pre- and post-dredging events to estimate the littoral and fluvial components of the sediment removed during USACE maintenance dredging of the federal navigation channel (USACE, 2010a). The USACE (2010a) approach to the estimate fluvial and littoral components of dredged sediment consisted of generating a digital surface using a Triangular Irregular Network (TIN) and then calculating the volume between the surfaces in the area where fluvial sediment was deposited (USACE, 2010a). For several pairs of years, a post-dredging survey (Condition Assessment) was completed in the spring which established a baseline condition, and the pre-dredging survey that was taken the following spring was used to calculate fluvial sediment accumulation (USACE, 2010a), the difference in sediment volume was compared to the total amount of sediment dredged (fluvial and littoral). Using this method, the littoral and fluvial components of the dredged sediment were separated and estimated to be 25% and 75%, respectively (USACE, 2010a).

For three Harbors, the USACE's estimate of fluvial sediment delivery was based on a portion of the USACE dredging data that was determined be representative of fluvial sediment delivery, these include: Monroe Harbor, River Raisin (29; dredging contract years 2003 to 2007); Manistique Harbor, Manistique River (49; dredging contract years 1963-1967); and Menominee River, Menominee Harbor (50: dredging contract years 1968 and 1969).

With respect to the 12 Harbors included in this research, the volume of sediment dredged from the initial dredging event or the most recent Rivers and Harbors Act of 1899 authorization through December 2019 was totaled. To account for sediment that has accumulated in the federal navigation channel but has not yet been removed, the estimated amount of USACE maintenance dredging backlog as of December 2019 (USACE, 2020b) within the navigation channel was added to the total amount of dredged sediment. The sediment backlog for each USACE-Detroit District navigation channel is determined on an annual basis during the conduct of Condition Assessments (bathymetric surveys; USACE, 2020a); examples of bathymetric surveys completed during Condition Assessments are shown on Figure 17 and Figure 18. To estimate the fluvial component of dredged sediment, the total amount of sediment dredged since the initial dredging event was adjusted to:

- remove the estimated littoral component of dredged sediment
- add in the current sediment backlog within the federal navigation channel based on the annual Condition Assessment (USACE, 2020b)
- and exclude dredged sediment that pre-dates an adjustment to the dimensions of the federal navigation channel (e.g. channel deepening) that was subject to Rivers & Harbors Act of 1899 authorization (USACE, 2010b).

A summary of the total volume of dredged sediment for each of these 12 Harbors are shown in Table 15. Table 15 also lists the adjustments for channel deepening subject to the Rivers and Harbors Act Authorization, adjustment for littoral component of dredged sediment, and the basis to exclude or retain a Harbor or navigation channel from further analysis.

3.8.1 USACE-Detroit District Dredging Forecasts and the Potential Impact of the Implementation of the USDA Conservation Reserve Program (CRP) and Sediment Best Management Practices During the Early 1990's

Review of average annual dredging volumes removed by the USACE since initiation of maintenance dredging in comparison to the USACE-Detroit District dredging forecasts (USACE, 2021c) revealed a marked decrease in the rate of sediment accumulation requiring maintenance dredging for 9 of the 12 Harbors and navigation channels that were selected for this research. Based on analysis of the USACE dredging data, the decrease in average annual dredging of the USACE Navigation Channels and Harbors appeared to occur during the early 1990's depending on the watershed. At the suggestion of the USACE-Detroit District, the potential impact of the U.S. Department of Agriculture's (USDA's) Conservation Reserve Program (CRP) and the State of Michigan's implementation of Non-Point Source Best Management Practices during the early 1990's were evaluated.

USDA Farm Service Agency's (FSA) Conservation Reserve Program is a voluntary program that contracts with agricultural producers so that environmentally sensitive agricultural land is not farmed or ranched, but instead devoted to conservation benefits; in return, USDA Farm Service Agency provides participants with rental payments and cost-share assistance, and contract duration is between 10 and 15 years (USDA, 2019). Across the United States, Conservation Reserve Program currently protects approximately 80,940 square kilometers of topsoil from erosion by reducing water runoff and sedimentation in rivers and lakes (USDA, 2021).

In each State, the area enrolled to the Conservation Reserve Program by County is updated on an annual basis and the enrollment data are available for the reporting years 1986-2019. In Michigan, the Conservation Reserve Program began in 1986 and 29.9 square kilometers were initially enrolled in the program. In 1993 and 1994, the area subject to the Conservation Reserve Program peaked at 1,342 square kilometers and has declined since (see Figure 20).

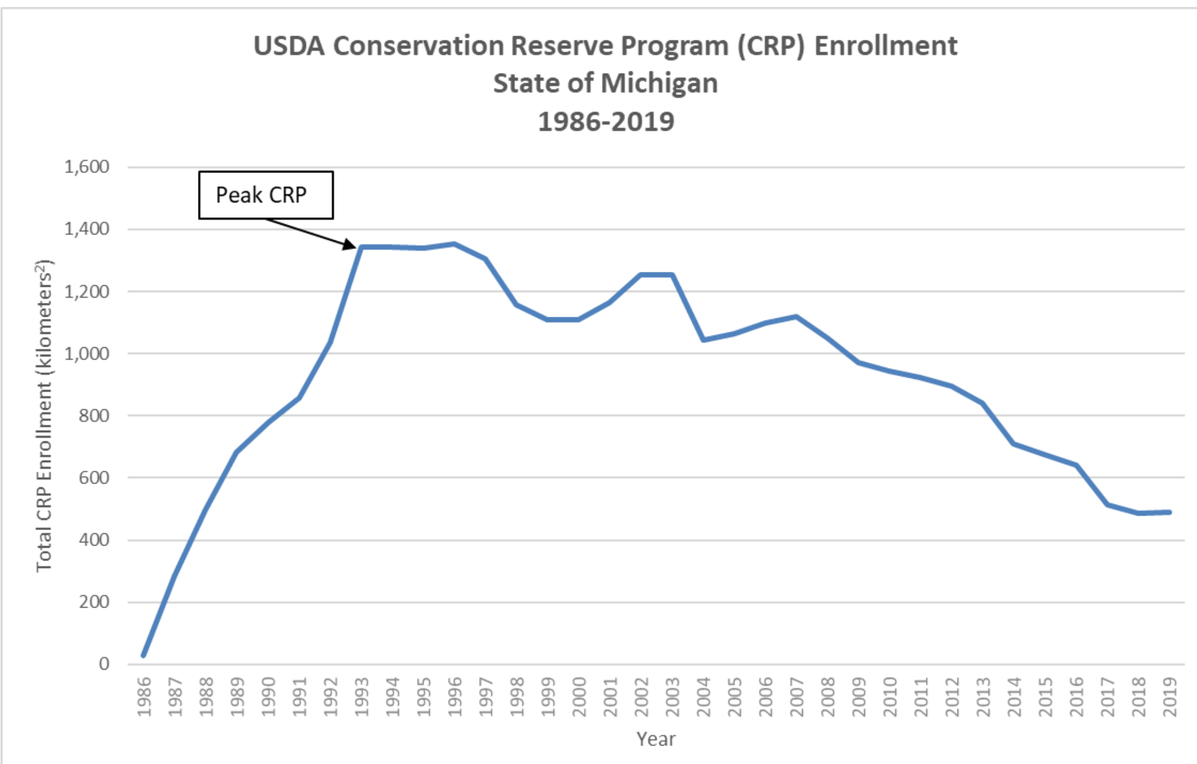


Figure 20. USDA (2021) Conservation Reserve Program Enrollment, State of Michigan, 1986-2019

In addition, during the 1990's, the State of Michigan initiated programs to foster control of Non-Point Source pollution, including preparing a series of Best Management

Practices to control sediment discharge to rivers and streams and were widely distributed to communities throughout Michigan (MDEQ, 1992 and 1998). Examples of Best Management Practices to minimize sediment discharge to rivers and streams include construction of riparian buffer strips, sedimentation basins, and check dams (MDEQ, 1992, 1998, 2017). The MDEQ sediment Best Management Practices guidance documents were developed and released following the publication of the MDEQ (1988) Nonpoint Pollution Assessment Report.

To further evaluate the potential impact of the Conservation Reserve Program enrollment as well as the implementation of sediment Best Management Practices within the State of Michigan to reduce sediment loading to rivers and streams, an assessment of the 4-year rolling average of annual dredged sediment was completed on three USACE Harbors and navigation channels. The following Harbors and navigation channels were evaluated: USACE Monroe Harbor, River Raisin (29); USACE Rouge River (31) Navigation Channel; and the USACE Saginaw River (32) Navigation Channel.

These watersheds were chosen based on a high frequency of USACE maintenance dredging events, a low estimate of the littoral component of the volume of sediment dredged, and with respect to the River Raisin (29) and the Saginaw River (32), a high percentage of the watershed containing agricultural land use (67% and 45%, see Appendices GG and JJ, respectively). The Rouge River was selected based a high frequency of maintenance dredging events, a low estimate of the littoral component of the volume of sediment dredged, and because this watershed has an active watershed community group that promotes Non-Point Source Pollution, Best Management Practices (the Friends of the Rouge River).

Review of 4-year rolling averages of dredged sediment for Monroe Harbor (Figure 21), Rouge River Navigation Channel (Figure 22), and the Saginaw River Navigation Channel (Figure 23) reveals that the 1993 date of peak Conservation Reserve Program participation in Michigan appears to largely coincide with the decrease in the volume of dredged sediment for that particular navigation channel (River Raisin; 29; Saginaw River, 32). With respect to the Rouge River (31), a similar decrease in 4-year rolling average was observed and given the low percentage of agricultural land use (5%), this decrease may be due in part to implementation of Non-Point Source Pollution, Best Management Practices within the watershed.

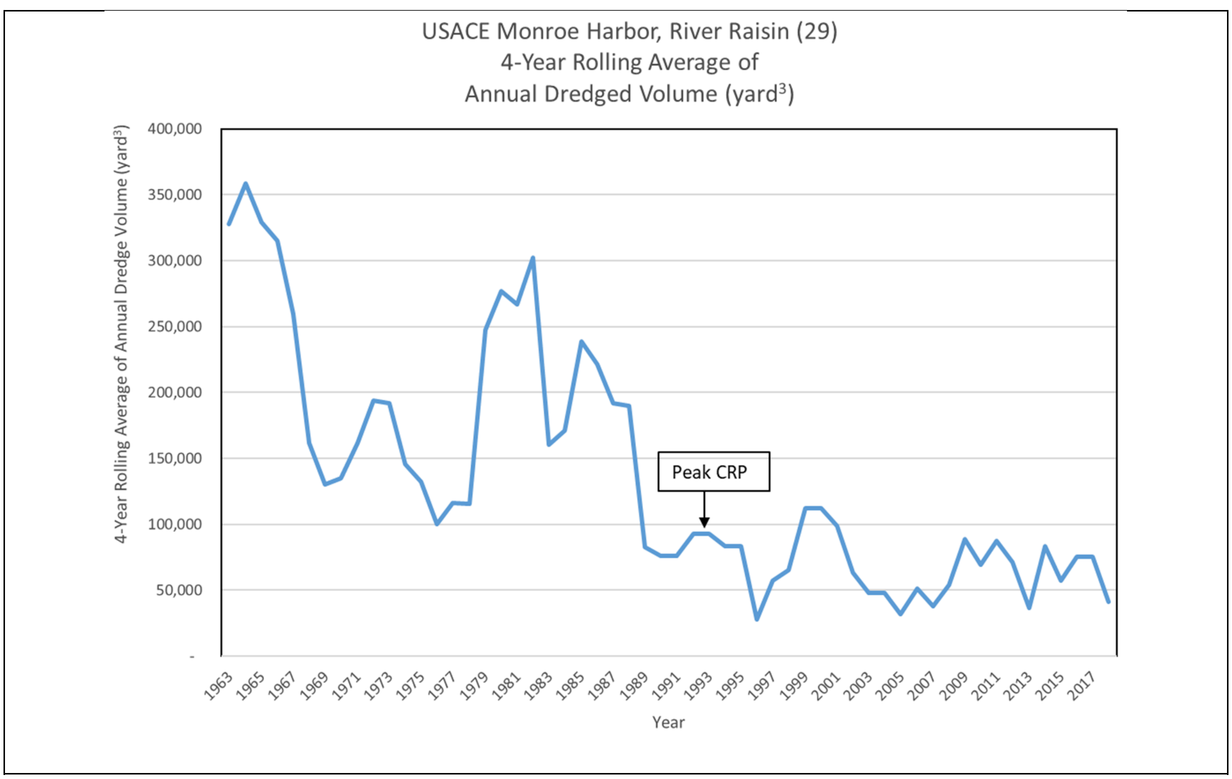


Figure 21. USACE Monroe Harbor, River Raisin (29), 4-Year Rolling Average of Annual Dredged Volume

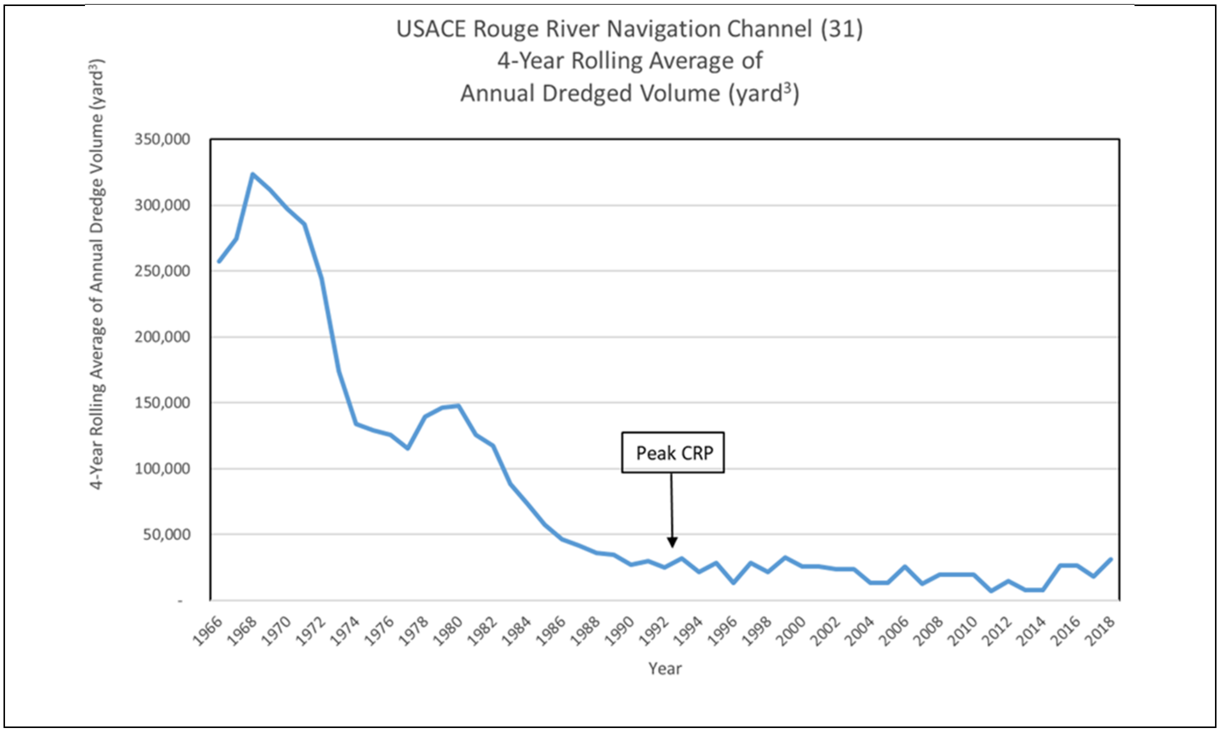


Figure 22. USACE Rouge River Navigation Channel (31), 4-Year Rolling Average of Annual Dredged Volume

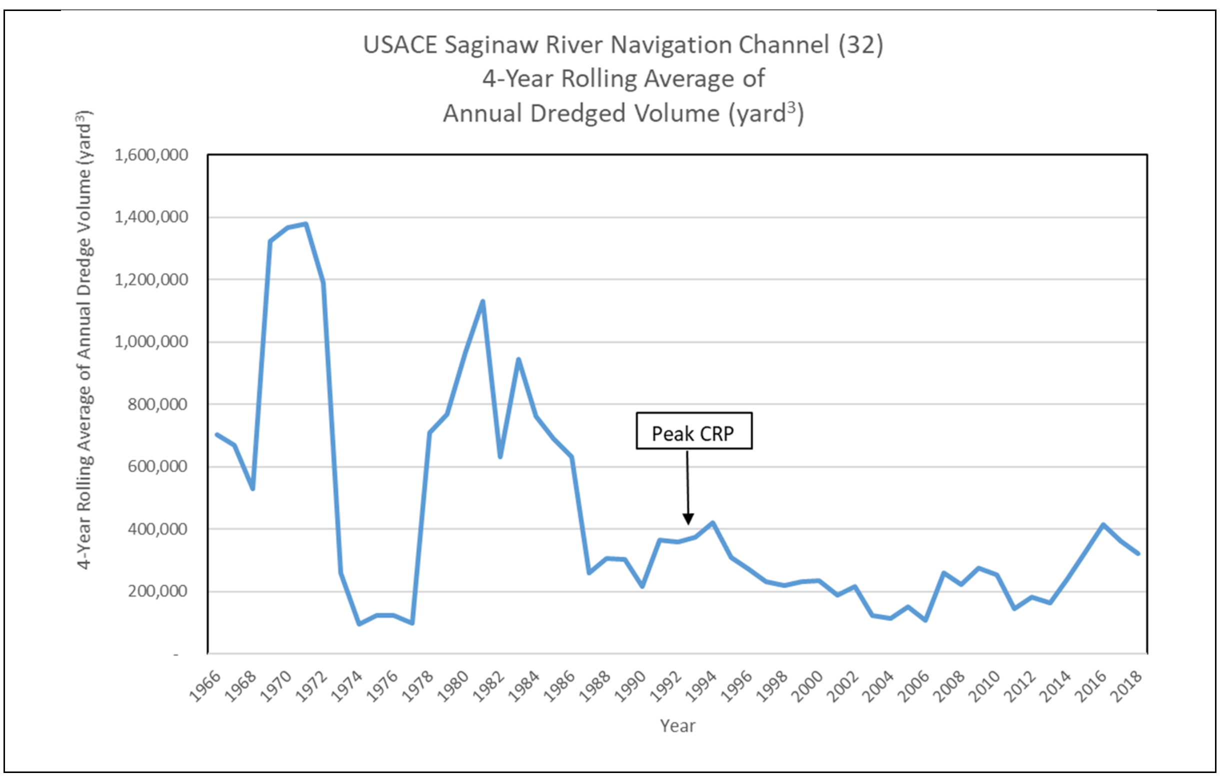


Figure 23. USACE Saginaw River Navigation Channel (32), 4-Year Rolling Average of Annual Dredged Volume

Based on these findings, the post-1993 USACE maintenance dredging data was utilized in this research to estimate the average annual rate of fluvial sediment delivery to the river outlet and was calculated by: (1) averaging the post-1993 USACE dredging data (1993 to 2019), (2) adding in the USACE estimate of dredging backlog through December 2019, and (3) adjusting volume dredged to remove the estimated littoral component. Using the post-1993 dredging data to estimate the average annual rate of sediment delivery to the river outlet resulted in annual rates that were very similar to the USACE (2020) dredging forecasts for 9 of the 11 watersheds, exceptions include: Black River-East (6) and the Saginaw River (32). The USACE-Detroit does not prepare a dredging forecast for Manistique River (49) so this comparison was not available.

3.8.2 Conversion of the Average Annual Volume Dredged to Metric Tonnes

To convert the average annual volume of dredged sediment to metric tonnes, USACE pre-dredge sediment quality data were assessed (see Table 16). USACE pre-dredge sediment quality samples are collected prior to dredging and represent composite samples of the dredge cut. A total of 821 pre-dredge sediment quality samples were evaluated during this research and samples were collected from each of the 30 Harbors (see Table 16). The specific weight of sediment was calculated using the bulk density and percent moisture data for each sediment sample. Then, the pre-dredge sediment quality sample locations were mapped, and pre-dredge sediment samples that were collected from the Outer Harbor (primarily littoral sediment) were removed from further consideration and the Inner Harbor (fluvial sediment) sample locations were retained. Based on analysis of the pre-dredge sediment quality data, a total of 752 pre-dredge sediment samples were collected from the Inner Harbor, these samples were collected

Table 16. Estimate of Specific Weight of Fluvial Sediment

			USACE Pre-Dredge Sediment Quality Data (Outer and Inner Harbor)						Inner Harbor, Fluvial Sediment	
Watershed Reference Number	River	USACE Harbor	Average In-Place Density, Pre-Dredge Sediment Quality Sampling	Average In-Place Density, Pre-Dredge Sediment Quality Sampling	Total Number of In-Place Density Measurements	Percent Moisture	Number of Percent Moisture Measurements	Solid Content of Dredged Sediment Adjusted for Moisture Content	Number of Pre-Dredge Specific Weight Measurements	Specific Weight, Pre-Dredge Sediment Quality Assess.
			lbs/gal	(lb/ft^3)	number	%	number	lbs/ft^3	number	lbs/ft^3
1	Au Gres River	Point Lookout Harbor	15.2	113.7	29	35.8	29	73.0	23	69.6
2	Au Sable River	Au Sable Harbor	17.5	130.9	11	16.6	23	109.1	11	110.8
4	Betsie River	Frankfort Harbor	13.0	97.2	15	48.2	16	50.4	14	50.3
6	Black River - East	Black River	15.4	115.2	20	28.1	20	82.9	20	83.0
7	Black River - West	South Haven Harbor	14.4	107.9	20	26.3	29	79.5	21	101.4
8	Macatawa River	Holland Harbor	10.7	80.0	31	63.0	31	29.6	31	31.2
10	Pine River	Charlevoix Harbor	16.3	121.9	4	36.3	8	77.6	4	95.8
12	Clinton River	Clinton River	12.0	90.1	27	44.6	27	49.9	25	51.9
14	Grand River	Grand Haven Harbor	15.5	115.9	25	28.2	37	83.2	25	76.6
17	Kalamazoo River	Saugatuch Harbor	13.7	102.5	15	39.5	15	62.0	10	53.3
20	Manistee River	Manistee Harbor	14.5	108.5	21	25.4	21	80.9	18	78.8
22	Muskegon River	Muskegon Harbor	16.2	121.2	10	23.2	16	93.0	2	91.1
24	Pentwater River	Pentwater Harbor	16.6	124.2	7	19.5	4	100.0	4	119.4
25	Pere Marquette River	Ludington Harbor	14.8	110.7	6	21.3	13	87.2	8	91.0
26	Pigeon River	Caseville Harbor	14.5	108.5	10	32.9	26	72.8	3	83.8
29	River Raisin	Monroe Harbor	11.8	88.3	69	48.4	69	45.5	35	42.3
31	Rouge River	Rouge River	11.4	85.3	51	47.2	51	45.1	50	45.2
32	Saginaw River	Saginaw River	15.9	118.7	20	37.8	88	73.9	83	64.2
33	Sebewaing River	Sebewaing River	12.7	95.0	17	41.1	24	56.0	18	57.8
34	St. Joseph River	St. Joseph River	17.2	128.7	29	31.7	29	87.9	20	73.1
36	Thunder Bay River	Alpena Harbor	14.0	104.7	17	38.3	22	64.6	6	84.9
37	White River	White Lake Harbor	10.5	78.5	59	71.7	64	22.2	56	23.1
40	Black River (Gogebic)	Black River Harbor	16.2	121.2	9	23.4	9	92.9	5	92.6
42	Cedar River	Cedar River Harbor	14.4	107.9	8	25.7	18	80.2	-	-
45	Dead River	Presque Isle Harbor	14.4	107.7	10	31.8	16	73.5	-	-
49	Manistique River	Manistique Harbor	12.7	95.0	189	27.6	260	68.8	189	68.2
50	Menominee River	Menominee Harbor	17.0	127.2	44	28.2	44	91.3	30	87.8
53	Ontonagon River	Ontonagon Harbor	16.2	121.2	18	22.9	18	93.4	14	93.3
55	Portage River	Keweenaw Waterway	13.5	101.0	19	37.5	31	63.1	27	64.0
63	Whitefish River	Whitefish Point Harbor	16.5	123.4	11	23.1	15	94.9	-	-
		Average:	**14.5**	**108.4**	**n = 821**	**34.2**	**n = 1,073**	**72.8**	**n = 752**	**73.5**
									Geometric Mean	**69.1**
									Weighted Average	**63.6**

from 27 of the 30 Harbors. The distribution of specific weight of the 752 fluvial sediment samples is shown on Figure 24.

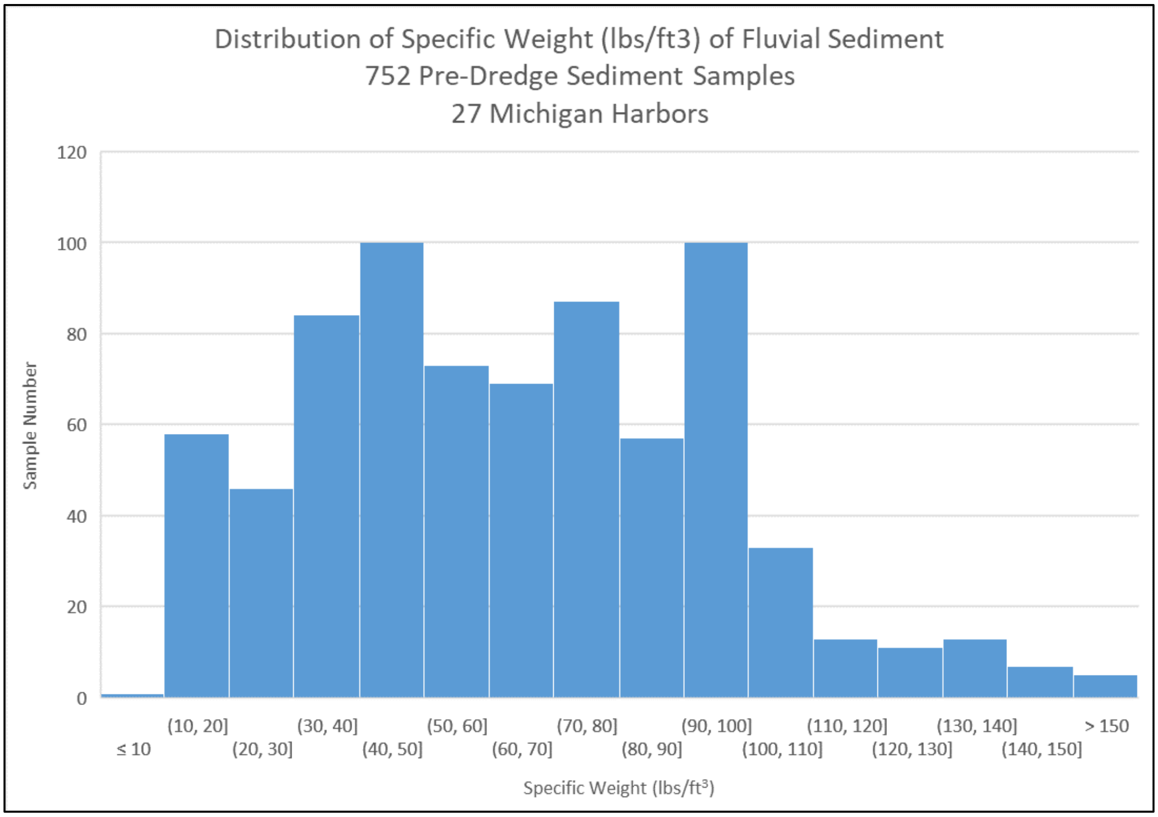


Figure 24. Distribution of Specific Weight, 752 Pre-Dredge Sediment Samples

With respect to specific weight of fluvial sediment from these 27 Harbors, the weighted average (based on the number of samples per Harbor), geometric mean, and mean were 63.6, 69.1, and 73.5 pounds/cubic feet of sediment, respectively. The geometric mean of 69 pounds/cubic feet of sediment was utilized to convert the average annual volume of sediment dredged to metric tonnes for the 12 Harbors included in this research (see Table 17). The average annual rate of fluvial sediment accumulation within the selected harbors served as the dependent variable in the subsequent regression analysis discussed in Chapter Four.

Table 17. Comparison of Estimates of Annual Fluvial Sediment Delivery: Since 1st Recorded Dredging Event and Post-CRP, and Adjusted to Removal Fluvial Sediment

				USACE Detroit District Forecast Dredging (March 2020)[3]						USACE Fluvial Sediment Delivery Since Peak CRP		
Watershed Reference Number	River	USACE Average Annual Dredging Since Base Event[4] (Including Backlog Through Dec 2019, Minus Channel Deepening) ($yard^3$)	Sediment Delivery to the River Outlet Based on Dredging Data and Removal of Littoral Component ($yard^3$)[1]	Forecast Dredging, Outer Harbor ($yard^3$)	Forecast Dredging - Low Estimate ($yard^3$)	Forecast Dredging - High Estimate ($yard^3$)	Forecast Dredging - Low Estimate (years)	Estimated Dredging - High Estimate (years)	Annual Forecast Dredging, Geometric Mean of Low and High Estimates ($yard^3$)	Dredging Base Year, Peak CRP	Annual Fluvial Sediment Delivery Since Peak CRP ($yard^3$)[2]	Average Annual Sediment Delivery Since 1993, Specific Weight of 69 lbs/ft^3 (tonnes/year)[2]
1	Au Gres River	**11,952**	**10,757**		20,000	20,000	5	6	**3,651**	1993	**5,156**	**4,400**
6	Black River - East	**11,151**	**11,151**		15,000	35,000	5	10	**3,240**	1991	**12,809**	**11,000**
8	Macatawa River	**66,885**	**23,410**	**35,000**	45,000	65,000	2	4	**19,121**	1993	**20,486**	**17,000**
12	Clinton River	**10,450**	**9,405**		20,000	20,000	3	5	**5,164**	1992	**10,678**	**9,000**
14	Grand River	**87,512**	**17,502**	**35,000**	20,000	40,000	2	4	**10,000**	1993	**11,566**	**10,000**
29	River Raisin	**129,030**	**69,780**		90,000	135,000	1	2	**77,942**	1992	**73,351**	**62,000**
31	Rouge River	**80,084**	**80,084**		50,000	60,000	2	5	**17,321**	1993	**25,625**	**22,000**
32	Saginaw River	**446,042**	**401,438**	**180,000**	50,000	100,000	2	3	**28,868**	1992	**223,740**	**190,000**
34	St. Joseph River	**70,210**	**17,552**	**40,000**	30,000	60,000	2	4	**15,000**	1993	**14,071**	**12,000**
49	Manistique River	**6,948**	**13,190**		-	-	-	-	**NA**	NA	**13,190**	**11,000**
50	Menominee River	**4,525**	**8,599**		25,000	50,000	5	10	**5,000**	NA	**8,599**	**7,300**
53	Ontonagon River	**53,651**	**40,239**		40,000	40,000	1	1	**40,000**	1993	**35,359**	**30,000**

1. Estimated annual fluvial sediment delivery to the river outlet since the 1st recorded USACE dredging event or the most recent Rivers and Harbors Authorization, including USACE backlog through December 2019 and adjusted to remove littoral sediment.
2. Estimated fluvial sediment delivery, basis: USACE average annual dredging since 1993 (Peak CRP), including backlog through Dec. 2019 and adjusted to remove littoral sediment.
3. For Macatawa River (8), Grand River (14), Saginaw Rive (32), and St. Joseph River (34), the USACE-Detroit District Prepared Prepared Dredging Forecasts for Both the Outer and Inner Harbor. For The Remaining Eight Harbors, the USACE Dredging Forecast Combines The Outer and Inner Harbor Dredging.
4. Base Event, either the 1st dredging event or the most recent Rivers and Harbors Authorization, whichever is later.

3.9 Assessment of Fluvial Depositional Areas, Upland and Aquatic Wetlands, Natural Lakes and Manmade Reservoirs

In conjunction with the calculation of watershed Curve Numbers, this research included the assessment of depositional areas within each of the 60 watersheds and five sub-watersheds, these depositional areas include: aquatic wetlands, upland wetlands, natural lakes and manmade reservoirs. The Michigan Resource Information System (MIRIS), Land Use/Cover Polygons (MDNR, 1978) were used to calculate the percentage of each watershed covered in aquatic wetlands, upland wetlands, and natural lakes. The percentage of the watershed covered in manmade reservoirs was calculated from the EGLE (2020) dam inventory database.

With respect to aquatic wetlands (non-forested wetlands), the following MIRIS Land Use designations (land use classification number) were utilized: aquatic bed (621), emergent (622), and flats (623). With respect upland wetlands (forested wetlands), the following MIRIS Land Use designations were used: wooded (611) and shub/scrub (622). With respect to natural surface water bodies, the following MIRIS Land Use designations were used: stream (51) and lake (52). The MIRIS Land Use designation for reservoirs is 53.

Based on the initial set of regressions (discussed in Chapter 4.2 and 4.3), the percentage of watershed covered by manmade reservoirs and natural lakes were identified as important variables. However, based on analysis of the MIRIS data (MDNR, 1978), the percentage of watershed covered in manmade reservoirs appears to have been under reported in virtually all of the watersheds and is likely due to the inadvertent inclusion of reservoir pool surface areas in watershed areas identified as natural Lakes.

To assess the percentage of the watershed covered in manmade reservoirs, the EGLE (2020) Dam Safety Unit provided an updated inventory of dams located in Michigan. Comparison to the 2018 to the 2020 inventory of dams reveals that 48 dams were added to the inventory that now totals 2,607 structures. In conjunction with this research, the EGLE dam inventory was updated to include the reservoir pool surface areas for 43 dams in addition to updating the location information for several hundred of the dams to ensure that they were located within one of the 60 watersheds and five sub-watersheds that are the subject of this research. Of the 2,607 dams located in Michigan, 262 are located in the drainage areas of the Great Lakes ("Lake drainage areas") and are not assigned to one of the 60 Michigan watersheds and were excluded from this research.

Of the remaining 2,345 dams located in Michigan, 1,378 dams are located within the 60 watersheds and five sub-watersheds included in this research, these dams include FERC dams (dams regulated by the Federal Energy Regulatory Commission), hydropower dams, retired hydropower dams, farm ponds, and private and recreational dams (see Table 18). The remaining dams are not located on rivers, rather they are used for other purposes such as: water supply for industrial purposes (e.g. mining, agriculture), stormwater retention ponds, wastewater lagoons, tailing or debris ponds, and water level control structures (Table 18).

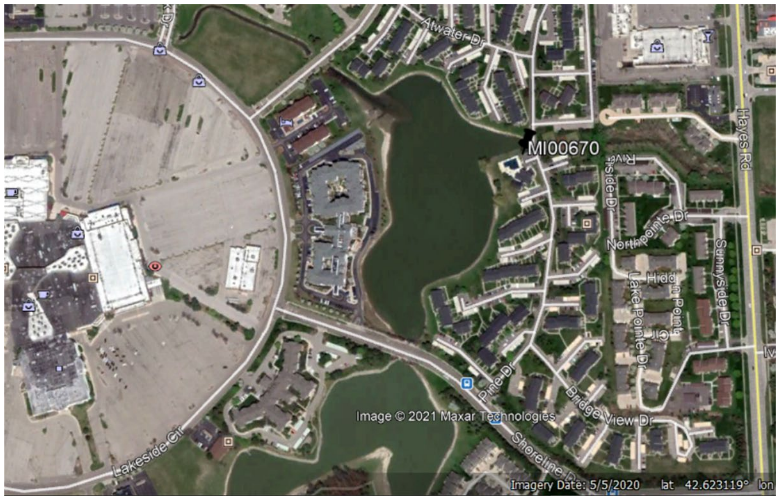
Table 18. Summary of Dam Type and Use, 60 Michigan Watersheds

Dam Type and Use	Number
FERC Dam	**87**
Hydropower Dam	**16**
Retired Hydropower Dam	**104**
Farm Pond, Private, Recreational Dam	**1,171**
Water Supply Dam	**67**
Stormwater Retention Pond Dam	**65**
Wastewater Lagoon Dam	**15**
Tailings or Debris Pond Dam	**14**
Level Control Structure Dam	**806**
Total Number of Dams:	**2,345**

FERC Dam - a hydropower dam regulated by the Federal Energy Regulatory Commission.

Because the stormwater retention ponds, water supply ponds, wastewater lagoons, tailing or debris ponds, and water level control structures, are not located on the river where their presence could impact watershed sediment delivery to the river outlet, the reservoir pool surface areas of these structures were not included in this research (examples of these structures are shown on Figure 25).

Review of the EGLE (2020) dam inventory with respect to the 1,378 dams located in 60 Michigan watersheds that the subject of this research reveals that most dams are small. The distribution of dam height and reservoir pool surface area are shown on Figure 26 and Figure 27, respectively.



Stormwater Retention Pond Dam (MI00670; Clinton River (12); Google Earth Pro 2021)

Wastewater Lagoon Dam (MI03004, Saginaw River (32) Google Earth Pro, 2021)

Tailings Pond Dam (MI00678; Portage River (55); Google Earth Pro, 2021)

Level Control Structure Dam (MI01729; Au Gres River (1); Google Earth Pro 2021)

Figure 25. Examples of Dams Not Included in the Percentage of Watershed Covered in Reservoirs

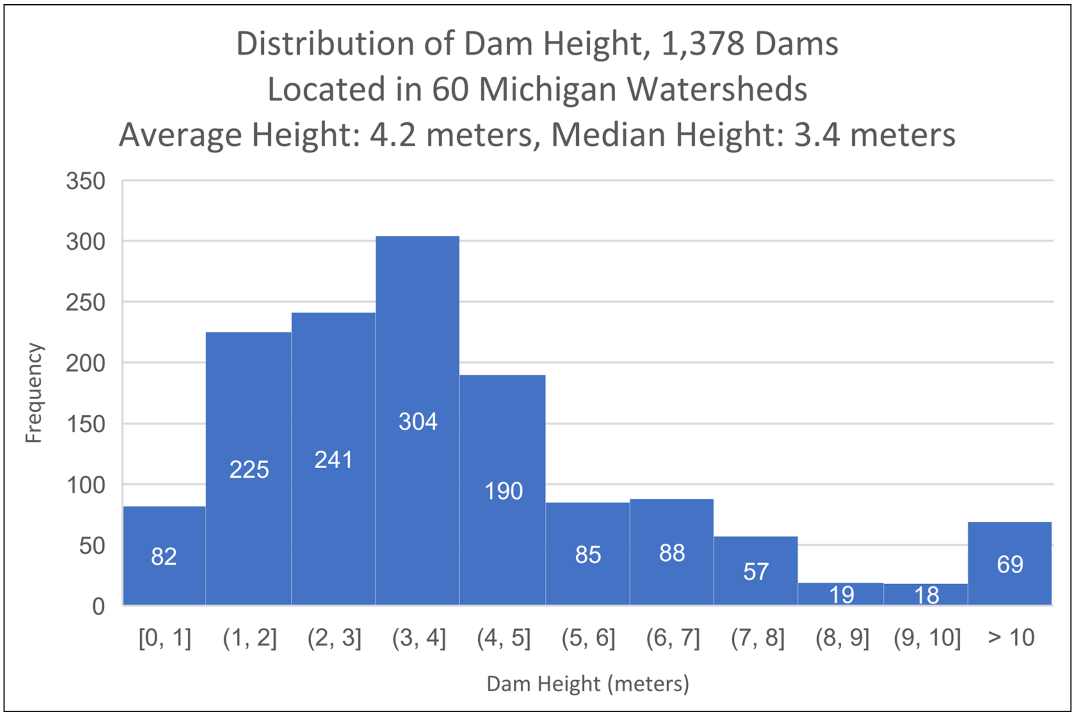


Figure 26. Distribution of Dam Height, 1,378 Dams Located in 60 Michigan Watersheds

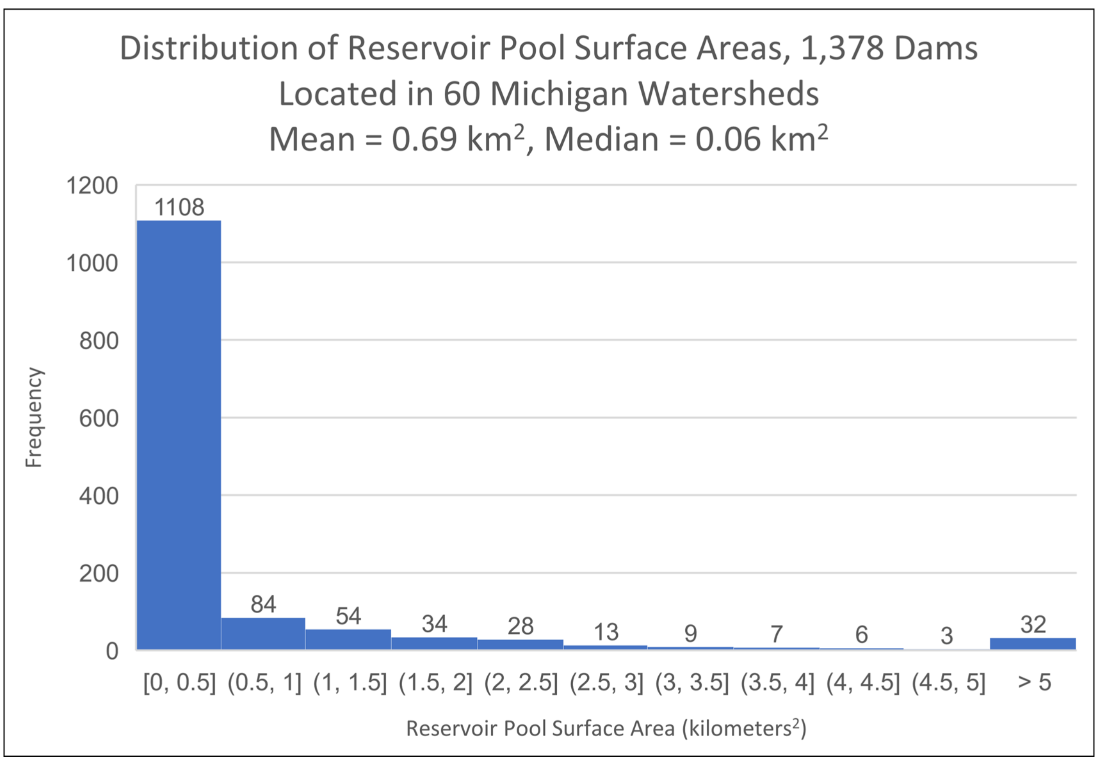


Figure 27. Distribution of Reservoir Pool Surface Areas, 1,378 Dams Located in 60 Michigan Watersheds

With respect to dam height, the maximum, average, and median elevations are 64 meters, 4.2 meters, 3.4 meters. The Victoria Dam (MI00203) on the Ontonagon River (53) is the highest dam in Michigan at 64 meters. There are 69 dams within these 60 Michigan watersheds that have a dam height of 10 meters or larger. Most dam heights in Michigan are small and reflect the low river slopes discussed previously. Of the 1,378 dams located in these 60 Michigan watersheds, 1,042 dams have dam heights of less than 5 meters (see Figure 26). Because most dams were built in glacial outwash deposits and have corresponding low river slopes, the reservoir pool surface areas are small. The maximum, average, and median reservoir pool surface areas are 72 square kilometers (Cheboygan Dam, MI00520), 0.69 square kilometers, and 0.06 square kilometers. Thirty-two dams have reservoir pool surface areas greater than 5 square kilometers. Of the 1,378 dams located in these 60 Michigan watersheds, 1,108 dams have reservoir pool surface areas that are less than 0.5 square kilometers (see Figure 27).

The percentage of the watershed covered in natural surface water bodies (lakes and rivers) from the MIRIS land use data (MDNR, 1978) was adjusted to account for percentage watershed covered in reservoirs based on the reservoir pool surface area contained the updated EGLE (2020) dam inventory. The total area of the watershed covered with reservoirs based on the MIRIS land use data (MDNR, 1978) and the updated EGLE (2020) dam inventory are 343 square kilometers and 1,107 square kilometers, respectively.

Although the 2011 National Land Cover Database does not separate out the area covered in reservoirs, the percentage of the watershed covered in surface water based on the MIRIS land use (MDNR, 1978) and the National Land Cover Database are very similar. However, there were significant differences between the percent of the watershed covered in upland and aquatic wetlands based on comparison of MIRIS land use (MDNR, 1978) and the 2011 National Land Cover Database. Based on analysis of the 2011 NLCD, the percentage of watershed covered in wetlands was much greater than the area calculated using the MIRIS Land Use/Cover Polygons (MDNR, 1978). The difference in the percentage of watershed covered by aquatic and upland wetlands is likely due differences in how wetland land use was identified and categorized. The 2011 NLCD relies on pixel analysis of aerial photographs and the resolution is lower than the MIRIS land use resolution that is based on a raster file (EGLE, 2020). Because, the MIRIS Land Use/Cover Polygons (MDNR, 1978) were used to calculate the watershed Curve Numbers used in this research and because this data set served as the baseline watershed inventory for the State of Michigan, the MIRIS data set was used to calculate the percentage of the watershed covered in upland wetlands, aquatic wetlands, and surface water for each of the 60 watershed and five sub-watersheds included in this research.

3.10 Sediment Deposition and Reservoir Trapping Efficiency, Assessment of Reservoirs Trapping Efficiency Using the Brune GM (1953) Capacity/Inflow Methodology

Sediment deposition occurs throughout the watershed in the form of point bars, mid-channel bars, and deposition within adjacent and upland wetlands. Within a watershed, dams are very effective at reducing and sometimes nearly eliminating the downstream movement of bed material load (suspended load and bed load sediment).

The amount of sediment trapped by a reservoir depends on the incoming flow rate of the rivers that discharges to the reservoir, the capacity and geometry of the impoundment, and the size of the sediment particles. An example of a dam with excessive accumulation of sediment within the reservoir is shown in Figure 28.

Figure 28. Photograph of the Cedar River Dam Spillway, Extensive Reservoir Deposition is Apparent on the East Side of the Cedar River Dam Reservoir, (MI00516), Built in 1890, Elk River Watershed (13) (Aerial Photograph, Google Earth Pro, 2021)

The USACE (1995) has observed that reservoir trapping efficiencies of fine sand sized particles (particle sizes greater than 0.125 millimeters) and larger to be nearly 100 percent; silts and clays are more difficult to settle out, but impoundments with as small a ratio as 0.1 of reservoir capacity to average annual rate of river inflow can retain nearly 80-95% of the bed material load. Depending upon the hydraulic retention time and geometry of the impoundment, frequently, only wash load (fine silts and clays) will be transported through the impoundment and downstream of the dam and bedload will be retained (USACE, 1995).

The trapping efficiency (E) of a reservoir can be defined as the percentage of the total inflowing sediment that is retained within the reservoir:

$$E = \frac{Ys(in) - Ys(\text{out})}{Ys(in)} \quad (10)$$

E = trapping efficiency (expressed as a decimal or percentage)

Ys = Sediment yield (weight units)

(in) = sediment inflow into the impoundment

(out) = sediment outflow out of the impoundment

As sediment is trapped, the reservoir water storage capacity decreases and trapping efficiency decreases. Factors affecting reservoir sediment trapping efficiency include (USACE, 1995):

- Ratio of Reservoir Storage Capacity (cubic meters) to the Inflow Rate (cubic meters/second) of Rivers that Discharge to the Impoundment: The reservoir capacity-inflow ratio is a measure of retention time. The greater the retention time, the higher the rate of sediment deposition within the reservoir.
- Sediment Particle Size. Settling velocity is determined based on particle size. Evaluation of reservoir retention time in conjunction with settling velocity form the basis of many approaches used to evaluate reservoir trapping efficiency. Typically, only silts in clays are in suspension long enough to reach the dam outlet structure.

- Reservoir Shape: The shape of the reservoir affects the effective retention time and could cause "short circuiting" in which the effective retention time becomes much less than the retention time as determined by the reservoir capacity-inflow ratio.
- Type of Dam Outlet: The type of dam outlet (e.g. spillway or sluice gates) can affect the trapping efficiency by increasing or decreasing the reservoir retention time.
- Operational Conditions of the Dam: Lowering of the pool elevation of the impoundment decreases the retention time which subsequently decrease the reservoir trap efficiency.

There are three common methods to estimate reservoir trapping efficiency methods based on empirical data: the Capacity-Watershed Method (Brown's Curve), the Capacity-Inflow Method (Brune's Curve), and the Sediment Index Method (Churchill's Curve). A brief overview of these three methods as well as assessment of reservoir trapping efficiency of Michigan dams using one of these methods (the Brune Curve, 1953) are discussed in the following text and (USACE, 1995):

Brown CB (1943) developed a curve relating the ratio of reservoir capacity (C, in acre-ft) and watershed area (W, in square miles) to trap efficiency (E, in percent), using the following equation:

Reservoir Trapping Efficiency (E) = $100\left\{1-\frac{1}{\left(1+\frac{KC}{W}\right)}\right\}$ (11)

where,

K = coefficient

W = watershed area (miles^2)
C = reservoir capacity (acre-ft)

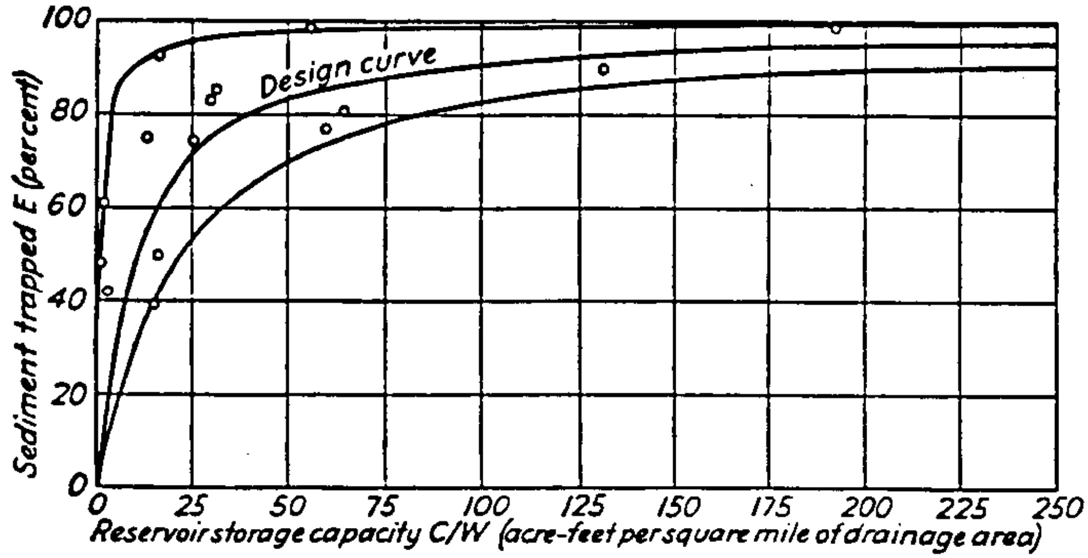


Figure 29. Brown Reservoir Trapping Efficiency Curve (from Brown 1943).

With respect to the Brown Curve (see Figure 29), the coefficient K varies from 1.0 (coarse sediments), 0.1 (medium sediments), and 0.046 (fine sediments), with a median value of 0.1 (Gill, 1979). A value for the coefficient K of 0.1 (Design Curve) was recommended for average conditions (Brown, 1943). The coefficient K increases to account for (1) for regions of smaller and varied retention time (calculated using the capacity-inflow ratio), (2) as the average grain size increases, and (3) for reservoir operations that prevent release of sediment through sluicing or movement of sediment toward the outlets by pool elevation regulation (USACE, 1995).

The Sediment Index Method (Churchill's Curve) relates the sedimentation index (SI) to reservoir trapping efficiency. Churchill (1948) used Tennessee Valley Authority Reservoir data to generate the curve shown in Figure 30. The sedimentation index (SI) of a reservoir is the period of retention (R) divided by the reservoir mean velocity; note that if the retention time or mean velocity cannot be obtained from field data, approximation can be made by assuming the effective retention time to be equal to the retention time as computed by using the C/I ratio (USACE, 1995).

As discussed in USACE (1995), the period of retention (R, in seconds) can then be computed by obtaining the capacity (C; cubic feet) of the reservoir at the mean operating pool elevation and dividing by the average daily inflow rate of the river (I; feet^3/sec). The mean velocity (V; feet/second) is obtained by dividing the average daily inflow rate by the average cross-sectional area of reservoir (A, square feet) in which the average cross-sectional area is obtained by dividing the capacity by the reservoir length (L; feet), at the mean operating pool elevation (USACE, 1995).

$$\text{Sedimentation Index (SI)} = \frac{Period\ of\ Retention\ (seconds)}{Mean\ Velocity\ (\frac{ft}{sec})} \tag{12}$$

$$\text{Period of Retention (R; seconds)} = \frac{Reservoir\ Capacity\ (ft3)}{Daily\ Inflow\ Rate\ (\frac{ft3}{\text{sec}})} \tag{13}$$

$$\text{Mean Velocity (V; ft/sec)} = \frac{Average\ Daily\ Inflow\ Rate\ (\frac{ft3}{sec})}{Average\ Cross{-}Sectional\ Area\ of\ the\ Impoundment\ (ft2)} \tag{14}$$

$$\text{Cross Sectional Area of the Impoundment (A; ft}^2\text{)} = \frac{Reservoir\ Capacity\ (ft3)}{Reservoir\ Length\ (ft)} \tag{15}$$

$$\text{Sedimentation Index (SI)} = (CA)/I^2 = (C/I^2)(C/L) = (C/I)^2/L \tag{16}$$

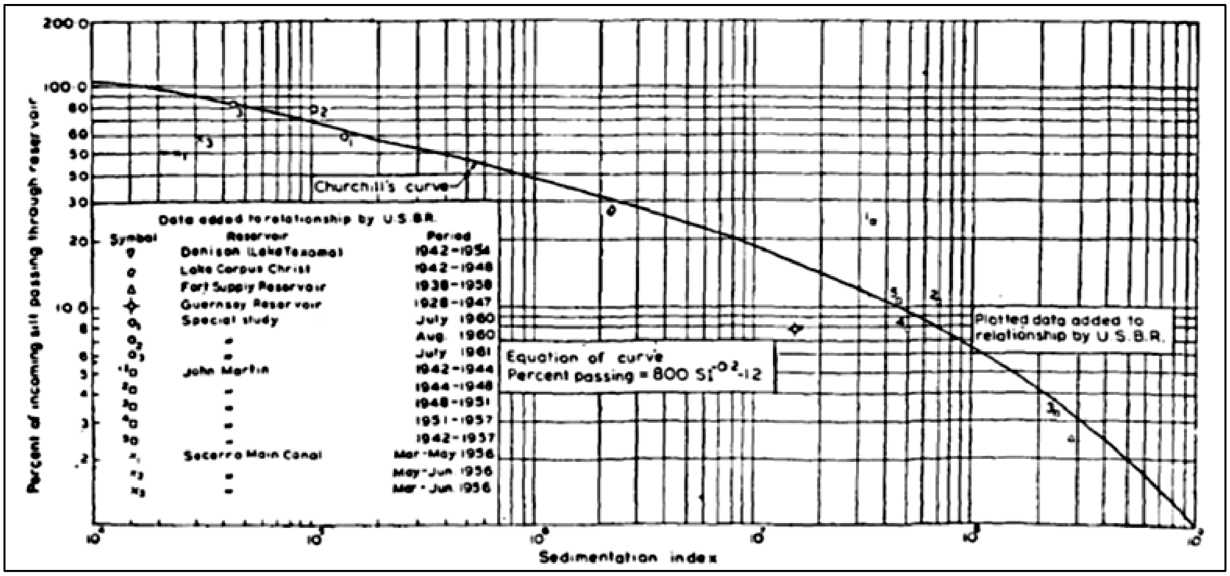


Figure 30. Churchill's Curve (from Churchill MA, 1948)

Churchill's Curve (Churchill MA, 1948) is presented on Figure 30 and represents the "percentage of incoming silt passing through reservoir" on the ordinate, which necessitates determining the difference between the value obtained and 100% to get the reservoir trapping efficiency; the term "silt" on the ordinate axis meant all the size classes of sediment when Churchill developed this relationship (USACE, 1995).

Although the use of the Churchill (1948) curves may give a better prediction of trapping efficiency than Brune's (1953) curve, it is very difficult to obtain the input data for calculating the sedimentation index; this is probably the reason why Brune's (1953) approach continues to be used so extensively as opposed to that of Churchill's (1948) Curve (Verstraeten G and Poesen J, 2000).

Brune GM (1953) analyzed 44 records of reservoir trapping efficiency and developed the Capacity-Inflow Method (Brune's Curve). The Brune Curve is an empirical relationship between reservoir trapping efficiency and the ratio of reservoir capacity to mean annual inflow, both in the same volume units (USACE, 1995; Brune GM, 1953). The capacity inflow ratio (C/I) is the total reservoir storage capacity (C) divided by the average annual inflow (I) of water to the reservoir. The capacity inflow ratio (C/I) is also the hydraulic retention time of the impoundment, and reflects the average number of times water is replaced in the reservoir during a year (USGS, 1984c).

The Brune GM (1953) curves shown in Figure 31 reflects coarse grained sand, the middle curve reflects a mixture of sediment particle size (sand and silt), and the lower curve reflects fine grained sediments such as silts and clays (Verstraeten G and Poesen, J, 2000; USDA-SCS, 1983).

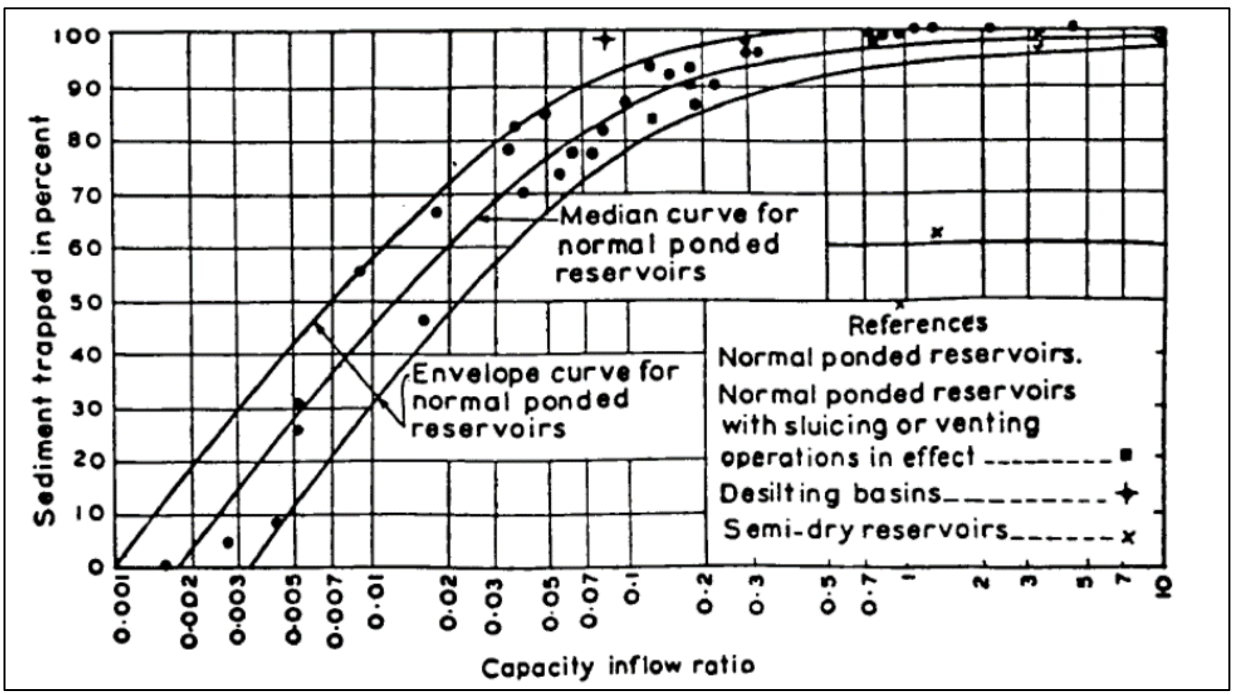


Figure 31. Reservoir Trapping Efficiency Curves, Capacity Inflow Ratio (from Brune GM, 1953)

The Brune GM (1953) curves were used to calculate sediment trapping efficiency and can be described using the equations listed in Table 19 (Verstraeten G and Poesen, J, 2000; USDA-SCS, 1983):

Table 19. Equations Developed by Verstraeten G and Poesen J (2000) and USDA-SCS (1983) That Describe the Brune (1953) Reservoir Trapping Efficiencies Curves.

Brune (1953) Curve	C/I > 1	1 > C/I > 0.02	C/I < 0.02
Upper Curve (gravel and sand)	100	$100 - (0.485[\ln(C/I)]^{2.99})$	$124 - (6.59[\ln(C/I)]^{1.52})$
Medium Curve (silt and sand)	97	$97 - (1.275[\ln(C/I)]^{2.47})$	$128 - (11.51[\ln(C/I)]^{1.304})$
Lower Curve (clay and silt)	94	$94 - (3.38[\ln(C/I)]^{1.92})$	$94 - (3.38[\ln(C/I)]^{1.92})$

Note : [ln(C/I)] is the absolute value of the natural log of Capacity/Inflow (C/I).

Over the years, many authors have suggested improvements to Brown's (1943), Brune's (1953), and Churchill's (1948) approaches to sediment trap efficiency, however these changes typically involved either the addition of new data or minor modifications to the original curves (Gill MA, 1979; Dendy FE, 1974, Heinmann HG, 1981: Garg J and Jothiprakash J, 2008). Of these three methods, Brune's (1953) and Brown's (1943) approaches still remain in widespread use today (Mulu A and Dwarakish GS, 2015; Garg J and Jothiprakash J, 2008; Minear JT and Kondolf MG, 2009).

3.10.1 Estimated Settling Velocities of Sediment Using Stoke's Law and Ferguson and Church (2004) for Sand, Silt, and Clay-sized Particles

One possible reason that the Brown (1943), Brune (1953), and Churchill (1948) methods have stood the test of time, is that the trapping efficiency of reservoirs with respect to silt and sand sized particles is very evident based on calculation of settling velocities using Stoke's Law. Sediment deposition within the reservoir can be observed at many Great Lakes dams by: inspection of the reservoir, especially the area where the river enters the reservoir (delta deposits) from a watercraft or using aerial photographs;

bathymetric surveying of the reservoir to compare to the initial storage volume to the current storage volume; sampling of the suspended sediment where the river enters the reservoir and downstream of the dam during and following rainfall events; and, observations made during a dam removal when the sediment that has accumulated within the reservoir can be physically inspected.

Stoke's Law predicts the settling velocity of glass spheres in vertical laboratory tubes, however these settling velocities are conservative and apply to sediment particles where settling velocity is dominated by viscous drag. Examples of settling velocities calculated using Stoke's Law for sediment particle sizes common in the Great Lakes watershed are shown on Table 20. As the particle size becomes larger than very fine sand or silt, turbulent drag in the wake behind each sediment grain slows sand sized (and larger) sediment as they move through the water column; settling velocity based on turbulent drag can be represented as follows (Ferguson RI and Church, 2004):

$$V_s = ((4)(R)(g)(d)/(3)(C_2))^{0.5} \tag{17}$$

where,

R = submerged specific gravity (1.65 for quartz in water)

g = acceleration due to gravity (9.81 meters/second squared)

d = diameter (meters)

C_2 = constant, equals 0.4 for smooth spheres and 1 for natural grains

Table 20. Example Sediment Settling Velocities Calculated Using Stokes Law (at 70F)

Stoke's Law

$$V_t = \frac{gd^2(\rho_p - \rho_m)}{18\mu}$$

Acceleration due to gravity (g)	9.8	meter/second^2
Particle diameter (d)	variable	meter
Submerged density of particle (ρ_p) - sediment	1.65	gram/centimeter^3
Density of particle (ρ_p) - sediment	2,650	kilogram/meter^3
Density of medium (ρ_m) - water	1,000	kilogram/meter^3

Dynamic Viscosity of medium (μ) - water	Kinematic Viscosity of medium (μ) - water	
0.0013 kilogram/(meter-second) at 50F	1.267E-06 m^2/sec	1.27E-03 kilogram/(meter-second) at 50F
0.0011 kilogram/(meter-second) at 60F	1.094E-06 m^2/sec	1.09E-03 kilogram/(meter-second) at 60F
0.001 kilogram/(meter-second) at 70F	9.536E-07 m^2/sec	9.54E-04 kilogram/(meter-second) at 70F
0.0009 kilogram/(meter-second) at 80F	8.395E-07 m^2/sec	8.40E-04 kilogram/(meter-second) at 80F

			Stoke's Law		
Particle Diameter (meters)	Particle Diameter (millimeters)	USACE Classification	Settling Velocity (meter/second)	Settling Velocity (feet/second)	Settling Velocity (feet/day)
0.00200000	2.00000	coarse sand	3.670411985	12.0389513	1,040,165.39
0.00050000	0.50000		0.229400749	0.7524345	65,010.34
0.00050000	0.50000	medium sand	0.229400749	0.7524345	65,010.34
0.00025000	0.25000		0.057350187	0.1881086	16,252.58
0.00025000	0.25000	fine sand	0.057350187	0.1881086	16,252.58
0.00006250	0.06250		0.003584387	0.0117568	1,015.79
0.00006250	0.06250	silt	0.003584387	0.0117568	1,015.79
0.00000390	0.00390		0.000013957	0.0000458	3.96
0.00000390	0.00390	clay	0.000013957	0.0000458	3.96
0.00000200	0.00200		0.000003670	0.0000120	1.04

A settling velocity (V_s) equation combining both Stokes Law and the effects of fluid drag (turbulence) was developed for natural sediment particles by Ferguson and Church (2004) and is expressed in the following equation:

$$V_s = \frac{Rgd^2}{C_1 v + (0.75 C_2 Rgd^3)^{0.5}} \tag{18}$$

where,

R = submerged specific gravity (1.65 for quartz in water)

g = acceleration due to gravity (9.81 meters/second squared)

d = diameter (meters)

C_1 = constant with a theoretical value of 18

v = kinematic viscosity (1.0 x 10^{-6} kilograms per meter per second)

C_2 = constant, equals 0.4 for smooth spheres and 1 for natural grains

Settling velocities for a range of sediment particle sizes common to the Great Lake watersheds using both Stoke's Law and the Ferguson R and Church M (2004) equation are presented on Table 20 and Table 21. Review of Table 20 and Table 21 shows that Stokes Law adequately predicts settling velocities for particles smaller than fine silt, but due to turbulent drag, Stokes Law greatly over predicts settling velocities of coarser sized sediment particles in comparison to the Ferguson R and Church M (2004) methodology that is based on natural grains.

Table 21. Settling Velocities Calculated Using Ferguson and Church (2004) Methodology

			Ferguson and Church (2004)		
Particle Diameter (meters)	**Particle Diameter (millimeters)**	**USACE Classification**	**Settling Velocity (meter/second)**	**Settling Velocity (feet/second)**	**Settling Velocity (feet/day)**
0.00200000	2.00000	coarse sand	0.196807701	2,323.91	17,004.19
0.00050000	0.50000		0.072058333	850.86	6,225.84
0.00050000	0.50000	medium sand	0.072058333	850.86	6,225.84
0.00025000	0.25000		0.032673578	385.81	2,823.00
0.00025000	0.25000	fine sand	0.032673578	385.81	2,823.00
0.00006250	0.06250		0.003344484	39.49	288.96
0.00006250	0.06250	silt	0.003344484	39.49	288.96
0.00000390	0.00390		0.000014306	0.17	1.24
0.00000390	0.00390	clay	0.000014306	0.17	1.24
0.00000200	0.00200		0.000003766	0.04	0.33

Although there are other factors that affect reservoir trapping efficiency and the settling velocities of sediment discharged into the reservoir (e.g. water temperature, particle shape and density, turbulence and shear velocity, concentration affects, flocculation of clay sized particles, etc.), the particle size of the incoming sediment, reservoir geometry, and the hydraulic retention time of the reservoir (the ratio of reservoir capacity to the inflow rate of rivers discharging to the impoundment) are clearly critical factors and support observations that most Great Lakes dams/reservoirs are very effective in retaining sediment larger than silt and sand sized particles (Alighalehbabakhani et al, 2017a; Alighalehbabakhani et al, 2017b; Baskaran et al, 2015; Jweda J and Baskaran M, 2011; Mabit et al, 2013; Mabit et al., 2014; USACE, 1995; Vorosmarty et al., 2003).

3.10.2 Estimated Reservoir Trapping Efficiency Using the Brune (1953) Capacity/Inflow Ratio Methodology

To further evaluate the impact of reservoirs on fluvial sediment delivery to the river outlet, this research involved a preliminary assessment of the reservoir trapping efficiency using the Brune GM (1953) capacity/inflow methodology of the dams located within the 60 watersheds included in this research. Of the 1,378 dams located in fluvial systems, the EGLE (2020) dam inventory contained information to calculate capacity/inflows for approximately 58% (802) of the dams. The equations presented in Table 19 (Verstraeten G and Poesen, J, 2000; USDA-SCS, 1983) were used to calculated the reservoir trapping efficiencies with respect to this research. With respect to dam capacity (C), the Normal Storage volume as reported in EGLE (2020) dam inventory was utilized. With respect to inflow (I), the inflow (I) is based on the ratio of the watershed area of the dam as reported by EGLE (2020) to the total watershed area of the river system and was applied to the annual mean flow at the river outlet (see Table 2, Table 3, Table 4, and Table 5). With respect to the 802 reservoirs that were evaluated, the average capacity/inflow ratio is 0.19 and the median value is 0.036, the distribution of reservoir capacity/inflows is summarized on Figure 32.

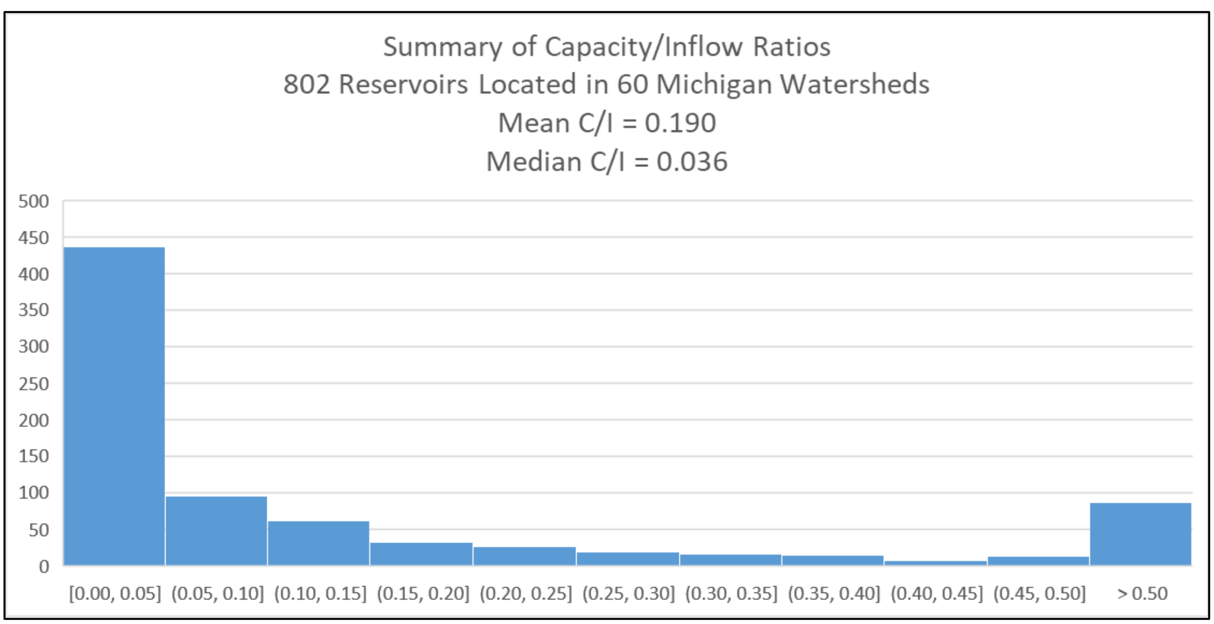


Figure 32. Summary of Reservoir Capacity/Inflow Ratios, 802 Reservoirs Located in 60 Michigan Watersheds

The Brune GM (1953) capacity/inflow estimates of reservoir trapping efficiencies are summarized in Figure 33 for the following sediment particle sizes: sand and gravel (upper curve), silt and sand (middle curve), and clay and silt (lower curve). Using the Brune GM (1953) capacity/inflow methodology, the average, estimated reservoir trapping efficiencies for sand and gravel, silt and sand, and clay silt are 75.6%, 68.5%, and 62.7%. As shown in Figure 33, Figure 34, and Figure 35, the reservoir trapping efficiencies decrease as a function of sediment particle size. These trapping efficiencies support observations and research that most Great Lakes dams/reservoirs are effective in retaining sediment larger than silt and sand sized particles (Alighalehbabakhani et al, 2017a; Alighalehbabakhani et al, 2017b; Baskaran et al, 2015; Creech et al, 2010; and, USACE, 1995 and 2008). For this reason, the total reservoir pool surface area within the 60 watersheds and five sub-watersheds was included as an independent variable in the regression analysis discussed in Chapter Four.

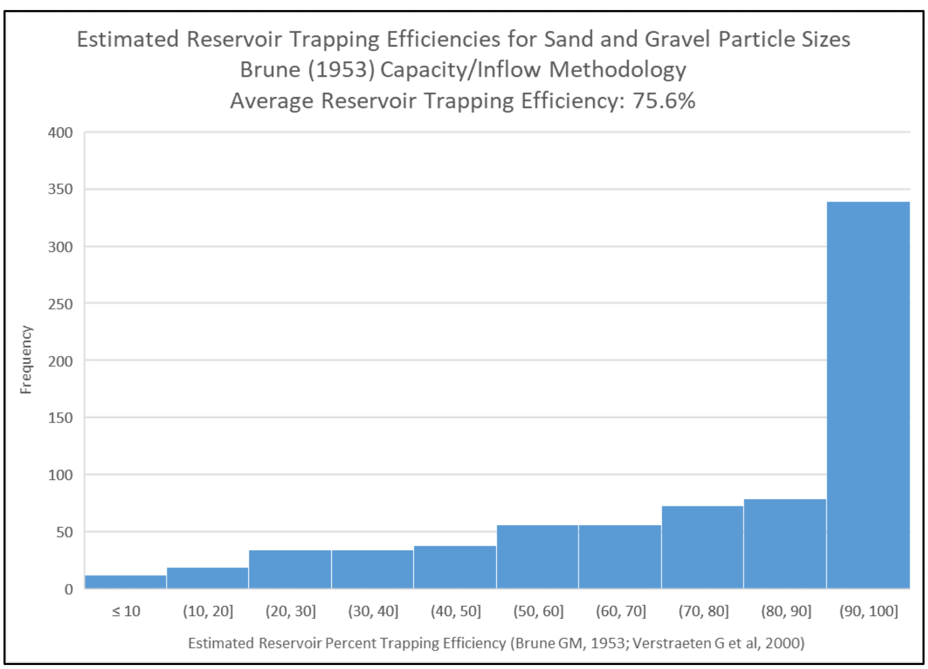


Figure 33. Estimated Reservoir Trapping Efficiencies for Sand and Gravel Particle Sizes, Brune (1953) Capacity/Inflow Methodology

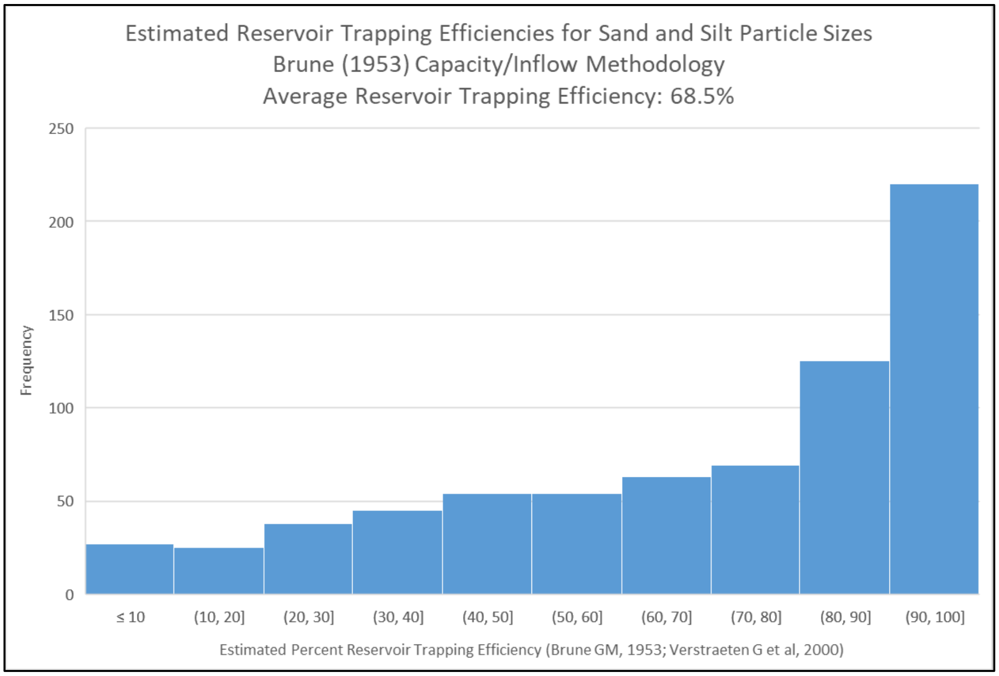


Figure 34. Estimated Reservoir Trapping Efficiencies for Silt and Sand Sized Particles, Brune (1953) Capacity/Inflow Methodology

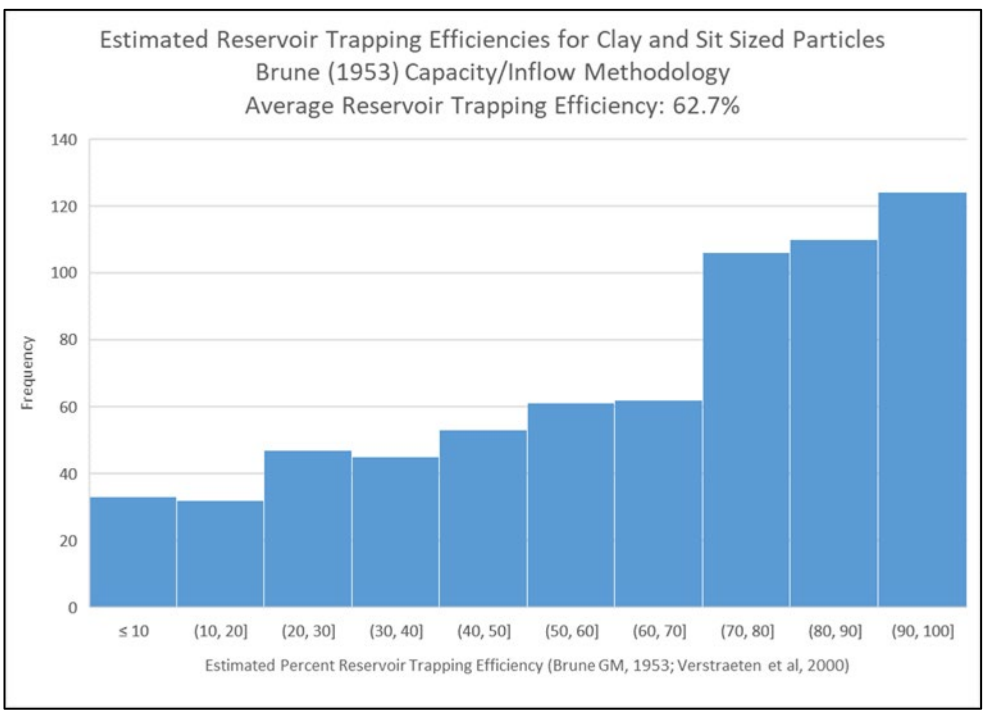


Figure 35. Estimated Reservoir Trapping Efficiencies for Clay and Silt Sized Particles, Brune (1953) Capacity/Inflow Methodology

With respect to the reservoirs that form the five sub-watersheds where radiometric dating of setting cores was completed (see Section 3.7), Brune (1953) reservoir trapping efficiencies were calculated using the method described previously and are summarized on Table 22.

Table 22. Summary of Estimated Reservoir Trapping Efficiencies for the Mio Dam (2A), Boardman Dam (9A), Webber Dam (14A), Ford Dam (15A), and Riley Dam (34A)

Dam ID	Dam Name	Watershed	Capacity/ Inflow	Sand and Gravel Brune (1953), Verstraeten et	Silt and Sand Brune (1953), Verstraeten et al (2000)	Clay and Silt Brune (1953), Verstraeten et al (2000)
MI00186	Mio Dam, 2A	Au Sable River	0.009	53%	40%	26%
MI00512	Boardman Dam, 9A	Boardman River	0.003	27%	13%	0%
MI00206	Webber Dam, 14A	Grand River	0.006	44%	30%	15%
MI00194	Ford Lake Dam, 15A	Huron River	0.045	86%	76%	64%
MI00533	Riley Dam, 34A	St. Joseph River	0.009	54%	40%	27%

The reservoir trapping efficiencies for medium grained sediment (sand and silt sized particles) ranged from 13% (Boardman Dam, 9A) to 76% (Ford Lake Dam, 15A). With respect to these five reservoirs, the capacity/inflow ratio and corresponding reservoir trapping efficiency of coarse, medium, and fine grained sediment reflects the large river inflow into a reservoir whose reservoir storage capacity is typical of dams constructed in low gradient streams in Michigan.

In conjunction with this research, 757 USACE pre-dredge sediment samples that were collected from the Inner Harbor (fluvial sediment) were evaluated with respect to grainsize distribution. Of the 757 pre-dredge samples, the weight percent of fines (silts and clays) was measured in 738 pre-dredge sediment samples, the distribution of percent fines is shown on Figure 36. Of the 757 pre-dredge sediment samples, 218 sediment samples have greater than 50% silt and clay sized particles (‘fines”).

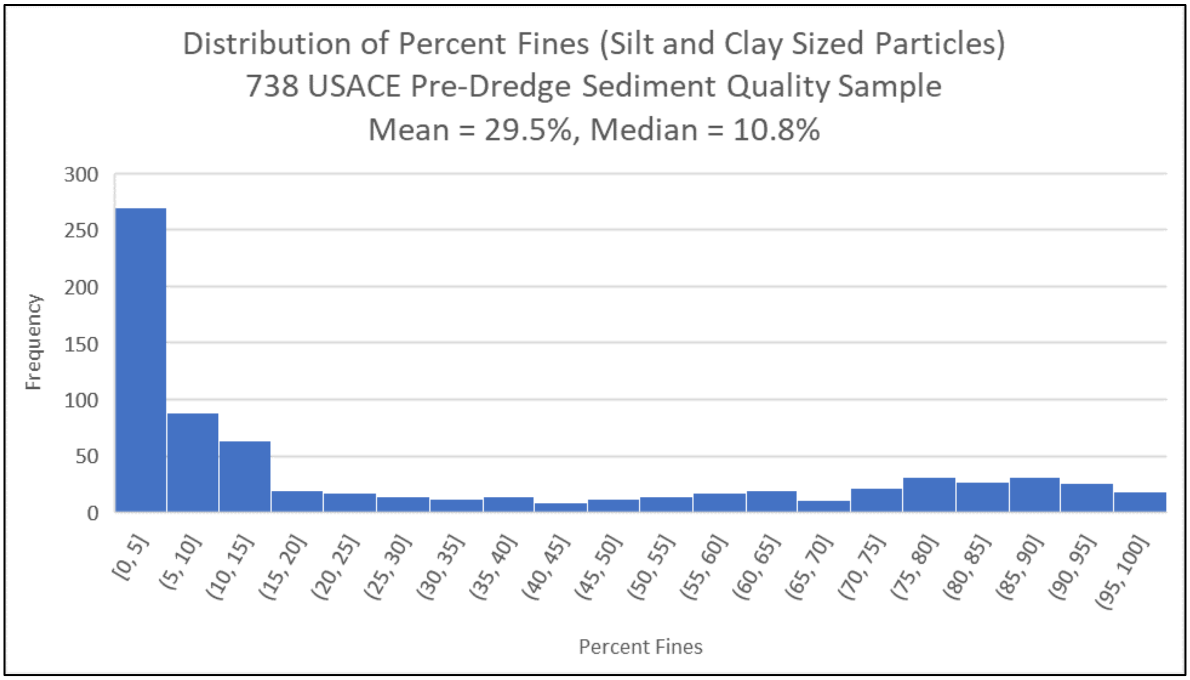


Figure 36. Distribution of Percent Fines (Silt and Clay Sized Particles), 738 USACE Pre-Dredge Sediment Quality Samples

Review of Figure 36 reveals that the distribution of percent fines is skewed towards coarser sediment (fine to medium grained sand) and is consistent with bedload. Grainsize distribution analysis was completed by the USACE on 252 of 757 pre-dredge sediment quality samples, and the distribution of D_{50} (the value of the particle diameter at 50% in the cumulative distribution) is presented on Figure 37. Of these 252 samples, the mean and median grainsizes are 0.417 millimeters and 0.267 millimeters which corresponds to medium grained sand.

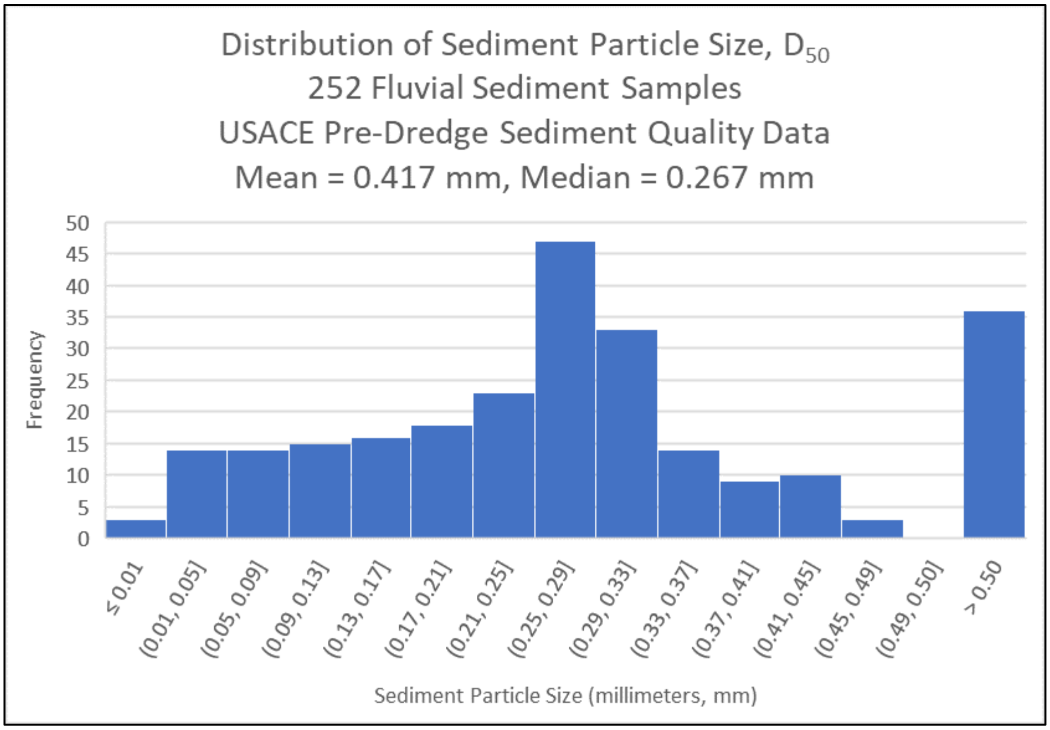


Figure 37, Distribution of Sediment Particle Size, D50, 252 USACE Pre-Dredge Sediment Quality Samples

Given the example settling velocities calculated using Stokes Law (Table 20) and Ferguson R and Church M (2004; Table 21) and the estimated reservoir trapping efficiencies presented on Figures 28-30 (Brune,1953), the grainsize distribution of the USACE pre-dredge sediment quality samples supports the observation that Great Lakes dams/reservoirs are effective in retaining fluvial silt to sand sized and larger sediment particles with reservoir sediment trapping efficiencies ranging from 62.7% to 75.6%.

CHAPTER 4 RESULTS AND DISCUSSION

This research involved development of an empirical equation that can be utilized as a statistical model to describe the relationship between bedload sediment delivery to the river outlet and significant watershed characteristics. This empirical equation was developed using step-wise regression analysis to identify predictive variables. The dependent variable is the annual watershed sediment delivery to the river outlet for 12 rivers based on USACE-Detroit District dredging data (see Table 17) and for five sub-watersheds using ^{137}Cs and ^{210}Pb radiometric dating (see Table 13). Dependent and independent variables are shown on Tables 23 to 28. Four sets of regression analyses were completed, these include:

- Assessment of watershed variables in conjunction with prediction of mean annual river flow and selected recurrence interval flows using non-transformed dependent and independent variables.
- Assessment of watershed variables in conjunction with prediction of watershed sediment delivery at the river outlet using non-transformed dependent and independent variables, 12 watersheds
- Assessment of watershed variables in conjunction with prediction of watershed sediment delivery at river outlet using non-transformed dependent and independent variables, 17 watersheds
- Assessment of watershed variables in conjunction with prediction of watershed sediment delivery at the river outlet using natural log transformed dependent and independent variables, 17 watersheds.

Table 23. Watershed Area, Curve Number, River Slope, Maximum and Average Relief, Mean Basin Temperature and Precipitation, Watersheds 1-30

			tonnes/year	kilometers²		unitless	meter/meter	meters	meters	°C	persons-km2
MDEQ Watershed Reference Number	River	USACE Harbor	Watershed Sediment Delivery to the River Outlet	Watershed Area	Watershed Area Basis	Watershed Runoff Curve Number (CN)	River Slope	Relief: Maximum Elevation minus Receiving Water Elevation	Relief: Average Elevation minus Receiving Water Elevation	Annual Mean Basin Temperature	Population Density
1	Au Gres River	Point Lookout Harbor	4,400	629	Contributing	75.0	0.0013	112.6	50.9	7.10	14.3
2	Au Sable River	Au Sable Harbor		4,351	Contributing	55.9	0.0008	278.6	164.6	7.35	11.5
2A	Au Sable River	NA; Mio Dam	9,500	2,735	Contributing	51.7	0.0007	177.4	78.9	6.74	11.1
3	Belle River	NA		588	Contributing	79.1	0.0007	151.3	61.2	7.90	60.5
4	Betsie River	Frankfort Harbor		603	Contributing	57.0	0.0003	186.6	73.6	7.75	37.3
5	Big Sable	NA		427	Contributing	61.8	0.0004	158.6	40.9	8.00	12.4
6	Black River (East)	Black River	11,000	1,839	Contributing	76.8	0.0006	131.7	58.9	9.20	38.0
7	Black River (West)	South Haven Harbor		738	Contributing	69.1	0.0007	69.6	28.2	10.20	38.0
8	Macatawa River	Holland Harbor	17,000	451	Contributing	75.9	0.0001	57.6	23.1	9.75	256.1
9	Boardman	NA		572	Contributing	56.1	0.0020	219.6	122.9	7.45	56.3
9A	Boardman River	NA; Brown Bridge Dam	1,100	311	Contributing	53.3	0.0015	153.3	73.3	7.13	18.8
10	Pine River	Charlevoix Harbor		808	Contributing	61.5	0.0020	208.6	83.6	8.25	28.7
11	Cheboygan River	Cheboygan Harbor		3,691	Contributing	61.5	0.0035	295.6	85.9	6.25	12.3
12	Clinton River	Clinton River	9,000	2,064	Total	77.5	0.0011	190.0	68.8	8.85	696.1
13	Elk River	NA		1,035	Contributing	60.3	0.0001	275.6	89.9	5.90	22.1
14	Grand River	Grand Haven Harbor	10,000	14,100	Contributing	75.2	0.0003	169.6	77.4	8.80	110.8
14A	Grand River	NA; Webber Dam	19,000	4,501	Contributing	77.0	0.0004	172.4	51.5	8.45	89.8
15	Huron River	NA		2,258	Contributing	73.9	0.0006	188.8	101.3	9.10	259.7
15A	Huron River	NA; Ford Dam	12,000	2,018	Contributing	73.0	0.0006	154.4	76.2	9.86	248.9
17	Kalamazoo River	Saugatuck Harbor		5,260	Total	70.8	0.0006	204.6	87.2	8.40	90.8
18	Kawkawlin River	NA		585	Contributing	79.2	0.0005	60.6	22.1	7.45	76.6
19	Lincoln River	NA		256	Contributing	67.4	0.0008	81.6	33.1	8.00	22.5
20	Manistee River	Manistee Harbor		4,349	Contributing	54.1	0.0007	342.6	147.8	8.50	12.3
22	Muskegon River	Muskegon Harbor		6,550	Contributing	63.9	0.0005	345.6	149.4	9.10	38.1
23	Oqueoc River	NA		370	Contributing	64.6	0.0012	112.6	63.4	7.20	5.3
24	Pentwater River	Pentwater Harbor		430	Contributing	60.7	0.0015	128.6	47.1	7.65	20.4
25	Pere Marquette River	Ludington Harbor		1,673	Contributing	58.7	0.0011	249.6	92.7	8.00	14.1
26	Pigeon River	Caseville Harbor		378	Contributing	80.6	0.0005	74.6	29.2	8.00	16.3
27	Pine River	NA		505	Total	77.6	0.0009	80.3	33.8	7.90	56.5
28	Platte River	NA		360	Contributing	54.1	0.0002	188.6	74.7	7.75	37.8
29	River Raisin	Monroe Harbor	62,000	2,771	Total	79.2	0.0006	199.3	75.6	9.40	65.8
30	Rifle River	NA		984	Total	67.0	0.0009	279.6	101.2	7.10	16.8

Table 24. Watershed Area, Curve Number, River Slope, Maximum and Average Relief, Mean Basin Temperature and Precipitation, Watersheds 31-60

			tonnes/year	kilometers^2		unitless	meter/meter	meters	meters	°C	persons-km2
MDEQ Watershed Reference Number	River	USACE Harbor	Watershed Sediment Delivery to the River Outlet	Watershed Area	Watershed Area Basis	Watershed Runoff Curve Number (CN)	River Slope	Relief: Maximum Elevation minus Receiving Water Elevation	Relief: Average Elevation minus Receiving Water Elevation	Annual Mean Basin Temperature	Population Density
31	Rouge River	Rouge River	22,000	1,204	Total	81.5	0.0007	131.3	49.4	10.05	1087.3
32	Saginaw River	Saginaw River	190,000	15,882	Contributing	75.5	0.0004	197.6	66.6	7.80	75.7
33	Sebewaing River	Sebewaing River		269	Contributing	78.9	0.0015	67.6	20.6	7.55	18.0
34	St. Joseph River	St. Joseph Harbor	12,000	12,196	Total	72.4	0.0011	195.6	89.9	9.05	81.7
34A	St. Joseph River	NA; Riley Dam	4,500	1,357	Contributing	75.4	0.0008	114.2	45.2	10.07	40.9
35	Stoney Creek	NA		319	Contributing	75.7	0.0006	72.8	33.3	9.40	180.4
36	Thunder Bay River	Alpena Harbor		3,116	Contributing	66.8	0.0007	256.6	86.7	6.90	2.6
37	White River	White Lake Harbor		1,178	Contributing	60.6	0.0012	204.6	68.7	9.10	27.5
38	Willow Creek	NA		246	Contributing	79.0	0.0014	82.6	44.9	7.75	8.3
39	Au Train	NA		285	Contributing	67.4	0.0006	151.6	88.3	6.20	4.2
40	Black River (Gogebic)	Black River Harbor		660	Contributing	77.6	0.0037	366.0	263.4	4.40	7.5
41	Carp River	NA		440	Contributing	72.8	0.0012	127.6	65.6	5.45	1.6
42	Cedar River	Cedar River Harbor		976	Contributing	76.8	0.0013	173.6	66.2	5.45	5.3
43	Chocolay River	NA		399	Contributing	63.5	0.0032	257.6	108.5	6.20	15.1
44	Days River	NA		161	Contributing	69.8	0.0025	145.6	76.1	5.85	16.8
45	Dead River	Presque Isle Harbor		422	Contributing	65.7	0.0045	381.6	269.3	6.20	20.1
46	Escanaba River	NA		2,341	Contributing	65.1	0.0019	372.6	196.9	5.55	8.5
47	Ford River	NA		1,197	Contributing	70.2	0.0013	295.6	150.2	5.55	3.7
48	Falls River	NA		117	Contributing	60.9	0.0053	392.6	212.7	4.80	3.9
49	Manistique River	Manistique Harbor	11,000	3,792	Total	67.7	0.0005	295.6	150.2	5.40	2.5
50	Menominee River	Menominee Harbor	7,300	10,500	Total	68.7	0.0016	371.6	223.4	5.45	6.7
51	Montreal River	NA		699	Contributing	76.8	0.0042	387.2	256.0	3.80	12.6
52	Munuscong River	NA		464	Contributing	75.7	0.0006	135.6	33.2	5.55	13.0
53	Ontonagon River	Ontonagon Harbor	30,000	3,585	Total	71.4	0.0032	382.6	235.7	6.15	2.2
54	Pine River	NA		710	Contributing	71.1	0.0003	127.6	55.8	4.65	3.2
55	Portage River	Keweenaw Waterway		2,572	Total	72.8	0.0015	359.6	155.8	5.15	14.8
56	Presque Isle River	NA		935	Contributing	76.0	0.0020	386.9	284.7	6.15	3.4
57	Rapid River	NA		357	Contributing	71.7	0.0027	173.6	93.3	5.85	3.2
58	Sturgeon River	NA		567	Total	63.4	0.0012	127.6	58.1	5.85	2.8
60	Tahquamenon River	NA		2,095	Total	68.3	0.0002	170.6	61.0	4.15	3.2
61	Two Hearted River	NA		536	Total	66.8	0.0010	166.6	60.7	5.55	1.4
62	Waiska River	NA		383	Total	72.6	0.0013	104.6	36.8	4.65	10.5
63	Whitefish River	NA		811	Contributing	69.9	0.0024	202.6	93.2	5.85	4.1

Table 25. Mean Annual River Flow and Recurrence Interval Flows, Watersheds 1-30

MDEQ Watershed Reference Number	River	USACE Harbor	Mean Annual River Flow (meters3/sec)	1.5 year Recurrence Interval Flow (meters3/sec)	2.0 year Recurrence Interval Flow (meters3/sec)	5 year Recurrence Interval Flow (meters3/sec)	10 year Recurrence Interval Flow (meters3/sec)	25 year Recurrence Interval Flow (meters3/sec)	50 year Recurrence Interval Flow (meters3/sec)	100 year Recurrence Interval Flow (meters3/sec)
1	Au Gres River	Point Lookout Harbor	4.6	42.5	51.0	65.1	76.5	90.6	99.1	107.6
2	Au Sable River	Au Sable Harbor	42.2	96.3	104.8	130.3	144.4	164.2	172.7	186.9
2A	Au Sable River	NA; Mio Dam	28.0	73.6	82.1	96.3	104.8	116.1	124.6	133.1
3	Belle River	NA	4.2	59.5	73.6	107.6	130.3	161.4	184.1	209.5
4	Betsie River	Frankfort Harbor	8.2	25.5	26.9	31.1	36.8	39.6	41.1	43.9
5	Big Sable	NA	5.7	13.0	15.6	21.2	25.5	31.1	34.0	39.6
6	Black River (East)	Black River	12.5	186.9	220.9	311.5	356.5	424.8	476.0	522.4
7	Black River (West)	South Haven Harbor	10.2	17.0	24.1	45.3	65.1	93.4	116.1	147.2
8	Macatawa River	Holland Harbor	5.4	107.6	144.4	235.0	311.5	396.4	481.4	566.3
9	Boardman	NA	8.8	18.4	21.2	28.3	34.0	42.5	48.1	51.0
9A	Boardman River	NA; Brown Bridge Dam	4.5	12.7	14.2	18.4	21.2	24.1	26.9	28.3
10	Pine River	Charlevoix Harbor	13.0	53.8	65.1	85.0	96.3	113.3	121.8	133.1
11	Cheboygan River	Cheboygan Harbor	37.7	76.5	82.1	99.1	107.6	118.9	127.4	133.1
12	Clinton River	Clinton River	17.6	28.3	45.3	76.5	101.9	135.9	167.1	192.6
13	Elk River	NA	20.1	28.3	34.0	42.5	48.1	53.8	59.5	62.3
14	Grand River	Grand Haven Harbor	127.1	481.4	594.7	849.5	1,047.7	1,302.6	1,500.8	1,727.3
14A	Grand River	NA; Webber Dam	36.0	135.9	181.2	311.5	396.4	509.7	623.0	707.9
15	Huron River	NA	16.7	76.5	99.1	150.1	203.9	260.5	311.5	339.8
15A	Huron River	NA; Ford Dam	17.8	73.6	90.6	135.9	167.1	212.4	246.4	283.2
17	Kalamazoo River	Saugatuck Harbor	51.5	127.4	152.9	212.4	254.9	311.5	368.1	424.8
18	Kawkawlin River	NA	3.7	51.0	62.3	87.8	107.6	130.3	150.1	169.9
19	Lincoln River	NA	2.8	21.2	24.1	31.1	36.8	42.5	48.1	53.8
20	Manistee River	Manistee Harbor	65.7	155.7	172.7	203.9	223.7	246.4	263.3	277.5
22	Muskegon River	Muskegon Harbor	66.0	175.6	203.9	277.5	339.8	396.4	453.1	509.7
23	Oqueoc River	NA	3.4	12.2	13.6	17.0	19.8	21.2	24.1	25.5
24	Pentwater River	Pentwater Harbor	5.1	39.6	48.1	65.1	76.5	90.6	104.8	116.1
25	Pere Marquette River	Ludington Harbor	22.4	51.0	59.5	82.1	96.3	113.3	124.6	138.8
26	Pigeon River	Caseville Harbor	2.5	34.0	48.1	85.0	107.6	141.6	167.1	192.6
27	Pine River	NA	8.5	53.8	68.0	107.6	135.9	169.9	201.0	232.2
28	Platte River	NA	5.4	13.6	15.6	19.8	22.7	25.5	28.3	31.1
29	River Raisin	Monroe Harbor	22.5	135.9	164.2	240.7	283.2	339.8	396.4	481.4
30	Rifle River	NA	10.2	62.3	70.8	96.3	110.4	130.3	141.6	155.7

Table 26. Mean Annual River Flow and Recurrence Interval Flows, Watersheds 31-60

			meters3/sec	meters3/sec	meters3/sec	meters3/sec	meters3/sec	meters3/sec	meters3/sec	meters3/sec
MDEQ Watershed Reference Number	River	USACE Harbor	Mean Annual River Flow	1.5 year Recurrence Interval Flow	2.0 year Recurrence Interval Flow	5 year Recurrence Interval Flow	10 year Recurrence Interval Flow	25 year Recurrence Interval Flow	50 year Recurrence Interval Flow	100 year Recurrence Interval Flow
31	Rouge River	Rouge River	8.8	85.0	116.1	206.7	283.2	396.4	481.4	594.7
32	Saginaw River	Saginaw River	124.9	764.6	877.8	1,161.0	1,330.9	1,557.4	1,699.0	1,868.9
33	Sebewaing River	Sebewaing River	1.6	53.8	65.1	93.4	113.3	138.8	158.6	175.6
34	St. Joseph River	St. Joseph Harbor	132.5	311.5	368.1	453.1	509.7	566.3	623.0	651.3
34A	St. Joseph River	NA; Riley Dam	13.3	36.8	42.5	59.5	73.6	87.8	99.1	110.4
35	Stoney Creek	NA	2.4	19.8	25.5	42.5	53.8	70.8	82.1	104.8
36	Thunder Bay River	Alpena Harbor	24.1	107.6	138.8	218.0	274.7	339.8	396.4	453.1
37	White River	White Lake Harbor	16.7	45.3	56.6	85.0	107.6	135.9	158.6	184.1
38	Willow Creek	NA	1.8	31.1	39.6	56.6	70.8	90.6	101.9	116.1
39	Au Train	NA	4.0	11.3	14.2	24.1	31.1	39.6	45.3	51.0
40	Black River (Gogebic)	Black River Harbor	8.5	99.1	127.4	201.0	260.5	339.8	424.8	509.7
41	Carp River	NA	4.0	70.8	76.5	85.0	93.4	101.9	107.6	110.4
42	Cedar River	Cedar River Harbor	7.6	48.1	59.5	85.0	101.9	124.6	141.6	161.4
43	Chocolay River	NA	10.8	36.8	45.3	68.0	82.1	101.9	116.1	130.3
44	Days River	NA	1.0	12.5	15.6	22.7	28.3	34.0	39.6	45.3
45	Dead River	Presque Isle Harbor	5.7	34.0	39.6	51.0	56.6	68.0	73.6	82.1
46	Escanaba River	NA	24.6	144.4	169.9	229.4	266.2	311.5	339.8	368.1
47	Ford River	NA	10.5	70.8	82.1	110.4	127.4	150.1	164.2	181.2
48	Falls River	NA	1.2	15.6	18.4	25.5	31.1	36.8	42.5	48.1
49	Manistique River	Manistique Harbor	51.5	198.2	235.0	311.5	368.1	453.1	509.7	566.3
50	Menominee River	Menominee Harbor	101.4	339.8	396.4	538.0	651.3	792.9	906.1	1,019.4
51	Montreal River	NA	9.3	73.6	90.6	138.8	172.7	220.9	254.9	283.2
52	Munuscong River	NA	5.7	73.6	82.1	101.9	118.9	135.9	147.2	158.6
53	Ontonagon River	Ontonagon Harbor	39.4	249.2	311.5	509.7	623.0	792.9	934.5	1,076.0
54	Pine River	NA	8.5	82.1	93.4	124.6	144.4	169.9	186.9	203.9
55	Portage River	Keweenaw Waterway	40.5	175.6	201.0	266.2	311.5	339.8	396.4	424.8
56	Presque Isle River	NA	10.8	76.5	90.6	121.8	141.6	164.2	181.2	198.2
57	Rapid River	NA	1.2	34.0	39.6	53.8	62.3	73.6	82.1	93.4
58	Sturgeon River	NA	6.2	31.1	36.8	45.3	53.8	59.5	65.1	70.8
60	Tahquamenon River	NA	26.9	113.3	127.4	158.6	178.4	198.2	215.2	229.4
61	Two Hearted River	NA	9.1	34.0	39.6	56.6	70.8	87.8	101.9	118.9
62	Waiska River	NA	5.9	48.1	56.6	76.5	87.8	104.8	116.1	127.4
63	Whitefish River	NA	8.8	65.1	79.3	107.6	127.4	152.9	172.7	192.6

Table 27. Watershed Land Use, 2011 NLCD and EGLE (1978) MIRIS Land Use, Watersheds 1-30

		2011 National Land Cover Database (USDA, 2011)								EGLE (1978) MIRIS Land Cover Database			
		percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent
MDEQ Watershed Reference Number	River	Surface Water	Developed	Barren	Forest	Shubland	Grassland	Agriculture	Wetlands	Surface Water	Reservoir Pool Surface Area (EGLE, 2020)	Total Aquatic Wetlands	Total Upland Wetlands
1	Au Gres River	2.22%	6.63%	0.42%	35.40%	1.99%	5.71%	24.44%	23.19%	0.82%	0.73%	0.71%	4.06%
2	Au Sable River	1.98%	8.48%	0.10%	55.89%	9.97%	7.55%	3.28%	12.75%	0.77%	0.72%	0.71%	3.43%
2A	Au Sable River	1.58%	8.79%	0.11%	54.48%	12.68%	9.18%	1.72%	11.47%	1.22%	0.15%	0.75%	3.10%
3	Belle River	0.40%	11.00%	0.31%	19.12%	0.34%	1.49%	57.17%	10.16%	0.17%	0.07%	0.39%	1.13%
4	Betsie River	9.63%	8.59%	0.15%	44.71%	3.09%	11.44%	7.41%	14.98%	9.19%	0.80%	1.21%	7.75%
5	Big Sable	5.05%	5.20%	0.87%	51.49%	2.97%	4.96%	11.65%	17.81%	0.89%	4.51%	1.52%	2.92%
6	Black River (East)	0.30%	8.10%	0.26%	13.35%	0.28%	1.11%	68.50%	8.09%	0.10%	0.03%	0.25%	3.38%
7	Black River (West)	1.42%	8.62%	0.21%	24.48%	0.56%	3.88%	43.97%	16.85%	1.40%	0.06%	0.42%	1.35%
8	Macatawa River	1.80%	34.07%	0.83%	7.48%	0.19%	0.90%	50.78%	3.94%	1.96%	0.00%	0.13%	0.71%
9	Boardman	2.25%	12.56%	0.20%	44.05%	6.16%	14.21%	9.79%	10.78%	1.18%	0.52%	0.34%	1.47%
9A	Boardman River	0.89%	8.58%	0.14%	48.02%	8.00%	16.35%	5.31%	12.71%	0.34%	0.25%	0.53%	0.99%
10	Pine River	8.76%	7.46%	0.22%	47.59%	1.37%	7.22%	15.20%	12.18%	8.99%	0.08%	0.27%	1.71%
11	Cheboygan River	6.41%	6.28%	0.12%	47.82%	4.90%	8.15%	6.78%	19.55%	2.81%	3.59%	0.57%	2.74%
12	Clinton River	2.69%	55.61%	0.65%	13.62%	0.16%	1.10%	18.32%	7.85%	1.16%	0.90%	0.91%	1.89%
13	Elk River	11.39%	7.90%	0.18%	44.46%	2.58%	11.29%	14.74%	7.45%	10.65%	0.54%	0.39%	1.33%
14	Grand River	1.54%	14.80%	0.38%	16.65%	0.25%	0.93%	53.45%	12.00%	0.87%	0.34%	0.81%	2.94%
14A	Grand River	1.18%	12.70%	0.33%	12.67%	0.14%	0.46%	59.10%	13.42%	0.54%	0.62%	1.24%	5.36%
15	Huron River	4.15%	32.83%	0.70%	21.83%	0.19%	1.15%	24.32%	14.83%	1.17%	2.23%	2.15%	4.87%
15A	Huron River	4.23%	31.09%	0.71%	22.37%	0.20%	1.12%	24.69%	15.60%	1.75%	1.97%	2.33%	5.14%
17	Kalamazoo River	2.29%	13.68%	0.45%	21.44%	0.39%	1.36%	48.01%	12.39%	1.36%	0.50%	1.10%	4.28%
18	Kawkawlin River	0.40%	13.26%	0.20%	19.95%	1.02%	2.84%	46.18%	16.14%	0.17%	0.29%	0.95%	3.09%
19	Lincoln River	2.39%	8.27%	0.10%	33.21%	2.83%	9.58%	27.79%	15.83%	2.51%	0.01%	1.29%	3.66%
20	Manistee River	1.35%	5.98%	0.15%	55.39%	5.15%	11.30%	9.01%	11.67%	0.82%	0.38%	0.69%	4.60%
22	Muskegon River	4.18%	8.52%	0.21%	39.47%	3.07%	6.97%	19.54%	18.03%	2.95%	0.79%	1.13%	4.53%
23	Oqueoc River	2.10%	4.65%	0.20%	41.34%	5.00%	6.91%	6.85%	32.95%	1.34%	0.47%	0.54%	3.30%
24	Pentwater River	1.07%	7.57%	0.22%	32.07%	1.90%	9.73%	34.07%	13.37%	0.86%	0.25%	0.75%	1.68%
25	Pere Marquette River	1.32%	5.94%	0.09%	57.01%	3.57%	5.26%	12.27%	14.53%	1.18%	0.07%	0.63%	3.11%
26	Pigeon River	0.19%	6.17%	0.05%	5.02%	0.07%	0.41%	81.79%	6.28%	0.03%	0.00%	0.05%	1.41%
27	Pine River	0.42%	11.08%	0.25%	32.49%	0.55%	2.70%	44.96%	7.55%	0.20%	0.02%	0.05%	0.47%
28	Platte River	7.61%	6.69%	0.29%	53.82%	2.12%	12.21%	9.17%	8.09%	9.61%	0.01%	0.44%	2.47%
29	River Raisin	1.50%	11.53%	0.30%	10.68%	0.21%	0.68%	67.04%	8.05%	1.04%	0.47%	0.69%	1.51%
30	Rifle River	1.46%	8.98%	0.13%	42.90%	3.50%	6.74%	17.44%	18.84%	0.92%	0.41%	0.32%	2.97%

Table 28. Watershed Land Use, 2011 NLCD and EGLE (1978) Land Use, Watersheds 30-60

		2011 National Land Cover Database (USDA, 2011)								EGLE (1978) MIRIS Land Cover Database			
		percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent
MDEQ Watershed Reference Number	River	Surface Water	Developed	Barren	Forest	Shubland	Grassland	Agriculture	Wetlands	Surface Water	Reservoir Pool Surface Area (EGLE, 2020)	Total Aquatic Wetlands	Total Upland Wetlands
31	Rouge River	0.90%	84.13%	0.37%	6.45%	0.07%	0.46%	5.00%	2.64%	0.78%	0.14%	0.38%	0.84%
32	Saginaw River	1.38%	12.73%	0.27%	22.61%	1.13%	2.83%	45.19%	13.86%	0.32%	0.62%	0.80%	3.13%
33	Sebewaing River	0.02%	6.28%	0.10%	3.64%	0.05%	0.34%	88.45%	1.13%	0.04%	0.00%	0.00%	0.22%
34	St. Joseph River	2.34%	13.73%	0.24%	11.36%	0.28%	0.97%	58.66%	12.42%	1.54%	0.62%	1.25%	3.21%
34A	St. Joseph River	2.40%	9.87%	0.22%	11.47%	0.20%	0.54%	60.54%	14.77%	1.47%	0.77%	0.97%	1.97%
35	Stoney Creek	0.40%	19.45%	0.64%	16.40%	0.17%	1.34%	53.70%	7.90%	0.09%	0.02%	0.18%	0.36%
36	Thunder Bay River	3.13%	6.01%	0.09%	42.65%	3.01%	5.75%	10.45%	28.90%	0.52%	1.55%	0.79%	4.58%
37	White River	1.35%	5.98%	0.15%	55.39%	5.15%	11.30%	9.01%	11.67%	1.64%	0.10%	0.56%	2.22%
38	Willow Creek	0.08%	5.75%	0.08%	9.10%	0.12%	0.74%	74.92%	9.22%	0.03%	0.00%	0.24%	4.80%
39	Au Train	3.38%	3.19%	0.06%	68.32%	1.23%	1.30%	7.74%	19.30%	1.56%	2.16%	0.37%	4.15%
40	Black River (Gogebic)	0.83%	3.54%	0.08%	61.96%	0.85%	1.43%	2.79%	28.52%	0.38%	0.47%	0.24%	4.25%
41	Carp River	1.74%	2.19%	0.04%	36.88%	1.51%	1.93%	0.97%	54.74%	1.79%	0.01%	2.24%	5.86%
42	Cedar River	0.49%	4.36%	0.23%	28.27%	1.65%	2.23%	9.58%	53.19%	0.45%	0.00%	1.82%	5.42%
43	Chocolay River	0.85%	5.61%	0.29%	65.15%	1.35%	4.10%	2.40%	20.26%	0.51%	0.17%	0.65%	2.86%
44	Days River	0.15%	4.20%	0.04%	37.44%	2.92%	1.29%	2.97%	51.00%	0.25%	0.01%	0.26%	6.71%
45	Dead River	4.83%	4.06%	0.49%	68.06%	2.70%	3.69%	0.02%	16.15%	0.91%	3.92%	1.67%	5.02%
46	Escanaba River	2.28%	3.97%	1.82%	44.34%	4.80%	4.28%	2.54%	35.97%	1.01%	0.17%	1.94%	7.39%
47	Ford River	0.27%	2.97%	0.13%	39.73%	2.89%	2.86%	4.12%	47.02%	0.16%	0.03%	0.57%	4.73%
48	Falls River	0.47%	4.98%	0.15%	82.13%	1.87%	2.39%	0.85%	6.97%	0.39%	0.04%	0.34%	1.84%
49	Manistique River	4.49%	2.92%	0.11%	37.37%	3.56%	4.17%	0.96%	46.41%	1.81%	2.98%	10.26%	9.16%
50	Menominee River	2.95%	3.90%	0.14%	53.46%	1.97%	2.40%	4.32%	30.86%	0.77%	1.49%	1.21%	6.38%
51	Montreal River	3.30%	5.49%	0.12%	58.51%	2.36%	1.37%	4.34%	24.52%	3.16%	0.14%	0.04%	4.11%
52	Munuscong River	0.12%	6.12%	1.07%	29.36%	1.66%	4.44%	24.71%	32.51%	0.07%	0.30%	1.34%	4.97%
53	Ontonagon River	4.16%	2.60%	0.07%	69.00%	2.11%	1.19%	3.45%	17.42%	2.57%	0.85%	0.81%	3.52%
54	Pine River	0.14%	3.58%	0.12%	39.43%	4.12%	4.15%	9.20%	39.26%	0.04%	0.14%	5.18%	4.91%
55	Portage River	3.49%	3.83%	0.27%	64.01%	1.89%	1.85%	5.61%	19.05%	3.05%	0.36%	1.28%	5.86%
56	Presque Isle River	5.13%	2.74%	0.03%	64.02%	0.51%	0.42%	0.05%	27.10%	1.10%	0.46%	0.43%	4.91%
57	Rapid River	0.13%	2.92%	0.07%	37.00%	1.56%	1.11%	3.11%	54.11%	0.09%	0.04%	0.99%	6.46%
58	Sturgeon River	2.77%	2.49%	0.34%	43.12%	2.29%	1.88%	0.19%	46.92%	2.31%	0.62%	3.10%	12.19%
60	Tahquamenon River	0.89%	2.33%	0.07%	35.19%	1.99%	2.79%	0.72%	56.02%	0.77%	0.24%	3.64%	10.34%
61	Two Hearted River	0.88%	2.08%	0.03%	42.18%	4.24%	3.20%	0.00%	47.39%	1.17%	0.00%	6.83%	8.80%
62	Waiska River	0.10%	5.51%	0.25%	35.92%	3.93%	5.11%	16.80%	32.39%	0.05%	0.07%	2.77%	8.08%
63	Whitefish River	0.36%	2.37%	0.23%	44.14%	2.34%	2.16%	3.64%	44.74%	0.45%	0.02%	2.25%	5.09%

The dependent and independent variables for each of the 60 watersheds and five sub-watersheds are shown on Table 23, Table 24, Table 25, Table 26, Table 27, and Table 28. With respect to watershed sediment delivery estimates of 12 watersheds where fluvial sediment delivery is based on USACE dredging data, these watersheds are highlighted in green. A yellow highlight identifies the five sub-watersheds where fluvial sediment delivery is based on ^{137}Cs and ^{210}Pb radiometric dating. Each of the four sets of stepwise regression analyses are further discussed in the following text.

4.1 Assessment of Watershed Variables in Conjunction with the Prediction of Mean Annual River Flow and Selected Recurrence Interval Flows

Due to their significant importance on watershed sediment transport, the initial focus of the regression analyses was the determination of watershed characteristics important to the prediction of mean annual river flow and recurrence interval flows. The mean annual river flow and recurrence interval flows were evaluated for the 60 watersheds relative to the following watershed characteristics: watershed curve number, maximum watershed relief, river slope, average annual Great Lake basin precipitation and temperature, and the percentage of the watershed covered by seven NLCD (2011) land use classifications (water, developed land, barren land, shrubland, grassland, agriculture and wetlands).

4.1.1 Relationship Between River Slope and Watershed Area

The relationship between river slope and watershed area is shown on Figure 38. The average slope of these 60 Michigan rivers is 0.0013 meter/meter. As expected, there is higher variability in river slopes among smaller watersheds, and the average slope of the watershed decreases as watershed area increases (see Figure 38).

Thirty-six of the 60 Michigan watersheds evaluated in this research have watershed areas less than 1,000 square kilometers; for these 36 watersheds, the average river slope is 0.00155 meter/meter with a standard deviation of 0.00128 meter/meter. The average slope (and standard deviation) of rivers with watershed areas ranging from 1,000 to 4,000 square kilometers is 0.00117 meter/meter (0.00098 meter/meter) and the average slope of rivers with watershed areas greater than 4,000 square kilometers is 0.00076 meter/meter (0.00041 meter/meter). As shown in Figure 38, the average river slope and standard deviation decrease as watershed area increases.

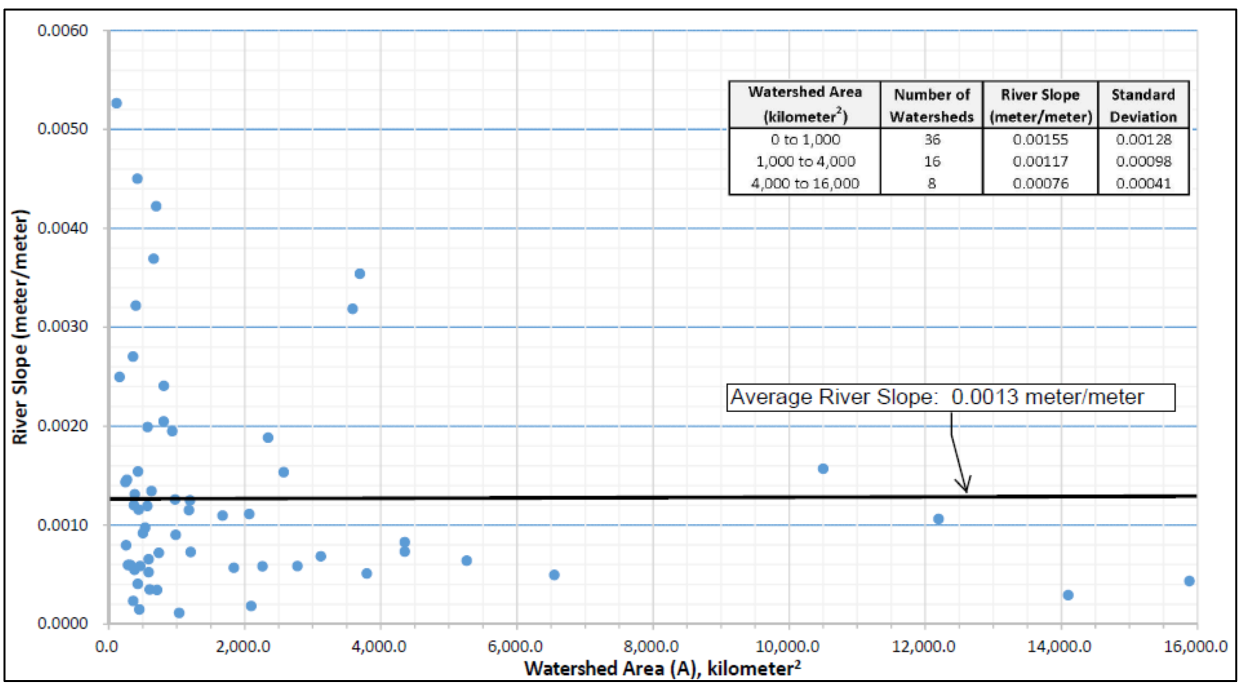


Figure 38. Relationship Between River Slope and Watershed Area

4.1.2 Watershed Curve Number

The area weighted watershed curve number for these 60 Michigan watersheds is 69.9, and the area weighted watershed curve numbers for the Michigan rivers that drain to Lake Superior, Lake Michigan, Lake Huron, and Lake Erie are 71.1, 68.2, 70.0, and 77.5, respectively (see Table 23 and Table 24). With the exception of the Lake Erie watershed, the Lake Superior, Lake Michigan, and Lake Huron watersheds are dominated by forest land, wetlands, and agriculture. The relative differences in the area-weighted watershed curve numbers for these Great Lakes watersheds are explained by land use and soil classification. Approximately half of the 60 Michigan watersheds evaluated in this research contain over 40% forest land and the average watershed contains 38.1% forest land. In addition, agricultural lands and wetlands dominate these 60 Michigan watersheds. Of the 60 watersheds evaluated, the average watershed area contains 21.5% agricultural land use and 21.9% wetlands. Thirty-four of the 60 Michigan watersheds included in this research contain greater than 15% wetlands.

Urban land use (identified as "Developed" in Table 27 and Table 28) constitutes an important percentage of watershed area for basins where Michigan's largest cities are located. The watershed with the highest percentage of urban development is the Rouge River within the City of Detroit (84.1%) with a watershed CN of 81.5 (Table 11). Other examples of watersheds that contain an elevated percentage of urban land use include the Macatawa River watershed (34.1 %; near the City of Holland, Michigan) with a watershed CN of 75.9; the Clinton River watershed (55.6%; north of the City of Detroit) with a watershed CN of 77.5; the Huron River watershed (32.8%; west and south of the

City of Detroit) with a watershed CN of 73.9; and the Saginaw River watershed (12.7%; encompassing the cities of Flint, Saginaw, and Bay City) with a watershed CN of 75.5.

The rivers that drain the Lake Erie watershed have an area weighted watershed CN of 77.5 (Table 11) that is reflected in the elevated percentages of urban land use within this basin; these rivers and watershed reference number include: Stoney Creek (35), the Pine River (27), the Belle River (3), the Rouge River (31), the Black River-East (6), the Clinton River (12), the Huron River (15), and the River Raisin (29). The watersheds for these eight rivers cover 11,549 square kilometers. The area weighted watershed CN of 77.5 was calculated from 383,577 polygons with an average polygon area of 0.035 square kilometers (Table 11). The watersheds of these eight rivers drain extensive urban areas stretching from the City of Port Huron located on the north end of the St. Clair River (Black River-East watershed; 6), including the City of Detroit, and extending to the south to the City of Monroe (River Raisin watershed; 29) located on western edge of Lake Erie (see Figure 4).

As shown on Table 27 and Table 28, the watersheds draining to Lake Superior, Lake Michigan, and Lake Huron have land use dominated by forest land, wetland, and agriculture. Excluding the urbanized Lake Erie watershed, the watershed CNs for the Lake Superior watershed (71.1), Lake Michigan watershed (68.2), and Lake Huron watershed (70.0) are similar. Figure 39 represents a comparison of watershed CN and watershed area for all 60 Michigan rivers. Unlike river slope, there is no significant relationship between watershed CN and watershed area.

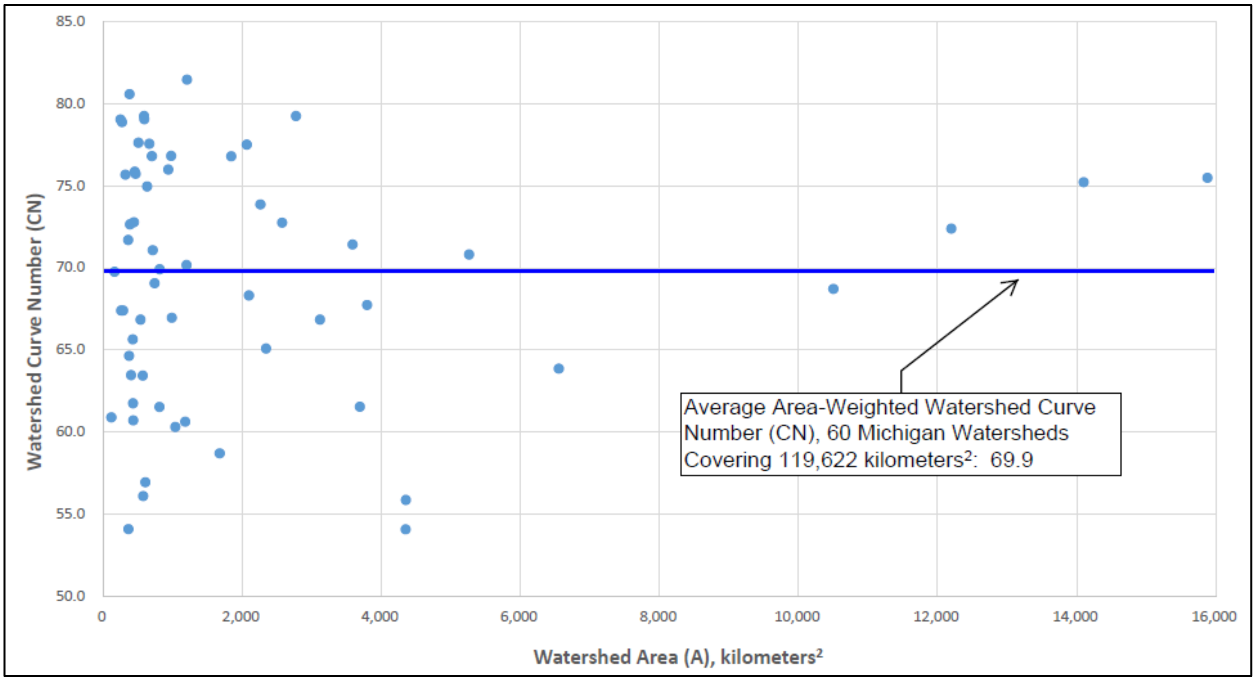


Figure 39. Relationship Between Watershed Curve Number and Watershed Area

Mean annual discharge or runoff per unit area is calculated by dividing the total mean annual river flow by the watershed area and these values are presented in Table 8, Table 9, Table 10, Table 11, and Table 12. The mean annual river flow is comprised of both surface water runoff and indirect groundwater discharge to rivers that drain the watershed. Due in large part to Michigan's glacial history, many rivers are located in permeable glacial outwash deposits and coarse textured glacial deposits (Farrand WR and Bell DL, 1982) and mean annual discharge of many Michigan rivers is composed primarily of groundwater (USGS, 2005). Based on a study of Great Lake basin water supply, USGS (1998) found that 22% to 42% of water entering the individual Great Lakes originated as indirect groundwater discharge from the rivers that drain the watershed and that overland surface water runoff ranged from 9% to 24% (the balance consists of over lake precipitation).

With respect to the individual Great Lakes, water entering Lake Superior was comprised of 11% surface water runoff and 33% indirect groundwater discharge, and the balance (56%) consisted of over lake precipitation (USGS, 1998). With respect to water entering Lake Michigan, Lake Huron, and Lake Erie, surface water runoff represents 9%, 16%, and 24% while indirect groundwater discharge from rivers represents 35%, 42%, and 22%, respectively (USGS, 2009). Using the hydrograph separation method at 195 gaging stations, USGS (1998) found that the majority of mean annual river flow is comprised of indirect groundwater discharge within the Lake Superior watershed (75%), Lake Michigan watershed (79%), and Lake Huron watershed (72%), while indirect groundwater flow represented about half (48%) in the Lake Erie basin. These data support the Great Lake watershed CNs discussed previously, where the rivers that drain the Lake Erie watershed have an area weighted watershed CN of 77.5 that is reflected in the elevated percentages of urban land use within this basin. The area weighted watershed CNs for the Michigan rivers that drain the Lake Superior watershed (71.1), Lake Michigan watershed (68.2), and Lake Huron watershed (70.0) reflect land use dominated by forest land, wetland, and agriculture.

4.1.3 Regression Analysis, Mean Annual River Flow and Recurrence Interval Flows v. Fourteen Watershed Characteristics

Previous research has confirmed a strong relationship between the prediction of mean annual river flow and watershed area in Michigan rivers. With respect to the 60 Michigan rivers included in this research, Barkach JH et al. (2020) found that the prediction of mean annual river flow is strongly correlated to watershed area with an R^2 of 0.95 (see Figure 40).

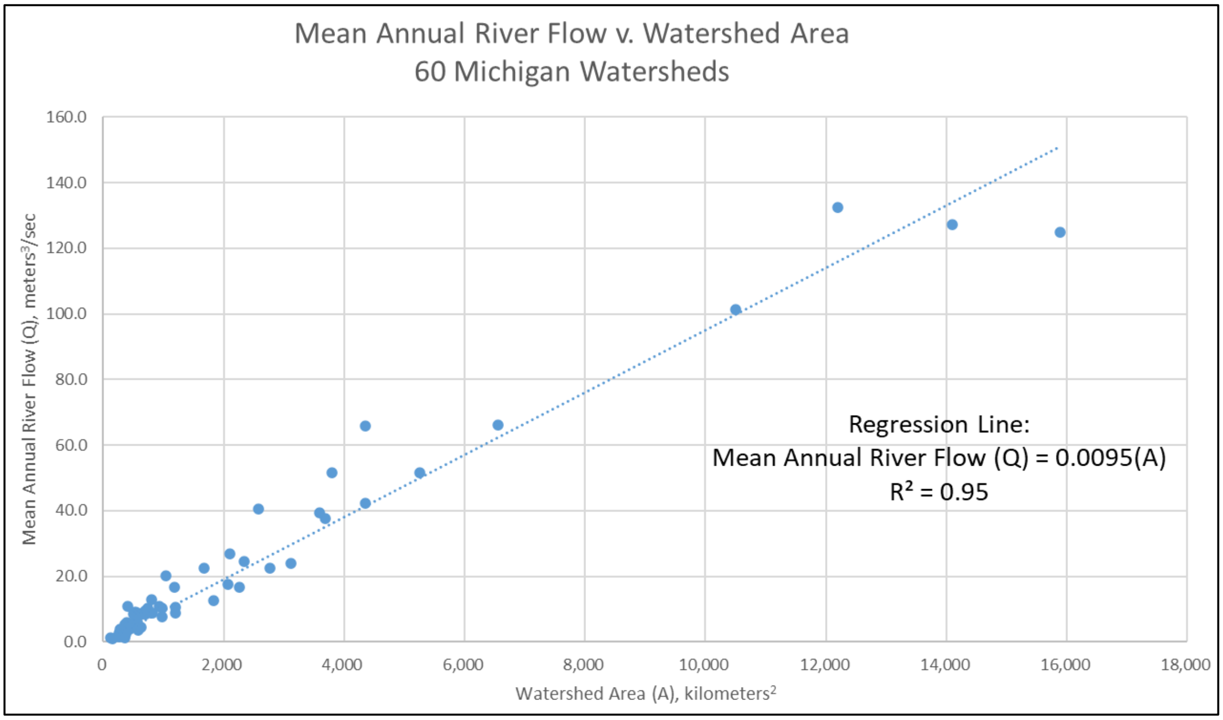


Figure 40. Relationship Between Mean Annual River Flow and Watershed Area (Barkach JH et al, 2020)

A recent study prepared for the State of Michigan's EGLE (Stantec, 2014) found a similar strong relationship between watershed area and mean annual river flow for 28 southern Michigan watersheds ranging in size from 24.8 square kilometers to 1,412 square kilometers with correlation coefficients ranging from 0.84 to 0.94. Syvitski and Milliman (2007) also found a strong correlation between mean annual river flow and watershed area with respect to the 488 rivers in their global database that cover 63% of the Earth's surface; their analysis of variables associated with watershed sediment delivery found the highest correlates to mean annual river flow (Q) were watershed area (R^2 =0.75) and relief (R^2=0.25).

In conjunction with this research, other watershed characteristics were evaluated relative to the prediction of mean annual river flow and selected recurrence interval flows. These additional characteristics include: watershed CN, maximum watershed relief, river slope, mean precipitation and basin temperature of the four Great Lake watersheds, and the percentage of the watershed covered by the following NLCD (USDA, 2011) land use categories: water, developed land, barren land, shrubland, grassland, agriculture and wetlands.

An example regression of all 14 independent variables versus 2-year recurrence interval flow is shown on Table 29. Review of Table 29 reveals that most important watershed characteristics with respect to the prediction of the 2-year recurrence interval flow is watershed area (A) and watershed curve number (CN) with P-values of 1.9 E-19 and 0.018 respectively. In conjunction with the step-wise regression analyses, watershed characteristics that were not predictive of 2-year recurrence interval flow include: maximum watershed relief, river slope, mean precipitation and temperature of the four Great Lake watersheds, and the percentage of the watershed covered by water, developed land, barren land, shrubland, grassland, agriculture and wetlands based on the 2011 NLCD (USDA, 2011). The importance of the watershed area and watershed curve number as independent variables was repeated for all of the recurrence intervals that were evaluated during this research, these include: 1.5-year, 2.0-year, 10-year, 25-year, 50-year and 100-year.

Table 29. Example Regression, 2-year Recurrence Interval Flow v. All Variables

Regression Statistics	
Multiple R	0.947
R Square	**0.897**
Adjusted R Square	0.865
Standard Error	53.244
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	***Significance F***
Regression	14	1112451.78	79460.84	28.03	**1.36189E-17**
Residual	45	127572.35	2834.94		
Total	59	1240024.13			

	Coefficients	*Standard Error*	*t Stat*	***P-value***	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	954.970	1576.085	0.606	0.548	-2219.428	4129.369	-2219.428	4129.369
Watershed Area (kilometers^2)	0.041	0.003	15.299	**1.9E-19**	0.036	0.047	0.036	0.047
Watershed Curve Number (CN)	5.774	2.360	2.447	**0.018**	1.021	10.526	1.021	10.526
Relief (meters)	-0.039	0.138	-0.280	0.781	-0.317	0.240	-0.317	0.240
River Slope (m/m)	-9447.030	9444.078	-1.000	0.323	-28468.380	9574.321	-28468.380	9574.321
Precipitation, NOAA, 2015 (mm/year)	0.346	0.909	0.381	0.705	-1.485	2.176	-1.485	2.176
Mean Watershed Temp., NOAA, (°C)	-10.852	17.335	-0.626	0.534	-45.765	24.062	-45.765	24.062
Water	-1846.526	1467.528	-1.258	0.215	-4802.280	1109.228	-4802.280	1109.228
Developed	-1615.885	1438.057	-1.124	0.267	-4512.280	1280.510	-4512.280	1280.510
Barren	1488.385	2949.461	0.505	0.616	-4452.134	7428.904	-4452.134	7428.904
Forest	-1428.055	1405.863	-1.016	0.315	-4259.609	1403.500	-4259.609	1403.500
Shubland	-2115.046	1598.591	-1.323	0.192	-5334.773	1104.682	-5334.773	1104.682
Grassland	-1129.028	1600.757	-0.705	0.484	-4353.118	2095.063	-4353.118	2095.063
Agriculture	-1592.338	1440.806	-1.105	0.275	-4494.269	1309.593	-4494.269	1309.593
Wetlands	-1586.215	1451.630	-1.093	0.280	-4509.949	1337.519	-4509.949	1337.519

With respect to mean annual river flow, the most important variables were watershed area followed by watershed curve number and maximum watershed relief. An example regression of mean annual river flow to watershed area, watershed curve number, maximum watershed relief and river slope is shown on Table 30. Watershed characteristics that were not predictive of mean annual river flow include: river slope, mean precipitation and temperature of the four Great Lake watersheds, and the percentage of the watershed covered by water, developed land, barren land, shrubland, grassland, agriculture and wetlands based on the NLCD (USDA, 2011).

Table 30. Example Regression, Mean Annual River Flow v. Watershed Area, Watershed CN, Maximum Relief, and River Slope

Regression Statistics	
Multiple R	0.983865
R Square	**0.96799**
Adjusted R Square	0.965662
Standard Error	5.767229
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	***Significance F***
Regression	4	55319.25	13829.81	415.797523	**2.17137E-40**
Residual	55	1829.351	33.26093		
Total	59	57148.6			

	Coefficientsandard Erro		*t Stat*	***P-value***	*Lower 95%*	*Upper 95%*
Intercept	14.92415	8.39374	1.778009	0.08093047	-1.897282355	31.74557866
Watershed Area (kilometers^2)	0.008908	0.000256	34.79334	**3.86E-39**	0.00839455	0.009420682
Watershed Curve Number (CN)	-0.22676	0.11093	-2.04414	**0.0457**	-0.449066802	-0.00444823
Relief (meters)	0.027358	0.01052	2.60043	**0.012**	0.00627422	0.048440988
River Slope (m/m)	-1348.99	860.3654	-1.56792	0.123	-3073.196706	375.224992

Based on regression analysis, the relationship between mean annual river flow (Q_m) as a function of watershed area, watershed CN, and relief is presented in Equation 1 ($R^2 = 0.97$).

$$\text{Mean Annual River Flow } (Q_m) = 17.3 + 0.0091(A) - 0.2608(CN) + 0.017(R) \quad (19)$$

where,

A = watershed area, square kilometers

CN = watershed CN, unitless

R = maximum watershed relief, meters

As shown in Figure 41, the addition of watershed CN and maximum relief (R) to watershed area (A) marginally improves the prediction of mean annual river flow and the resulting R^2 is 0.97 in comparison to mean annual river flow as a function of only watershed area (R^2 = 0.95 see Figure 40)

With respect to prediction of recurrence interval flows (1.5-year, 2.0-year, 10-year, 25-year, 50-year, and 100-year), the regression equation variable analysis and the P-values associated with watershed area, watershed CN, relief, and river slope are presented in Table 31. The most important variables are watershed area and watershed CN, and the R^2 of the resulting regression equations ranges from 0.87 (1.5-year and 2.0-year recurrence interval flow) to 0.80 (100-year recurrence interval flow). The strong R^2 of the predicted versus actual 2-year and 10-year recurrence interval flows as a function of watershed area (A) and watershed CN are shown in Figure 42 and Figure 43, respectively. As shown in Table 31, with respect to the prediction of mean annual river flow as well as the recurrence interval flows, the dominant watershed characteristic is watershed area.

Table 31. Summary of Regression Equation Intercept and Coefficients, Mean Annual River Flow and Recurrence Interval Flows

	Regression Equation		Regression Equation Intercept and Coefficients				P-Values: Regression Equation Variable Analysis				
Flow Rate	R Square	Significance F	Intercept	Watershed Area Coefficient ($kilometers^2$)	Watershed Curve Number Coefficient (CN)	Watershed Relief Coefficient (meters)	Intercept	Watershed Area ($kilometers^2$)	Watershed Curve Number (CN)	Watershed Relief (meters)	River Slope (meter/meter)
Mean Annual River Flow	0.97	2.85E-41	17.3	0.009	-0.261	0.017	8.09E-02	**3.86E-39**	**4.57E-02**	**0.01**	0.12
1.5-Year Exceedance Flow	0.87	6.38E-26	-143.1	0.034	2.408		7.67E-03	**7.93E-23**	**2.41E-03**	0.31	0.82
2.0-Year Exceedance Flow	0.87	1.86E-26	-192.7	0.040	3.211		2.55E-03	**2.95E-23**	**6.04E-04**	0.30	0.84
10-Year Exceedance Flow	0.85	4.89E-24	-409.3	0.062	6.751		3.50E-04	**1.07E-20**	**6.03E-05**	0.21	0.80
25-Year Exceedance Flow	0.83	1.04E-22	-535.1	0.074	8.786		2.82E-04	**2.34E-19**	**4.73E-05**	0.22	0.85
50-Year Exceedance Flow	0.82	6.77E-22	-641.0	0.082	10.512		1.76E-04	**1.68E-18**	**2.85E-05**	0.19	0.83
100-Year Exceedance Flow	0.80	7.64E-21	-759.4	0.091	12.417		1.82E-04	**2.04E-17**	**2.96E-05**	0.21	0.83

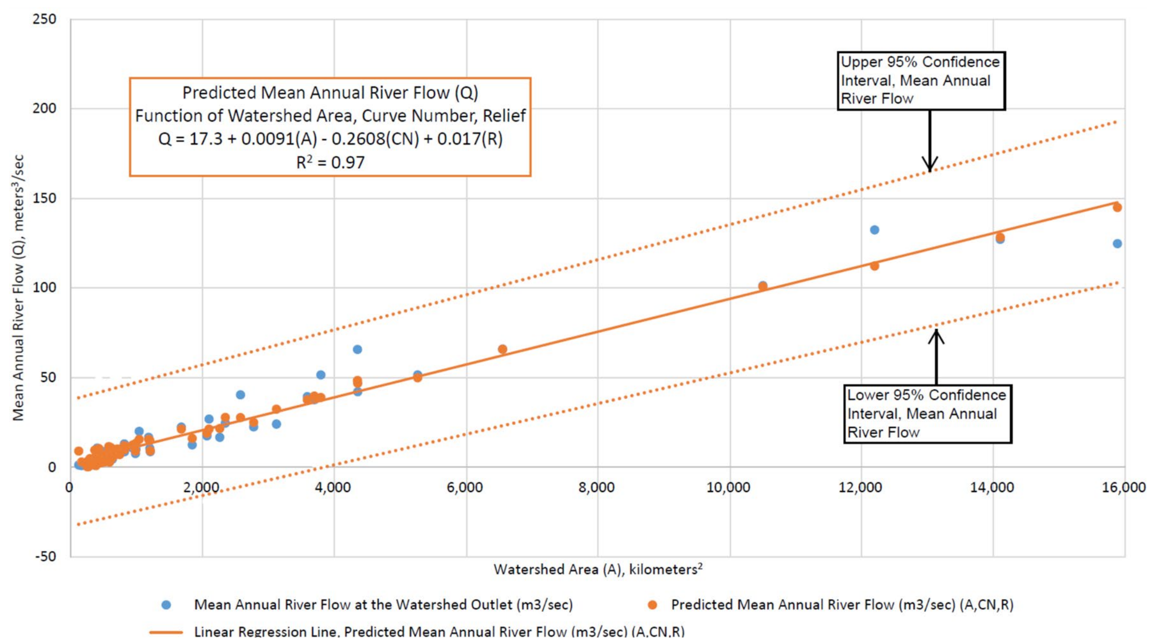


Figure 41. Predicted v. Actual Mean Annual River Flow, Predicted Flow is a Function of Watershed Area (A), Curve Number (CN), and Maximum Relief (R)

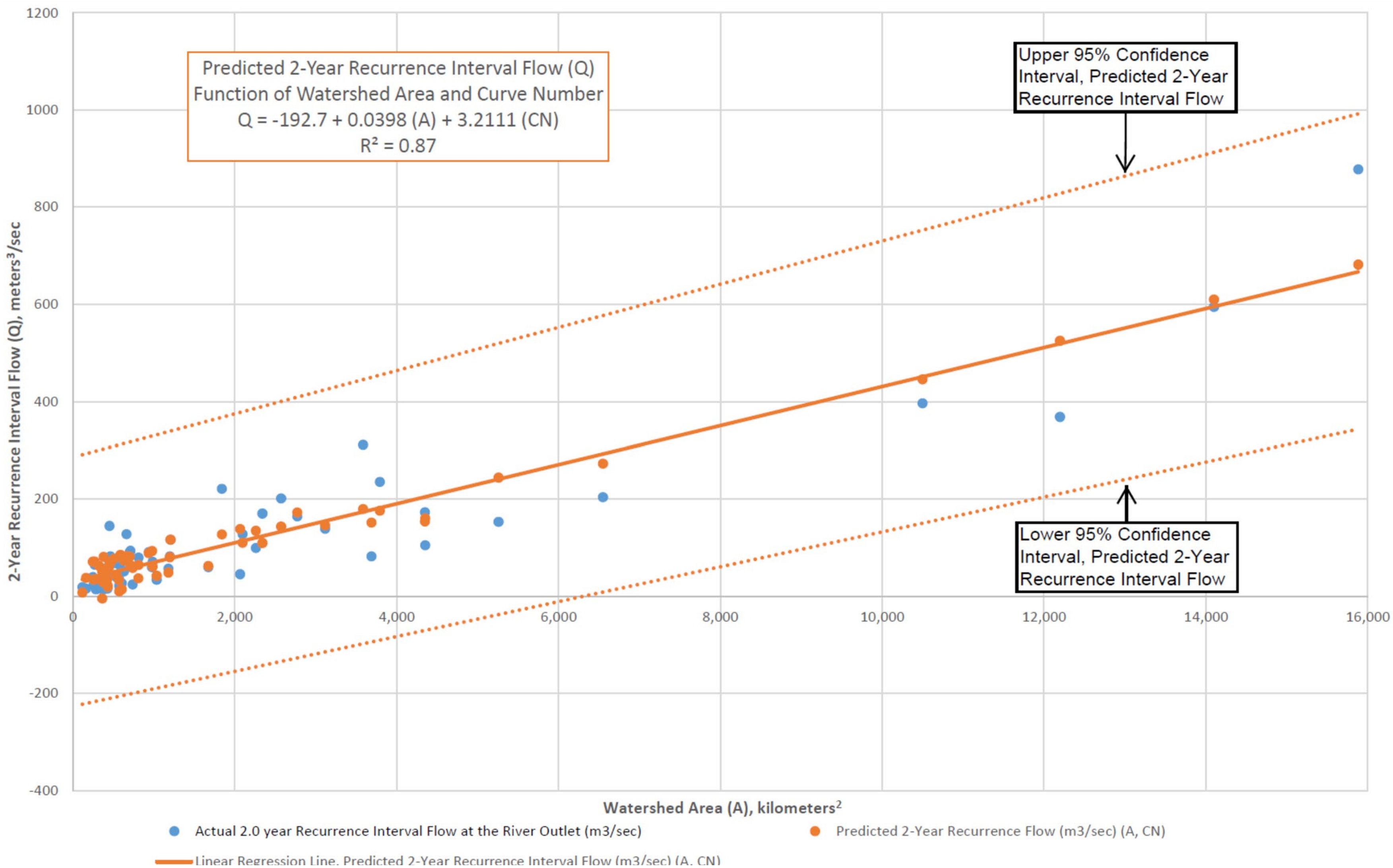


Figure 42. Predicted v. Actual 2-Year Recurrence Interval Flow, Predicted Flow is a Function of Watershed Area (A) and Curve Number (CN)

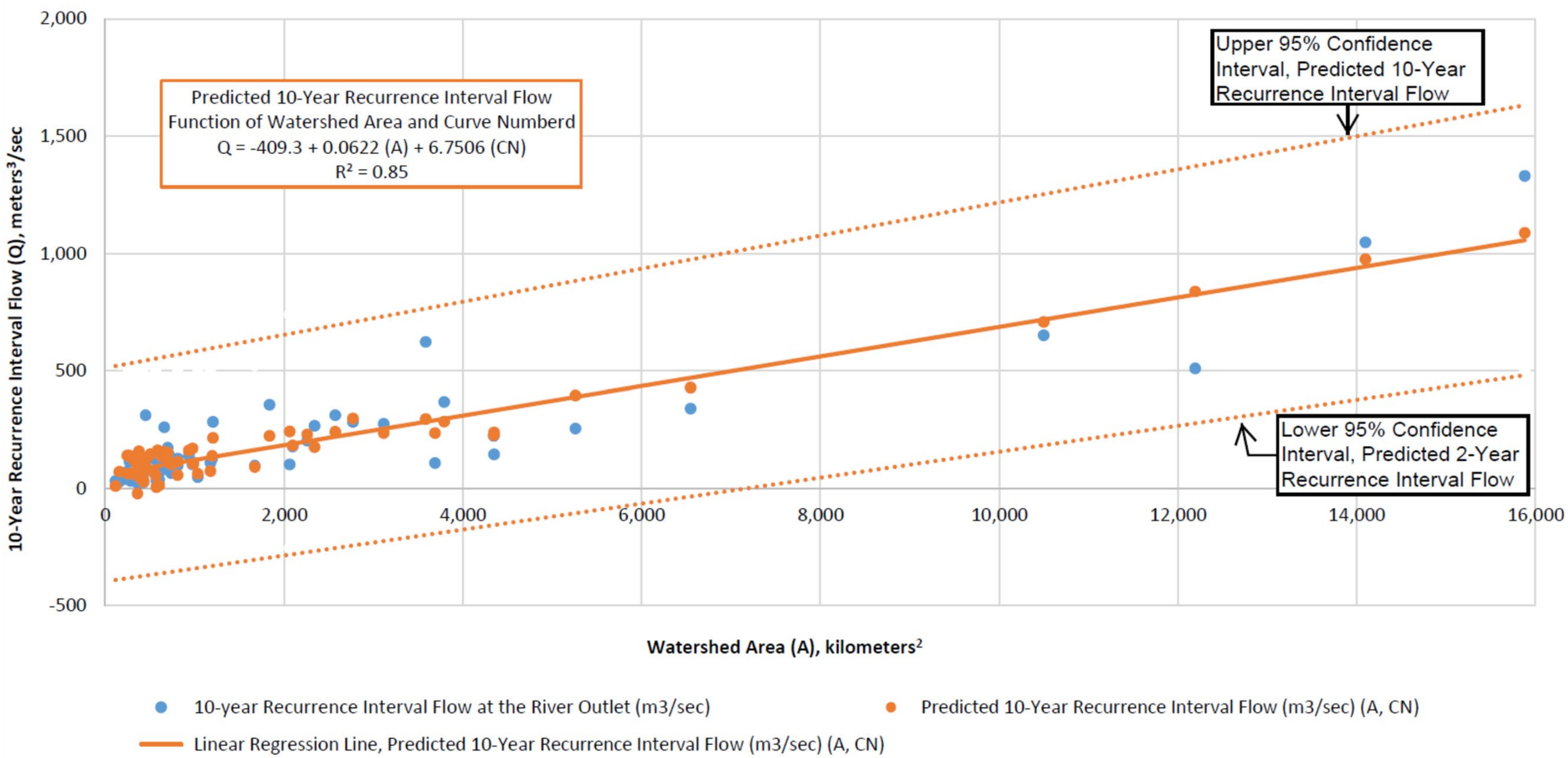


Figure 43. Predicted v. Actual 10-Year Recurrence Interval Flow, Predicted Flow is a Function of Watershed Area (A) and Curve Number (CN)

Watershed area has been referred to as the "great integrator" (Syvitski and Kettner, 2008). The complex glacial geology of Michigan and the resulting low gradient streams, as well as the low percentage of developed land in the majority of 60 watersheds evaluated in this research, likely explains why there is a strong correlation between the mean annual river flow to watershed area, watershed CN, and relief (see Figure 41). With respect to the 1.5-year, 2.0-year, 10-year, 25-year, 50-year, and 100-year recurrence interval flows, the R^2 of the regression equations for these 60 Michigan rivers as a function of watershed area and watershed CN ranged from 0.80 to 0.87 (see Table 31). As shown in Figure 42 and Figure 43 and summarized in Table 31, preliminary estimates of recurrence interval flows can be reasonably determined from two variables, watershed area and watershed CN, with respect to the prediction of recurrence interval flows.

4.2. Regression Set 1, Analysis of Watershed Variables in Conjunction with Prediction of Bedload Watershed Sediment Delivery at the River Outlet Using Non-Transformed Dependent and Independent Variables, 12 Watersheds

To identify predictor variables, the second set of regressions focused on non-transformed watershed sediment delivery estimates (dependent variable) and 15 watershed characteristics (independent variables). In this set of regressions, the dependent variable is watershed sediment delivery estimates to the river outlet based on USACE-Detroit District dredging data (12 rivers; see Table 17). The following 15 independent variables were considered, they include:

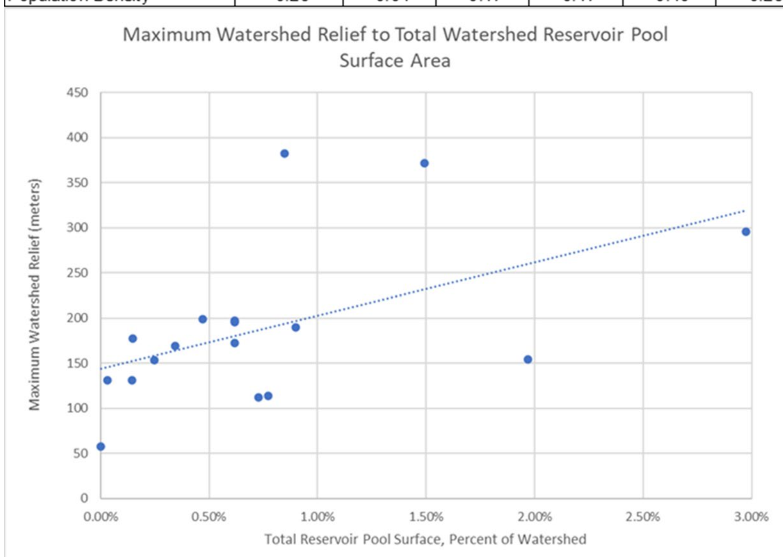
- Watershed Area (square kilometer)

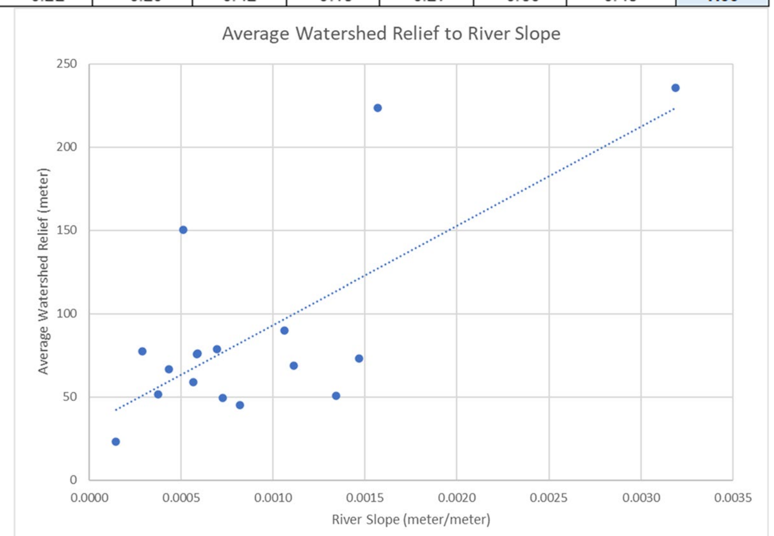
- Percent of Watershed, Total Surface Water Area (EGLE, 1978) MIRIS Land Use
- Percent of Watershed, Total Reservoir Pool Surface Area, EGLE (2020) Dam Inventory
- Percent of Watershed, Total Aquatic Wetlands (EGLE, 1978) MIRIS Land Use
- Percent of Watershed, Total Upland Wetlands (EGLE, 1978) MIRIS Land Use
- Mean Annual River Flow (cubic meters/second)
- 1.5-year Recurrence Interval Flow (cubic meters/second)
- 2.0-year Recurrence Interval Flow (cubic meters/second)
- 5-year Recurrence Interval Flow (cubic meters/second)
- Watershed Curve Number (unitless)
- River Slope (meter/meter)
- Relief: Net Watershed Elevation Difference, Maximum Watershed Elevation (meter)
- Relief: Net Watershed Elevation Difference, Average Watershed Elevation (meter)
- Mean Basin Temperature (°C)
- Population Density (people/square kilometer)

Review of the correlation coefficients (Table 32) reveals the strong relationship between watershed area and mean annual river flow and recurrence interval flows discussed in the Section 4.1. The correlation coefficients between watershed area and mean annual river flow, 1.5-year, 2-year, and 5-year recurrence intervals is 0.98, 0.92, 0.92, and 0.90. In addition, as expected, there is also a strong correlation (0.63) between maximum watershed relief and river slope.

Table 32. Correlation Matrix, 15 Independent Variables, Regression Set 1, 12 Watersheds

Correlation Matrix	Watershed Area	Total Surface Water	Total Reservoir Pool Surface	Total Aquatic Wetlands	Total Upland Wetlands	Mean Annual River Flow	1.5-year Recurrence Flow	2.0-year Recurrence Flow	5-year Recurrence Flow	Watershed Curve Number	River Slope	Relief: Maximum Elev.	Relief: Average Elev.	Mean Basin Temperature	Population Density
Watershed Area	**1.00**														
Total Surface Water	-0.19	**1.00**													
Total Reservoir Pool Surface	0.06	0.38	**1.00**												
Total Aquatic Wetlands	0.00	0.31	**0.85**	**1.00**											
Total Upland Wetlands	0.22	0.14	**0.83**	**0.77**	**1.00**										
Mean Annual River Flow	**0.98**	-0.08	0.13	0.09	0.29	**1.00**									
1.5-year Recurrence Flow	**0.92**	-0.19	0.03	0.01	0.19	**0.86**	**1.00**								
2.0-year Recurrence Flow	**0.92**	-0.18	0.02	0.01	0.18	**0.86**	**1.00**	**1.00**							
5-year Recurrence Flow	**0.90**	-0.15	0.00	-0.01	0.17	**0.84**	**0.99**	**0.99**	**1.00**						
Watershed Curve Number	0.09	-0.01	-0.05	-0.14	-0.12	0.03	0.16	0.18	0.22	**1.00**					
River Slope	-0.10	0.35	0.08	-0.13	0.03	-0.05	-0.09	-0.09	-0.06	-0.22	**1.00**				
Relief: Maximum Elev.	0.35	0.29	**0.52**	0.36	**0.56**	0.41	0.34	0.34	0.35	-0.19	**0.63**	**1.00**			
Relief: Average Elev.	0.25	0.38	0.49	0.31	**0.53**	0.33	0.25	0.25	0.27	-0.24	**0.72**	**0.97**	**1.00**		
Mean Basin Temperature	-0.17	-0.07	-0.44	-0.44	-0.61	-0.23	-0.20	-0.18	-0.17	**0.57**	-0.50	-0.74	-0.74	**1.00**	
Population Density	-0.23	-0.04	-0.17	-0.17	-0.40	-0.26	-0.24	-0.22	-0.20	0.42	-0.15	-0.27	-0.30	0.48	**1.00**





Lastly, there is also a significant correlation (0.52) between maximum (and average) watershed relief and the total reservoir pool surface area. Inspection of the digital elevation models contained in Appendices B to PPP in comparison to the location of dams reveals that most of the dams located in fluvial systems are located on the edges of the watershed where the river slopes are greatest. Many rivers (and dams) in Michigan are located in glacial outwash deposits flanked by glacial moraines, an example is the Loud Dam (MI00178) on the Au Sable River (see Figure 44).

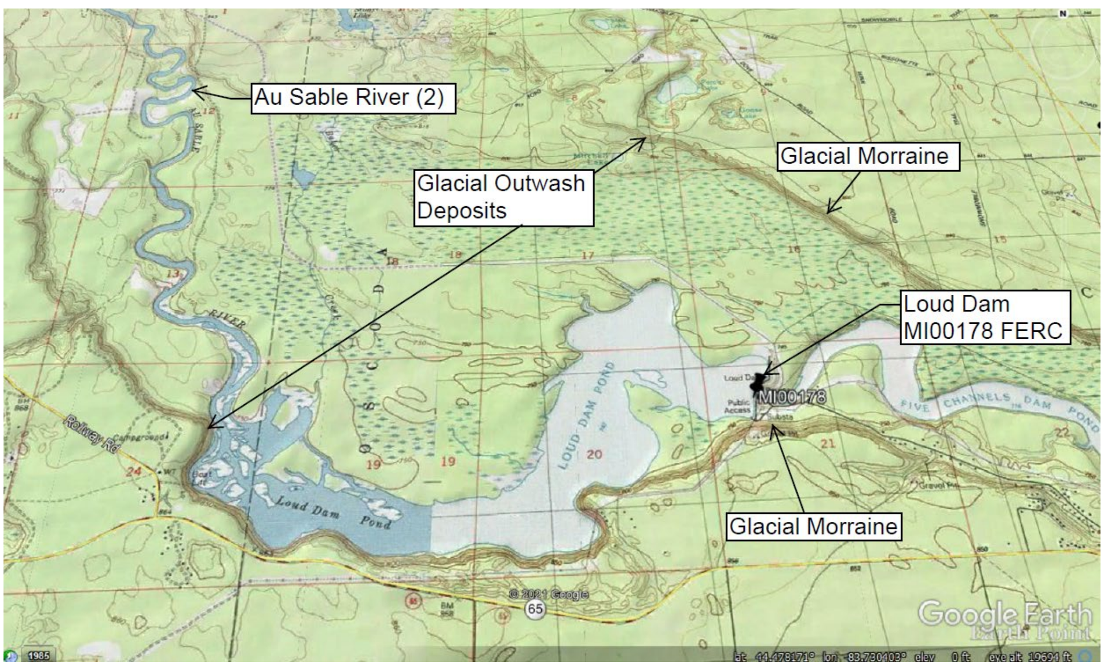


Figure 44. Loud Dam, MI00178, Au Sable River (2) (Google Earth Pro, 2021)

As discussed in Section 3.1, most of the dams in Michigan are small with dam heights of less than five meters. Michigan's extensive glacial heritage has resulted in relatively small differences in topography at the watershed scale in comparison to the elevation of the receiving water (the corresponding Great Lake or Great Lakes connecting channel, or reservoir). As discussed in Section 3.9, of the 1,378 dams located in these 60

Michigan watersheds, 1,042 dams have dam heights of less than 5 meters (see Figure 26). Because most dams were built in glacial outwash deposits and have corresponding low river slopes, the reservoir pool surface areas are also small. The mean and median reservoir pool surface areas are 0.69 square kilometers and 0.06 square kilometers, respectively (see Figure 27).

Regression analysis of watershed sediment delivery estimates based on USACE-Detroit District dredging data for 12 rivers in comparison to 10 watershed characteristics are summarized on Table 33, Table 34, and Table 35. A total of 26 regressions were completed. Review of Table 33, Table 34, Table 35 reveals that of the river flows considered, the 1.5-year recurrence interval flow was most important, followed by the annual mean flow and 2-year recurrence interval flow. Other important variables include: watershed area, percent of the watershed covered in surface water, reservoirs, aquatic wetlands, and upland wetlands. Regressions 1-18, 1-19, and 1-21 have good significance (<0.05), good R^2 (0.98 to 0.99), and many of the p-values of the independent variables were less than 0.05. However, when these regression equations were applied to the 60 watersheds and five sub-watersheds, negative estimates of watershed sediment delivery occurred at the 38 to 39 of the 65 total watersheds included in this research.

Table 33. Regressions 1-1 to 1-9, Watershed Sediment Delivery Based on USACE Dredging Data, 12 Watersheds, Non-Transformed

Regression Summary	Regression Set 1-1	Regression Set 1-2	Regression Set 1-3	Regression Set 1-4	Regression Set 1-5	Regression Set 1-6	Regression Set 1-7	Regression Set 1-8	Regression Set 1-9
Significance	**0.0442**	**0.0071**	**0.0135**	0.0522	0.1773	0.6191	0.6391	0.4458	0.2544
Multiple R	0.9998	0.9992	0.9917	0.9551	0.8617	0.6184	0.5233	0.5199	0.5121
R Square	**0.9997**	**0.9984**	**0.9835**	**0.9122**	**0.7425**	0.3824	0.2738	0.2703	0.2623
Adjusted R Square	0.9965	0.9913	0.9394	0.7586	0.4334	-0.1323	-0.1412	-0.0033	0.0984
Standard Error	3102	4859	12823	25599	39217	55440	55657	52186	49472
Observations	12	12	12	12	12	12	12	12	12
Coefficients									
Intercept	-1101888	-775810	35309	59664	-6505	59989	28512	26836	25625
Watershed Area	8	15	6	-40	45	5	4	4	4
Total Surface Water Area	5761947	4510564	934836	-4167213	1911145	-2176901	-1177935	-1168842	-1405931
Total Reservoir Pool Surface Area	2301642	1089746	3151221	11058344	1045041	3534373	-1424483	-610902	
Total Aquatic Wetlands	-794214	-29083	294078	-947216	660356	316883	262834		
Total Upland Wetlands	1078940	273471	-1917856	-3410569	-633369	-1853067			
Annual Mean Flow	-1125	-1658	-1136	2580	-4444				
1.5 year Recurrence Flow	3044	3007	2579	646					
2.0 year Recurrence Flow	-2395	-2405	-1980						
Watershed Curve Number (CN)	13469	9588							
River Slope	-8868731								
Total Surface Water and Reservoirs									
Total Wetlands (Aquatic and Upland)									
P-Values									
Intercept	0.116	0.053	0.174	0.185	0.888	0.285	0.510	0.495	0.487
Watershed Area	0.393	0.211	0.783	0.282	**0.033**	0.177	0.225	0.196	0.179
Total Surface Water Area	0.104	0.056	0.667	0.201	0.477	0.459	0.662	0.643	0.533
Total Reservoir Pool Surface Area	0.272	0.498	0.407	0.085	0.842	0.627	0.783	0.774	
Total Aquatic Wetlands	0.305	0.909	0.636	0.344	0.547	0.833	0.860		
Total Upland Wetlands	0.302	0.687	0.093	0.063	0.660	0.344			
Annual Mean Flow	0.267	0.130	0.557	0.402	**0.046**				
1.5 year Recurrence Flow	**0.031**	**0.006**	**0.018**	**0.050**					
2.0 year Recurrence Flow	**0.039**	**0.009**	**0.037**						
Watershed Curve Number (CN)	0.113	**0.049**							
River Slope	0.298								
Total Surface Water and Reservoirs									

Table 34. Regressions 1-10 to 1-18, Watershed Sediment Delivery Based on USACE Dredging Data, 12 Watersheds, Non-Transformed

Regression Summary	Regression Set 1-10	Regression Set 1-11	Regression Set 1-12	Regression Set 1-13	Regression Set 1-14	Regression Set 1-15	Regression Set 1-16	Regression Set 1-17	Regression Set 1-18
Significance	0.1166	**0.0269**	**0.0088**	**0.0074**	**0.0101**	**0.0054**	**0.0418**	**0.0143**	**0.0005**
Multiple R	0.4774	0.9434	0.9405	0.9129	0.8600	0.8284	0.8474	0.8455	0.9991
R Square	0.2279	**0.8899**	**0.8846**	**0.8333**	**0.7396**	**0.6862**	**0.7181**	**0.7149**	**0.9982**
Adjusted R Square	0.1507	0.7579	0.7885	0.7381	0.6419	0.6165	0.5570	0.6080	0.9935
Standard Error	48016	25637	23962	26664	31178	32266	34676	32620	4185
Observations	12	12	12	12	12	12	12	12	12
Coefficients									
Intercept	7060	364801	36706	9865	1788	-13406	-7779	-3385	-686771
Watershed Area	4	-10	-9	-9	-9	-9	-9	-9	13
Total Surface Water Area		-3037582	-1943618						4079881
Total Reservoir Pool Surface Area		7403071	6434144	4740582					1414434
Total Aquatic Wetlands									
Total Upland Wetlands		-3246423	-2441600	-1999881	-514391				
Annual Mean Flow									-1551
1.5 year Recurrence Flow		444	434	439	402	404	408	401	2959
2.0 year Recurrence Flow									-2354
Watershed Curve Number (CN)		-3912							8546
River Slope									-264264
Total Surface Water and Reservoirs							230,336		
Total Wetlands (Aquatic and Upland)							(231,204)		
P-Values									
Intercept	0.733	0.608	0.147	0.565	0.925	0.384	0.766	0.860	**0.001**
Watershed Area	0.117	**0.043**	**0.022**	**0.031**	0.060	0.052	0.078	0.061	**0.031**
Total Surface Water Area		0.289	0.154						**0.001**
Total Reservoir Pool Surface Area		0.070	**0.036**	0.088					**0.014**
Total Aquatic Wetlands									
Total Upland Wetlands		0.138	**0.021**	**0.046**	0.236				
Annual Mean Flow									**0.014**
1.5 year Recurrence Flow		**0.005**	**0.002**	**0.002**	**0.006**	**0.006**	**0.012**	**0.007**	**0.0003**
2.0 year Recurrence Flow									**0.0005**
Watershed Curve Number (CN)		0.644							**0.002**
River Slope									0.901
Total Surface Water and Reservoirs							0.871		

Table 35. Regressions 1-19 to 1-26, Watershed Sediment Delivery Based on USACE Dredging Data, 12 Watersheds, Non-Transformed

Regression Summary	Regression Set 1-19	Regression Set 1-20	Regression Set 1-21	Regression Set 1-22	Regression Set 1-23	Regression Set 1-24	Regression Set 1-25	Regression Set 1-26
Significance	**0.0003**	**0.0221**	**0.00002**	**0.00035**	**0.01795**	**0.00523**	**0.03008**	0.06004
Multiple R	0.9908	0.9166	0.9991	0.9908	0.9526	0.9506	0.9064	0.8776
R Square	**0.9817**	**0.8402**	**0.9982**	**0.9817**	**0.9074**	**0.9037**	**0.8215**	**0.7702**
Adjusted R Square	0.9597	0.7071	0.9951	0.9597	0.7962	0.8235	0.6728	0.5787
Standard Error	10455	28196	3635	10455	23522	21889	29801	33818
Observations	12	12	12	12	12	12	12	12
Coefficients								
Intercept	-823421	584	-690253	-823421	-9563	-12697	-691890	-668693
Watershed Area	-4	20	13	-4	31	33	-7	-7
Total Surface Water Area	3252444		4062124	3252444	3582527	3516752	802860	412562
Total Reservoir Pool Surface Area	1423356		1425048	1423356	-519699		2424235	2541932
Total Aquatic Wetlands								
Total Upland Wetlands								
Annual Mean Flow		-2507	-1540		-3279	-3540		
1.5 year Recurrence Flow	3002	1615	2957	3002	2594	2428	401	
2.0 year Recurrence Flow	-2301	-1227	-2351	-2301	-2136	-2003		332
Watershed Curve Number (CN)	10354		8588	10354			8560	8272
River Slope								
Total Surface Water and Reservoirs		850,208						
Total Wetlands (Aquatic and Upland)								
P-Values								
Intercept	**0.001**	0.981	**0.00013**	**0.00107**	0.65532	0.49714	0.08976	0.13576
Watershed Area	**0.039**	0.322	**0.01014**	**0.03935**	0.12528	0.06045	0.11902	0.18995
Total Surface Water Area	**0.004**		**0.00011**	**0.00449**	0.09017	0.06822	0.62767	0.82404
Total Reservoir Pool Surface Area	0.081		**0.00326**	0.08063	0.67639		0.22812	0.26189
Total Aquatic Wetlands								
Total Upland Wetlands								
Annual Mean Flow		0.178	**0.00363**					
1.5 year Recurrence Flow	**0.0006**	0.1054	**0.00003**	**0.00063**	0.07012	**0.02644**	**0.00840**	
2.0 year Recurrence Flow	**0.0012**	0.1470	**0.00004**	**0.00119**	**0.03129**	**0.01640**		**0.01871**
Watershed Curve Number (CN)	**0.001**		**0.00014**	**0.00101**	**0.04063**	**0.02413**	0.08976	0.13591
River Slope								
Total Surface Water and Reservoirs		0.473						

4.3. Regression Set 2, Analysis of Watershed Variables in Conjunction with the Prediction of Bedload Watershed Sediment Delivery at the River Outlet Using Non-Transformed Dependent and Independent Variables, 17 Watersheds

This set of regressions includes all 17 watersheds and was conducted to gain insight into identification of predictor variables with the addition of the five watersheds whose watershed sediment delivery estimates are based ^{137}Cs and ^{210}Pb radiometric dating (see Table 13). Non-transformed dependent and 15 independent variables were evaluated and are listed in Section 4.2.

Nineteen regressions were completed using these 15 independent variables. The step-wise regressions are summarized on Table 36 and Table 37. Review of Table 36 and Table 37 reveals that of the river flows considered, the 1.5-year recurrence interval flow was the most important, followed by the mean annual flow and 2-year recurrence interval flow. Other important variables include: watershed area and the percentage of the watershed covered in surface water (natural lakes, rivers and streams). Regressions 2-16 to 2-19 had acceptable significance (<0.05) and elevated R^2 (0.68 to 0.80) and at least some of the p-values of the independent variables were less than 0.05 (watershed area and the 1.5-year recurrence interval flow); however, when these regression equations were applied to the 60 watersheds and five sub-watersheds, negative estimates of watershed sediment delivery occurred at 17 to 35 watersheds. Eighteen of the 19 regressions produced large numbers of negative estimates of watershed sediment delivery to the river outlet with the exception of regression 2-15 which is a function of only watershed area. Although the significance of regression 2-15 was less than 0.05 (0.03) and P-value for watershed area was 0.032, the corresponding R^2 was low, only 0.271.

Table 36. Regressions 2-1 to 2-10, 17 Watershed Sediment Delivery Estimates, Non-Transformed

Regression Summary	Regression Set 2-1	Regression Set 2-2	Regression Set 2-3	Regression Set 2-4	Regression Set 2-5	Regression Set 2-6	Regression Set 2-7	Regression Set 2-8	Regression Set 2-9	Regression Set 2-10
Significance	0.294	0.068	**0.043**	0.084	**0.032**	**0.011**	**0.008**	**0.004**	**0.011**	**0.011**
Multiple R	0.995	0.995	0.988	0.964	0.963	0.962	0.951	0.945	0.901	0.857
R Square	**0.990**	**0.990**	**0.977**	**0.929**	**0.928**	**0.926**	**0.904**	**0.893**	**0.811**	**0.735**
Adjusted R Square	0.843	0.921	0.877	0.715	0.768	0.802	0.780	0.786	0.664	0.575
Standard Error	17674	12590	15687	23850	21508	19864	20930	20675	25875	29101
Observations	17	17	17	17	17	17	17	17	17	17
Coefficients										
Intercept	86,482	85,876	(8,665)	(83,443)	(76,985)	(64,902)	8,888	3,698	8,002	(2,093)
Watershed Area	(38)	(38)	(17)	35	34	29	28	26	15	43
Total Surface Water Area	477,716	443,098	842,310	2,203,907	2,116,805	1,976,374	1,729,065	1,811,614	138,218	1,591,464
Total Reservoir Pool Surface Area	5,204,783	5,274,485	2,537,019	(2,831,791)	(2,715,065)	(2,253,027)	(1,043,323)	(580,172)	1,528,199	(302,323)
Total Aquatic Wetlands	(1,685,440)	(1,685,516)	(821,575)	1,385,337	1,434,859	1,267,132	964,075	654,804	318,004	965,760
Total Upland Wetlands	(934,006)	(968,989)	(456,470)	(579,683)	(586,228)	(638,893)	(714,798)	(541,671)	(829,714)	(620,797)
Annual Mean Flow	3,102	3,108	965	(3,217)	(3,010)	(2,563)	(2,734)	(2,883)	(2,023)	(4,122)
1.5 year Recurrence Flow	3,713	3,693	2,600	3,316	3,715	4,004	2,928	1,672	245	
2.0 year Recurrence Flow	(4,083)	(4,067)	(2,511)	(3,377)	(3,936)	(4,326)	(3,047)	(1,304)		
5 year Recurrence Flow	945	946	450	398	553	669	448			
Watershed Curve Number (CN)	126	156	(360)	1,195	1,174	1,077				
River Slope	(12,014,023)	(12,215,644)	414,497	2,567,854	5,009,800					
Relief: Maximum Elevation	951	956	878	54						
Relief: Average Elevation	(1,910)	(1,914)	(1,539)							
Mean Basin Temperature	(11,940)	(11,979)								
Population Density	3									
P-Values										
Intercept	0.570	0.380	0.899	0.376	0.335	0.307	0.648	0.838	0.722	0.932
Watershed Area	0.466	0.258	0.551	0.200	0.155	0.083	0.099	0.109	0.411	**0.002**
Total Surface Water Area	0.803	0.713	0.554	0.274	0.227	0.199	0.266	0.234	0.931	0.318
Total Reservoir Pool Surface Area	0.426	0.211	0.454	0.412	0.370	0.350	0.641	0.785	0.529	0.902
Total Aquatic Wetlands	0.450	0.242	0.507	0.231	0.159	0.104	0.185	0.269	0.645	0.167
Total Upland Wetlands	0.417	0.175	0.369	0.426	0.366	0.270	0.236	0.319	0.214	0.388
Annual Mean Flow	0.500	0.294	0.691	0.216	0.162	0.076	0.066	**0.047**	0.203	**0.004**
1.5 year Recurrence Flow	0.345	0.145	0.242	0.285	0.119	0.052	0.095	**0.022**	0.088	
2.0 year Recurrence Flow	0.404	0.198	0.370	0.401	0.187	0.090	0.174	**0.039**		
5 year Recurrence Flow	0.452	0.244	0.516	0.691	0.427	0.231	0.399			
Watershed Curve Number (CN)	0.931	0.864	0.721	0.308	0.258	0.232				
River Slope	0.621	0.434	0.975	0.898	0.745					
Relief: Maximum Elevation	0.259	0.081	0.091	0.810						
Relief: Average Elevation	0.243	0.072	0.088							
Mean Basin Temperature	0.454	0.245								
Population Density	0.923									

Table 37. Regressions 2-11 to 2-19, 17 Watershed Sediment Delivery Estimates, Non-Transformed

Regression Summary	Regression Set 2-11	Regression Set 2-12	Regression Set 2-13	Regression Set 2-14	Regression Set 2-15	Regression Set 2-16	Regression Set 2-17	Regression Set 2-18	Regression Set 2-19
Significance	0.348	0.338	0.193	0.089	**0.032**	**0.015**	**0.004**	**0.001**	**0.0003**
Multiple R	0.603	0.544	0.544	0.541	0.521	0.892	0.837	0.830	0.826
R Square	0.364	0.296	0.296	0.292	0.271	**0.795**	0.700	0.689	0.683
Adjusted R Square	0.075	0.061	0.134	0.191	0.223	0.636	0.600	0.617	0.638
Standard Error	42959	43264	41567	40164	39366	26954	28250	27647	26883
Observations	17	17	17	17	17	17	17	17	17
Coefficients									
Intercept	36,959	16,600	16,596	16,058	3,856	19,343	(4,708)	(2,545)	(5,789)
Watershed Area	5	4	4	4	5	(9)	(9)	(8)	(9)
Total Surface Water Area	(1,414,871)	(800,521)	(800,634)	(987,514)		(729,801)			
Total Reservoir Pool Surface Area	1,766,783	(398,616)	(395,596)			3,300,097	599,625	(441,065)	
Total Aquatic Wetlands	229,248	1,143				(397,054)	(396,583)		
Total Upland Wetlands	(1,080,608)					(782,105)			
Annual Mean Flow									
1.5 year Recurrence Flow						392	380	369	372
2.0 year Recurrence Flow									
5 year Recurrence Flow									
Watershed Curve Number (CN)									
River Slope									
Relief: Maximum Elevation									
Relief: Average Elevation						(161)			
Mean Basin Temperature									
Population Density									
P-Values									
Intercept	0.265	0.526	0.506	0.503	0.774	0.364	0.709	0.830	0.543
Watershed Area	**0.046**	0.068	0.056	**0.049**	**0.032**	**0.037**	**0.030**	**0.030**	**0.023**
Total Surface Water Area	0.470	0.667	0.654	0.532		0.591			
Total Reservoir Pool Surface Area	0.618	0.890	0.794			0.168	0.746	0.634	
Total Aquatic Wetlands	0.806	0.999				0.534	0.515		
Total Upland Wetlands	0.302					0.278			
Annual Mean Flow									
1.5 year Recurrence Flow						**0.002**	**0.002**	**0.001**	**0.001**
2.0 year Recurrence Flow									
5 year Recurrence Flow									
Watershed Curve Number (CN)									
River Slope									
Relief: Maximum Elevation									
Relief: Average Elevation						0.336			
Mean Basin Temperature									
Population Density									

4.4 Regression Set 3, Analysis of Watershed Variables in Conjunction with Prediction of Bedload Watershed Sediment Delivery at the River Outlet Using Natural Log Transformed Dependent and Independent Variables, 17 Watersheds

As with Regression Set 2, Regression Set 3 utilized 17 watershed sediment delivery estimates consisting of 12 watershed sediment delivery estimates based on USACE-Detroit District dredging data (12 rivers; see Table 17) and five watersheds sediment delivery estimates based ^{137}Cs and ^{210}Pb radiometric dating (see Table 13). Eighteen independent variables were considered, they include:

- Watershed Area (square kilometer)
- Percent of Watershed, Total Surface Water Area (EGLE, 1978) MIRIS Land Use
- Percent of Watershed, Total Reservoir Pool Surface Area, EGLE (2020) Dam Inventory
- Percent of Watershed, Total Aquatic Wetlands (EGLE, 1978) MIRIS Land Use
- Percent of Watershed, Total Upland Wetlands (EGLE, 1978) MIRIS Land Use
- Mean Annual River Flow (cubic meters/second)
- 1.5-year Recurrence Interval Flow (cubic meters/second)
- 2.0-year Recurrence Interval Flow (cubic meters/second)
- 5-year Recurrence Interval Flow (cubic meters/second)
- Watershed Curve Number (unitless)
- River Slope (meter/meter)
- Relief: Net Watershed Elevation Difference, Maximum Watershed Elevation (meter)
- Relief: Net Watershed Elevation Difference, Average Watershed Elevation (meter)

- Mean Basin Temperature (°C)
- Population Density (people/square kilometer)
- Percent of Watershed, Total Surface Water and Aquatic Wetlands
- Percent of Watershed, Total Wetlands (Upland and Aquatic)
- Percent of Watershed, Total Surface Water and Reservoirs

The natural log transformed dependent (watershed sediment delivery estimates) and independent variables are shown on Table 38. Correlation coefficients of the independent variables are shown on Table 32. Review of Table 32 reveals the strong correlation between watershed area and mean annual river, and 1.5-year, 2-year, and 5-year recurrence interval flows. In addition, strong correlations were also observed between reservoir pool surface area and river slope and relief (average and maximum water elevation).

Forty-two regressions were completed and are summarized on Table 39, Table 40, Table 41, Table 42, and Table 43. Review of Table 39, Table 40, Table 41, Table 42, and Table 43 reveals that a significance of less than 0.05 was observed in 19 of 42 regressions. Due to the natural log transformation of the dependent and independent variables (USGS, 2021), all of the regressions equations result in positive estimates of bedload watershed sediment delivery at the river outlet.

Table 38. Natural Log Transformation of Dependent and Independent Variables

			tonnes/year	Ln Transfom. tonnes/year		Ln Transform kilometers^2	Ln Transform percent	Ln Transform percent	Ln Transform percent	Ln Transform percent
Watershed Reference Number	River	USACE Harbor	Sediment Delivery to the River Outlet	Sediment Delivery to the River Outlet	Watershed Area Basis	Watershed Area	Surface Water, Percent of Watershed	Pool Surface Area, Percent of Watershed	Total Aquatic Wetlands, Percent Watershed	Total Upland Wetlands, Percent of Watershed
1	Au Gres River	Point Lookout Harbor	4,400	8.39	Contributing	6.44	(4.81)	(4.92)	(4.95)	(3.20)
2A	Au Sable River	NA; Mio Dam	9,500	9.16	Contributing	7.91	(4.41)	(6.52)	(4.89)	(3.47)
6	Black River (East)	Black River	11,000	9.31	Contributing	7.52	(6.89)	(8.08)	(5.99)	(3.39)
8	Macatawa River	Holland Harbor	17,000	9.74	Contributing	6.11	(3.93)	(11.62)	(6.63)	(4.95)
9A	Boardman River	NA; Brown Bridge Dam	1,100	7.00	Contributing	5.74	(5.70)	(6.00)	(5.24)	(4.61)
12	Clinton River	Clinton River	9,000	9.10	Total	7.63	(4.45)	(4.71)	(4.70)	(3.97)
14	Grand River	Grand Haven Harbor	10,000	9.21	Contributing	9.55	(4.75)	(5.67)	(4.81)	(3.53)
14A	Grand River	NA; Webber Dam	19,000	9.85	Contributing	8.41	(5.22)	(5.09)	(4.39)	(2.93)
15A	Huron River	NA; Ford Dam	12,000	9.39	Contributing	7.61	(4.04)	(3.93)	(3.76)	(2.97)
29	River Raisin	Monroe Harbor	62,000	11.03	Total	7.93	(4.57)	(5.36)	(4.97)	(4.19)
31	Rouge River	Rouge River	22,000	10.00	Total	7.09	(4.86)	(6.54)	(5.58)	(4.78)
32	Saginaw River	Saginaw River	190,000	12.15	Contributing	9.67	(5.74)	(5.09)	(4.83)	(3.46)
34	St. Joseph River	St. Joseph Harbor	12,000	9.39	Total	9.41	(4.18)	(5.09)	(4.38)	(3.44)
34A	St. Joseph River	NA; Riley Dam	4,500	8.41	Contributing	7.21	(4.22)	(4.87)	(4.64)	(3.93)
49	Manistique River	Manistique Harbor	11,000	9.31	Total	8.24	(4.01)	(3.51)	(2.28)	(2.39)
50	Menominee River	Menominee Harbor	7,300	8.90	Total	9.26	(4.87)	(4.21)	(4.41)	(2.75)
53	Ontonagon River	Ontonagon Harbor	30,000	10.31	Total	8.18	(3.66)	(4.77)	(4.82)	(3.35)

			Ln Transform meters^3/sec	Ln Transform meters^3/sec	Ln Transform meters^3/sec	Ln Transform meters^3/sec	Ln Transform unitless	Ln Transform meter/meter	Ln Transform meters	Ln Transform meters	Ln Transform °C	Ln Transform persons-km^2
Watershed Reference Number	River	USACE Harbor	Mean Annual River Flow	1.5 year Recurrence Flow	2.0 year Recurrence Flow	5 year Recurrence Flow	Watershed Curve Number (CN)	River Slope	Relief: Maximum Elevation	Relief: Average Elevation	Mean Basin Temperature (Annual)	Population Density
1	Au Gres River	Point Lookout Harbor	1.52	3.75	3.93	4.18	4.32	(6.61)	4.72	3.93	1.96	2.66
2A	Au Sable River	NA; Mio Dam	3.33	4.30	4.41	4.57	3.95	(7.27)	5.18	4.37	1.91	2.41
6	Black River (East)	Black River	2.52	5.23	5.40	5.74	4.34	(7.47)	4.88	4.08	2.22	3.64
8	Macatawa River	Holland Harbor	1.68	4.68	4.97	5.46	4.33	(8.82)	4.05	3.14	2.28	5.55
9A	Boardman River	NA; Brown Bridge Dam	1.51	2.54	2.65	2.91	3.98	(6.52)	5.03	4.29	1.96	2.94
12	Clinton River	Clinton River	2.87	3.34	3.81	4.34	4.35	(6.80)	5.25	4.23	2.18	6.55
14	Grand River	Grand Haven Harbor	4.85	6.18	6.39	6.74	4.32	(8.14)	5.13	4.35	2.17	4.71
14A	Grand River	NA; Webber Dam	3.58	4.91	5.20	5.74	4.34	(7.88)	5.15	3.94	2.13	4.50
15A	Huron River	NA; Ford Dam	2.88	4.30	4.51	4.91	4.29	(7.43)	5.04	4.33	2.29	5.52
29	River Raisin	Monroe Harbor	3.11	4.91	5.10	5.48	4.37	(7.44)	5.29	4.33	2.24	4.19
31	Rouge River	Rouge River	2.17	4.44	4.75	5.33	4.40	(7.23)	4.88	3.90	2.31	6.99
32	Saginaw River	Saginaw River	4.83	6.64	6.78	7.06	4.32	(7.74)	5.29	4.20	2.05	4.33
34	St. Joseph River	St. Joseph Harbor	4.89	5.74	5.91	6.12	4.28	(6.85)	5.28	4.50	2.20	4.40
34A	St. Joseph River	NA; Riley Dam	2.59	3.61	3.75	4.09	4.32	(7.11)	4.74	3.81	2.31	3.71
49	Manistique River	Manistique Harbor	3.94	5.29	5.46	5.74	4.22	(7.58)	5.69	5.01	1.69	0.90
50	Menominee River	Menominee Harbor	4.62	5.83	5.98	6.29	4.23	(6.46)	5.92	5.41	1.70	1.90
53	Ontonagon River	Ontonagon Harbor	3.67	5.52	5.74	6.23	4.27	(5.75)	5.95	5.46	1.82	0.81

Table 39. Regressions 3-1 to 3-12, 17 Watershed Sediment Delivery Estimates, Natural Log Transformation

Regression Analysis Summary	Regression Set 3-1	Regression Set 3-2	Regression Set 3-3	Regression Set 3-4	Regression Set 3-5	Regression Set 3-6	Regression Set 3-7	Regression Set 3-8	Regression Set 3-9	Regression Set 3-10	Regression Set 3-11	Regression Set 3-12
Significance	0.635	0.354	0.327	0.527	0.397	0.254	0.197	0.113	0.058	0.157	0.313	0.204
Multiple R	0.972	0.969	0.944	0.872	0.864	0.863	0.845	0.845	0.842	0.740	0.617	0.607
R Square	**0.945**	**0.940**	**0.892**	**0.761**	**0.746**	**0.745**	**0.714**	**0.714**	**0.708**	**0.547**	0.381	0.368
Adjusted R Square	0.119	0.517	0.424	0.044	0.186	0.320	0.346	0.346	0.481	0.275	0.099	0.158
Standard Error	1.047	0.776	0.847	1.091	1.007	0.920	0.902	0.902	0.804	0.950	1.059	1.024
Observations	17	17	17	17	17	17	17	17	17	17	17	17
Coefficients												
Intercept	-4.193	-0.141	-5.590	-10.846	4.469	3.778	-4.972	-4.581	-5.279	-8.578	2.239	3.232
Watershed Area	-1.765	-1.238	1.215	2.823	2.877	3.080	2.194	2.082	2.299	3.420	0.706	0.653
Total Surface Water	0.731	0.628	0.572	0.327	0.231	0.222	0.172	0.165	0.197	0.242	0.109	0.172
Reservoir Pool Surface Area	0.364	0.434	0.060	0.068	0.093	0.020	-0.023	0.013	-0.008	-0.321	-0.107	-0.098
Total Aquatic Wetlands	-0.908	-0.732	0.021	0.333	0.620	0.750	0.602	0.578	0.615	0.642	-0.092	-0.279
Total Upland Wetlands	0.511	0.189	-0.486	-1.003	-1.095	-1.137	-0.929	-0.964	-0.997	-0.660	-0.310	
Annual Mean Flow	-0.320	-0.771	-2.187	-3.348	-3.351	-3.506	-2.388	-2.371	-2.559	-2.771		
1.5 year Recurrence Flow	-0.129	-2.642	1.545	0.599	0.279	0.544	1.622	0.386	1.060			
2.0 year Recurrence Flow	7.026	9.380	0.869	0.402	-0.328	-0.763	-1.773	0.709				
5 year Recurrence Flow	-4.696	-4.404	-0.944	0.074	1.430	1.561	1.140					
Watershed Curve Number	-2.398	-3.804	-1.309	-1.524	-3.350	-3.240						
River Slope	-0.359	-0.354	-0.093	-0.525	-0.093							
Relief: Maximum Elevation	9.039	8.049	5.804	1.196								
Relief: Average Elevation	-5.402	-4.991	-4.113									
Mean Basin Temperature	2.835	3.662										
Population Density	0.212											
Total Surface Water and Aquatic Wetlands												
Total Wetland												
Total Surface Water and Reservoirs												
P-Values												
Intercept	0.9265	0.9960	0.8487	0.7687	0.7804	0.7753	0.5168	0.5164	0.3811	0.2193	0.5571	0.2938
Watershed Area	0.7629	0.7285	0.6756	0.4289	0.3758	0.1964	0.2654	0.2480	0.1147	**0.0387**	**0.0283**	**0.0218**
Total Surface Water	0.4392	0.2354	0.2534	0.5455	0.6081	0.5793	0.6543	0.6449	0.5283	0.5091	0.7840	0.6323
Reservoir Pool Surface Area	0.7595	0.5778	0.9313	0.9381	0.9071	0.9548	0.9467	0.9647	0.9759	0.2449	0.6893	0.7038
Total Aquatic Wetlands	0.7133	0.6366	0.9881	0.8500	0.6829	0.3539	0.4258	0.4111	0.3416	0.3957	0.8956	0.6146
Total Upland Wetlands	0.8015	0.8518	0.5767	0.3459	0.2540	0.1522	0.1879	0.1405	0.0993	0.3089	0.6457	
Annual Mean Flow	0.9432	0.7810	0.4206	0.3160	0.2692	0.1474	0.1841	0.1587	0.0666	0.0843		
1.5 year Recurrence Flow	0.9928	0.7009	0.7931	0.9351	0.9667	0.9227	0.7608	0.8979	0.0527			
2.0 year Recurrence Flow	0.7410	0.4734	0.9295	0.9742	0.9766	0.9356	0.8461	0.8203				
5 year Recurrence Flow	0.6034	0.4551	0.8395	0.9898	0.7584	0.7007	0.7709					
Watershed Curve Number	0.8076	0.4970	0.7926	0.8079	0.4679	0.4257						
River Slope	0.8238	0.7412	0.9313	0.6958	0.9163							
Relief: Maximum Elevation	0.3466	0.1352	0.1516	0.6396								
Relief: Average Elevation	0.3334	0.1401	0.1525									
Mean Basin Temperature	0.6573	0.3362										
Population Density												
Total Surface Water and Aquatic Wetlands	0.8074											
Total Wetland												
Total Surface Water and Reservoirs												

Table 40. Regressions 3-13 to 3-23, 17 Watershed Sediment Delivery Estimates, Natural Log Transformation

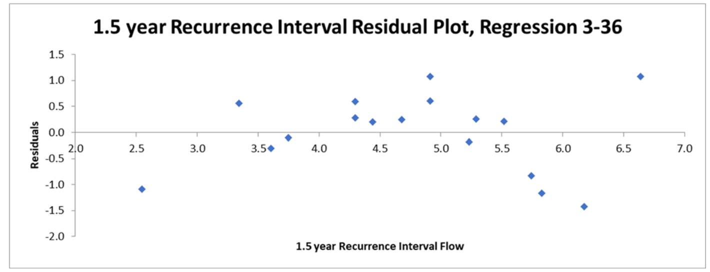
Regression Analysis Summary	Regression Set 3-13	Regression Set 3-14	Regression Set 3-15	Regression Set 3-16	Regression Set 3-17	Regression Set 3-18	Regression Set 3-19	Regression Set 3-20	Regression Set 3-21	Regression Set 3-22	Regression Set 3-23
Significance	0.117	0.116	**0.034**	0.137	0.131	0.081	**0.012**	**0.036**	0.075	**0.012**	**0.003**
Multiple R	0.595	0.515	0.515	0.793	0.753	0.689	0.685	0.685	0.745	0.682	0.678
R Square	0.354	0.265	0.265	**0.629**	**0.567**	0.474	0.470	0.470	**0.556**	0.465	0.460
Adjusted R Square	0.205	0.160	0.216	0.341	0.308	0.299	0.394	0.347	0.354	0.389	0.424
Standard Error	0.995	1.022	0.988	0.906	0.928	0.934	0.869	0.901	0.897	0.872	0.847
Observations	17	17	17	17	17	17	17	17	17	17	17
Coefficients											
Intercept	3.788	5.691	5.580	9.154	4.890	7.016	6.696	6.670	3.667	5.829	6.093
Watershed Area	0.635	0.491	0.491	-0.358	-0.274	-0.159	-0.170	-0.166			
Total Surface Water	0.101	0.023		0.154	0.071	0.094			0.076		
Reservoir Pool Surface Area	-0.201			0.374	0.211	-0.011		-0.002	0.131	-0.043	
Total Aquatic Wetlands				-0.164	-0.061				-0.049		
Total Upland Wetlands				-0.569	-0.699				-0.668		
Annual Mean Flow											
1.5 year Recurrence Flow				1.314	1.137	0.852	0.858	0.854	0.886	0.708	0.703
2.0 year Recurrence Flow											
5 year Recurrence Flow											
Watershed Curve Number											
River Slope											
Relief: Maximum Elevation											
Relief: Average Elevation				-0.732							
Mean Basin Temperature											
Population Density											
Total Surface Water and Aquatic Wetlands											
Total Wetland											
Total Surface Water and Reservoirs											
P-Values											
Intercept	0.1782	**0.0274**	**0.0047**	0.0922	0.1908	**0.0470**	**0.0007**	**0.0371**	0.1649	**0.0003**	**0.0000**
Watershed Area	**0.0195**	**0.0414**	**0.0345**	0.5117	0.6176	0.7691	0.6239	0.7496			
Total Surface Water	0.7517	0.9427		0.6589	0.8390	0.7553			0.8207		
Reservoir Pool Surface Area	0.2041			0.2443	0.4628	0.9535		0.9915	0.5652	0.7179	
Total Aquatic Wetlands				0.7882	0.9209				0.9336		
Total Upland Wetlands				0.3674	0.2742				0.2745		
Annual Mean Flow											
1.5 year Recurrence Flow				0.0416	0.0646	0.1236	**0.0356**	0.1088	**0.0039**	**0.0036**	**0.0028**
2.0 year Recurrence Flow											
5 year Recurrence Flow											
Watershed Curve Number											
River Slope											
Relief: Maximum Elevation											
Relief: Average Elevation				0.2506							
Mean Basin Temperature											
Population Density											
Total Surface Water and Aquatic Wetlands											
Total Wetland											
Total Surface Water and Reservoirs											

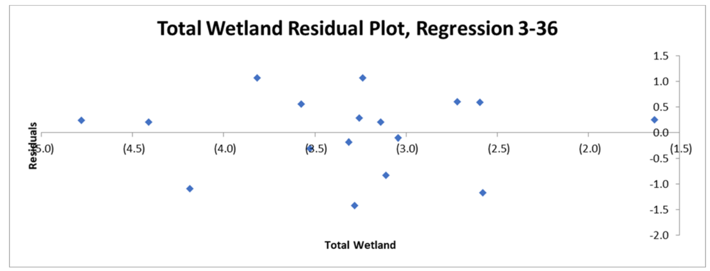
Table 41. Regressions 3-24 to 3-33, 17 Watershed Sediment Delivery Estimates, Natural Log Transformation

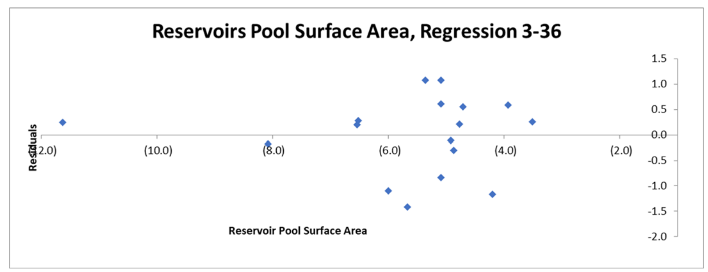
Regression Analysis Summary	Regression Set 3-24	Regression Set 3-25	Regression Set 3-26	Regression Set 3-27	Regression Set 3-28	Regression Set 3-29	Regression Set 3-30	Regression Set 3-31	Regression Set 3-32	Regression Set 3-33
Significance	0.513	0.355	0.116	**0.034**	**0.013**	**0.036**	0.068	**0.030**	0.067	**0.036**
Multiple R	0.539	0.537	0.515	0.744	0.744	0.686	0.752	0.752	0.753	0.685
R Square	0.291	0.288	0.265	**0.554**	**0.554**	0.470	**0.565**	**0.565**	**0.567**	0.470
Adjusted R Square	**-0.031**	0.051	0.160	0.405	0.450	0.348	0.368	0.420	0.370	0.347
Standard Error	1.133	1.087	1.023	0.861	0.827	0.901	0.887	0.849	0.885	0.901
Observations	17	17	17	17	17	17	17	17	17	17
Coefficients										
Intercept	5.779	5.467	6.704	3.389	3.370	6.229	4.646	4.645	4.739	6.670
Watershed Area							-0.278	-0.278	-0.262	-0.166
Total Surface Water	0.084					0.098				
Reservoir Pool Surface Area	-0.042	-0.055	-0.170	0.120	0.125	-0.050	0.202	0.202	0.190	-0.002
Total Aquatic Wetlands	-0.288	-0.214		0.018			0.002			
Total Upland Wetlands	-0.134	-0.185		-0.715	-0.705		-0.743	-0.742	-0.759	
Annual Mean Flow	0.614	0.619	0.557							
1.5 year Recurrence Flow				0.889	0.888	0.712	1.143	1.143	1.130	0.854
2.0 year Recurrence Flow										
5 year Recurrence Flow										
Watershed Curve Number										
River Slope										
Relief: Maximum Elevation										
Relief: Average Elevation										
Mean Basin Temperature										
Population Density										
Total Surface Water and Aquatic Wetlands									0.072	
Total Wetland										
Total Surface Water and Reservoirs										
P-Values										
Intercept	0.0820	**0.0488**	**0.0004**	0.1270	0.1035	**0.0030**	0.1666	0.1451	0.1594	**0.0371**
Watershed Area							0.5959	0.5781	0.6184	0.7496
Total Surface Water	0.8812					0.7358				
Reservoir Pool Surface Area	0.8424	0.8366	0.2825	0.5720	0.4250	0.6869	0.4546	0.3461	0.4132	0.9915
Total Aquatic Wetlands	0.6995	0.7291		0.9704			0.9976			
Total Upland Wetlands	0.8484	0.7676		0.1970	0.1334		0.1976	0.1303	0.1446	
Annual Mean Flow	0.0660	0.0528	**0.0417**							
1.5 year Recurrence Flow				**0.0025**	**0.0016**	**0.0048**	0.0512	**0.0413**	0.0544	0.1088
2.0 year Recurrence Flow										
5 year Recurrence Flow										
Watershed Curve Number										
River Slope										
Relief: Maximum Elevation										
Relief: Average Elevation										
Mean Basin Temperature										
Population Density										
Total Surface Water and Aquatic Wetlands									0.8401	
Total Wetland										
Total Surface Water and Reservoirs										

Table 42. Regressions 3-34 to 3-36, 17 Watershed Sediment Delivery Estimates, Natural Log Transformation

Regression Analysis Summary	Regression Set 3-34	Regression Set 3-35	Regression Set 3-36
Significance	**0.041**	**0.015**	**0.014**
Multiple R	0.734	0.734	0.734
R Square	**0.539**	**0.538**	**0.538**
Adjusted R Square	0.385	0.432	0.432
Standard Error	0.875	0.841	0.841
Observations	17	17	17
Coefficients			
Intercept	4.762	4.801	3.901
Watershed Area	0.007		
Total Surface Water			
Reservoir Pool Surface Area			0.150
Total Aquatic Wetlands			
Total Upland Wetlands			
Annual Mean Flow			
1.5 year Recurrence Flow	0.811	0.817	0.858
2.0 year Recurrence Flow			
5 year Recurrence Flow			
Watershed Curve Number			
River Slope			
Relief: Maximum Elevation			
Relief: Average Elevation			
Mean Basin Temperature			
Population Density			
Total Surface Water and Aquatic Wetlands			
Total Wetland	-0.488	-0.485	**-0.694**
Total Surface Water and Reservoirs	0.203	0.203	
P-Values			
Intercept	0.1192	**0.0182**	**0.0405**
Watershed Area	0.9859		
Total Surface Water			
Reservoir Pool Surface Area			0.3874
Total Aquatic Wetlands			
Total Upland Wetlands			
Annual Mean Flow			
1.5 year Recurrence Flow	0.0553	**0.0019**	**0.0017**
2.0 year Recurrence Flow			
5 year Recurrence Flow			
Watershed Curve Number			
River Slope			
Relief: Maximum Elevation			
Relief: Average Elevation			
Mean Basin Temperature			
Population Density			
Total Surface Water and Aquatic Wetlands			
Total Wetland	0.2166	0.1640	0.1489
Total Surface Water and Reservoirs	0.4991	0.4785	







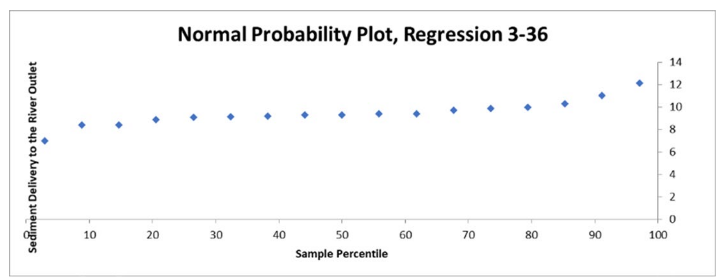


Table 43. Regressions 3-37 to 3-42, 17 Watershed Sediment Delivery Estimates, Natural Log Transformation

Regression Analysis Summary	Regression Set 3-37	Regression Set 3-38	Regression Set 3-39	Regression Set 3-40	Regression Set 3-41	Regression Set 3-42
Significance	**0.035**	**0.034**	**0.033**	**0.013**	**0.033**	**0.031**
Multiple R	0.743	0.744	0.745	0.744	0.746	0.750
R Square	**0.553**	**0.554**	**0.555**	**0.554**	**0.557**	**0.562**
Adjusted R Square	0.404	0.405	0.407	0.450	0.409	0.416
Standard Error	0.862	0.861	0.859	0.827	0.858	0.853
Observations	17	17	17	17	17	17
Coefficients						
Intercept	4.312	3.389	3.655	3.370	3.593	5.321
Watershed Area						-0.311
Total Surface Water	0.101		0.062			
Reservoir Pool Surface Area	0.142	0.120	0.118	0.125	0.114	0.242
Total Aquatic Wetlands		0.018				
Total Upland Wetlands		-0.715	-0.696	-0.705	-0.731	
Annual Mean Flow						
1.5 year Recurrence Flow	0.863	0.889	0.889	0.888	0.891	1.144
2.0 year Recurrence Flow						
5 year Recurrence Flow						
Watershed Curve Number						
River Slope						
Relief: Maximum Elevation						
Relief: Average Elevation						
Mean Basin Temperature						
Population Density						
Total Surface Water and Aquatic Wetlands					0.098	
Total Wetland	-0.696					-0.750
Total Surface Water and Reservoirs						
P-Values						
Intercept	0.061	0.127	0.147	0.104	0.118	0.086
Watershed Area						0.538
Total Surface Water	0.715		0.823			
Reservoir Pool Surface Area	0.430	0.572	0.476	0.425	0.495	0.303
Total Aquatic Wetlands		0.970				
Total Upland Wetlands		0.197	0.155	0.133	0.142	
Annual Mean Flow						
1.5 year Recurrence Flow	**0.0024**	**0.0025**	**0.0024**	**0.0016**	**0.0023**	**0.0423**
2.0 year Recurrence Flow						
5 year Recurrence Flow						
Watershed Curve Number						
River Slope						
Relief: Maximum Elevation						
Relief: Average Elevation						
Mean Basin Temperature						
Population Density						
Total Surface Water and Aquatic Wetlands					0.774	
Total Wetland	0.163					0.138
Total Surface Water and Reservoirs						

Of these 42 regressions, Regression 3-36 provided the best balance of significance (0.014), R^2 (0.538), and relative low p-values for the following independent variables (see Table 42):

- 1.5 year recurrence interval flow (P-value: 0.002),
- percent of watershed covered in upland and aquatic wetlands (P-value: 0.149),
- percent of the watershed covered in reservoirs (p-value: 0.387).

With respect to Regression 3-36, the regression summary is presented in Table 44. As discussed in Section 4.1.3, because watershed area is highly correlated with the 1.5-year recurrence interval flow, watershed area can be removed from the regression equation 3-36 without reduction in significance (see Section 4.1.3 and Table 42). Review of the residual plots reveals that the three independent variables (1.5-year recurrence interval flow; percentage of the watershed covered in wetlands, aquatic and upland; and, total reservoir pool surface area) are distributed randomly about zero (see Table 42). In addition, the normal probability plot of Regression 3-36 is linear.

Table 44. Regression 3-36 Summary Statistics

Regression Statistics	
Multiple R	0.740
R Square	**0.547**
Adjusted R Square	0.443
Standard Error	0.833
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	***Significance F***
Regression	3	10.9049	3.6350	5.2417	**0.014**
Residual	13	9.0151	0.6935		
Total	16	19.9200			

	Coefficients	*Standard Error*	*t Stat*	***P-value***	*Lower 95%*	*Upper 95%*
Intercept	**3.901**	1.7149	2.2749	**0.040**	0.1965	7.6061
Total Wetland	**-0.694**	0.4527	-1.5342	**0.149**	-1.6724	0.2834
Reservoir Pool Surface	**0.150**	0.1674	0.8943	**0.387**	-0.2120	0.5114
1.5 year Recurrence Flow	**0.858**	0.2171	3.9527	**0.002**	0.3890	1.3269

The Regression 3-36 bedload watershed sediment delivery equation is presented as follows:

$$Q_b = EXP(3.901) * EXP(-0.694)^{LN(W)} * EXP(0.150)^{LN(R)} * EXP(0.858)^{LN(Q_{1.5})} \quad (20)$$

Where,

Q_b – Bedload Watershed Sediment Delivery (tonnes/year)

$Q_{1.5}$ – 1.5-year Recurrence Interval Flow at the River Outlet (cubic meters/second)

W - Percent of the Watershed Covered in Both Upland and Aquatic Wetlands (EGLE, 1978 MIRIS Land Use)

R - Percent of the Watershed Covered in Reservoirs (EGLE, 2020 updated dam inventory)

With respect to the independent variables, 1.5-year recurrence interval flow is the most important (P-value: 0.002), and had consistently lower P-values than either annual mean flow or 2-year recurrence interval flow in Regression Sets 1,2, and 3. As discussed in Section 2.2, the 1.5-year recurrence interval flow is associated with 'bankfull flow" and is the flow rate where the river performs the most work (e.g. transporting sediment). Due to the strong correlation between watershed area and the 1.5-year recurrence interval flow, the removal of watershed area from Regression 3-36 results in an improvement in significance from 0.031 (Regression 3-42; Table 43) to 0.014 (Regression 3-36; Table 42).

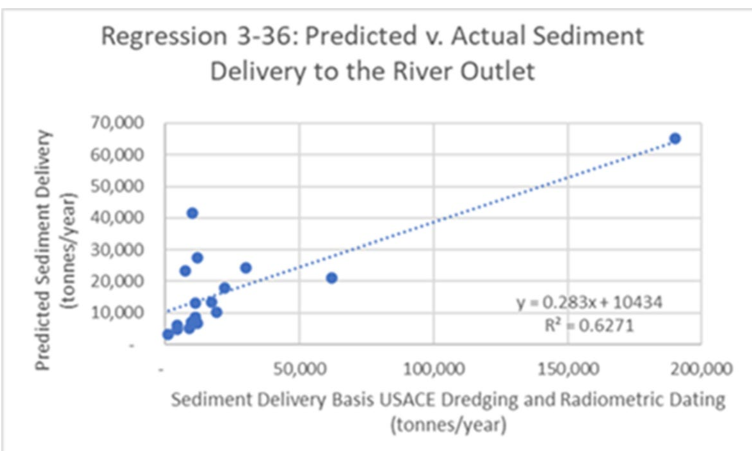
With respect to regression 3-36, the percentage of the watershed covered in total wetlands (aquatic and upland) was determined to be an important predictor variable. In conjunction with the 1.5-year recurrence interval flow and the total percentage of watershed covered in wetlands, the percentage of the watershed covered in reservoirs was also determined to be an effective predictor variable of bedload watershed sediment delivery to the river outlet. As discussed in Section 3.10.2, although most dams in Michigan are small, they are effective at retaining sediment that would otherwise be transported in fluvial systems to the river outlet.

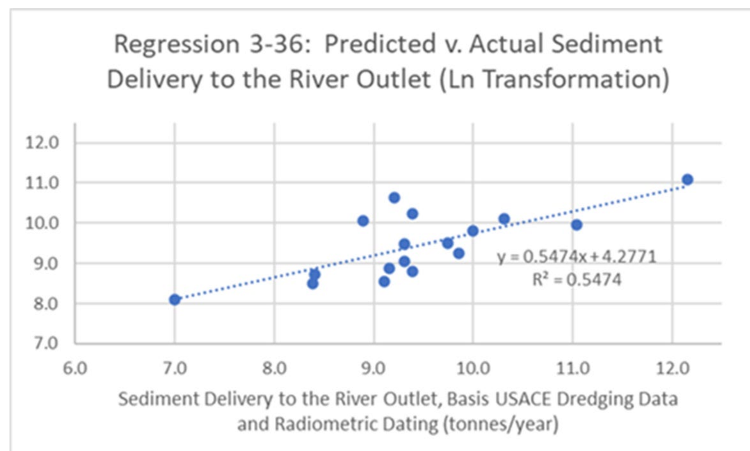
Review of Table 45 reveals that the predicted watershed sediment delivery estimates using Regression 3-36 in comparison to the estimated watershed sediment delivery estimates based on USACE dredging data and radiometric dating are within +/- 70% for 13 of the 17 watersheds. The average difference between predicted watershed sediment delivery using regression 3-36 and the watershed delivery estimates based on USACE dredging data and radiometric dating was -31%.

The largest differences based on total metric tonnes between predicted sediment delivery using regression 3-36 and the watershed sediment delivery estimates based on either USACE dredging data or radiometric dating were noted at the Saginaw River (32), Grand River (14), St. Joseph River (34) and the Menominee River (50). With the exception of the Saginaw River (32), the predicted watershed sediment delivery using regression 3-36 were lower than the watershed sediment delivery estimates based on

Table 45. Predicted Sediment Delivery Using Regression 3-36 in Comparison to Estimated Sediment Delivery Using USACE Dredging Data and Radiometric Dating

Watershed Reference Number	River	USACE Harbor	Estimated Watershed Sediment Delivery to the River Outlet (tonnes/year)	Estimated Watershed Sediment Delivery to the River Outlet (tonnes/year/km^2)	Basis	Regression 3-36: Predicted Sediment Delivery to the River Outlet (tonnes/year)	Percent Difference: Regression 3-36 v. Estimated Watershed Sediment Delivery	USACE (2020) Average Annual Dredging Forecast (tonnes/year)	BQART Sediment Load (Qs) (Syvitski and Milliman, 2007) (tonnes/year)	USACE (2010) Great Lakes Regional Trend Line $S_y = 177.6*A^{0.77}$ (A: km^2) (tonnes/year)	USACE 516(e) Study (tonnes/year)
1	Au Gres River	Point Lookout Harbor	4,400	6.99	USACE Dredging Data	4,900	11%	3,100	11,000	25,000	
2A	Au Sable River	NA; Mio Dam	9,500	3.47	Radiometric Dating	7,100	-25%		58,000	79,000	
6	Black River (East)	Black River	11,000	5.98	USACE Dredging Data	13,000	18%	2,700	37,000	58,000	
8	Macatawa River	Holland Harbor	17,000	37.72	USACE Dredging Data	13,000	-24%	16,000	2,000	20,000	
9A	Boardman River	NA; Brown Bridge Dam	1,100	3.54	Radiometric Dating	3,300	200%		10,000	15,000	
12	Clinton River	Clinton River	9,000	4.36	USACE Dredging Data	5,200	-42%	4,400	18,000	63,000	73,000
14	Grand River	Grand Haven Harbor	10,000	0.71	USACE Dredging Data	41,000	310%	8,500	260,000	280,000	250,000
14A	Grand River	NA; Webber Dam	19,000	4.22	Radiometric Dating	10,000	-47%		95,000	120,000	
15A	Huron River	NA; Ford Dam	12,000	5.95	Radiometric Dating	6,700	-44%		16,000	62,000	
29	River Raisin	Monroe Harbor	62,000	22.37	USACE Dredging Data	21,000	-66%	66,000	85,000	79,000	
31	Rouge River	Rouge River	22,000	18.27	USACE Dredging Data	18,000	-18%	15,000	8,900	42,000	
32	Saginaw River	Saginaw River	190,000	11.96	USACE Dredging Data	65,000	-66%	180,000	290,000	300,000	250,000
34	St. Joseph River	St. Joseph Harbor	12,000	0.98	USACE Dredging Data	28,000	133%	13,000	290,000	250,000	76,000
34A	St. Joseph River	NA; Riley Dam	4,500	3.32	Radiometric Dating	6,100	36%		31,000	46,000	
49	Manistique River	Manistique Harbor	11,000	2.90	USACE Dredging Data	8,500	-23%	NA	110,000	100,000	
50	Menominee River	Menominee Harbor	7,300	0.70	USACE Dredging Data	23,000	215%	4,200	290,000	220,000	
53	Ontonagon River	Ontonagon Harbor	30,000	8.37	USACE Dredging Data	24,000	-20%	34,000	140,000	97,000	180,000





USACE dredging data for Grand River (14), St. Joseph River (34) and the Menominee River (50).

Of these four rivers, the Saginaw River had the largest total difference where the predicted annual watershed sediment delivery using regression 3-36 is 65,000 metric tonnes per year in comparison to the 190,000 metric tonnes per year based on USACE dredging data. Note, that with respect to the USACE's (2020) annual maintenance dredging forecast of 180,000 metric tonnes for the Saginaw River, 155,000 metric tonnes is forecast for the Entrance Channel located in Saginaw Bay and 25,000 metric tonnes is forecast for the Upper Saginaw River navigation channel (Inner Harbor). The littoral component of sediment delivery was estimated by USACE (2020) to be 10% (see Table 15) but based on the USACE (2020) dredging forecast, the littoral component could be much larger; further research is needed to separate fluvial and littoral sediment within the Saginaw River navigation channel.

With respect to the Grand River (14), the predicted annual watershed sediment delivery using regression 3-36 is 41,000 metric tonnes per year in comparison to the 10,000 metric tonnes per year based on USACE dredging data. With respect to the St. Joseph River (34), the predicted annual watershed sediment delivery using regression 3-36 is 28,000 metric tonnes per year in comparison to the 12,000 metric tonnes per year based on USACE dredging data. With respect to the Grand River (14) and St. Joseph River (34), the differences in predicted sediment delivery using regression 3-36 in comparison to the watershed sediment delivery estimates based on USACE dredging data may be to the presence of large depositional areas near the river outlet (Figure 45).

Figure 45. Aerial Photographs, Grand River (14), St. Joseph River (34), Menominee River (50)

With respect to the Grand River (14), a large depositional area covering 15 square kilometers is located a short distance from the river outlet. Although smaller, similar areas of channel widening and large depositional areas are located near the river outlet of the St. Joseph River (34) and are shown on Figure 45. The impact of natural lakes and depositional areas in close proximity to the river outlet in conjunction with the prediction of watershed sediment delivery is a topic of further research. With respect to the Menominee River (50), the large difference in the predicted annual watershed sediment delivery using regression 3-36 (23,000 metric tonnes per year) in comparison to the 7,300 metric tonnes per year based on USACE dredging data is likely due to the reservoir trapping efficiency of the Park Mill Dam (MI00531) that is located approximately six kilometers from the river outlet (see Figure 45).

Of the watersheds where USACE 516e studies were completed, the USACE-Detroit District completed a bathymetric analysis of several pairs of pre- and post-dredging events at the Ontonagon Harbor (Ontonagon River, 53) to estimate the littoral and fluvial components of the sediment removed during USACE maintenance dredging of the federal navigation channel (USACE, 2010a). The USACE (2010) approach to the estimate fluvial and littoral components of dredged sediment consisted of generating a digital surface using a Triangular Irregular Network (TIN) and then calculating the volume between the surfaces in the area where fluvial sediment was deposited (USACE, 2010a). This method also provides a good estimate of bedload sediment delivery to the river outlet. As shown in Table 45, the estimated watershed sediment delivery using USACE dredging data is 30,000 metric tonnes per year and is in close agreement with the predicted bedload sediment delivery using Regression 3-36 of 24,000 metric tonnes per year.

The percentage of bedload calculated using Regression 3-36 in comparison to the estimated total watershed sediment delivery estimated using the USACE (2010) Great Lakes Regional Trend Line for all 65 watersheds is presented Figure 46. The mean and median values of the percentage of bedload to total watershed sediment delivery are 19.4% and 13.3% and are within the range of 5-20% reported by USGS (2011) and similar to 10% that has been reported by others (MacArthur RC et al, 2008; USACE, 1995).

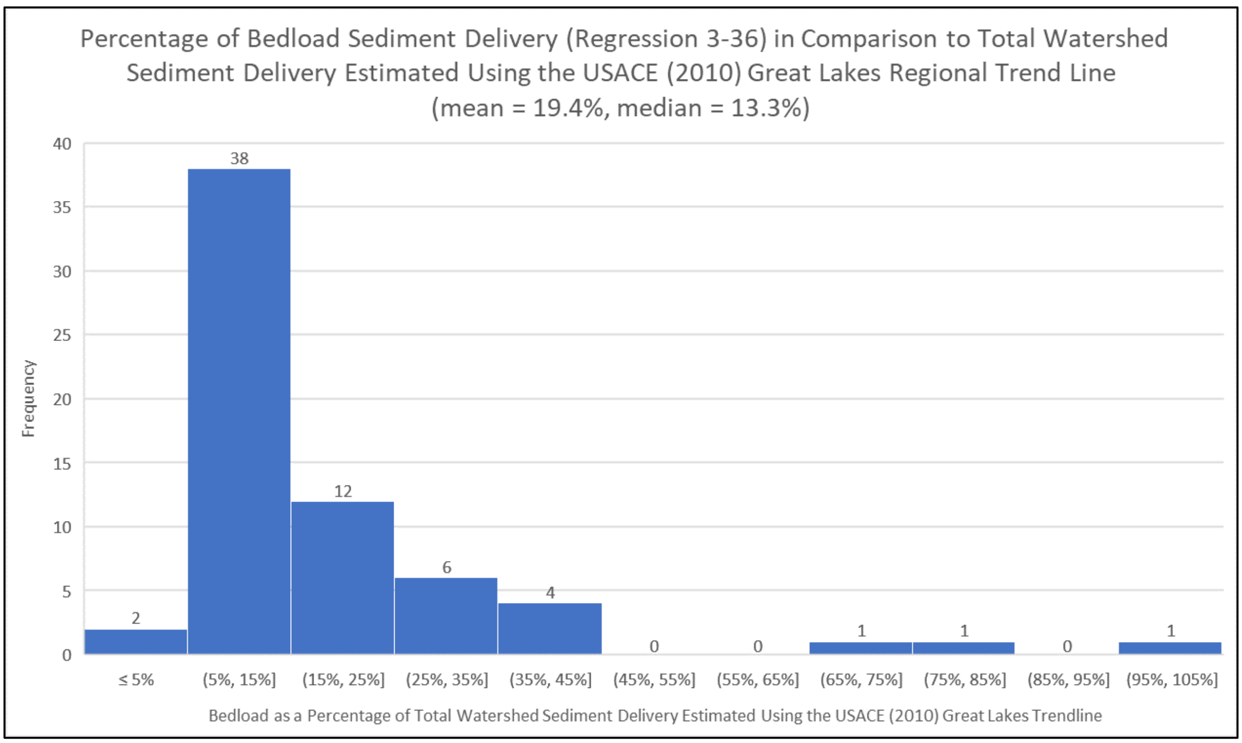


Figure 46. Percentage of Bedload Sediment Delivery in Comparison to Total Watershed Sediment Delivery

The Regression 3-36 predicted bedload watershed sediment delivery and the watershed sediment delivery based on the USACE (2010a) trendline and the BQART Equation for all 60 watersheds and five sub-watersheds are sumarized on Table 46 and Table 47. In addition, Table 46 and Table 47 list the the bedload watershed sediment delivery using regression 3-36 nomalized to watershed area as well as the percent bedload described previously. With respect to Regression 3-36, the predicted bedload watershed sediment delivery to the river outlet and at the corresponding sub-watersheds for the Grand River (14) and St. Joseph River (34) normalized to watershed area are similar. For the Grand River (14) at Grand Haven Harbor and the Weber Dam (14A), the bedload watershed sediment delivery as a function of watershed area are 2.9 tonnes/year/kilosquare meter and 2.3 tonnes/year/kilosquare meter, respectively. For the St. Joseph River (14) and the Riley Dam (34A), the bedload watershed sediment delivery as a function of watershed area are 2.3 tonnes/year/kilosquare meter and 4.5 tonnes/year/kilosquare meter, respectively. Although these are only two comparisons, Regression 3-36 provides good agreement of predicted bedload sediment delivery within the sub-watersheds of the Grand River (14) and St. Joseph River (34).

Table 46. Comparison of Regression 3-36 Predicted Bedload Sediment Delivery and Watershed Sediment Delivery Predicted Using the USACE (2010) Trendline and the BQART Equation, Watersheds 1-30

Watershed Reference Number	River	USACE Harbor	Predicted Sediment Delivery, Regression Set 3-36 (tonnes/yr)	Predicted Sediment Delivery, Regression Set 3-36 (tonnes/yr/km^2)	Sediment Delivery, BQART Equation (Syvitski and Milliman, 2007) (tonnes/yr)	Watershed Sediment Delivery, USACE (2010) Great Lakes Regional Trend Line (tonnes/yr)	Percent Bedload: Predicted Bedload Discharge as a Percentage of Total Watershed Sediment Delivery (USACE 2010 Trendline)
1	**Au Gres River**	**Point Lookout Harbor**	4,900	7.8	11,000	25,000	19%
2	Au Sable River	Au Sable Harbor	11,000	2.5	140,000	110,000	10%
2A	Au Sable River	NA; Mio Dam	7,100	2.6	58,000	79,000	9%
3	Belle River	NA	10,000	17.2	15,000	24,000	42%
4	Betsie River	Frankfort Harbor	2,100	3.4	22,000	25,000	8%
5	Big Sable	NA	2,400	5.7	15,000	19,000	13%
6	**Black River (East)**	**Black River**	13,000	7.1	37,000	58,000	23%
7	Black River (West)	South Haven Harbor	3,000	4.1	13,000	29,000	11%
8	**Macatawa River**	**Holland Harbor**	13,000	29.5	2,000	20,000	68%
9	Boardman	NA	4,400	7.8	25,000	24,000	19%
9A	Boardman River	NA; Brown Bridge Dam	3,300	10.5	10,000	15,000	22%
10	Pine River	Charlevoix Harbor	8,000	9.9	36,000	31,000	26%
11	Cheboygan River	Cheboygan Harbor	13,000	3.6	110,000	99,000	13%
12	**Clinton River**	**Clinton River**	5,200	2.5	18,000	63,000	8%
13	Elk River	NA	6,700	6.5	44,000	37,000	18%
14	**Grand River**	**Grand Haven Harbor**	41,000	2.9	260,000	280,000	15%
14A	Grand River	NA; Webber Dam	10,000	2.3	95,000	115,000	9%
15	Huron River	NA	7,300	3.2	19,000	68,000	11%
15A	Huron River	NA; Ford Dam	6,700	3.3	16,000	62,000	11%
17	Kalamazoo River	Saugatuck Harbor	11,000	2.1	140,000	130,000	8%
18	Kawkawlin River	NA	5,600	9.6	5,400	24,000	23%
19	Lincoln River	NA	1,400	5.3	4,700	13,000	11%
20	Manistee River	Manistee Harbor	13,000	2.9	230,000	110,000	11%
22	Muskegon River	Muskegon Harbor	15,000	2.3	310,000	150,000	10%
23	Oqueoc River	NA	1,800	4.9	7,500	17,000	11%
24	Pentwater River	Pentwater Harbor	6,300	14.6	11,000	19,000	33%
25	Pere Marquette River	Ludington Harbor	4,800	2.8	70,000	54,000	9%
26	Pigeon River	Caseville Harbor	2,400	6.4	5,100	17,000	14%
27	Pine River	NA	17,000	32.8	9,100	21,000	77%
28	Platte River	NA	1,300	3.6	15,000	17,000	8%
29	**River Raisin**	**Monroe Harbor**	21,000	7.7	85,000	79,000	27%
30	Rifle River	NA	8,000	8.2	42,000	36,000	22%

Table 47. Comparison of Regression 3-36 Predicted Bedload Delivery and Watershed Sediment Delivery Predicted Using the USACE (2010) Trend line and the BQART Equation, Watersheds 31-63

Watershed Reference Number	River	USACE Harbor	Predicted Sediment Delivery, Regression Set 3-36 (tonnes/yr)	Predicted Sediment Delivery, Regression Set 3-36 (tonnes/yr/km^2)	Sediment Delivery, BQART Equation (Syvitski and Milliman, 2007) (tonnes/yr)	Watershed Sediment Delivery, USACE (2010) Great Lakes Regional Trend Line (tonnes/yr)	Percent Bedload: Predicted Bedload Discharge as a Percentage of Total Watershed Sediment Delivery (USACE 2010 Trendline)
31	**Rouge River**	**Rouge River**	18,000	14.9	8,900	42,000	43%
32	**Saginaw River**	**Saginaw River**	65,000	4.1	290,000	300,000	21%
33	Sebewaing River	Sebewaing River	13,000	48.9	3,200	13,000	100%
34	**St. Joseph River**	**St. Joseph Harbor**	28,000	2.3	290,000	250,000	11%
34A	St. Joseph River	NA; Riley Dam	6,100	4.5	31,000	46,000	13%
35	Stoney Creek	NA	6,600	20.8	5,200	15,000	44%
36	Thunder Bay River	Alpena Harbor	11,000	3.6	87,000	87,000	13%
37	White River	White Lake Harbor	5,600	4.7	50,000	41,000	14%
38	Willow Creek	NA	1,000	3.9	4,000	12,000	8%
39	Au Train	NA	1,900	6.7	8,000	14,000	14%
40	Black River (Gogebic)	Black River Harbor	9,900	14.9	26,000	26,000	37%
41	Carp River	NA	2,600	6.0	7,400	19,000	14%
42	Cedar River	Cedar River Harbor	1,700	1.7	18,000	36,000	5%
43	Chocolay River	NA	4,300	10.8	22,000	18,000	24%
44	Days River	NA	600	3.9	3,500	8,900	7%
45	Dead River	Presque Isle Harbor	4,100	9.7	27,000	19,000	22%
46	Escanaba River	NA	7,100	3.0	89,000	70,000	10%
47	Ford River	NA	4,300	3.6	39,000	42,000	10%
48	Falls River	NA	2,300	19.9	7,200	6,900	33%
49	**Manistique River**	**Manistique Harbor**	8,500	2.2	110,000	100,000	8%
50	**Menominee River**	**Menominee Harbor**	23,000	2.2	290,000	220,000	11%
51	Montreal River	NA	6,700	9.6	26,000	28,000	24%
52	Munuscong River	NA	5,700	12.2	9,100	20,000	28%
53	**Ontonagon River**	**Ontonagon Harbor**	24,000	6.8	140,000	97,000	25%
54	Pine River	NA	4,000	5.6	10,000	28,000	14%
55	Portage River	Keweenaw Waterway	11,000	4.4	97,000	75,000	15%
56	Presque Isle River	NA	7,000	7.5	50,000	34,000	20%
57	Rapid River	NA	1,900	5.4	6,600	16,000	12%
58	Sturgeon River	NA	1,600	2.9	10,000	23,000	7%
60	Tahquamenon River	NA	4,600	2.2	30,000	64,000	7%
61	Two Hearted River	NA	500	0.9	14,000	22,000	2%
62	Waiska River	NA	2,200	5.7	5,400	17,000	13%
63	Whitefish River	NA	3,100	3.9	22,000	31,000	10%

CHAPTER 5 CONCLUSIONS

The purpose of this research was to determine if an empirical equation can be developed as a statistical model to describe the relationship between bedload watershed sediment delivery to the river outlet and significant watershed characteristics. This research involved regression analysis to identify key variables characteristic of the fluvial system and watershed to predict watershed sediment delivery of bedload to the river outlet of 60 Michigan rivers and five sub-watersheds.

The identification of predictor variables was conducted by evaluating the dependent variable which consisted of 17 watershed sediment delivery estimates based on 12 watershed sediment delivery estimates developed from USACE-Detroit District dredging data and five watersheds sediment delivery estimates based ^{137}Cs and ^{210}Pb radiometric dating. Eighteen independent variables were considered in the regression analysis, they include:

- Watershed Area (square kilometers)
- Percent of the Watershed Covered in Natural Surface Water Bodies
- Percent of the Watershed Covered in Reservoirs Located on Rivers
- Percent of Watershed Covered in Aquatic Wetlands Use
- Percent of Watershed Covered in Upland Wetlands
- Mean Annual River Flow (cubic meters/second)
- 1.5-year Recurrence Interval Flow (cubic meters/second)
- 2.0-year Recurrence Interval Flow (cubic meters/second)
- 5-year Recurrence Interval Flow (cubic meters/second)

- Watershed Curve Number (unitless)
- River Slope (meter/meter)
- Relief: Net Watershed Elevation Difference Based on the Maximum Watershed Elevation (meter)
- Relief: Net Watershed Elevation Difference Based on the Average Watershed Elevation (meter)
- Mean Basin Temperature (°C)
- Population Density (people/square kilometer)
- Percent of Watershed Covered in Natural Surface Water Bodies and Aquatic Wetlands
- Percent of Watershed Covered in Total Wetlands (Upland and Aquatic)
- Percent of Watershed Covered in Natural Surface Water Bodies and Manmade Reservoirs

Eighty-seven regressions were completed using both non-transformed and natural log transformed dependent and independent variables. Based on the natural log normal regression analyses of dependent and independent variables, Regression 3-36 provided the best balance of significance (0.014), R^2 (0.538), and relative low P-values for the following three predictor variables (see Table 42):

- 1.5 year recurrence interval flow (P-value: 0.002),
- percent of watershed covered in upland and aquatic wetlands (P-value: 0.149),
- percent of the watershed covered in manmade reservoirs (P-value: 0.387).

The Regression 3-36 bedload watershed sediment delivery equation is presented as follows:

$$Q_b = EXP(3.901) * EXP(-0.694)^{LN(W)} * EXP(0.150)^{LN(R)} * EXP(0.858)^{LN(Q_{1.5})}$$

where,

Q_b – Bedload Watershed Sediment Delivery (tonnes/year)

$Q_{1.5}$ – 1.5-year Recurrence Interval Flow at the River Outlet (cubic meters/second)

W - Percent of the Watershed Covered in Both Upland and Aquatic Wetlands (EGLE, 1978 MIRIS Land Use)

R - Percent of the Watershed Covered in Reservoirs (EGLE, 2020 updated dam inventory)

Review of the residual plots reveals that the three independent variables (1.5-year recurrence interval flow; percentage of the watershed covered in wetlands, aquatic and upland; and, total reservoir pool surface area) are distributed randomly about zero. In addition, the normal probability plot of regression 3-36 is linear.

Review of the predicted watershed sediment delivery estimates using Regression 3-36 in comparison to the estimated watershed sediment delivery estimates based on USACE dredging data and radiometric dating are within +/- 70% for 13 of the 17 watersheds. The largest differences (based on total metric tonnes) between the predicted sediment delivery using regression 3-36 and the watershed sediment delivery estimates based on either USACE dredging data or radiometric dating were noted for the Saginaw River (32), Grand River (14), St. Joseph River (34) and the Menominee River (50).

Of the four rivers, the Saginaw River (32) has the largest difference between predicted sediment delivery using Regression 3-36 (65,000 metric tonnes/year) and the watershed sediment delivery estimate based on USACE dredging data (190,000 metric tonnes/year). This difference may be attributed in part to differences in the USACE's estimate of the separation of fluvial and littoral sediment at the river outlet; the percentage of maintenance dredging attributed to littoral sediment transport could be much larger than 10% that was utilized in this research. With respect to the Grand River (14) and St. Joseph River (34), the underprediction of watershed sediment delivery using Regression 3-36 is likely due to the impact of large depositional areas located in close proximity to the river outlet. With respect to the Menominee River (50), the difference in the predicted annual watershed sediment delivery using regression 3-36 (23,000 metric tonnes per year) in comparison to the 7,300 metric tonnes per year based on USACE dredging data is likely due to the reservoir trapping efficiency of a large dam (Park Mill Dam, MI00531) that is located approximately six kilometers from the river outlet.

The percentage of bedload predicted using Regression 3-36 in comparison to the estimated total watershed sediment delivery estimated using the USACE (2010a) Great Lakes Regional Trend Line is within the reported range of other published studies. The mean and median values of the percentage of bedload to total watershed sediment delivery for the 60 watersheds and five sub-watersheds included in this research are

19.4% and 13.3% and are within the range of 5-20% reported by USGS (2011) and similar to 10% that has been reported by others (MacArthur RC et al, 2008; USACE, 1995).

Of the watersheds where USACE 516e studies were completed, the USACE-Detroit District completed a bathymetric analysis at the Ontonagon Harbor (Ontonagon River, 53) of several pairs of pre- and post-dredging events to estimate the littoral and fluvial components of the sediment removed during USACE maintenance dredging of the federal navigation channel (USACE, 2010a). This method also provides a good estimate of bedload sediment delivery to the river outlet of Ontonagon Harbor. As shown in Table 45, the estimated watershed sediment delivery using USACE dredging data is 30,000 metric tonnes per year and is in close agreement with the predicted bedload sediment delivery using Regression 3-36 of 24,000 metric tonnes per year.

This research was successful in demonstrating that bedload watershed sediment delivery can be estimated from characteristics of the river and watershed. Areas of future study to improve Regression 3-36 are discussed in Chapter 6.

CHAPTER 6 AREAS OF FURTHER RESERACH

Based on this research, several suggestions follow to continue to improve the predictive capabilities of the bedload watershed sediment delivery described in Regression 3-36, these include:

Increase the Number of Estimates of Watershed Sediment Delivery By Conducting Radiometric Dating of Sediment Cores at RESSED Reservoirs Located in Michigan. The regression analysis completed during this research was based 17 estimates of watershed sediment delivery, 12 using USACE dredging data and five using radiometric dating. Increasing the number of data sets could be accomplished by conducting radiometric dating and bathymetric surveys of RESSED reservoirs located in Michigan (Table 48 and Figure 47), in addition to completing the analysis of fluvial and watershed characteristics as presented in this research.

Of the 21 RESSED reservoirs located in Michigan, radiometric dating has already completed at one reservoir (Ford Dam, 15A; RESSED 22-029; WSU, 2017), and one reservoir is located in the Lake Area of the Pine River (10L; RESSED 23-001) and not within one of the 60 watersheds included in this research. Eighteen of the 19 remaining RESSED reservoirs are located in southeast Michigan within the Huron River (16), River Raisin (29) and Rouge River (31) watersheds and one reservoir is located in the Manistee River (20) watershed (see Table 48). Note that watershed sediment delivery estimates that were completed at the RESSED reservoirs located in Michigan were incorporated into the USACE (2010) Great Lakes Regional Trend Line. Increasing the number of comparisons from 17 may increase both the significance and R^2 of the revised bedload sediment delivery equation.

Incorporate Additional Harbors Where the USACE Has Separated Outer Harbor and Inner Harbor Dredging Projects. Beginning in 1999 and culminating in 2014, a period of below average Great Lakes water levels (USACE, 2021d) resulted in increased maintenance dredging of commercial, State and Federally maintained Harbor inlets and navigation channels which resulted in an increased focus on the beneficial re-use of dredged sediment for beach replenishment and other coastal projects (GLC, 2001; USEPA and USACE, 2007). During 2018, the State of Michigan revised testing requirements for dredged sediment to facilitate beneficial reuse of sediment that contains greater than 90% sand (EGLE, 2018). Going forward, the USACE-Detroit District plans to expand the separation of Outer and Inner Harbor maintenance dredging projects to facilitate beneficial reuse of dredged sediment (USACE, 2019c). If this occurs, it is possible that additional USACE Harbors and navigation channels with high estimated littoral components of dredged sediment could be included in a future update of this research, especially those located on Lake Michigan and Lake Superior.

Incorporate Additional Pre-Dredge Sediment Quality Data to Improve the Conversion of the Volume of Dredged Sediment to Metric Tonnes. The USACE-Detroit District typically conducts 5-10 pre-dredge sediment quality assessments at USACE navigation channels and harbors each year. This research would involve continued update the physical characteristics of the fluvial dredged sediment to improve the conversion of the volume of dredged sediment to metric tonnes.

Table 48. RESSED Reservoirs Located in Michigan Watersheds

Watershed Number	Dam ID Number	RESSED ID	Latitude	Longitude	Watershed	Year Built	Date of RESSED Survey	Elapsed Time (years)	Original Capacity (acre-feet)	Percent Storage Lost
15	MI00735	22-024	42.33500	-83.82500	Huron River	1927	1969	42	76.7	37.55%
15	MI00557	22-028	42.21440	-83.44080	Huron River	1929	1969	40	19945	9.85%
15	MI00560	22-030	42.30830	-83.75430	Huron River	1915	1969	54	3150	17.43%
20	MI00229	22-002	44.21667	-85.90000	Manistee River	1912	1953	41	640	95.78%
29	MI00128	22-016	42.15500	-84.18333	River Raisin	1939	1951	12.3	248	25.00%
29	MI00328	22-017	42.17679	-84.09297	River Raisin	1927	1969	42	258.1	44.25%
29	MI00121	22-018	42.10938	-84.24561	River Raisin	1948	1969	21	249.3	25.27%
29	MI00391	22-019	42.14960	-84.02360	River Raisin	1945	1969	24	288.9	10.18%
29	MI00392	22-020	42.10000	-84.08667	River Raisin	1869	1969	100	1551	25.27%
29	MI00485	22-022	42.16333	-83.78833	River Raisin	1937	1969	32	240.1	46.02%
29	MI00715	22-023	42.15010	-84.03860	River Raisin	1906	1969	63	21.33	48.90%
29	MI04016	22-027	42.04997	-84.11175	River Raisin	1827	1969	142	227.8	58.43%
29	MI00593	22-031	42.01333	-83.94222	River Raisin	1850	1969	119	677	50.37%
29	MI00709	22-032	41.98667	-84.17667	River Raisin	1962	1969	7	121.3	4.37%
29	MI00594	22-034	41.91053	-84.03753	River Raisin	1942	1969	27	1000	14.90%
31	MI00397	22-021	42.39276	-83.46703	Rouge River	1869	1969	100	225	24.44%
31	-	22-025	42.53041	-83.30543	Rouge River	1833	1969	136	97.8	86.61%
31	MI00399	22-026	42.41500	-83.46833	Rouge River	1869	1969	100	173	41.62%
31	MI00396	22-033	42.36670	-83.41130	Rouge River	1933	1969	36	667.8	15.71%

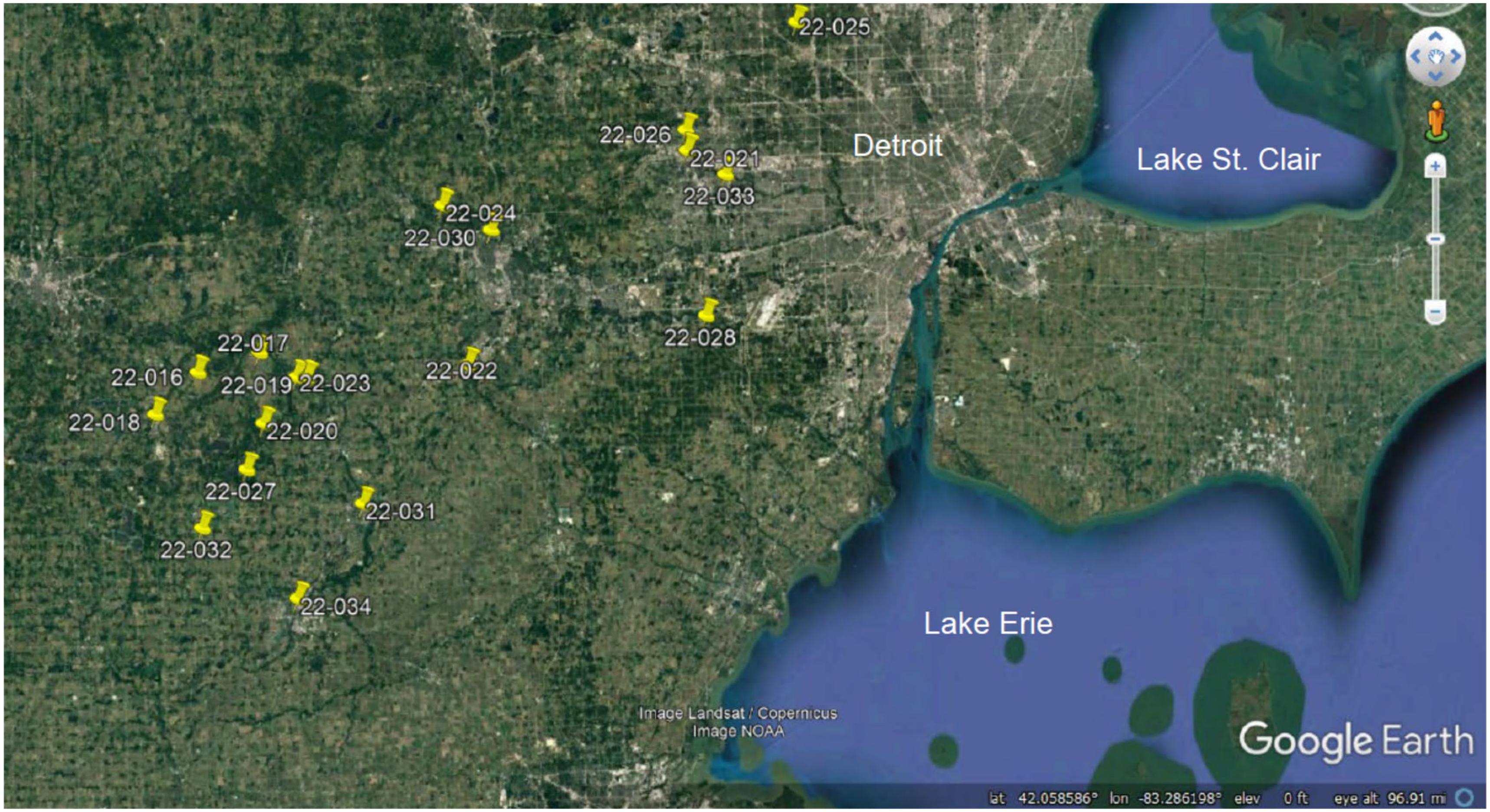


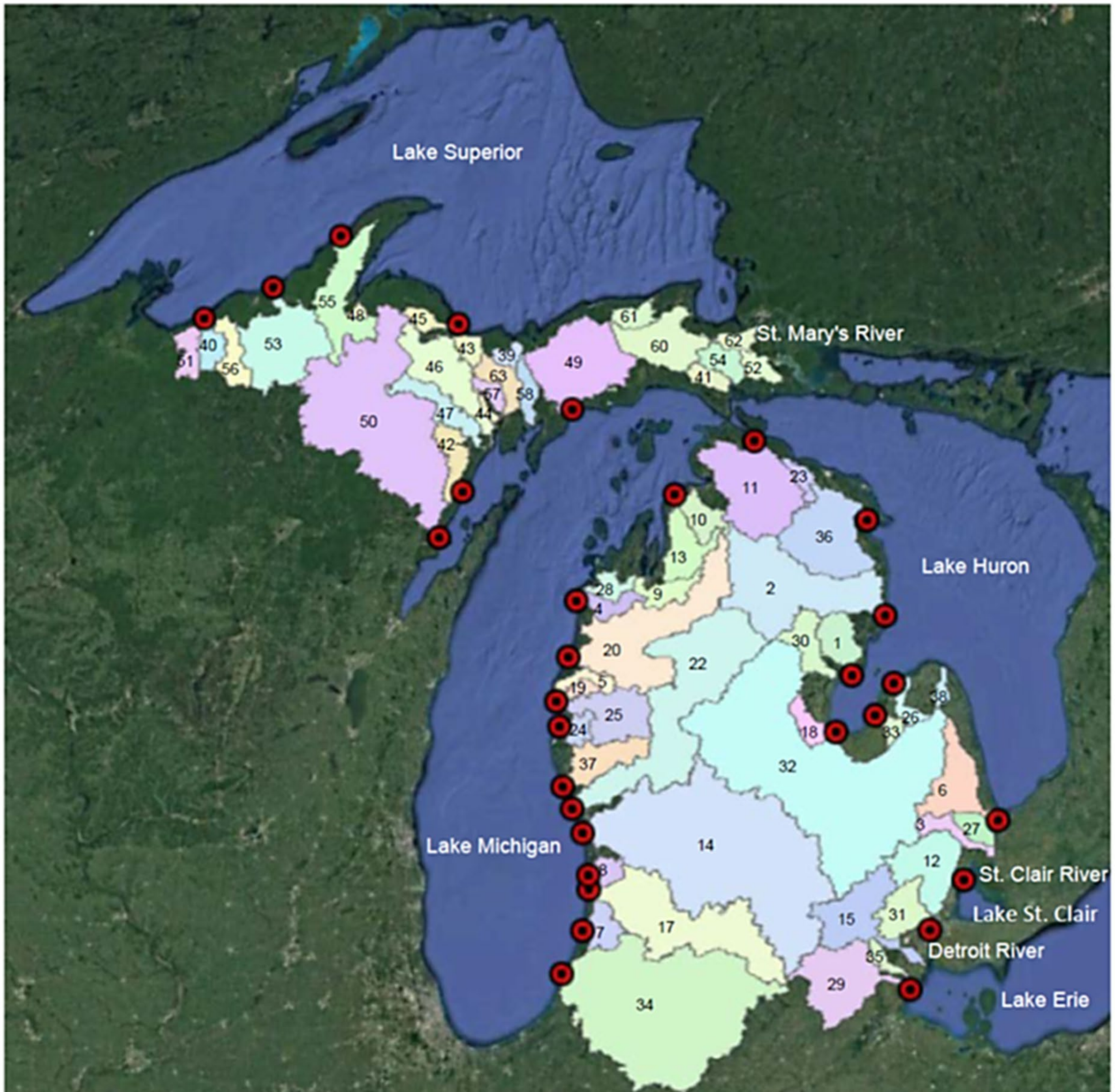
Figure 47. RESSED Reservoirs Located in Southeast Michigan (Google Earth Pro, 2021)

Conduct Additional Regression Analyses to Further Evaluate the 2011 NLCD Land Use Data as Predictor Variables of Bedload Watershed Sediment Delivery. As discussed in this research, the percentage of the watershed covered by the following 2011 NLCD land use categories were not predictive of bedload sediment delivery at the river outlet, these include: water, developed land, barren land, shrubland, grassland, agriculture and wetlands. Based on analysis of the 2011 NLCD watershed land use data, the percentage of watershed covered in wetlands was much greater than the wetland areas identified in the MIRIS Land Use/Cover Polygons (MDNR, 1978). The difference in the percentage of watershed covered by aquatic and upland wetlands is likely due differences in how the wetland area was identified and categorized. The 2011 NLCD relies on pixel analysis of aerial photographs, and the resolution is lower than the MIRIS land use resolution that is based on a raster file (EGLE, 2020).

Because, the MIRIS Land Use/Cover Polygons (MDNR, 1978) were used to calculate the watershed Curve Numbers used in this research and because this data set served as the baseline wetland inventory for the State of Michigan, the MIRIS data set was used to calculate the percentage of the watershed covered in upland wetlands, aquatic wetlands, and surface water for each of the 60 watershed and five sub-watersheds included in this research. Further, there were significant differences between the percent of the watershed covered in upland and aquatic wetlands based on comparison of MIRIS land use (MDNR, 1978) and the 2011 National Land Cover Database. Given the ease of access of obtaining the NLCD land use data, especially in States other than Michigan, further evaluation of the 2011 NLCD land use data could be warranted to develop an equation that could be used in other Great Lakes states.

Expand the Assessment of the Impact of Reservoir Trapping Efficiency on Fluvial Sediment Delivery to the River Outlet. This research incorporated the use of total reservoir pool surface area to account for the impact of reservoirs on fluvial sediment delivery to the river outlet. Of the 1,378 dams located in fluvial systems, the EGLE (2020) dam inventory contained information to calculate approximate capacity/inflows to estimate reservoir trapping efficiency for approximately 58% (802) of the dams. Given the effectiveness of manmade reservoirs at retaining fluvial sediment, additional research could be completed to conduct an updated assessment of reservoir trapping efficiency utilizing the mean annual river flows and watershed mapping tools present in the USEPA (2021) Watershed Assessment, Tracking & Environmental Results System (WATERS) that is now available in Michigan. In addition, research could be conducted to re-evaluate the watershed area of each reservoir and to develop a basin-wide trapping efficiency methodology similar to the method proposed by Vorosmarty et al (2003).

APPENDIX A. MICHIGAN WATERSHED NUMBER REFERENCE MAP

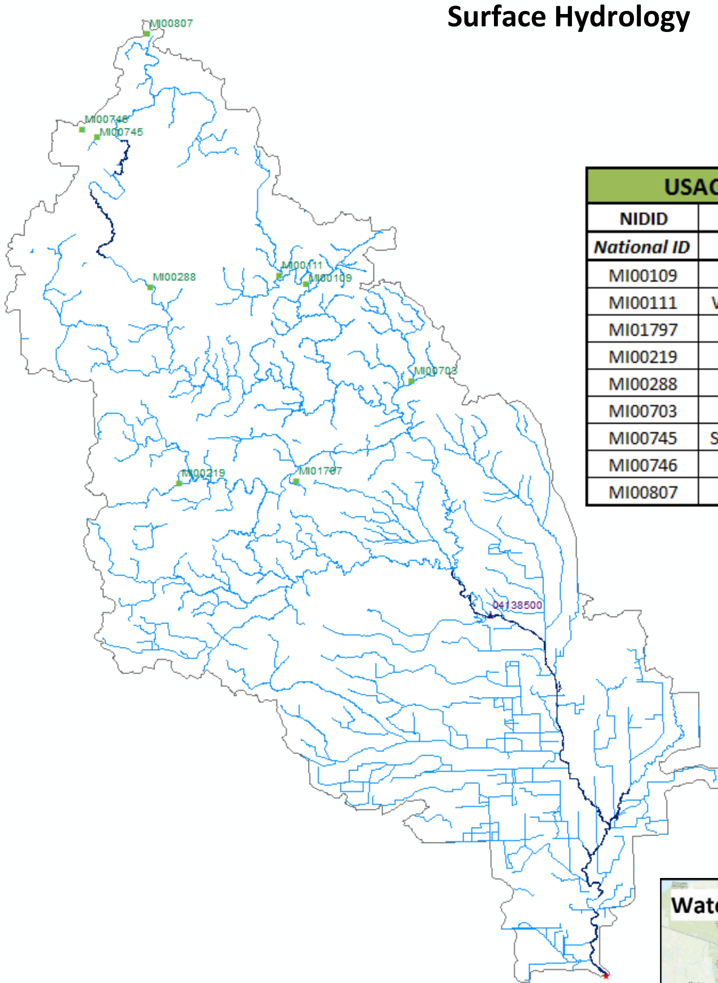


Watershed Reference Number	River	U.S. Army Corps of Engineers Harbor or Navigation Channel
1	Au Gres River	Point Lookout Harbor
2	Au Sable River	Au Sable Harbor
3	Belle River	NA
4	Betsie River	Frankfort Harbor
5	Big Sable	NA
6	Black River (East)	Black River
7	Black River (West)	South Haven Harbor
8	Macatawa River	Holland Harbor
9	Boardman	NA
10	Pine River	Charlevoix Harbor
11	Cheboygan River	Cheboygan Harbor
12	Clinton River	Clinton River
13	Elk River	NA
14	Grand River	Grand Haven Harbor
15	Huron River	NA
17	Kalamazoo River	Saugatuch Harbor
18	Kawkawlin River	NA
19	Lincoln River	NA
20	Manistee River	Manistee Harbor
22	Muskegon River	Muskegon Harbor
23	Oqueoc River	NA
24	Pentwater River	Pentwater Harbor
25	Pere Marquette River	Ludington Harbor
26	Pigeon River	Caseville Harbor
27	Pine River	NA
28	Platte River	NA
29	River Raisin	Monroe Harbor
30	Rifle River	NA
31	Rouge River	Rouge River
32	Saginaw River	Saginaw River
33	Sebewaing River	Sebewaing River
34	St. Joseph River	St. Joseph Harbor
35	Stoney Creek	NA
36	Thunder Bay River	Alpena Harbor
37	White River	White Lake Harbor
38	Willow Creek	NA
39	Au Train	NA
40	Black River (Gogebic)	Black River Harbor
41	Carp River	NA
42	Cedar River	Cedar River Harbor
43	Chocolay River	NA
44	Days River	NA
45	Dead River	Presque Isle Harbor
46	Escanaba River	NA
47	Ford River	NA
48	Falls River	NA
49	Manistique River	Manistique Harbor
50	Menominee River	Menominee Harbor
51	Montreal River	NA
52	Munuscong River	NA
53	Ontonagon River	Ontonagon Harbor
54	Pine River	NA
55	Portage River	Keweenaw Waterway
56	Presque Isle River	NA
57	Rapid River	NA
58	Sturgeon River	NA
60	Tahquamenon River	NA
61	Two Hearted River	NA
62	Waiska River	NA
63	Whitefish River	NA

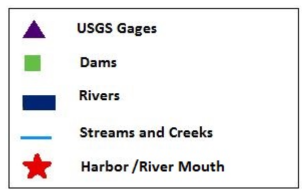
Notes: [red circle symbol] - USACE Maintained Harbor or Navigation Channel; NA – not applicable. Google Earth Image: Data SIO/NOAA/US Navy; NOAA 2018, Image Landsat/Copernicus.

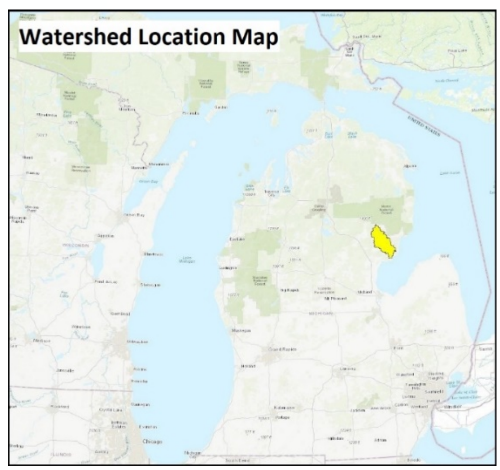
APPENDIX B. AU GRES RIVER WATERSHED (1)

Surface Hydrology



USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00109	Barnes Dam	-83.84167	44.31333
MI00111	Webber Ranch Dam	-83.85667	44.31667
MI01797	Bear Creek Dam	-83.85000	44.23278
MI00219	Bay Land Dam	-83.91666	44.23333
MI00288	Stylus Lake Dam	-83.93000	44.31333
MI00703	Latter Creek Dam	-83.78346	44.27249
MI00745	Schumacher Dam #2	-83.95834	44.37500
MI00746	Kelly Lake Dam	-83.96667	44.37833
MI00807	Mandeville Dam	-83.92805	44.41694



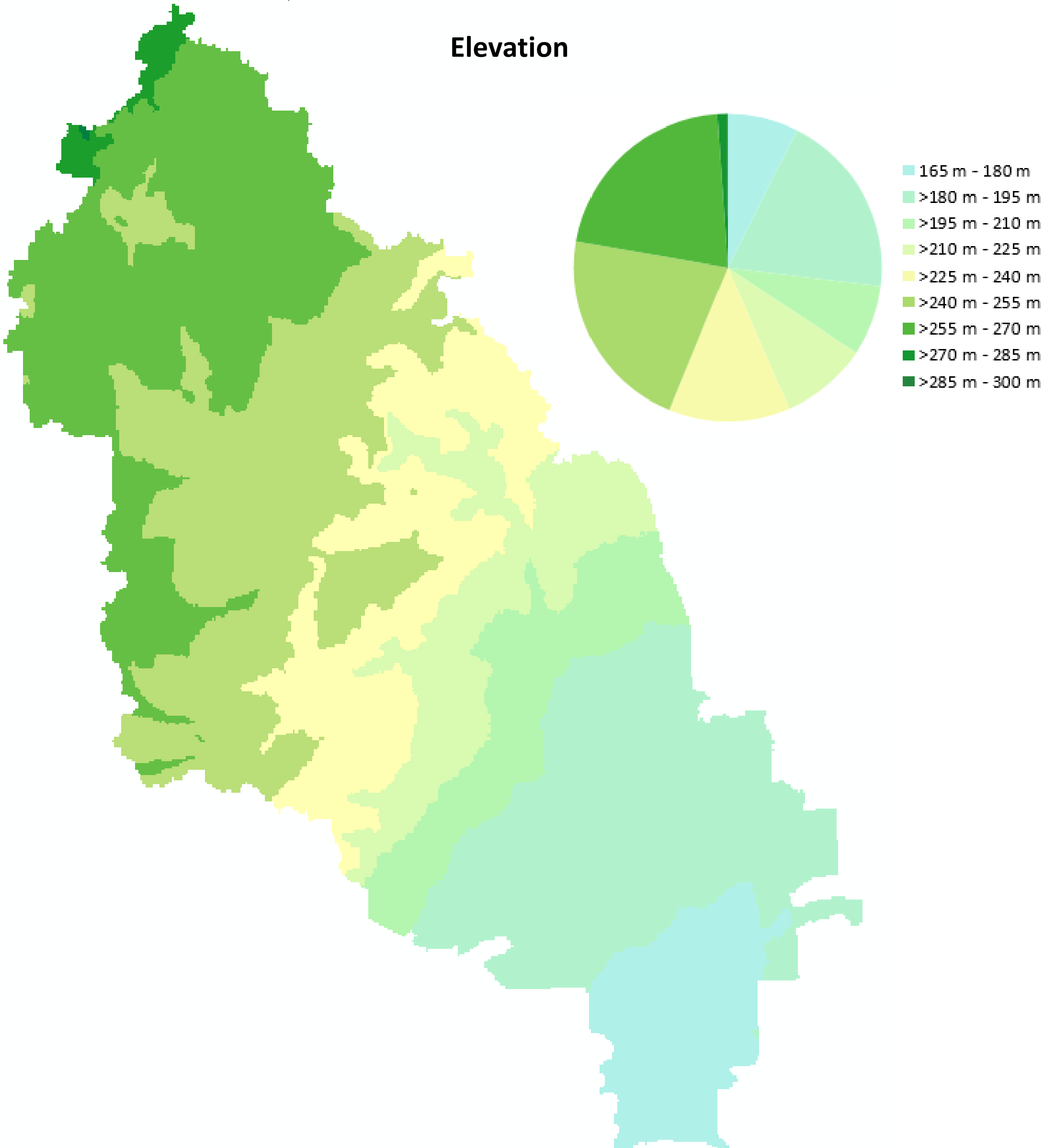


USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4138500	AU GRES RIVER AT COX ROAD NEAR NATIONAL CITY, MI	-83.742485	44.17613	
Number of Active USGS Stream Gage's in Drainage Area (2009)				**0**

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

1, AU GRES RIVER WATERSHED

Elevation



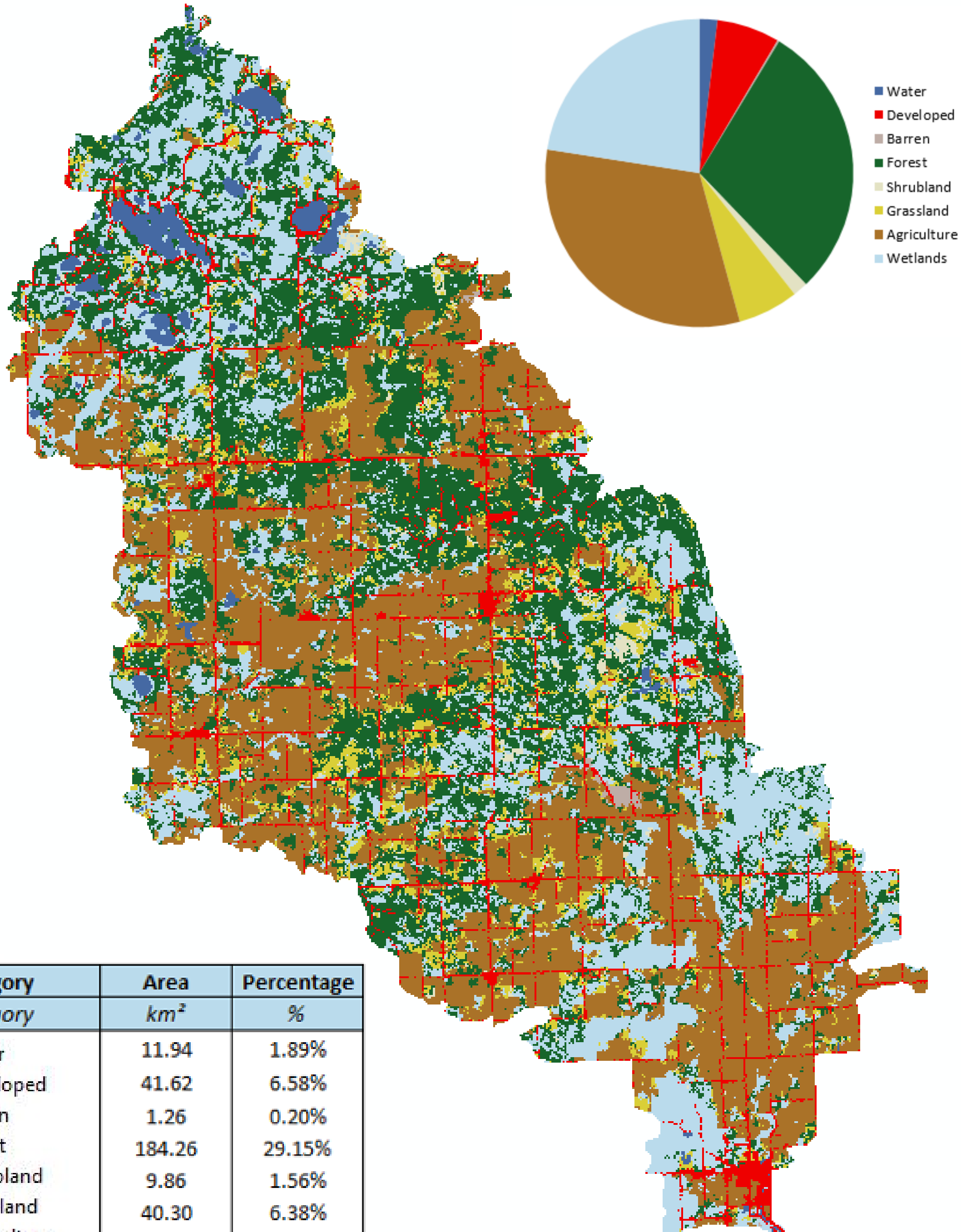
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	46.91	7.42%
>180 m - 195 m	123.29	19.51%
>195 m - 210 m	46.68	7.39%
>210 m - 225 m	57.68	9.13%
>225 m - 240 m	80.74	12.78%
>240 m - 255 m	135.94	21.51%
>255 m - 270 m	133.90	21.19%
>270 m - 285 m	6.71	1.06%
>285 m - 300 m	0.18	0.03%
Size of Drainage Area	632.03	100.00%

Au Gres Watershed		
Elevation Statistics		
Size of Drainage Area	**632.03**	***km²***
Maximum	289.00	*m*
Minimum	177.00	*m*
Average	224.61	*m*
Standard Deviation	29.76	*m*

All Elevation Measurements with Respect to North American Datum 1983

1, AU GRES RIVER WATERSHED

Land Use



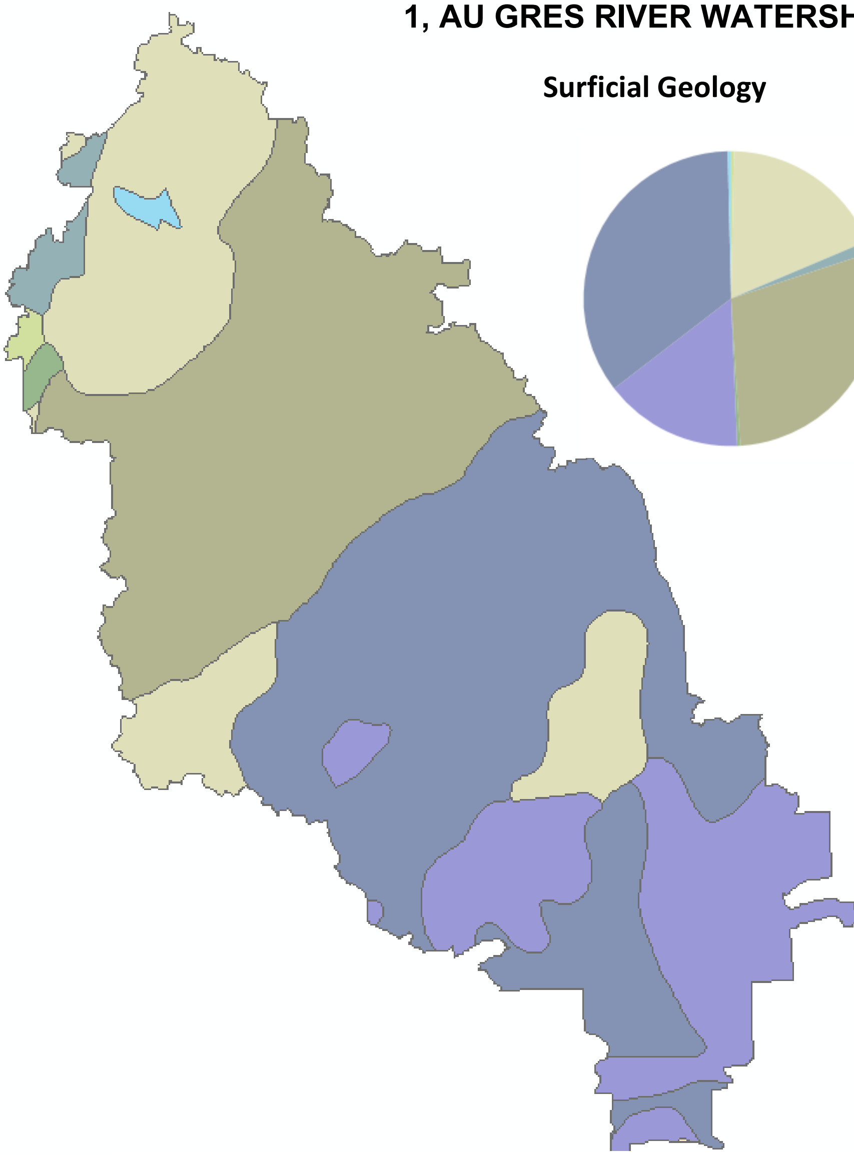
Category	Area	Percentage
Category	*km²*	*%*
Water	11.94	1.89%
Developed	41.62	6.58%
Barren	1.26	0.20%
Forest	184.26	29.15%
Shrubland	9.86	1.56%
Grassland	40.30	6.38%
Agriculture	200.31	31.69%
Wetlands	142.48	22.54%
Total	632.03	100.00%

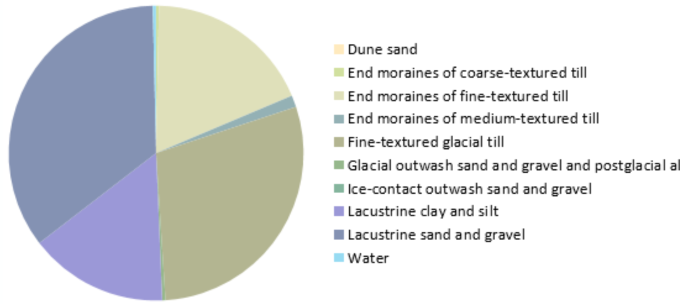
EGLE Runoff Curve Number
75.0

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

1, AU GRES RIVER WATERSHED

Surficial Geology



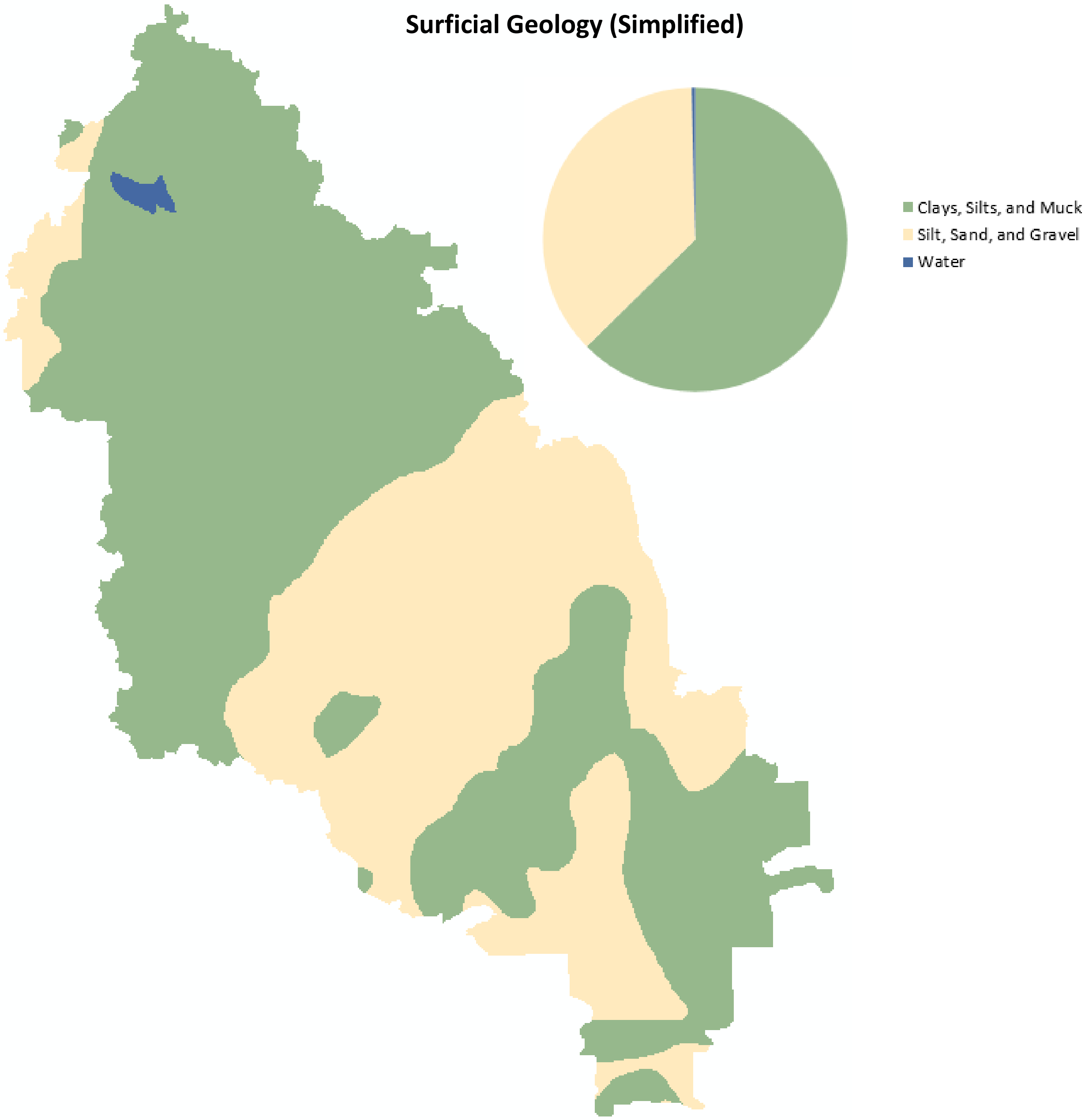


Category	Area	Percentage
Category	*km²*	*%*
Dune sand	0.03	0.01%
End moraines of coarse-textured till	1.97	0.31%
End moraines of fine-textured till	115.75	18.31%
End moraines of medium-textured till	8.10	1.28%
Fine-textured glacial till	183.77	29.08%
Glacial outwash sand and gravel and postglacial alluvium	2.23	0.35%
Ice-contact outwash sand and gravel	0.03	0.00%
Lacustrine clay and silt	96.17	15.22%
Lacustrine sand and gravel	221.70	35.08%
Water	2.28	0.36%
Total Watershed Area	632.03	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

1, AU GRES RIVER WATERSHED

Surficial Geology (Simplified)



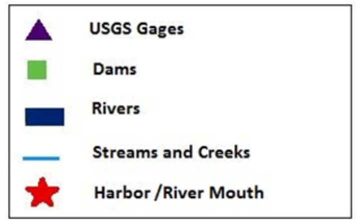
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	395.70	62.61%
Silt, Sand, and Gravel	234.06	37.03%
Water	2.28	0.36%
Total Watershed Area	632.03	100.00%

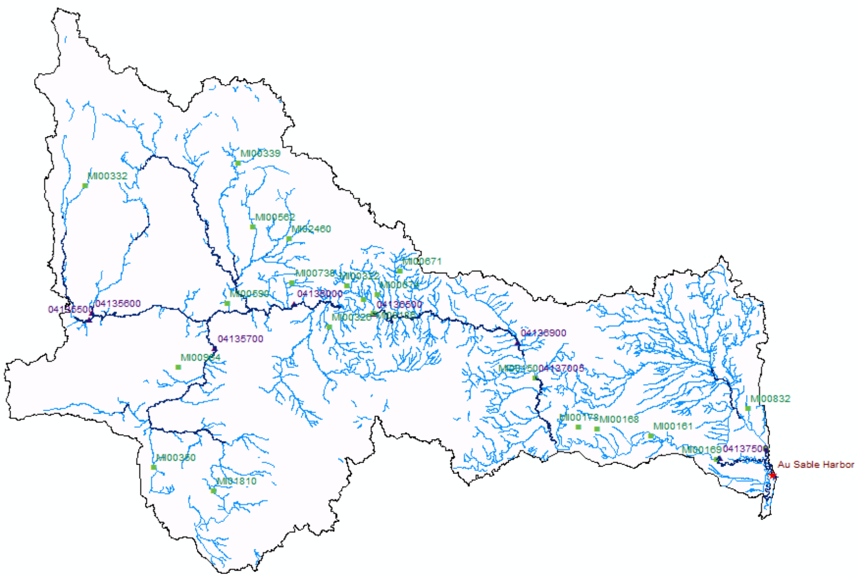
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX C. AU SABLE RIVER WATERSHED (2)

Surface Hydrology

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4135500	AU SABLE RIVER AT GRAYLING, MI	*-84.712529*	*44.659737*	
4135600	EAST BRANCH AU SABLE RIVER AT GRAYLING, MI	-84.705584	44.668904	
4135700	SOUTH BRANCH AU SABLE RIVER NEAR LUZERNE, MI	-84.455575	44.614738	yes
4136000	AU SABLE RIVER NEAR RED OAK, MI	-84.292515	44.676959	yes
4136500	AU SABLE RIVER AT MIO, MI	-84.131117	44.660014	yes
4136900	AU SABLE RIVER NEAR MC KINLEY, MI	-83.837778	44.612778	yes
4137005	AU SABLE RIVER NEAR CURTISVILLE, MI	-83.802764	44.560847	yes
4137500	AU SABLE RIVER NEAR AU SABLE, MI	-83.433861	44.436404	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				6



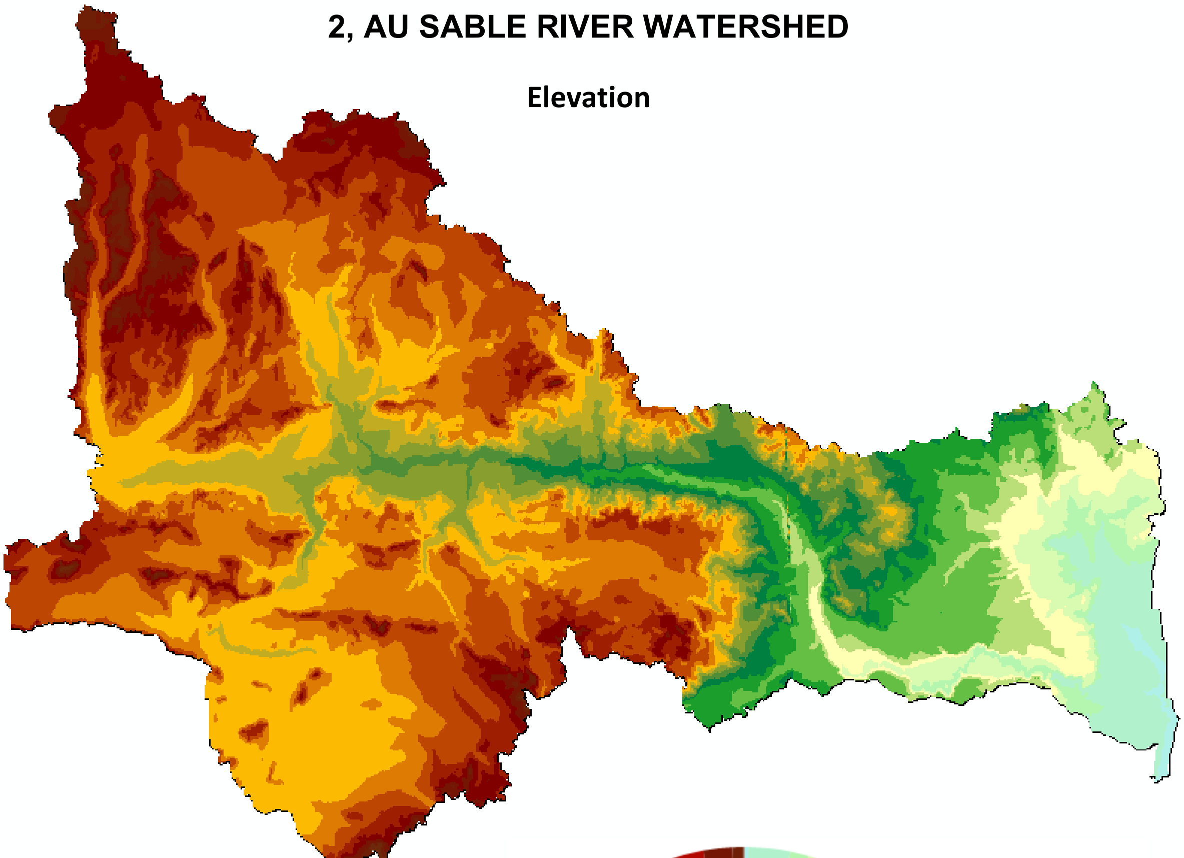


USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00169	Foote	-83.44000	44.43500
MI00150	Alcona	-83.80420	44.56190
MI00186	Mio	-84.13170	44.66090
MI00178	Loud	-83.72000	44.48830
MI00161	Cooke	-83.57170	44.47250
MI00168	Five Channels	-83.68170	44.48500
MI01810	Lake St Helen Lake Level Control	-84.46333	44.40833
MI02460	Upper Boron Dam	-84.30000	44.77333
MI00318	Bills Dam	-84.15000	44.68167
MI00322	Davis Dam	-84.18333	44.70167
MI00326	Dumka Dam	-84.22166	44.64333
MI00332	Big Bradford Lake Level Control Structure	-84.715	44.855
MI00339	7th Spectacle Lake Dam	-84.40166	44.885
MI00350	Robinson Creek Flooding Dam	-84.585	44.44333
MI00562	Big Creek Dam	-84.37334	44.79167
MI00590	Conners Marsh Dam	-84.42869	44.67985
MI00671	Okie Kauffman Dam	-84.075	44.72167
MI00674	Blamer Dam	-84.12167	44.68833
MI00737	Van Etten Lake Dam	-83.34	44.4485
MI00738	Glen Lake Dam	-84.295	44.70833
MI00832	Simpson Dam	-83.37291	44.50834
MI00964	Forest Dunes Lake Dam	-84.53167	44.58833

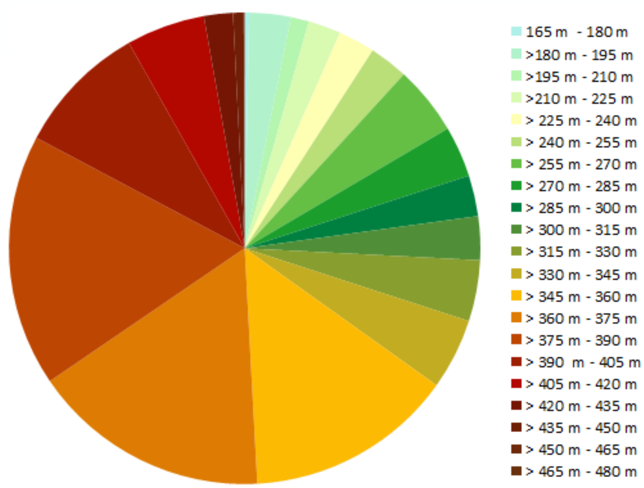
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Stream Gages includes only active gages and gages with 20+ years of discharge records since 1950

2, AU SABLE RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	16.56	0.31%
>180 m - 195 m	150.56	2.84%
>195 m - 210 m	65.51	1.23%
>210 m - 225 m	119.21	2.25%
>225 m - 240 m	133.68	2.52%
>240 m - 255 m	140.87	2.65%
>255 m - 270 m	250.81	4.73%
> 270 m - 285 m	185.52	3.50%
>285 m - 300 m	148.34	2.79%
>300 m - 315 m	158.64	2.99%
>315 m - 330 m	222.22	4.19%
>330 m - 345 m	258.61	4.87%
>345 m - 360 m	758.26	14.29%
>360 m - 375 m	866.54	16.33%
>375 m - 390 m	917.57	17.29%
>390 m - 405 m	481.23	9.07%
>405 m - 420 m	286.82	5.40%
>420 m - 435 m	105.09	1.98%
>435 m - 450 m	38.75	0.73%
>450 m - 465 m	3.10	0.06%
>465 m - 480 m	0.06	0.00%
Size of Drainage Area	5307.95	100.00%

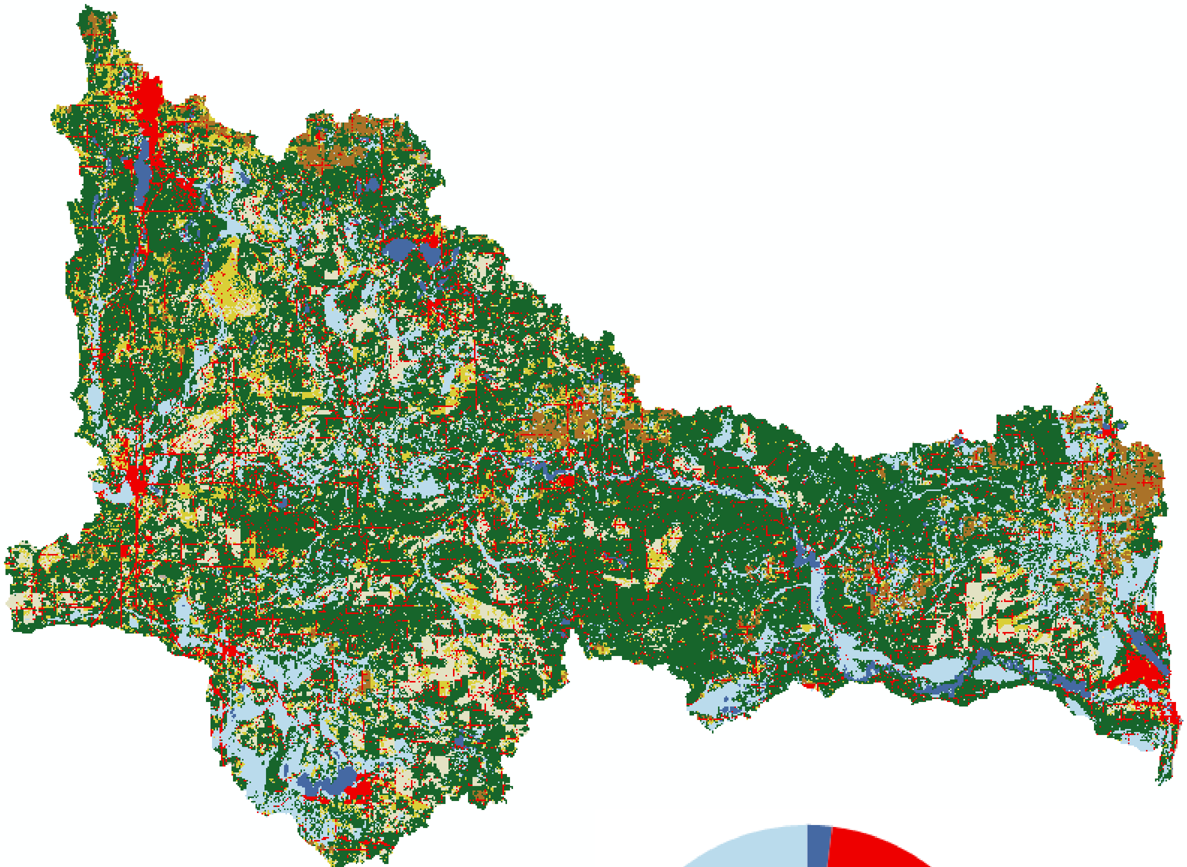


Au Sable Watershed		
Elevation Statistics		
Size of Drainage Area	5307.95	*km²*
Maximum	471.00	*m*
Minimum	176.00	*m*
Average	341.08	*m*
Standard Deviation	60.35	*m*

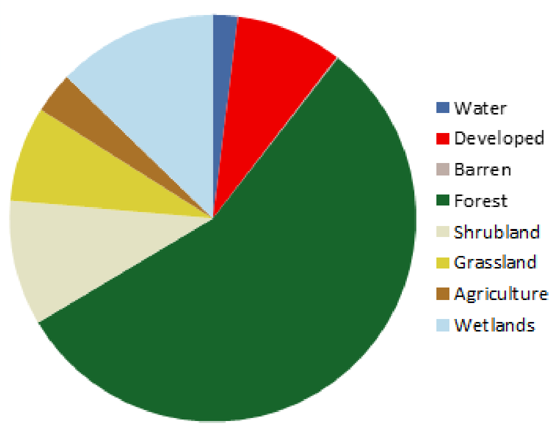
All Elevation Measurements with Respect to North American Datum 1983

2, AU SABLE RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	105.18	1.98%
Developed	449.86	8.48%
Barren	5.38	0.10%
Forest	2966.66	55.89%
Shrubland	529.03	9.97%
Grassland	401.00	7.55%
Agriculture	173.89	3.28%
Wetlands	676.96	12.75%
Total	5307.95	100.00%

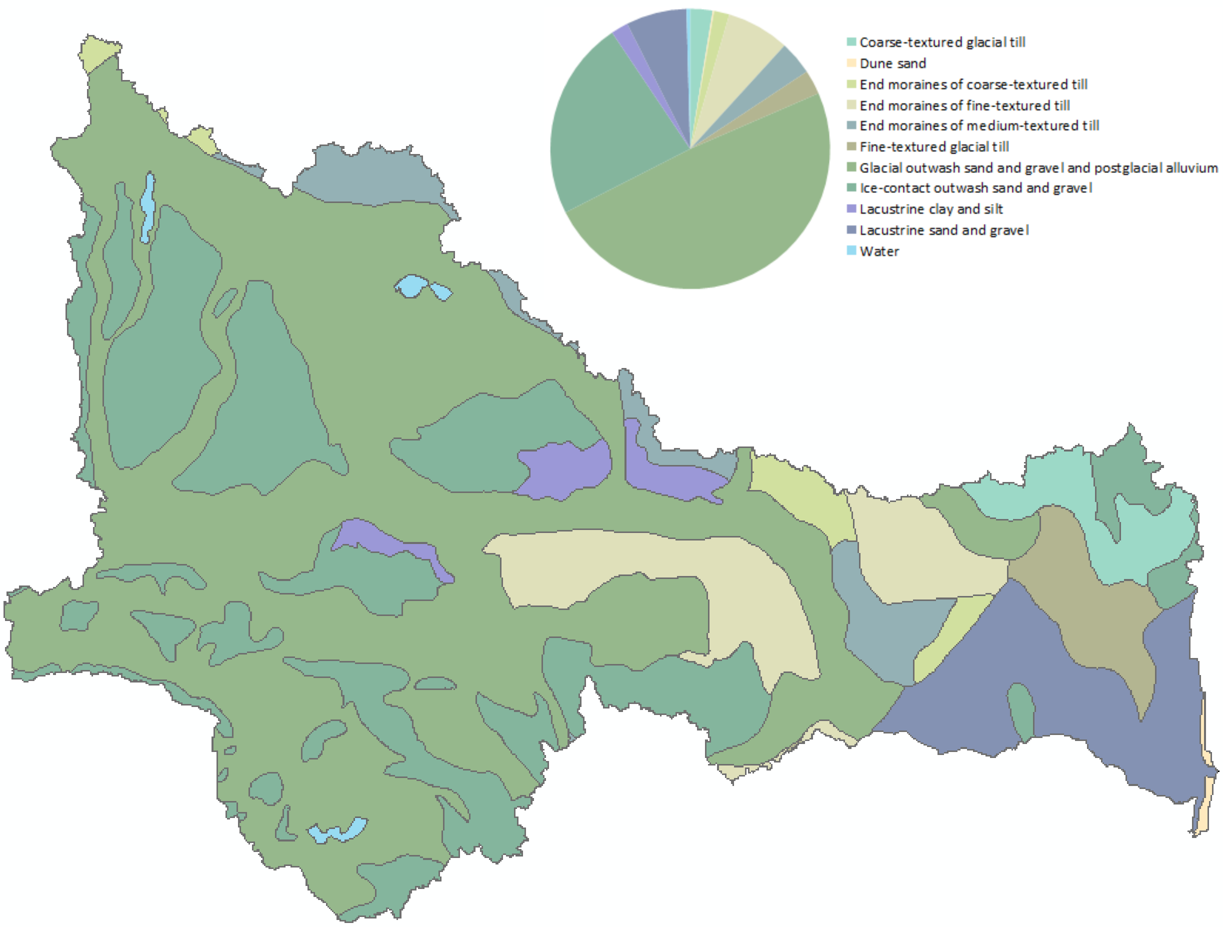


EGLE Runoff Curve Number
55.9

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

2, AU SABLE RIVER WATERSHED

Surficial Geology

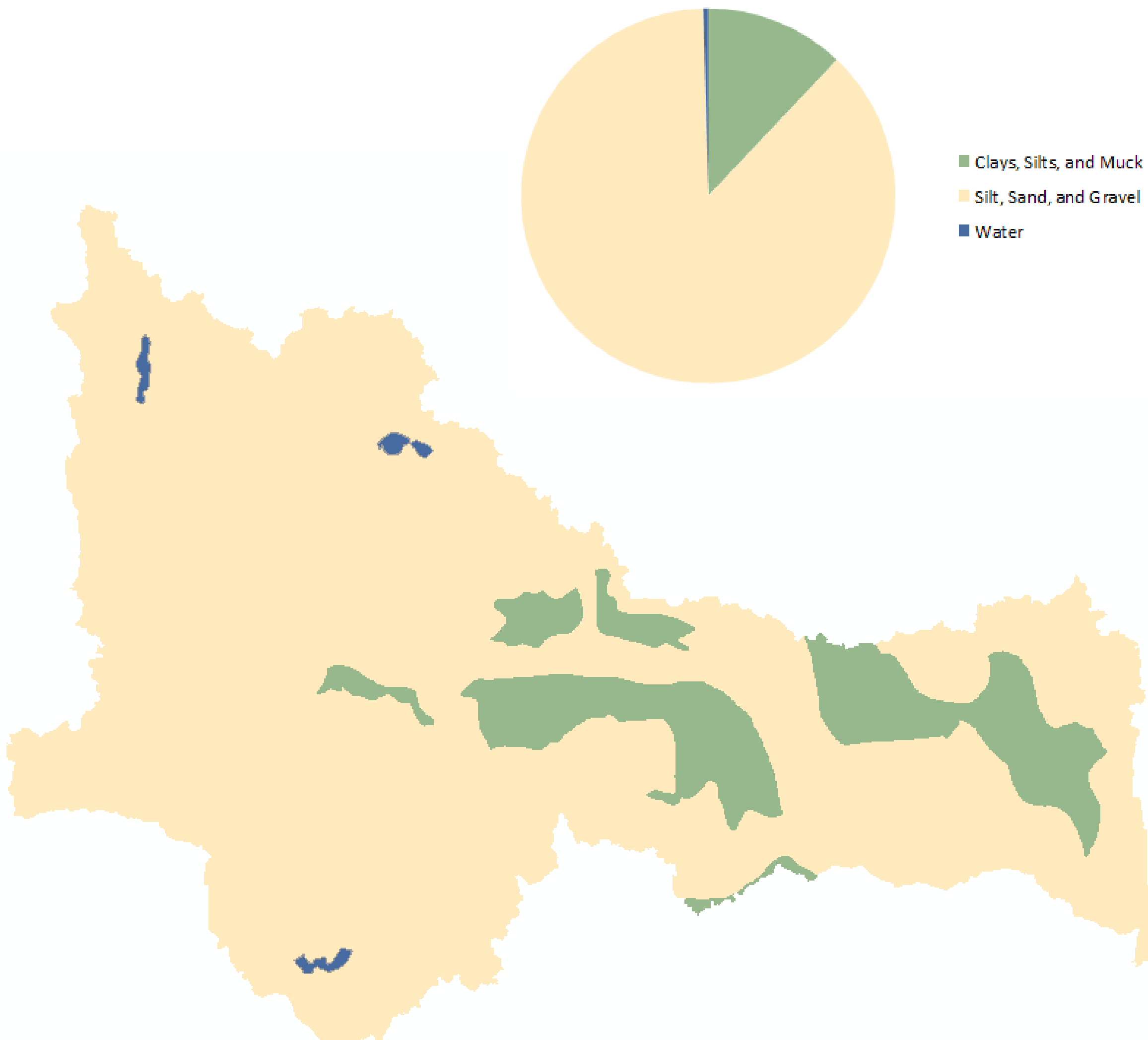


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	136.94	2.58%
Dune sand	8.86	0.17%
End moraines of coarse-textured till	94.39	1.78%
End moraines of fine-textured till	385.58	7.26%
End moraines of medium-textured till	207.51	3.91%
Fine-textured glacial till	149.11	2.81%
Glacial outwash sand and gravel and postglacial alluvium	2601.03	49.00%
Ice-contact outwash sand and gravel	1224.36	23.07%
Lacustrine clay and silt	105.76	1.99%
Lacustrine sand and gravel	372.16	7.01%
Water	22.25	0.42%
Total Watershed Area	5307.95	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

2, AU SABLE RIVER WATERSHED

Surficial Geology (Simplified)

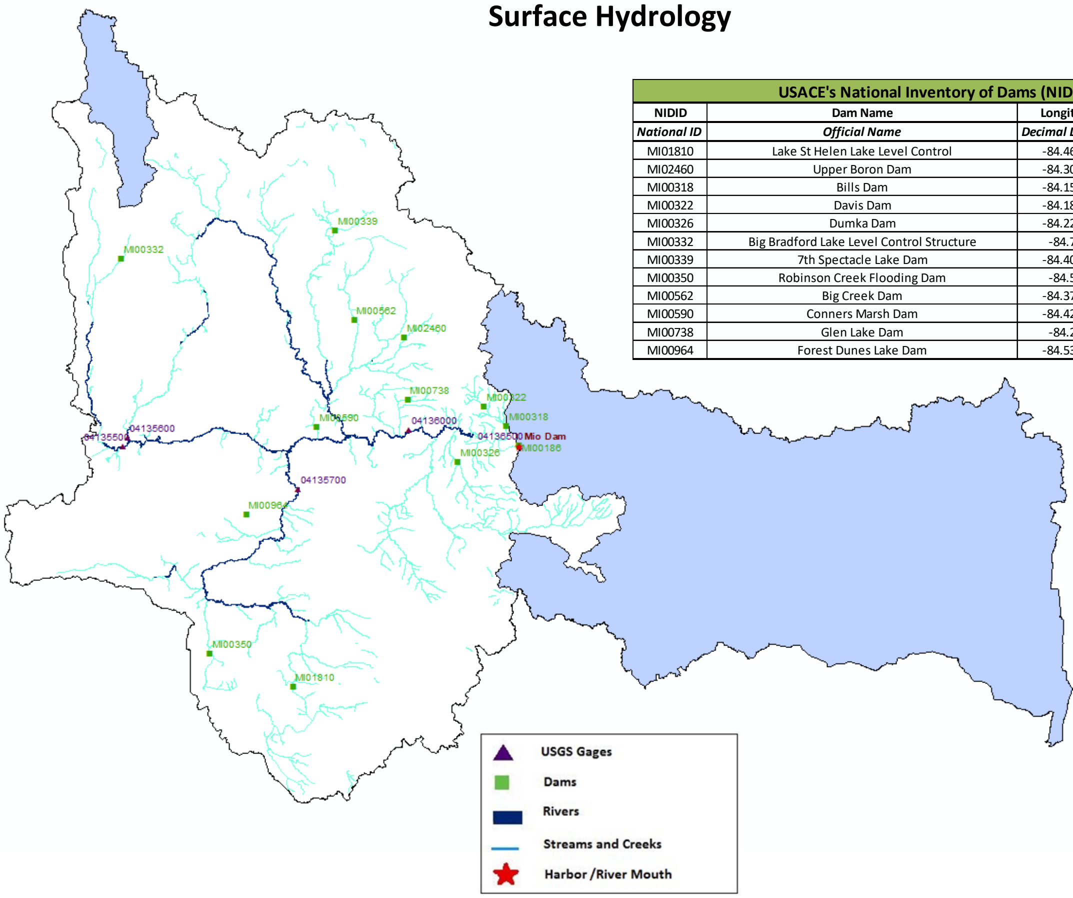


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	640.45	12.07%
Silt, Sand, and Gravel	4645.25	87.51%
Water	22.25	0.42%
Total Watershed Area	5307.95	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX D. AU SABLE RIVER WATERSHED, MIO DAM (2A)

Surface Hydrology



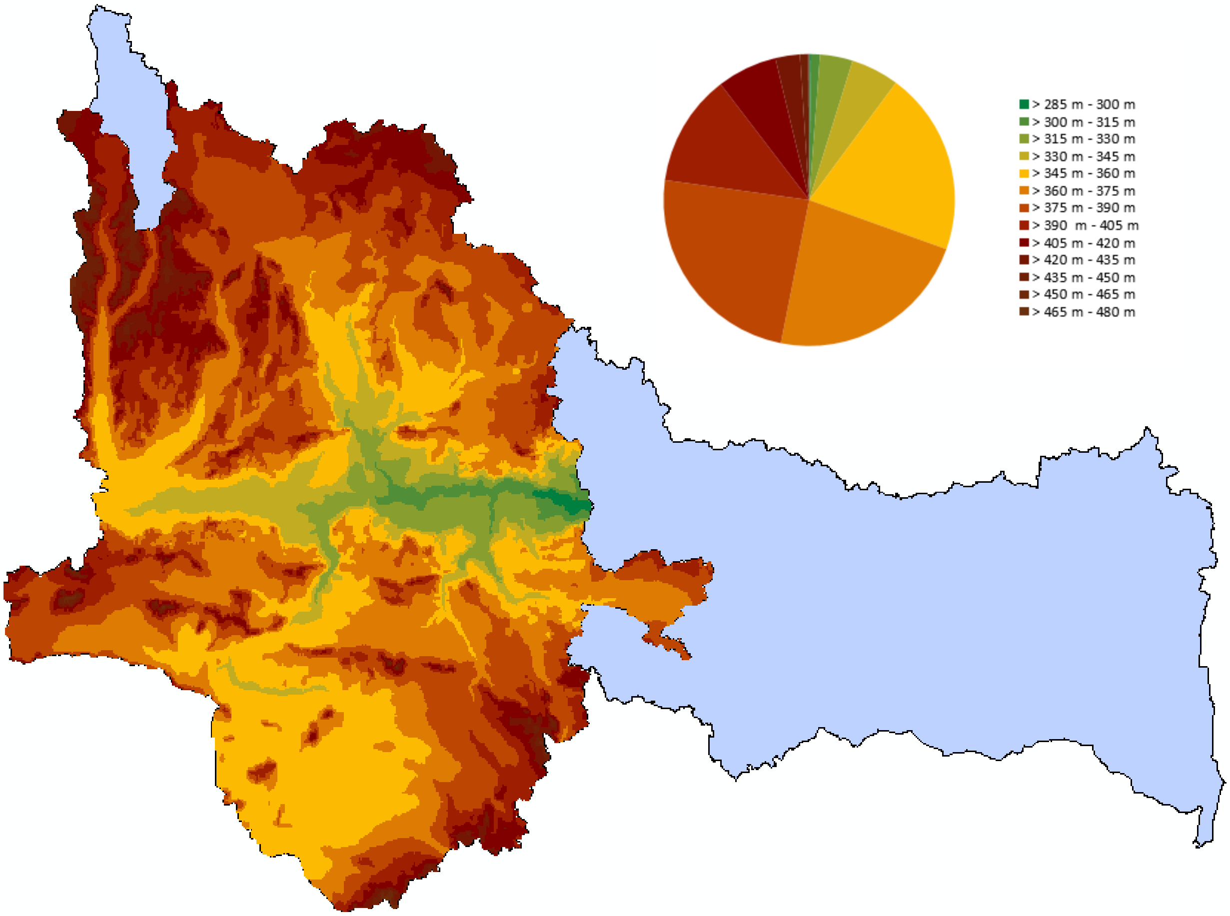
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01810	Lake St Helen Lake Level Control	-84.46333	44.40833
MI02460	Upper Boron Dam	-84.30000	44.77333
MI00318	Bills Dam	-84.15000	44.68167
MI00322	Davis Dam	-84.18333	44.70167
MI00326	Dumka Dam	-84.22166	44.64333
MI00332	Big Bradford Lake Level Control Structure	-84.715	44.855
MI00339	7th Spectacle Lake Dam	-84.40166	44.885
MI00350	Robinson Creek Flooding Dam	-84.585	44.44333
MI00562	Big Creek Dam	-84.37334	44.79167
MI00590	Conners Marsh Dam	-84.42869	44.67985
MI00738	Glen Lake Dam	-84.295	44.70833
MI00964	Forest Dunes Lake Dam	-84.53167	44.58833

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4135500	AU SABLE RIVER AT GRAYLING, MI	-84.712529	44.659737	
4135600	EAST BRANCH AU SABLE RIVER AT GRAYLING, MI	-84.705584	44.668904	
4135700	SOUTH BRANCH AU SABLE RIVER NEAR LUZERNE, MI	-84.455575	44.614738	yes
4136000	AU SABLE RIVER NEAR RED OAK, MI	-84.292515	44.676959	yes
4136500	AU SABLE RIVER AT MIO, MI	-84.131117	44.660014	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				3

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

2A, AU SABLE RIVER WATERSHED, MIO DAM

Elevation



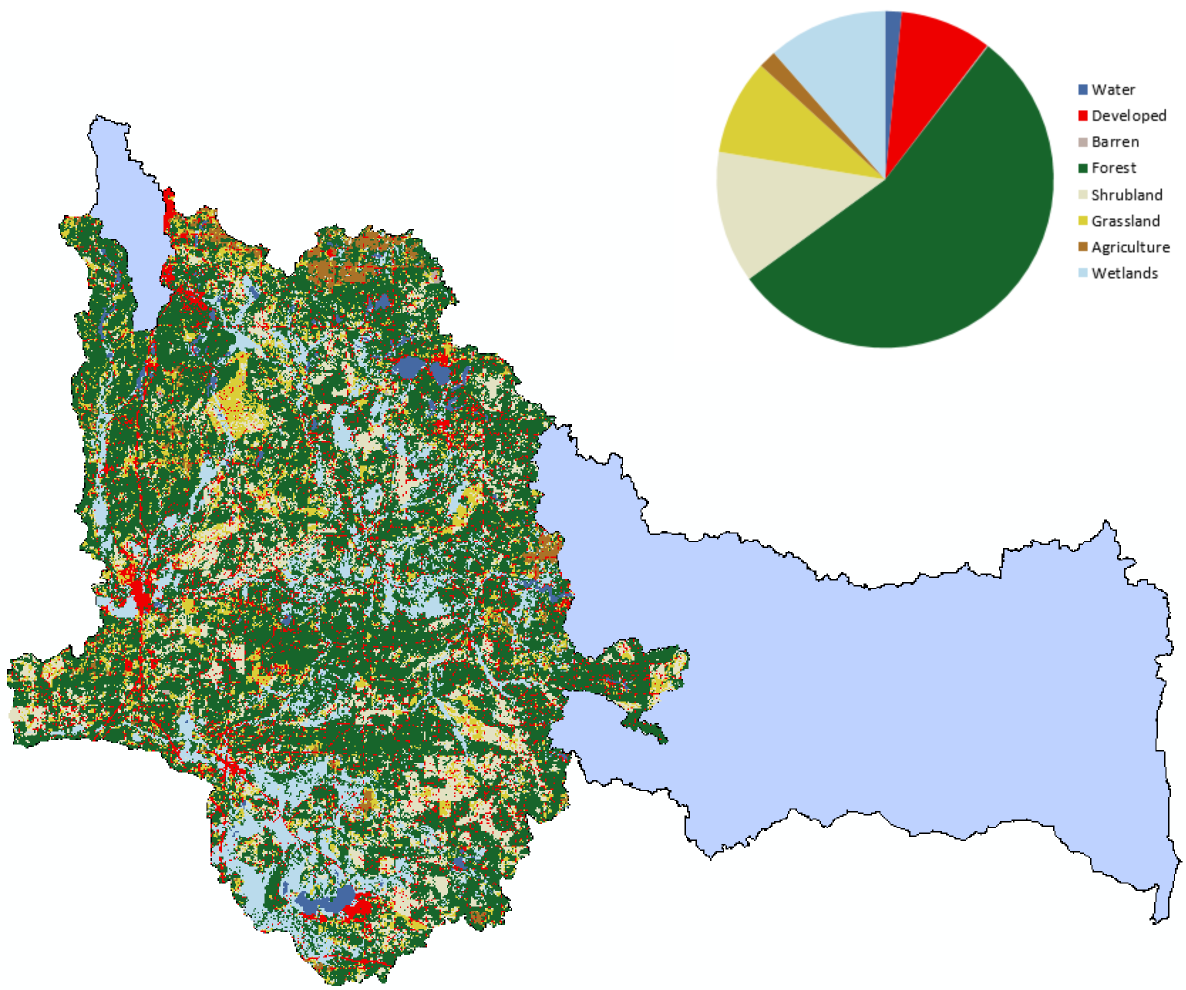
Category	Area	Percentage
Category	*km²*	%
>285 m - 300 m	6.46	0.19%
>300 m - 315 m	33.02	0.99%
>315 m - 330 m	120.80	3.63%
>330 m - 345 m	177.52	5.33%
>345 m - 360 m	676.35	20.32%
>360 m - 375 m	754.50	22.66%
>375 m - 390 m	800.83	24.06%
>390 m - 405 m	412.75	12.40%
>405 m - 420 m	221.86	6.66%
>420 m - 435 m	90.89	2.73%
>435 m - 450 m	30.91	0.93%
>450 m - 465 m	3.01	0.09%
>465 m - 480 m	0.06	0.00%
Size of Drainage Area	3328.97	100.00%

Mio Dam		
Elevation Statistics		
Size of Drainage Area	**3328.97**	***km²***
Maximum	471.00	*m*
Minimum	289.00	*m*
Average	372.52	*m*
Standard Deviation	25.25	*m*

All Elevation Measurements with Respect to North American Datum 1983

2A, AU SABLE RIVER WATERSHED, MIO DAM

Land Use



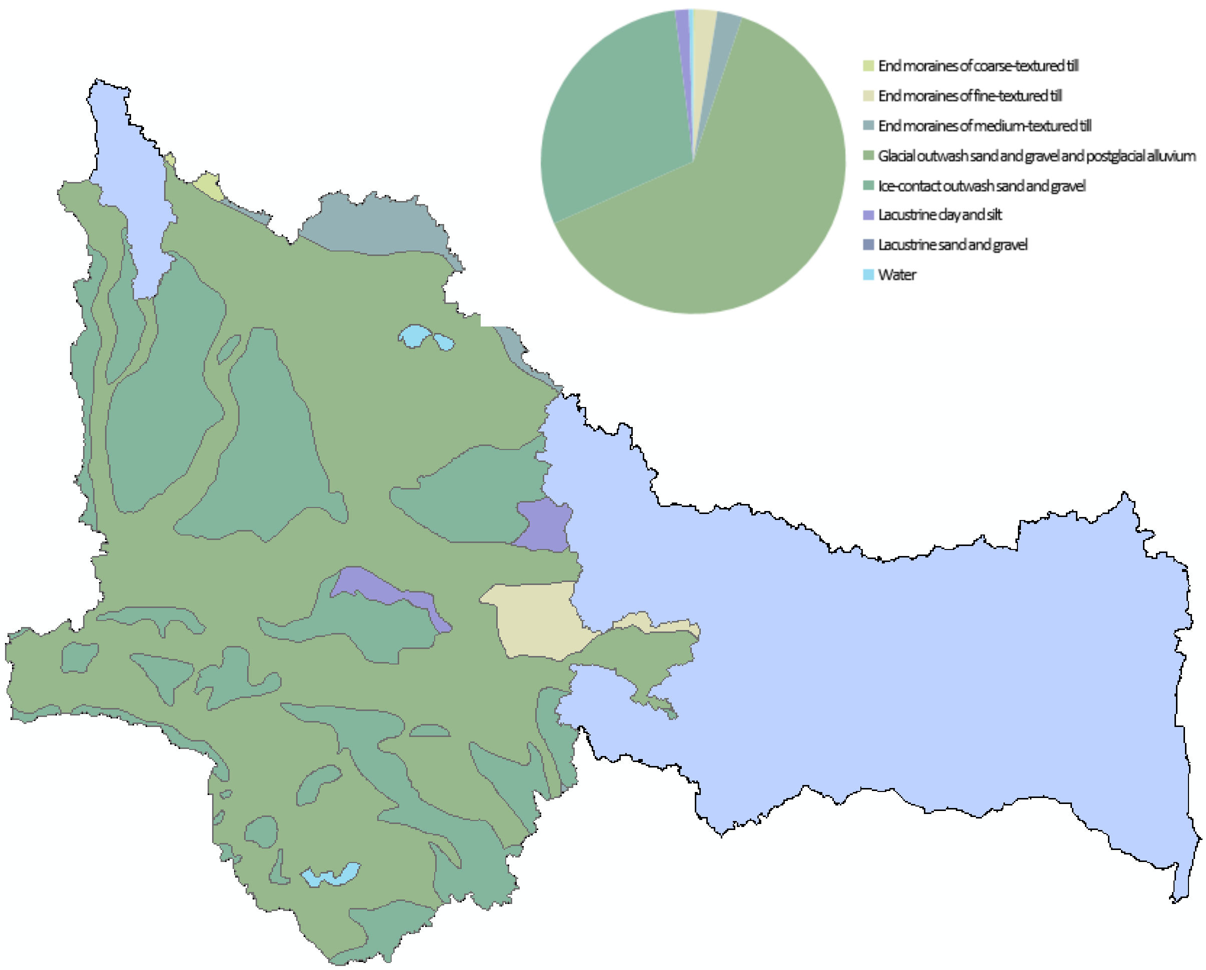
Category	Area	Percentage
Category	*km²*	*%*
Water	52.49	1.58%
Developed	292.71	8.79%
Barren	3.52	0.11%
Forest	1813.47	54.48%
Shrubland	422.22	12.68%
Grassland	305.48	9.18%
Agriculture	57.09	1.72%
Wetlands	381.99	11.47%
Total	3328.97	100.00%

EGLE Runoff Curve Number
51.7

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

2A, AU SABLE RIVER WATERSHED, MIO DAM

Surficial Geology

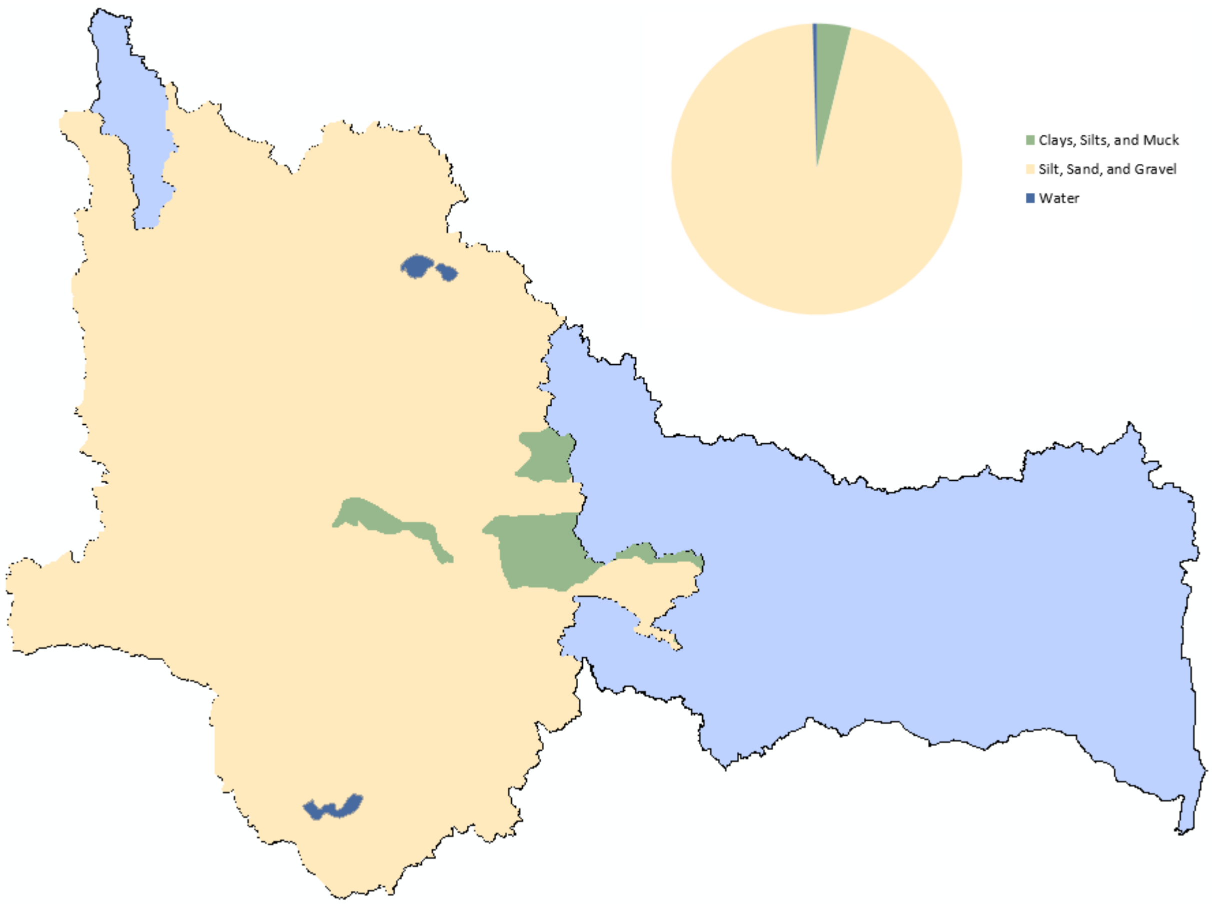


Category	Area	Percentage
Category	*km²*	*%*
End moraines of coarse-textured till	6.67	0.20%
End moraines of fine-textured till	77.75	2.34%
End moraines of medium-textured till	88.92	2.67%
Glacial outwash sand and gravel and postglacial alluvium	2101.29	63.12%
Ice-contact outwash sand and gravel	990.14	29.74%
Lacustrine clay and silt	48.97	1.47%
Lacustrine sand and gravel	0.00	0.00%
Water	15.24	0.46%
Total Watershed Area	3328.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

2A, AU SABLE RIVER WATERSHED, MIO DAM

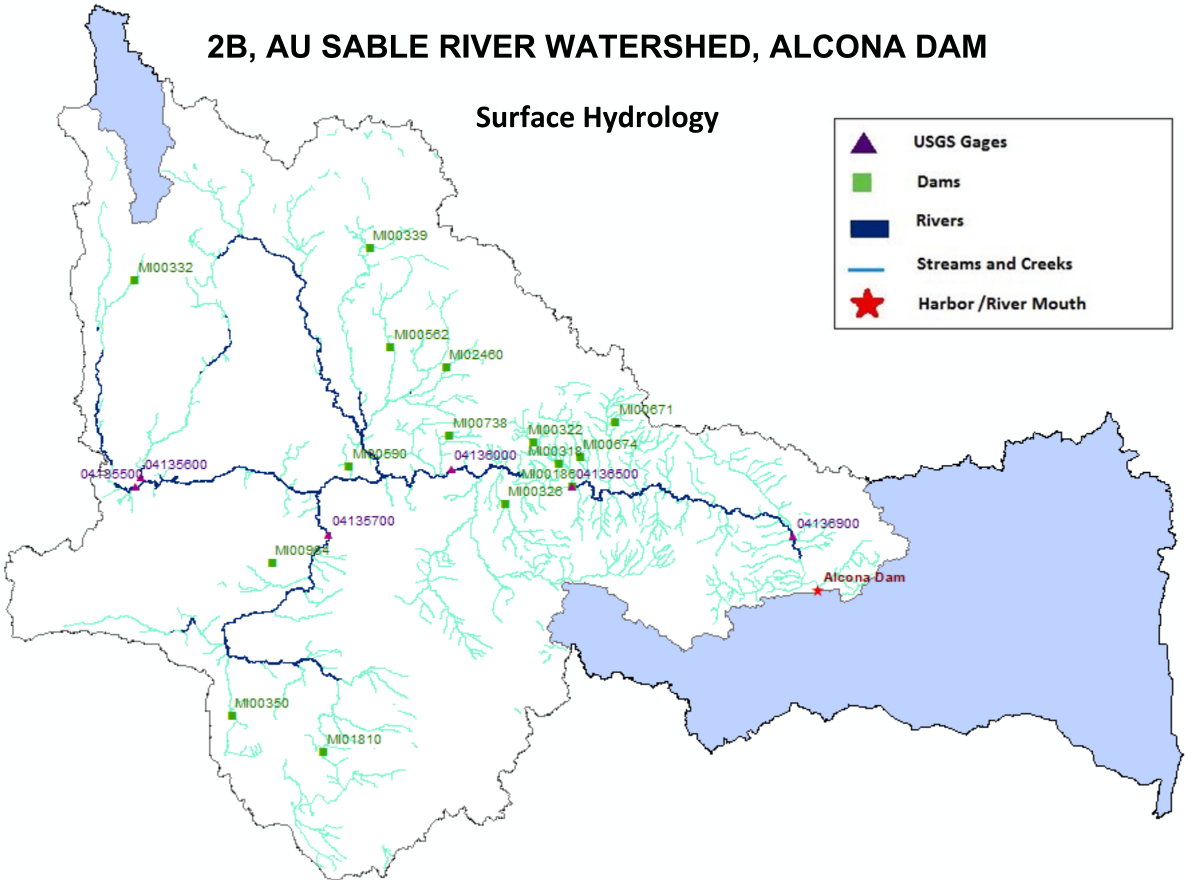
Surficial Geology (Simplified)

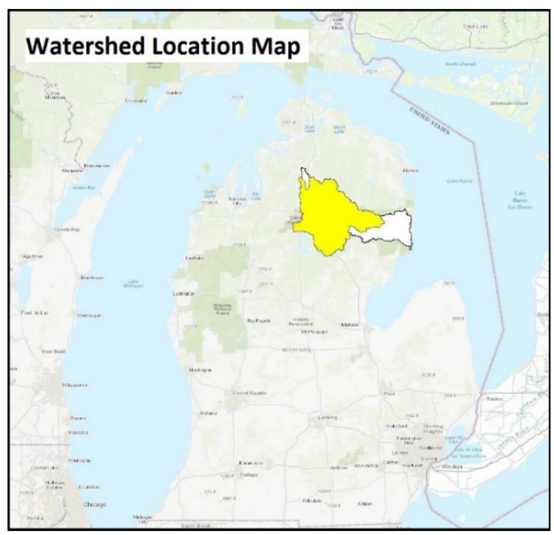


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	126.72	3.81%
Silt, Sand, and Gravel	3187.02	95.74%
Water	15.24	0.46%
Total Watershed Area	3328.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

2B, AU SABLE RIVER WATERSHED, ALCONA DAM





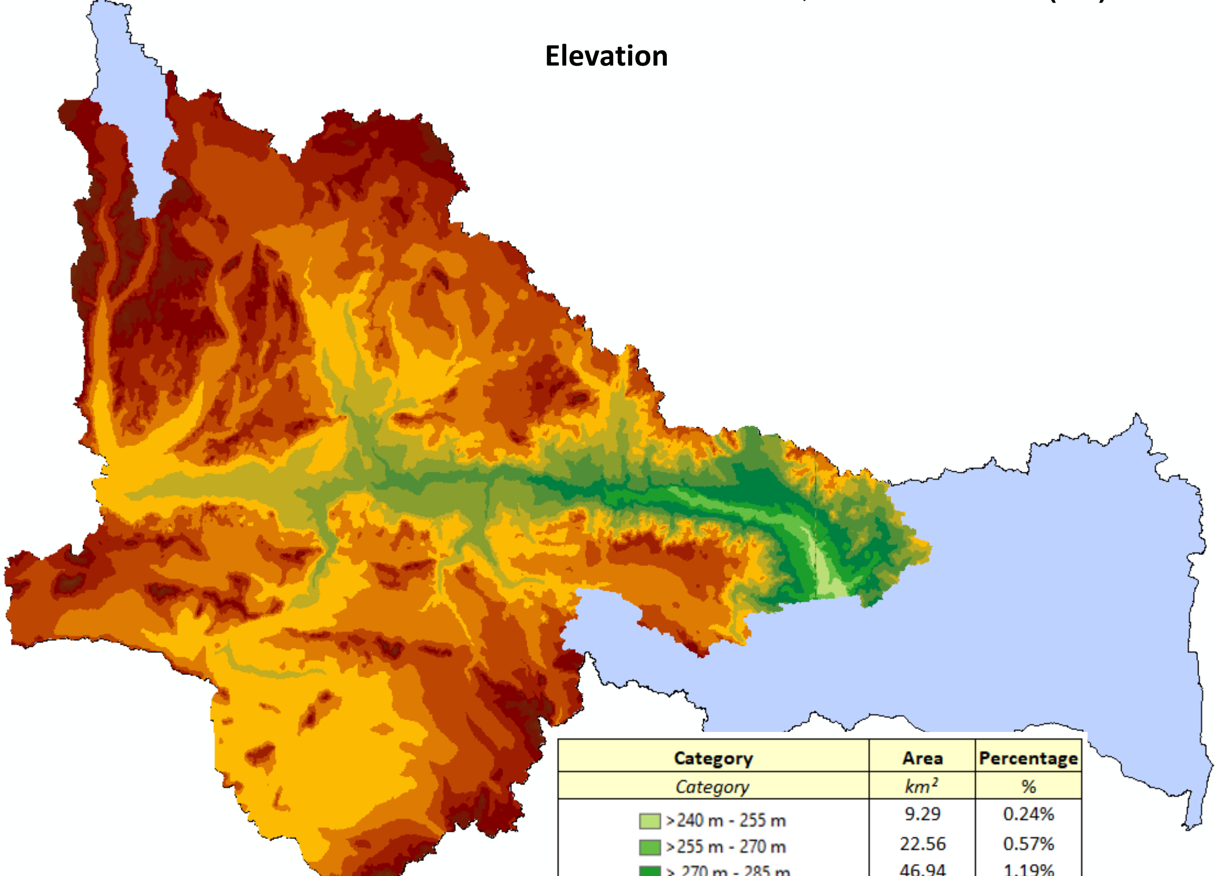
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00186	Mio	-84.13170	44.66090
MI01810	Lake St Helen Lake Level Control	-84.46333	44.40833
MI02460	Upper Boron Dam	-84.30000	44.77333
MI00318	Bills Dam	-84.15000	44.68167
MI00322	Davis Dam	-84.18333	44.70167
MI00326	Dumka Dam	-84.22166	44.64333
MI00332	Big Bradford Lake Level Control Structure	-84.715	44.855
MI00339	7th Spectacle Lake Dam	-84.40166	44.885
MI00350	Robinson Creek Flooding Dam	-84.585	44.44333
MI00562	Big Creek Dam	-84.37334	44.79167
MI00590	Conners Marsh Dam	-84.42869	44.67985
MI00671	Okie Kauffman Dam	-84.075	44.72167
MI00674	Blamer Dam	-84.12167	44.68833
MI00738	Glen Lake Dam	-84.295	44.70833
MI00964	Forest Dunes Lake Dam	-84.53167	44.58833

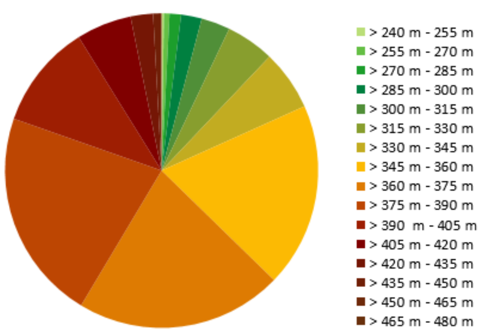
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4135500	AU SABLE RIVER AT GRAYLING, MI	*-84.712529*	*44.659737*	
4135600	EAST BRANCH AU SABLE RIVER AT GRAYLING, MI	-84.705584	44.668904	
4135700	SOUTH BRANCH AU SABLE RIVER NEAR LUZERNE, MI	-84.455575	44.614738	yes
4136000	AU SABLE RIVER NEAR RED OAK, MI	-84.292515	44.676959	yes
4136500	AU SABLE RIVER AT MIO, MI	-84.131117	44.660014	yes
4136900	AU SABLE RIVER NEAR MC KINLEY, MI	-83.837778	44.612778	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				4

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

APPENDIX E. AU SABLE RIVER WATERSHED, ALCONA DAM (2B)

Elevation





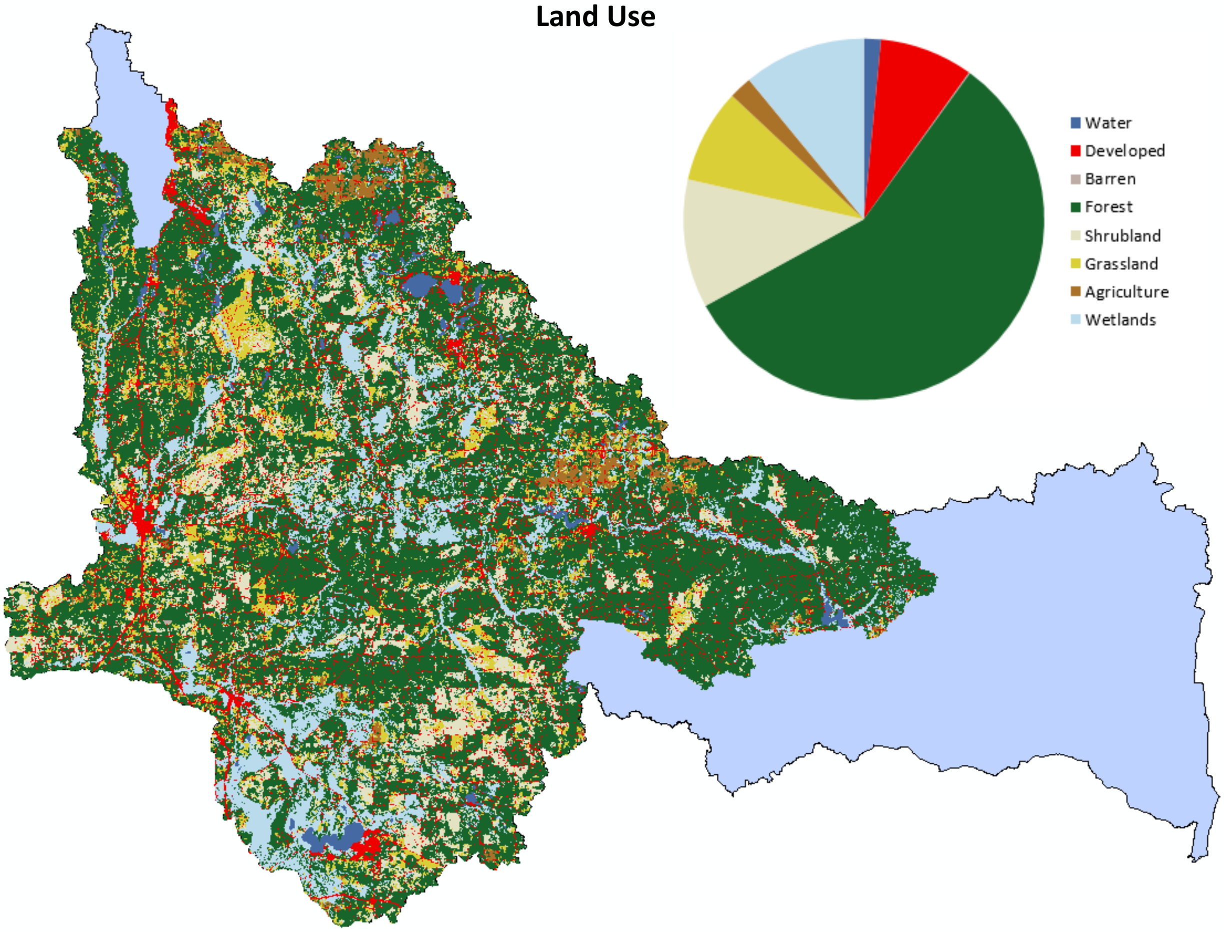
Category	Area	Percentage
Category	*km²*	*%*
>240 m - 255 m	9.29	0.24%
>255 m - 270 m	22.56	0.57%
> 270 m - 285 m	46.94	1.19%
>285 m - 300 m	83.98	2.13%
>300 m - 315 m	117.34	2.98%
>315 m - 330 m	196.80	4.99%
>330 m - 345 m	244.04	6.19%
>345 m - 360 m	747.23	18.96%
>360 m - 375 m	841.16	21.34%
>375 m - 390 m	857.22	21.75%
>390 m - 405 m	424.43	10.77%
>405 m - 420 m	224.34	5.69%
>420 m - 435 m	91.43	2.32%
>435 m - 450 m	31.10	0.79%
>450 m - 465 m	3.02	0.08%
>465 m - 480 m	0.06	0.00%
Size of Drainage Area	3940.97	100.00%

Alcona Dam Watershed		
Elevation Statistics		
Size of Drainage Area	**3940.97**	***km²***
Maximum	471.00	*m*
Minimum	246.00	*m*
Average	365.58	*m*
Standard Deviation	31.82	*m*

All Elevation Measurements with Respect to North American Datum 1983

2B, AU SABLE RIVER WATERSHED, ALCONA DAM

Land Use



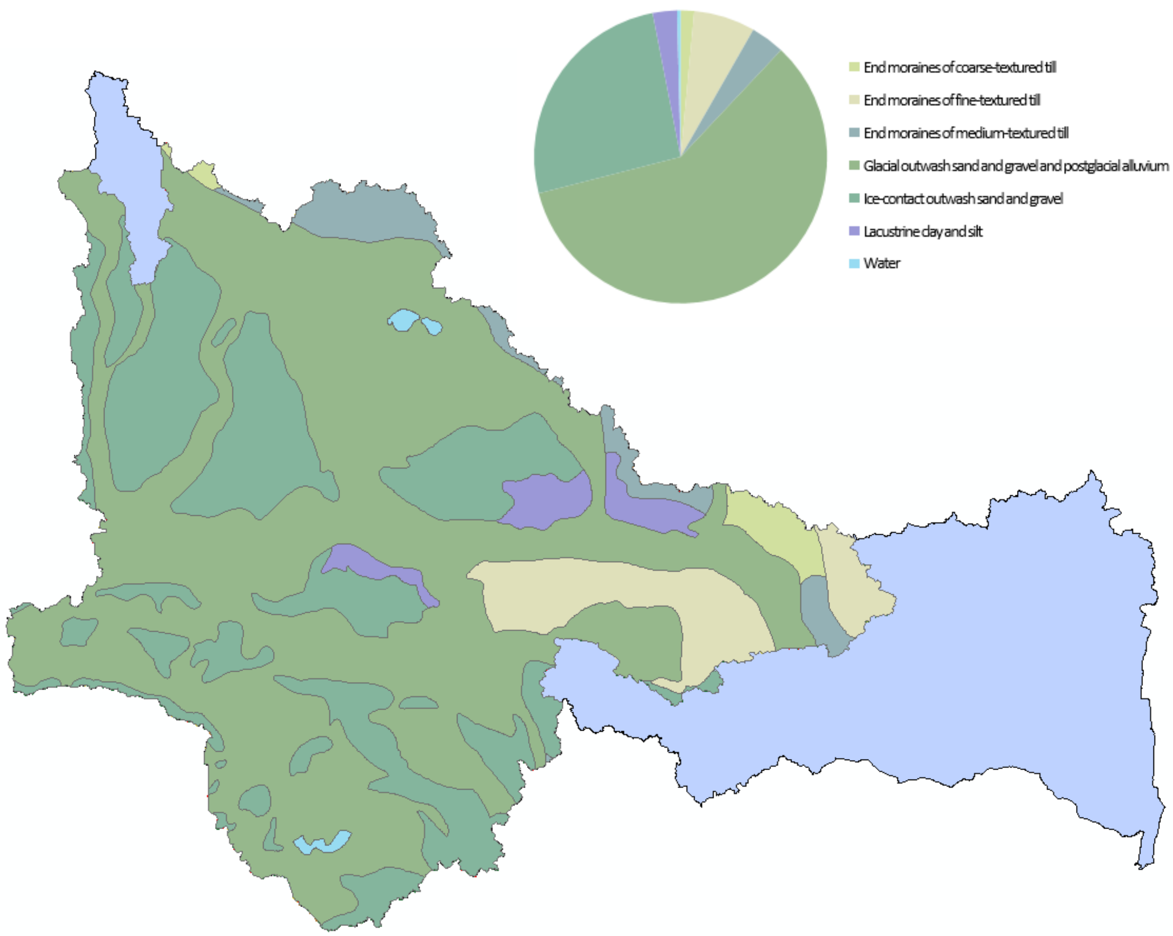
Category	Area	Percentage
Category	*km²*	*%*
Water	60.08	1.52%
Developed	330.90	8.40%
Barren	3.67	0.09%
Forest	2247.49	57.03%
Shrubland	453.52	11.51%
Grassland	332.08	8.43%
Agriculture	80.71	2.05%
Wetlands	432.51	10.97%
Total	3940.97	100.00%

EGLE Runoff Curve Number
52.1

Data Obtained from National Land Cover Database 2011 (NLCD 2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

2B, AU SABLE RIVER WATERSHED, ALCONA DAM

Surficial Geology

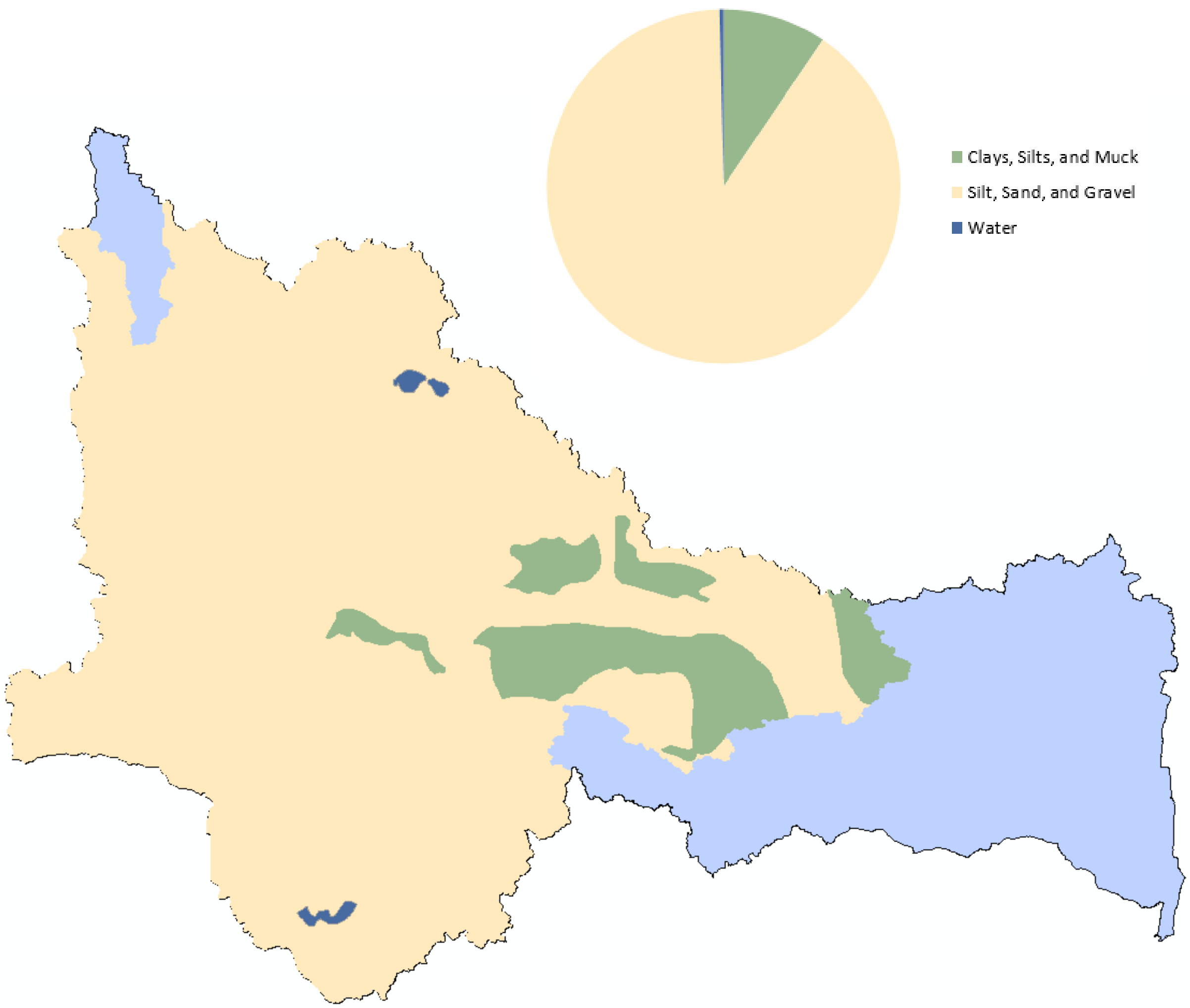


Category	Area	Percentage
Category	*km²*	*%*
End moraines of coarse-textured till	58.60	1.49%
End moraines of fine-textured till	267.65	6.79%
End moraines of medium-textured till	147.40	3.74%
Glacial outwash sand and gravel and postglacial alluvium	2323.97	58.97%
Ice-contact outwash sand and gravel	1022.36	25.94%
Lacustrine clay and silt	105.74	2.68%
Water	15.25	0.39%
Total Watershed Area	3940.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

2B, AU SABLE RIVER WATERSHED, ALCONA DAM

Surficial Geology (Simplified)

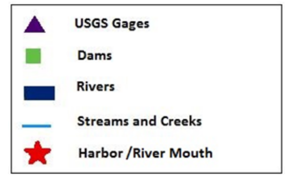


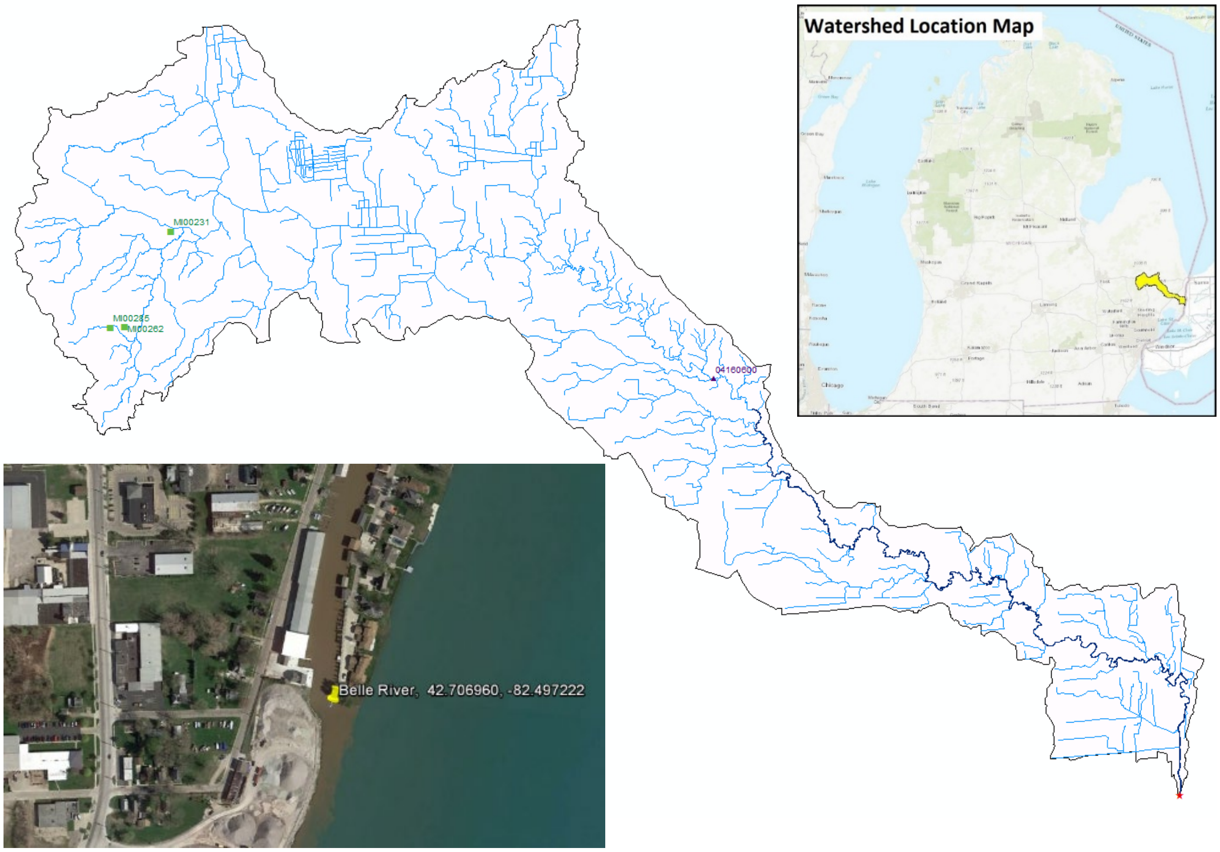
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	373.39	9.47%
Silt, Sand, and Gravel	3552.33	90.14%
Water	15.25	0.39%
Total Watershed Area	3940.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX F. BELLE RIVER WATERSHED (3)

Surface Hydrology





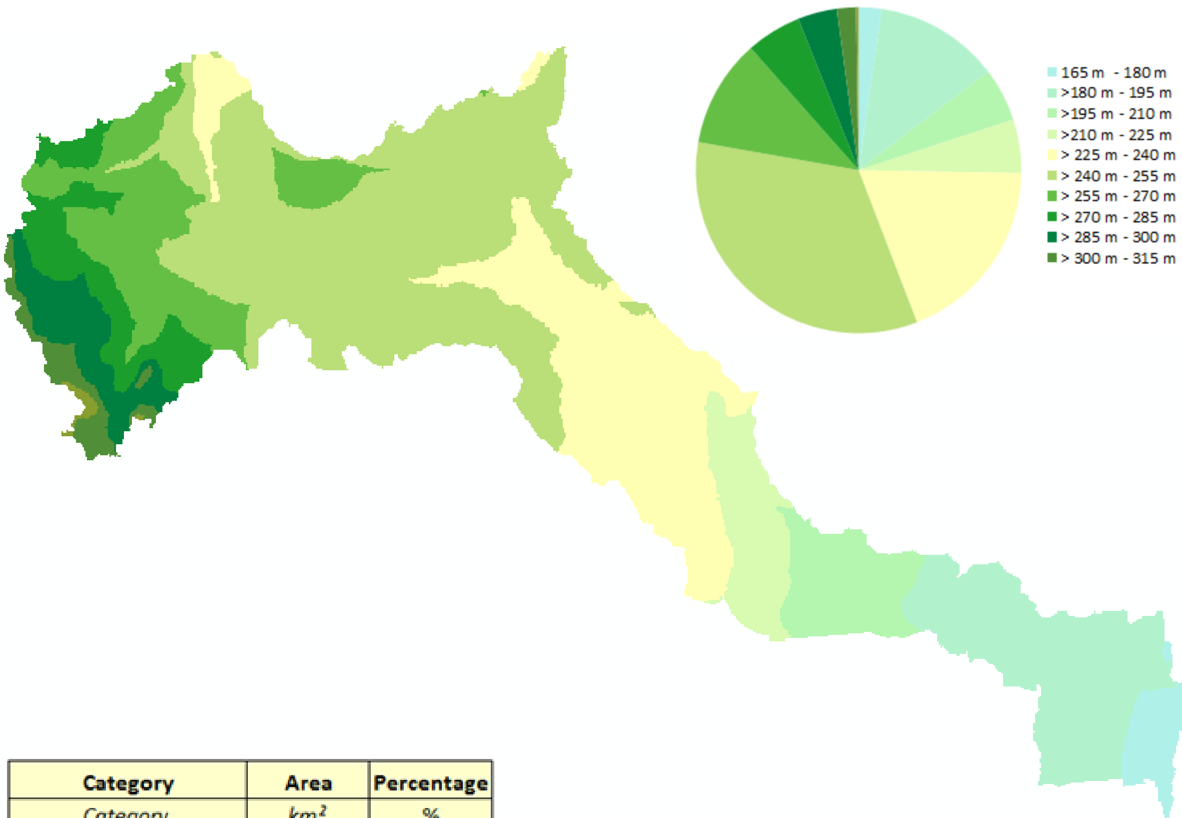
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00231	Foltz Dam	-83.095000	42.975000
MI00262	Niobe Dam	-83.125000	42.933330
MI00285	Marciniak Dam #1	-83.133330	42.933330

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
04160600	BELLE RIVER AT MEMPHIS, MI	*-82.769091*	*42.900862*	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

3, BELLE RIVER WATERSHED

Elevation



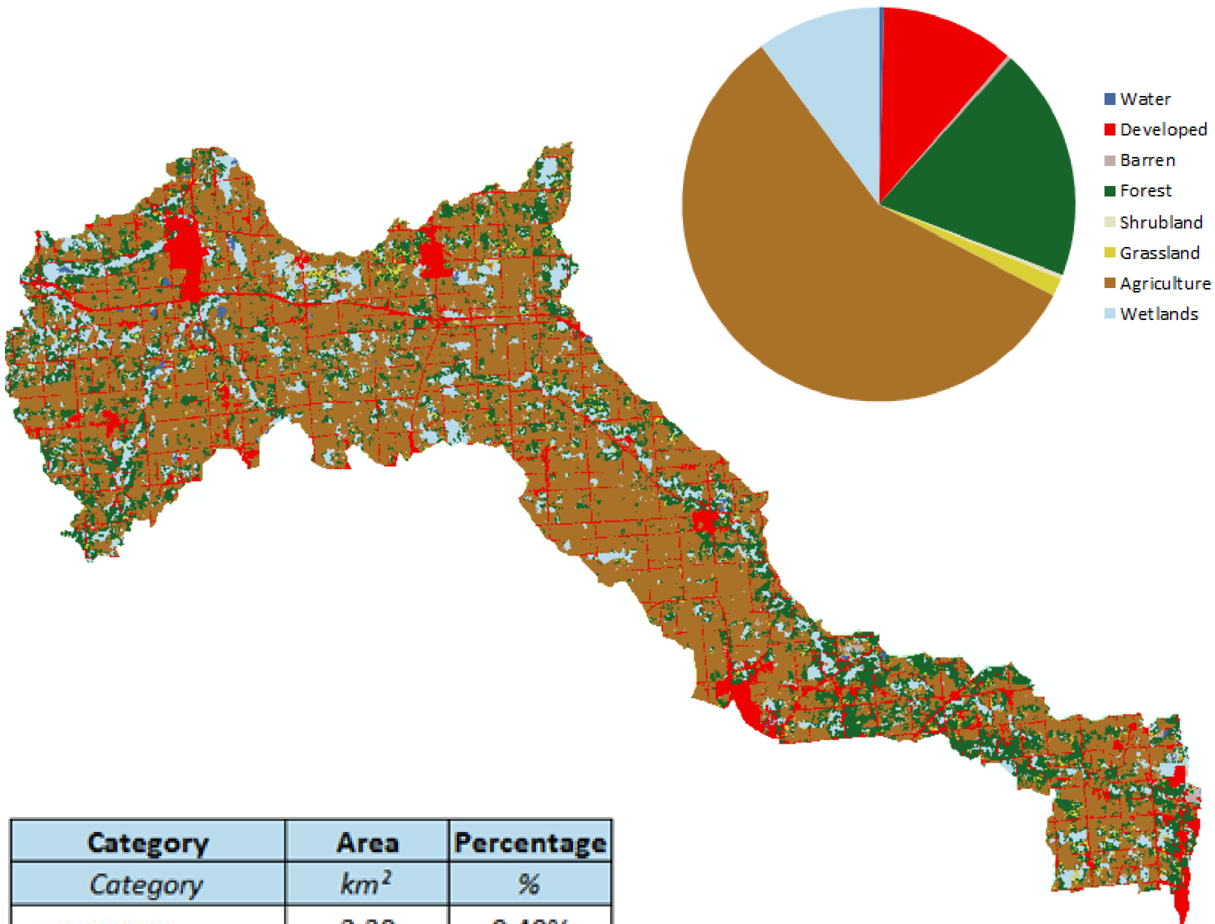
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	13.41	2.28%
>180 m - 195 m	72.86	12.38%
>195 m - 210 m	31.33	5.32%
>210 m - 225 m	31.21	5.30%
>225 m - 240 m	111.09	18.87%
>240 m - 255 m	197.88	33.61%
>255 m - 270 m	63.08	10.72%
> 270 m - 285 m	32.21	5.47%
>285 m - 300 m	23.01	3.91%
>300 m - 315 m	11.13	1.89%
>315 m - 330 m	1.48	0.25%
Size of Drainage Area	588.69	100.00%

Belle Watershed		
Elevation Statistics		
Size of Drainage Area	**588.69**	***km²***
Maximum	327.00	*m*
Minimum	176.00	*m*
Average	236.88	*m*
Standard Deviation	29.78	*m*

All Elevation Measurements with Respect to North American Datum 1983

3, BELLE RIVER WATERSHED

Land Use



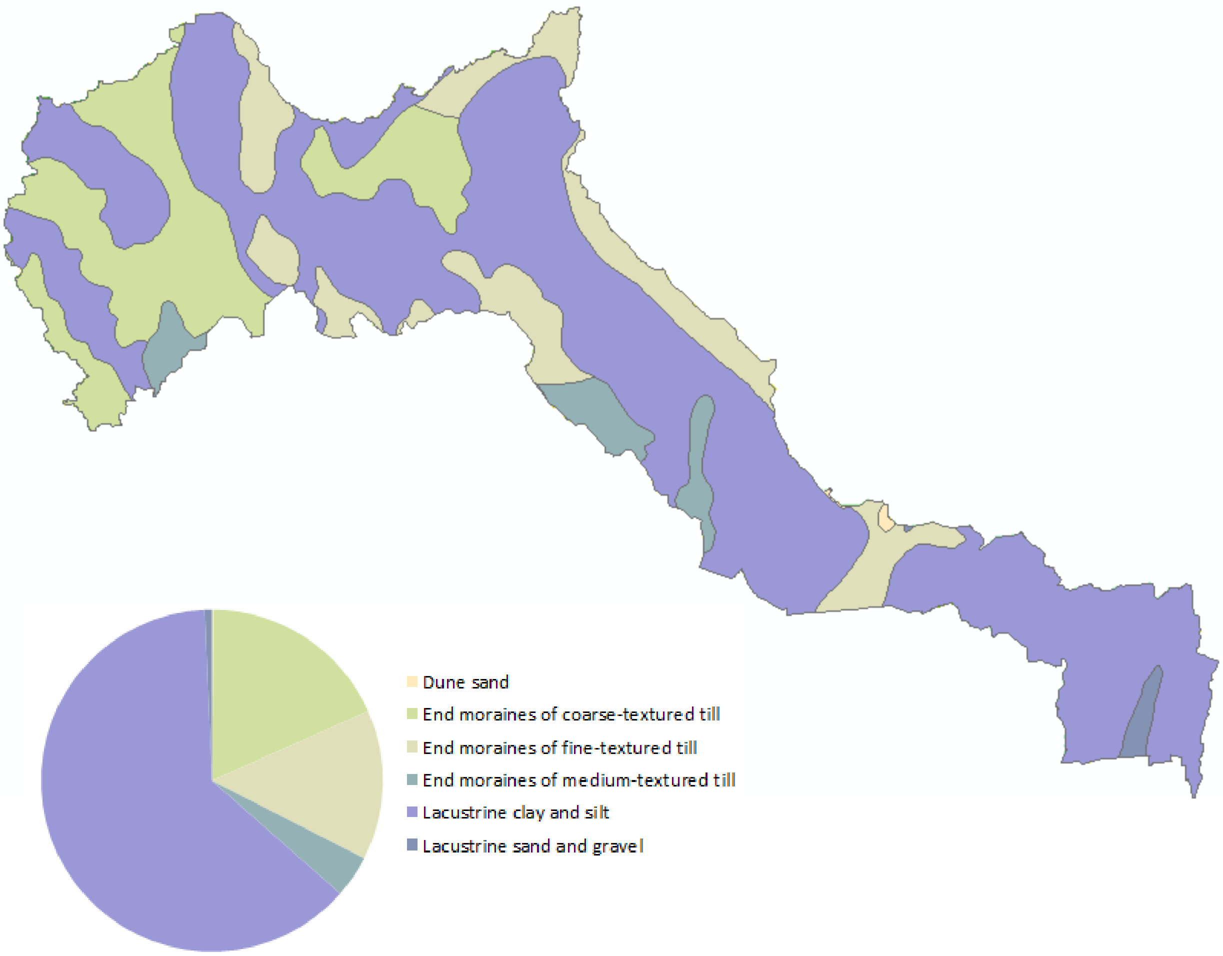
Category	Area	Percentage
Category	*km²*	*%*
Water	2.38	0.40%
Developed	64.74	11.00%
Barren	1.84	0.31%
Forest	112.55	19.12%
Shrubland	2.02	0.34%
Grassland	8.80	1.49%
Agriculture	336.58	57.17%
Wetlands	59.79	10.16%
Total	588.69	100.00%

EGLE Runoff Curve Number
79.1

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

3, BELLE RIVER WATERSHED

Surficial Geology

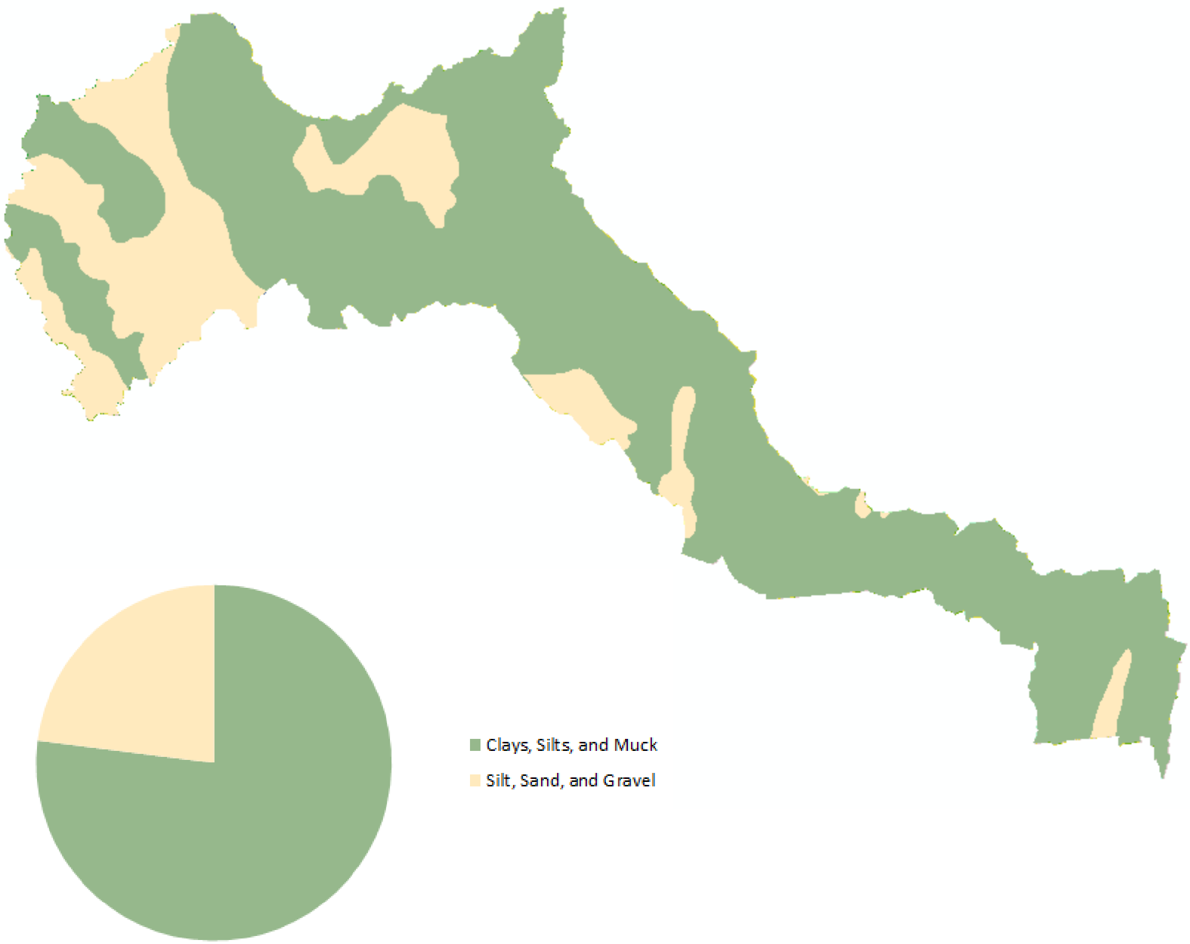


Category	Area	Percentage
Category	*km²*	*%*
Dune sand	0.84	0.14%
End moraines of coarse-textured till	107.06	18.19%
End moraines of fine-textured till	83.50	14.18%
End moraines of medium-textured till	23.40	3.97%
Lacustrine clay and silt	369.78	62.81%
Lacustrine sand and gravel	4.13	0.70%
Total Watershed Area	588.69	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

3, BELLE RIVER WATERSHED

Surficial Geology (Simplified)

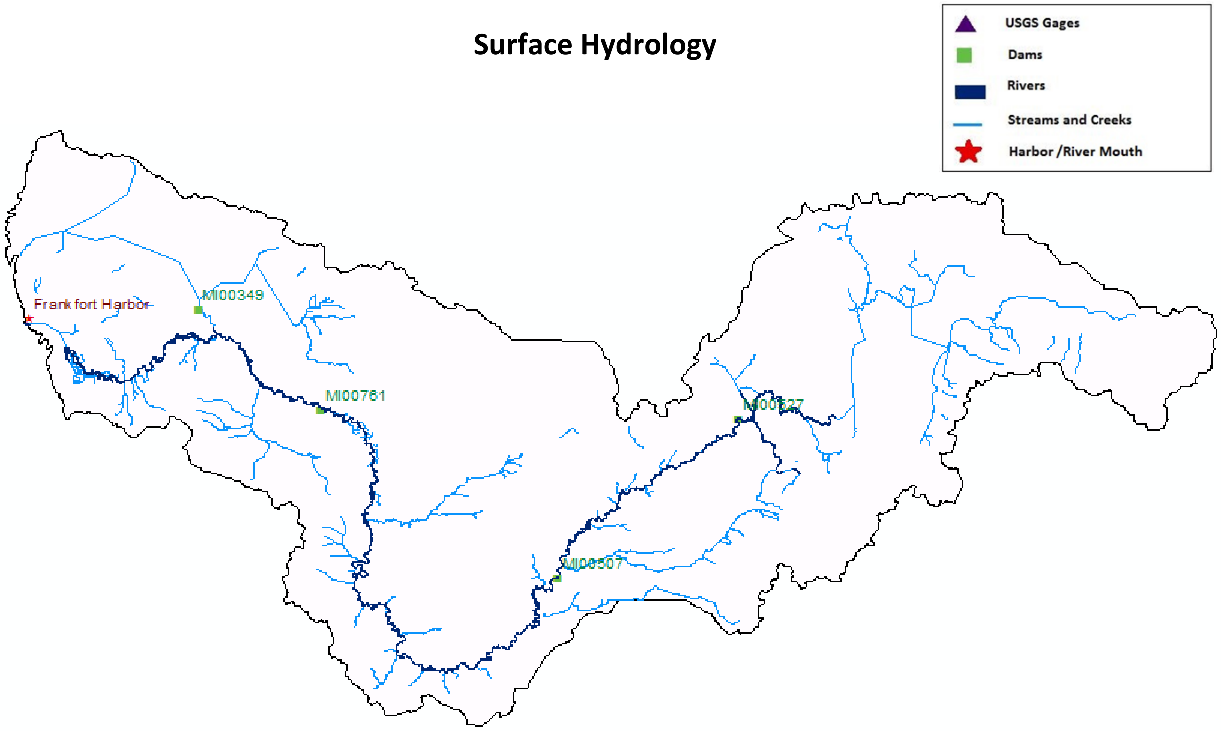


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	453.27	77.00%
Silt, Sand, and Gravel	135.42	23.00%
Total Watershed Area	588.69	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX G. BETSIE RIVER WATERSHED (4)

Surface Hydrology

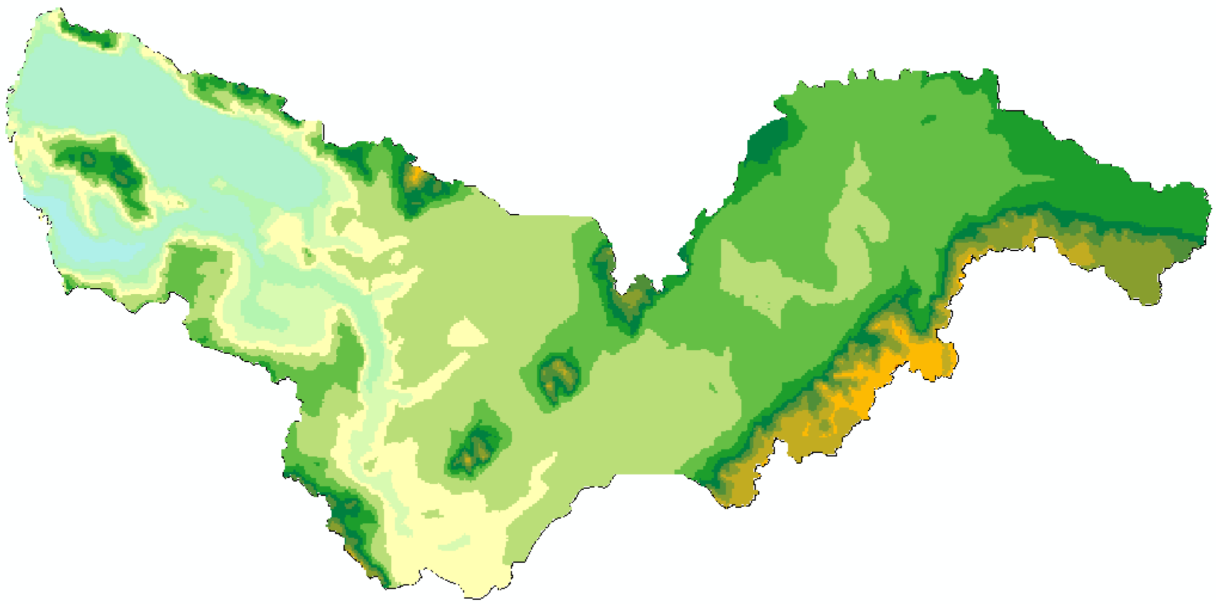


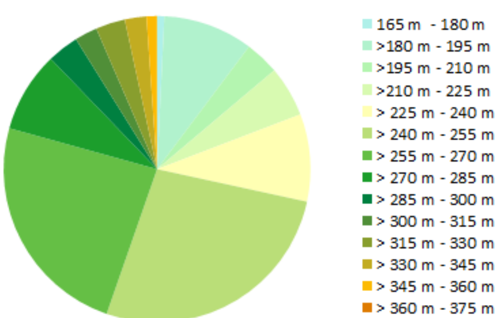
USACE's National Inventory of Dams (NID)			
NIDID	***Dam Name***	***Longitude***	***Latitude***
MI00349	Crystal Lake Level Control Dam	-86.14833	44.63500
MI00507	Thompsonville Dam	-85.94833	44.52833
MI00527	Grass Lake Dam	-85.84834	44.59167
MI00761	Homestead Dam	-86.08000	44.59500

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

4, BETSIE RIVER WATERSHED

Elevation





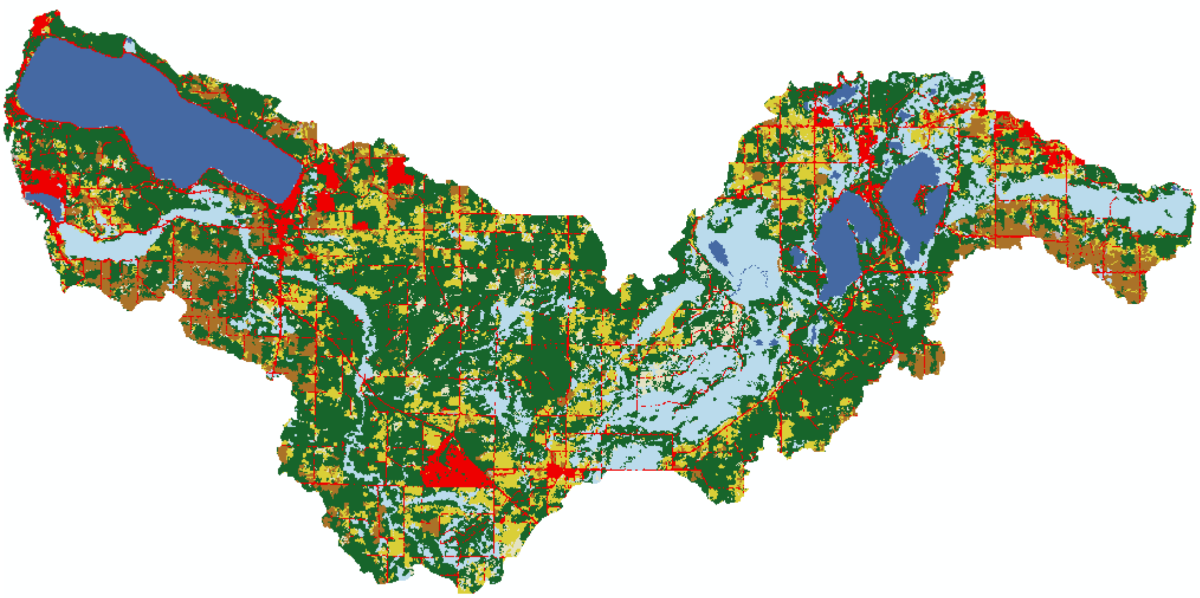
Betsie Watershed		
Elevation Statistics		
Size of Drainage Area	**627.90**	***km²***
Maximum	363.00	*m*
Minimum	176.00	*m*
Average	250.01	*m*
Standard Deviation	36.19	*m*

Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	4.77	0.76%
>180 m - 195 m	59.46	9.47%
>195 m - 210 m	22.61	3.60%
>210 m - 225 m	33.54	5.34%
>225 m - 240 m	58.00	9.24%
>240 m - 255 m	169.10	26.93%
>255 m - 270 m	150.54	23.97%
>270 m - 285 m	53.37	8.50%
>285 m - 300 m	20.86	3.32%
>300 m - 315 m	14.96	2.38%
>315 m - 330 m	19.47	3.10%
>330 m - 345 m	14.32	2.28%
>345 m - 360 m	6.89	1.10%
>360 m - 375 m	0.03	0.01%
Size of Drainage Area	627.90	100.00%

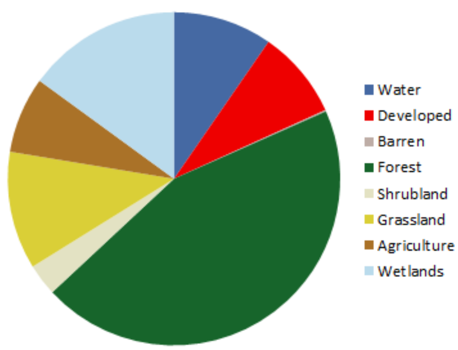
All Elevation Measurements with Respect to North American Datum 1983

4, BETSIE RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	60.48	9.63%
Developed	53.94	8.59%
Barren	0.92	0.15%
Forest	280.71	44.71%
Shrubland	19.42	3.09%
Grassland	71.83	11.44%
Agriculture	46.54	7.41%
Wetlands	94.07	14.98%
Total	627.90	100.00%

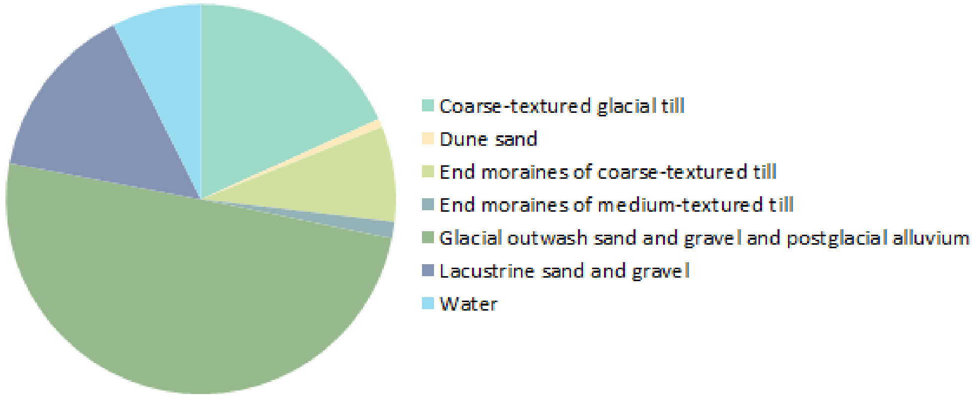


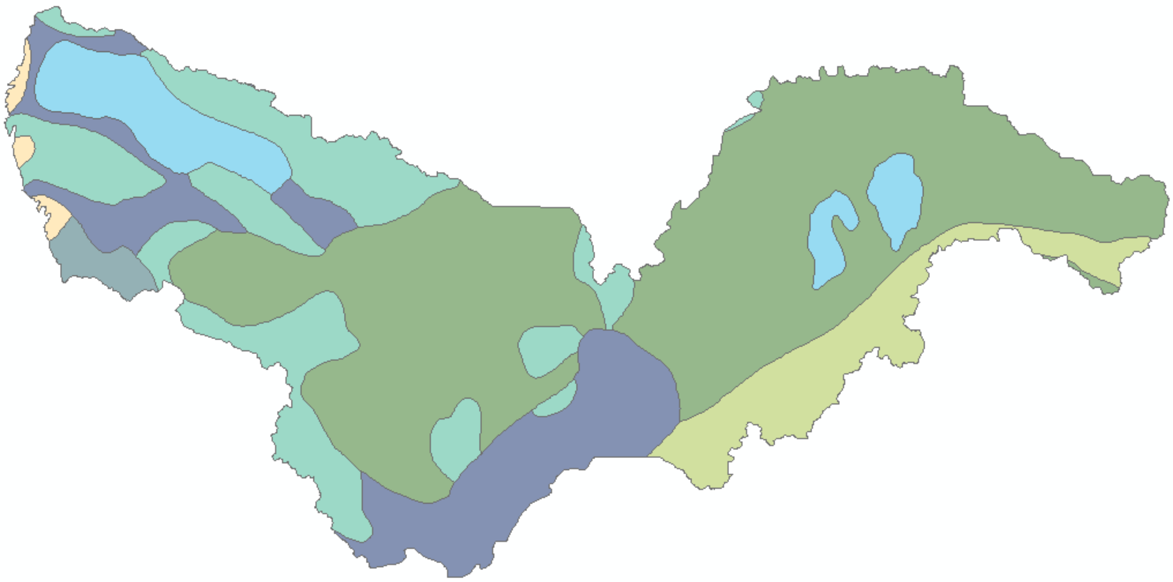
EGLE Runoff Curve Number
57.0

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

4, BETSIE RIVER WATERSHED

Surficial Geology



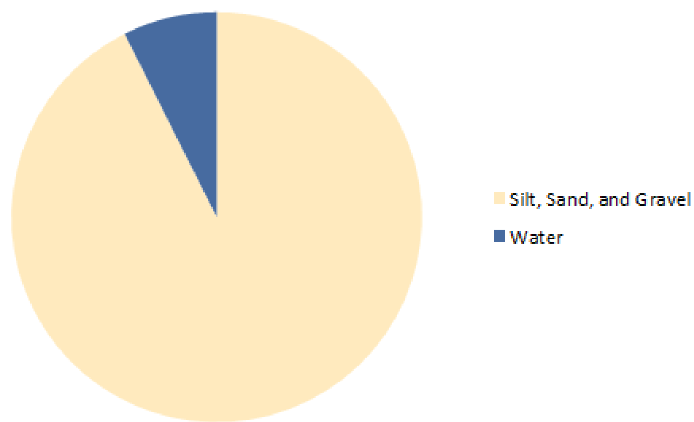


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	114.56	18.24%
Dune sand	4.41	0.70%
End moraines of coarse-textured till	49.60	7.90%
End moraines of medium-textured till	8.58	1.37%
Glacial outwash sand and gravel and postglacial alluvium	312.36	49.75%
Lacustrine sand and gravel	91.88	14.63%
Water	46.50	7.41%
Total Watershed Area	627.90	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

4, BETSIE RIVER WATERSHED

Surficial Geology (Simplified)

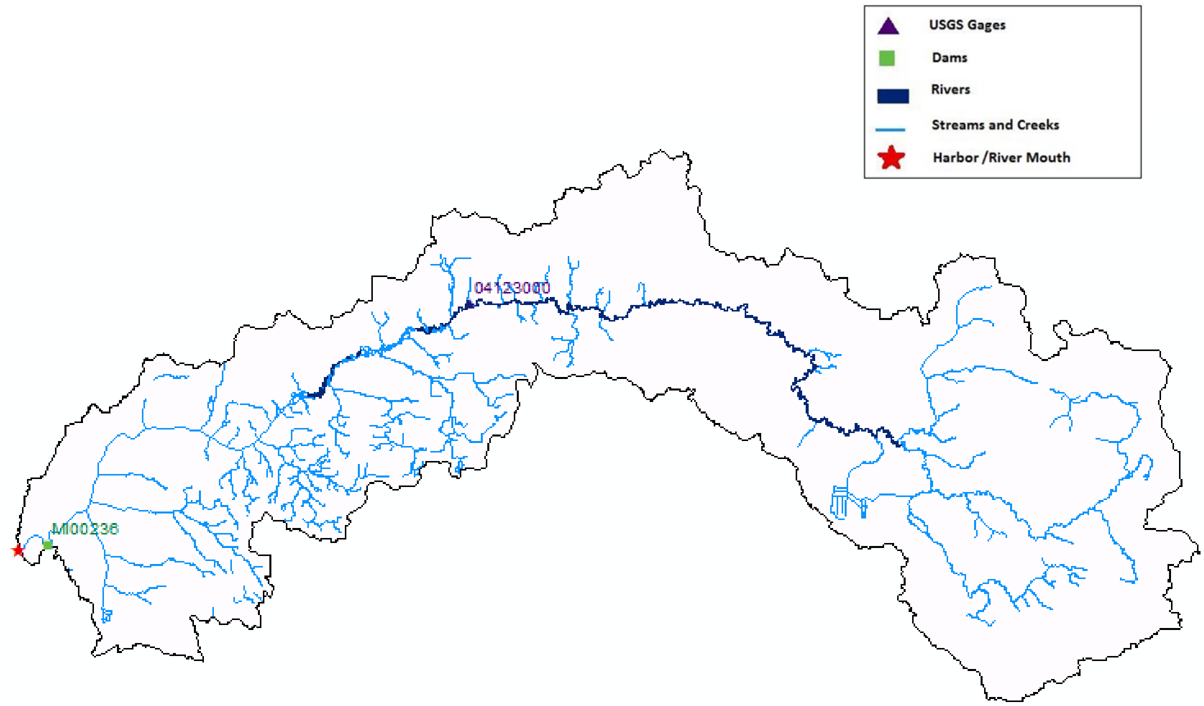


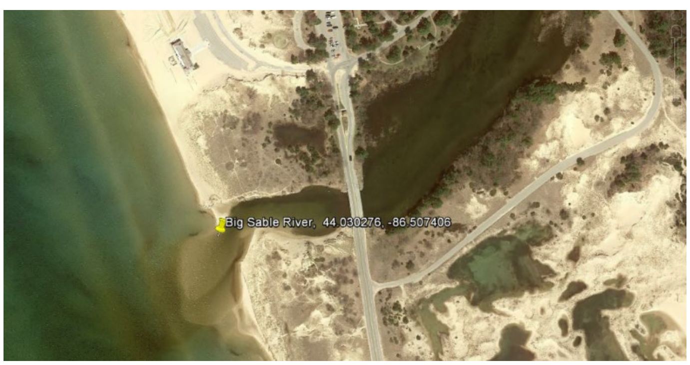
Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	581.40	92.59%
Water	46.50	7.41%
Total Watershed Area	627.90	100.00%

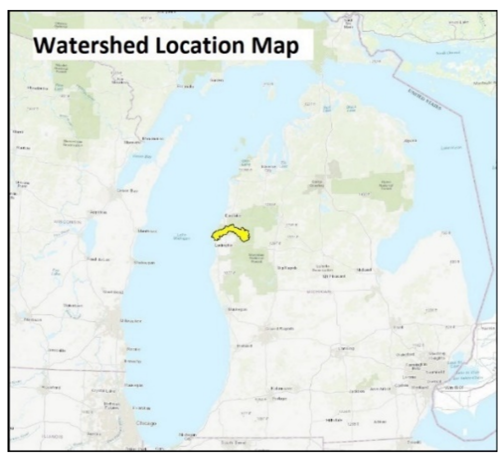
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX H. BIG SABLE WATERSHED (5)

Surface Hydrology







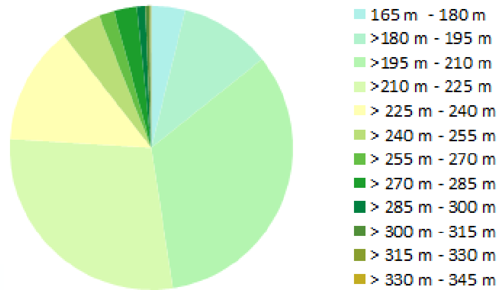
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00236	Hamlin Lake Dam	-86.492230	44.032500

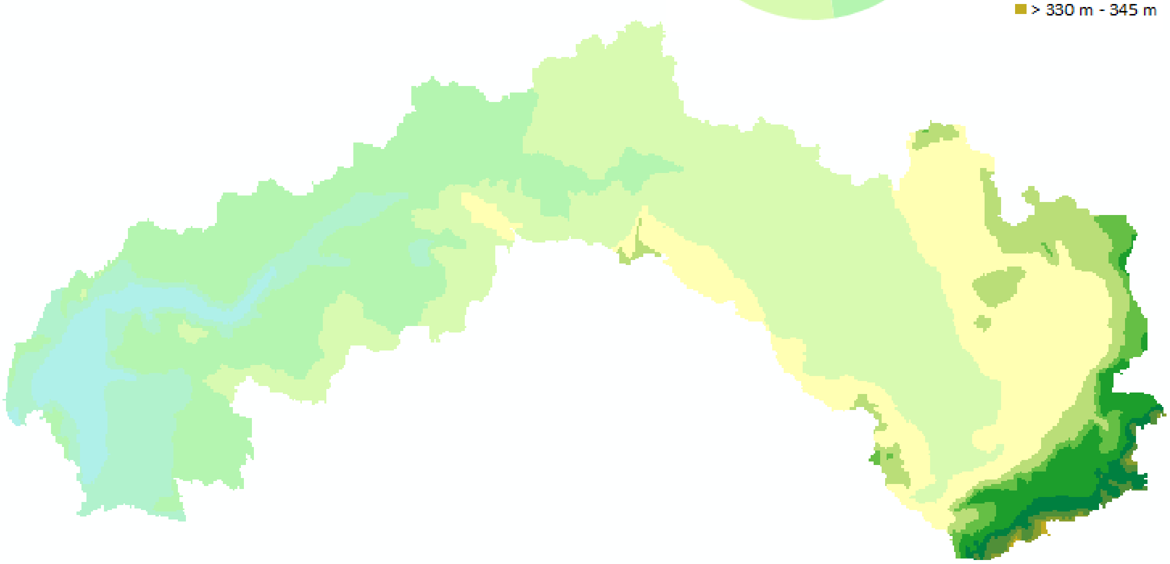
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4123000	BIG SABLE RIVER NEAR FREESOIL, MI	*-86.280083*	*44.120282*	
Number of Active USGS Stream Gage's in Drainage Area (2009)				0

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

5, BIG SABLE WATERSHED

Elevation





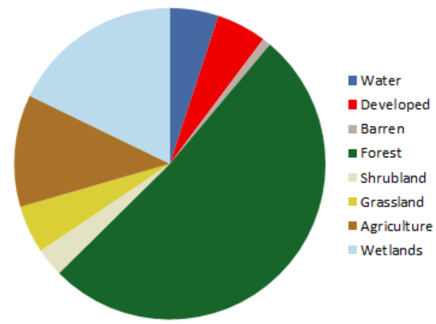
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	19.01	4.12%
>180 m - 195 m	38.93	8.44%
>195 m - 210 m	110.07	23.87%
>210 m - 225 m	159.01	34.48%
>225 m - 240 m	77.49	16.80%
>240 m - 255 m	25.46	5.52%
>255 m - 270 m	9.00	1.95%
>270 m - 285 m	12.82	2.78%
>285 m - 300 m	5.40	1.17%
>300 m - 315 m	2.95	0.64%
>315 m -330 m	0.90	0.19%
>330 m - 345 m	0.18	0.04%
Size of Drainage Area	461.20	100.00%

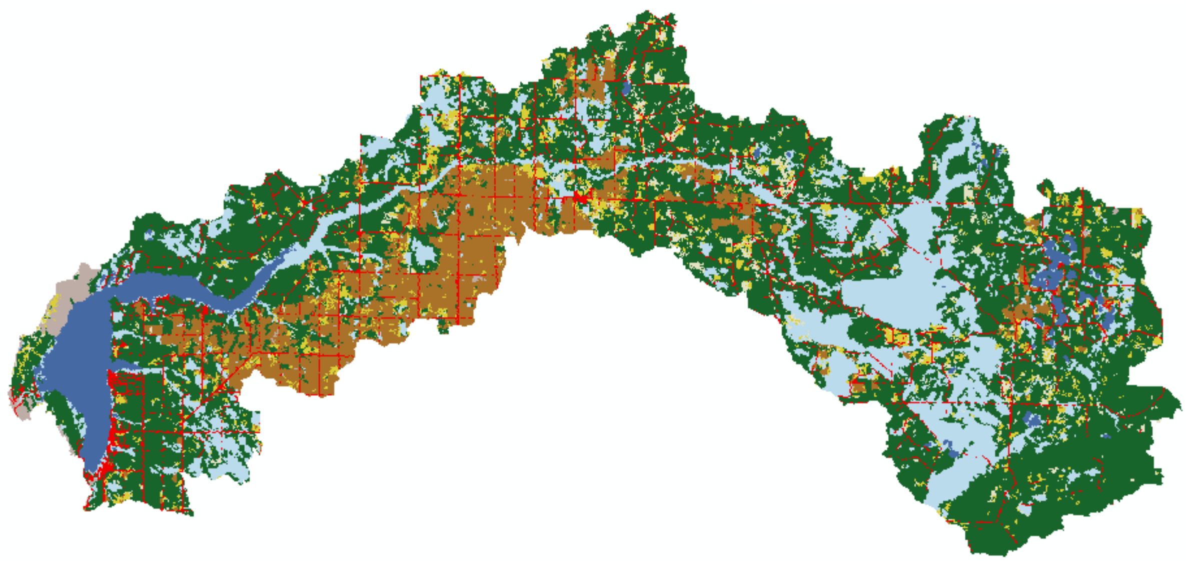
Big Sable Watershed		
Elevation Statistics		
Size of Drainage Area	**461.20**	***km²***
Maximum	335.00	*m*
Minimum	176.00	*m*
Average	217.33	*m*
Standard Deviation	23.81	*m*

All Elevation Measurements with Respect to North American Datum 1983

5, BIG SABLE WATERSHED

Land Use





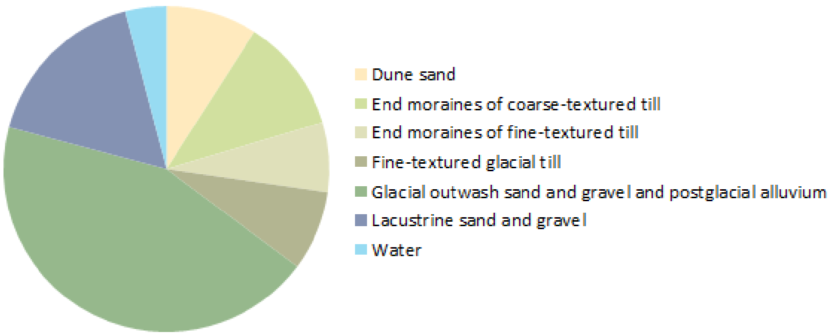
Category	Area	Percentage
Category	*km²*	*%*
Water	23.27	5.05%
Developed	23.99	5.20%
Barren	4.02	0.87%
Forest	237.47	51.49%
Shrubland	13.68	2.97%
Grassland	22.89	4.96%
Agriculture	53.74	11.65%
Wetlands	82.14	17.81%
Total	461.20	100.00%

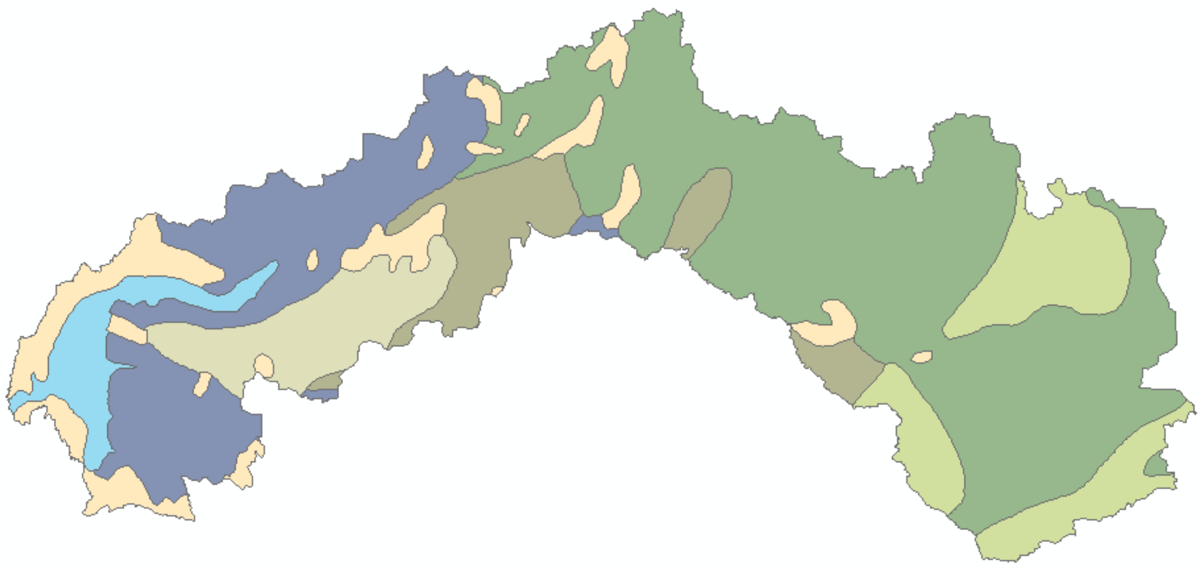
EGLE Runoff Curve Number
61.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

5, BIG SABLE WATERSHED

Surficial Geology



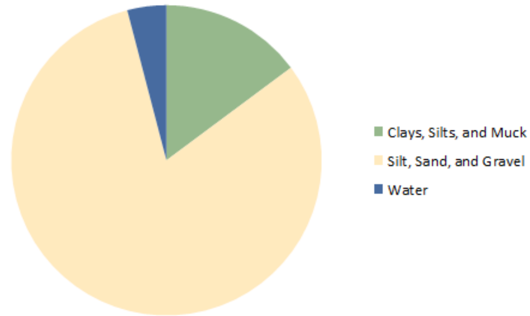


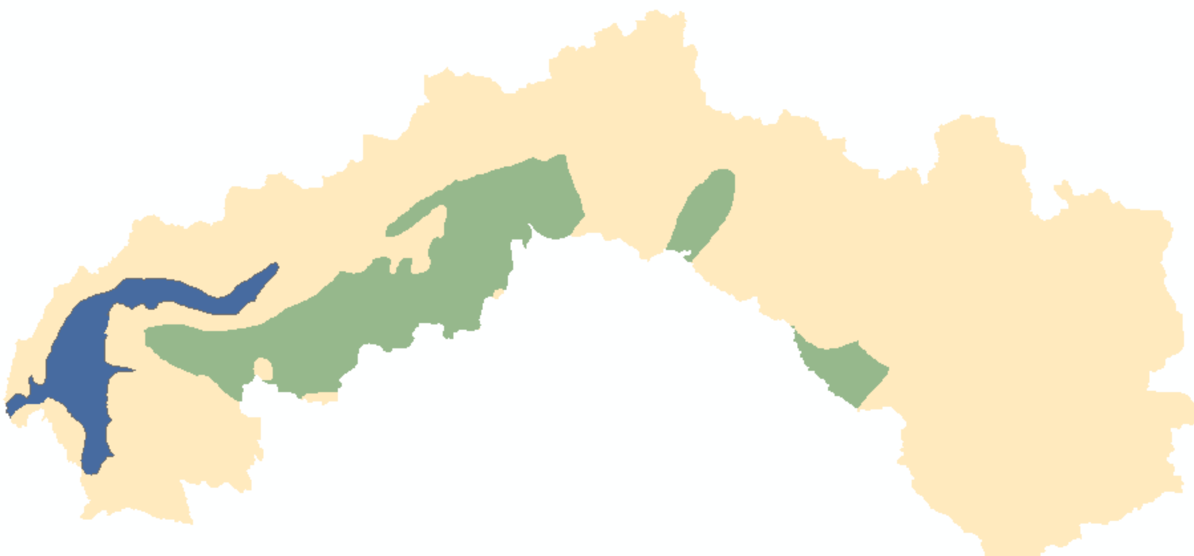
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	41.86	9.08%
End moraines of coarse-textured till	52.11	11.30%
End moraines of fine-textured till	31.87	6.91%
Fine-textured glacial till	36.49	7.91%
Glacial outwash sand and gravel and postglacial alluvium	202.66	43.94%
Lacustrine sand and gravel	77.46	16.80%
Water	18.75	4.07%
Total Watershed Area	461.20	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

5, BIG SABLE WATERSHED

Surficial Geology (Simplified)



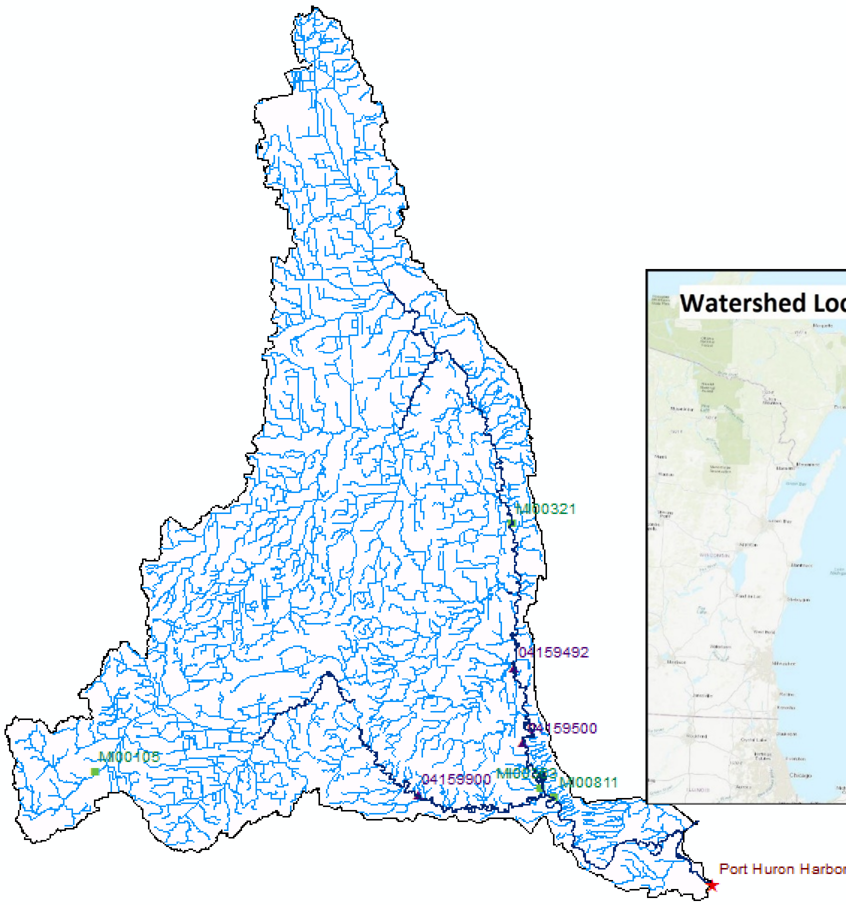


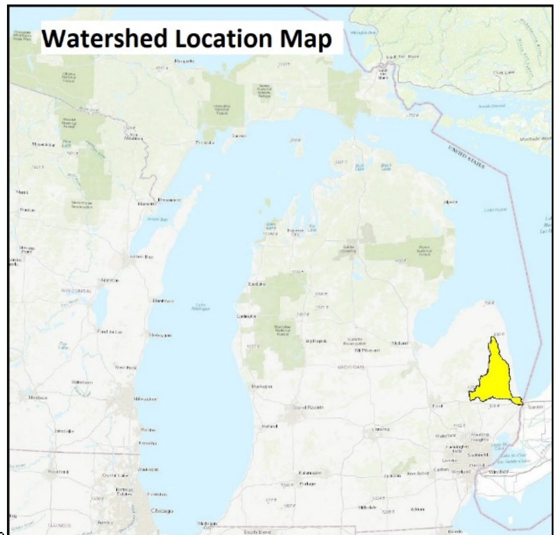
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	68.36	14.82%
Silt, Sand, and Gravel	374.09	81.11%
Water	18.75	4.07%
Total Watershed Area	461.20	85.18%

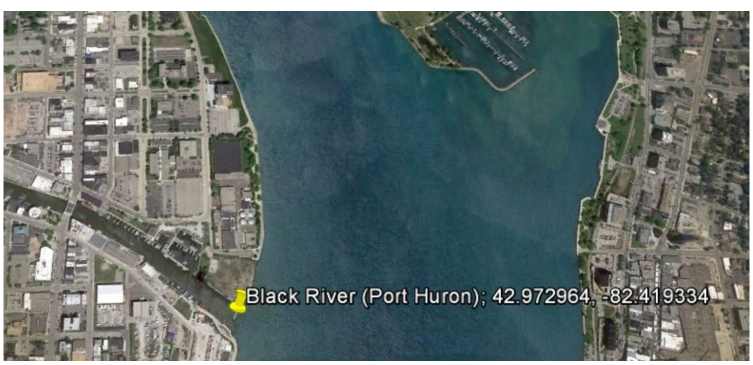
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX I. BLACK RIVER WATERSHED, EAST (6)

Surface Hydrology







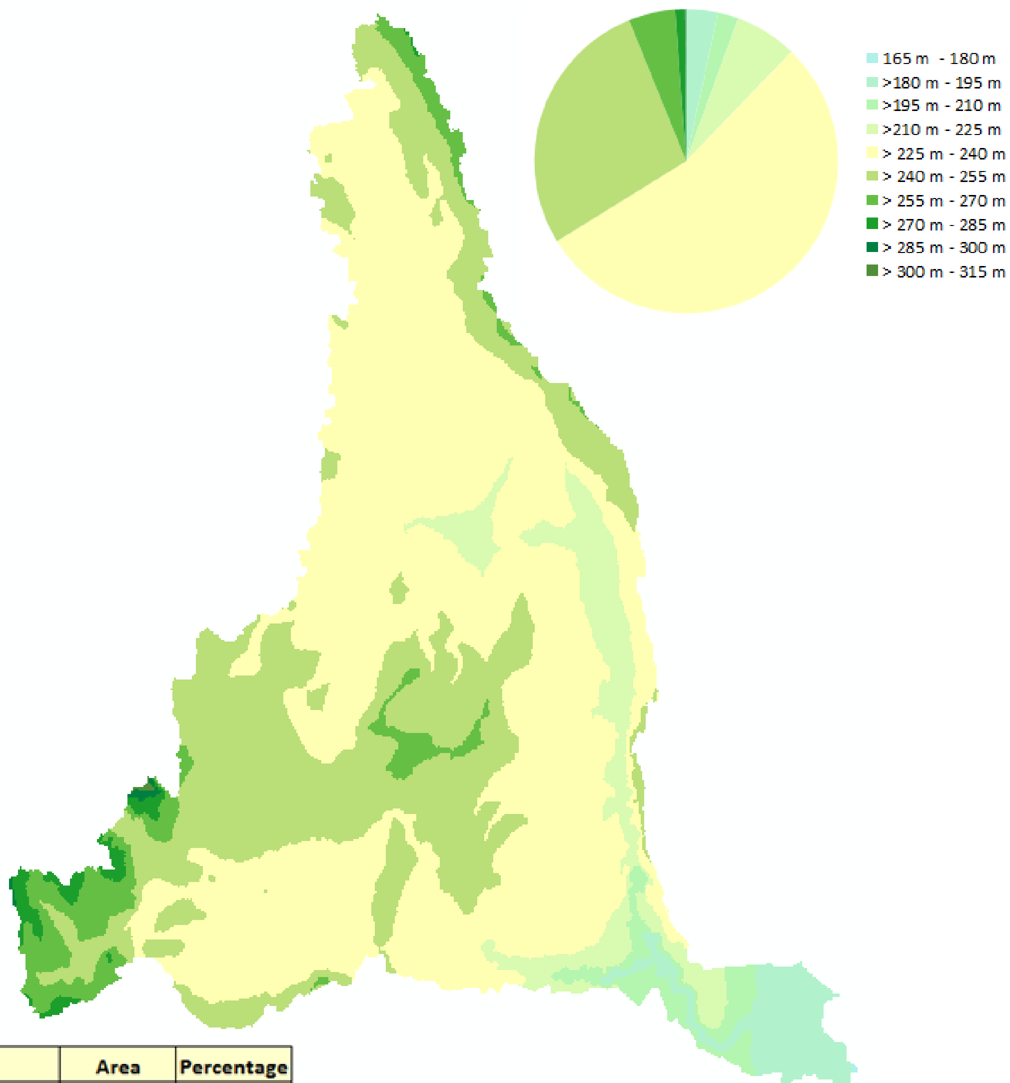
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
04159492	BLACK RIVER NEAR JEDDO, MI	*-82.624092*	*43.152527*	yes
04159500	BLACK RIVER NEAR FARGO, MI	-82.61798	43.092250	
04159900	MILL CREEK NEAR AVOCA, MI	-82.73465	43.054471	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				2

USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00105	Mill Creek Structure	-83.083340	43.083330
MI00321	Croswell Dam	-82.620640	43.267860
MI00363	Fords Dam	-82.600000	43.056670
MI00811	Port Huron SGA #4	-82.586390	43.048330

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

6, BLACK RIVER WATERSHED (EAST)

Elevation



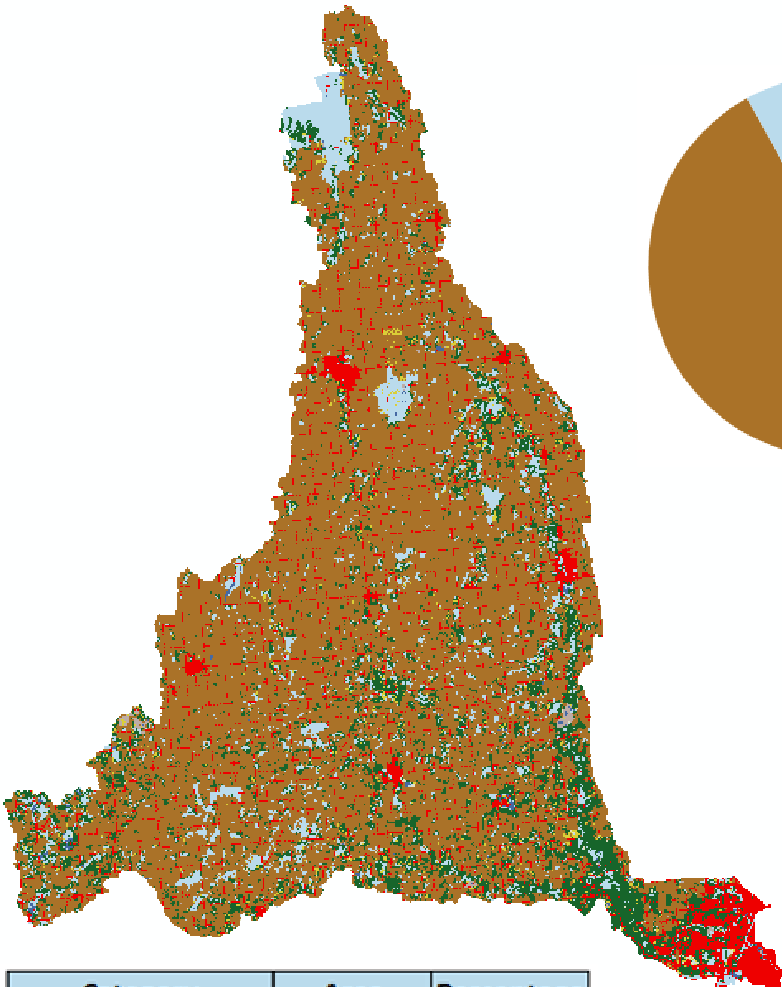
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.29	0.02%
>180 m - 195 m	61.69	3.35%
>195 m - 210 m	40.57	2.20%
>210 m - 225 m	122.17	6.64%
>225 m - 240 m	993.13	53.97%
>240 m - 255 m	509.35	27.68%
>255 m - 270 m	91.42	4.97%
>270 m - 285 m	19.03	1.03%
>285 m - 300 m	1.84	0.10%
>300 m - 315 m	0.70	0.04%
Size of Drainage Area	1840.19	100.00%

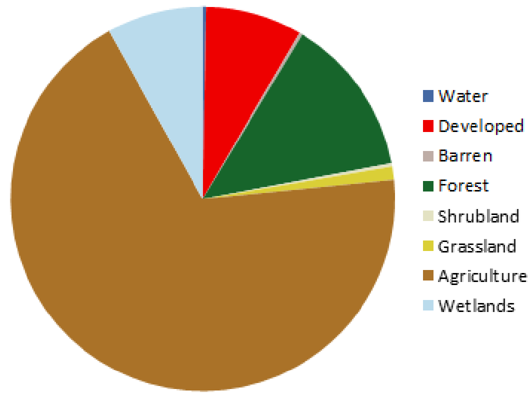
Black (East) Watershed		
Elevation Statistics		
Size of Drainage Area	**1840.19**	***km²***
Maximum	308.00	*m*
Minimum	177.00	*m*
Average	235.19	*m*
Standard Deviation	14.81	*m*

All Elevation Measurements with Respect to North American Datum 1983

6, BLACK RIVER WATERSHED (EAST)

Land Use





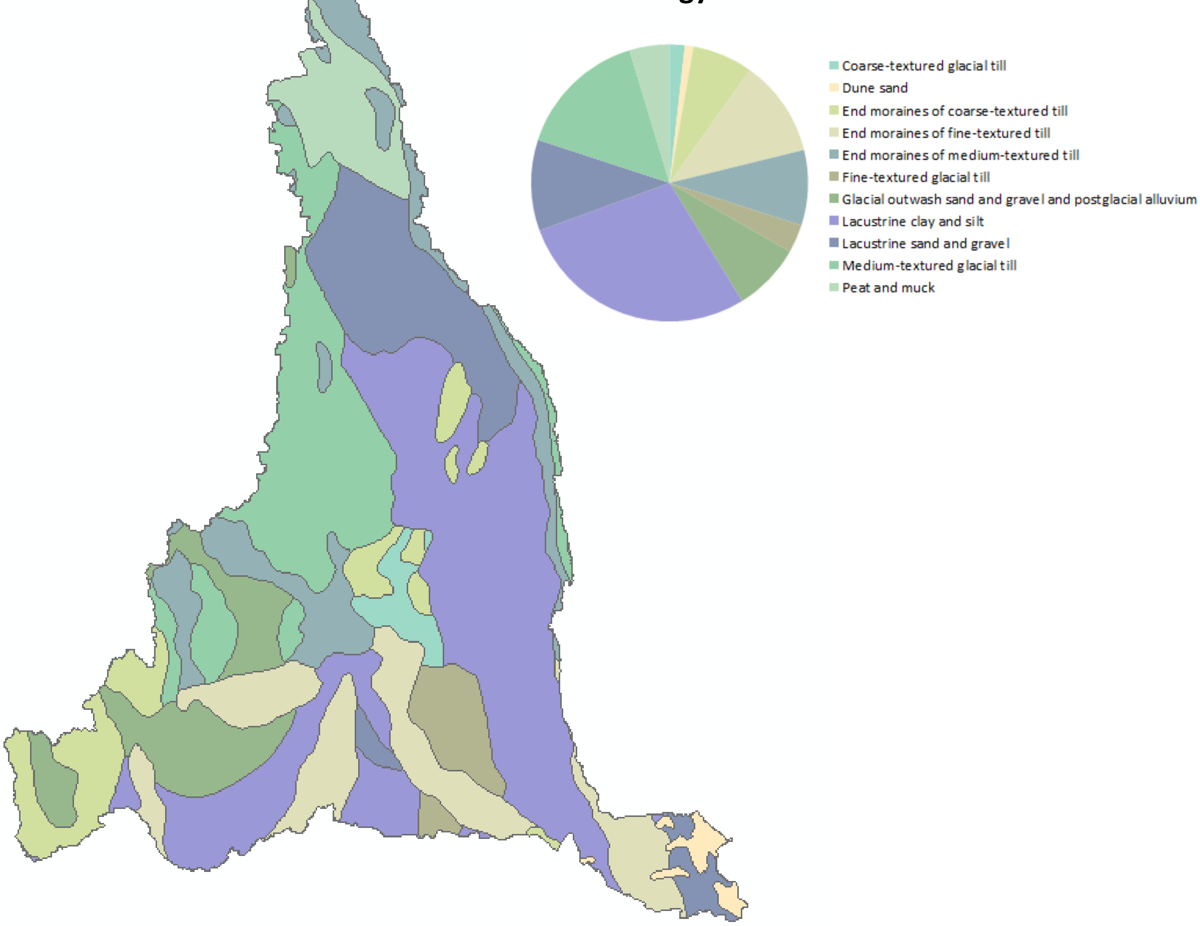
Category	Area	Percentage
Category	*km²*	*%*
Water	5.56	0.30%
Developed	149.01	8.10%
Barren	4.86	0.26%
Forest	245.67	13.35%
Shrubland	5.09	0.28%
Grassland	20.46	1.11%
Agriculture	1260.60	68.50%
Wetlands	148.93	8.09%
Total	1840.19	100.00%

EGLE Runoff Curve Number
76.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

6, BLACK RIVER WATERSHED (EAST)

Surficial Geology

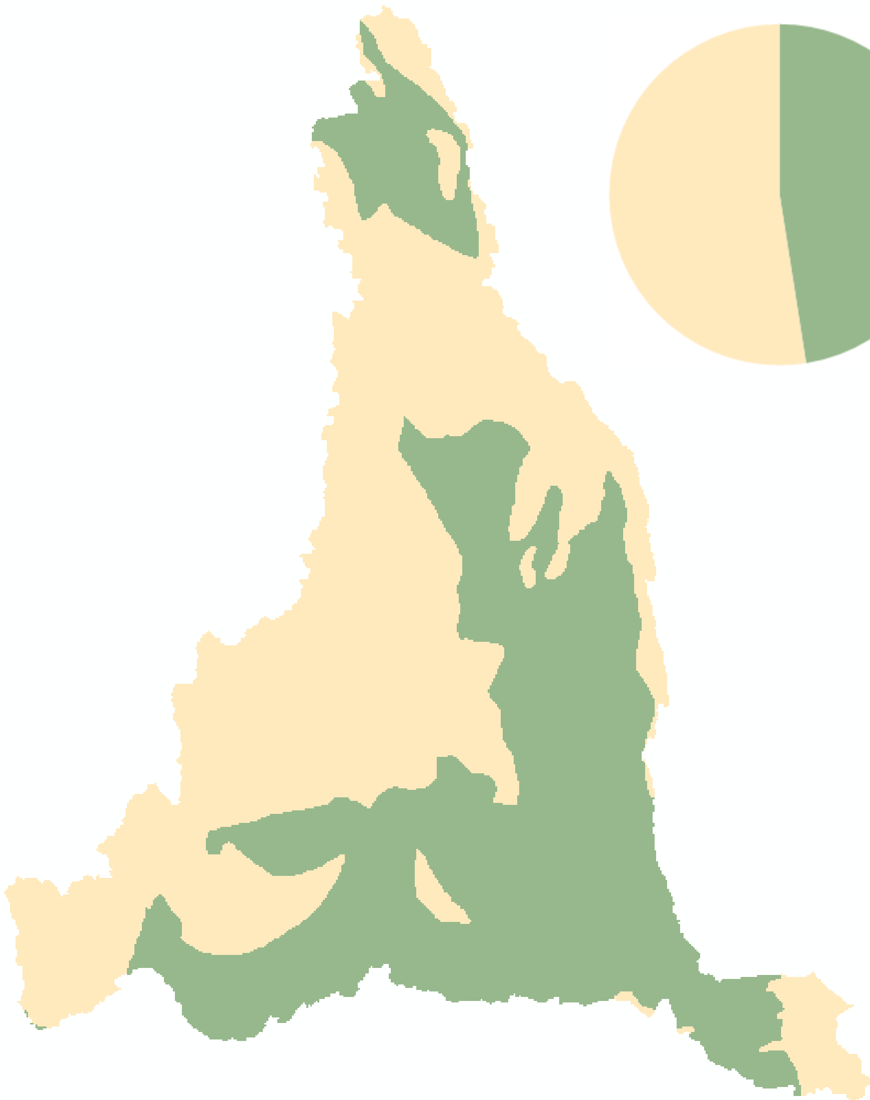


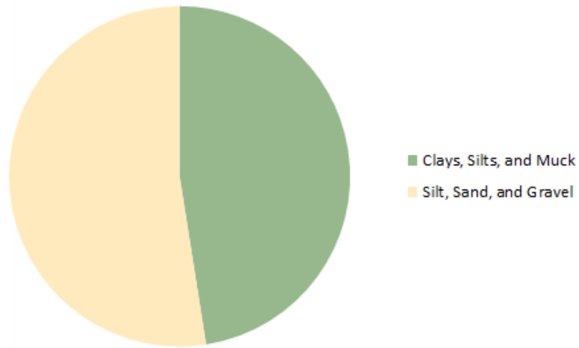
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	32.43	1.76%
Dune sand	18.80	1.02%
End moraines of coarse-textured till	130.12	7.07%
End moraines of fine-textured till	208.16	11.31%
End moraines of medium-textured till	161.58	8.78%
Fine-textured glacial till	60.95	3.31%
Glacial outwash sand and gravel and postglacial alluvium	146.40	7.96%
Lacustrine clay and silt	519.14	28.21%
Lacustrine sand and gravel	195.09	10.60%
Medium-textured glacial till	281.48	15.30%
Peat and muck	86.03	4.68%
Total Watershed Area	1840.19	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

6, BLACK RIVER WATERSHED (EAST)

Surficial Geology (Simplified)



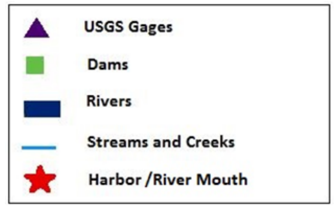


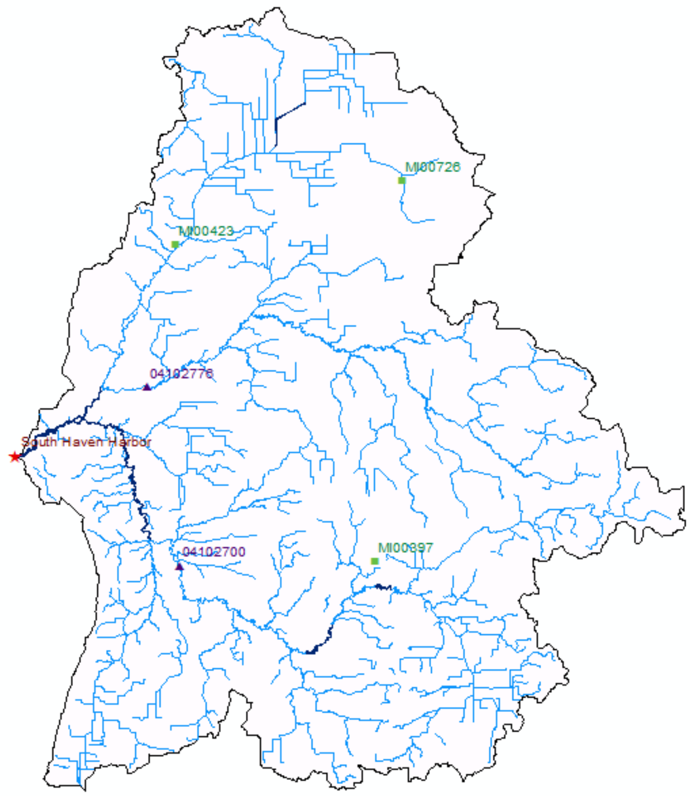
Category	Area	Percentage
Category	*km²*	*%*
Clay,Silt, and Muck	874.28	47.51%
Silt, Sand, and Gravel	965.91	52.49%
Total Watershed Area	1840.19	100.00%

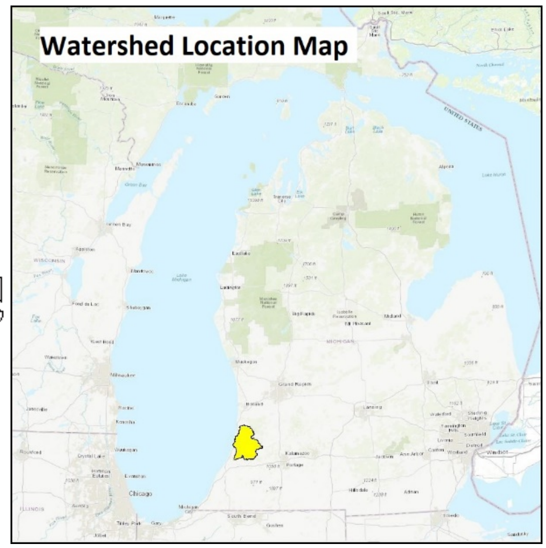
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX J. BLACK RIVER WATERSHED, WEST (7)

Surface Hydrology





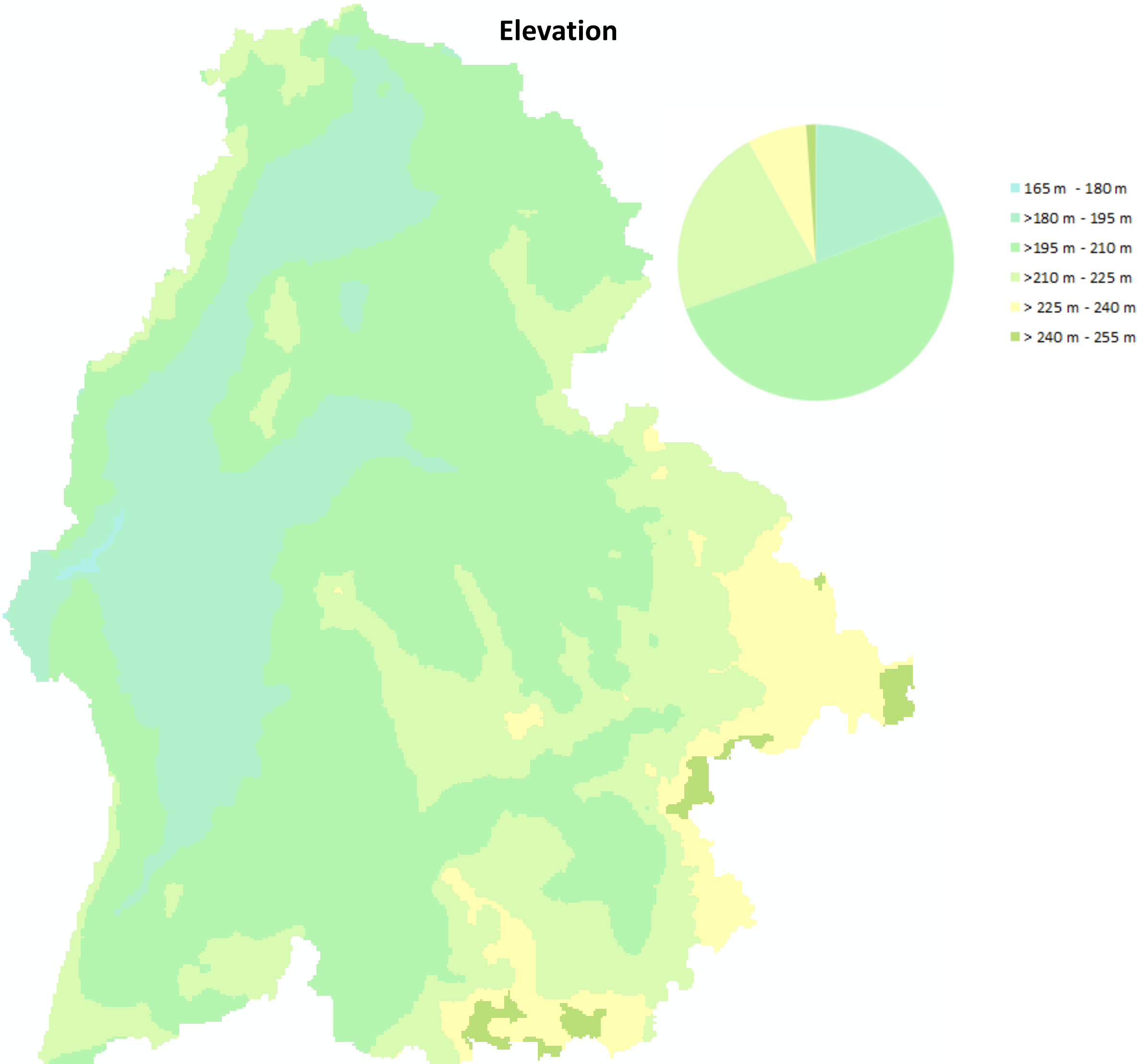


USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00397	Phoenix Dam	-86.071660	42.356670
MI00423	Black River Dam	-86.190000	42.495000
MI00726	Crooked Lake Dam (Structure #4)	-86.055500	42.523500

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4102700	SOUTH BRANCH BLACK RIVER NEAR BANGOR, MI	-86.18753	42.354200	yes
4102776	MIDDLE BRANCH BLACK RIVER NEAR SOUTH HAVEN, MI	-86.20697	42.432531	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				2

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

7, BLACK RIVER WATERSHED (WEST)



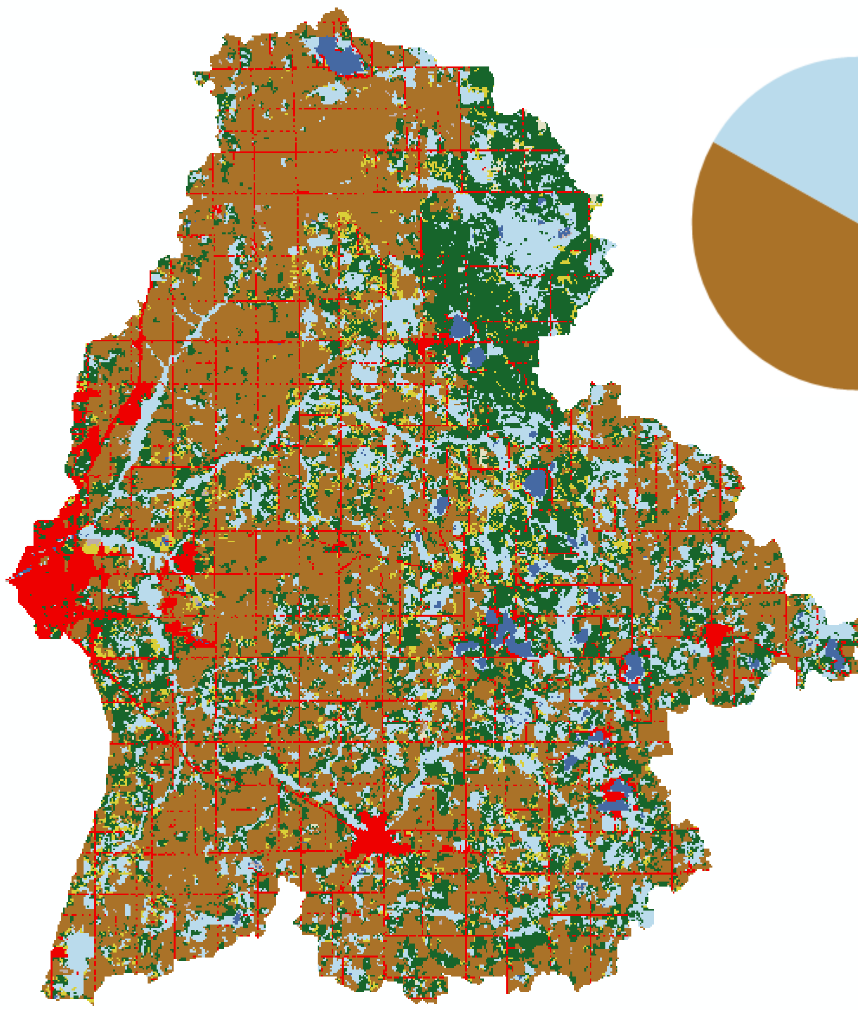
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.97	0.13%
>180 m - 195 m	141.56	19.07%
>195 m - 210 m	373.70	50.35%
>210 m - 225 m	165.96	22.36%
>225 m - 240 m	51.79	6.98%
>240 m - 255 m	8.28	1.12%
Size of Drainage Area	742.26	100.00%

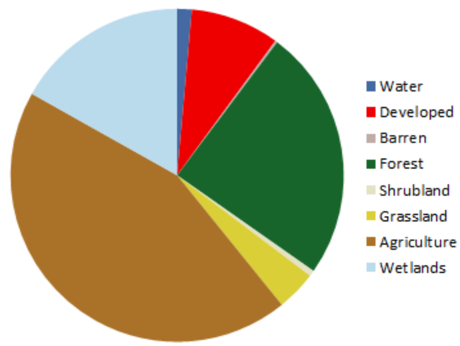
Black Watershed (West)		
Elevation Statistics		
Size of Drainage Area	**742.26**	***km²***
Maximum	246.00	*m*
Minimum	179.00	*m*
Average	204.62	*m*
Standard Deviation	12.16	*m*

All Elevation Measurements with Respect to North American Datum 1983

7, BLACK RIVER WATERSHED (WEST)

Land Use





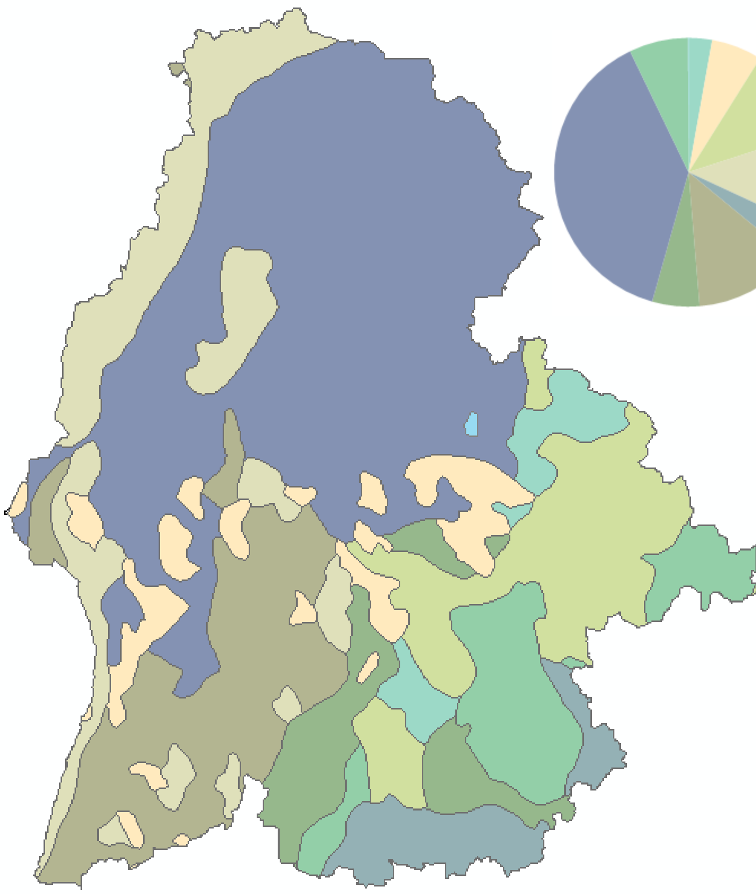
Category	Area	Percentage
Category	*km²*	*%*
Water	10.52	1.42%
Developed	64.01	8.62%
Barren	1.58	0.21%
Forest	181.73	24.48%
Shrubland	4.17	0.56%
Grassland	28.81	3.88%
Agriculture	326.35	43.97%
Wetlands	125.10	16.85%
Total	742.26	100.00%

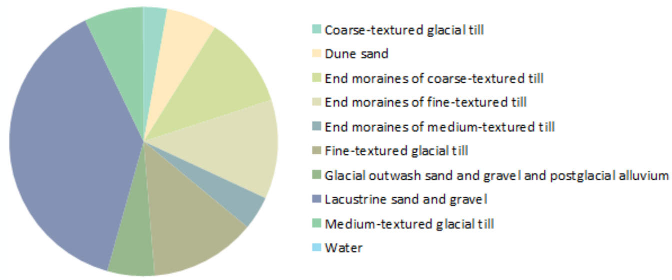
EGLE Runoff Curve Number
69.1

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

7, BLACK RIVER WATERSHED (WEST)

Surficial Geology



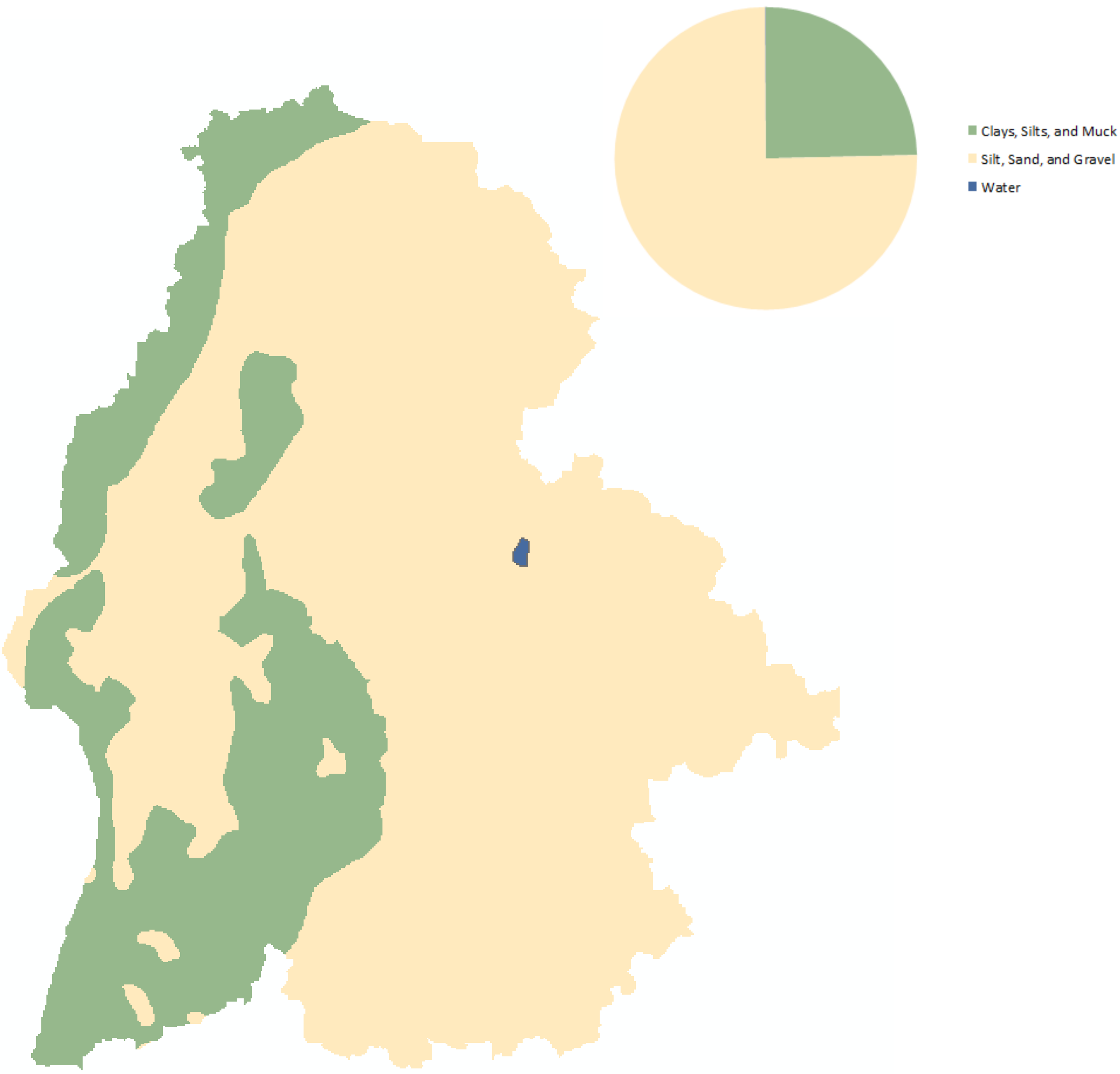


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	20.94	2.82%
Dune sand	45.26	6.10%
End moraines of coarse-textured till	82.34	11.09%
End moraines of fine-textured till	88.38	11.91%
End moraines of medium-textured till	30.02	4.04%
Fine-textured glacial till	94.46	12.73%
Glacial outwash sand and gravel and postglacial alluvium	42.13	5.68%
Lacustrine sand and gravel	285.53	38.47%
Medium-textured glacial till	52.74	7.11%
Water	0.47	0.06%
Total Watershed Area	742.26	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

7, BLACK RIVER WATERSHED (WEST)

Surficial Geology (Simplified)

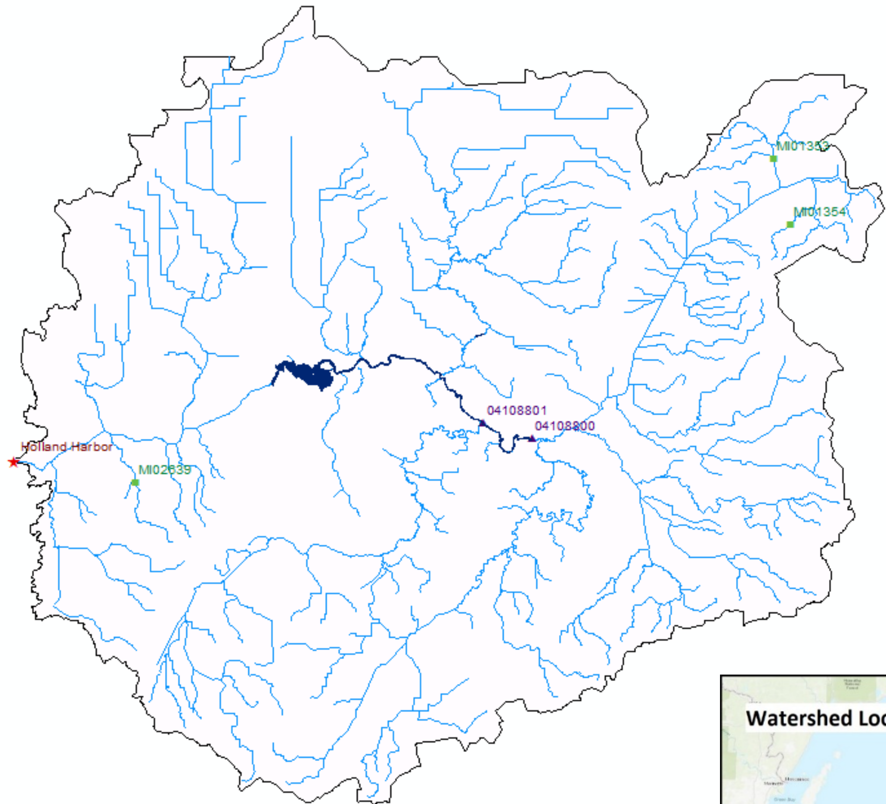


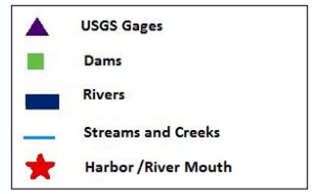
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	182.85	24.63%
Silt, Sand, and Gravel	558.94	75.30%
Water	0.47	0.06%
Total Watershed Area	742.26	100.00%

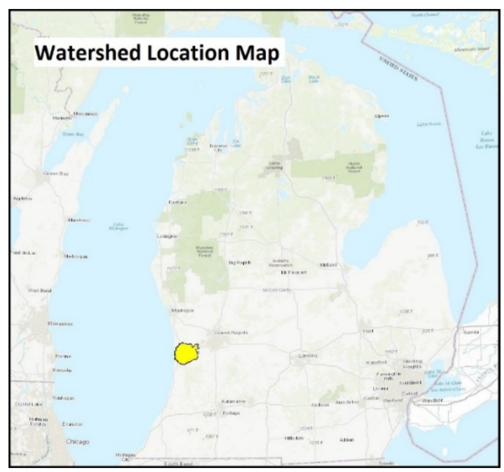
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX K. MACATAWA RIVER WATERSHED (8)

Surface Hydrology







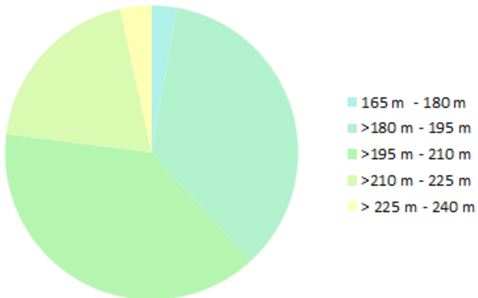
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01353	Beren s Dam	-85.927290	42.856950
MI01354	Steenwyk Dam	-85.921200	42.838690
MI02639	Ottogan Dam	-86.167050	42.767180

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4108800	MACATAWA RIVER AT STATE ROAD NEAR ZEELAND, MI	-85.43673	44.656670	yes
4108801	MACATAWA RIVER NEAR ZEELAND, MI	-85.51951	44.638336	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

8, MACATAWA RIVER WATERSHED

Elevation



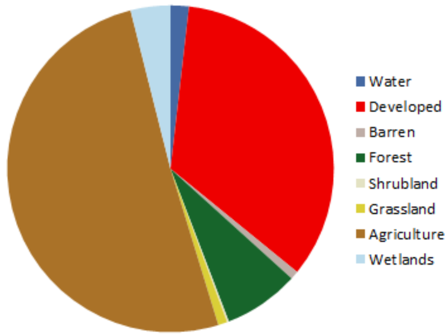
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	12.29	2.72%
>180 m - 195 m	160.21	35.47%
>195 m - 210 m	175.36	38.83%
>210 m - 225 m	88.04	19.49%
>225 m - 240 m	15.71	3.48%
Size of Drainage Area	451.61	100.00%

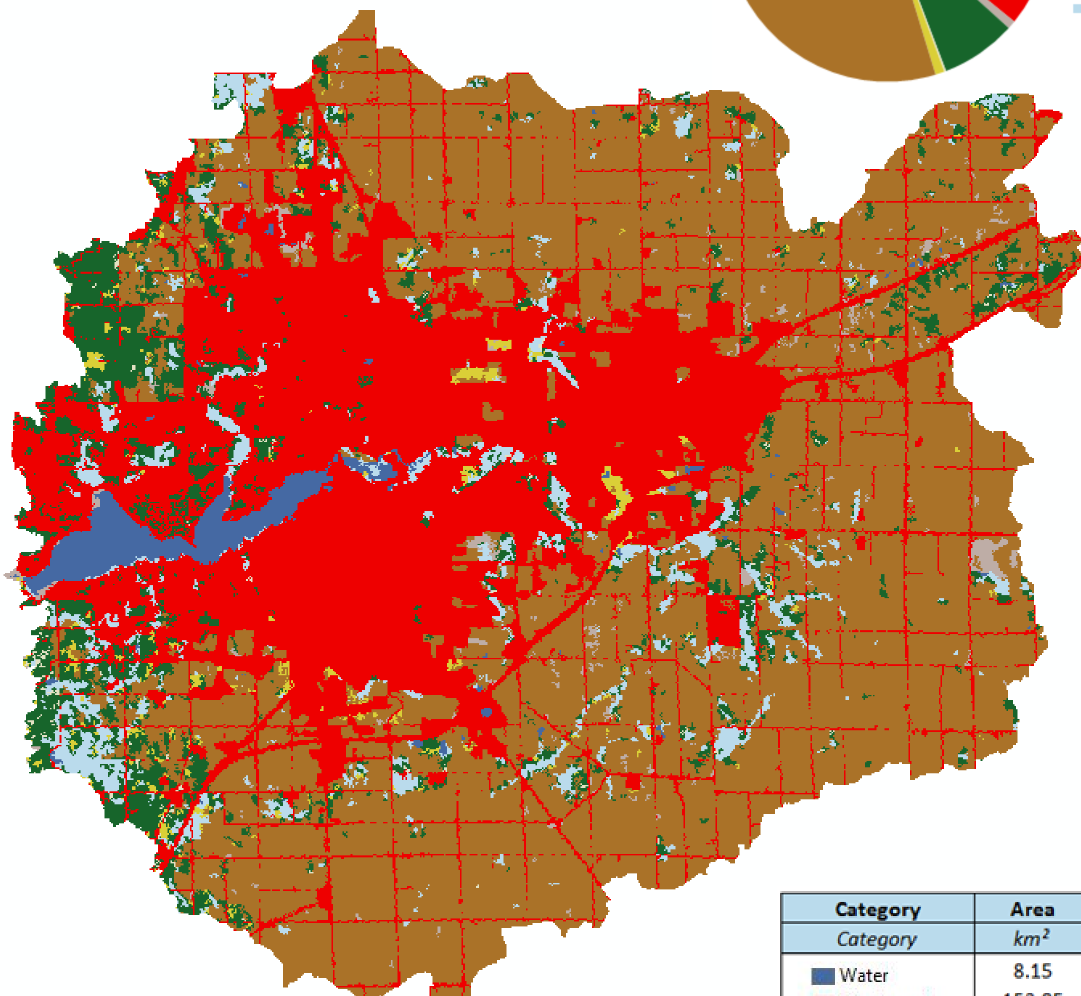
Macatawa Watershed		
Elevation Statistics		
Size of Drainage Area	**451.61**	***km²***
Maximum	234.00	*m*
Minimum	176.00	*m*
Average	199.53	*m*
Standard Deviation	12.32	*m*

All Elevation Measurements with Respect to North American Datum 1983

8, MACATAWA RIVER WATERSHED

Land Use



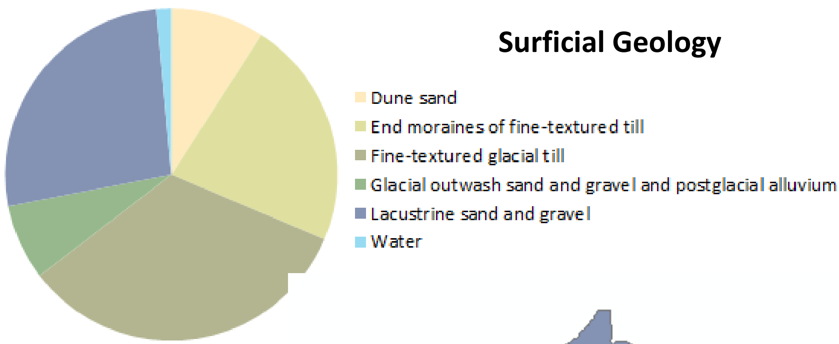


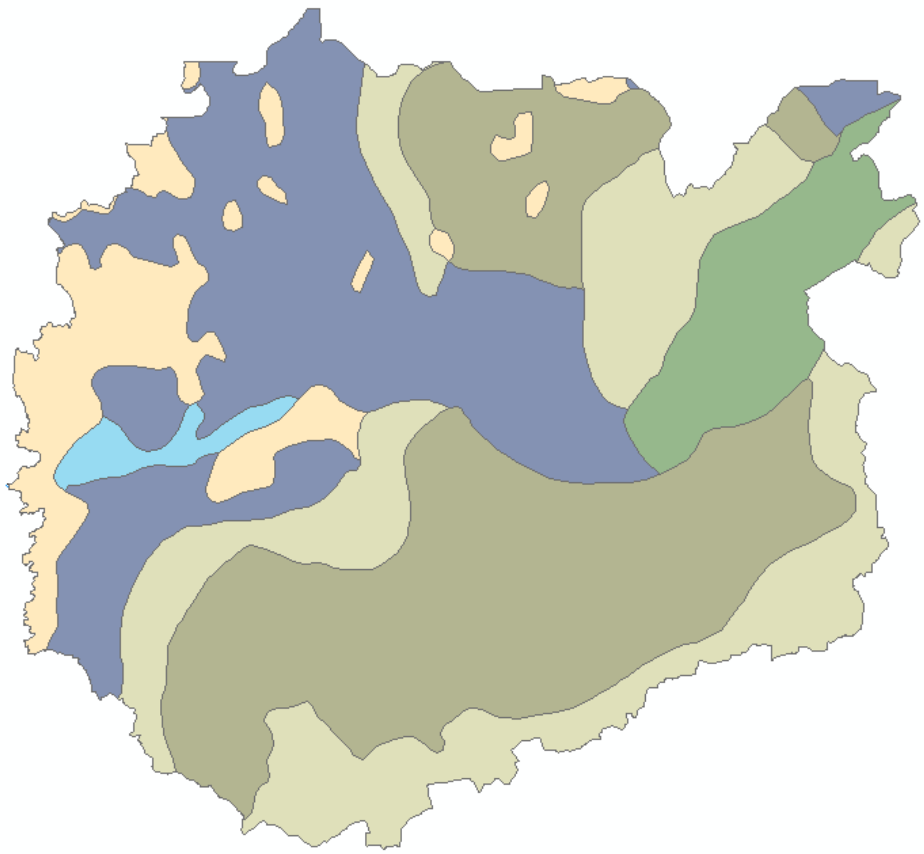
EGLE Runoff Curve Number
75.9

Category	Area	Percentage
Category	*km²*	*%*
Water	8.15	1.80%
Developed	153.85	34.07%
Barren	3.76	0.83%
Forest	33.80	7.48%
Shrubland	0.84	0.19%
Grassland	4.06	0.90%
Agriculture	229.34	50.78%
Wetlands	17.80	3.94%
Total	451.61	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

8, MACATAWA RIVER WATERSHED



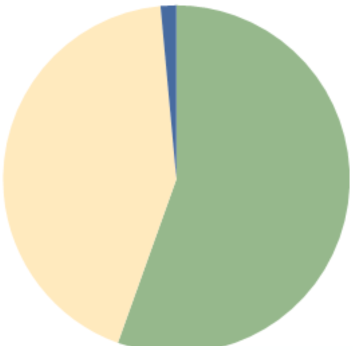


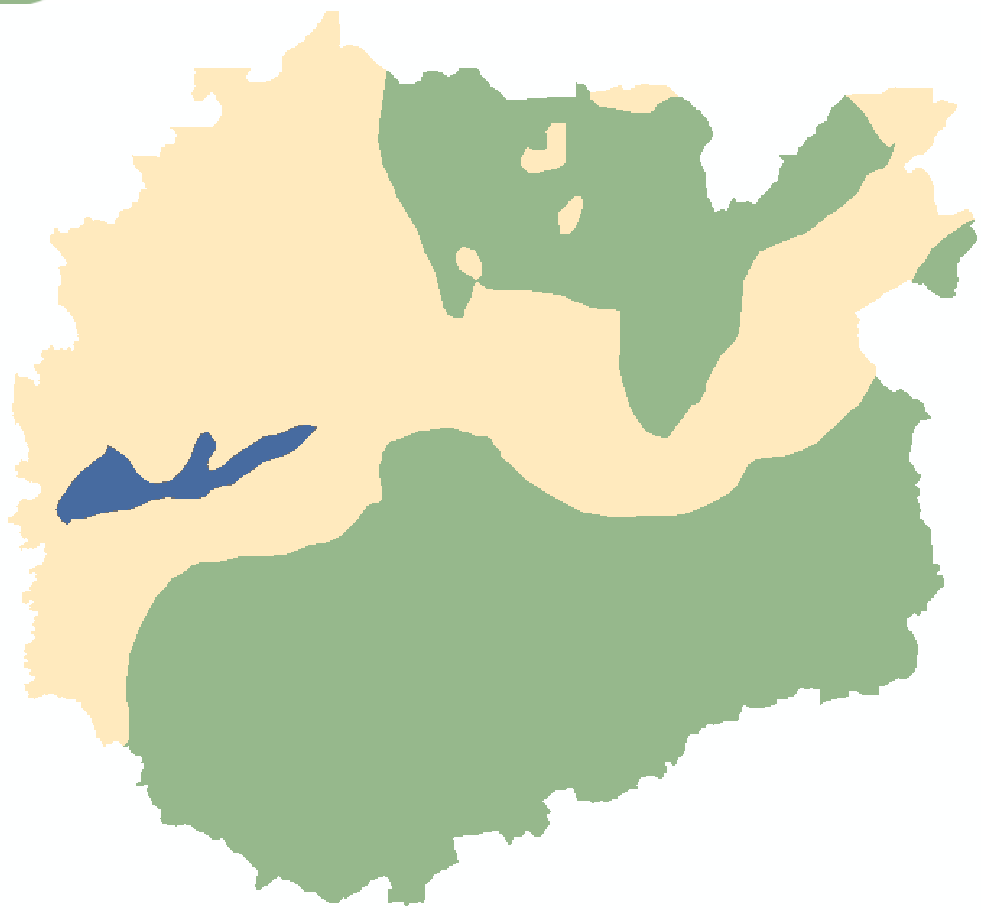
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	41.11	9.10%
End moraines of fine-textured till	100.52	22.26%
Fine-textured glacial till	150.05	33.23%
Glacial outwash sand and gravel and postglacial alluvium	33.25	7.36%
Lacustrine sand and gravel	120.07	26.59%
Water	6.61	1.46%
Total Watershed Area	451.61	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

8, MACATAWA RIVER WATERSHED

Surficial Geology (Simplified)



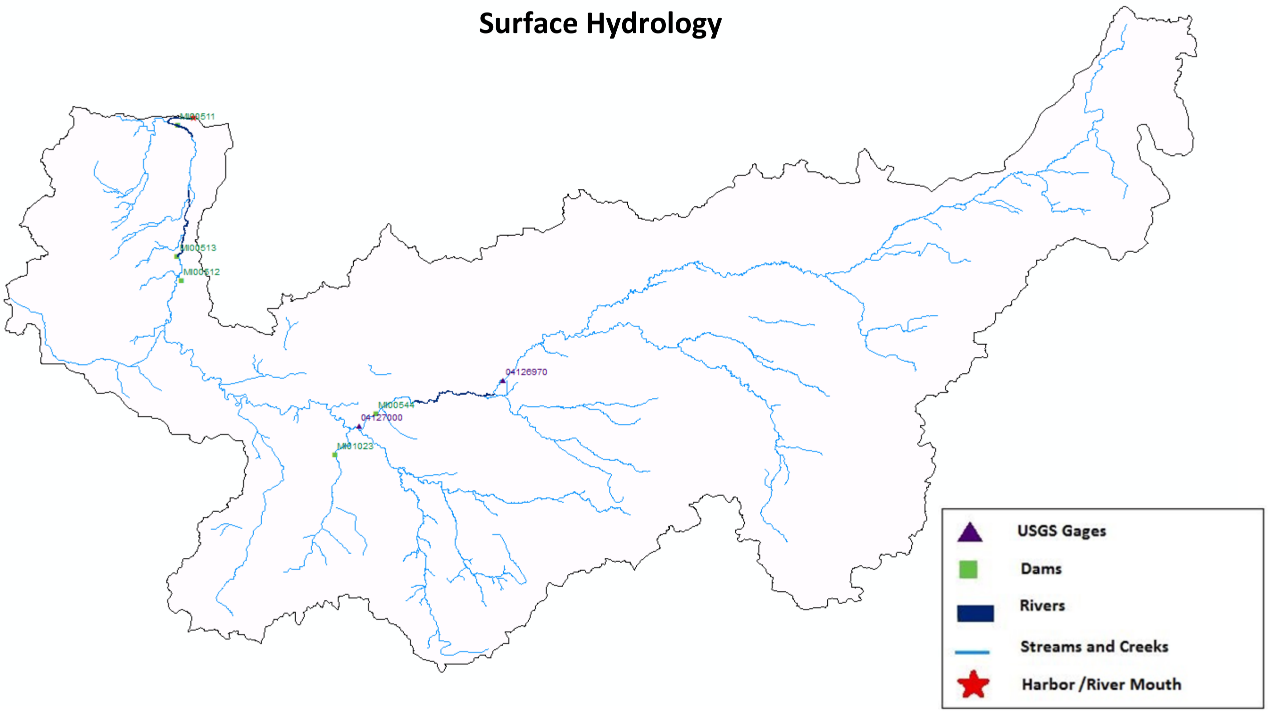


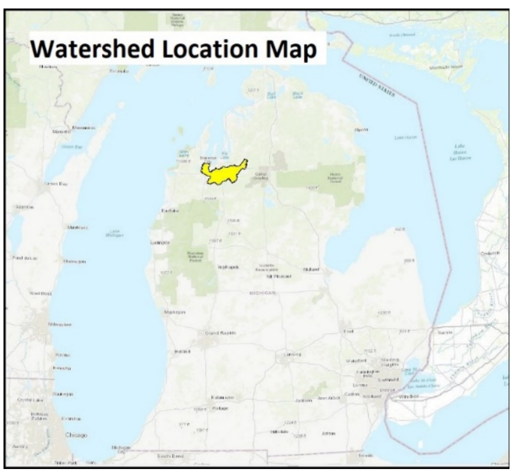
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	250.57	55.48%
Silt, Sand, and Gravel	194.43	43.05%
Water	6.61	1.46%
Total Watershed Area	451.61	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

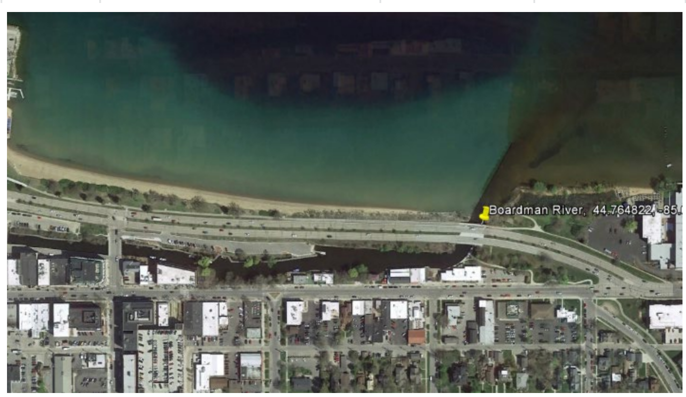
APPENDIX L. BOARDMAN RIVER WATERSHED (9)

Surface Hydrology





USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01023	Mayfield Electric Light Plant Dam	-85.533330	44.626670
MI00511	Union Street Dam	-85.622440	44.761650
MI00512	Boardman Dam	-85.620550	44.698330
MI00513	Sabin Dam	-85.622830	44.708030
MI00544	Brown Bridge Dam	-85.509510	44.643420

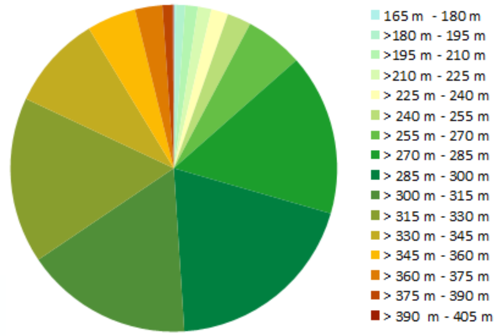


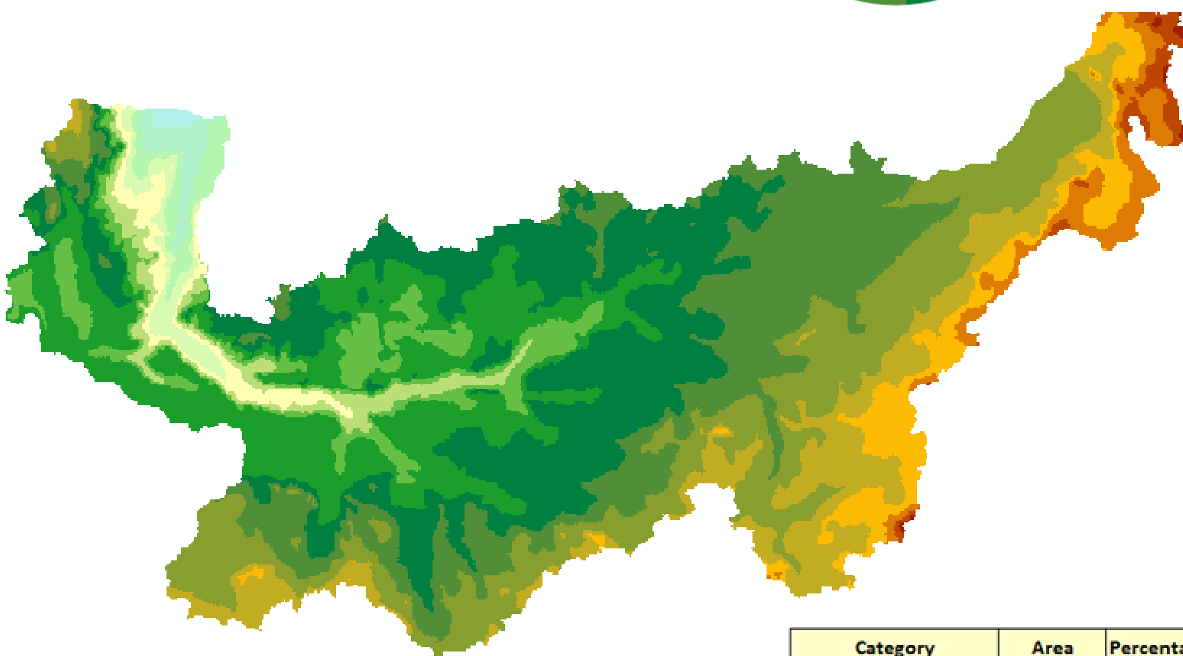
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
04126970	BOARDMAN R ABOVE BROWN BRIDGE ROAD NR MAYFIELD, MI	-85.43673	44.656670	yes
04127000	BOARDMAN RIVER NEAR MAYFIELD, MI	-85.51951	44.638336	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

9, BOARDMAN RIVER WATERSHED

Elevation





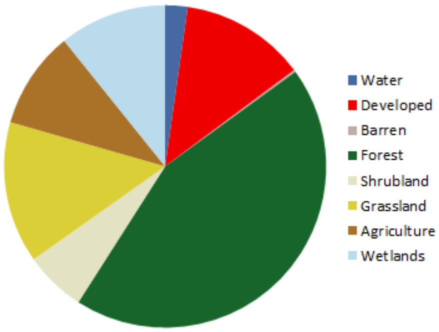
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.57	0.21%
>180 m - 195 m	6.68	0.91%
>195 m - 210 m	9.20	1.25%
>210 m - 225 m	9.82	1.34%
>225 m - 240 m	12.38	1.68%
>240 m - 255 m	17.32	2.36%
>255 m - 270 m	42.32	5.76%
>270 m - 285 m	117.26	15.95%
>285 m - 300 m	143.38	19.51%
>300 m - 315 m	121.90	16.58%
>315 m -330 m	120.83	16.44%
>330 m - 345 m	68.52	9.32%
>345 m - 360 m	35.79	4.87%
>360 m - 375 m	19.88	2.70%
>375 m - 390 m	7.37	1.00%
>390 m - 405 m	0.82	0.11%
Size of Drainage Area	735.03	100.00%

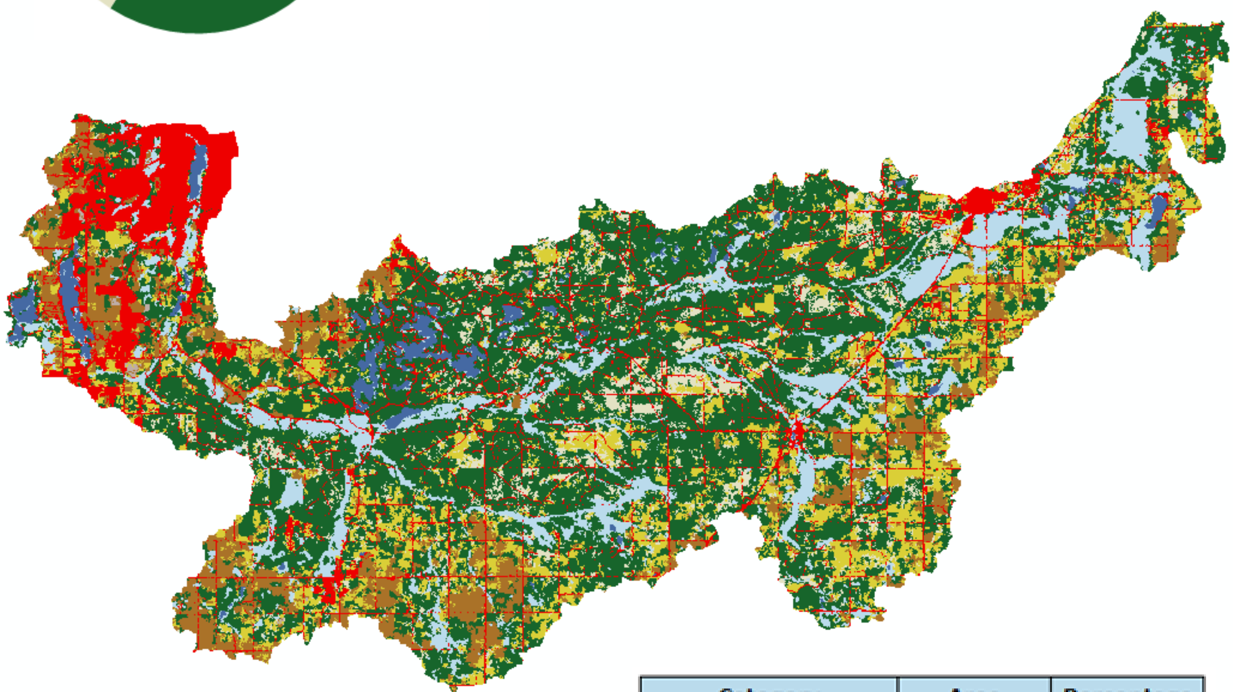
Boardman Watershed		
Elevation Statistics		
Size of Drainage Area	**735.03**	***km²***
Maximum	396.00	*m*
Minimum	177.00	*m*
Average	299.36	*m*
Standard Deviation	35.01	*m*

All Elevation Measurements with Respect to North American Datum 1983

9, BOARDMAN RIVER WATERSHED

Land Use





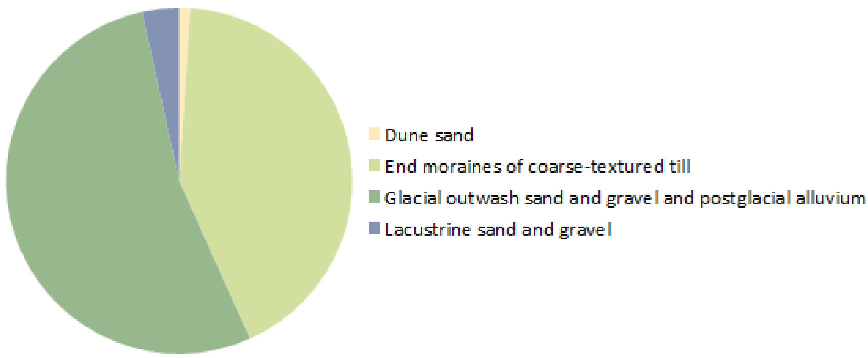
Category	Area	Percentage
Category	*km²*	*%*
Water	16.50	2.25%
Developed	92.31	12.56%
Barren	1.51	0.20%
Forest	323.75	44.05%
Shrubland	45.31	6.16%
Grassland	104.43	14.21%
Agriculture	71.95	9.79%
Wetlands	79.26	10.78%
Total	735.03	100.00%

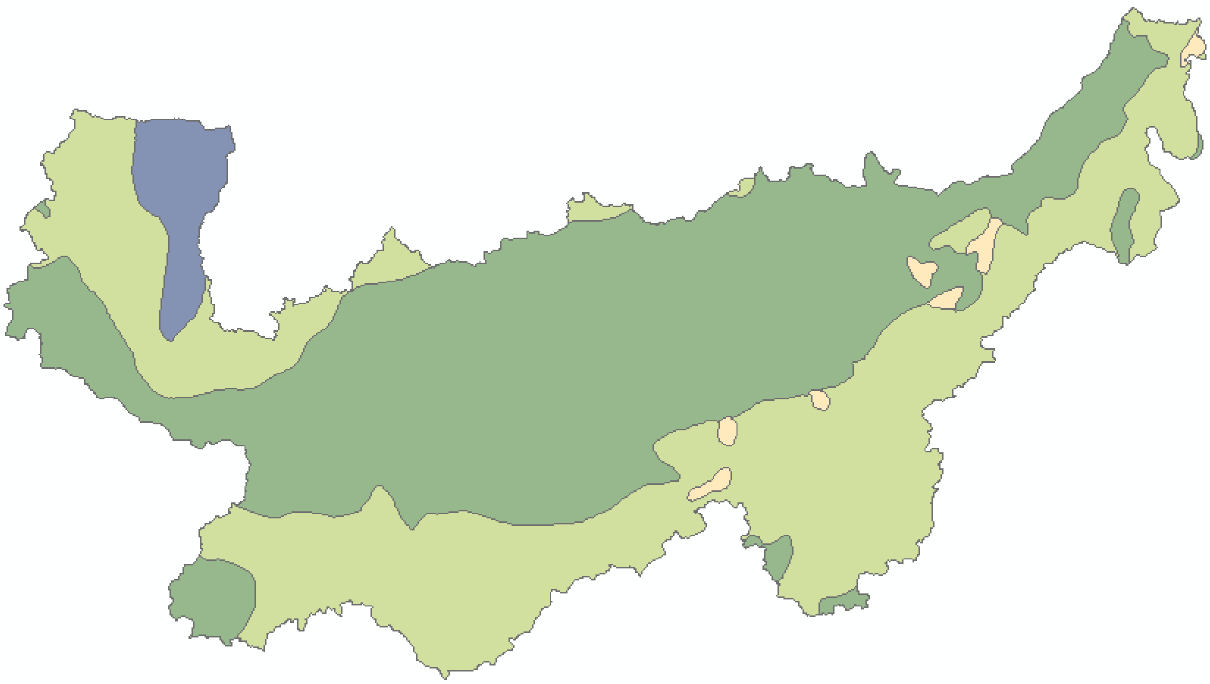
EGLE Runoff Curve Number
56.1

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

9, BOARDMAN RIVER WATERSHED

Surficial Geology



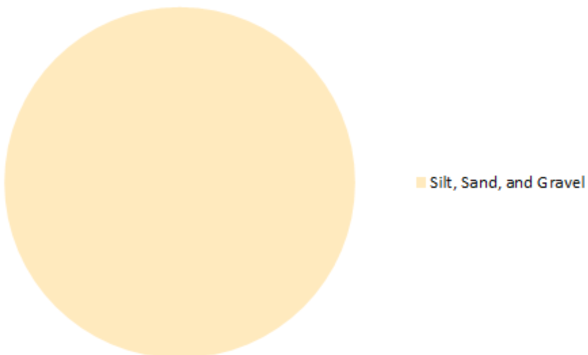


Category	Area	Percentage
Category	*km²*	*%*
Dune sand	7.56	1.03%
End moraines of coarse-textured till	310.72	42.27%
Glacial outwash sand and gravel and postglacial alluvium	391.35	53.24%
Lacustrine sand and gravel	25.39	3.45%
Total Watershed Area	735.03	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

9, BOARDMAN RIVER WATERSHED

Surficial Geology (Simplified)

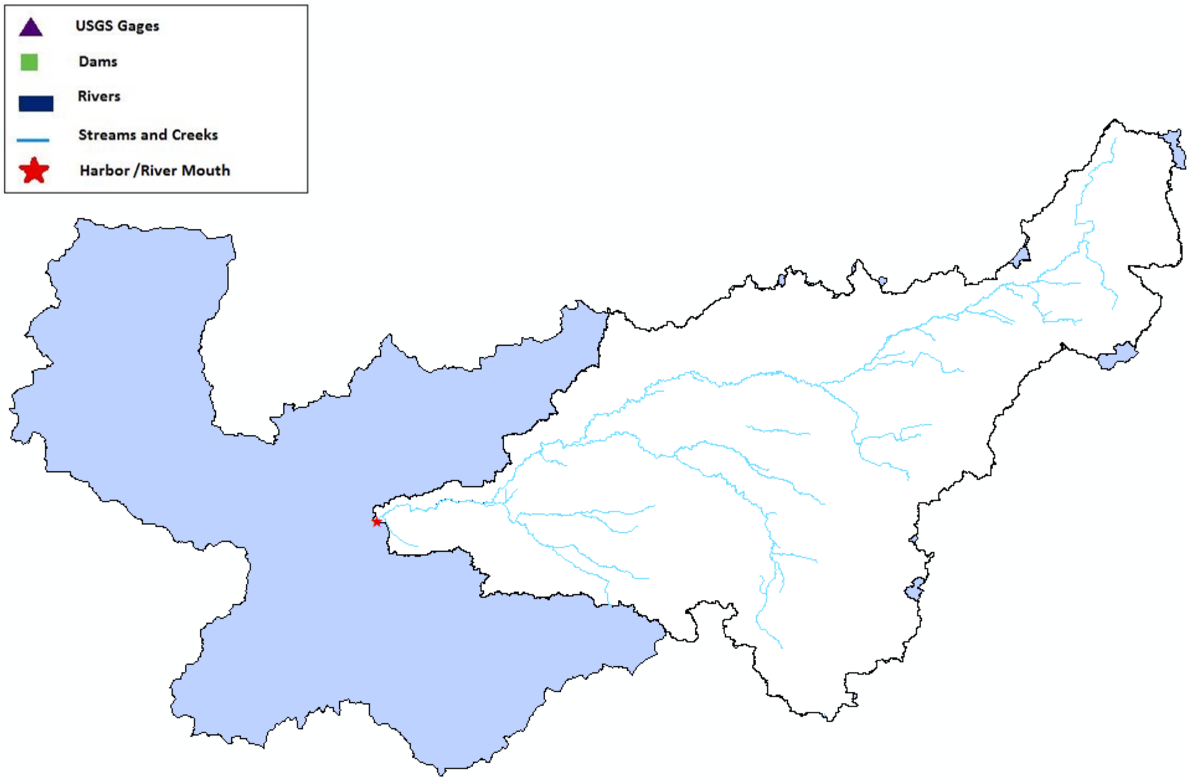


Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	735.03	100.00%
Total Watershed Area	735.03	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX M. BOARDMAN RIVER WATERSHED, BROWN BRIDGE POND (9A)

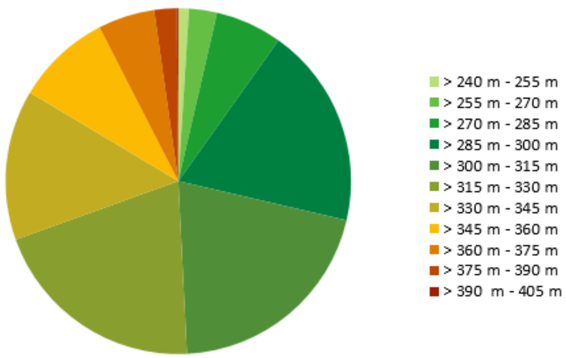
Surface Hydrology

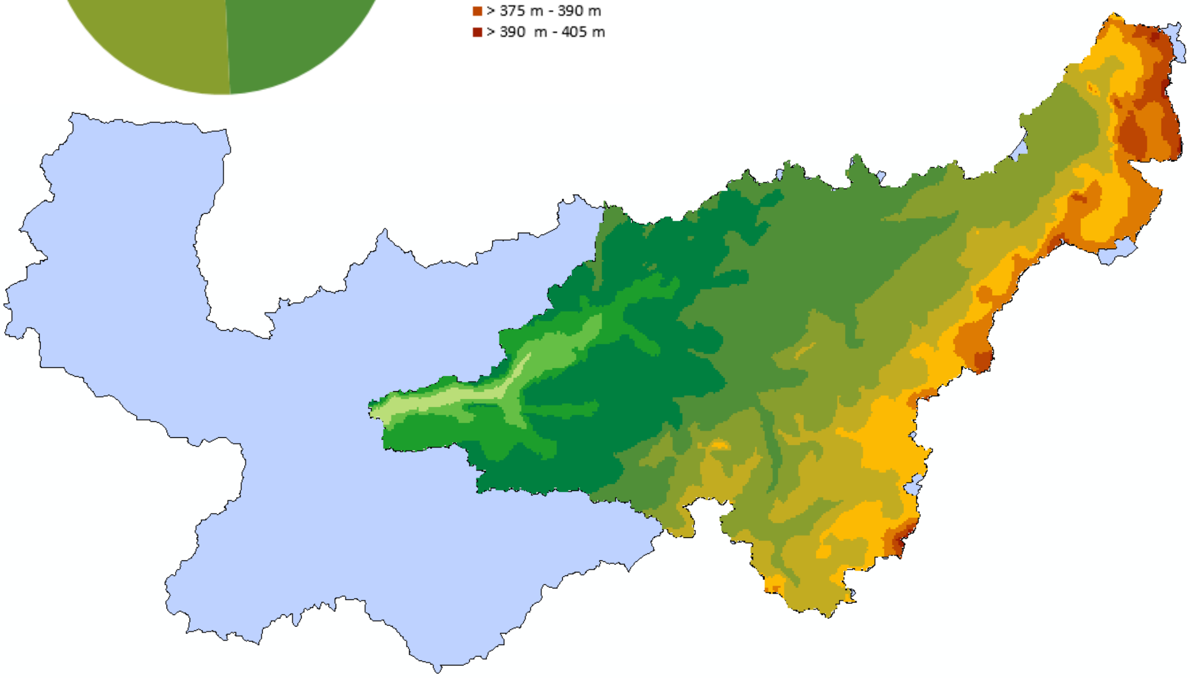


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

9A, BOARDMAN RIVER WATERSHED, BROWN BRIDGE POND

Elevation





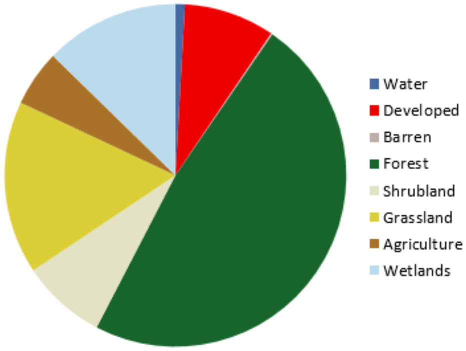
Category	Area	Percentage
Category	*km²*	*%*
>240 m - 255 m	3.94	1.00%
>255 m - 270 m	10.36	2.62%
>270 m - 285 m	24.69	6.24%
>285 m - 300 m	74.32	18.78%
>300 m - 315 m	81.39	20.57%
>315 m - 330 m	80.38	20.31%
>330 m - 345 m	55.60	14.05%
>345 m - 360 m	35.20	8.89%
>360 m -375 m	20.96	5.30%
>375 - 390 m	8.25	2.08%
>390 m - 405 m	0.64	0.16%
Size of Drainage Area	395.74	100.00%

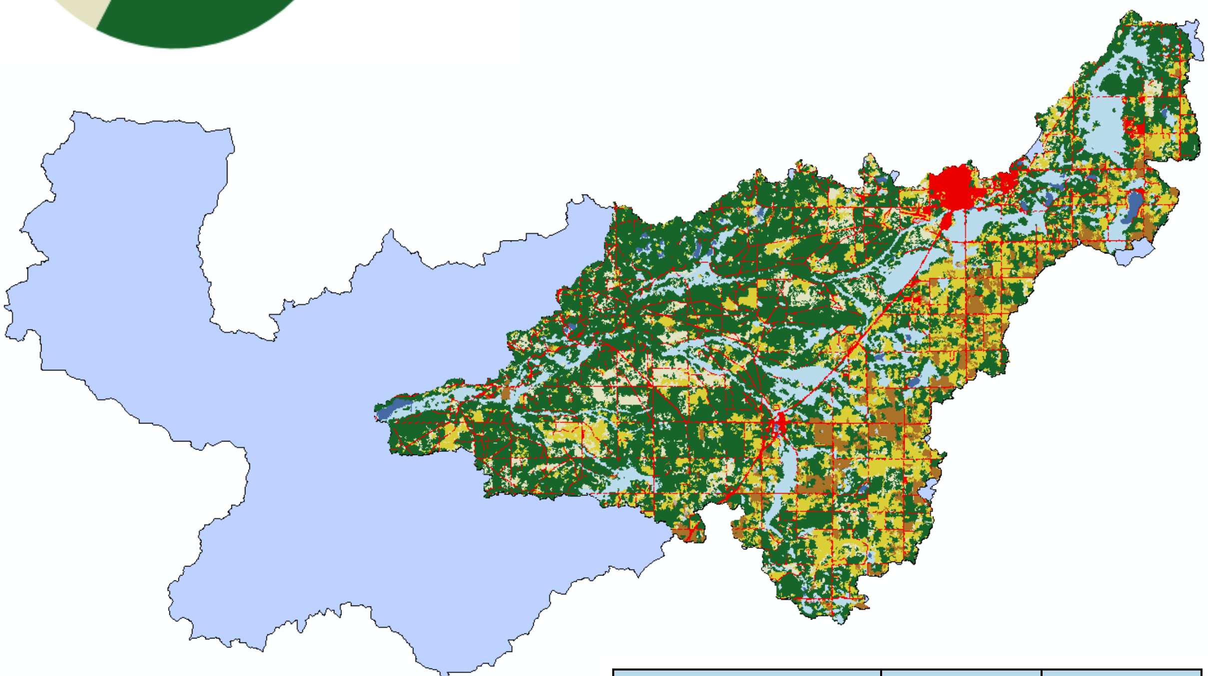
Brown Bridge Dam		
Elevation Statistics		
Size of Drainage Area	**395.74**	***km²***
Maximum	396.00	*m*
Minimum	243.00	*m*
Average	316.04	*m*
Standard Deviation	27.64	*m*

All Elevation Measurements with Respect to North American Datum 1983

9A, BOARDMAN RIVER WATERSHED, BROWN BRIDGE POND

Land Use





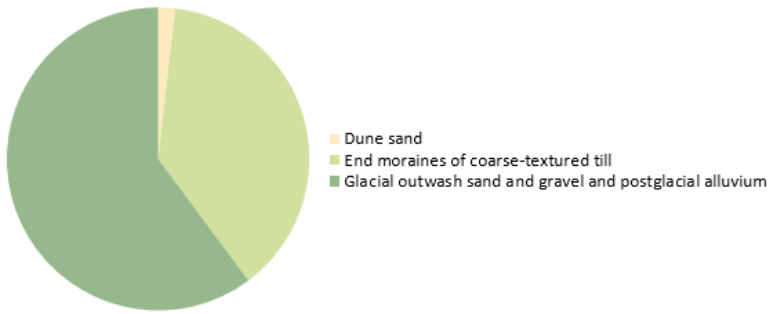
Category	Area	Percentage
Category	*km²*	*%*
Water	3.50	0.89%
Developed	33.95	8.58%
Barren	0.57	0.14%
Forest	190.05	48.02%
Shrubland	31.68	8.00%
Herbaceous	64.69	16.35%
Agriculture	21.01	5.31%
Wetlands	50.30	12.71%
Total	395.74	100.00%

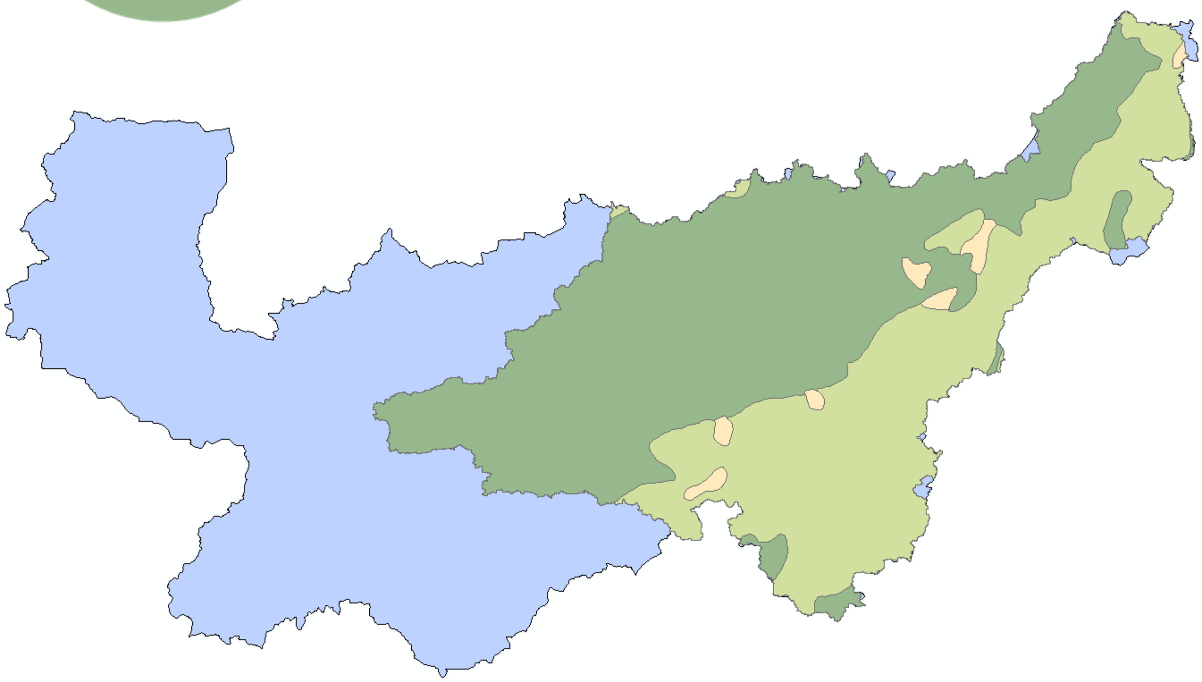
EGLE Runoff Curve Number
53.3

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

9A, BOARDMAN RIVER WATERSHED, BROWN BRIDGE POND

Surficial Geology



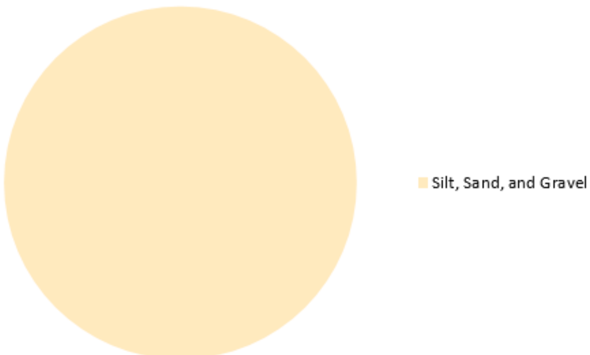


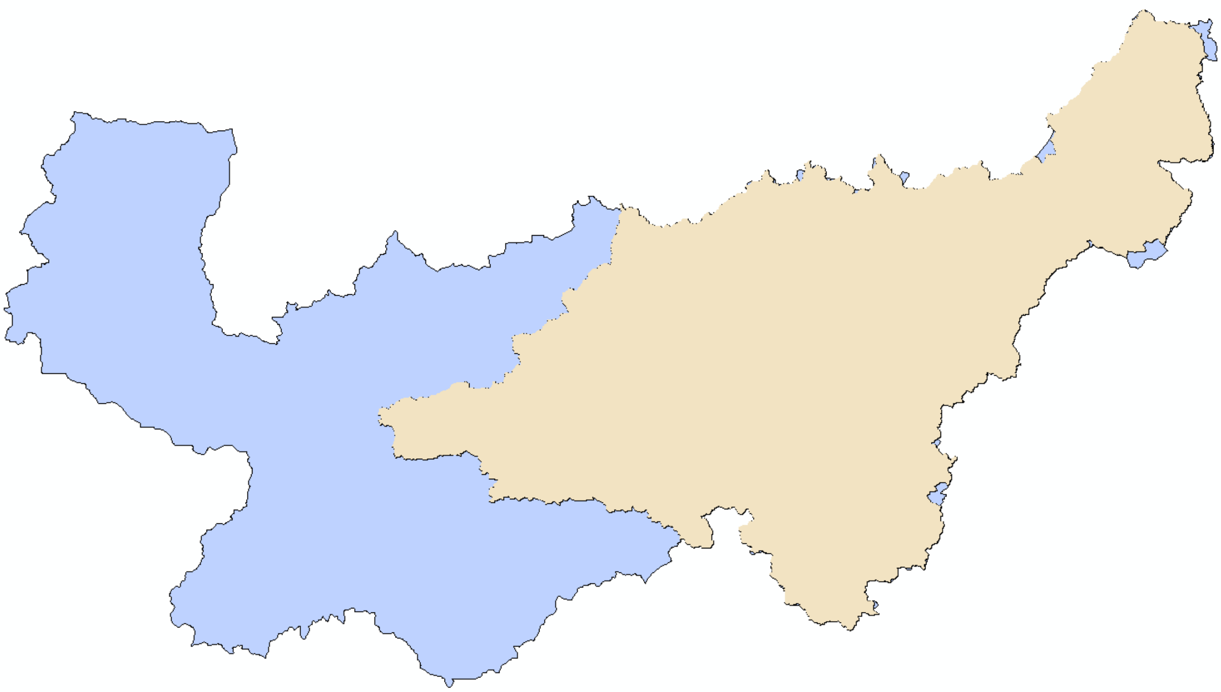
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	7.14	1.80%
End moraines of coarse-textured till	150.44	38.02%
Glacial outwash sand and gravel and postglacial alluvium	238.16	60.18%
Total Watershed Area	395.74	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

9A, BOARDMAN RIVER WATERSHED, BROWN BRIDGE POND

Surficial Geology (Simplified)



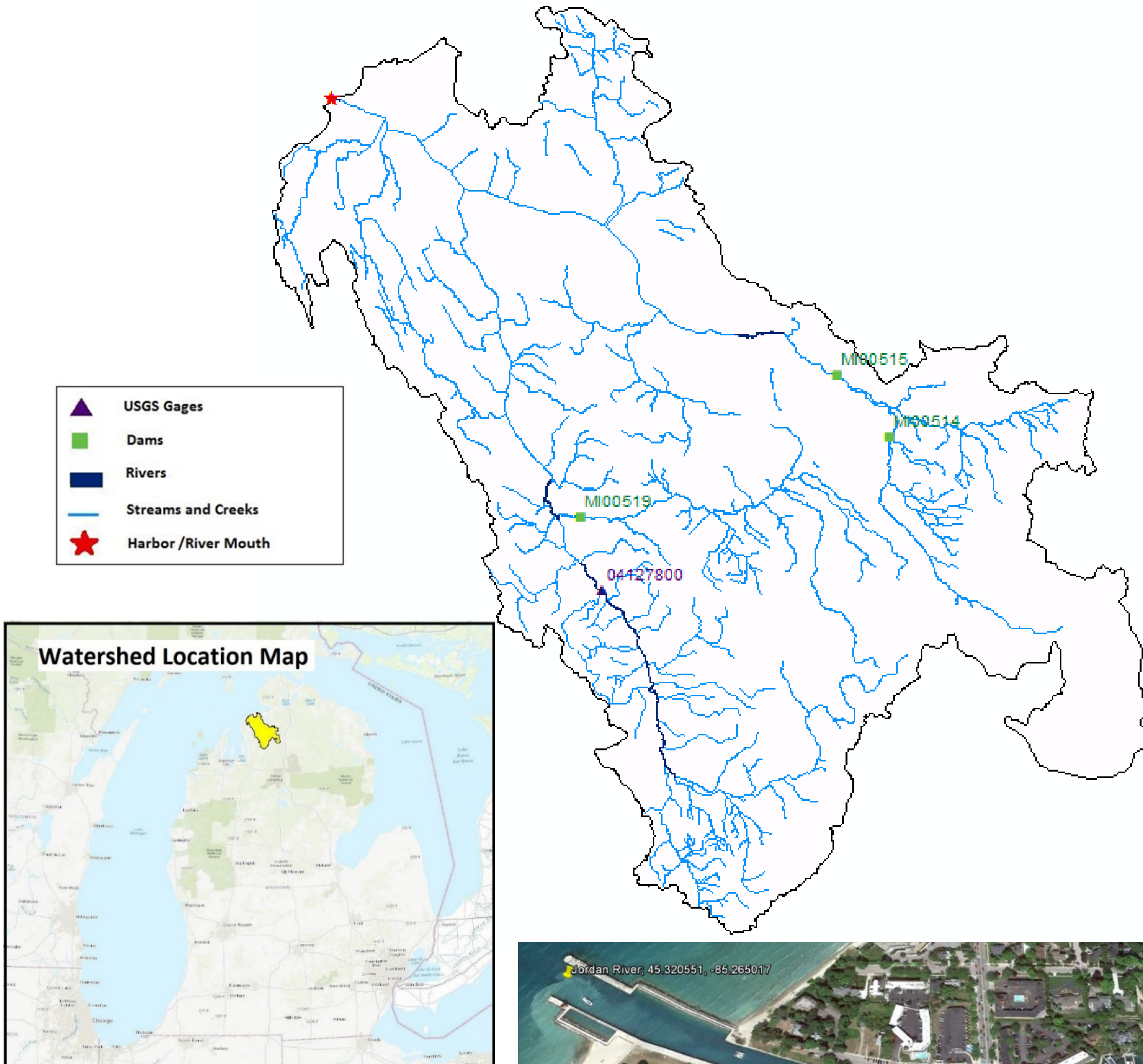


Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	395.74	100.00%
Total Watershed Area	395.74	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX N. PINE RIVER WATERSHED (10)

Surface Hydrology



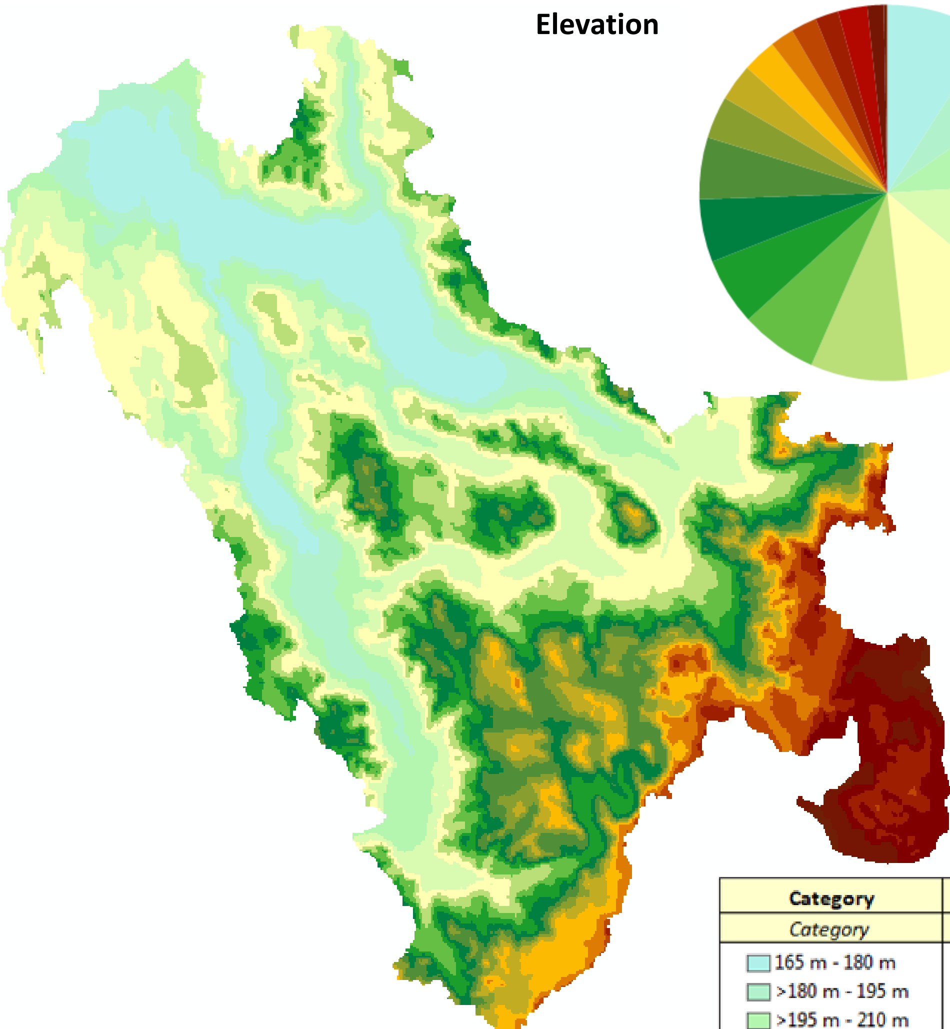
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00515	Boyne River	-84.952000	45.195800
MI00514	Boyne Falls Dam	-84.919720	45.168610
MI00519	East Jordan Dam	-85.111660	45.135000

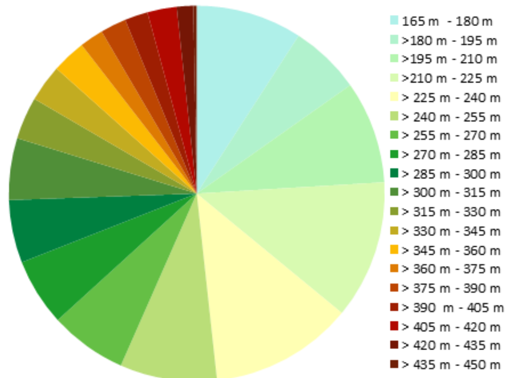
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4127800	JORDAN RIVER NEAR EAST JORDAN, MI	-85.09811	45.102507	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

10, PINE RIVER WATERSHED

Elevation





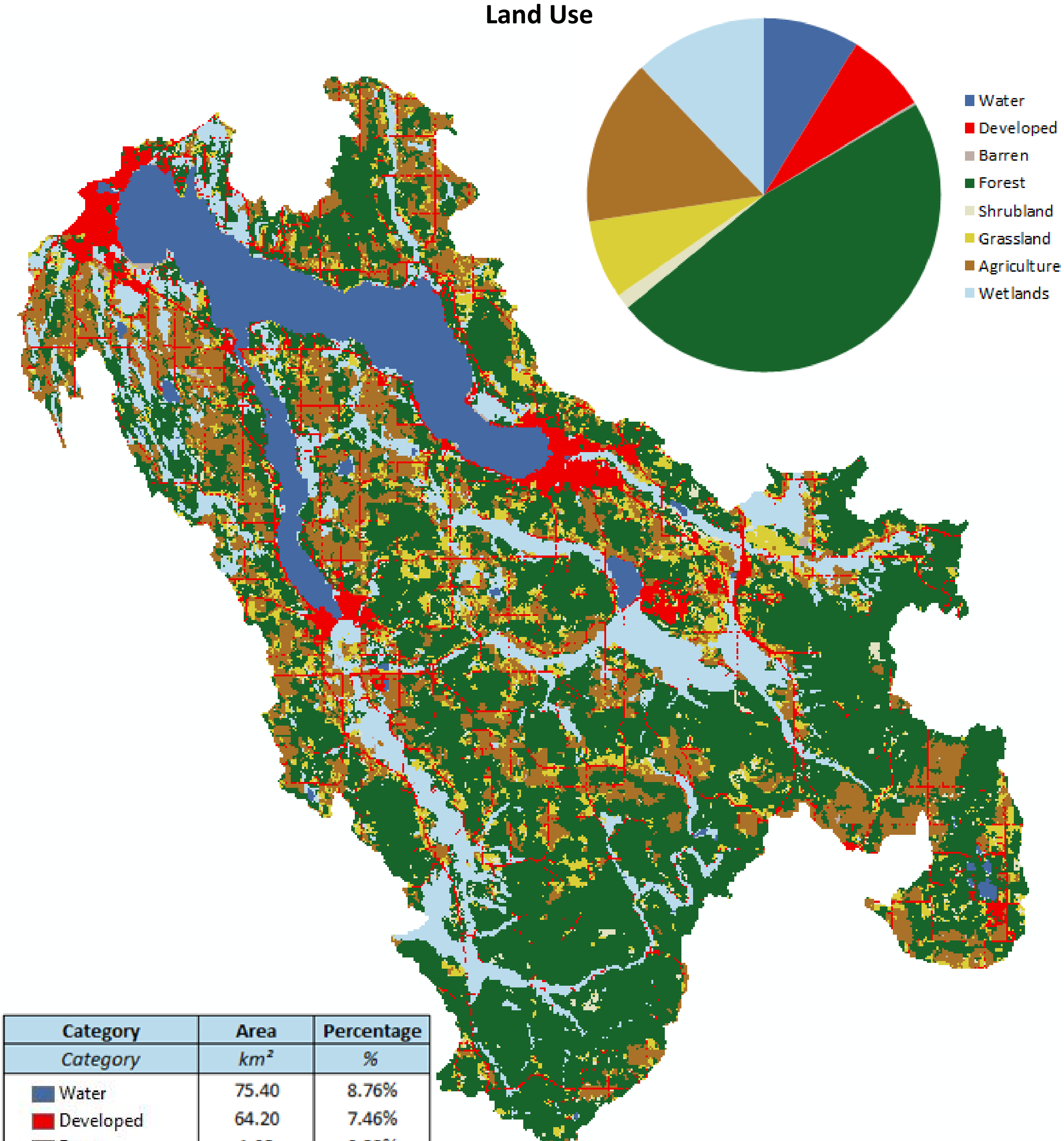
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	78.50	9.12%
>180 m - 195 m	52.38	6.09%
>195 m - 210 m	75.98	8.83%
>210 m - 225 m	102.57	11.92%
>225 m - 240 m	106.06	12.32%
>240 m - 255 m	71.75	8.34%
>255 m - 270 m	57.10	6.63%
>270 m - 285 m	49.88	5.80%
>285 m - 300 m	46.56	5.41%
>300 m - 315 m	45.74	5.32%
>315 m - 330 m	31.30	3.64%
>330 m - 345 m	27.42	3.19%
>345 m - 360 m	25.15	2.92%
>360 m - 375 m	17.58	2.04%
>375 m - 390 m	19.19	2.23%
>390 m - 405 m	17.14	1.99%
>405 m- 420 m	21.62	2.51%
>420 m - 435 m	12.17	1.41%
>435 m - 450 m	2.54	0.29%
Size of Drainage Area	860.65	100.00%

Pine Watershed		
Elevation Statistics		
Size of Drainage Area	**860.65**	***km²***
Maximum	444.00	*m*
Minimum	176.00	*m*
Average	260.05	*m*
Standard Deviation	66.05	*m*

All Elevation Measurements with Respect to North American Datum 1983

10, PINE RIVER WATERSHED

Land Use



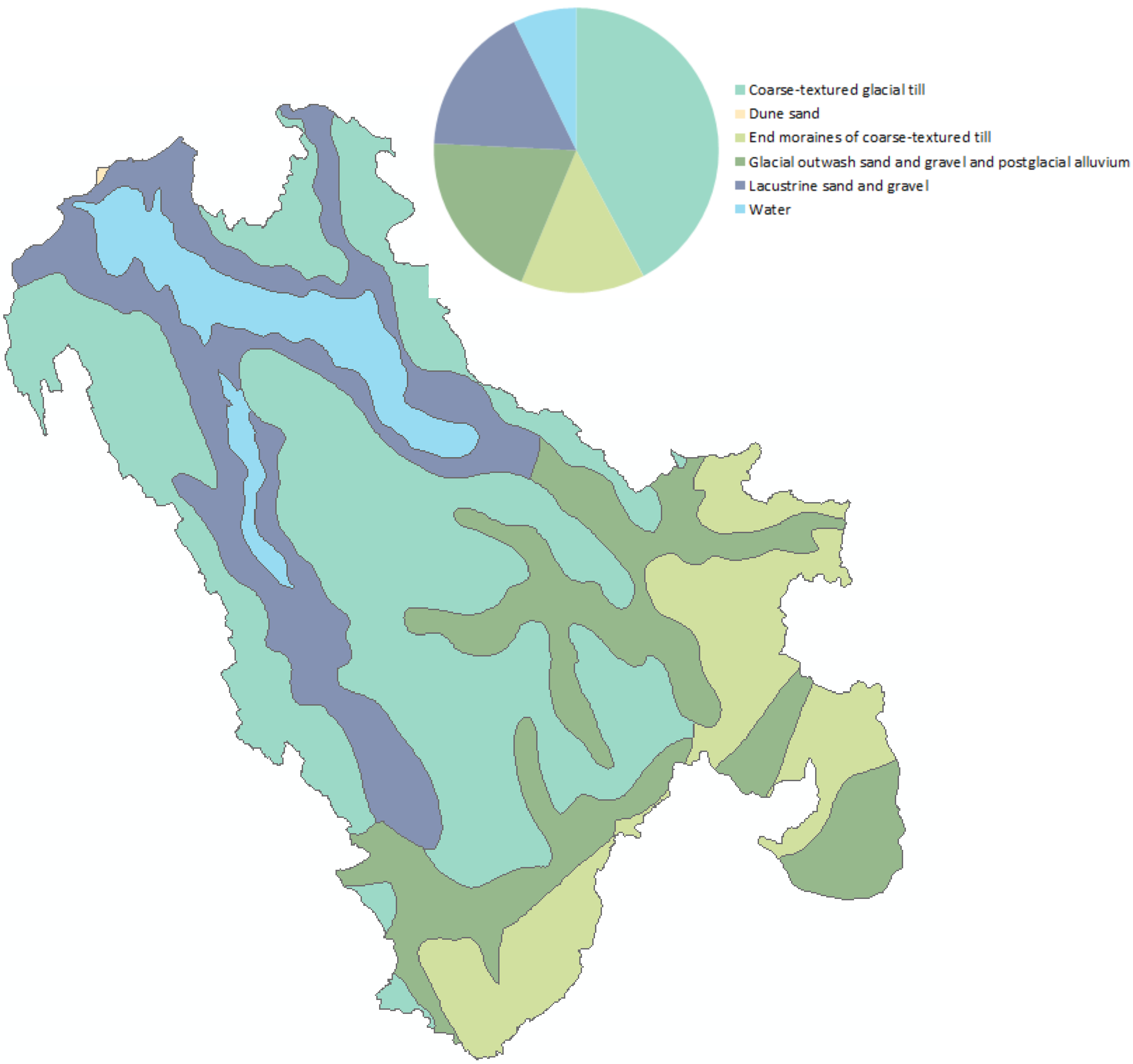
Category	Area	Percentage
Category	*km²*	*%*
Water	75.40	8.76%
Developed	64.20	7.46%
Barren	1.92	0.22%
Forest	409.54	47.59%
Shrubland	11.81	1.37%
Grassland	62.17	7.22%
Agriculture	130.79	15.20%
Wetlands	104.81	12.18%
Total	860.65	100.00%

EGLE Runoff Curve Number
61.5

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

10, PINE RIVER WATERSHED

Surficial Geology



Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	362.95	42.17%
Dune sand	0.30	0.04%
End moraines of coarse-textured till	121.38	14.10%
Glacial outwash sand and gravel and postglacial alluvium	167.32	19.44%
Lacustrine sand and gravel	146.75	17.05%
Water	61.94	7.20%
Total Watershed Area	860.65	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

10, PINE RIVER WATERSHED

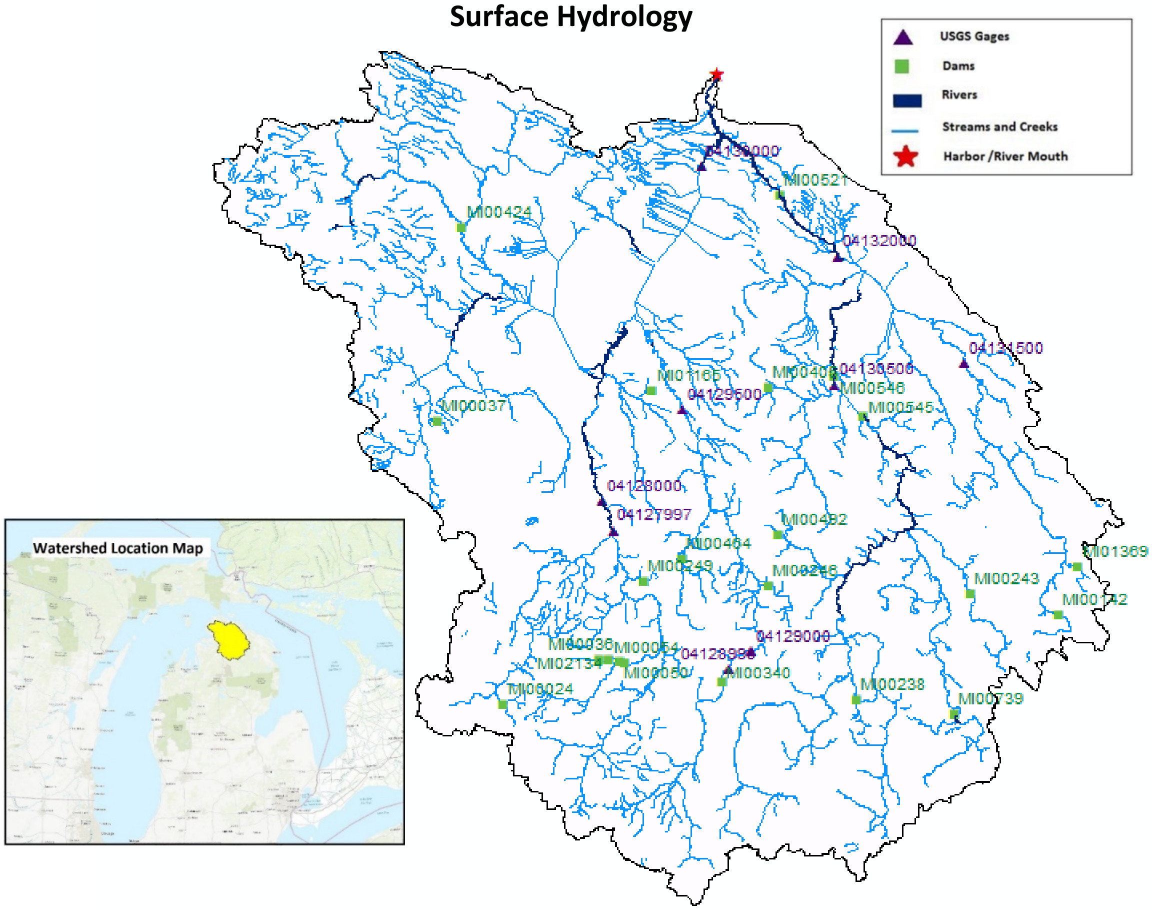
Surficial Geology (Simplified)

Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	798.70	92.80%
Water	61.94	7.20%
Total Watershed Area	860.65	100.00%

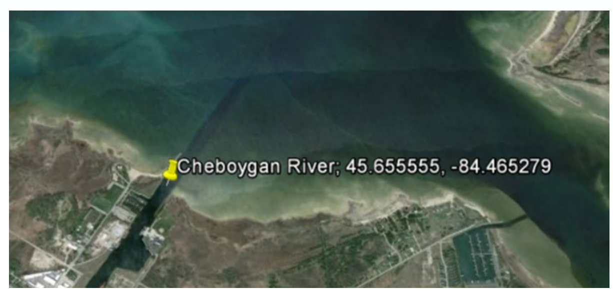
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX O. CHEBOYGAN RIVER WATERSHED (11)

Surface Hydrology



USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01369	FRANCIS DAM	-84.050000	45.236700
MI00545	Tower	-84.300000	45.366700
MI00546	Kleber	-84.333300	45.400000
MI01165	Roberts Lake Dam	-84.550000	45.391670
MI00521	Alverno	-84.395000	45.551700
MI00142	Rainy River Dam	-84.075000	45.196670
MI02134	Fontinalis Club Upper Dam	-84.608330	45.166670
MI00238	Foch Lakes Dam	-84.315000	45.130000
MI00024	Woodin Lake Dam	-84.732520	45.130840
MI00243	Tomahawk Creek Flooding Dam	-84.178610	45.216110
MI00246	Cornwall Creek Dam	-84.416390	45.225830
MI00249	Wildwood Lake Dam	-84.565000	45.231670
MI00340	Golden Lotus Dam	-84.473340	45.146670
MI00036	Quigley Dam	-84.618330	45.166670
MI00037	Starks Mill Dam	-84.806660	45.368330
MI00405	Stony Creek Dam	-84.412500	45.391670
MI00424	Maple River Dam	-84.773330	45.530000
MI00464	Echo Lake Dam	-84.518330	45.250560
MI00492	Dog Lake Dam	-84.404170	45.268890
MI00050	Fontinalis Club Middle Dam	-84.595000	45.165000
MI00054	Fontinalis Club Home Dam	-84.588330	45.163330
MI00739	Muskellunge Lake Level Control Struct	-84.200000	45.115000

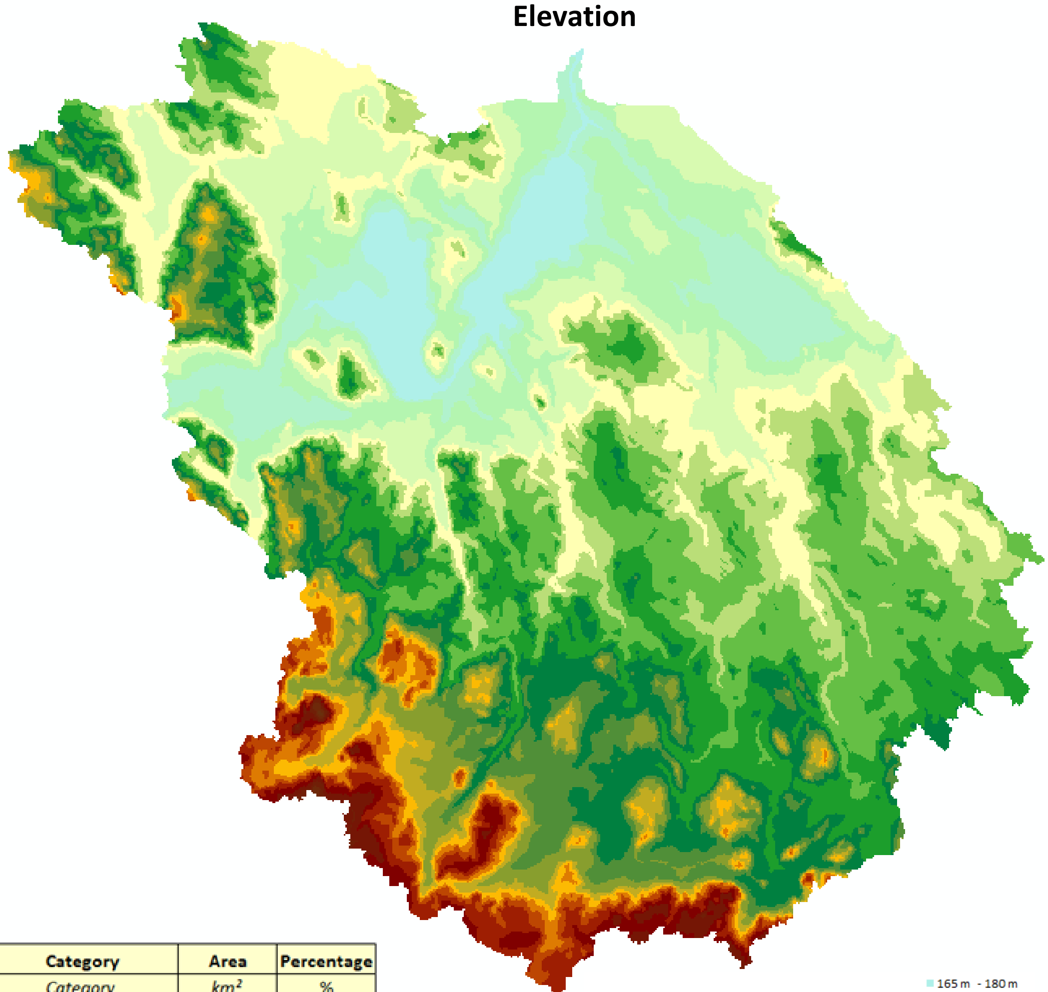


USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
04127997	STURGEON RIVER AT WOLVERINE, MI	-84.60003	45.274457	yes
04128000	STURGEON RIVER NEAR WOLVERINE, MI	-84.61114	45.298902	
04128990	PIGEON R AT STURGEON VALLEY RD NEAR VANDERBILT, MI	-84.46669	45.156680	yes
04129000	PIGEON RIVER NEAR VANDERBILT, MI	-84.43836	45.170846	
04129500	PIGEON RIVER AT AFTON, MI	-84.51503	45.373901	
04130000	CHEBOYGAN RIVER NEAR CHEBOYGAN, MI	-84.48754	45.577234	
04130500	BLACK RIVER NEAR TOWER, MI	-84.33336	45.392512	
04131500	RAINY RIVER NEAR OCQUEOC, MI	-84.17918	45.408345	
04132000	BLACK RIVER NEAR CHEBOYGAN, MI	-84.32669	45.499733	
Number of Active USGS Stream Gage's in Drainage Area (2009)				2

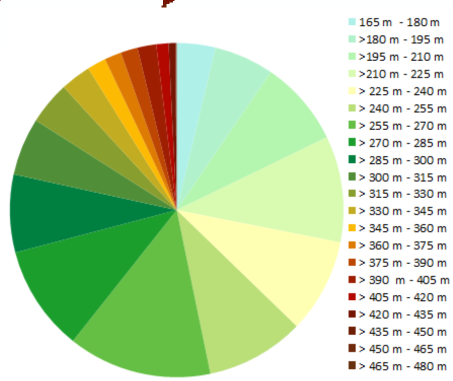
Data Obtained from USGS National Hydrography Dataset and USACE's National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

11, CHEBOYGAN RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	145.07	3.75%
>180 m - 195 m	224.19	5.79%
>195 m - 210 m	320.43	8.28%
>210 m - 225 m	397.30	10.27%
>225 m - 240 m	353.79	9.14%
>240 m - 255 m	368.53	9.52%
>255 m - 270 m	538.62	13.92%
>270 m - 285 m	395.95	10.23%
>285 m - 300 m	291.31	7.53%
>300 m - 315 m	216.05	5.58%
>315 m - 330 m	160.26	4.14%
>330 m - 345 m	114.05	2.95%
>345 m - 360 m	70.35	1.82%
>360 m - 375 m	63.37	1.64%
>375 m - 390 m	63.72	1.65%
>390 m - 405 m	70.64	1.83%
>405 m - 420 m	45.65	1.18%
>420 m - 435 m	26.11	0.67%
>435 m - 450 m	3.03	0.08%
>450 m - 465 m	0.96	0.02%
>465 m - 480 m	0.11	0.00%
Size of Drainage Area	3869.49	100.00%



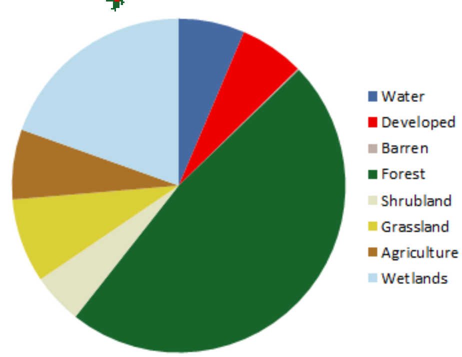
Cheboygan Watershed		
Elevation Statistics		
Size of Drainage Area	3869.49	*km²*
Maximum	472.00	*m*
Minimum	176.00	*m*
Average	262.38	*m*
Standard Deviation	55.53	*m*

All Elevation Measurements with Respect to North American Datum 1983

11, CHEBOYGAN RIVER WATERSHED

Land Use

Category	Area	Percentage
Category	*km²*	*%*
Water	247.90	6.41%
Developed	242.99	6.28%
Barren	4.79	0.12%
Forest	1850.39	47.82%
Shrubland	189.43	4.90%
Grassland	315.28	8.15%
Agriculture	262.21	6.78%
Wetlands	756.48	19.55%
Total	3869.49	100.00%

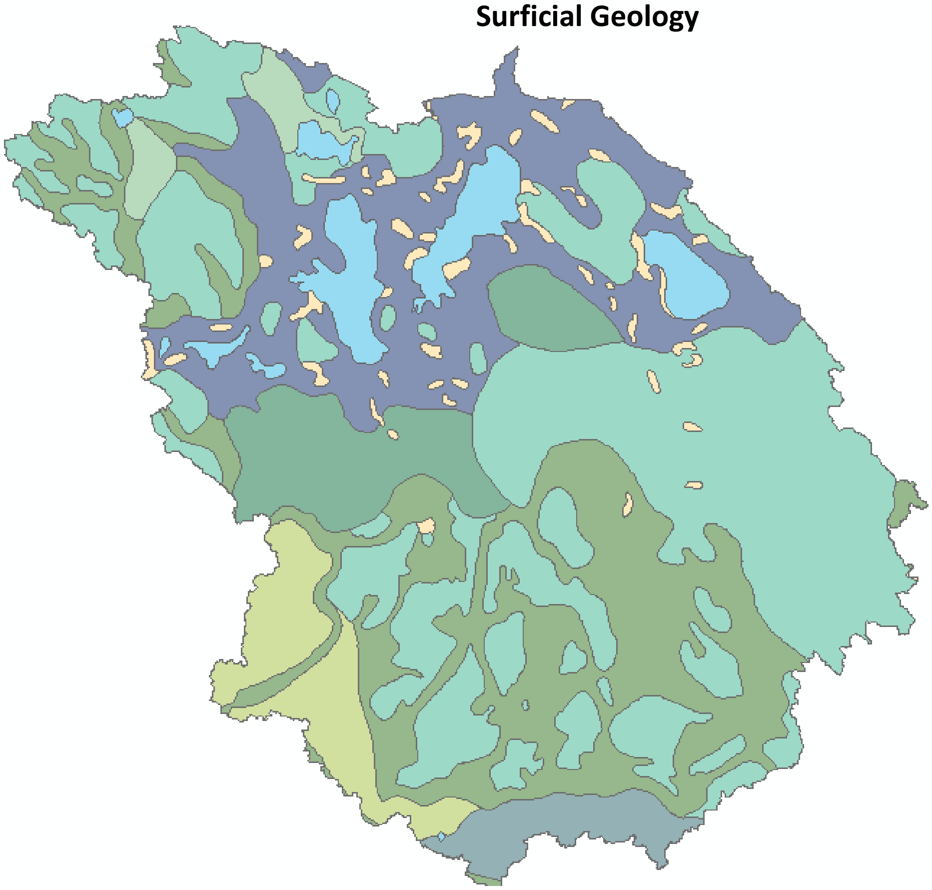


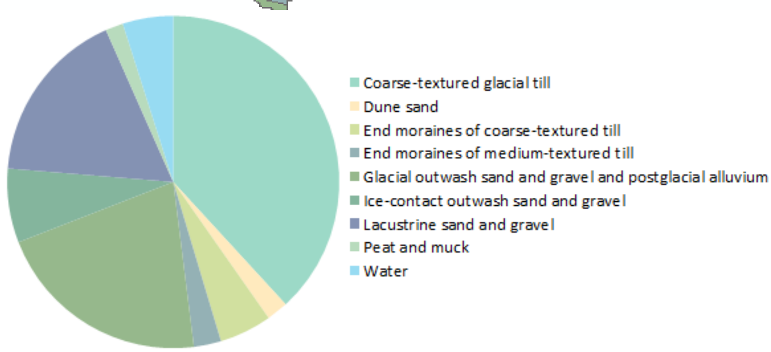
EGLE Runoff Curve Number
61.5

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

11, CHEBOYGAN RIVER WATERSHED

Surficial Geology



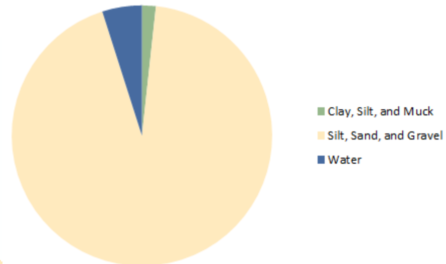


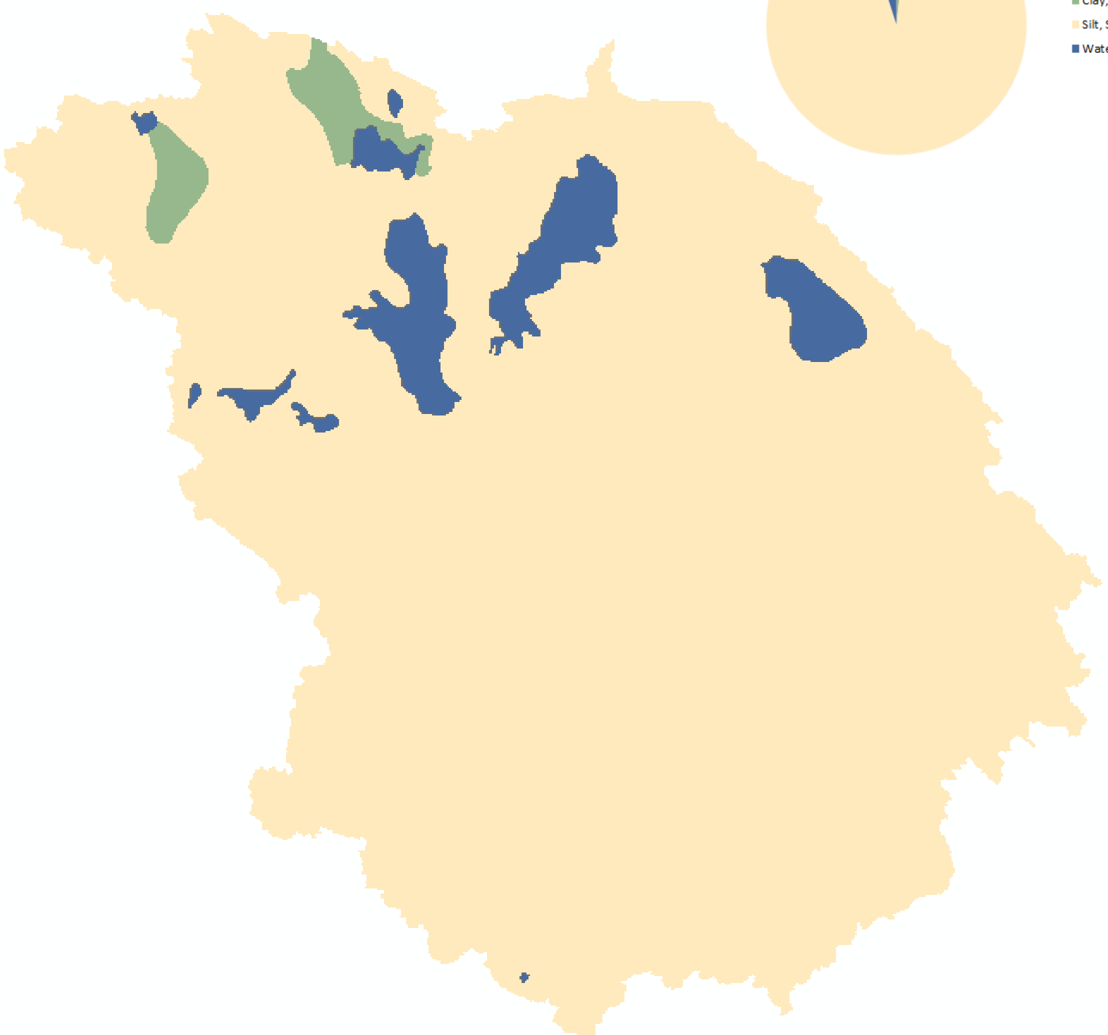
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	1476.72	38.16%
Dune sand	80.89	2.09%
End moraines of coarse-textured till	197.66	5.11%
End moraines of medium-textured till	102.66	2.65%
Glacial outwash sand and gravel and postglacial alluvium	815.69	21.08%
Ice-contact outwash sand and gravel	279.04	7.21%
Lacustrine sand and gravel	659.70	17.05%
Peat and muck	66.54	1.72%
Water	190.60	4.93%
Total Watershed Area	3869.49	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

11, CHEBOYGAN RIVER WATERSHED

Surficial Geology (Simplified)

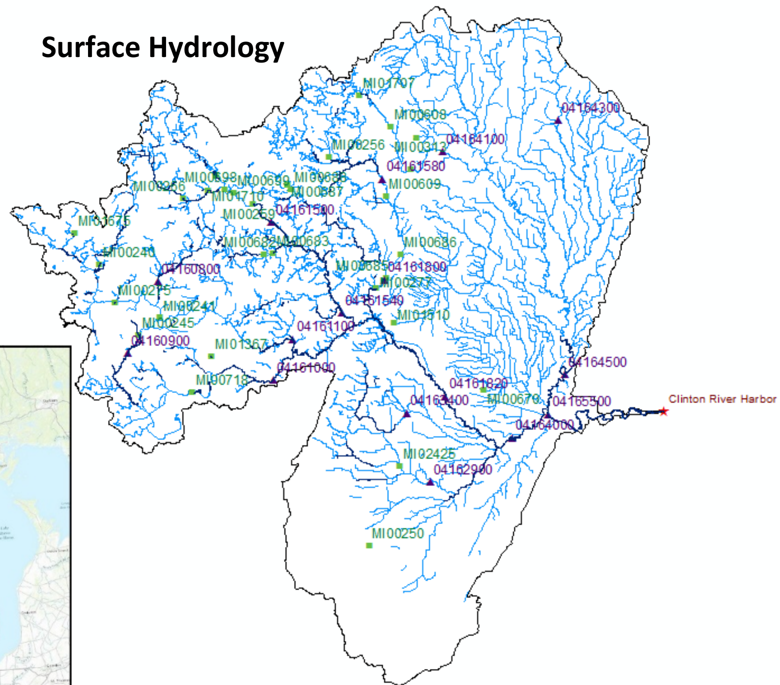


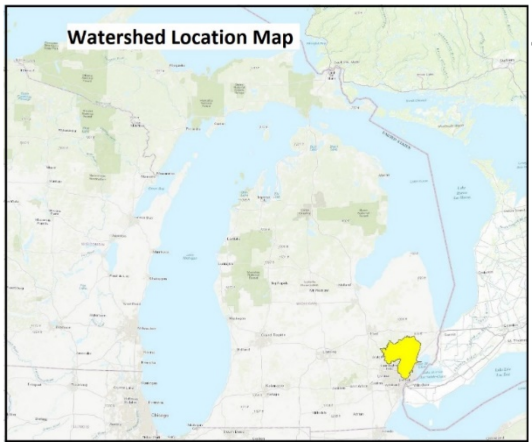


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	66.54	1.72%
Silt, Sand, and Gravel	3612.35	93.35%
Water	190.60	4.93%
Total Watershed Area	3869.49	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX P. CLINTON RIVER WATERSHED (12)





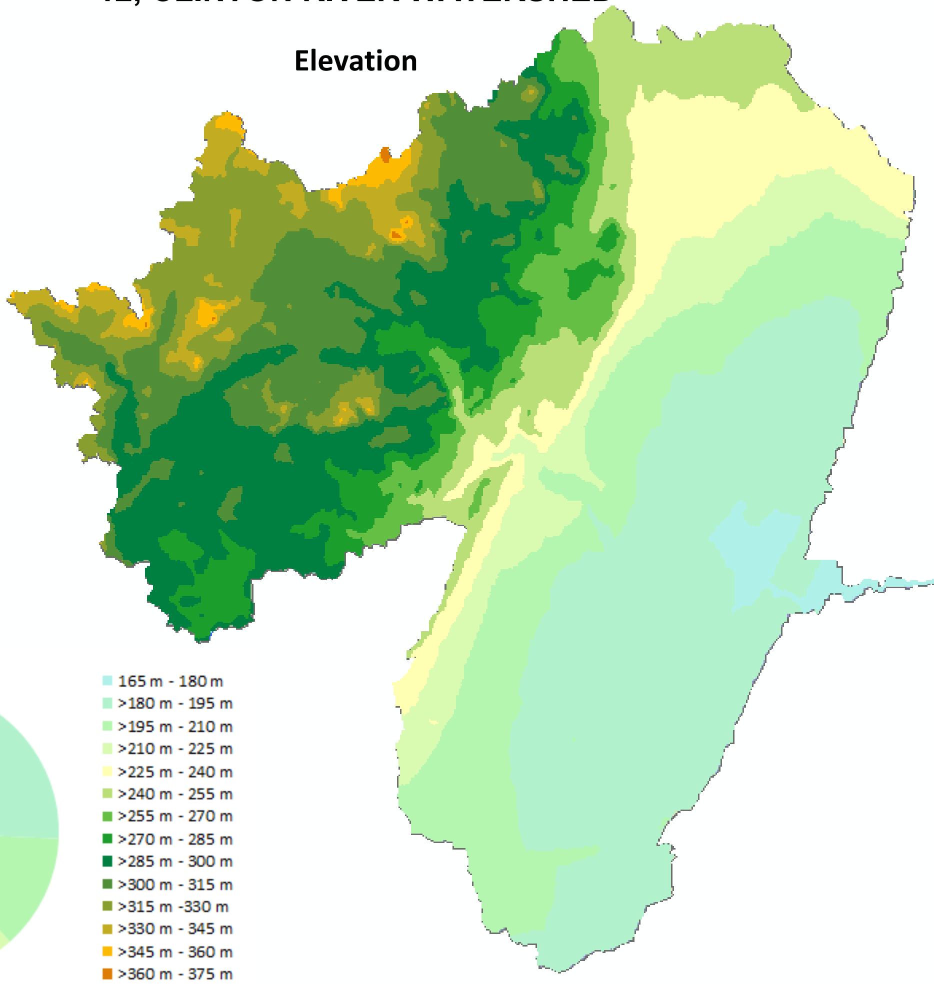
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01367	Pontiac Motor Division Detention Basin	-83.29333	42.65500
MI01510	Chestnut Lake Dam	-83.08167	42.67833
MI01675	Wau-Me-Gah Lake Dam	-83.44722	42.76389
MI01707	Secord Lake Dam	-83.11333	42.87333
MI01710	Lake Araho Dam	-83.29166	42.79667
MI00237	Oxford Multi-lakes	-83.28167	42.80833
MI00240	Clarkston Dam	-83.42000	42.73667
MI00241	Clintonville Dam	-83.35167	42.69000
MI02425	Autumn Ridge Detention Dam	-83.08167	42.55667
MI00245	Loon Lake Dam	-83.37666	42.67500
MI00250	Gehrke Dam	-83.12000	42.49000
MI00256	Lakeville Lake Dam	-83.15000	42.82167
MI00259	Lake Orion Dam	-83.24000	42.78333
MI00266	Pungs Dam	-83.32000	42.79000
MI00275	Waterford Multi-Lakes Level Control	-83.40334	42.70333
MI00277	Winkler Pond Dam	-83.10167	42.70833
MI00313	Hidden Lake Dam	-83.04833	42.83500
MI00607	East Mill Lake Dam	-83.05666	42.80833
MI00608	Fisher Dam	-83.07833	42.84500
MI00609	Clifton Mill Pond Dam	-83.08667	42.78667
MI00670	Sterling Mall Dam	-82.98167	42.61833
MI00682	Upper Trout Lake Dam	-83.22972	42.74028
MI00683	Lower Trout Lake Dam	-83.21889	42.74111
MI00685	Lower Stony Lake Dam	-83.09000	42.71667
MI00686	Upper Stony Lake Dam	-83.07166	42.73667
MI00687	Indian Lake Dam	-83.20000	42.79833
MI00688	Prince Lake Dam	-83.19595	42.79527
MI00698	Duck Lake Dam	-83.27167	42.79667
MI00699	Indianwood Lake Dam	-83.26167	42.79333
MI00718	Dawson Millpond Dam	-83.31667	42.62500

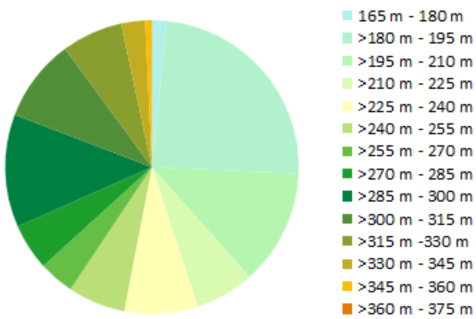
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4160800	SASHABAW CREEK NEAR DRAYTON PLAINS, MI	*-83.353551*	*42.720031*	yes
4160900	CLINTON RIVER NEAR DRAYTON PLAINS, MI	-83.390216	42.660309	yes
4161000	CLINTON RIVER AT AUBURN HILLS, MI	-83.224378	42.633366	yes
4161100	GALLOWAY CREEK NEAR AUBURN HEIGHTS, MI	-83.20049	42.667255	
4161500	PAINT CREEK NEAR LAKE ORION, MI	-83.219938	42.767531	
4161540	PAINT CREEK AT ROCHESTER, MI	-83.142989	42.688366	yes
4161580	STONY CREEK NEAR ROMEO, MI	-83.090212	42.800864	yes
4161800	STONY CREEK NEAR WASHINGTON, MI	-83.091877	42.715309	yes
4161820	CLINTON RIVER AT STERLING HEIGHTS, MI	-83.026593	42.614478	yes
4162900	BIG BEAVER CREEK NEAR WARREN, MI	-83.047703	42.54198	
4163400	PLUM BROOK AT UTICA, MI	-83.071316	42.601423	yes
4164000	CLINTON RIVER NEAR FRASER, MI	-82.951311	42.577257	yes
4164100	EAST POND CREEK AT ROMEO, MI	-83.02021	42.82253	yes
4164300	EAST BRANCH COON CREEK AT ARMADA, MI	-82.884928	42.845863	yes
4164500	NORTH BRANCH CLINTON RIVER NEAR MT. CLEMENS, MI	-82.88881	42.6292	yes
4165500	CLINTON RIVER AT MORAVIAN DRIVE AT MT. CLEMENS, MI	-82.90881	42.595867	yes
	Number of Active USGS Stream Gage's in Drainage Area (2009)			13

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

12, CLINTON RIVER WATERSHED

Elevation



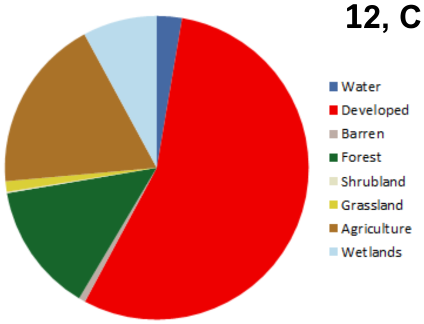


Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	32.72	1.58%
>180 m - 195 m	498.13	24.13%
>195 m - 210 m	262.39	12.71%
>210 m - 225 m	134.21	6.50%
>225 m - 240 m	167.63	8.12%
>240 m - 255 m	130.61	6.33%
>255 m - 270 m	80.30	3.89%
>270 m - 285 m	105.72	5.12%
>285 m - 300 m	256.45	12.42%
>300 m - 315 m	188.23	9.12%
>315 m -330 m	138.53	6.71%
>330 m - 345 m	54.37	2.63%
>345 m - 360 m	14.25	0.69%
>360 m - 375 m	0.88	0.04%
Total Watershed Area	2064.43	100.00%

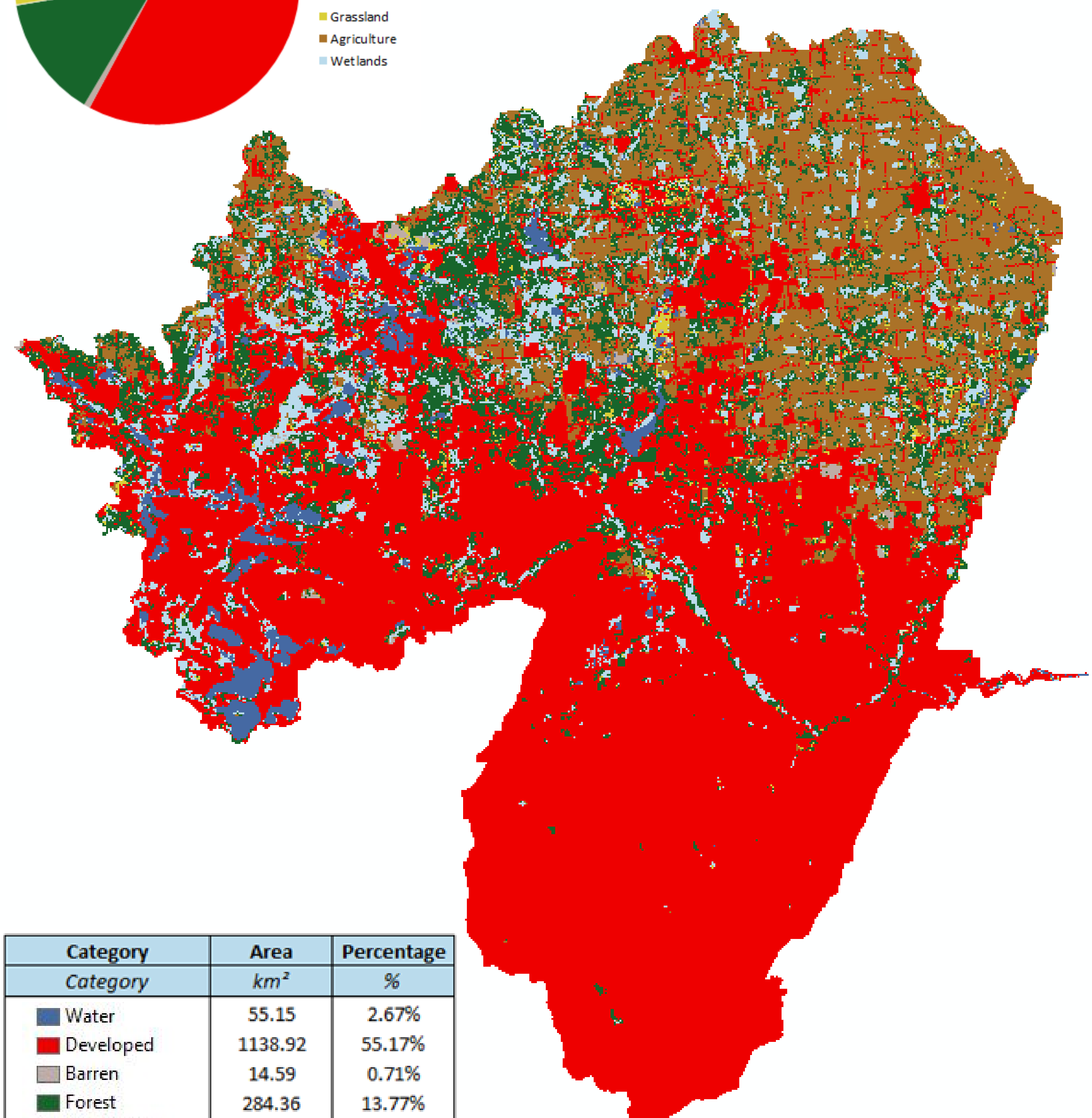
Clinton River Watershed		
Elevation Statistics		
Size of Drainage Area	2064.43	*km²*
Maximum	365.00	*m*
Minimum	174.00	*m*
Average	243.83	*m*
Standard Deviation	50.02	*m*

All Elevation Measurements with Respect to North American Datum 1983

12, CLINTON RIVER WATERSHED



Land Use



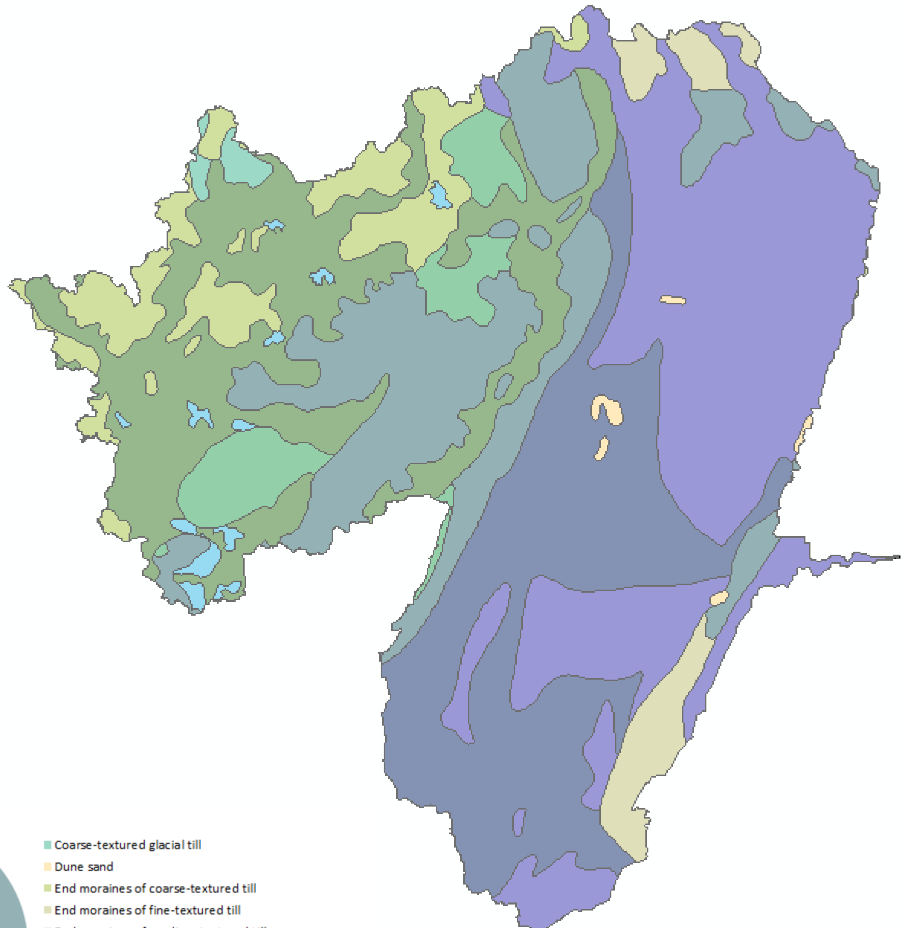
Category	Area	Percentage
Category	*km²*	*%*
Water	55.15	2.67%
Developed	1138.92	55.17%
Barren	14.59	0.71%
Forest	284.36	13.77%
Shrubland	3.04	0.15%
Grassland	23.11	1.12%
Agriculture	382.15	18.51%
Wetlands	163.10	7.90%
Total	2064.43	100.00%

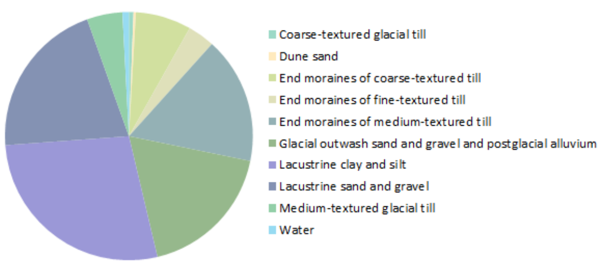
EGLE Runoff Curve Number
77.5

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

12, CLINTON RIVER WATERSHED

Surficial Geology



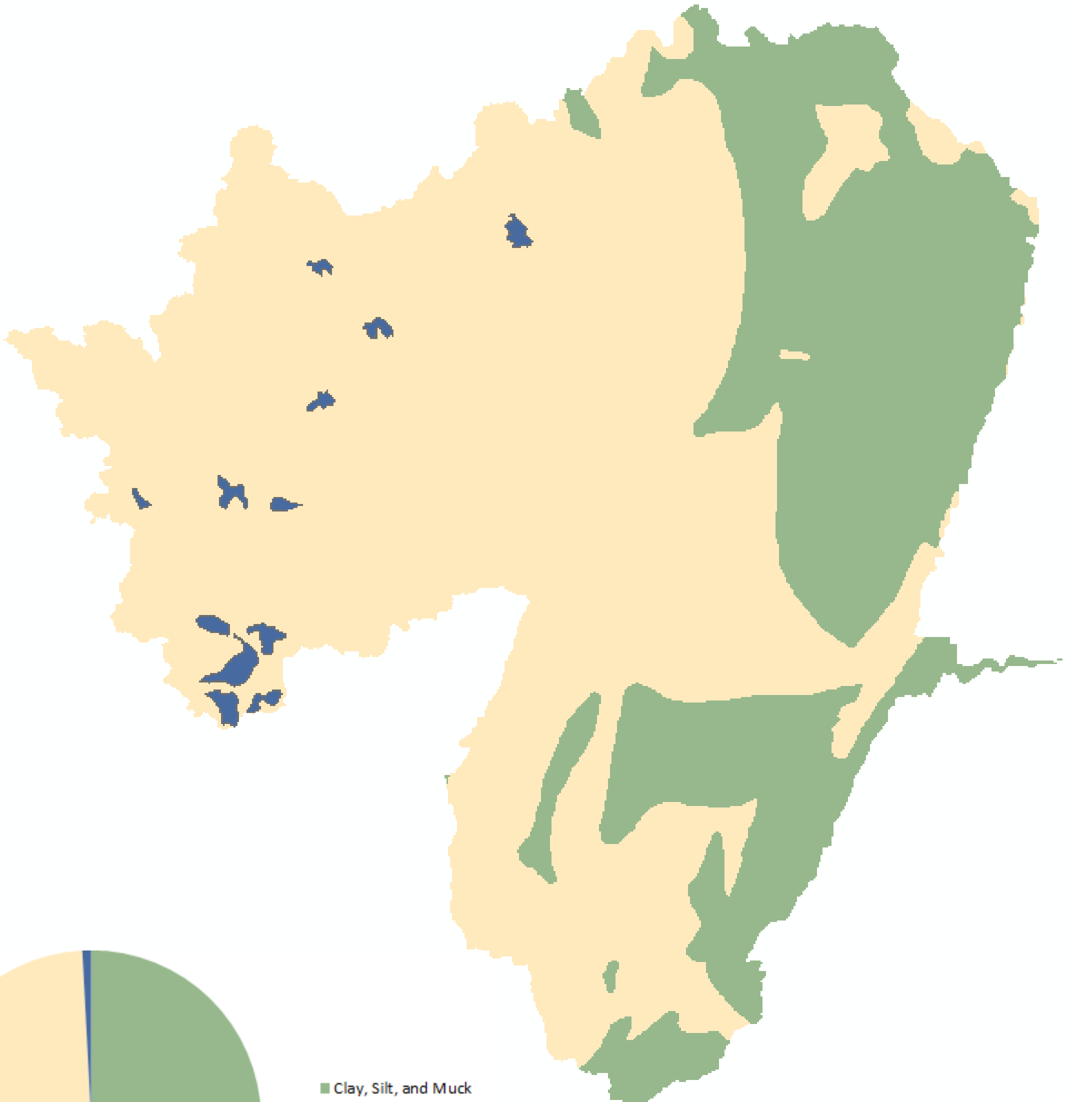


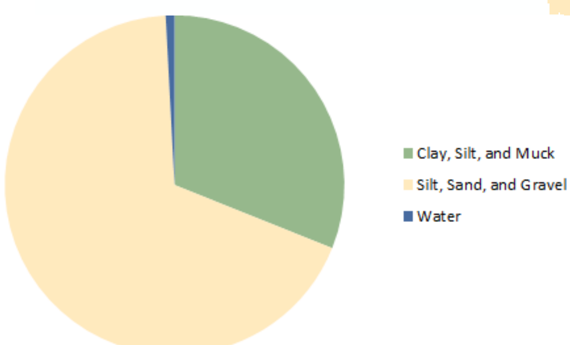
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	12.27	0.59%
Dune sand	6.42	0.31%
End moraines of coarse-textured till	149.94	7.26%
End moraines of fine-textured till	72.55	3.51%
End moraines of medium-textured till	341.11	16.52%
Glacial outwash sand and gravel and postglacial alluvium	373.36	18.09%
Lacustrine clay and silt	568.69	27.55%
Lacustrine sand and gravel	427.02	20.68%
Medium-textured glacial till	95.79	4.64%
Water	17.27	0.84%
Total Watershed Area	2064.43	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

12, CLINTON RIVER WATERSHED

Surficial Geology (Simplified)



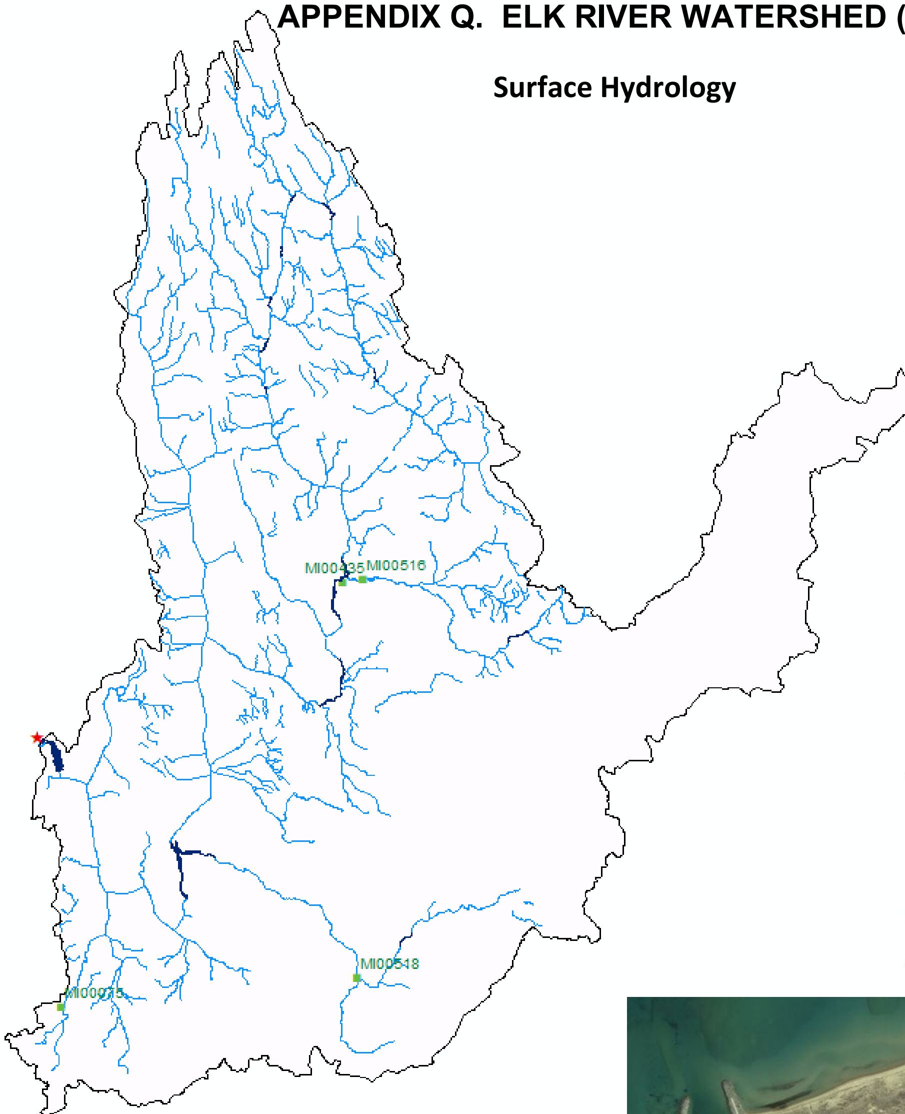


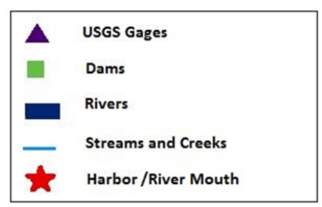
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	641.24	31.06%
Silt, Sand, and Gravel	1405.92	68.10%
Water	17.27	0.84%
Total Watershed Area	2064.43	100.00%

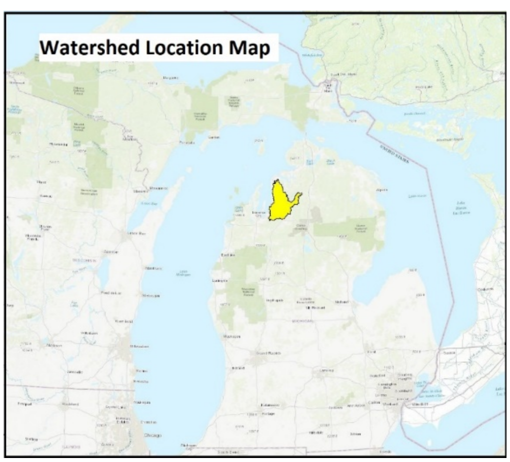
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX Q. ELK RIVER WATERSHED (13)

Surface Hydrology





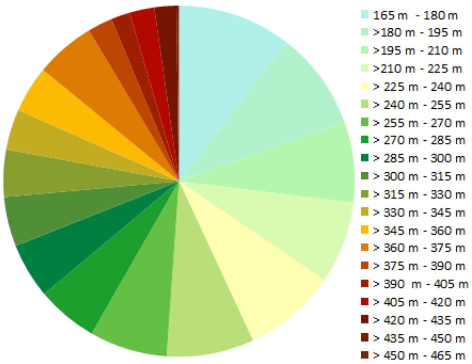


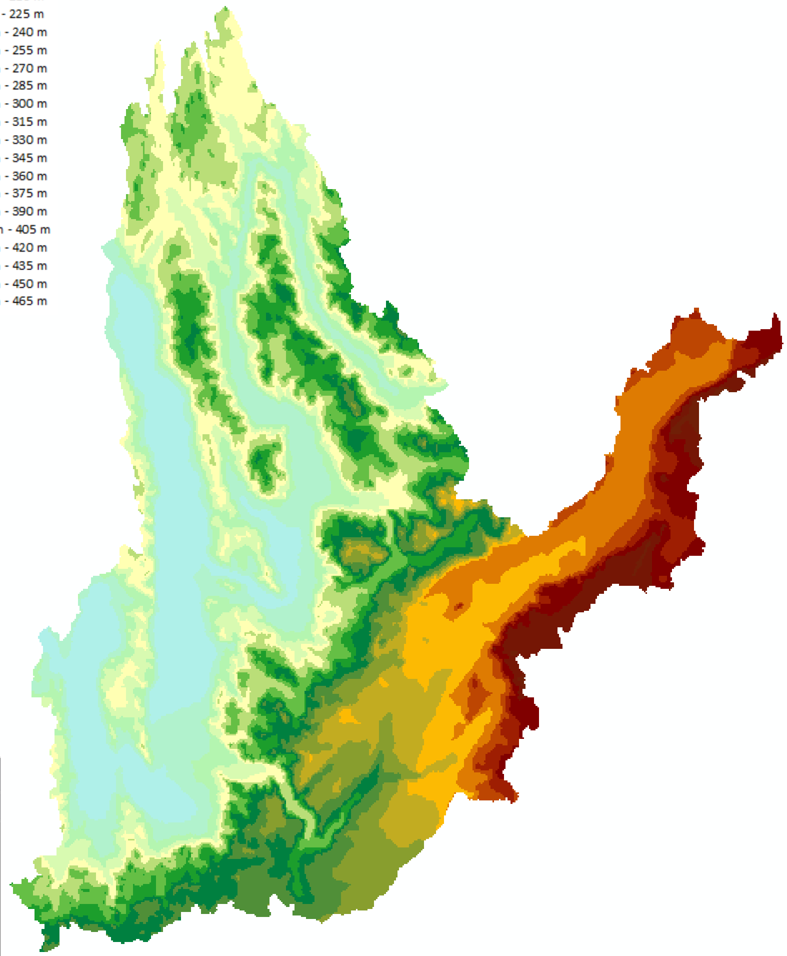
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00435	Bellaire Dam	-85.206670	44.976670
MI00516	Cedar River Dam	-85.193340	44.978330
MI00518	Rugg Pond Dam	-85.200000	44.783330
MI00075	Bissell Pond Dam	-85.403340	44.770000

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

13, ELK RIVER WATERSHED

Elevation





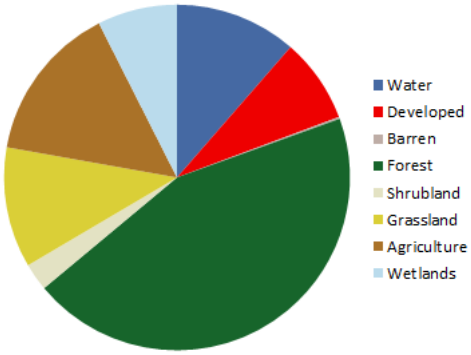
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	136.16	10.47%
>180 m - 195 m	118.24	9.09%
>195 m - 210 m	96.03	7.39%
>210 m - 225 m	98.18	7.55%
>225 m - 240 m	111.46	8.57%
>240 m - 255 m	104.65	8.05%
>255 m - 270 m	92.96	7.15%
>270 m - 285 m	73.12	5.62%
>285 m - 300 m	66.22	5.09%
>300 m - 315 m	59.36	4.57%
>315 m -330 m	56.44	4.34%
>330 m - 345 m	48.60	3.74%
>345 m - 360 m	55.73	4.29%
>360 m - 375 m	71.61	5.51%
>375 m - 390 m	29.73	2.29%
>390 m - 405 m	22.58	1.74%
>405 m - 420 m	29.80	2.29%
>420 m - 435 m	26.20	2.02%
>435 m - 450 m	3.05	0.23%
>450 m - 465 m	0.02	0.00%
Size of Drainage Area	1300.13	100.00%

Elk Watershed		
Elevation Statistics		
Size of Drainage Area	**1300.13**	***km²***
Maximum	452.00	*m*
Minimum	176.00	*m*
Average	266.29	*m*
Standard Deviation	70.74	*m*

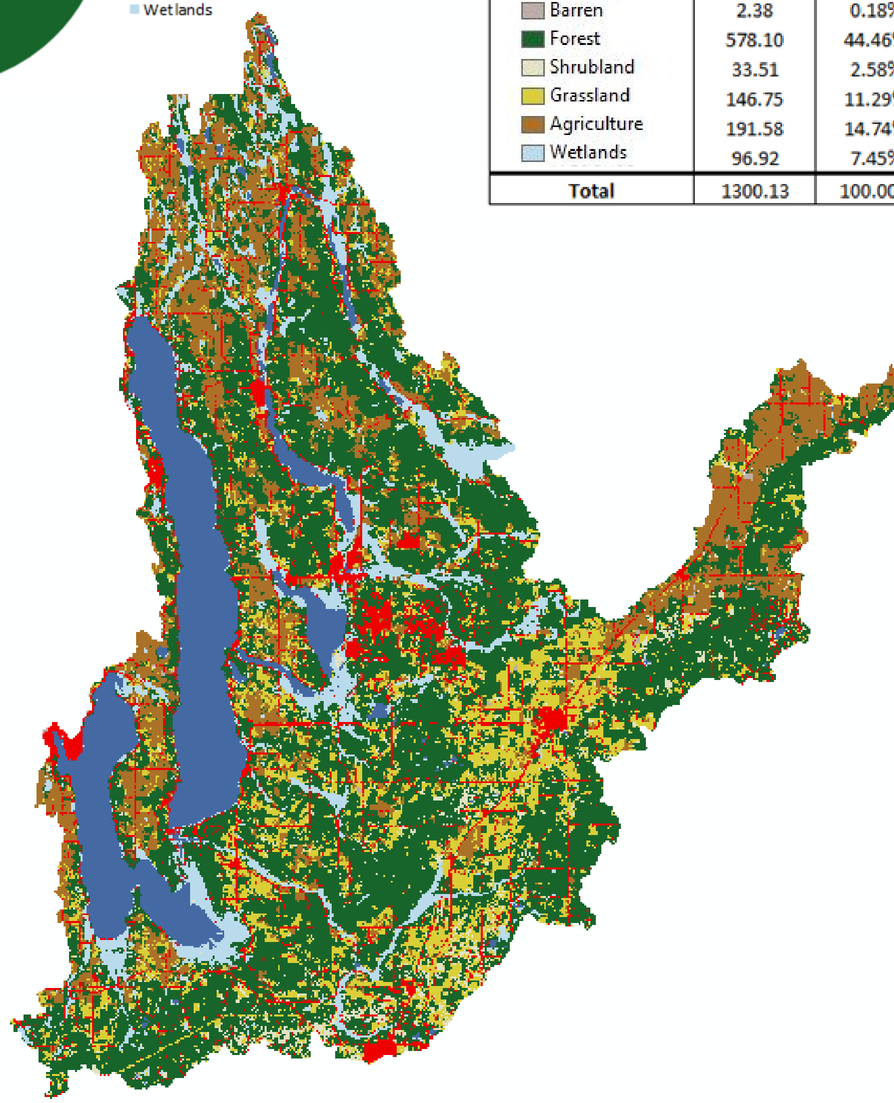
All Elevation Measurements with Respect to North American Datum 1983

13, ELK RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	148.14	11.39%
Developed	102.77	7.90%
Barren	2.38	0.18%
Forest	578.10	44.46%
Shrubland	33.51	2.58%
Grassland	146.75	11.29%
Agriculture	191.58	14.74%
Wetlands	96.92	7.45%
Total	1300.13	100.00%

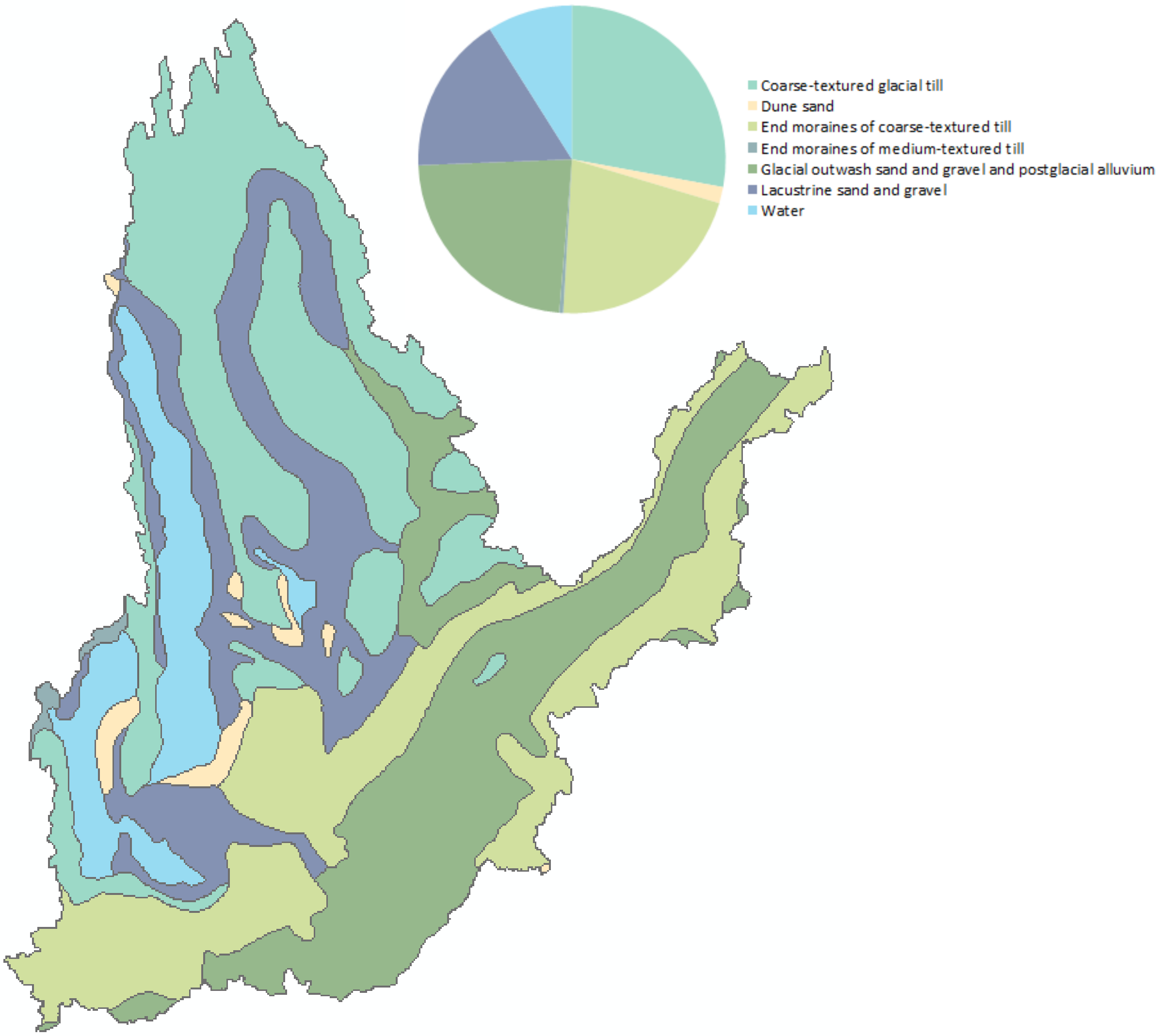


EGLE Runoff Curve Number
60.3

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use SystemLegend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

13, ELK RIVER WATERSHED

Surficial Geology



Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	362.60	27.89%
Dune sand	22.27	1.71%
End moraines of coarse-textured till	276.95	21.30%
End moraines of medium-textured till	5.62	0.43%
Glacial outwash sand and gravel and postglacial alluvium	299.64	23.05%
Lacustrine sand and gravel	216.49	16.65%
Water	116.55	8.96%
Total Watershed Area	1300.13	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

13, ELK RIVER WATERSHED

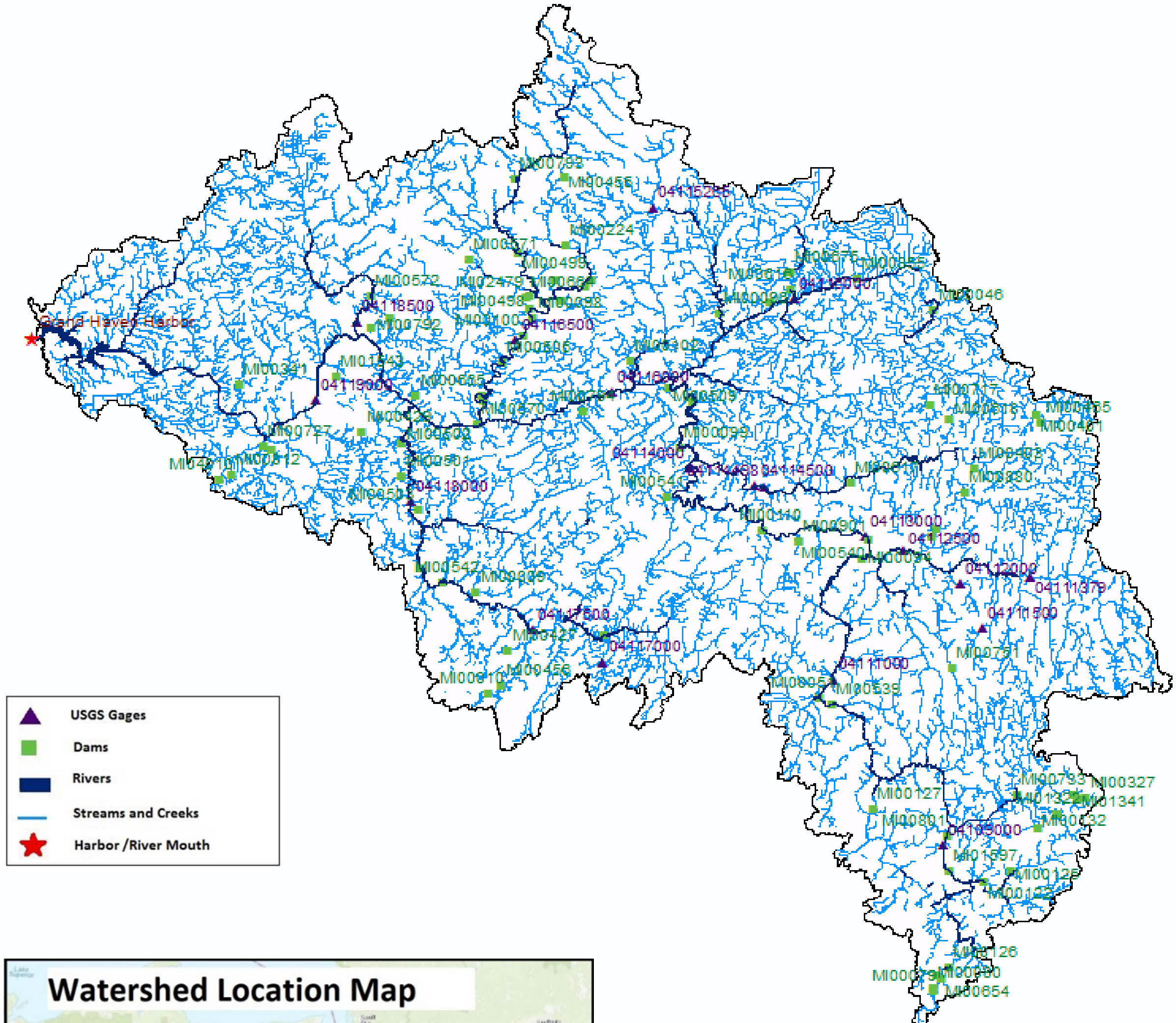
Surficial Geology (Simplified)

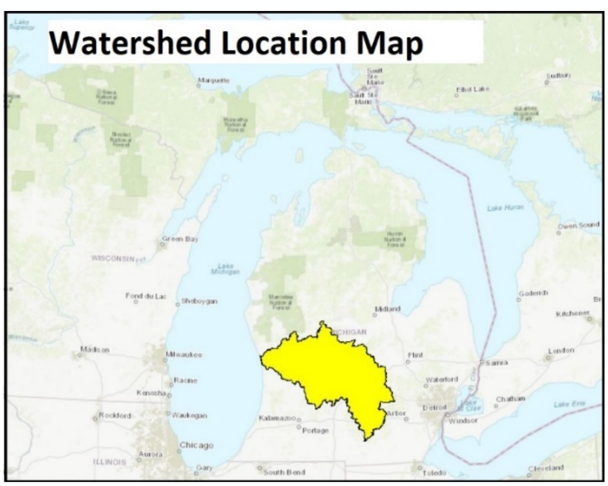
Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	1183.58	91.04%
Water	116.55	8.96%
Total Watershed Area	1300.13	100.00%

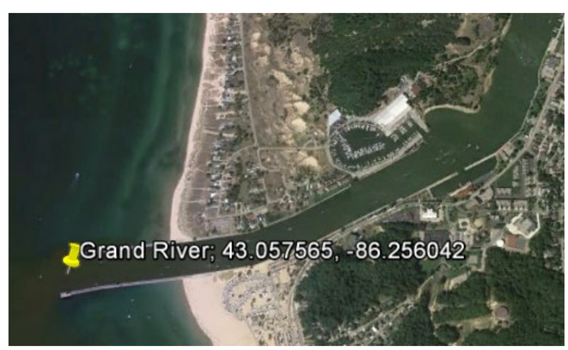
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX R. GRAND RIVER WATERSHED (14)

Surface Hydrology







14, GRAND RIVER WATERSHED

Dam Identification and USGS Streamgages

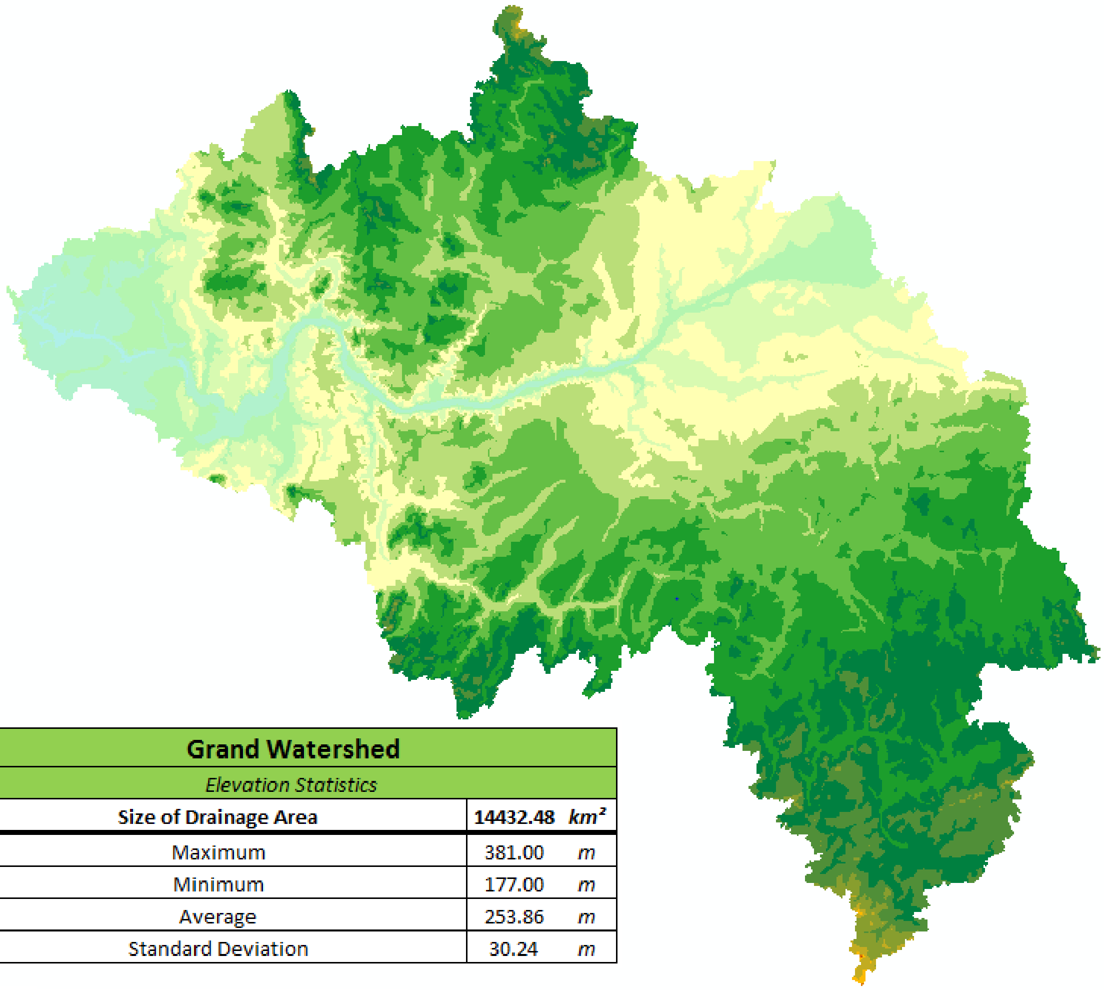
USACE's National Inventory of Dams (NID)							
NIDID	**Dam Name**	**Longitude**	**Latitude**	**NIDID**	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***	***National ID***	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00206	Webber	-84.903300	42.956700	MI00427	North Branch Cedar Creek Dam	-85.286670	42.586670
MI00501	Ada	-85.500000	42.850000	MI00429	Eastbrook Lake Level Control Structure	-85.580200	42.917800
MI00502	Cascade	-85.500000	42.900000	MI00440	Little Rainbow Lake Dam	-84.696660	43.150000
MI00506	Fallasburg Dam	-85.331000	42.962000	MI00453	Grass Lake Level Control Structure	-85.521670	43.088330
MI00506	Flat River Diversion Dam	-85.335900	42.970200	MI00455	Stanton Lake Dam	-85.163060	43.298050
MI00505	White Bridge	-85.292800	43.020600	MI00456	Topski Dam	-85.300000	42.533330
MI00498	Belding	-85.234700	43.100300	MI00046	Elsie Dam	-84.405940	43.089670
MI00010	Cedar Creek Dam	-85.326670	42.521670	MI00465	Cummings Lake Dam	-84.190000	42.916670
MI00100	Smyrna Milling Company Dam	-85.250000	43.060000	MI00499	Greenville Dam	-85.258330	43.183330
MI00102	Sterner Dam	-85.028340	43.020000	MI00509	Lyons Dam	-84.953330	42.980000
MI00540	North Lansing Dam	-84.550000	42.746700	MI00541	Weippert Dam	-84.958340	42.815000
MI00094	Moores Park Dam	-84.560800	42.718400	MI00570	King Milling Company Dam	-85.346660	42.926670
MI00110	Grand Ledge Dam	-84.763340	42.763330	MI00571	Wabasis Lake Level Control Structure	-85.358330	43.175000
MI00543	Middleville	-85.465000	42.711700	MI00572	Rockford Dam	-85.561870	43.120510
MI00051	Mix	-84.655000	42.510000	MI00616	Rainbow Lake Dam	-84.698330	43.123330
MI00539	Smithville	-84.629000	42.499700	MI00617	Lake Geneva Dam	-84.583340	42.833330
MI00503	La Barge	-85.466700	42.800000	MI00618	Lake Victoria Dam	-84.377900	42.924140
MI00542	Irving	-85.418300	42.690000	MI00651	Thunder Hole Dam	-84.742780	43.105930
MI00099	Portland	-84.930800	42.889100	MI00652	Lake Of The Hills Dam	-84.418870	42.749700
MI00012	Nashville Dam	-85.091670	42.608330	MI00654	Mirror Lake Dam	-84.418330	42.083330
MI00122	Michigan Center Dam	-84.327400	42.229000	MI00664	Ranney Lake Dam	-85.241670	43.116660
MI00125	Leoni Dam	-84.271670	42.245000	MI00665	Westdale Family Dam	-85.470000	42.970000
MI00126	Liberty Dam	-84.400000	42.100000	MI00675	Sadilek Dam	-84.700000	43.150000
MI00127	Minard Mill Dam	-84.550000	42.340000	MI00704	North Branch Rush Creek Retention Basin Dam	-85.766670	42.891670
MI00130	Waterloo Dam	-84.140000	42.355000	MI00717	Sleepy Hollow Dam	-84.418330	42.946670
MI00132	Portage Creek Trout Pond Dam	-84.216670	42.306670	MI00722	Putney Dam	-84.425000	42.088330
MI01322	Baldwin Flooding Dam	-84.176870	42.328180	MI00727	Kenowa Lake Level Control Structure	-85.783800	42.896900
MI01341	Mud Lake Dam	-84.133330	42.350000	MI00733	Portage Lake Dam	-84.256670	42.358330
MI01543	General Growth Dam	-85.633330	43.000000	MI00751	Mason Wildlife Dam	-84.383330	42.550000
MI01597	Holton Dam	-84.396670	42.245000	MI00079	Lake Le-Ann South Dam	-84.433330	42.065000
MI01957	Lake Lansing Dam	-84.410000	42.761670	MI00792	Secluded Lake Dam	-85.560000	43.075000
MI00224	County Farm Dam	-85.160000	43.195000	MI00793	Hunter Lake Level Control Structure	-85.263340	43.296670
MI02479	County Line Flooding Dam	-85.236660	43.120000	MI00794	Sessions Creek Dam	-85.127490	42.945450
MI02526	Greens Flooding Dam	-85.122500	43.133340	MI00080	Lake Le-Ann North Dam	-84.433330	42.070000
MI02527	Snaky Run Flooding Dam	-85.181950	43.143050	MI00801	Jackson Prison Dam	-84.397780	42.297220
MI00327	Winnewana Dam	-84.116670	42.350000	MI00812	Rush Creek Detention Basin Dam #2	-85.848610	42.851940
MI00341	Root Dam	-85.831670	42.990000	MI00880	Rose Lake Flooding Dam	-84.350000	42.813890
MI00355	Milli-Ander Pond Dam	-84.562770	43.139720	MI00009	Algonquin Lake Dam	-85.350000	42.675000
MI00383	Good Point Flooding Dam	-85.110000	43.143610	MI00901	Myers-Henderson Detention Pond	-84.690280	42.745000
MI00401	Lake Manitou Dam	-84.201670	42.928330	MI00096	Hubbardston Dam	-84.846660	43.090000
MI04010	Buttermilk Creek Detention Dam	-85.873680	42.845750	MI00097	Humany Dam	-85.169100	43.112800
MI00403	Scenic Lake Dam	-84.330410	42.849430	MI00098	Cannon Creek Dam	-85.228610	43.085560

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4109000	GRAND RIVER AT JACKSON, MI	*-84.408848*	*42.283647*	yes
4111000	GRAND RIVER NEAR EATON RAPIDS, MI	-84.623035	42.534759	yes
4111379	RED CEDAR RIVER NEAR WILLIAMSTON, MI	-84.219133	42.68309	yes
4111500	DEER CREEK NEAR DANSVILLE, MI	-84.320803	42.608369	yes
4112000	SLOAN CREEK NEAR WILLIAMSTON, MI	-84.363861	42.675868	yes
4112500	RED CEDAR RIVER AT EAST LANSING, MI	-84.477754	42.727813	yes
4113000	GRAND RIVER AT LANSING, MI	-84.555257	42.75059	yes
4114000	GRAND RIVER AT PORTLAND, MI	-84.912218	42.856423	yes
4114498	LOOKING GLASS RIVER NEAR EAGLE, MI	-84.759434	42.82809	yes
4114500	LOOKING GLASS RIVER AT HINMAN RD NEAR EAGLE, MI	-84.778601	42.829479	
4115000	MAPLE RIVER AT MAPLE RAPIDS, MI	-84.693052	43.109755	yes
4115265	FISH CREEK NEAR CRYSTAL, MI	-84.981125	43.249755	yes
4116000	GRAND RIVER AT IONIA, MI	-85.069172	42.971977	yes
4116500	FLAT RIVER AT SMYRNA, MI	-85.264739	43.052809	
4117000	QUAKER BROOK NEAR NASHVILLE, MI	-85.093609	42.565869	yes
4117500	THORNAPPLE RIVER NEAR HASTINGS, MI	-85.236393	42.615869	yes
4118000	THORNAPPLE RIVER NEAR CALEDONIA, MI	-85.483352	42.811143	
4118500	ROGUE RIVER NEAR ROCKFORD, MI	-85.590865	43.082249	yes
4119000	GRAND RIVER AT GRAND RAPIDS, MI	-85.67642	42.964471	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				16

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

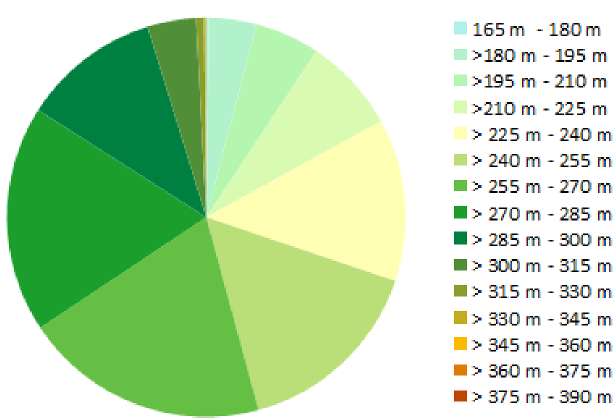
14, GRAND RIVER WATERSHED

Elevation



Grand Watershed		
Elevation Statistics		
Size of Drainage Area	**14432.48**	***km²***
Maximum	381.00	*m*
Minimum	177.00	*m*
Average	253.86	*m*
Standard Deviation	30.24	*m*

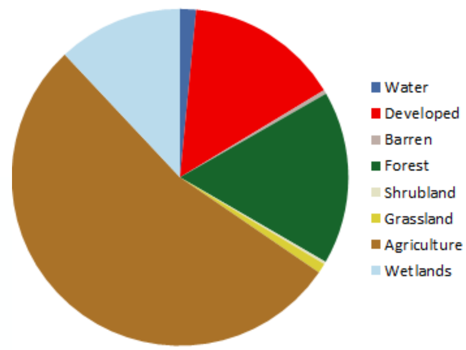
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	33.98	0.24%
>180 m - 195 m	550.82	3.82%
>195 m - 210 m	761.14	5.27%
>210 m - 225 m	1106.27	7.67%
>225 m - 240 m	1901.24	13.17%
>240 m - 255 m	2252.62	15.61%
>255 m - 270 m	2870.76	19.89%
>270 m - 285 m	2651.47	18.37%
>285 m - 300 m	1616.36	11.20%
>300 m - 315 m	570.15	3.95%
>315 m -330 m	91.82	0.64%
>330 m - 345 m	20.61	0.14%
>345 m - 360 m	4.73	0.03%
>360 m - 375 m	0.43	0.00%
>375 m - 390 m	0.08	0.00%
Size of Drainage Area	14432.48	100.00%

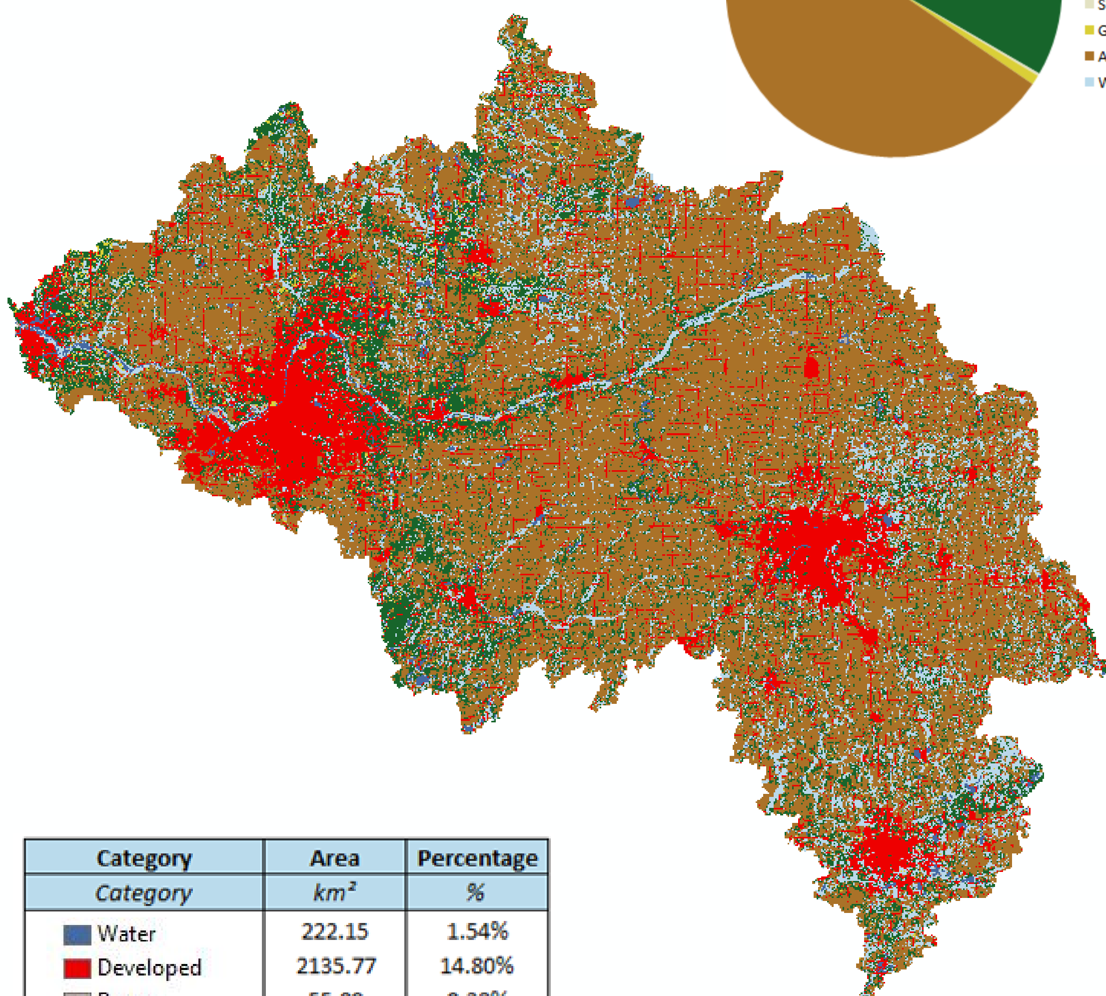


All Elevation Measurements with Respect to North American Datum 1983

14, GRAND RIVER WATERSHED

Land Use





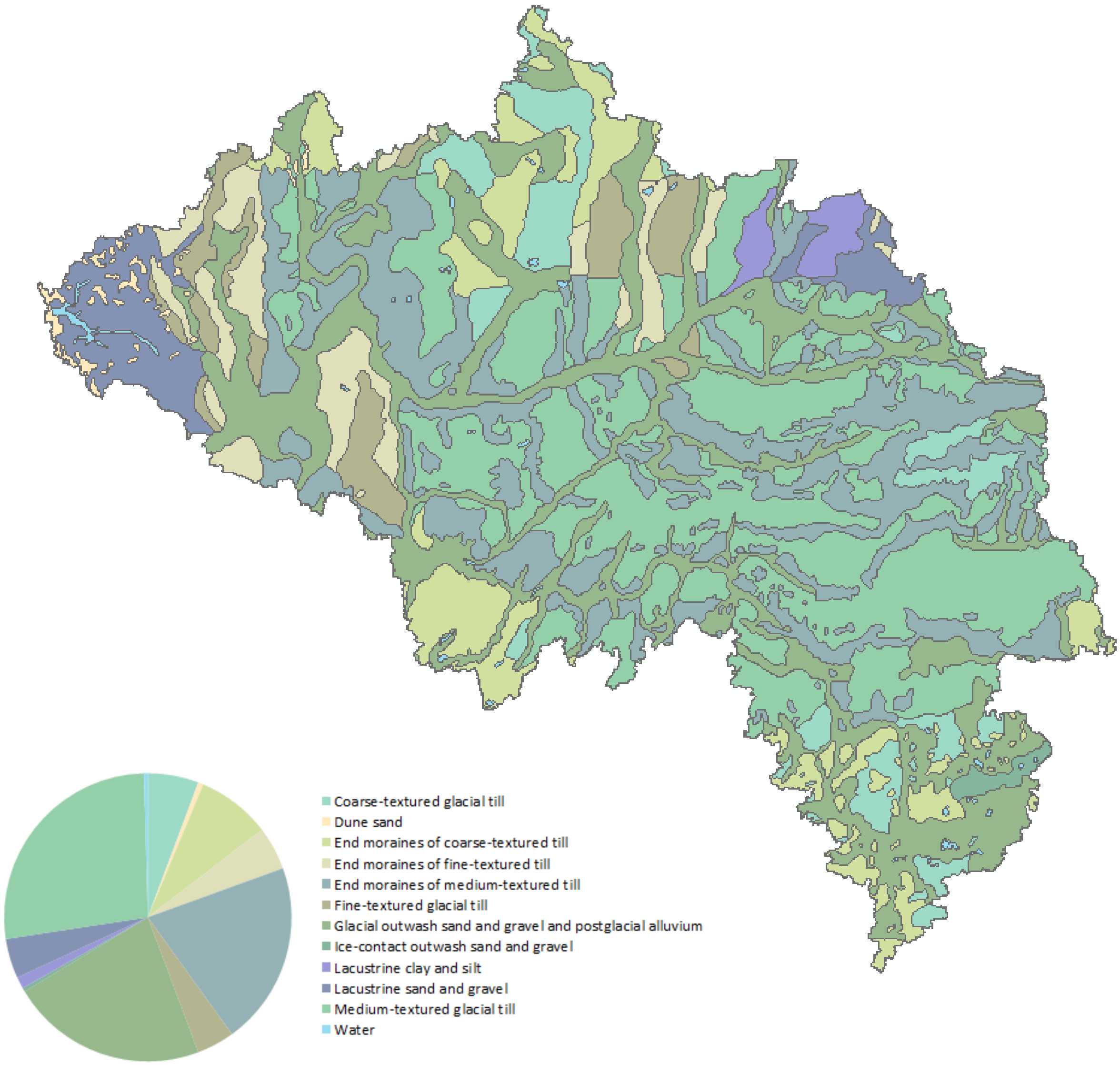
Category	Area	Percentage
Category	*km²*	*%*
Water	222.15	1.54%
Developed	2135.77	14.80%
Barren	55.09	0.38%
Forest	2402.33	16.65%
Shrubland	36.31	0.25%
Grassland	134.88	0.93%
Agriculture	7713.61	53.45%
Wetlands	1732.33	12.00%
Total	14432.48	100.00%

EGLE Runoff Curve Number
75.2

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

14, GRAND RIVER WATERSHED

Surficial Geology

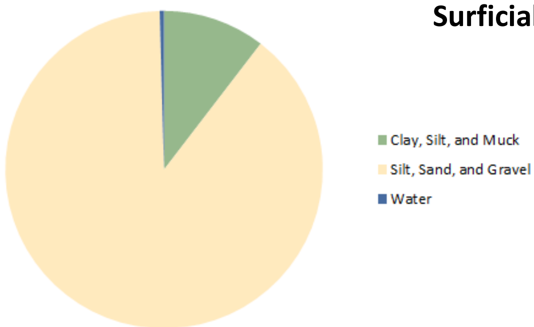


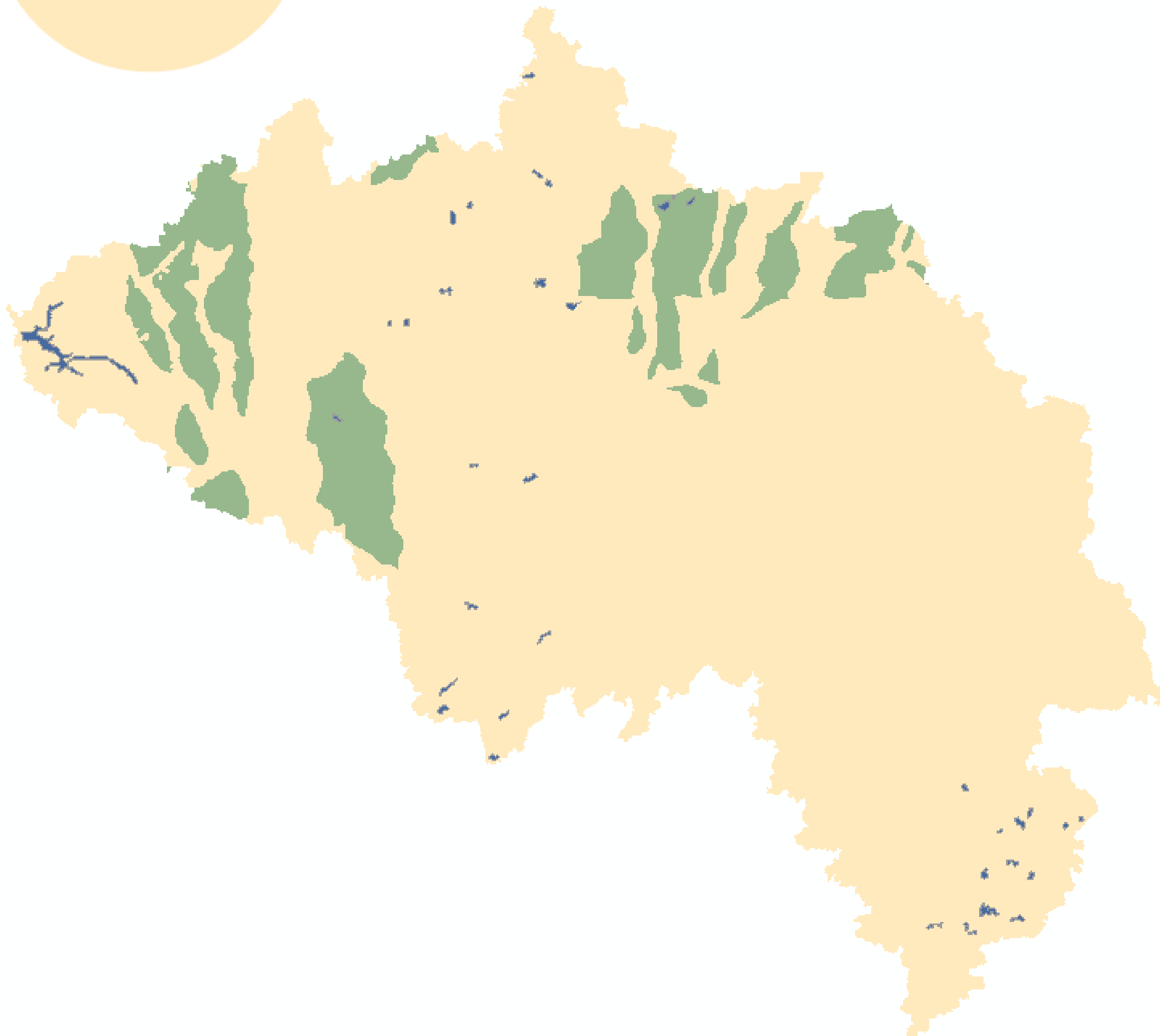
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	825.20	5.72%
Dune sand	86.82	0.60%
End moraines of coarse-textured till	1196.20	8.29%
End moraines of fine-textured till	703.15	4.87%
End moraines of medium-textured till	2966.86	20.56%
Fine-textured glacial till	612.89	4.25%
Glacial outwash sand and gravel and postglacial alluvium	3191.81	22.12%
Ice-contact outwash sand and gravel	62.88	0.44%
Lacustrine clay and silt	188.32	1.30%
Lacustrine sand and gravel	643.47	4.46%
Medium-textured glacial till	3892.63	26.97%
Water	62.24	0.43%
Total Watershed Area	14432.48	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

14, GRAND RIVER WATERSHED

Surficial Geology (Simplified)



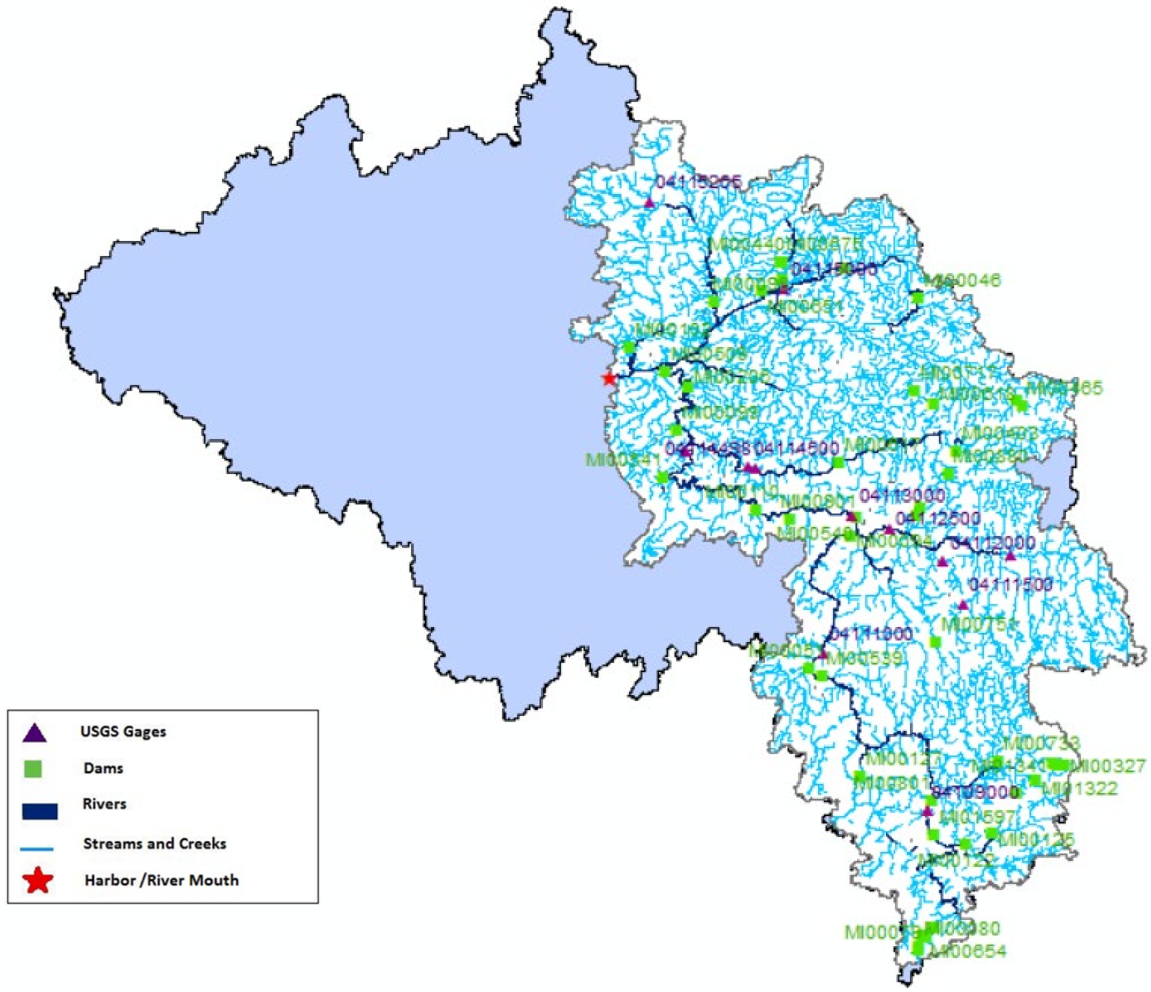


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*1504.37*	10.42%
Silt, Sand, and Gravel	12865.87	89.15%
Water	62.24	0.43%
Total Watershed Area	14432.48	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX S. GRAND RIVER WATERSHED, WEBBER DAM (14A)

Surface Hydrology



14A, GRAND RIVER WATERSHED, WEBBER DAM

Dam Identification and USGS Streamgages

USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00102	Sterner Dam	-85.028340	43.020000
MI00540	North Lansing Dam	-84.550000	42.746700
MI00094	Moores Park Dam	-84.560800	42.718400
MI00110	Grand Ledge Dam	-84.763340	42.763330
MI00051	Mix	-84.655000	42.510000
MI00539	Smithville	-84.629000	42.499700
MI00099	Portland	-84.930800	42.889100
MI00122	Michigan Center Dam	-84.327400	42.229000
MI00125	Leoni Dam	-84.271670	42.245000
MI00126	Liberty Dam	-84.400000	42.100000
MI00127	Minard Mill Dam	-84.550000	42.340000
MI00130	Waterloo Dam	-84.140000	42.355000
MI00132	Portage Creek Trout Pond Dam	-84.216670	42.306670
MI01322	Baldwin Flooding Dam	-84.176870	42.328180
MI01341	Mud Lake Dam	-84.133330	42.350000
MI01597	Holton Dam	-84.396670	42.245000
MI01957	Lake Lansing Dam	-84.410000	42.761670
MI00327	Winnewana Dam	-84.116670	42.350000
MI00355	Milli-Ander Pond Dam	-84.562770	43.139720
MI00401	Lake Manitou Dam	-84.201670	42.928330
MI00403	Scenic Lake Dam	-84.330410	42.849430
MI00440	Little Rainbow Lake Dam	-84.696660	43.150000
MI00046	Elsie Dam	-84.405940	43.089670
MI00465	Cummings Lake Dam	-84.190000	42.916670
MI00509	Lyons Dam	-84.953330	42.980000
MI00541	Weippert Dam	-84.958340	42.815000
MI00616	Rainbow Lake Dam	-84.698330	43.123330
MI00617	Lake Geneva Dam	-84.583340	42.833330
MI00618	Lake Victoria Dam	-84.377900	42.924140
MI00651	Thunder Hole Dam	-84.742780	43.105930
MI00652	Lake Of The Hills Dam	-84.418870	42.749700
MI00654	Mirror Lake Dam	-84.418330	42.083330
MI00675	Sadilek Dam	-84.700000	43.150000
MI00717	Sleepy Hollow Dam	-84.418330	42.946670
MI00722	Putney Dam	-84.425000	42.088330
MI00733	Portage Lake Dam	-84.256670	42.358330
MI00751	Mason Wildlife Dam	-84.383330	42.550000
MI00079	Lake Le-Ann South Dam	-84.433330	42.065000
MI00080	Lake Le-Ann North Dam	-84.433330	42.070000
MI00801	Jackson Prison Dam	-84.397780	42.297220
MI00880	Rose Lake Flooding Dam	-84.350000	42.813890
MI00901	Myers-Henderson Detention Pond	-84.690280	42.745000
MI00096	Hubbardston Dam	-84.846660	43.090000

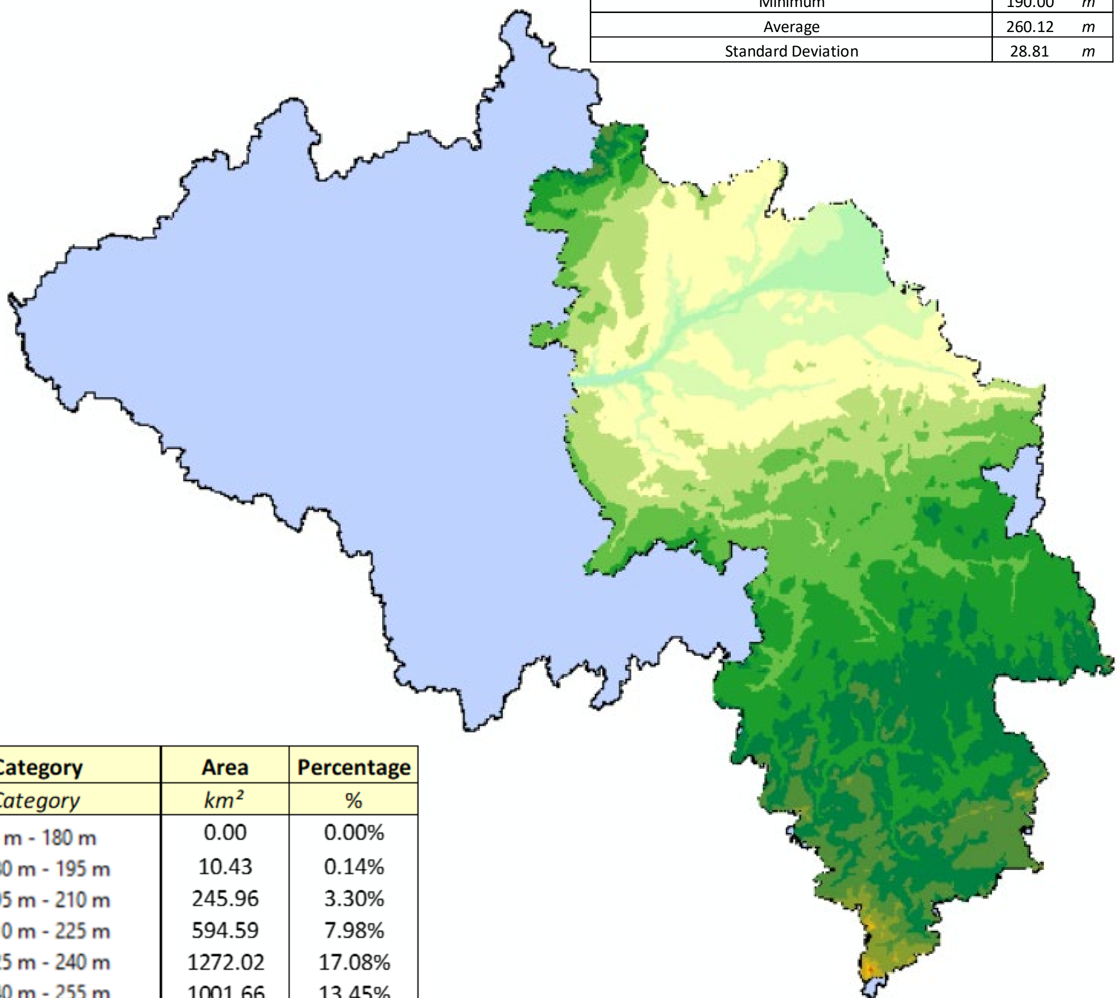
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4109000	GRAND RIVER AT JACKSON, MI	-84.408848	42.283647	yes
4111000	GRAND RIVER NEAR EATON RAPIDS, MI	-84.623035	42.534759	yes
4111379	RED CEDAR RIVER NEAR WILLIAMSTON, MI	-84.219133	42.68309	yes
4111500	DEER CREEK NEAR DANSVILLE, MI	-84.320803	42.608369	yes
4112000	SLOAN CREEK NEAR WILLIAMSTON, MI	-84.363861	42.675868	yes
4112500	RED CEDAR RIVER AT EAST LANSING, MI	-84.477754	42.727813	yes
4113000	GRAND RIVER AT LANSING, MI	-84.555257	42.75059	yes
4114000	GRAND RIVER AT PORTLAND, MI	-84.912218	42.856423	yes
4114498	LOOKING GLASS RIVER NEAR EAGLE, MI	-84.759434	42.82809	yes
4114500	LOOKING GLASS RIVER AT HINMAN RD NEAR EAGLE, MI	-84.778601	42.829479	
4115000	MAPLE RIVER AT MAPLE RAPIDS, MI	-84.693052	43.109755	yes
4115265	FISH CREEK NEAR CRYSTAL, MI	-84.981125	43.249755	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				11

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

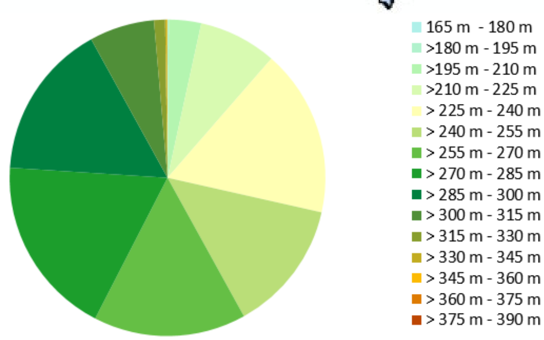
14A, GRAND RIVER WATERSHED, WEBBER DAM

Elevation

Webber Dam		
Elevation Statistics		
Size of Drainage Area	**7447.63**	***km²***
Maximum	381.00	*m*
Minimum	190.00	*m*
Average	260.12	*m*
Standard Deviation	28.81	*m*



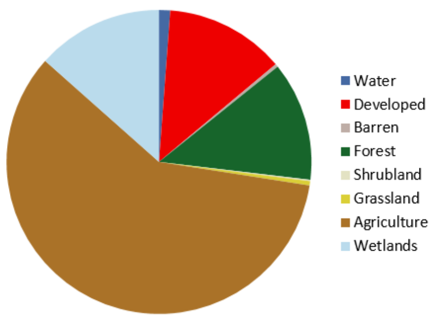
Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	0.00	0.00%
>180 m - 195 m	10.43	0.14%
>195 m - 210 m	245.96	3.30%
>210 m - 225 m	594.59	7.98%
>225 m - 240 m	1272.02	17.08%
>240 m - 255 m	1001.66	13.45%
>255 m - 270 m	1163.21	15.62%
>270 m - 285 m	1373.17	18.44%
>285 m - 300 m	1188.73	15.96%
>300 m - 315 m	495.64	6.65%
>315 m - 330 m	84.28	1.13%
>330 m - 345 m	15.17	0.20%
>345 m - 360 m	2.29	0.03%
>360 m - 375 m	0.39	0.01%
>375 m - 390 m	0.08	0.00%
Size of Drainage Area	7447.63	100.00%

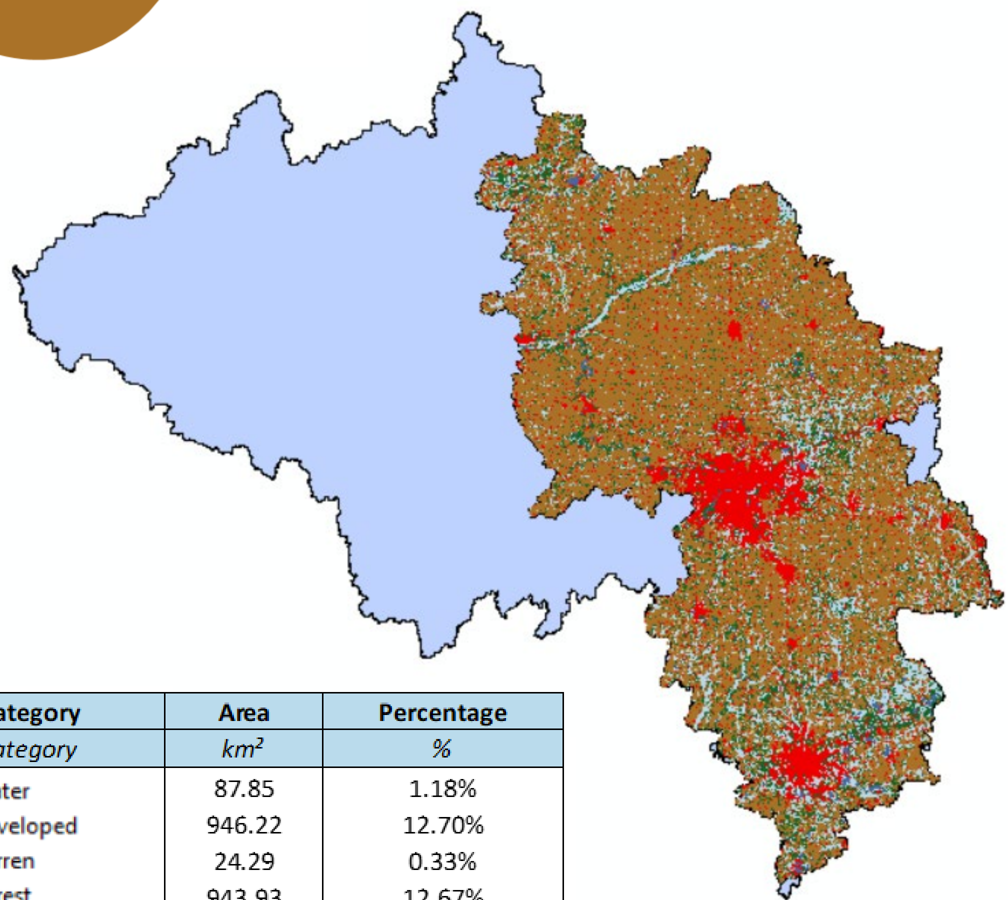


All Elevation Measurements with Respect to North American Datum 1983

14A, GRAND RIVER WATERSHED, WEBBER DAM (14A)

Land Use





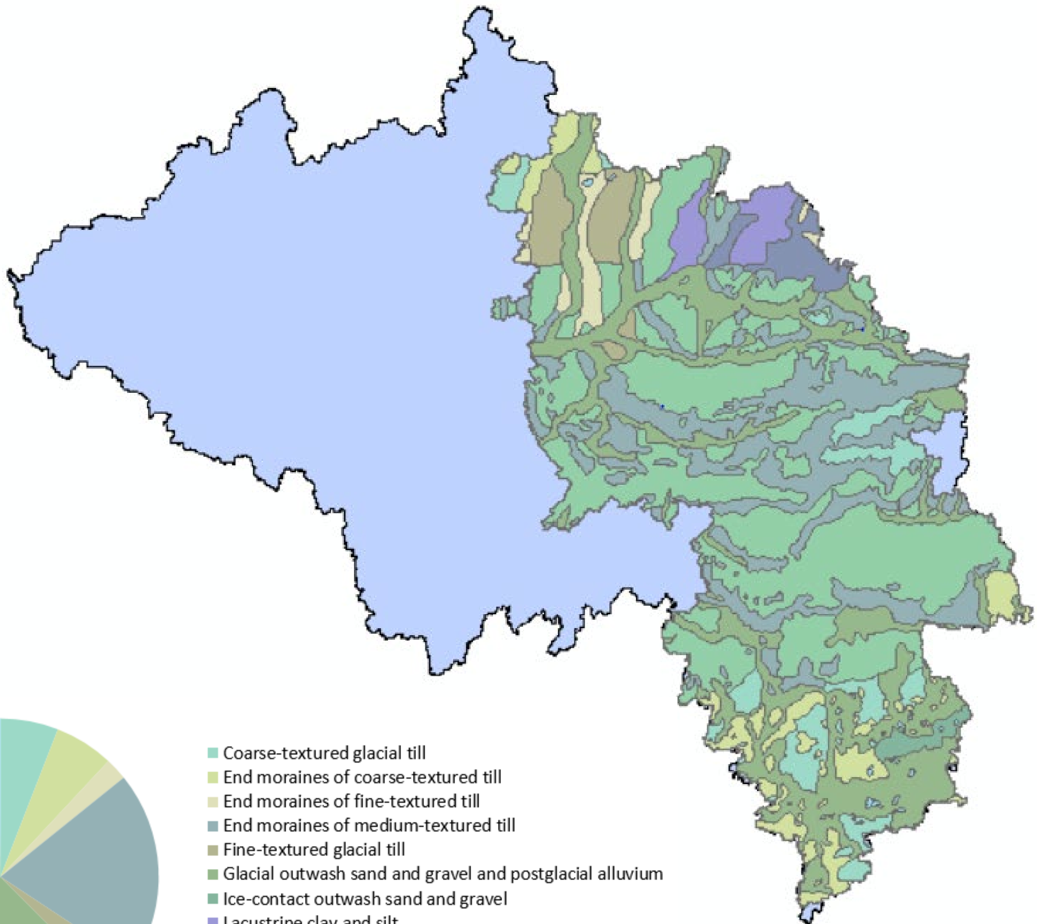
Category	Area	Percentage
Category	*km²*	*%*
Water	87.85	1.18%
Developed	946.22	12.70%
Barren	24.29	0.33%
Forest	943.93	12.67%
Shrubland	10.21	0.14%
Herbaceous	34.27	0.46%
Agriculture	4401.39	59.10%
Wetlands	999.46	13.42%
Total	7447.63	100.00%

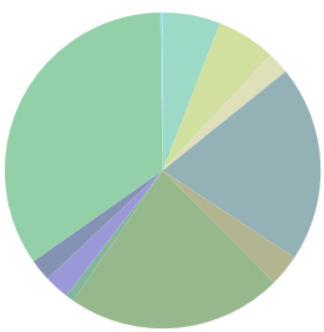
EGLE Runoff Curve Number
76.0

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

14A, GRAND RIVER WATERSHED, WEBBER DAM

Surficial Geology (Original)



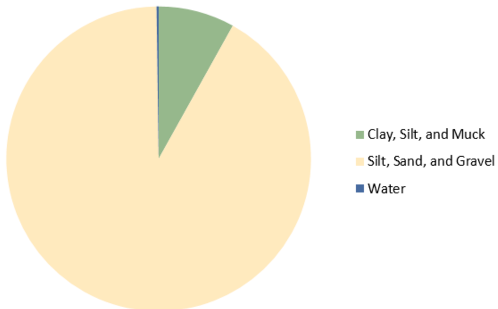


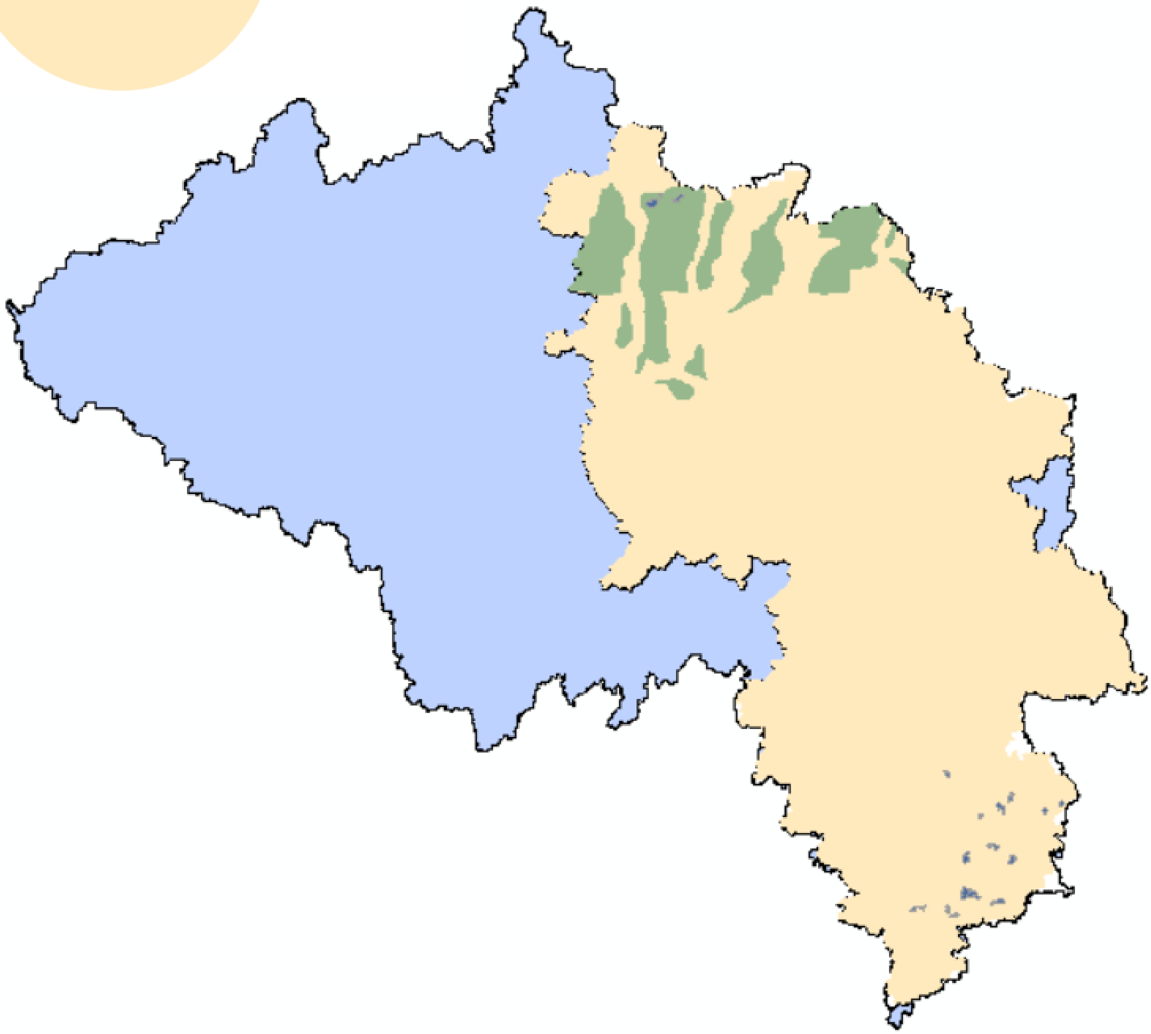
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	440.50	5.91%
End moraines of coarse-textured till	449.44	6.03%
End moraines of fine-textured till	168.90	2.27%
End moraines of medium-textured till	1494.64	20.07%
Fine-textured glacial till	244.19	3.28%
Glacial outwash sand and gravel and postglacial alluvium	1641.44	22.04%
Ice-contact outwash sand and gravel	63.90	0.86%
Lacustrine clay and silt	189.86	2.55%
Lacustrine sand and gravel	167.21	2.25%
Medium-textured glacial till	2571.12	34.52%
Water	16.44	0.22%
Total Watershed Area	7447.63	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

14A, GRAND RIVER WATERSHED, WEBBER DAM

Surficial Geology (Simplified)



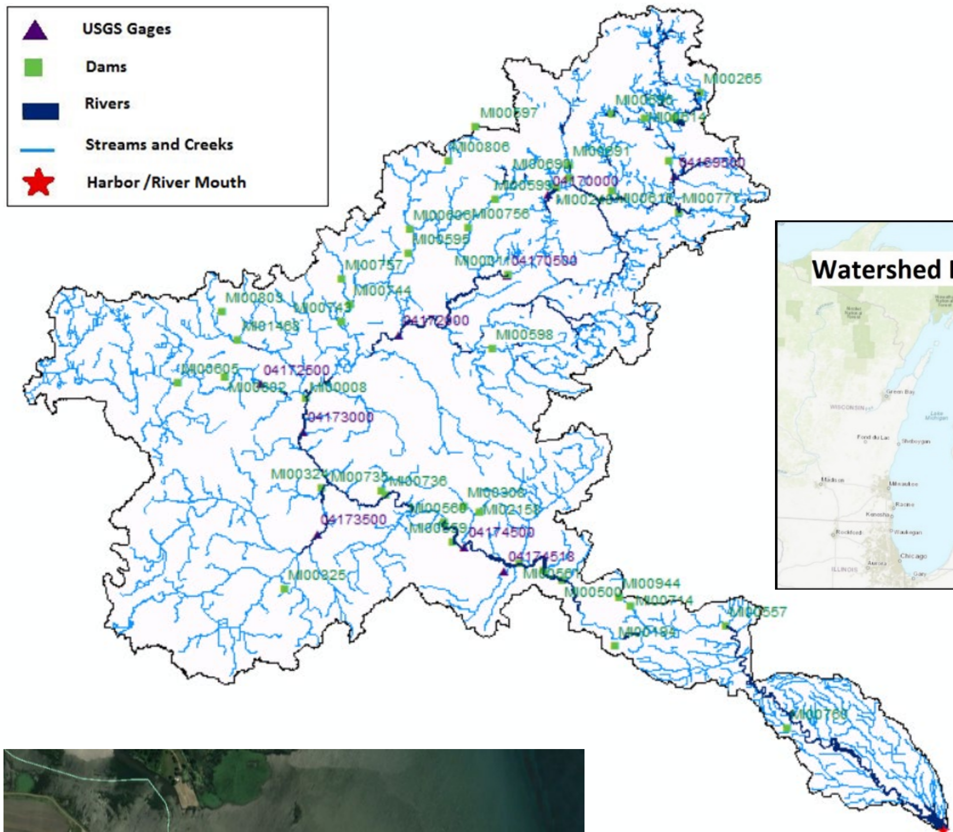


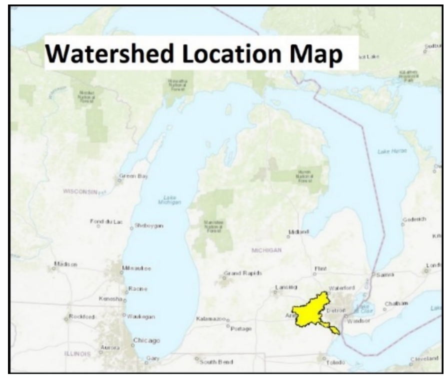
Category	Area	Percentage
--	km^2	%
Clay, Silt, and Muck	602.95	8.10%
Silt, Sand, and Gravel	6828.24	91.68%
Water	16.44	0.22%
Total Watershed Area	7447.63	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX T. HURON RIVER WATERSHED (15)

Surface Hydrology





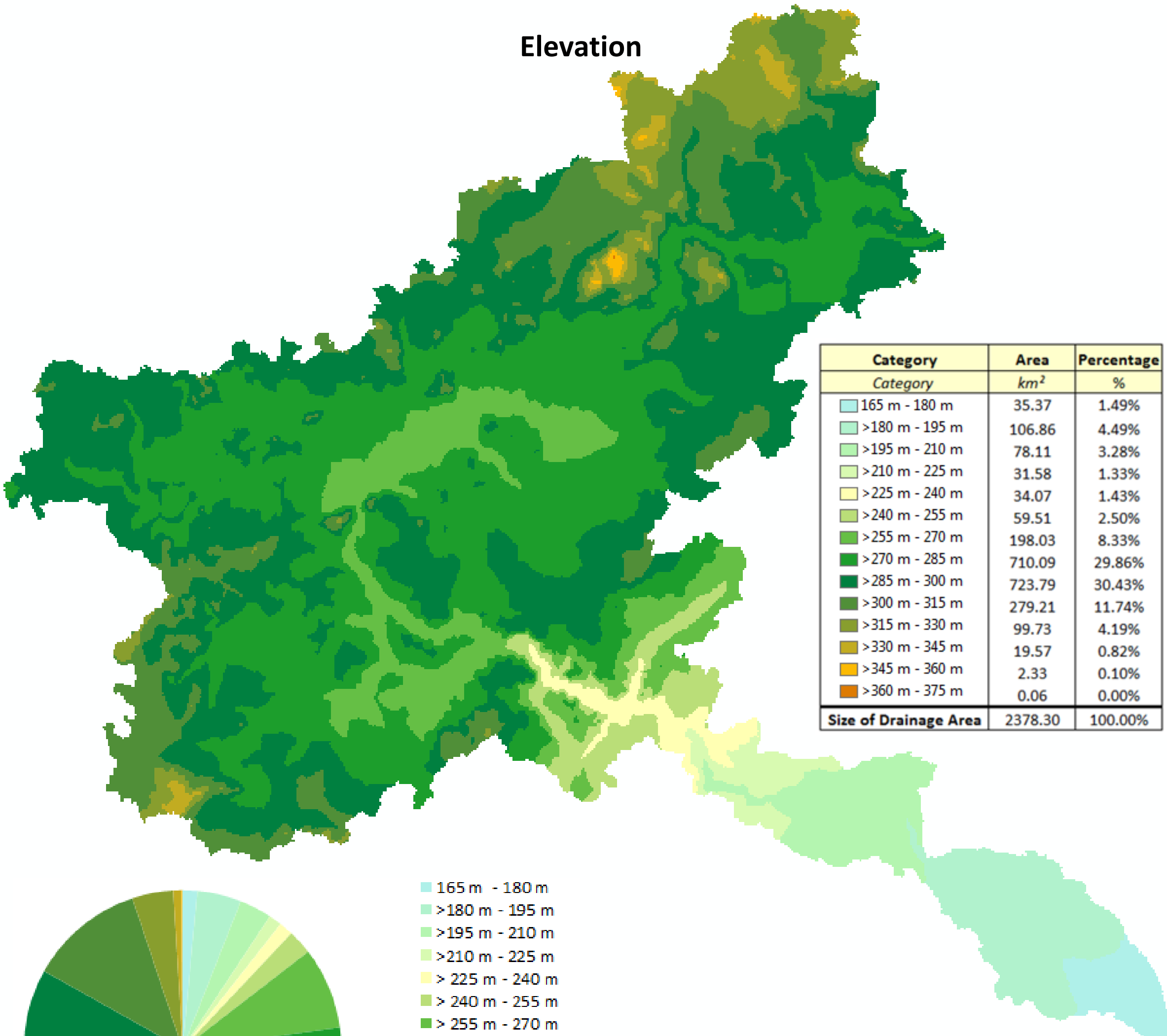
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4169500	HURON RIVER AT COMMERCE, MI	*-83.482994*	*42.591143*	
4170000	HURON RIVER AT MILFORD, MI	-83.626608	42.578921	yes
4170500	HURON RIVER NEAR NEW HUDSON, MI	-83.676329	42.512533	yes
4172000	HURON RIVER NEAR HAMBURG, MI	-83.799943	42.465312	yes
4172500	PORTAGE RIVER AT TIPLADY ROAD NEAR PINCKNEY, MI	-83.958558	42.426979	
4173000	HURON RIVER NEAR DEXTER, MI	-83.911056	42.386147	
4173500	MILL CREEK NEAR DEXTER, MICH. .	-83.898555	42.300037	yes
4174500	HURON RIVER AT ANN ARBOR, MI	-83.733274	42.286149	yes
4174518	MALLETTS CREEK AT ANN ARBOR, MI	-83.688273	42.264761	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				6

USACE's National Inventory of Dams (NID)							
NIDID	Dam Name	Longitude	Latitude	NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*	*National ID*	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00560	Barton Dam	-83.754300	42.308300	MI00602	HiLand Lake Dam	-83.997530	42.433650
MI00558	Superior Dam	-83.644200	42.265500	MI00605	Unadilla Mill Dam	-84.051670	42.430000
MI00194	Ford Lake	-83.566700	42.200000	MI00606	Woodland Lake Dam	-83.785000	42.553330
MI00557	French Landing	-83.440800	42.214400	MI00614	Lake Neva Dam	-83.515000	42.641670
MI00011	Kent Lake Dam	-83.675000	42.513330	MI00615	Lake Sherwood Dam	-83.555000	42.581670
MI01468	Marsh Unit Flooding #4	-83.981670	42.465000	MI00690	Pettibone Creek Dam No 2	-83.601670	42.593330
MI02001	Fox Lake Dam	-83.488330	42.605000	MI00691	Moore Lake Dam	-83.602640	42.603180
MI02158	Traver Lake Dam #5	-83.715000	42.315000	MI00696	Haven Hill Lake Dam	-83.551670	42.645000
MI00248	Ford Dam #3 (Hubbell Pond)	-83.616670	42.585000	MI00714	Tyler Dam	-83.546670	42.233330
MI00263	Oxbow Dam	-83.481670	42.640000	MI00735	Bridgeway Lake Dam	-83.825000	42.335000
MI00265	Pontiac Lake Dam	-83.451670	42.661670	MI00736	Green Oak Lake Dam	-83.820000	42.331670
MI00308	Traver Creek Retention Dam	-83.731670	42.320000	MI00743	Pettysville Mill Dam	-83.865000	42.478330
MI00324	Dexter Dam	-83.891670	42.338890	MI00744	Caroga Lake Level Control Structure	-83.855000	42.491660
MI00325	Sutton Lake Dam	-83.936670	42.255000	MI00756	Moraine Lake Dam	-83.718330	42.553330
MI00500	Peninsular Paper Dam	-83.624090	42.256180	MI00757	Lower Chilson Pond Dam	-83.863330	42.513330
MI00559	Argo Dam	-83.745500	42.290590	MI00760	Washago Pond Dam	-83.375000	42.126670
MI00561	Geddes Dam	-83.671300	42.271000	MI00777	Wolverine Lake Dam	-83.480000	42.561940
MI00595	Brighton Lake Dam	-83.786670	42.533330	MI00008	Flook Dam	-83.906750	42.414570
MI00597	Bullard Lake Dam	-83.706670	42.638330	MI00803	Gregory State Game Area #2 Dam	-84.000000	42.488330
MI00598	Inchwagh Lake Dam	-83.695000	42.451670	MI00806	Long Lake Control Stucture	-83.739170	42.610550
MI00599	General Motors Dam	-83.686670	42.576670	MI00944	Willow Run Hydro Dam	-83.559680	42.240800

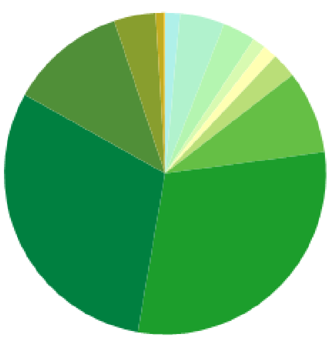
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

15, HURON RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	35.37	1.49%
>180 m - 195 m	106.86	4.49%
>195 m - 210 m	78.11	3.28%
>210 m - 225 m	31.58	1.33%
>225 m - 240 m	34.07	1.43%
>240 m - 255 m	59.51	2.50%
>255 m - 270 m	198.03	8.33%
>270 m - 285 m	710.09	29.86%
>285 m - 300 m	723.79	30.43%
>300 m - 315 m	279.21	11.74%
>315 m - 330 m	99.73	4.19%
>330 m - 345 m	19.57	0.82%
>345 m - 360 m	2.33	0.10%
>360 m - 375 m	0.06	0.00%
Size of Drainage Area	2378.30	100.00%

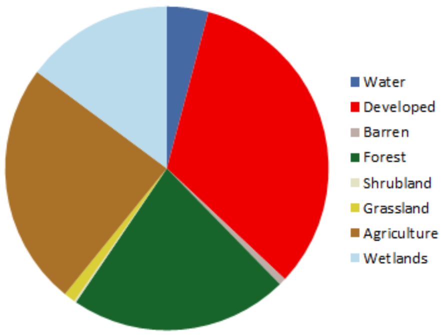


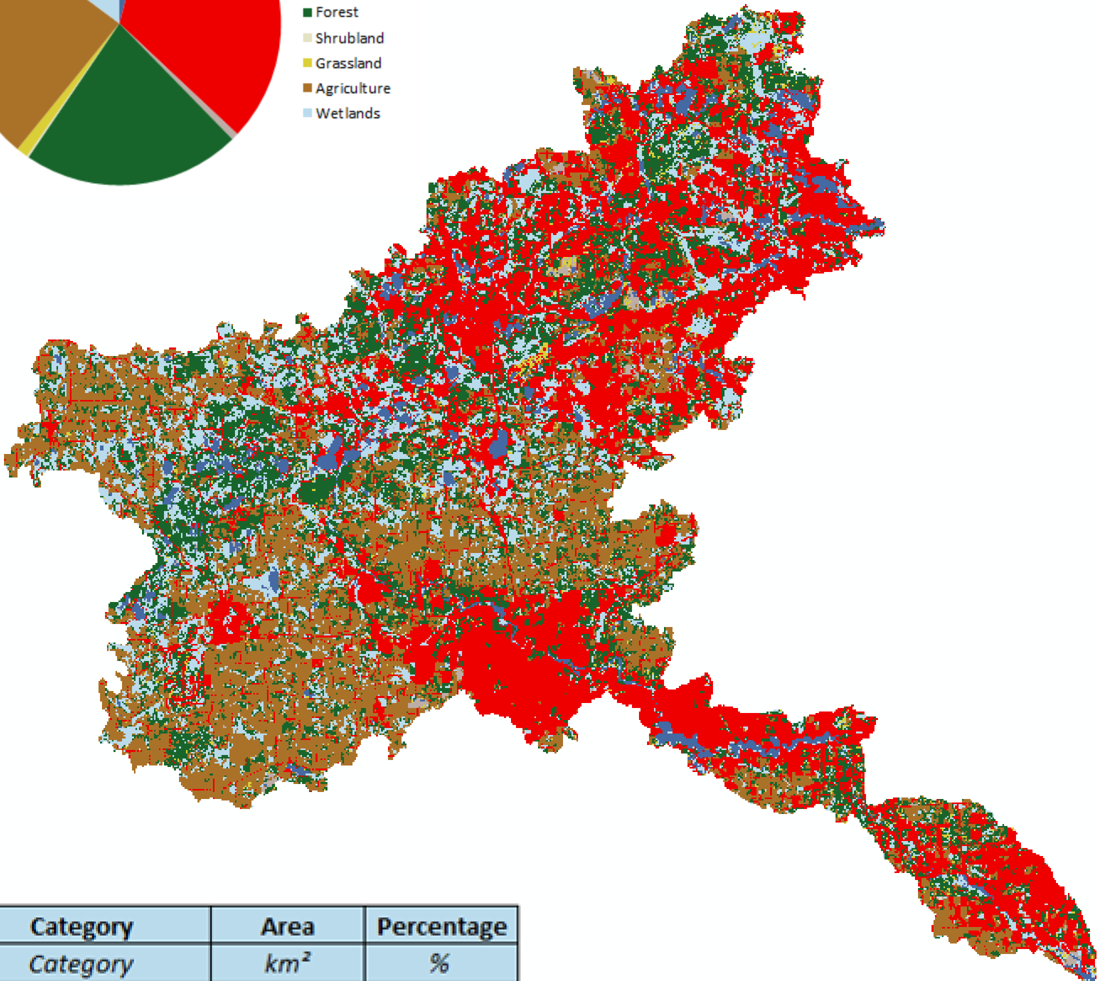
Huron River Watershed		
Elevation Statistics		
Size of Drainage Area	**2378.30**	***km²***
Maximum	363.00	*m*
Minimum	174.00	*m*
Average	275.46	*m*
Standard Deviation	33.02	*m*

All Elevation Measurements with Respect to North American Datum 1983

15, HURON RIVER WATERSHED

Land Use





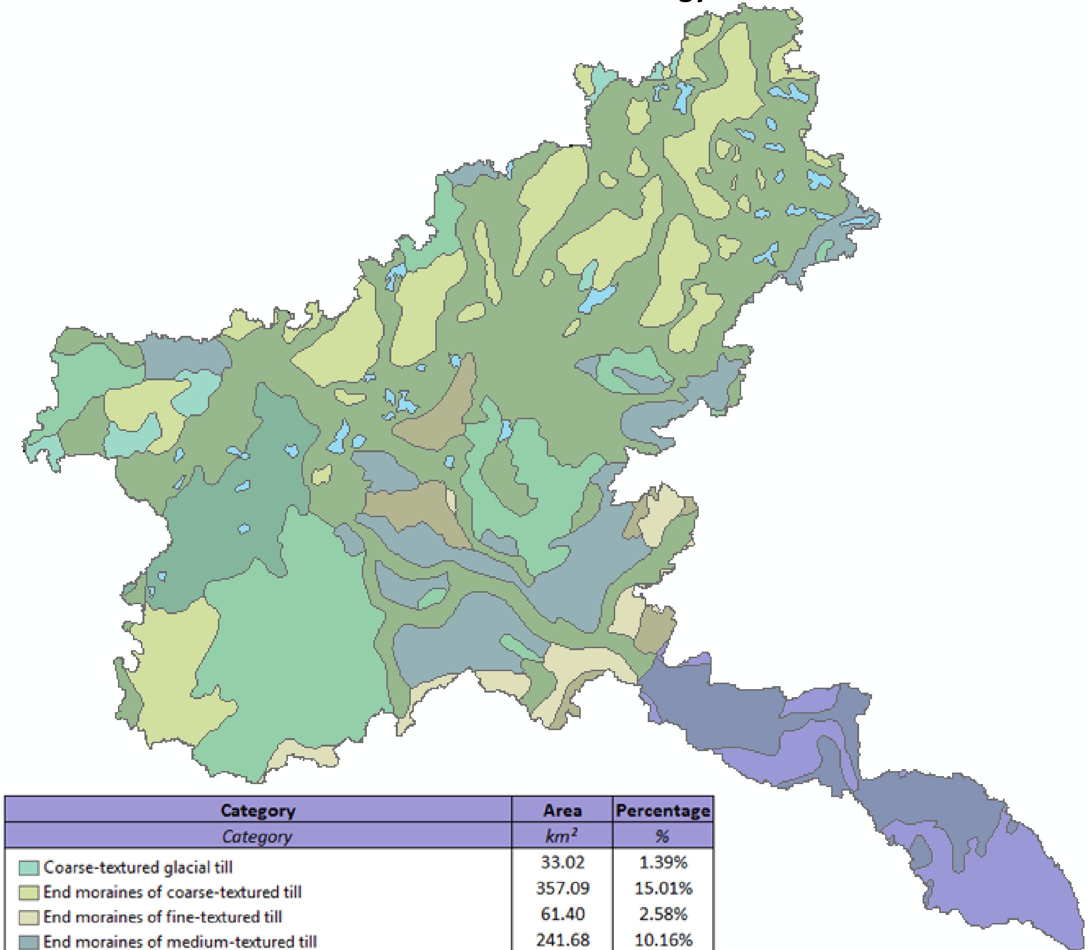
Category	Area	Percentage
Category	*km²*	*%*
Water	98.63	4.15%
Developed	780.91	32.83%
Barren	16.74	0.70%
Forest	519.18	21.83%
Shrubland	4.50	0.19%
Grassland	27.39	1.15%
Agriculture	578.35	24.32%
Wetlands	352.60	14.83%
Total	2378.30	100.00%

EGLE Runoff Curve Number
73.9

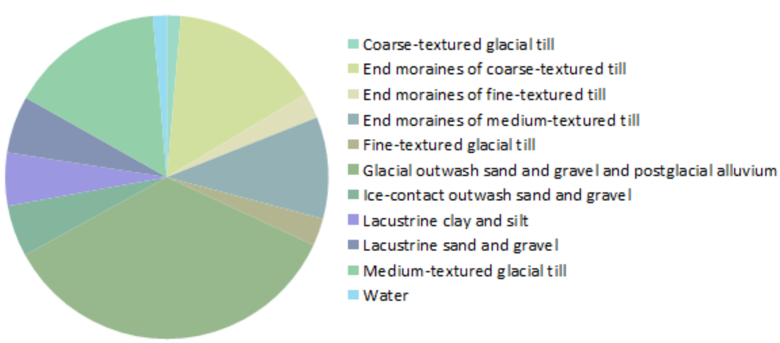
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

15, HURON RIVER WATERSHED

Surficial Geology



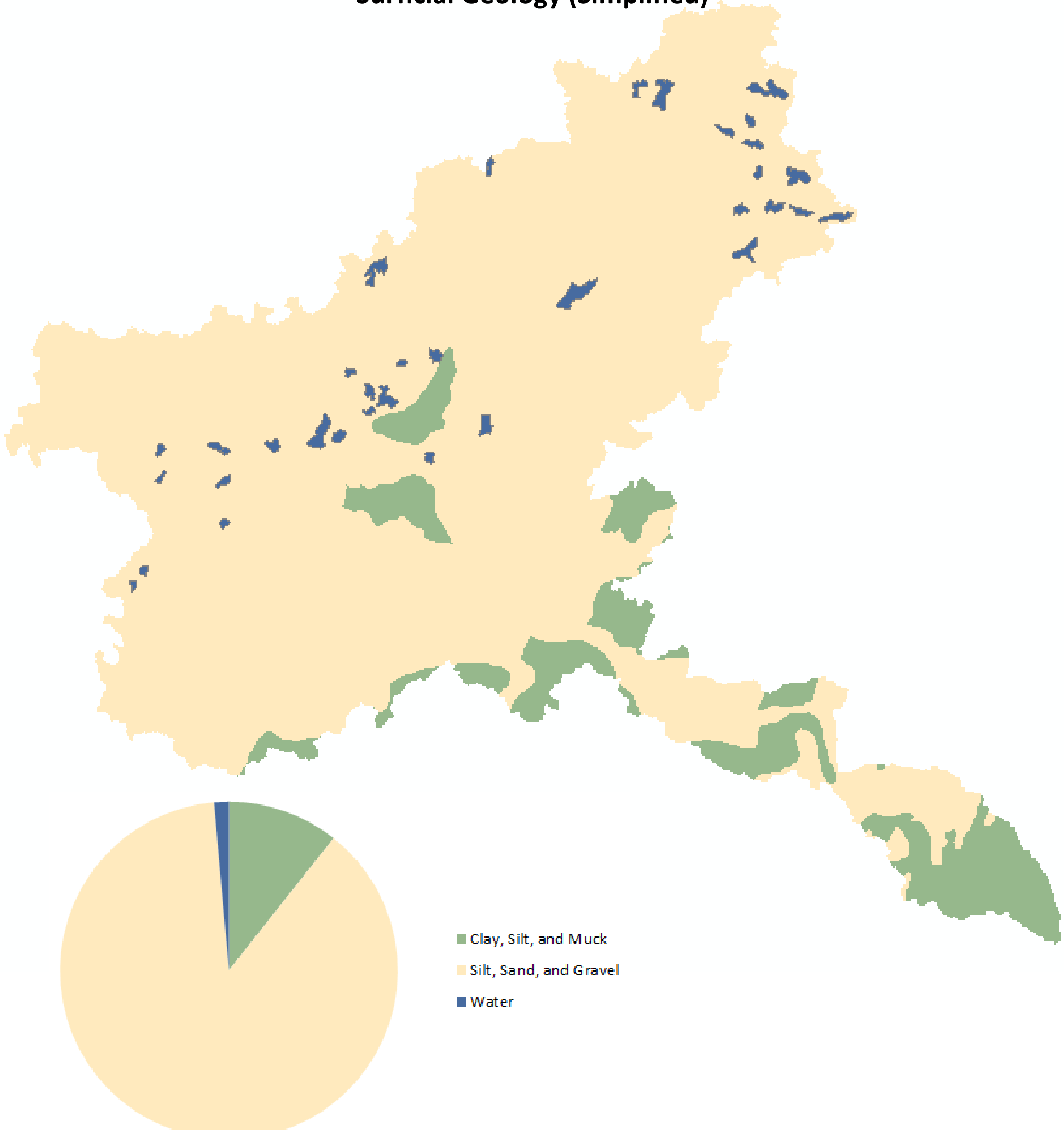
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	33.02	1.39%
End moraines of coarse-textured till	357.09	15.01%
End moraines of fine-textured till	61.40	2.58%
End moraines of medium-textured till	241.68	10.16%
Fine-textured glacial till	65.37	2.75%
Glacial outwash sand and gravel and postglacial alluvium	835.11	35.11%
Ice-contact outwash sand and gravel	122.12	5.13%
Lacustrine clay and silt	126.59	5.32%
Lacustrine sand and gravel	135.63	5.70%
Medium-textured glacial till	367.12	15.44%
Water	33.17	1.39%
Total Watershed Area	2378.30	100.00%



Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

15, HURON RIVER WATERSHED

Surficial Geology (Simplified)

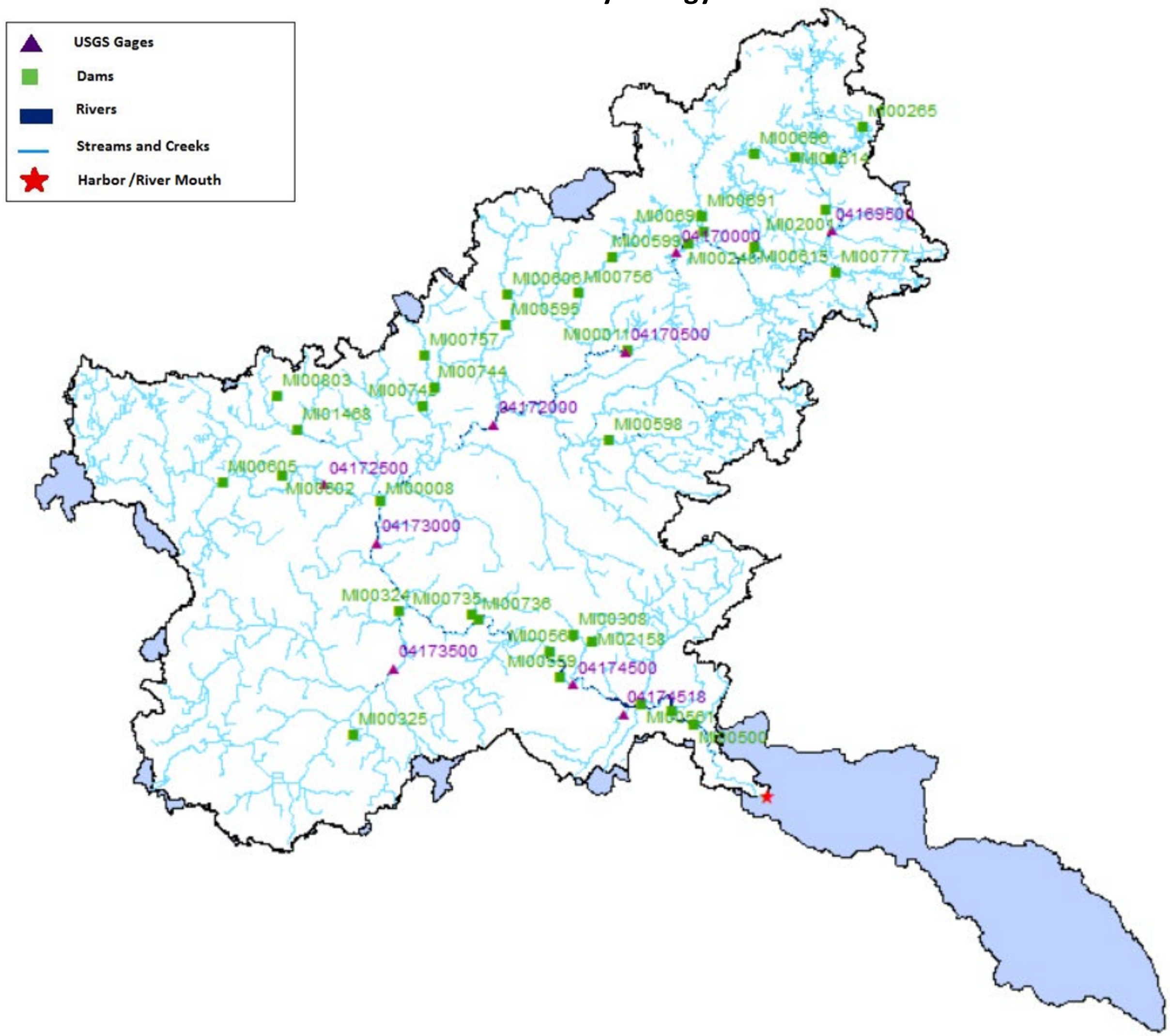


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*253.36*	10.65%
Silt, Sand, and Gravel	2091.77	87.95%
Water	33.17	1.39%
Total Watershed Area	2378.30	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX U. HURON RIVER WATERSHED, FORD LAKE (15A)

Surface Hydrology



15A, HURON RIVER WATERSHED, FORD DAM

Dam Information and USGS Streamgages

USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00560	Barton Dam	-83.754300	42.308300
MI00558	Superior Dam	-83.644200	42.265500
MI00011	Kent Lake Dam	-83.675000	42.513330
MI01468	Marsh Unit Flooding #4	-83.981670	42.465000
MI02001	Fox Lake Dam	-83.488330	42.605000
MI02158	Traver Lake Dam #5	-83.715000	42.315000
MI00248	Ford Dam #3 (Hubbell Pond)	-83.616670	42.585000
MI00263	Oxbow Dam	-83.481670	42.640000
MI00265	Pontiac Lake Dam	-83.451670	42.661670
MI00308	Traver Creek Retention Dam	-83.731670	42.320000
MI00324	Dexter Dam	-83.891670	42.338890
MI00325	Sutton Lake Dam	-83.936670	42.255000
MI00500	Peninsular Paper Dam	-83.624090	42.256180
MI00559	Argo Dam	-83.745500	42.290590
MI00561	Geddes Dam	-83.671300	42.271000
MI00595	Brighton Lake Dam	-83.786670	42.533330
MI00598	Inchwagh Lake Dam	-83.695000	42.451670
MI00599	General Motors Dam	-83.686670	42.576670
MI00602	HiLand Lake Dam	-83.997530	42.433650
MI00605	Unadilla Mill Dam	-84.051670	42.430000
MI00606	Woodland Lake Dam	-83.785000	42.553330
MI00614	Lake Neva Dam	-83.515000	42.641670
MI00615	Lake Sherwood Dam	-83.555000	42.581670
MI00690	Pettibone Creek Dam No 2	-83.601670	42.593330
MI00691	Moore Lake Dam	-83.602640	42.603180
MI00696	Haven Hill Lake Dam	-83.551670	42.645000
MI00735	Bridgeway Lake Dam	-83.825000	42.335000
MI00736	Green Oak Lake Dam	-83.820000	42.331670
MI00743	Pettysville Mill Dam	-83.865000	42.478330
MI00744	Caroga Lake Level Control Structure	-83.855000	42.491660
MI00756	Moraine Lake Dam	-83.718330	42.553330
MI00757	Lower Chilson Pond Dam	-83.863330	42.513330
MI00777	Wolverine Lake Dam	-83.480000	42.561940
MI00008	Flook Dam	-83.906750	42.414570
MI00803	Gregory State Game Area #2 Dam	-84.000000	42.488330

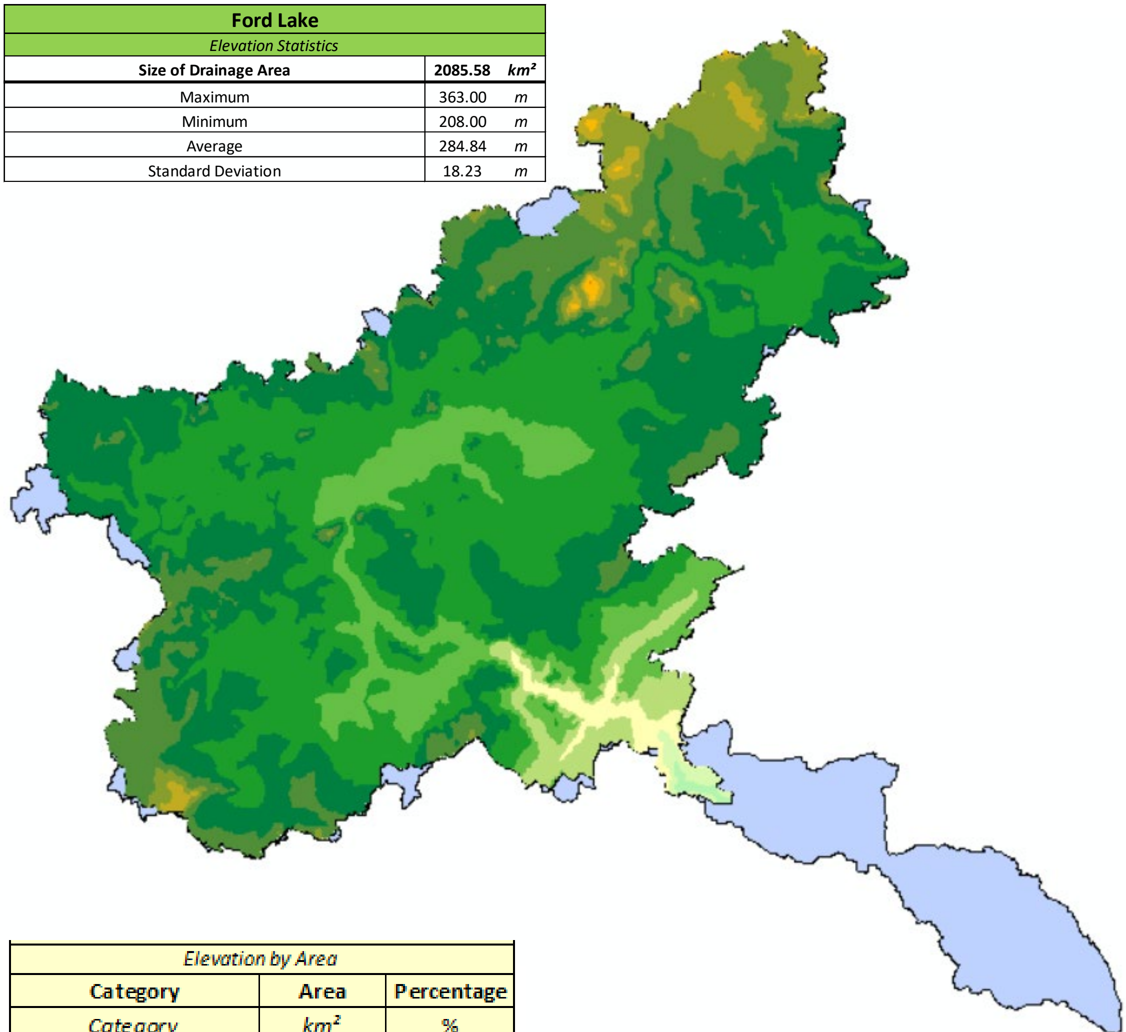
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4169500	HURON RIVER AT COMMERCE, MI	*-83.482994*	*42.591143*	
4170000	HURON RIVER AT MILFORD, MI	-83.626608	42.578921	yes
4170500	HURON RIVER NEAR NEW HUDSON, MI	-83.676329	42.512533	yes
4172000	HURON RIVER NEAR HAMBURG, MI	-83.799943	42.465312	yes
4172500	PORTAGE RIVER AT TIPLADY ROAD NEAR PINCKNEY, MI	-83.958558	42.426979	
4173000	HURON RIVER NEAR DEXTER, MI	-83.911056	42.386147	
4173500	MILL CREEK NEAR DEXTER, MICH. .	-83.898555	42.300037	yes
4174500	HURON RIVER AT ANN ARBOR, MI	-83.733274	42.286149	yes
4174518	MALLETTS CREEK AT ANN ARBOR, MI	-83.688273	42.264761	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				6

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

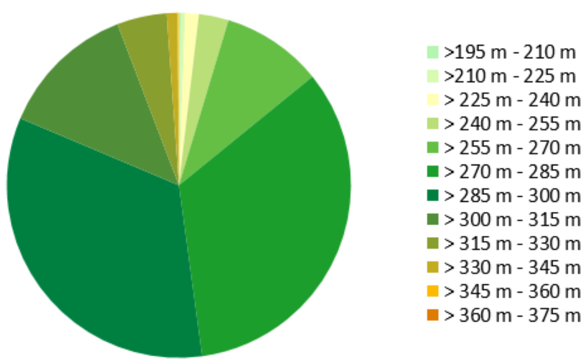
15A, HURON RIVER WATERSHED, FORD DAM

Elevation

Ford Lake		
Elevation Statistics		
Size of Drainage Area	**2085.58**	***km²***
Maximum	363.00	*m*
Minimum	208.00	*m*
Average	284.84	*m*
Standard Deviation	18.23	*m*



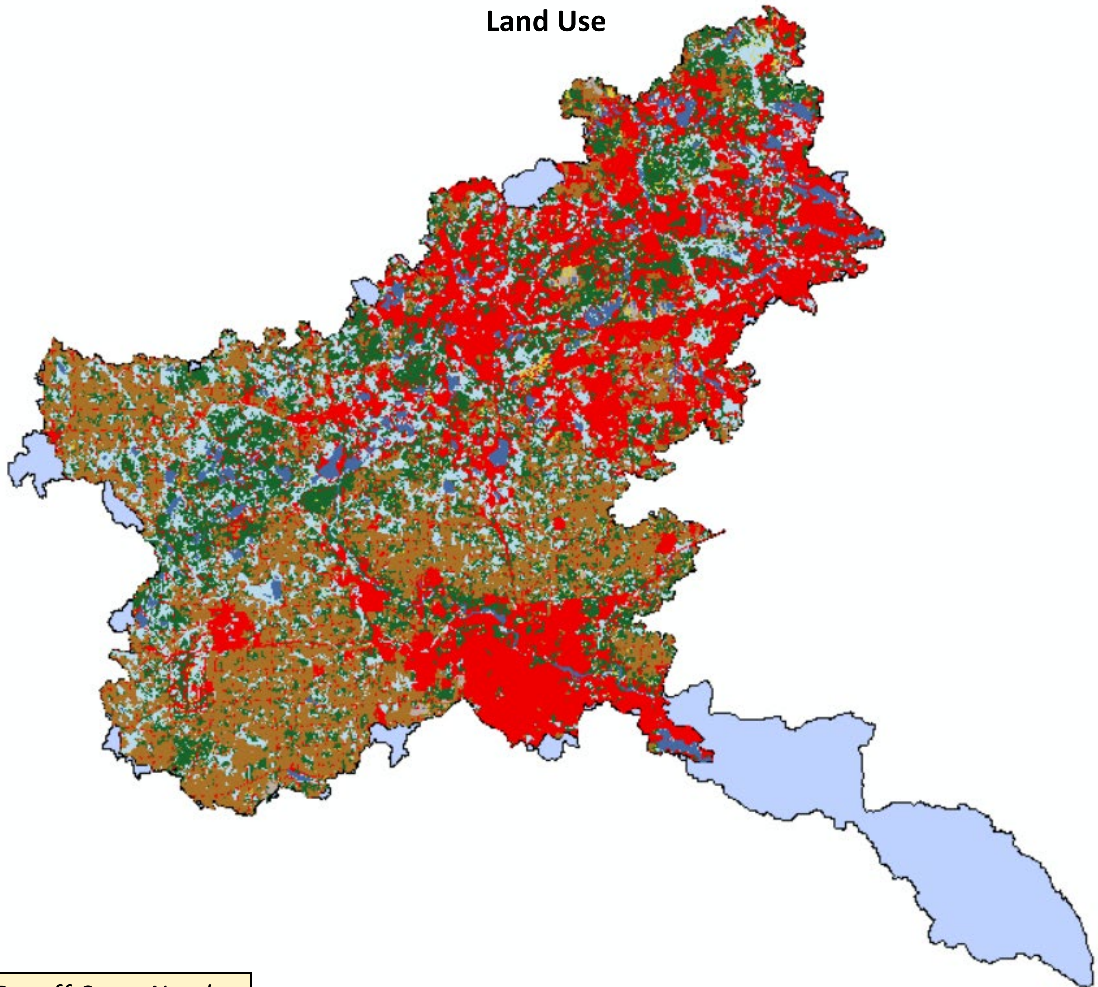
Elevation by Area		
Category	**Area**	**Percentage**
Category	*km²*	*%*
>195 m - 210 m	3.79	0.18%
>210 m - 225 m	8.42	0.40%
>225 m - 240 m	26.73	1.28%
>240 m - 255 m	58.22	2.79%
>255 m - 270 m	197.89	9.49%
>270 m - 285 m	702.44	33.68%
>285 m - 300 m	699.08	33.52%
>300 m - 315 m	267.90	12.85%
>315 m - 330 m	97.43	4.67%
>330 m - 345 m	20.99	1.01%
>345 m - 360 m	2.62	0.13%
>360 m - 375 m	0.06	0.00%
Size of Drainage Area	2085.58	100.00%



All Elevation Measurements with Respect to North American Datum 1983

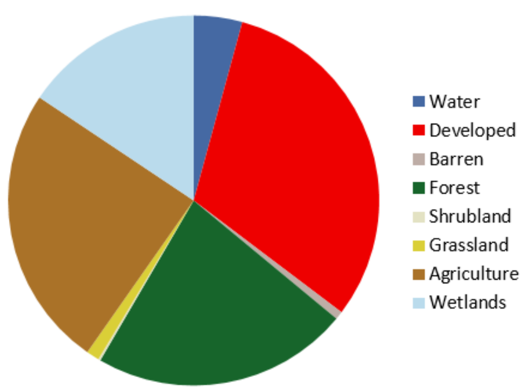
15A, HURON RIVER WATERSHED, FORD DAM

Land Use



EGLE Runoff Curve Number
73.0

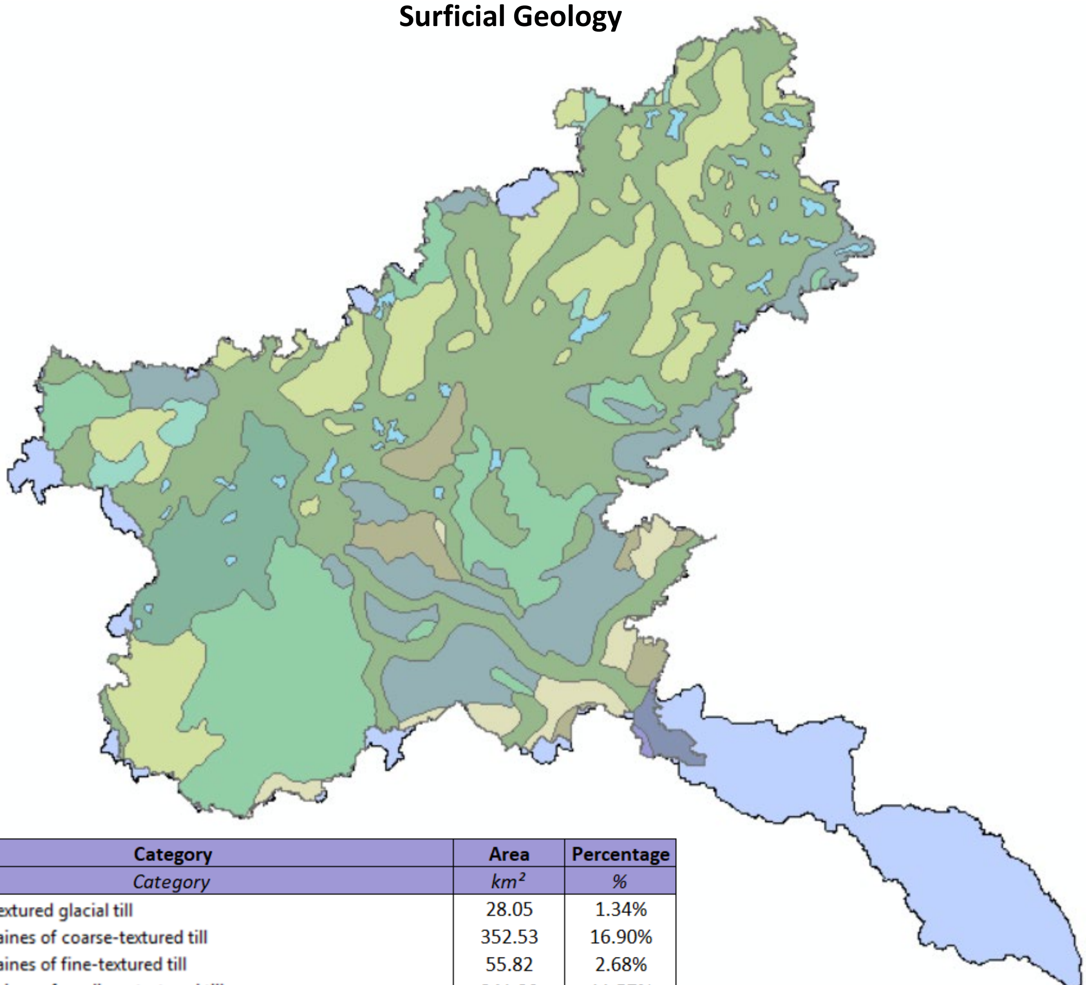
Category	Area	Percentage
Category	*km²*	*%*
Water	88.22	4.23%
Developed	648.32	31.09%
Barren	14.76	0.71%
Forest	466.63	22.37%
Shrubland	4.08	0.20%
Herbaceous	23.44	1.12%
Agriculture	514.85	24.69%
Wetlands	325.29	15.60%
Total	2085.58	100.00%



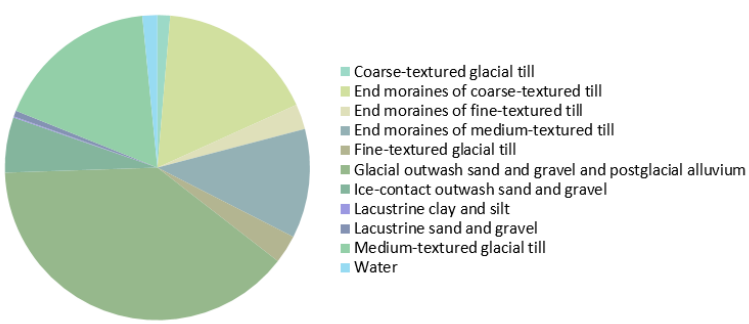
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

15A, HURON RIVER WATERSHED, FORD DAM

Surficial Geology



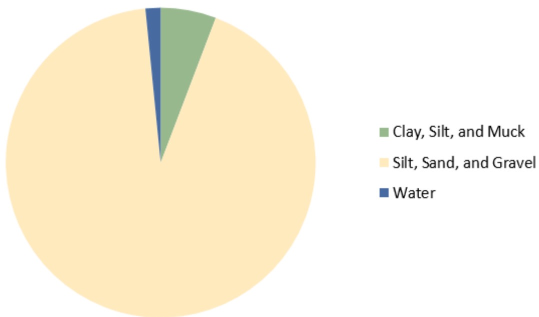
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	28.05	1.34%
End moraines of coarse-textured till	352.53	16.90%
End moraines of fine-textured till	55.82	2.68%
End moraines of medium-textured till	241.29	11.57%
Fine-textured glacial till	62.68	3.01%
Glacial outwash sand and gravel and postglacial alluvium	812.88	38.98%
Ice-contact outwash sand and gravel	122.22	5.86%
Lacustrine clay and silt	2.30	0.11%
Lacustrine sand and gravel	13.29	0.64%
Medium-textured glacial till	361.57	17.34%
Water	32.96	1.58%
Total Watershed Area	2085.58	100.00%

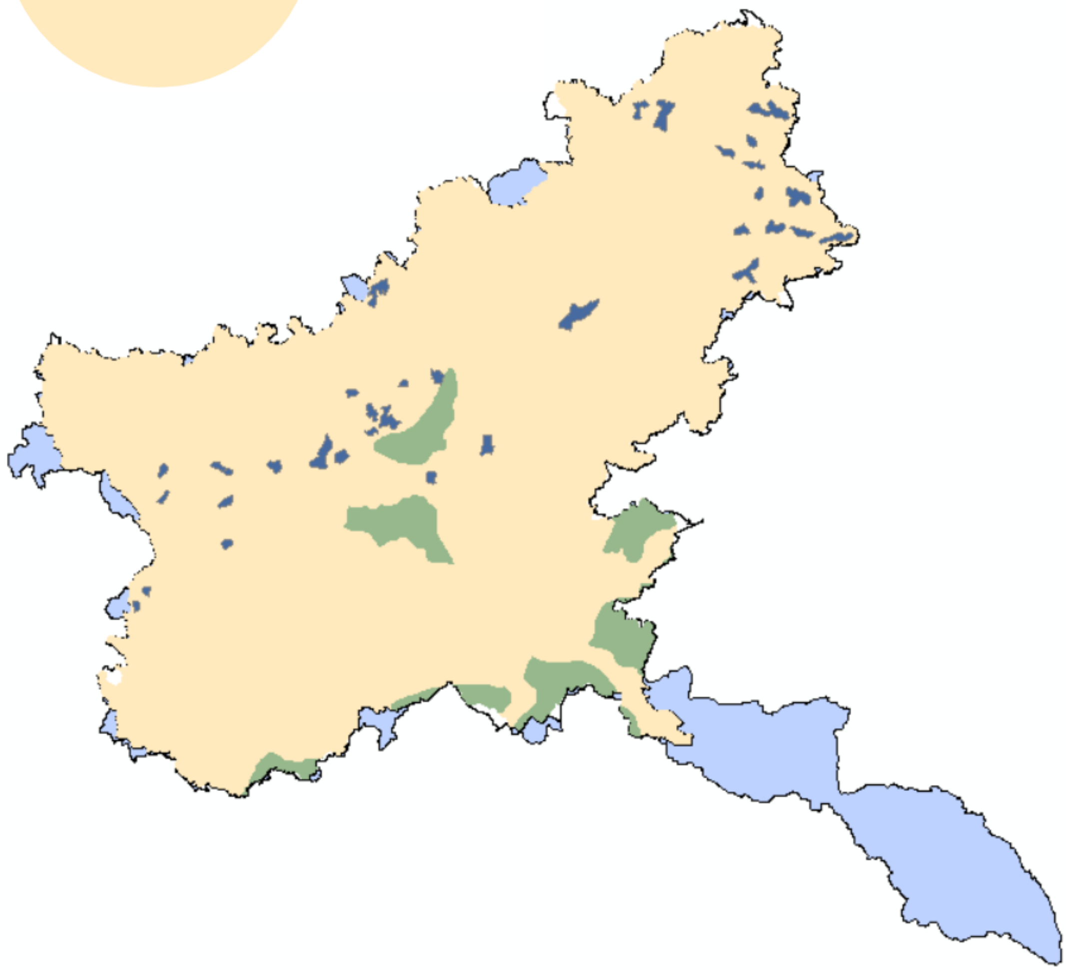


Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

15A, HURON RIVER WATERSHED, FORD DAM

Surficial Geology (Simplified)



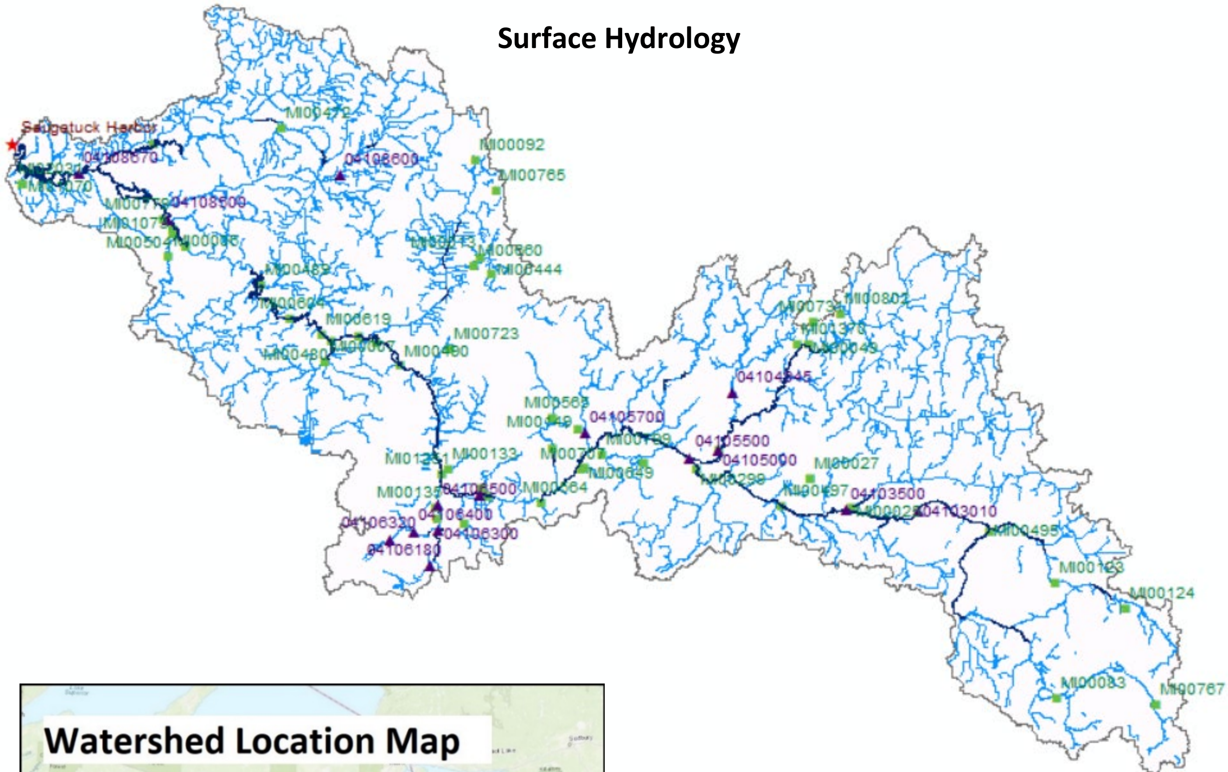


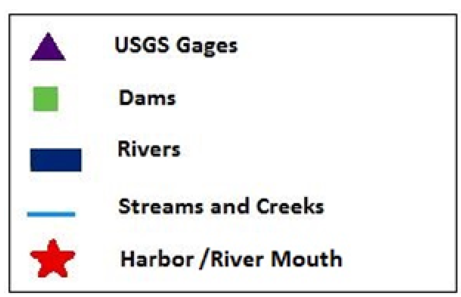
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*120.80*	5.79%
Silt, Sand, and Gravel	1931.82	92.63%
Water	32.96	1.58%
Total Watershed Area	2085.58	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX V. KALAMAZOO RIVER WATERSHED (17)

Surface Hydrology





Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

17, KALAMAZOO RIVER WATERSHED

Dam Identification and USGS Streamgages

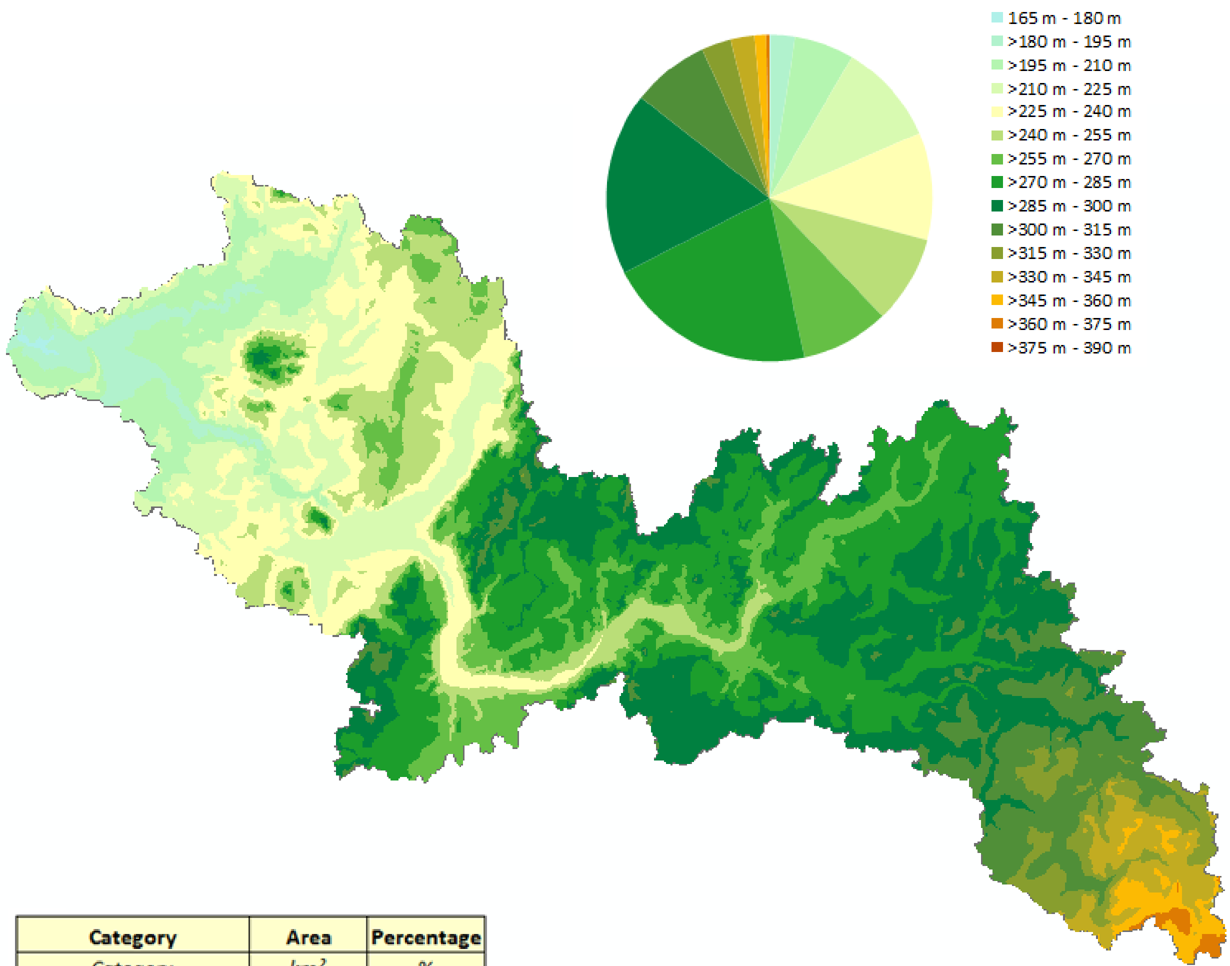
USACE's National Inventory of Dams (NID)							
MI00151	Allegan	-85.95330	42.56340	MI00480	Pine Creek Dam	-85.73500	42.45667
MI00027	Redmon (Marshall) Perrin 1	-85.01670	42.30000	MI00490	Plainwell Dam Number 2	-85.63167	42.43000
MI00027	Perrin Dam No 2	-85.01670	42.30000	MI00491	Plainwell Dam #1	-85.66760	42.45590
MI00146	Morrow	-85.50000	42.28330	MI00495	Albion Dam	-84.74667	42.23833
MI00049	Bellevue Mill Dam	-85.01670	42.45000	MI00496	Hamilton Dam	-86.00333	42.67667
MI01070	Silver Valley Ponds Dam	-86.20000	42.63334	MI00497	Ceresco Dam	-85.06000	42.27000
MI01073	Highbanks Dam	-85.97285	42.57722	MI00504	Cross Dike Dam	-85.97230	42.58210
MI01144	Verona Dam	-85.15334	42.33167	MI00522	Menasha Dam	-85.69240	42.46320
MI00489	Allegan City Dam	-85.84000	42.52000	MI00564	Upjohn Dam	-85.42000	42.27500
MI00123	Concord Dam	-84.65000	42.17833	MI00565	Gull Lake Dam	-85.40350	42.36966
MI00124	Horton Dam	-84.54500	42.15000	MI00006	Swan Creek Dam	-85.98000	42.55167
MI01251	Williams Pond Dam	-85.57000	42.30833	MI00604	Trowbridge Dam	-85.79660	42.48290
MI00013	Orangeville Dam	-85.50833	42.55000	MI00619	Otsego Dam	-85.74960	42.46500
MI00133	Spring Valley Park Dam	-85.56052	42.31318	MI00649	Jackson Hole Dam	-85.35540	42.31500
MI00135	Bryant Mill Dam	-85.57833	42.27000	MI00660	Canterbury Lake Dam	-85.52000	42.54000
MI00136	Lower Comstock Dam	-85.51000	42.28833	MI00666	Vanrick Industrial Park Dam	-85.53500	42.25333
MI00137	Middle Comstock Dam	-85.51000	42.29167	MI00007	Williams Mill Dam	-85.74333	42.43333
MI01370	Cheney Lake Dam	-85.03333	42.45000	MI00707	Whitford Lake Dam	-85.36010	42.31220
MI00141	Howlandsburg Dam	-85.40226	42.33587	MI00723	Lake Doster Dam	-85.55666	42.44833
MI00145	Monarch Paper Mill Dam	-85.57667	42.25834	MI00731	Giesler Dam	-85.00833	42.47500
MI00149	Brook Lodge Dam	-85.36500	42.35667	MI00765	Hall Lake Dam	-85.48500	42.62500
MI02031	Van Dragt s Dam	-86.20000	42.63334	MI00767	Fowle Mill Dam	-84.50166	42.04167
MI00025	Rice Creek Dam	-84.95333	42.26667	MI00779	Palmer Bayou Dam	-85.98720	42.59330
MI02583	Engineer Lake Dam	-85.26527	42.31944	MI00799	Eagle Lake Dam	-85.32880	42.32810
MI00299	Monroe Street Dam	-85.18667	42.31167	MI00802	Gregory State Game Area Dam #3	-84.96697	42.48320
MI00444	Lower Crystal Lake Dam	-85.49167	42.53167	MI00083	Big Mosherville Dam	-84.65000	42.05000
MI00472	Monterey Lake Dam	-85.80833	42.69500	MI00092	Bowen Mill Dam	-85.51667	42.65833

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4103010	KALAMAZOO RIVER NEAR MARENGO, MI	*-84.855812*	*42.261708*	yes
4103500	KALAMAZOO RIVER AT MARSHALL, MI	-84.96387	42.264764	yes
4104945	WANADOGA CREEK NEAR BATTLE CREEK, MI	-85.13166	42.396428	yes
4105000	BATTLE CREEK AT BATTLE CREEK, MI	-85.154158	42.331985	yes
4105500	KALAMAZOO RIVER NEAR BATTLE CREEK, MI	-85.197493	42.32393	yes
4105700	AUGUSTA CREEK NEAR AUGUSTA, MI	-85.353889	42.353373	yes
4106000	KALAMAZOO RIVER AT COMSTOCK, MI	-85.513893	42.285597	yes
4106180	PORTAGE CREEK AT PORTAGE, MI	-85.589725	42.205876	
4106300	PORTAGE CREEK NEAR KALAMAZOO, MI	-85.575837	42.246153	yes
4106320	WEST FORK PORTAGE CREEK NEAR OSHTEMO, MI	-85.648339	42.235318	yes
4106400	WEST FORK PORTAGE CREEK AT KALAMAZOO, MI	-85.613894	42.244485	yes
4106500	PORTAGE CREEK AT KALAMAZOO, MI	-85.576394	42.274208	
4108500	KALAMAZOO RIVER NEAR FENNVILLE, MI	-85.984199	42.593363	
4108600	RABBIT RIVER NEAR HOPKINS, MI	-85.721968	42.642254	yes
4108670	KALAMAZOO RIVER NEAR NEW RICHMOND, MI	-86.116147	42.644749	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				12

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

17, KALAMAZOO RIVER WATERSHED

Elevation



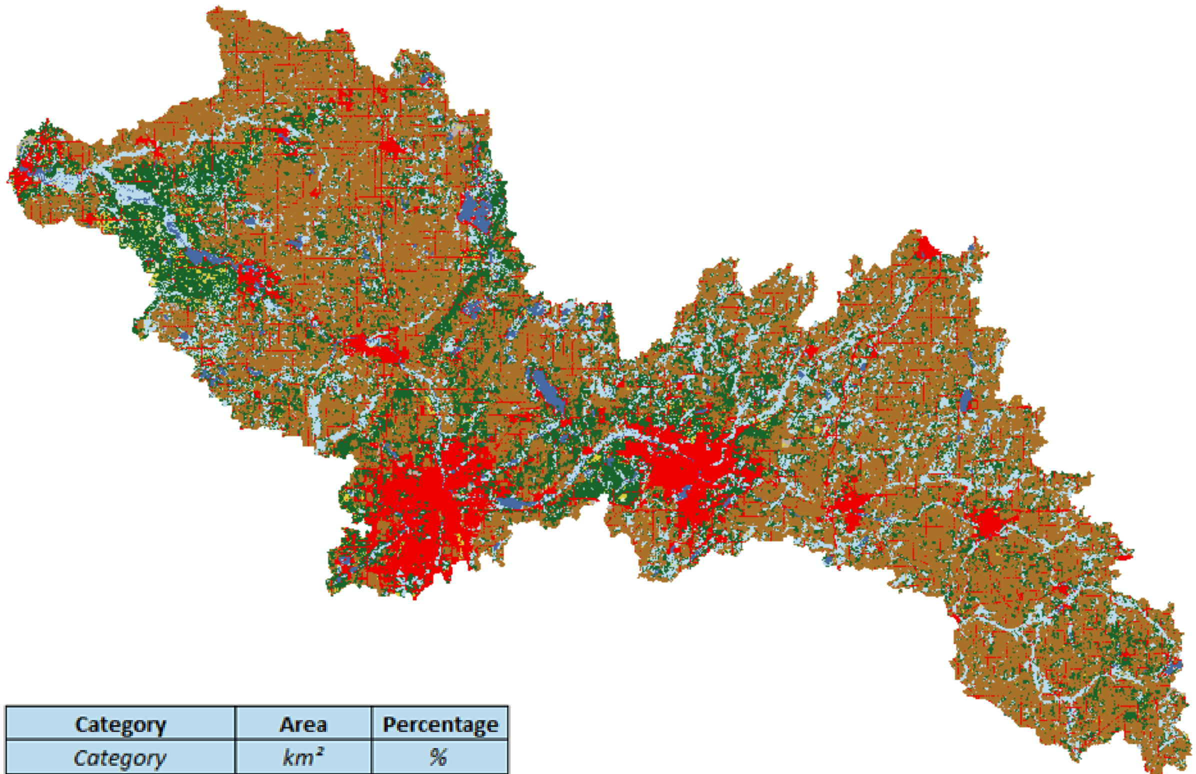
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	5.00	0.09%
>180 m - 195 m	128.01	2.43%
>195 m - 210 m	309.56	5.88%
>210 m - 225 m	531.13	10.09%
>225 m - 240 m	558.91	10.62%
>240 m - 255 m	458.55	8.72%
>255 m - 270 m	457.61	8.70%
>270 m - 285 m	1099.94	20.91%
>285 m - 300 m	953.41	18.12%
>300 m - 315 m	403.45	7.67%
>315 m -330 m	154.71	2.94%
>330 m - 345 m	122.32	2.32%
>345 m - 360 m	62.03	1.18%
>360 m - 375 m	16.90	0.32%
>375 m - 390 m	0.06	0.00%
Size of Drainage Area	5261.58	100.00%

Kalamazoo River Watershed		
Elevation Statistics		
Size of Drainage Area	**5261.58**	***km²***
Maximum	381.00	*m*
Minimum	179.00	*m*
Average	263.68	*m*
Standard Deviation	37.12	*m*

All Elevation Measurements with Respect to North American Datum 1983

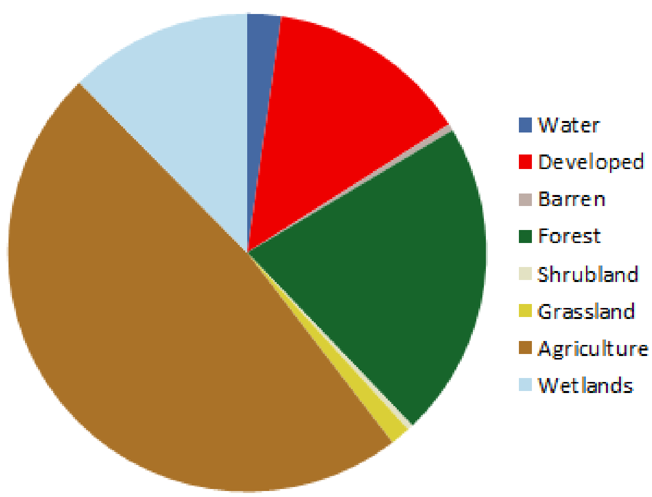
17, KALAMAZOO RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	120.53	2.29%
Developed	719.90	13.68%
Barren	23.87	0.45%
Forest	1127.84	21.44%
Shrubland	20.26	0.39%
Grassland	71.42	1.36%
Agriculture	2526.02	48.01%
Wetlands	651.74	12.39%
Total	5261.58	100.00%

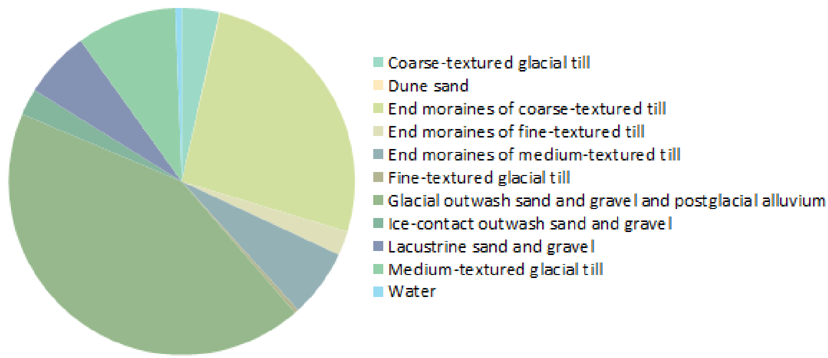
EGLE Runoff Curve Number
70.8

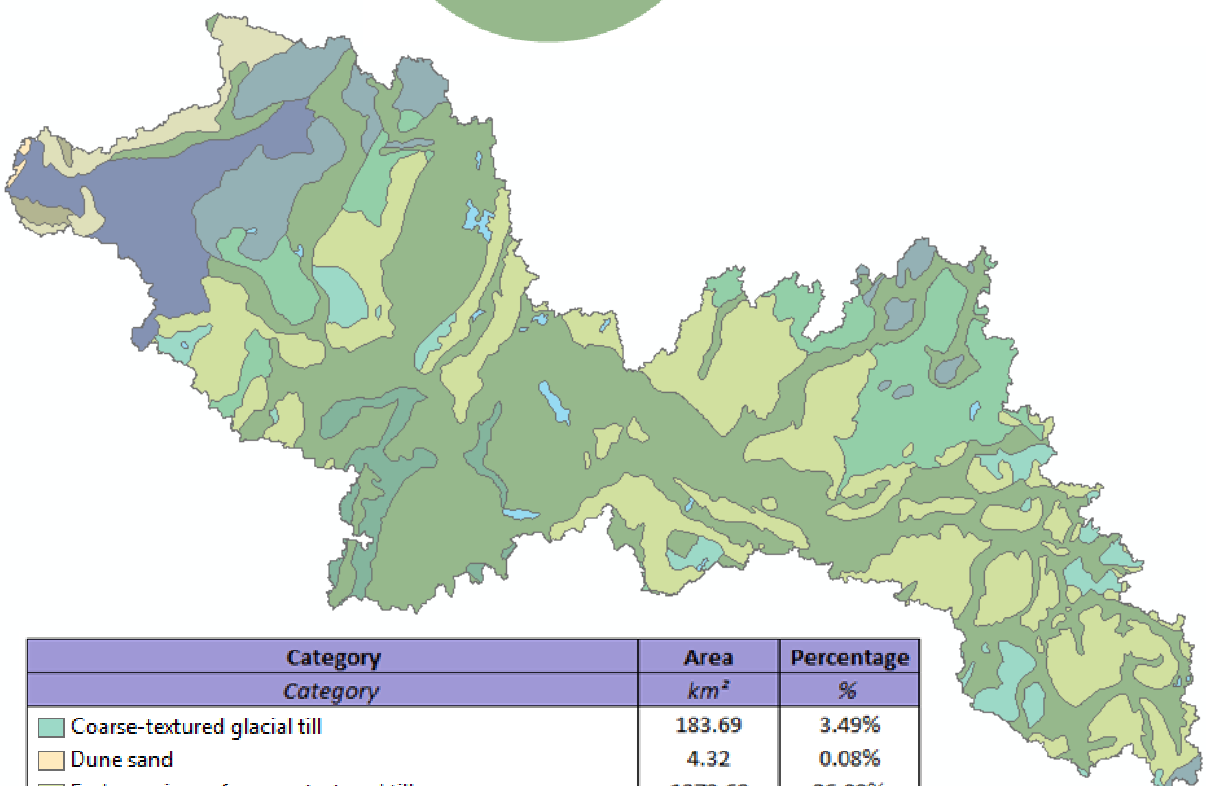


Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

17, KALAMAZOO RIVER WATERSHED

Surficial Geology



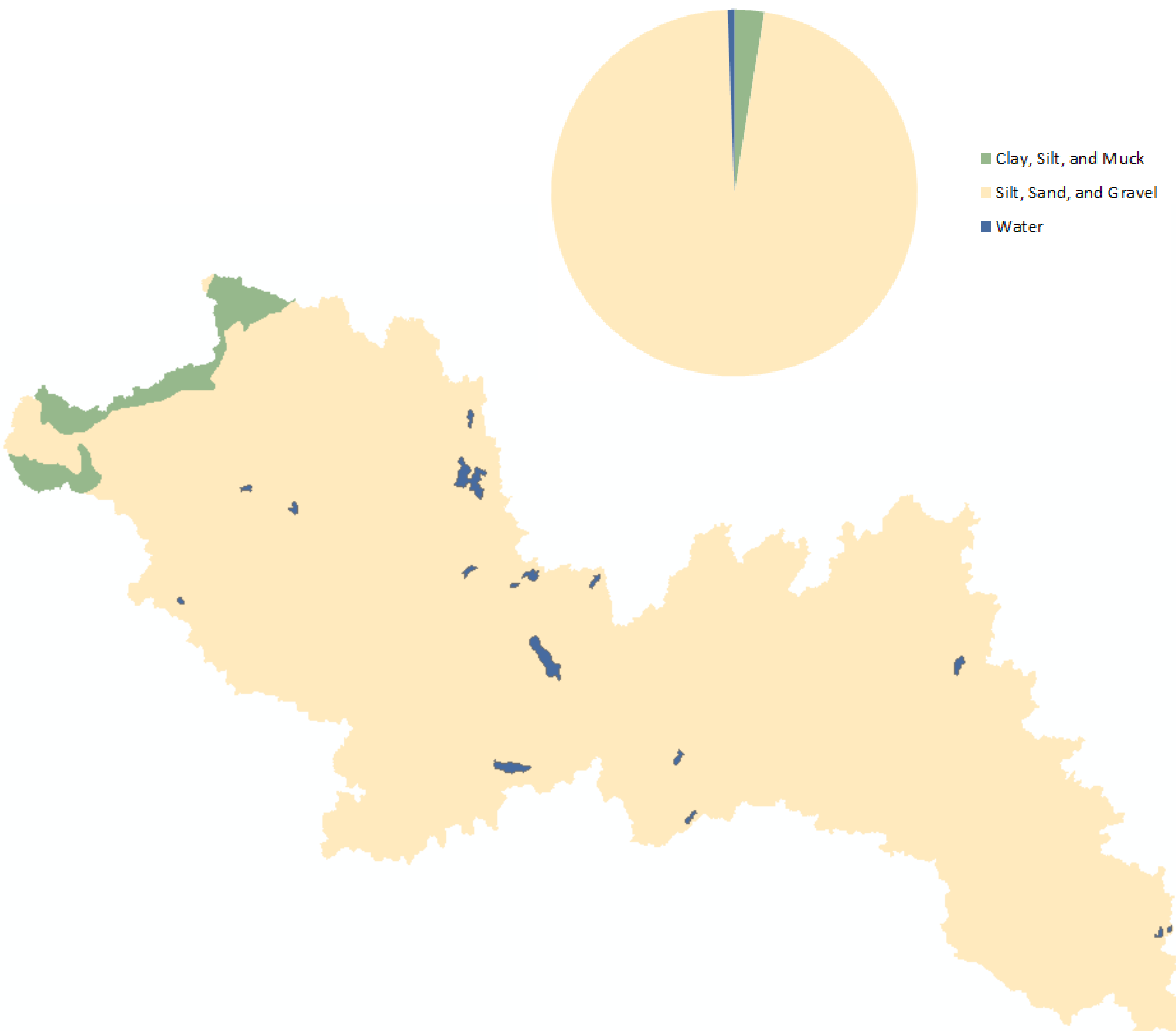


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	183.69	3.49%
Dune sand	4.32	0.08%
End moraines of coarse-textured till	1372.68	26.09%
End moraines of fine-textured till	119.19	2.27%
End moraines of medium-textured till	334.20	6.35%
Fine-textured glacial till	19.24	0.37%
Glacial outwash sand and gravel and postglacial alluvium	2247.49	42.72%
Ice-contact outwash sand and gravel	130.00	2.47%
Lacustrine sand and gravel	328.87	6.25%
Medium-textured glacial till	490.71	9.33%
Water	31.18	0.59%
Total Watershed Area	5261.58	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

17, KALAMAZOO RIVER WATERSHED

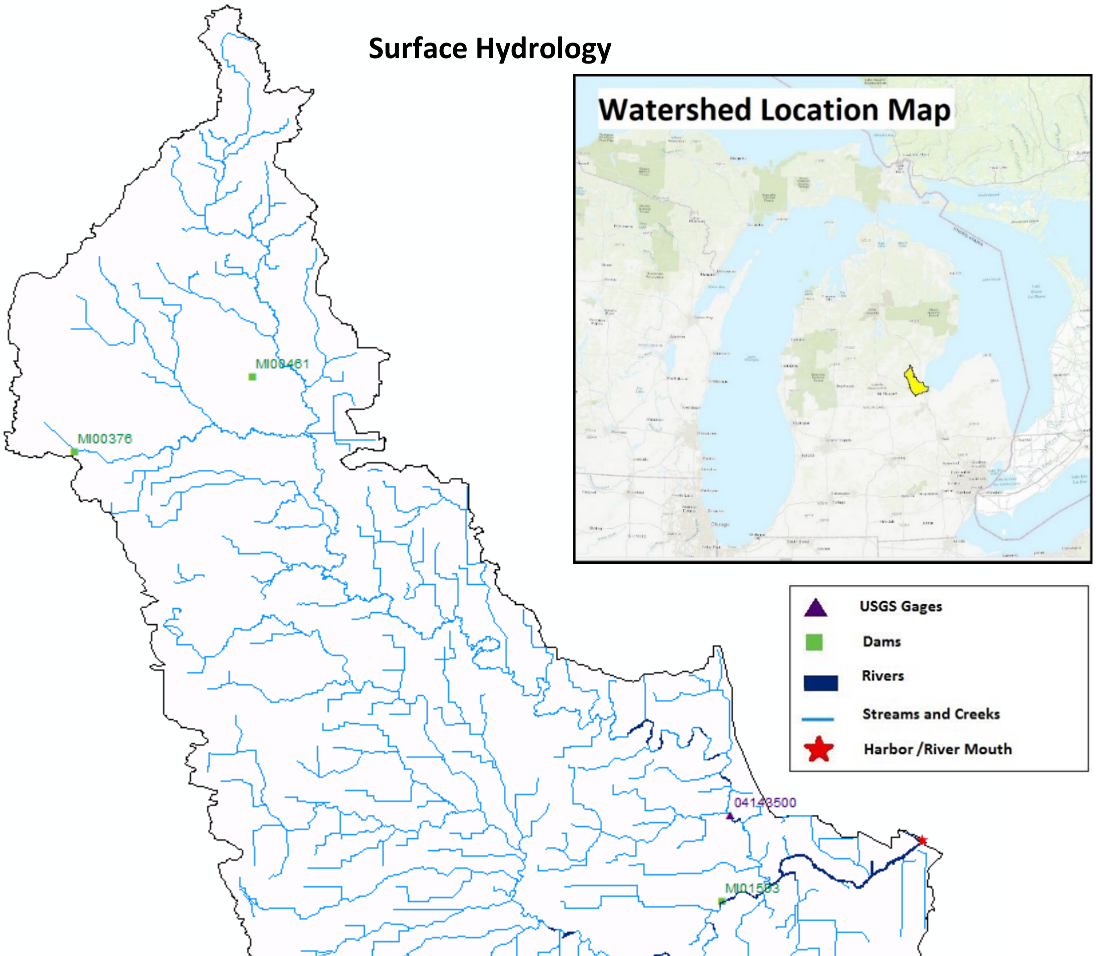
Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*138.43*	2.63%
Silt, Sand, and Gravel	5091.96	96.78%
Water	31.18	0.59%
Total Watershed Area	5261.58	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX W. KAWKAWLIN RIVER WATERSHED (18)



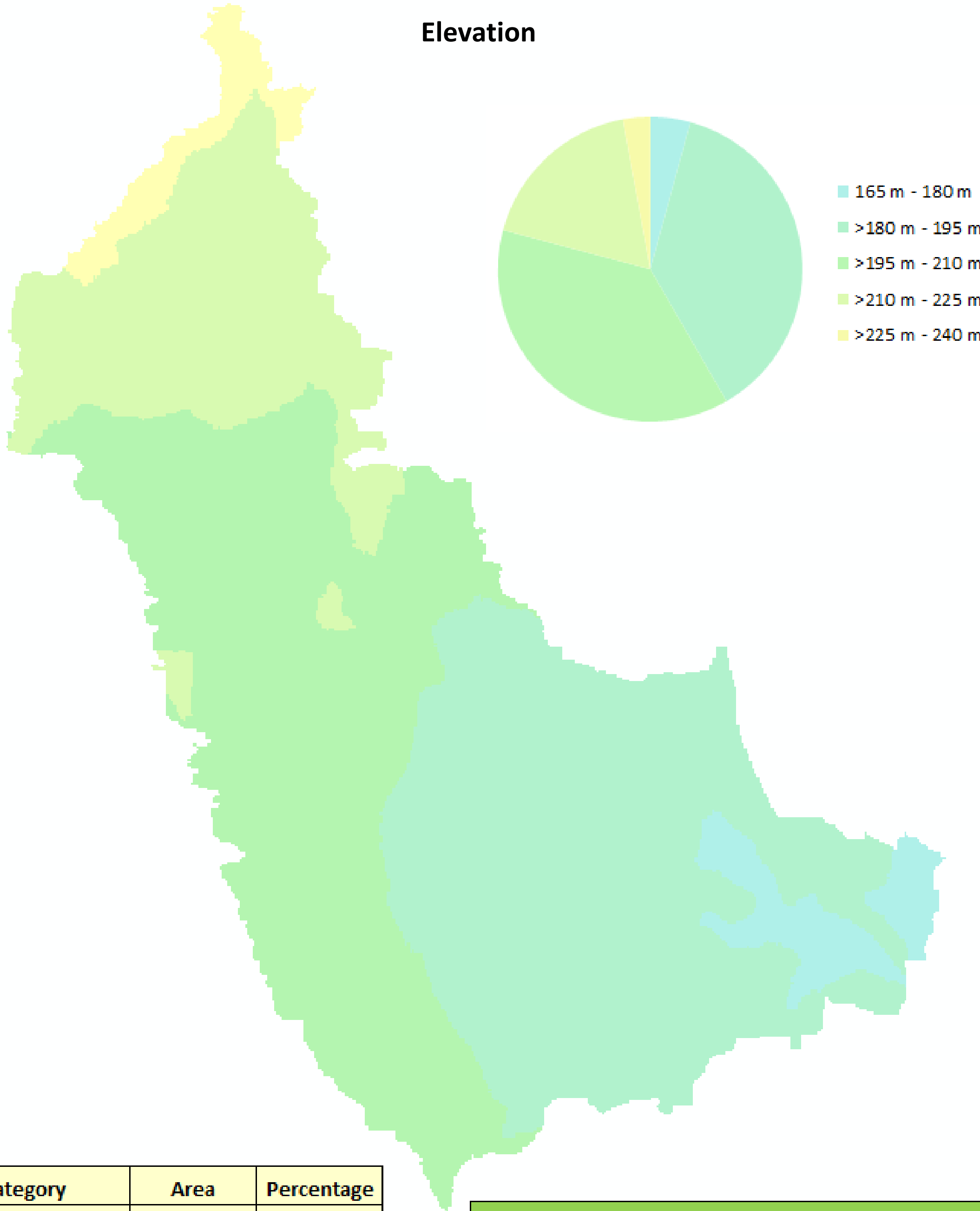
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
04143500	NORTH BRANCH KAWKAWLIN RIVER NEAR KAWKAWLIN, MI	*-83.970259*	43.668079	
Number of Active USGS Stream Gage's in Drainage Area (2009)				**0**

USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI01593	Kawkawlin River Walleye Pond Dam	-83.975000	43.640000
MI00376	Kawkawlin Flooding Dam	-84.265000	43.793330
MI00461	Robert Dulude Dam	-84.183330	43.816670

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

18, KAWKAWLIN RIVER WATERSHED

Elevation



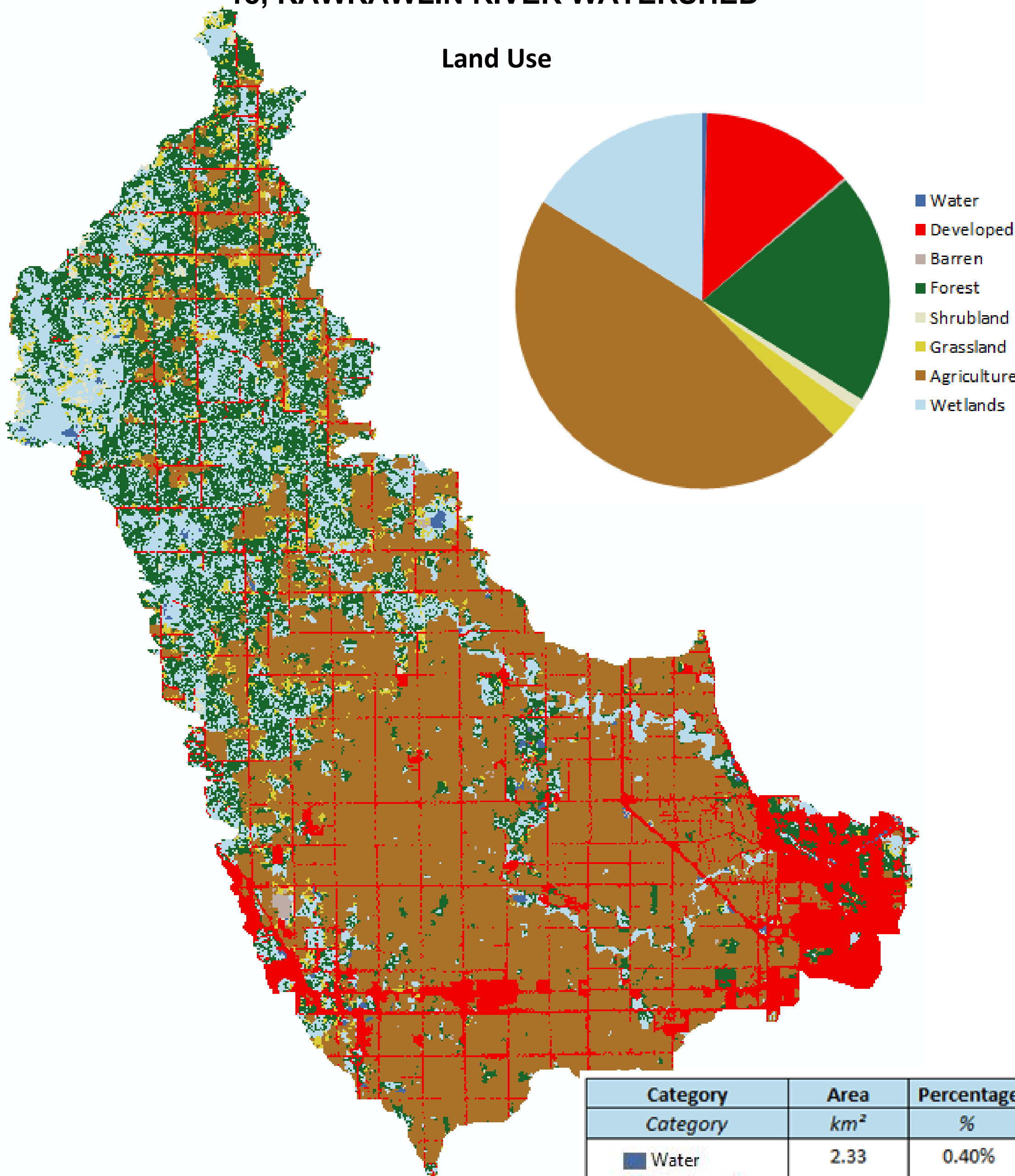
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	24.79	4.25%
>180 m - 195 m	218.15	37.40%
>195 m - 210 m	218.68	37.49%
>210 m - 225 m	104.82	17.97%
>225 m - 240 m	16.91	2.90%
Size of Drainage Area	583.35	100.00%

Kawkawlin Watershed		
Elevation Statistics		
Size of Drainage Area	**583.35**	***km²***
Maximum	237.00	*m*
Minimum	177.00	*m*
Average	198.56	*m*
Standard Deviation	12.83	*m*

All Elevation Measurements with Respect to North American Datum 1983

18, KAWKAWLIN RIVER WATERSHED

Land Use



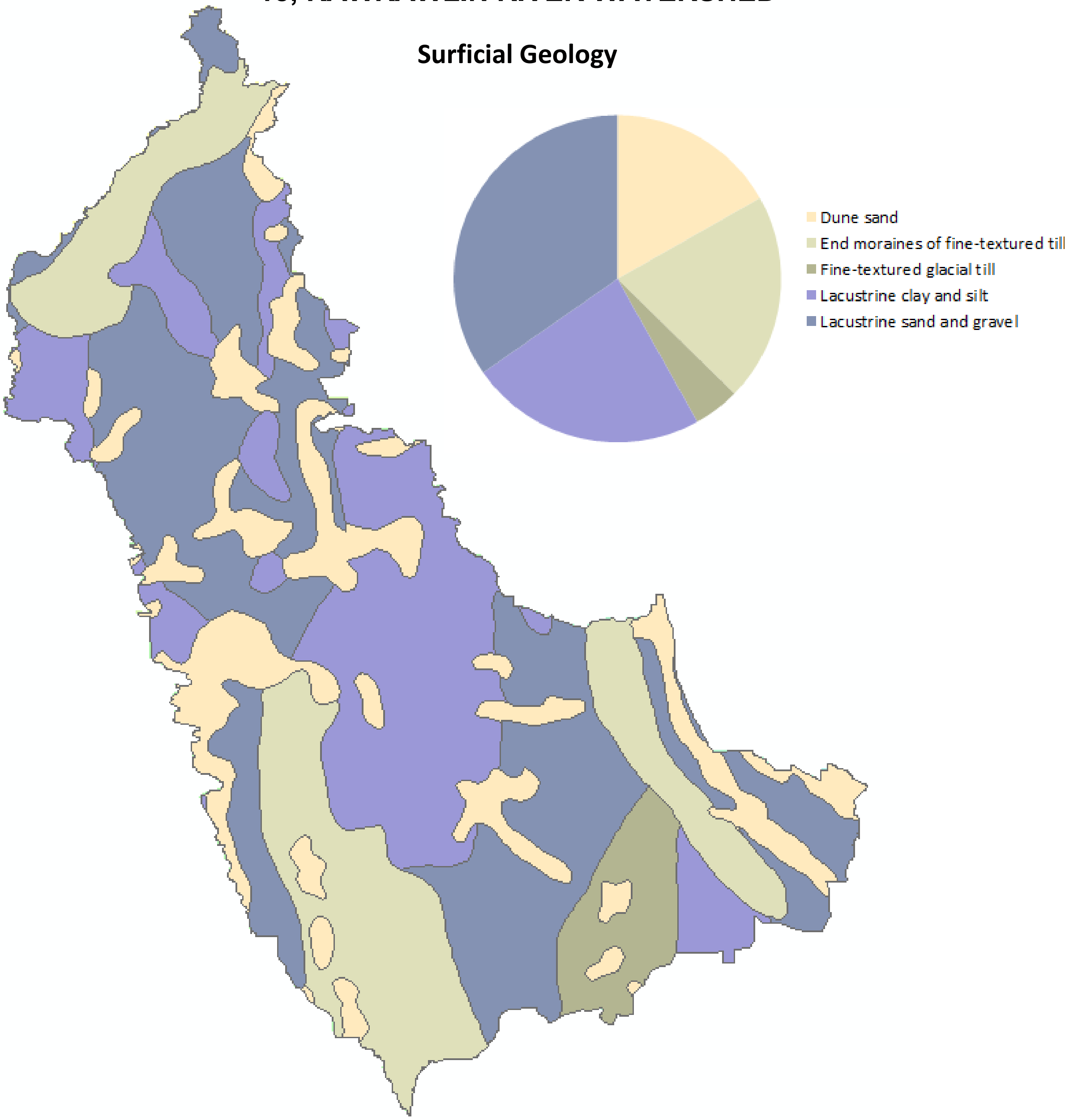
Category	Area	Percentage
Category	*km²*	*%*
Water	2.33	0.40%
Developed	77.36	13.26%
Barren	1.19	0.20%
Forest	116.36	19.95%
Shrubland	5.96	1.02%
Grassland	16.58	2.84%
Agriculture	269.42	46.18%
Wetlands	94.15	16.14%
Total	583.35	100.00%

EGLE Runoff Curve Number
79.2

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

18, KAWKAWLIN RIVER WATERSHED

Surficial Geology

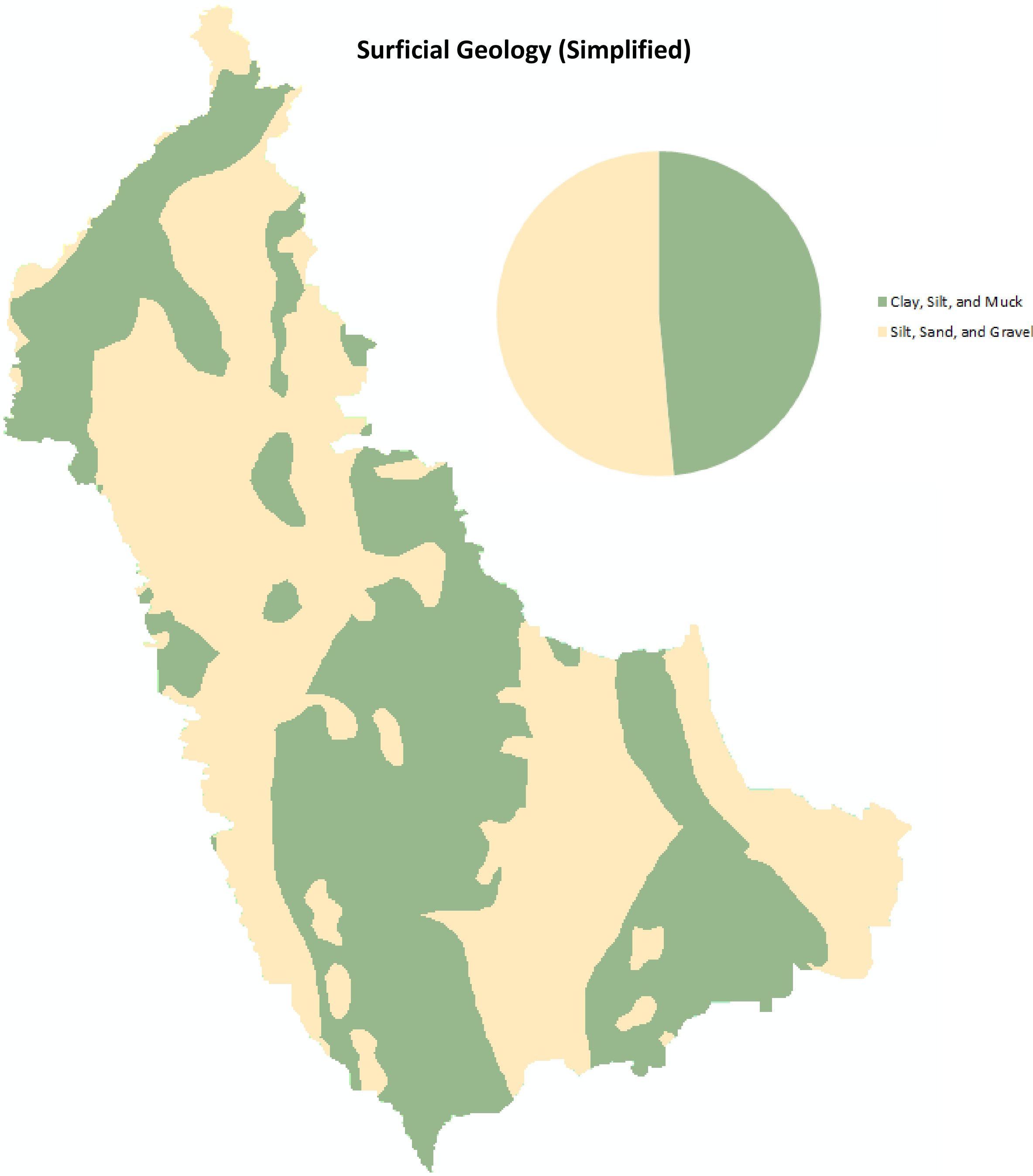


Category	Area	Percentage
Category	*km²*	*%*
Dune sand	97.87	16.78%
End moraines of fine-textured till	120.06	20.58%
Fine-textured glacial till	26.45	4.53%
Lacustrine clay and silt	136.56	23.41%
Lacustrine sand and gravel	202.41	34.70%
Total Watershed Area	583.35	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

18, KAWKAWLIN RIVER WATERSHED

Surficial Geology (Simplified)

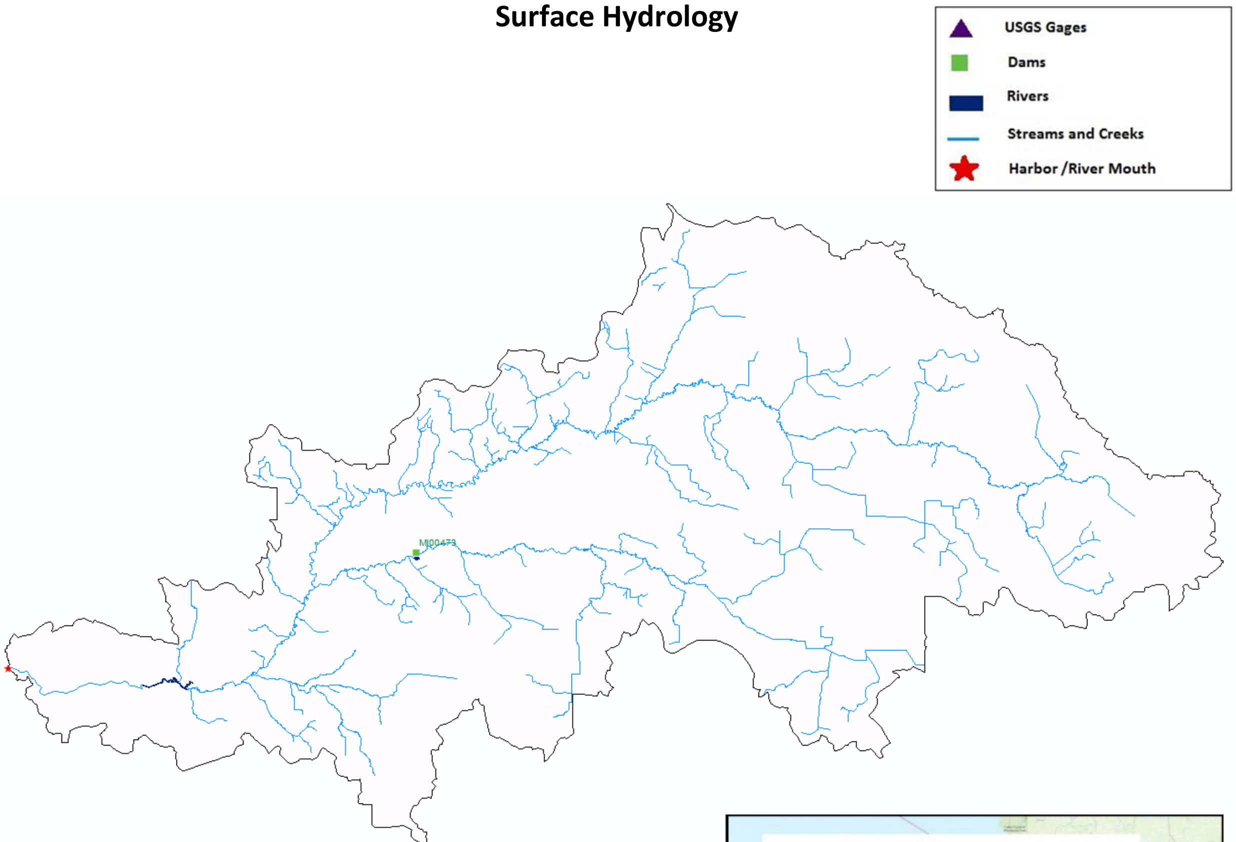


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*283.07*	48.52%
Silt, Sand, and Gravel	300.28	51.48%
Total Watershed Area	583.35	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX X. LINCOLN RIVER WATERSHED (19)

Surface Hydrology

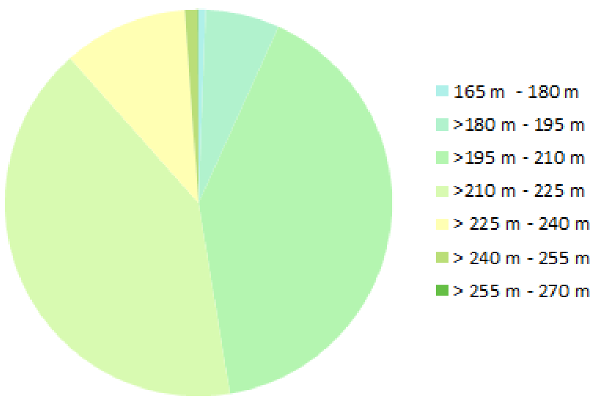


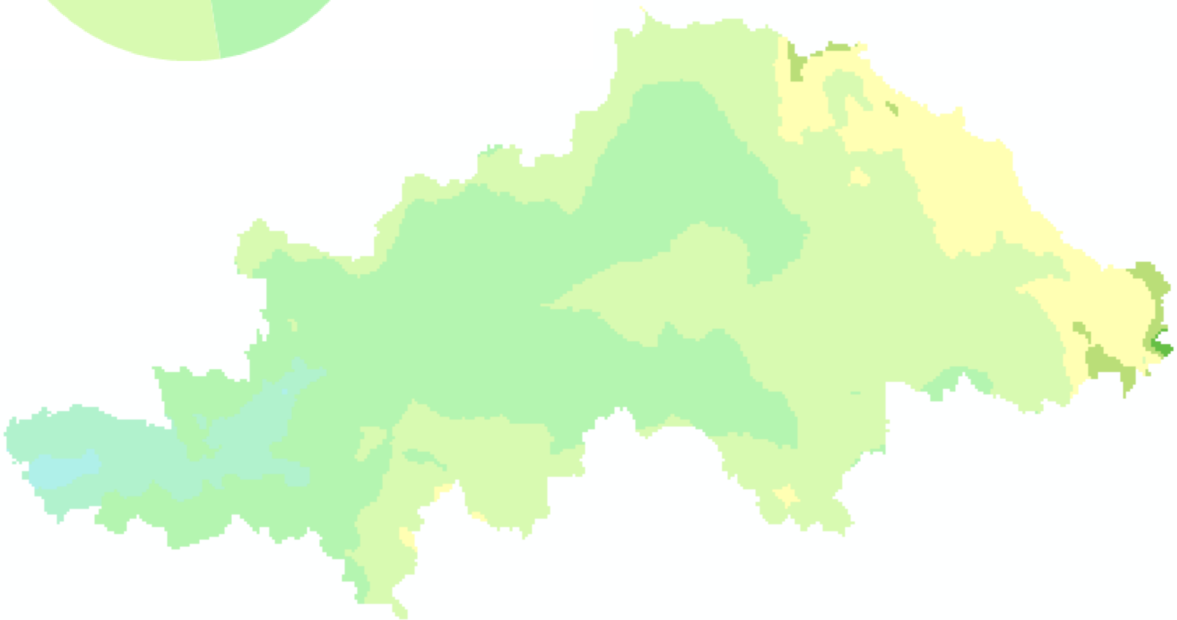
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00473	West Shore Community College Dam	-86.333340	44.013330

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

19, LINCOLN RIVER WATERSHED

Elevation





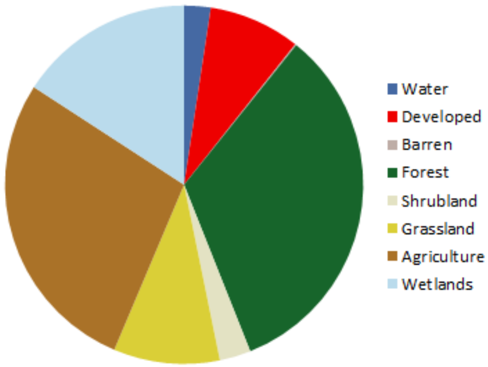
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.55	0.59%
>180 m - 195 m	16.27	6.19%
>195 m - 210 m	106.86	40.64%
>210 m - 225 m	107.91	41.03%
>225 m - 240 m	27.35	10.40%
>240 m - 255 m	2.83	1.08%
>255 m - 270 m	0.19	0.07%
Size of Drainage Area	262.96	100.00%

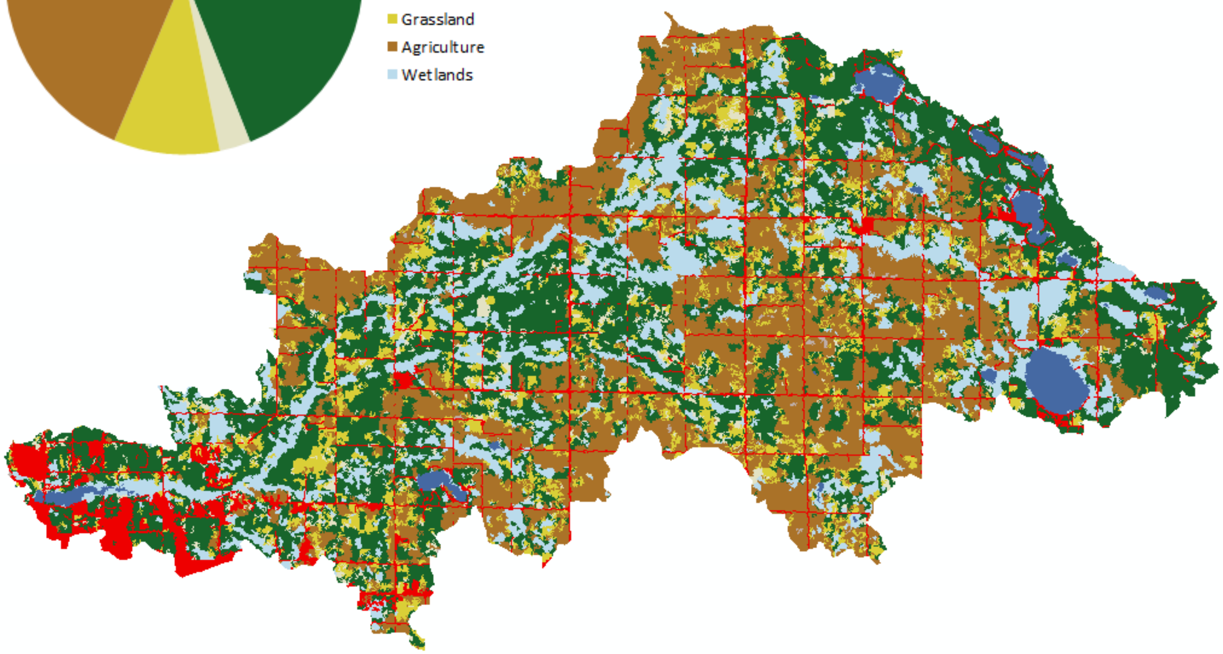
Lincoln Watershed		
Elevation Statistics		
Size of Drainage Area	262.96	*km²*
Maximum	258.00	*m*
Minimum	178.00	*m*
Average	209.51	*m*
Standard Deviation	11.72	*m*

All Elevation Measurements with Respect to North American Datum 1983

19, LINCOLN RIVER WATERSHED

Land Use





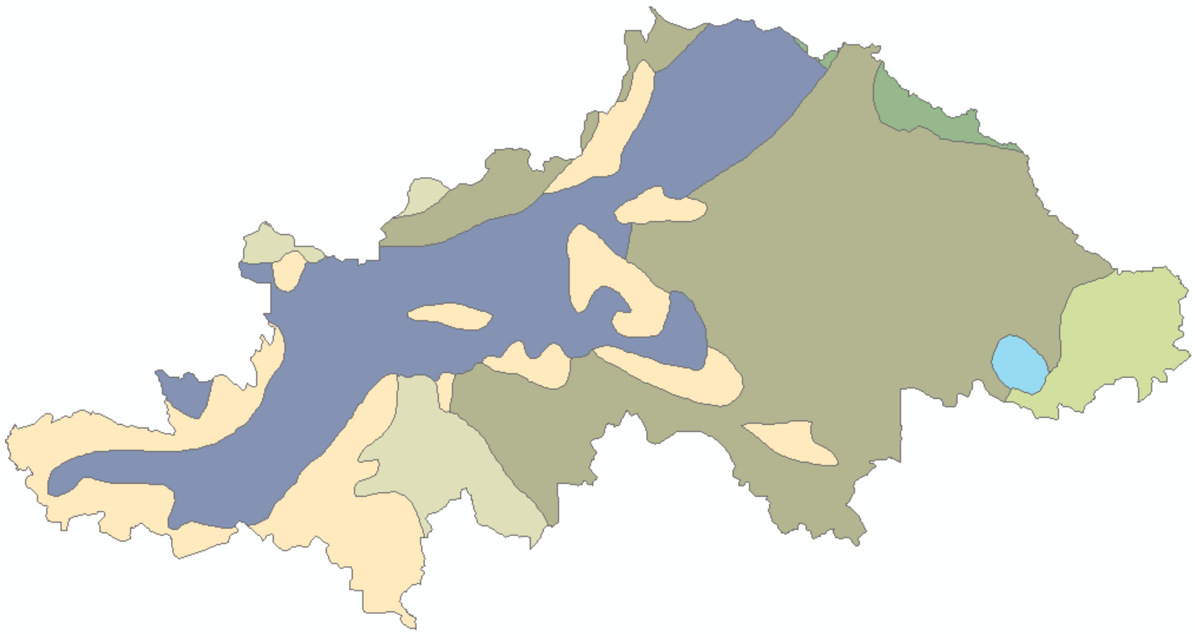
Category	Area	Percentage
Category	*km²*	*%*
Water	6.29	2.39%
Developed	21.75	8.27%
Barren	0.27	0.10%
Forest	87.33	33.21%
Shrubland	7.43	2.83%
Grassland	25.19	9.58%
Agriculture	73.07	27.79%
Wetlands	41.64	15.83%
Total	262.96	100.00%

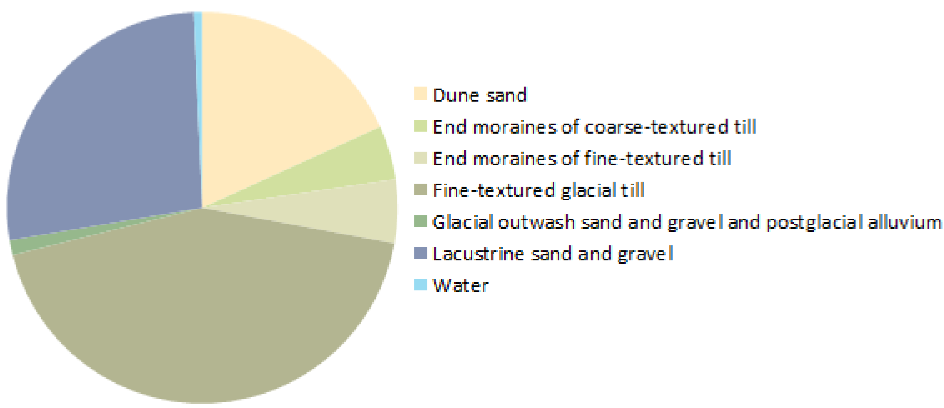
EGLE Runoff Curve Number
67.4

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

19, LINCOLN RIVER WATERSHED

Surficial Geology



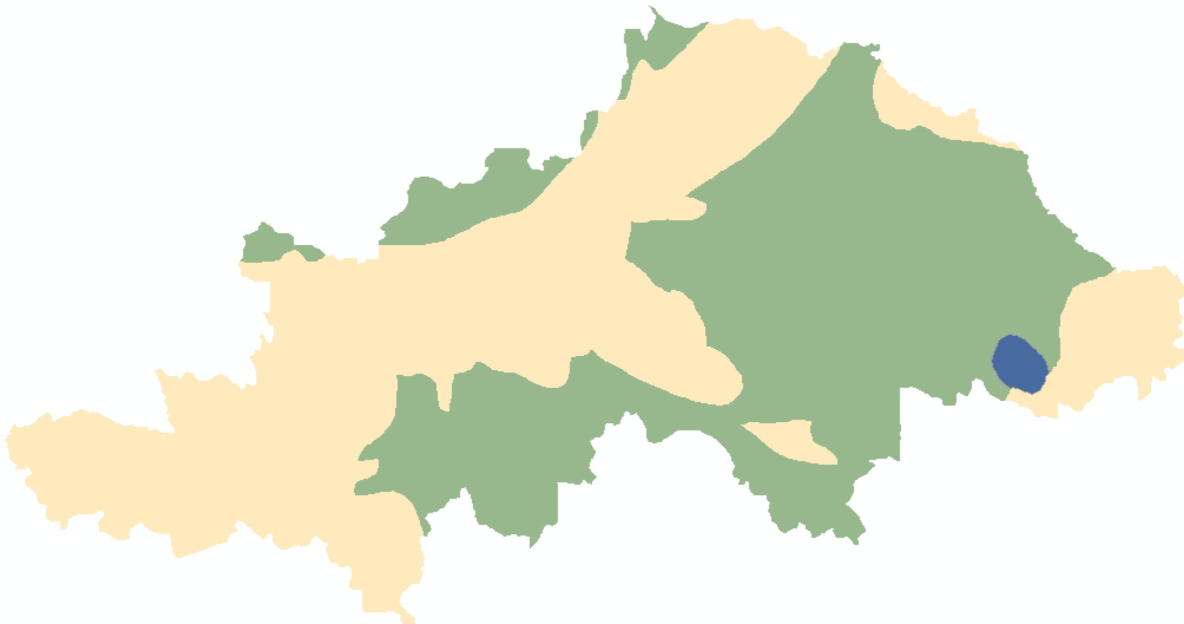


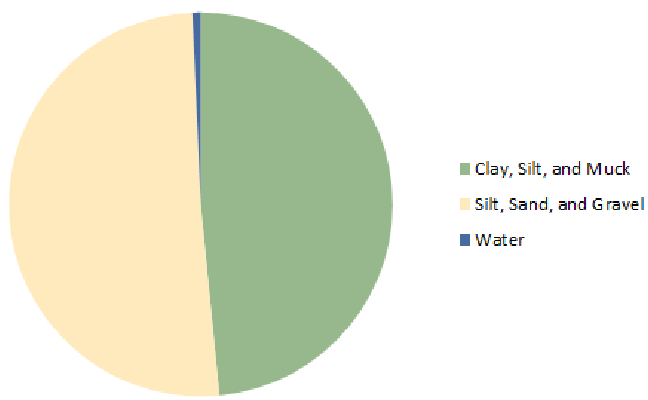
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	47.88	18.21%
End moraines of coarse-textured till	11.73	4.46%
End moraines of fine-textured till	13.76	5.23%
Fine-textured glacial till	113.65	43.22%
Glacial outwash sand and gravel and postglacial alluvium	3.24	1.23%
Lacustrine sand and gravel	70.86	26.95%
Water	1.84	0.70%
Total Watershed Area	262.96	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

19, LINCOLN RIVER WATERSHED

Surficial Geology (Simplified)



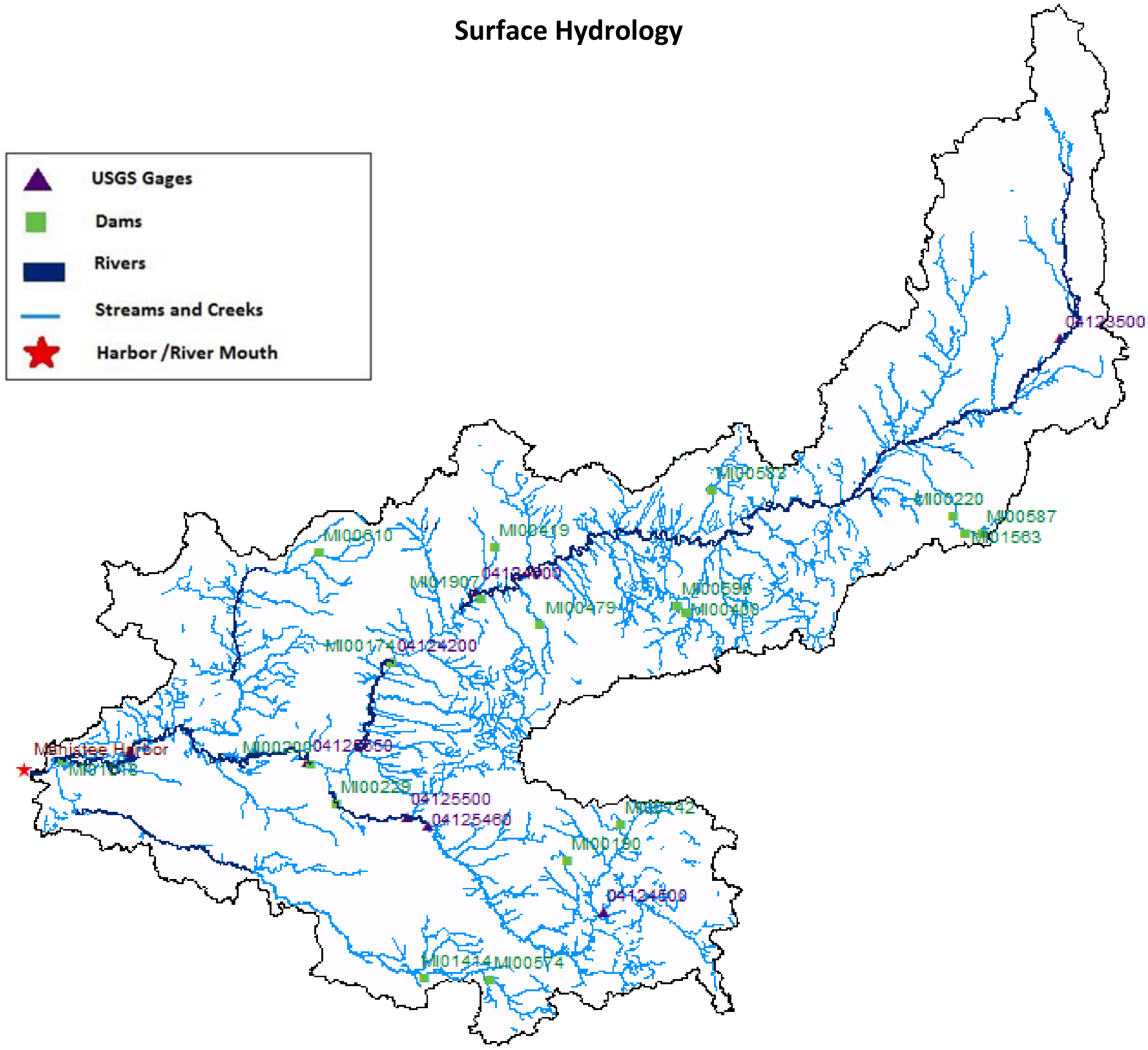


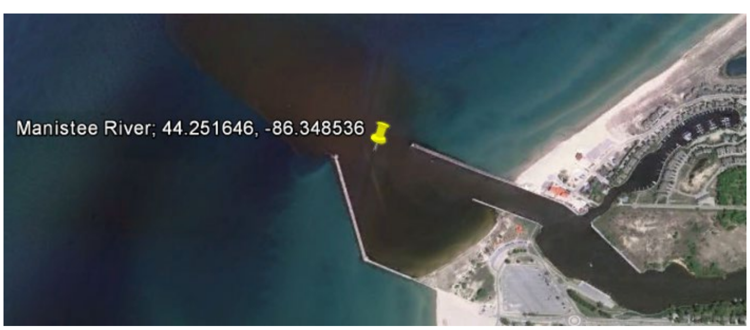
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*127.41*	48.45%
Silt, Sand, and Gravel	133.71	50.85%
Water	1.84	0.70%
Total Watershed Area	262.96	100.00%

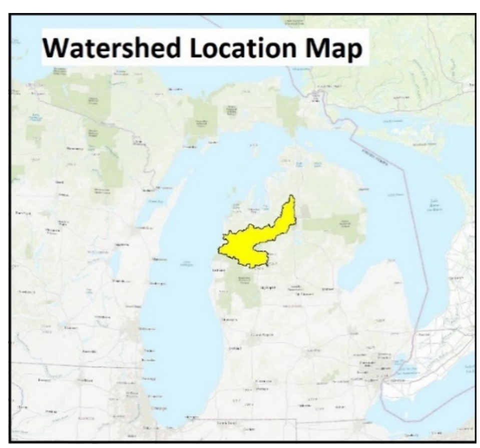
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX Y. MANISTEE RIVER WATERSHED (20)

Surface Hydrology







20, MANISTEE RIVER WATERSHED

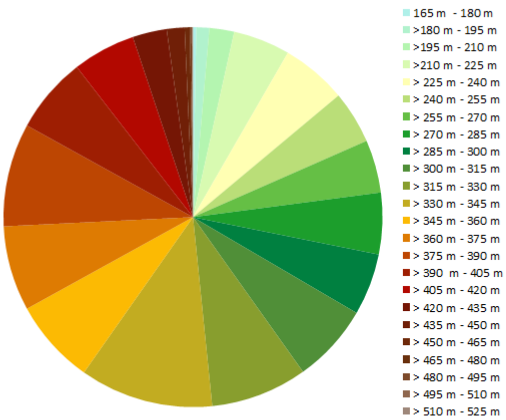
Dam Information and USGS Streamgages

USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00200	Tippy	-85.938300	44.258300
MI00174	Hodenpyl	-85.820000	44.363000
MI01414	Little Widewaters Flooding Dam	-85.774910	44.036020
MI01518	Peters Bayou Dam	-86.295000	44.261670
MI01563	Cannon Creek #2 Flooding Dam	-84.988390	44.493130
MI00190	Olga Lake Dam	-85.568860	44.157480
MI01907	Kerr Upper Dam	-85.691670	44.428330
MI00220	Horseshoe Lake Dam	-85.006810	44.509930
MI00229	Stronach Dam	-85.900000	44.216670
MI00400	Lake Billings Dam	-85.395000	44.413330
MI00419	Wheeler Creek Dam	-85.670000	44.483330
MI00479	White Lake Dam	-85.605000	44.401670
MI00574	Luther Pond Dam	-85.681300	44.034860
MI00583	Headquarters Lake Dam	-85.355000	44.540000
MI00587	Cannon Creek Dam #1	-84.964830	44.492180
MI00596	Manton Millpond Dam	-85.407640	44.420810
MI00610	Copemish Dam	-85.925000	44.478330
MI00742	Norman Smith Dam	-85.491670	44.195000

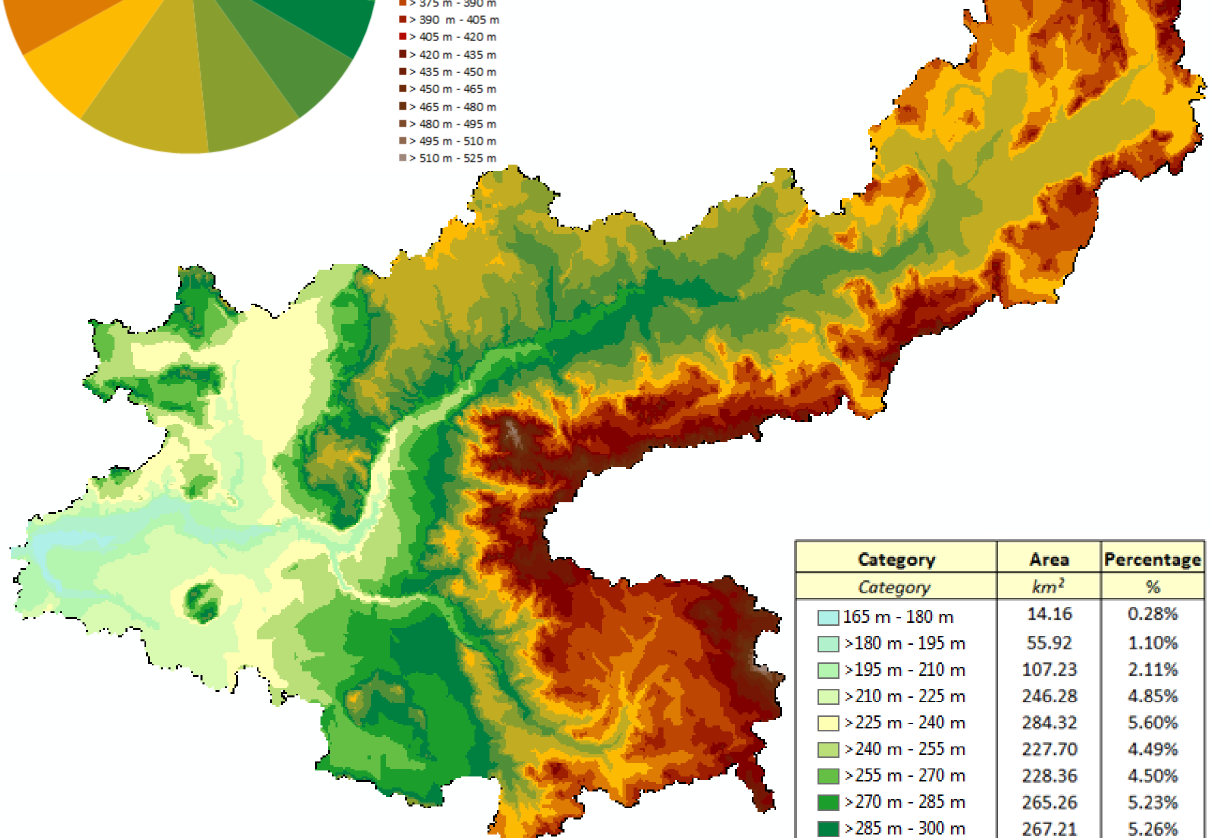
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4123500	MANISTEE RIVER NEAR GRAYLING, MI	-84.847258	*44.693068*	
4124000	MANISTEE RIVER NEAR SHERMAN, MI	-85.698679	44.436392	yes
4124200	MANISTEE RIVER NEAR MESICK, MI	-85.820905	44.36306	yes
4124500	EAST BRANCH PINE RIVER NEAR TUSTIN, MI	-85.517277	44.102511	yes
4125460	PINE RIVER AT HIGH SCHOOL BRIDGE NR HOXEYVILLE, MI	-85.769786	44.19334	yes
4125500	PINE RIVER NEAR HOXEYVILLE, MI	-85.799510	44.203062	
4125550	MANISTEE RIVER NEAR WELLSTON, MI	-85.941742	44.25945	yes
4126000	MANISTEE RIVER NEAR MANISTEE, MI	-86.198973	44.270559	
Number of Active USGS Stream Gage's in Drainage Area (2009)				5

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

20, MANISTEE RIVER WATERSHED



Elevation



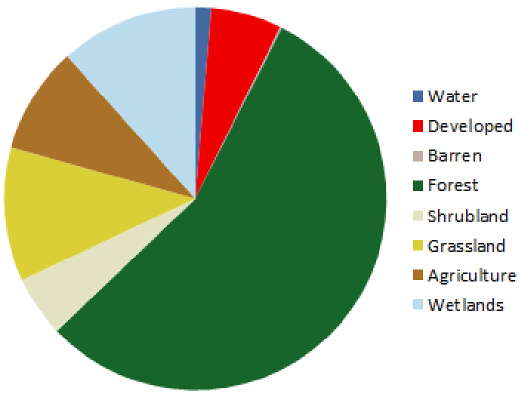
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	14.16	0.28%
>180 m - 195 m	55.92	1.10%
>195 m - 210 m	107.23	2.11%
>210 m - 225 m	246.28	4.85%
>225 m - 240 m	284.32	5.60%
>240 m - 255 m	227.70	4.49%
>255 m - 270 m	228.36	4.50%
>270 m - 285 m	265.26	5.23%
>285 m - 300 m	267.21	5.26%
>300 m - 315 m	341.57	6.73%
>315 m - 330 m	417.98	8.23%
>330 m - 345 m	577.77	11.38%
>345 m - 360 m	367.06	7.23%
>360 m - 375 m	367.26	7.23%
>375 m - 390 m	445.93	8.78%
>390 m - 405 m	329.08	6.48%
>405 m - 420 m	272.04	5.36%
>420 m - 435 m	148.33	2.92%
>435 m - 450 m	77.30	1.52%
>450 m - 465 m	22.48	0.44%
>465 m - 480 m	7.08	0.14%
>480 m - 495 m	3.52	0.07%
>495 m - 510 m	2.04	0.04%
>510 m - 525 m	0.60	0.01%
Size of Drainage Area	5076.49	100.00%

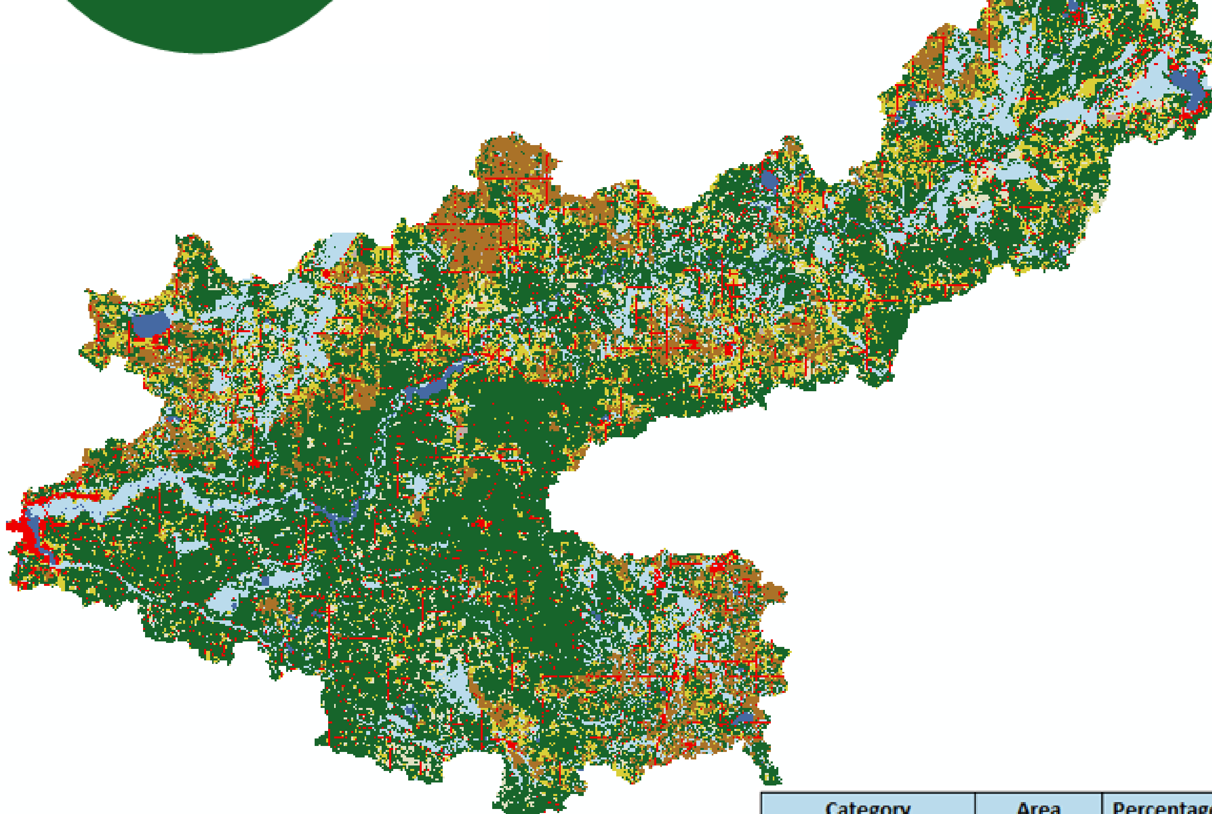
Manistee Watershed		
Elevation Statistics		
Size of Drainage Area	**5076.49**	***km²***
Maximum	519.00	*m*
Minimum	176.00	*m*
Average	324.20	*m*
Standard Deviation	64.70	*m*

All Elevation Measurements with Respect to North American Datum 1983

20, MANISTEE RIVER WATERSHED

Land Use





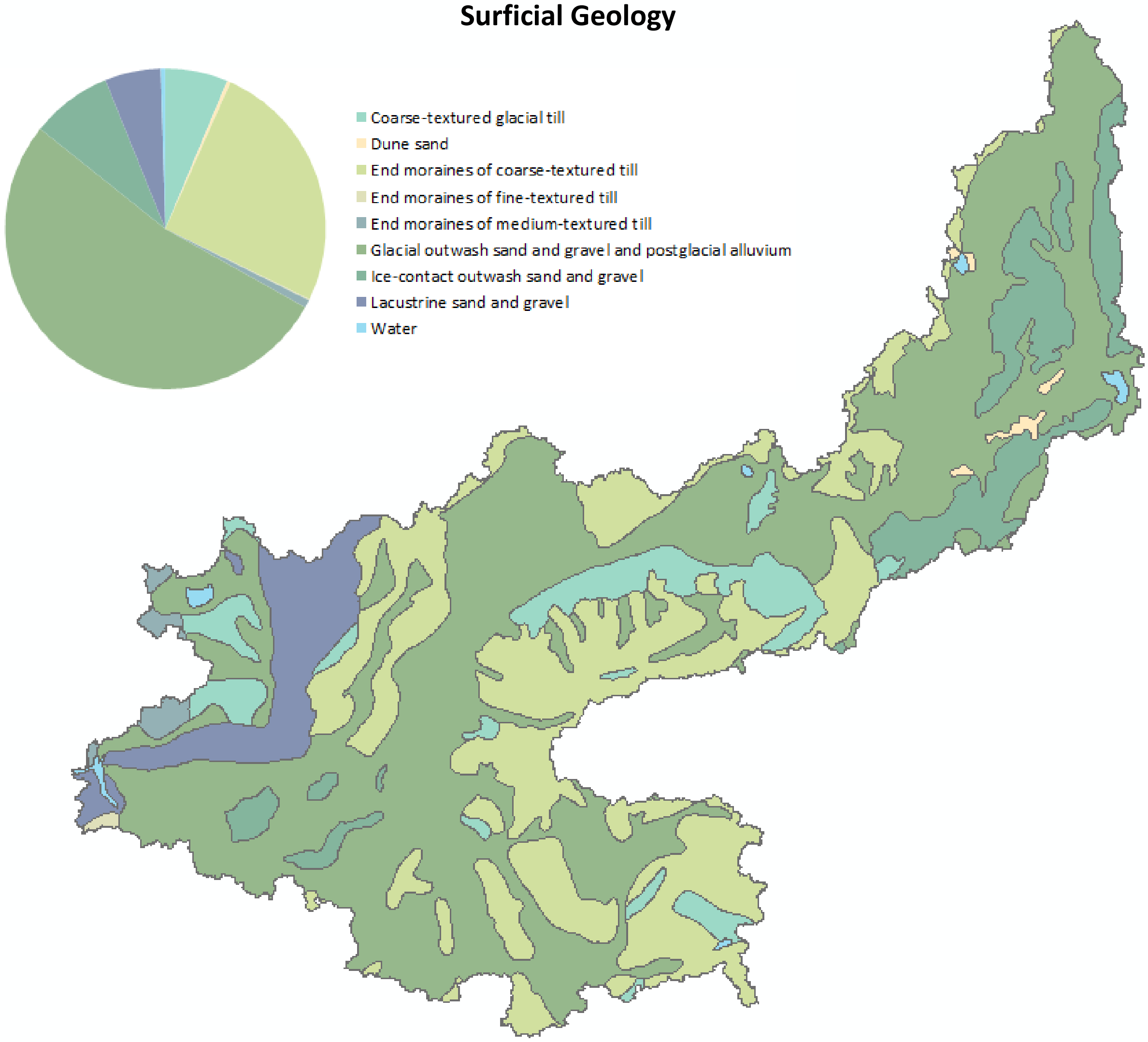
EGLE Runoff Curve Number
54.1

Category	Area	Percentage
Category	*km²*	*%*
Water	68.68	1.35%
Developed	303.76	5.98%
Barren	7.85	0.15%
Forest	2811.62	55.39%
Shrubland	261.36	5.15%
Grassland	573.43	11.30%
Agriculture	457.62	9.01%
Wetlands	592.17	11.67%
Total	5076.49	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

20, MANISTEE RIVER WATERSHED

Surficial Geology

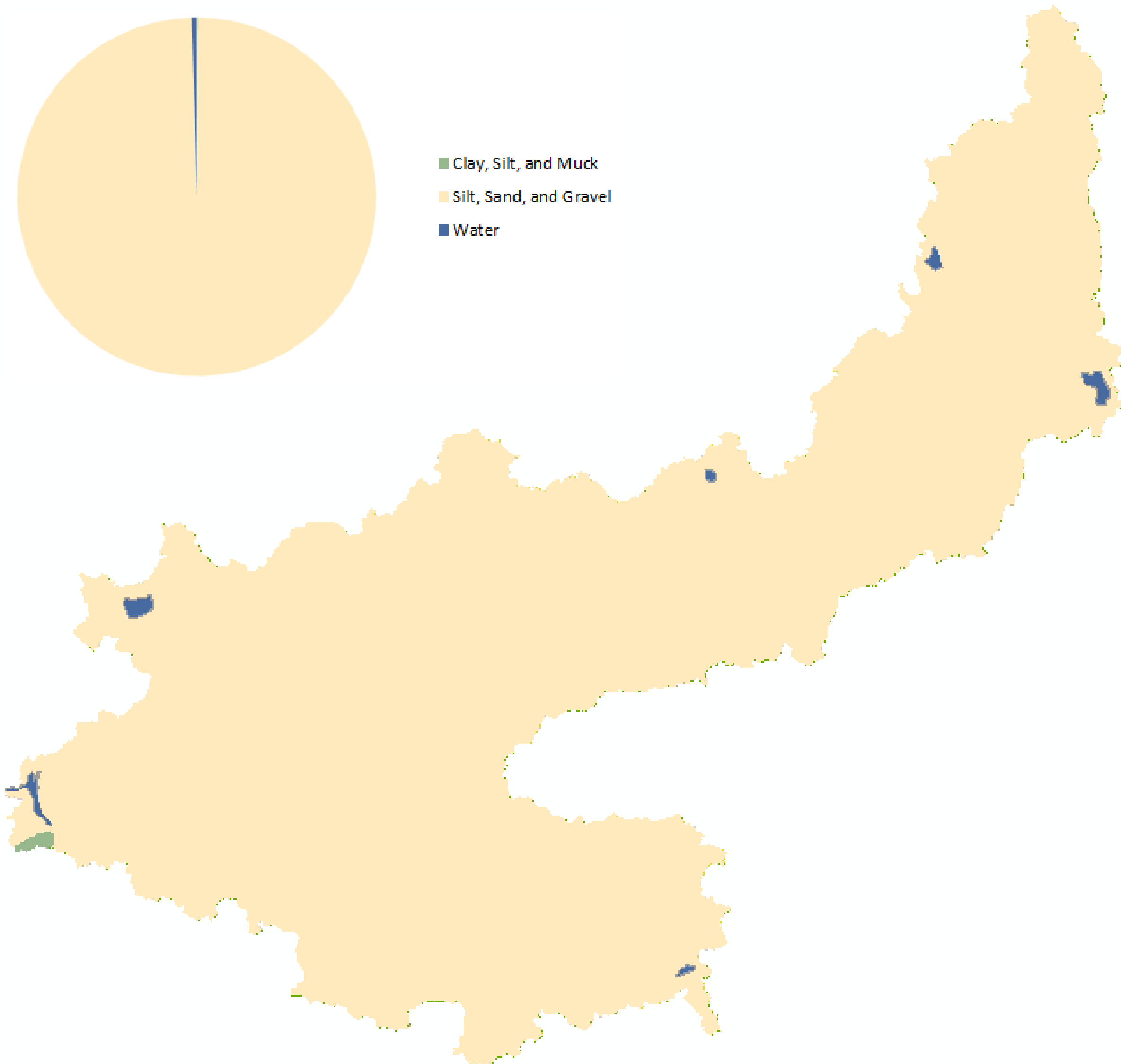


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	320.36	6.31%
Dune sand	18.16	0.36%
End moraines of coarse-textured till	1296.67	25.54%
End moraines of fine-textured till	6.07	0.12%
End moraines of medium-textured till	41.03	0.81%
Glacial outwash sand and gravel and postglacial alluvium	2669.21	52.58%
Ice-contact outwash sand and gravel	414.60	8.17%
Lacustrine sand and gravel	286.21	5.64%
Water	24.18	0.48%
Total Watershed Area	5076.49	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

20, MANISTEE RIVER WATERSHED

Surficial Geology (Simplified)

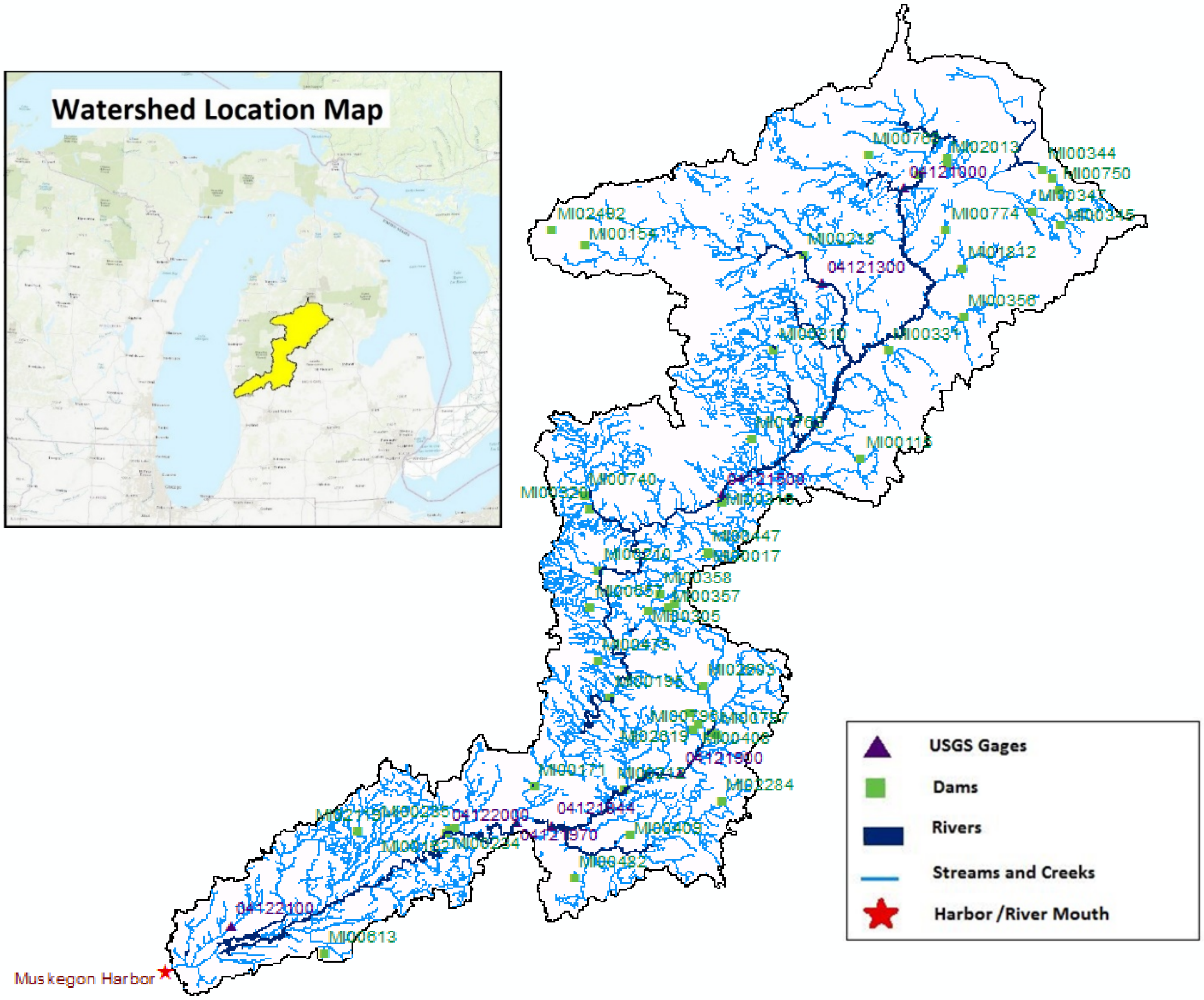


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	6.07	0.12%
Silt, Sand, and Gravel	5046.24	99.40%
Water	24.18	0.48%
Total Watershed Area	5076.49	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX Z. MUSKEGON RIVER WATERSHED (22)

Surface Hydrology



22, MUSKEGON RIVER WATERSHED

Dam Information and USGS Streamgages

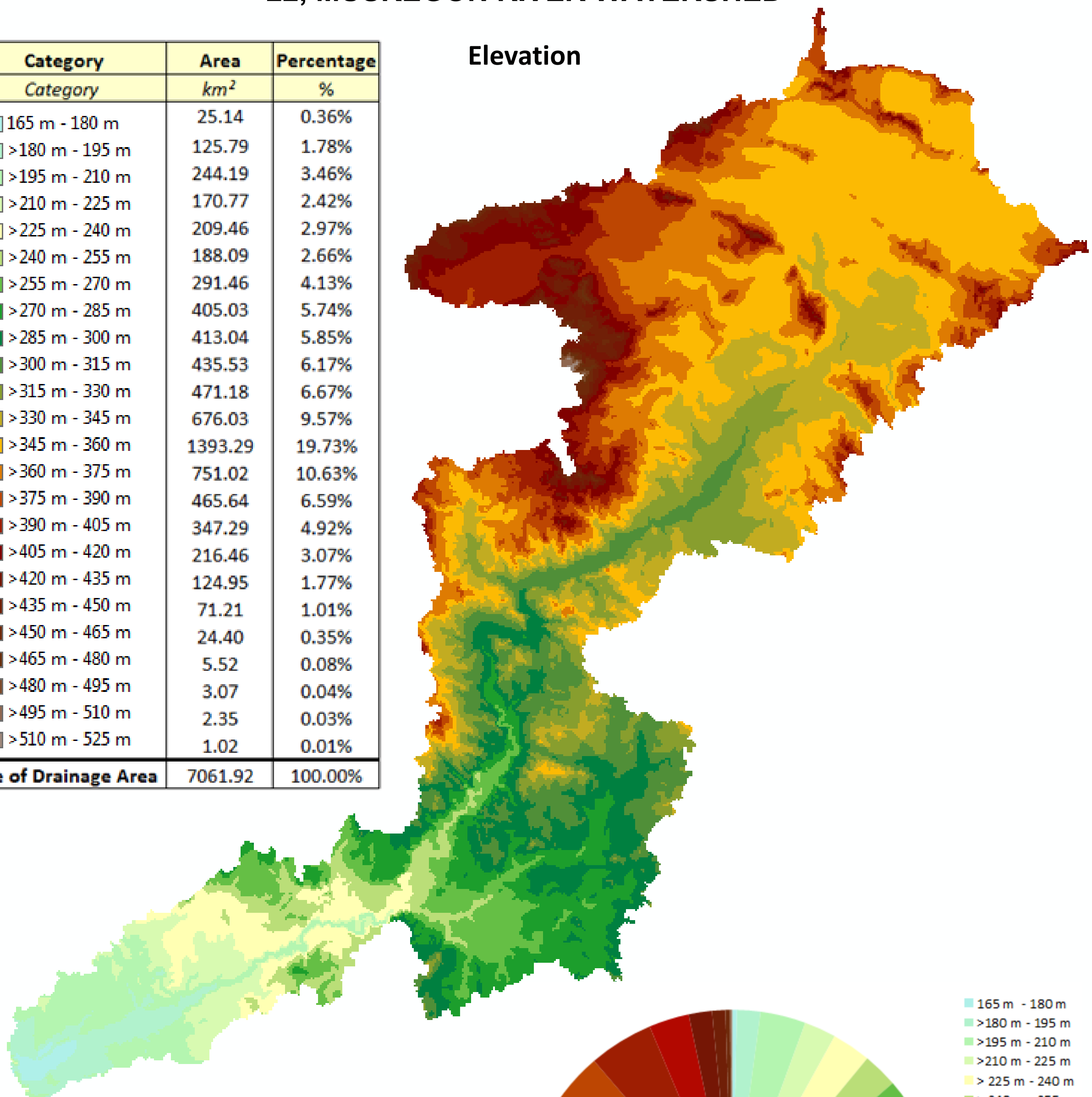
USACE's National Inventory of Dams (NID)							
NIDID	Dam Name	Longitude	Latitude	NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*	*National ID*	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00195	Rogers	-85.478300	43.613300	MI00316	Lake Lure Dam	-85.258330	43.891670
MI00171	Hardy	-85.629100	43.487000	MI00320	Nartron Dam	-85.516670	43.883340
MI00162	Croton	-85.801700	43.421700	MI00331	Old Fur Farm Dam	-84.925000	44.105000
MI00212	Morley Dam	-85.450000	43.483300	MI00343	Backus Creek Dam	-84.595000	44.346670
MI00115	Doc and Tom Lake Level Control Structure	-84.983330	43.950000	MI00344	Little Mud Lake Dam	-84.611730	44.358750
MI00154	Brandy Brook Dam	-85.523330	44.258340	MI00345	Denton Creek Flooding Dam	-84.577770	44.279380
MI00017	Lower Lake Miramichi Dam	-85.283330	43.816670	MI00347	Lake James Dam	-84.633330	44.298330
MI01763	Woods Dam	-85.196660	43.980000	MI00356	Townline Creek Flooding Dam	-84.773330	44.151670
MI01812	Wraco Lodge Dam	-84.774100	44.221000	MI00357	Pickerel Lake Dam	-85.363330	43.741660
MI02012	Houghton Lake Flats North Unit Dam	-84.803340	44.378330	MI00358	Featherbed Dam	-85.380000	43.761670
MI02013	Houghton Lake Flats South Unit Dam	-84.803340	44.371670	MI00408	Lower Canadian Lakes Dam	-85.306660	43.573330
MI00210	Buckhorn Creek Dam	-85.500000	43.793330	MI00409	Indian Lake Dam	-85.442150	43.416590
MI02119	Peterson Dam	-85.973630	43.424600	MI00447	Lake Miramichi Dam (Upper)	-85.283330	43.820000
MI00214	Haymarsh Lake Dam	-85.350000	43.746670	MI00475	Baumunk Dam	-85.503330	43.666670
MI00218	Falmouth Dam	-85.090000	44.241660	MI00482	Brook Cherith Dam	-85.550000	43.356670
MI00222	Reedsburg Dam	-84.860000	44.355000	MI00613	Muskegon Waste Water Lagoons	-86.041660	43.250000
MI02284	Tamarack Creek Dam	-85.263340	43.463330	MI00657	Ray C. Andres Dam	-85.516670	43.741660
MI00234	Rowe Dam No 1	-85.796670	43.425000	MI00705	Upper Canadian Lakes Dam	-85.323330	43.590000
MI00235	Rowe Dam No 2	-85.786670	43.428330	MI00740	Thompson s Pond Dam	-85.526660	43.901670
MI02492	Archie Castle s Dam	-85.588610	44.281670	MI00750	Backus Lake Dam	-84.581670	44.330000
MI02603	Lower Dead Stream Dam	-85.296390	43.630000	MI00768	Lake Street Dam And Flume	-84.958340	44.385000
MI02619	Olger Lake Dam	-85.315900	43.566700	MI00774	Hardacre Dam	-84.806660	44.275000
MI00305	Little John Flooding Dam	-85.403340	43.736670	MI00796	Sunset Lake Dam	-85.279750	43.561670
MI00310	Marion Dam	-85.150000	44.106670	MI00797	Lake Laura Dam	-85.272220	43.560550

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4121000	MUSKEGON RIVER NEAR MERRITT, MI	-84.890033	*44.33557*	
4121300	CLAM RIVER AT VOGEL CENTER, MI	-85.052815	44.200569	yes
4121500	MUSKEGON RIVER AT EVART, MI	-85.255319	43.899186	yes
4121900	LITTLE MUSKEGON RIVER NEAR MORLEY, MI	-85.342536	43.502529	
4121944	LITTLE MUSKEGON RIVER NEAR OAK GROVE, MI	-85.595599	43.430858	yes
4121970	MUSKEGON RIVER NEAR CROTON, MI	-85.665324	43.434746	yes
4122000	MUSKEGON RIVER AT NEWAYGO, MI	-85.801162	43.422243	
4122100	BEAR CREEK NEAR MUSKEGON, MI	-86.222838	43.288625	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				5

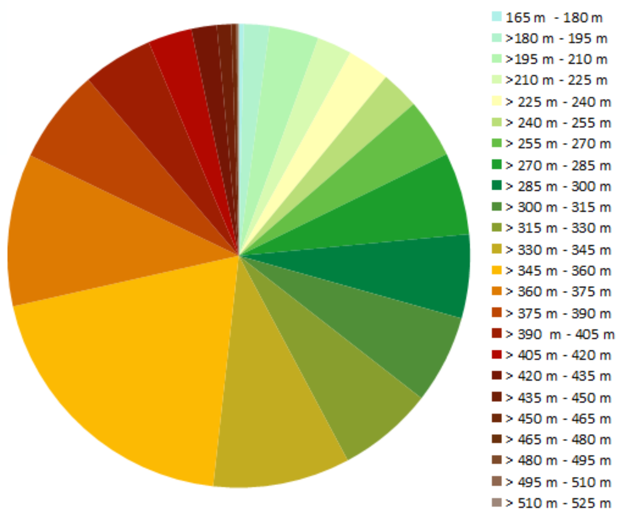
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

22, MUSKEGON RIVER WATERSHED

Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	25.14	0.36%
>180 m - 195 m	125.79	1.78%
>195 m - 210 m	244.19	3.46%
>210 m - 225 m	170.77	2.42%
>225 m - 240 m	209.46	2.97%
>240 m - 255 m	188.09	2.66%
>255 m - 270 m	291.46	4.13%
>270 m - 285 m	405.03	5.74%
>285 m - 300 m	413.04	5.85%
>300 m - 315 m	435.53	6.17%
>315 m - 330 m	471.18	6.67%
>330 m - 345 m	676.03	9.57%
>345 m - 360 m	1393.29	19.73%
>360 m - 375 m	751.02	10.63%
>375 m - 390 m	465.64	6.59%
>390 m - 405 m	347.29	4.92%
>405 m - 420 m	216.46	3.07%
>420 m - 435 m	124.95	1.77%
>435 m - 450 m	71.21	1.01%
>450 m - 465 m	24.40	0.35%
>465 m - 480 m	5.52	0.08%
>480 m - 495 m	3.07	0.04%
>495 m - 510 m	2.35	0.03%
>510 m - 525 m	1.02	0.01%
Size of Drainage Area	7061.92	100.00%



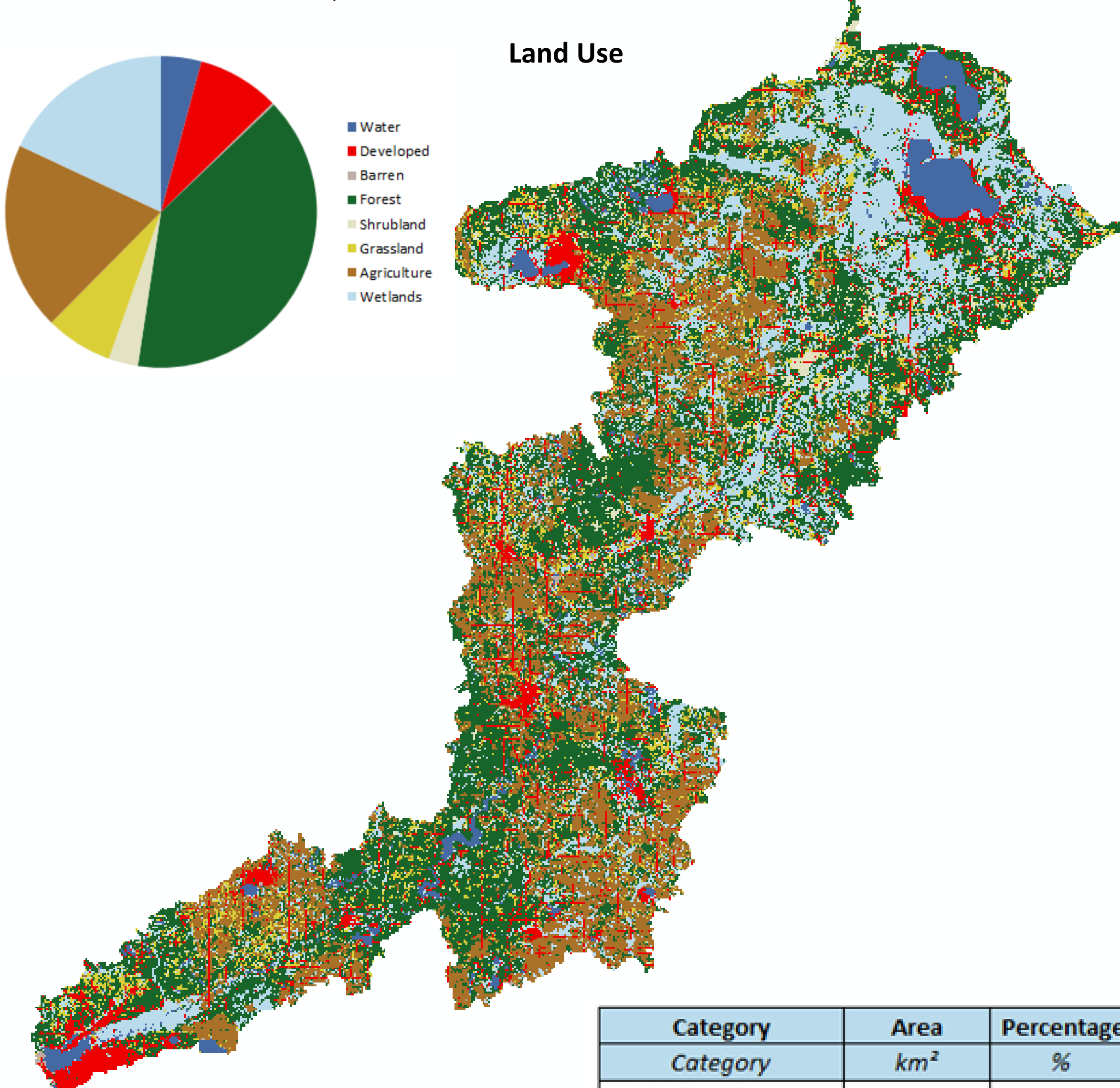
Muskegon Watershed		
Elevation Statistics		
Size of Drainage Area	**7061.92**	***km²***
Maximum	522.00	*m*
Minimum	177.00	*m*
Average	325.85	*m*
Standard Deviation	59.09	*m*



All Elevation Measurements with Respect to North American Datum 1983

22, MUSKEGON RIVER WATERSHED

Land Use



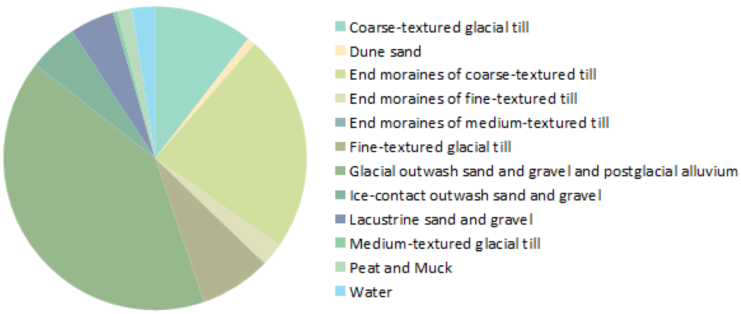
Category	Area	Percentage
Category	*km²*	*%*
Water	295.37	4.18%
Developed	601.87	8.52%
Barren	14.62	0.21%
Forest	2787.34	39.47%
Shrubland	217.12	3.07%
Grassland	492.18	6.97%
Agriculture	1380.22	19.54%
Wetlands	1273.21	18.03%
Total	7061.92	100.00%

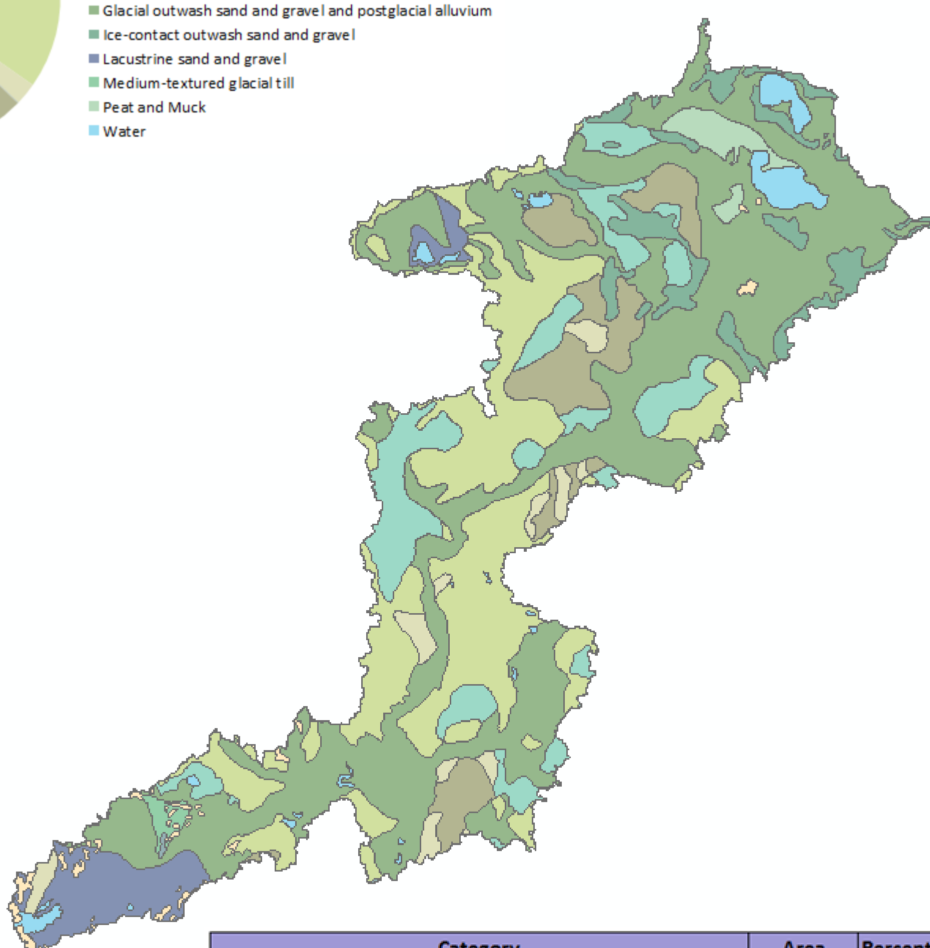
EGLE Runoff Curve Number
63.9

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

22, MUSKEGON RIVER WATERSHED

Surficial Geology



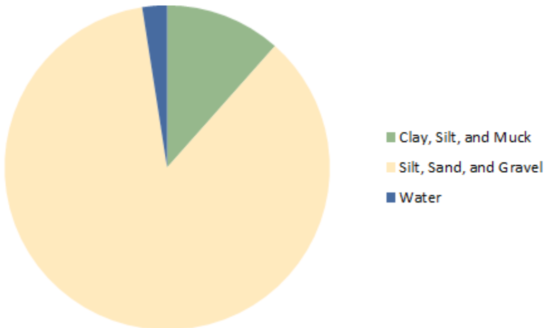


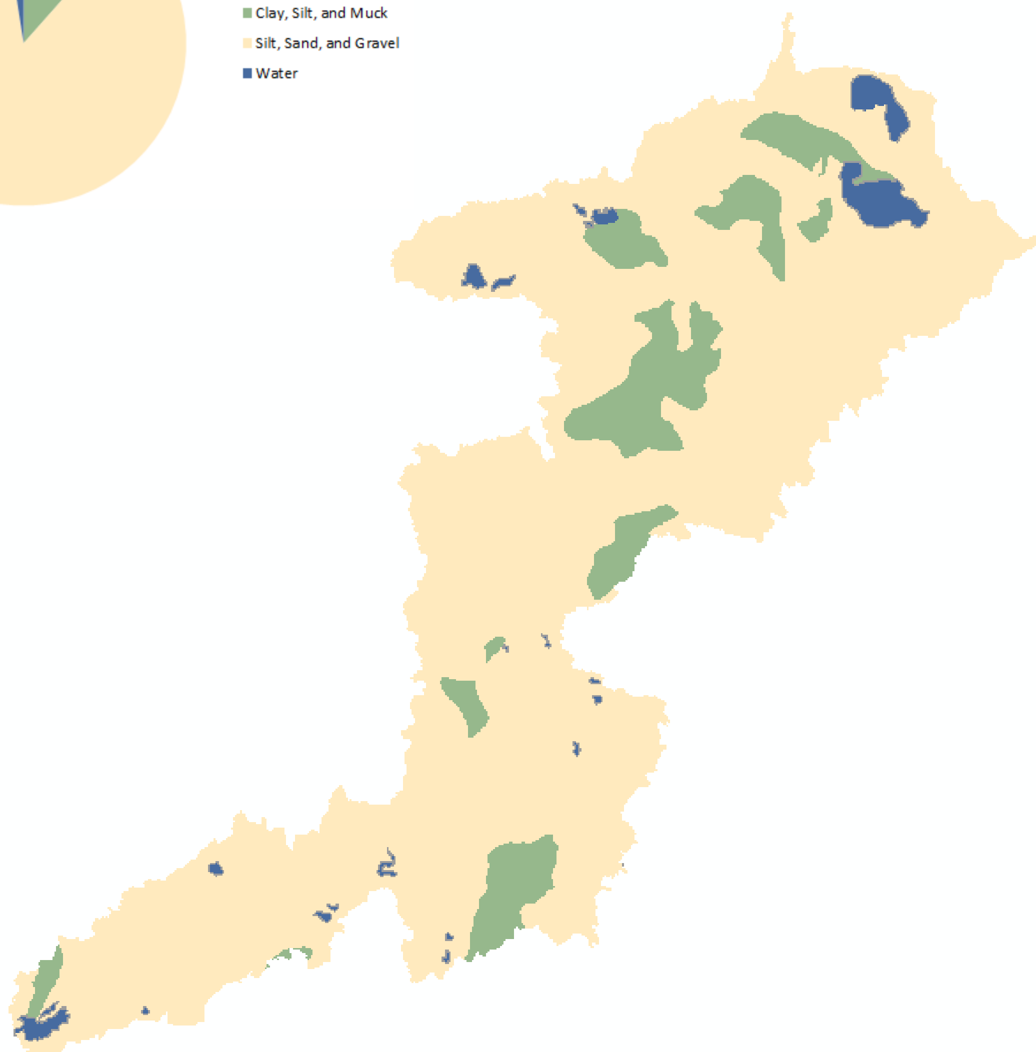
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	742.50	10.51%
Dune sand	63.70	0.90%
End moraines of coarse-textured till	1647.24	23.33%
End moraines of fine-textured till	170.32	2.41%
End moraines of medium-textured till	3.94	0.06%
Fine-textured glacial till	533.88	7.56%
Glacial outwash sand and gravel and postglacial alluvium	2881.07	40.80%
Ice-contact outwash sand and gravel	370.12	5.24%
Lacustrine sand and gravel	332.25	4.70%
Medium-textured glacial till	32.56	0.46%
Peat and muck	110.54	1.57%
Water	173.78	2.46%
Total Watershed Area	7061.92	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

22, MUSKEGON RIVER WATERSHED

Surficial Geology (Simplified)



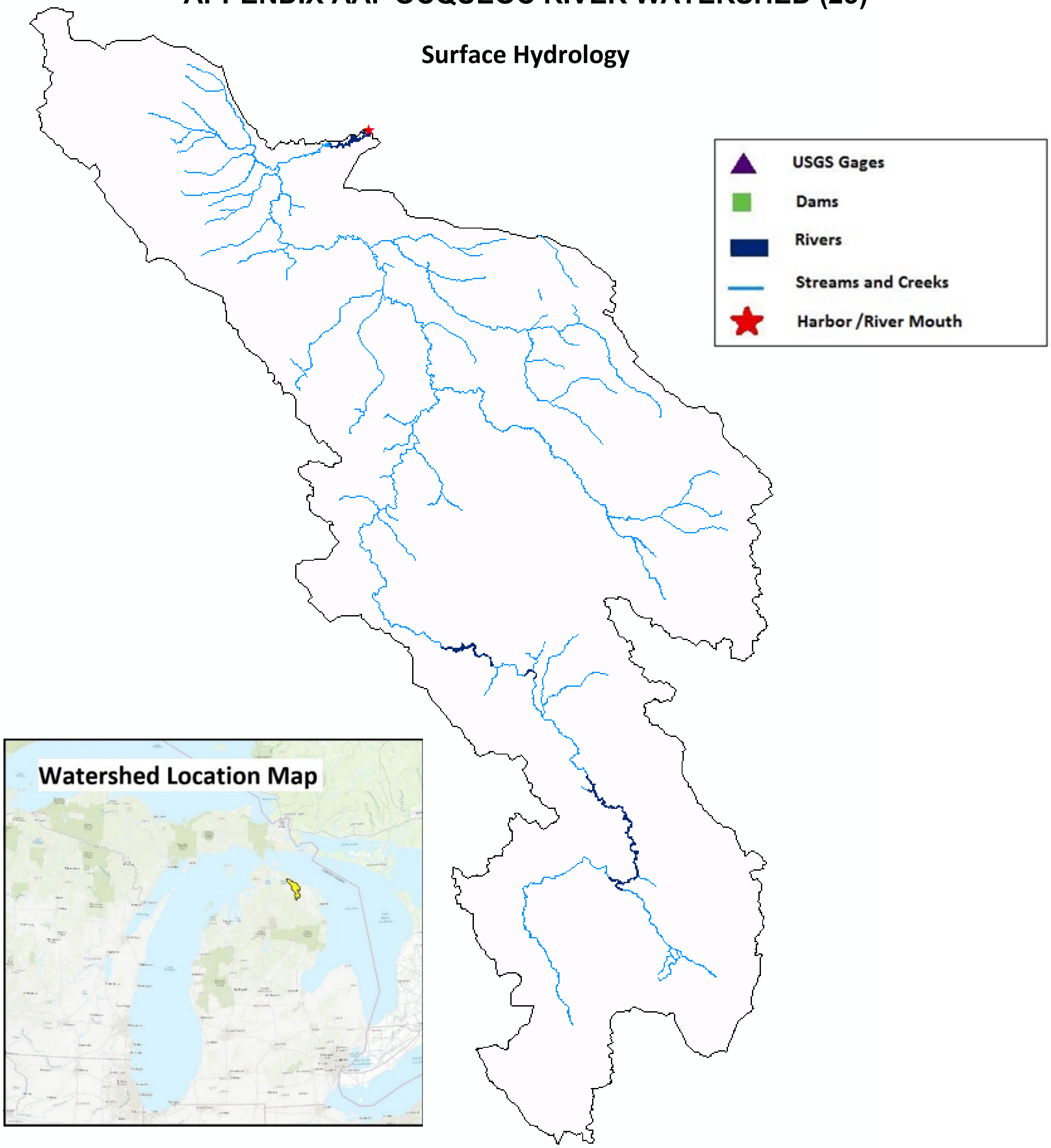


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*814.74*	11.54%
Silt, Sand, and Gravel	6073.40	86.00%
Water	173.78	2.46%
Total Watershed Area	7061.92	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX AA. OCQUEOC RIVER WATERSHED (23)

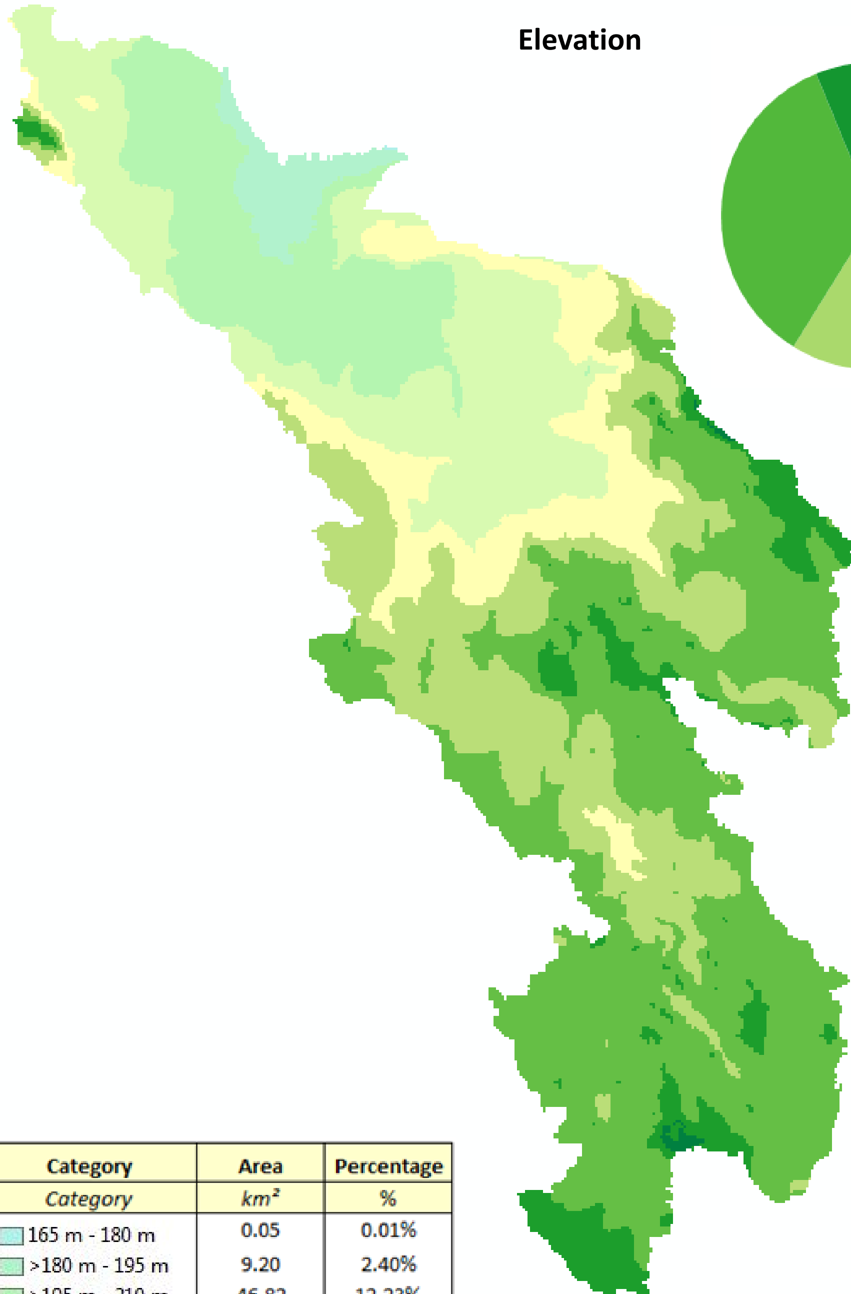
Surface Hydrology

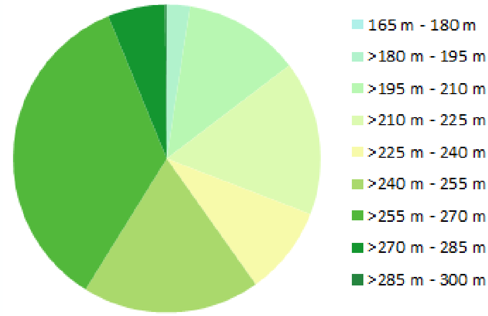


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

23, OCQUEOC RIVER WATERSHED

Elevation





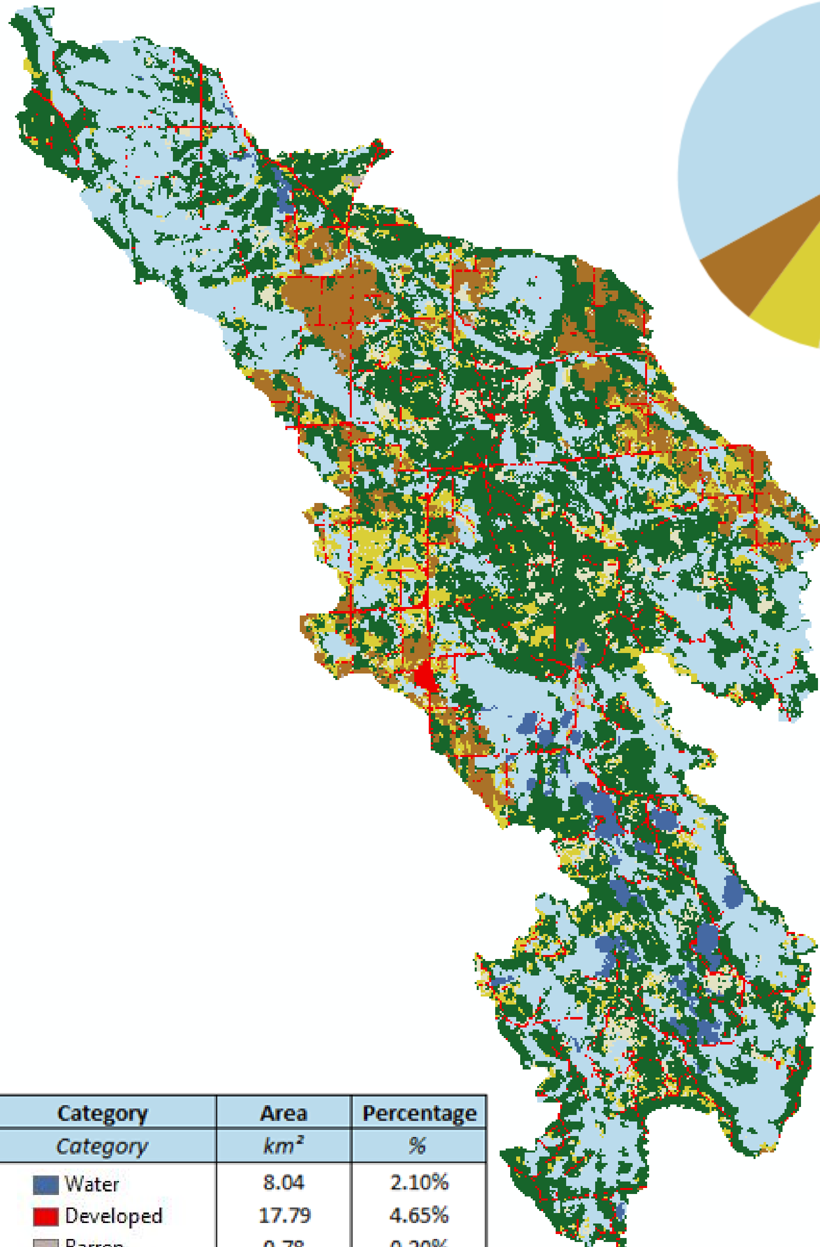
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.05	0.01%
>180 m - 195 m	9.20	2.40%
>195 m - 210 m	46.82	12.23%
>210 m - 225 m	62.02	16.21%
>225 m - 240 m	35.69	9.33%
>240 m - 255 m	71.42	18.66%
>255 m - 270 m	133.69	34.94%
>270 m - 285 m	22.98	6.01%
>285 m - 300 m	0.78	0.20%
Size of Drainage Area	382.65	100.00%

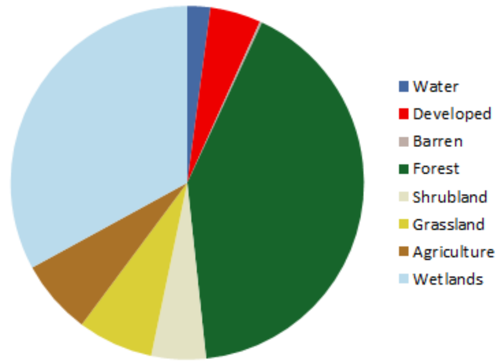
Ocqueoc Watershed		
Elevation Statistics		
Size of Drainage Area	**382.65**	***km²***
Maximum	289.00	*m*
Minimum	178.00	*m*
Average	239.82	*m*
Standard Deviation	23.45	*m*

All Elevation Measurements with Respect to North American Datum 1983

23, OCQUEOC RIVER WATERSHED

Land Use





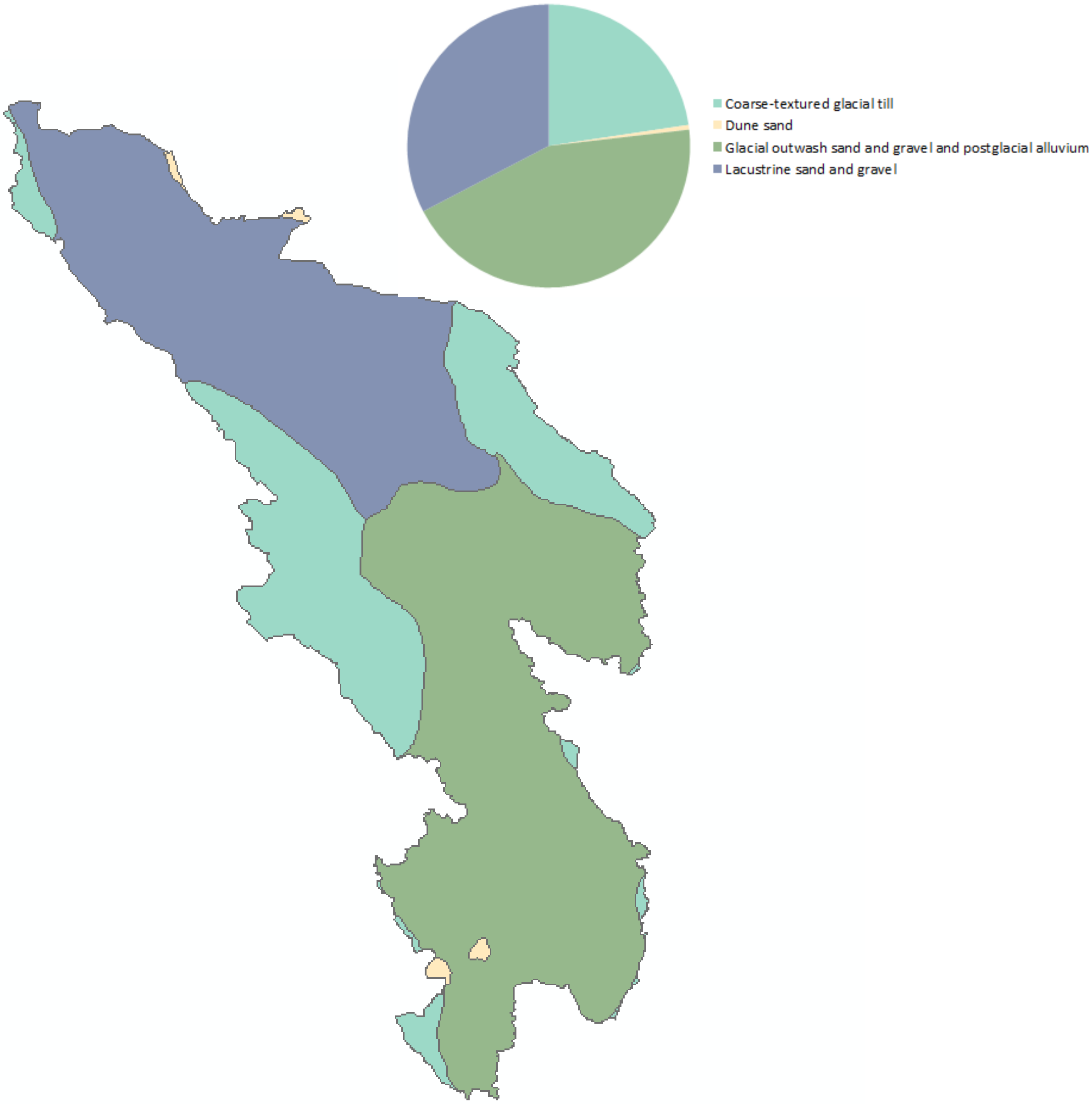
Category	Area	Percentage
Category	*km²*	*%*
Water	8.04	2.10%
Developed	17.79	4.65%
Barren	0.78	0.20%
Forest	158.19	41.34%
Shrubland	19.12	5.00%
Grassland	26.42	6.91%
Agriculture	26.21	6.85%
Wetlands	126.10	32.95%
Total	382.65	100.00%

MDEQ CN Calculation
64.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

23, OCQUEOC RIVER WATERSHED

Surficial Geology



Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	86.57	22.62%
Dune sand	2.05	0.54%
Glacial outwash sand and gravel and postglacial alluvium	169.14	44.20%
Lacustrine sand and gravel	124.89	32.64%
Total Watershed Area	382.65	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

23, OCQUEOC RIVER WATERSHED

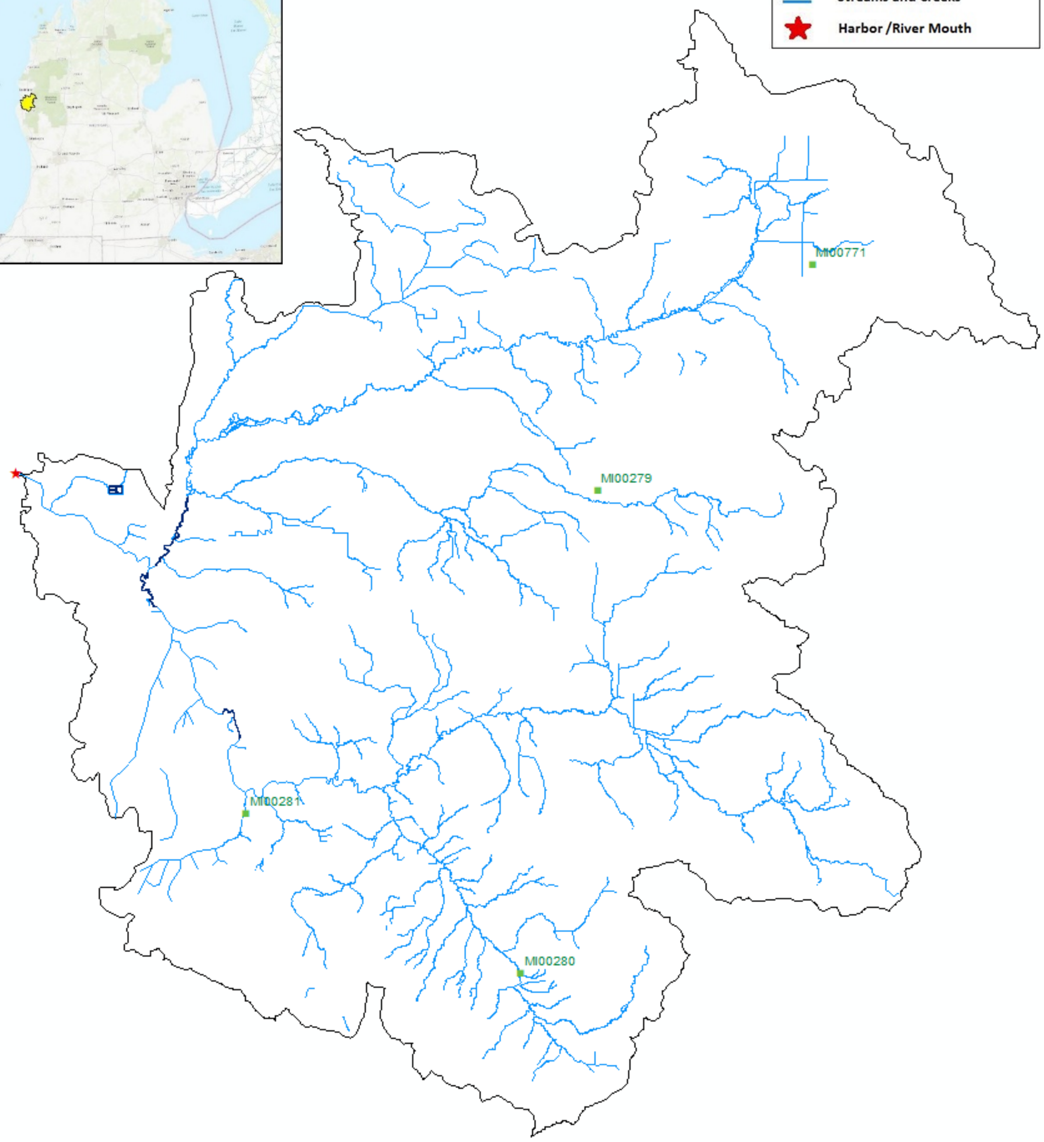
Surficial Geology (Simplified)

Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	382.65	100.00%
Total Watershed Area	382.65	100.00%

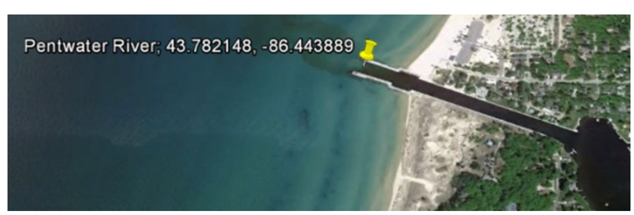
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX BB. PENTWATER RIVER WATERSHED (24)

Surface Hydrology



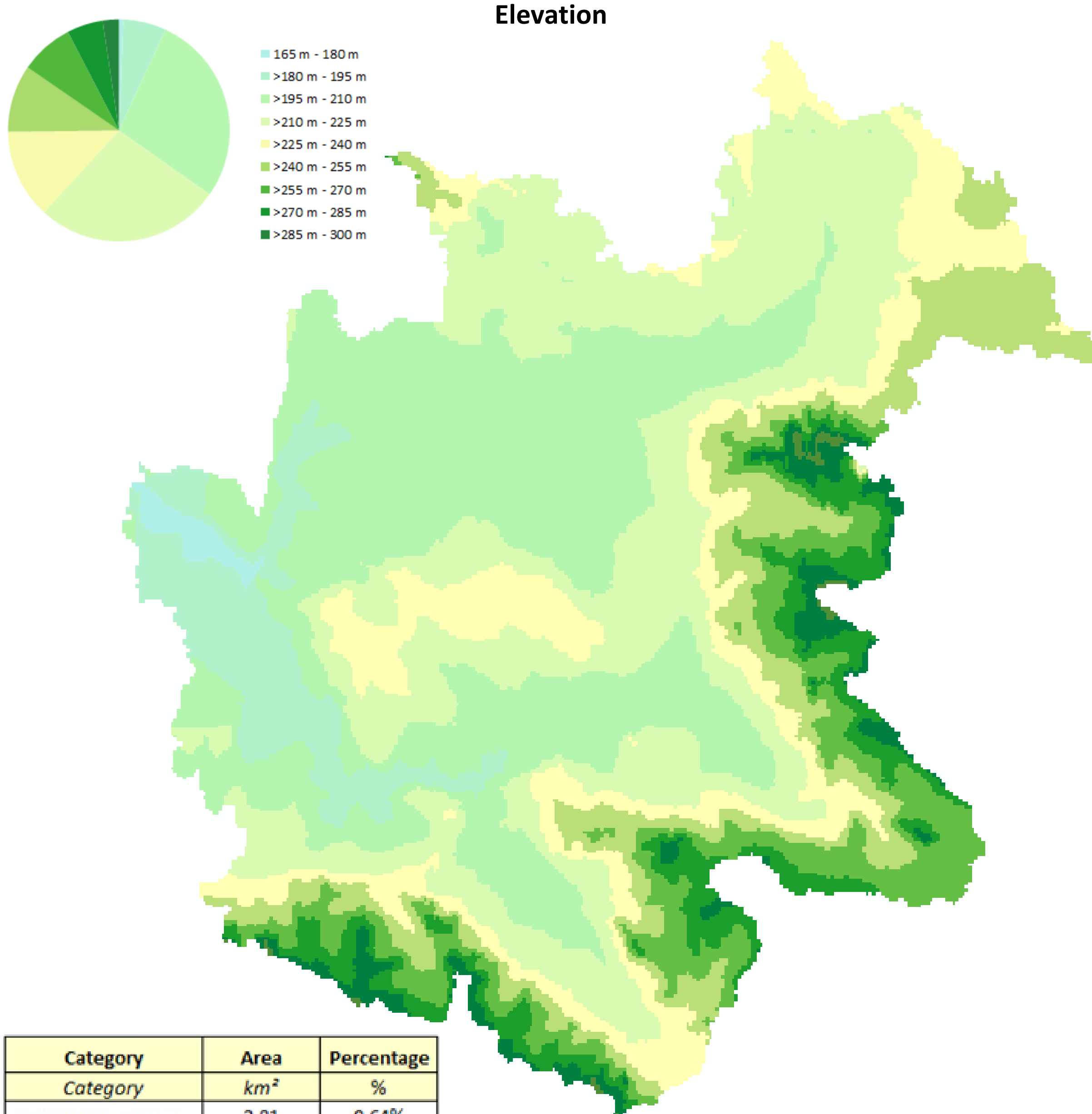
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00281	Hart Lake	-86.366700	43.700000
MI00279	Crystal Valley Dam	-86.250000	43.778330
MI00280	Gales Pond Dam	-86.275000	43.661670
MI00771	Whiskey Creek Dam #2	-86.178340	43.833330



Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

24, PENTWATER RIVER WATERSHED

Elevation



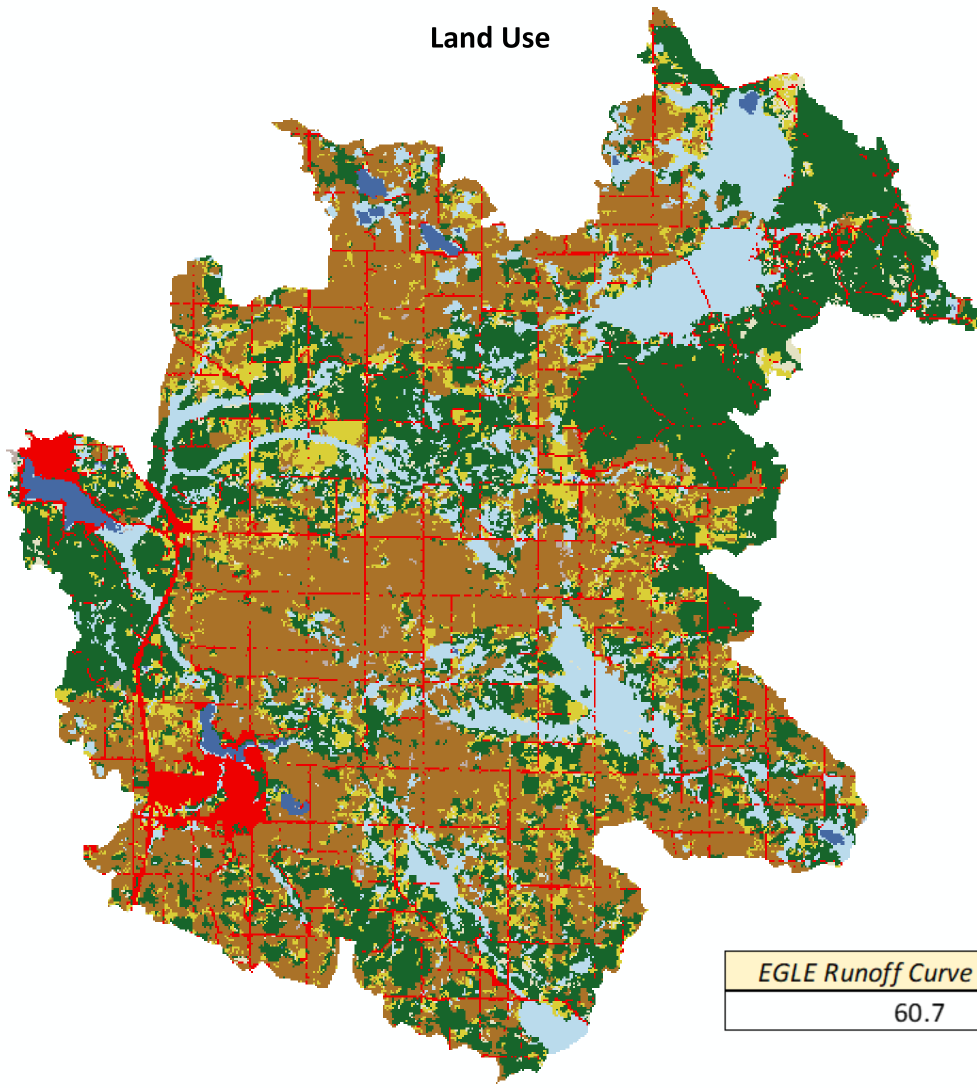
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	2.81	0.64%
>180 m - 195 m	27.56	6.24%
>195 m - 210 m	123.01	27.83%
>210 m - 225 m	119.26	26.98%
>225 m - 240 m	57.34	12.97%
>240 m - 255 m	43.23	9.78%
>255 m - 270 m	34.28	7.76%
>270 m - 285 m	23.15	5.24%
>285 m - 300 m	10.46	2.37%
>300 m - 315 m	0.95	0.22%
Size of Drainage Area	442.06	100.00%

Pentwater Watershed		
Elevation Statistics		
Size of Drainage Area	**442.06**	***km²***
Maximum	305.00	*m*
Minimum	177.00	*m*
Average	223.55	*m*
Standard Deviation	26.12	*m*

All Elevation Measurements with Respect to North American Datum 1983

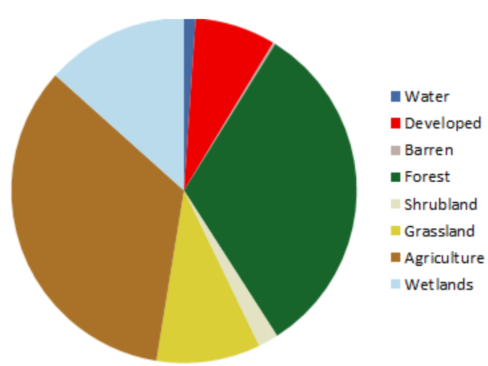
24, PENTWATER RIVER WATERSHED

Land Use



EGLE Runoff Curve Number
60.7

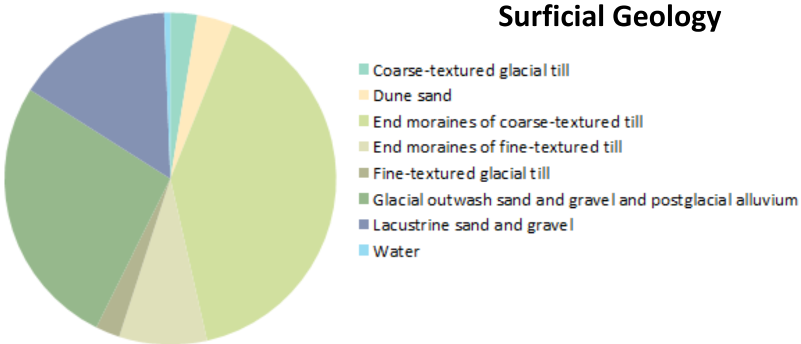
Category	Area	Percentage
Category	*km²*	*%*
Water	4.74	1.07%
Developed	33.46	7.57%
Barren	0.99	0.22%
Forest	141.76	32.07%
Shrubland	8.38	1.90%
Grassland	43.03	9.73%
Agriculture	150.60	34.07%
Wetlands	59.09	13.37%
Total	442.06	100.00%

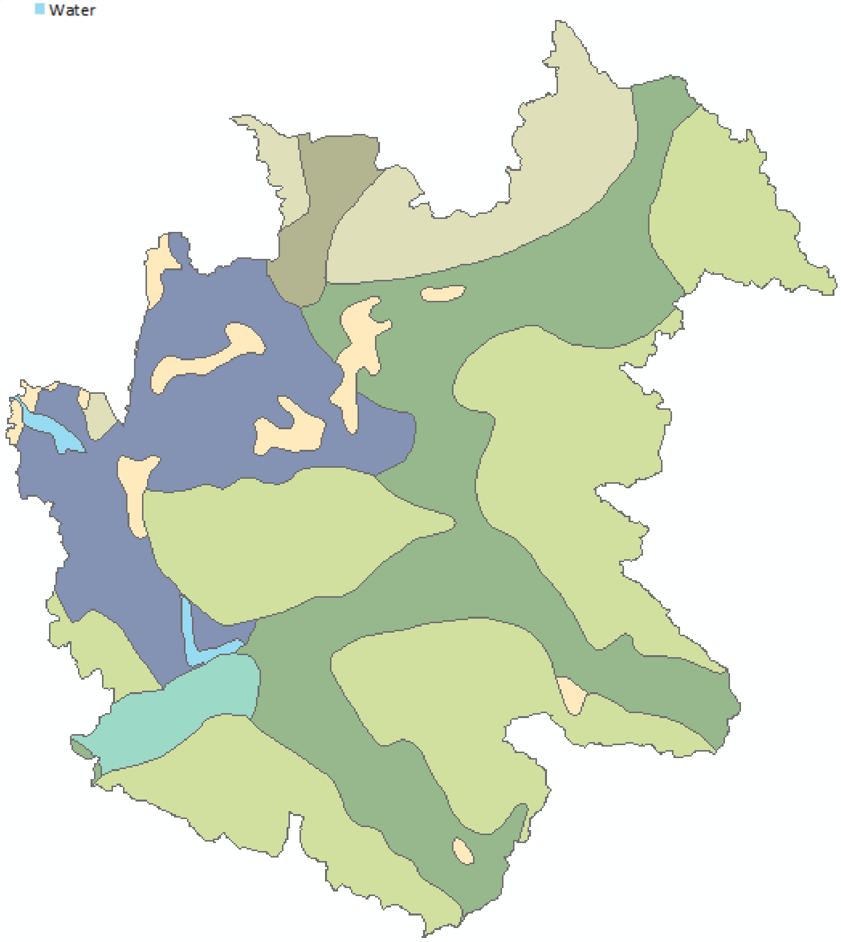


Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

24, PENTWATER RIVER WATERSHED

Surficial Geology



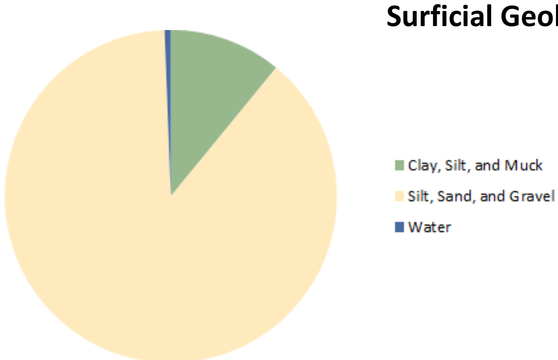


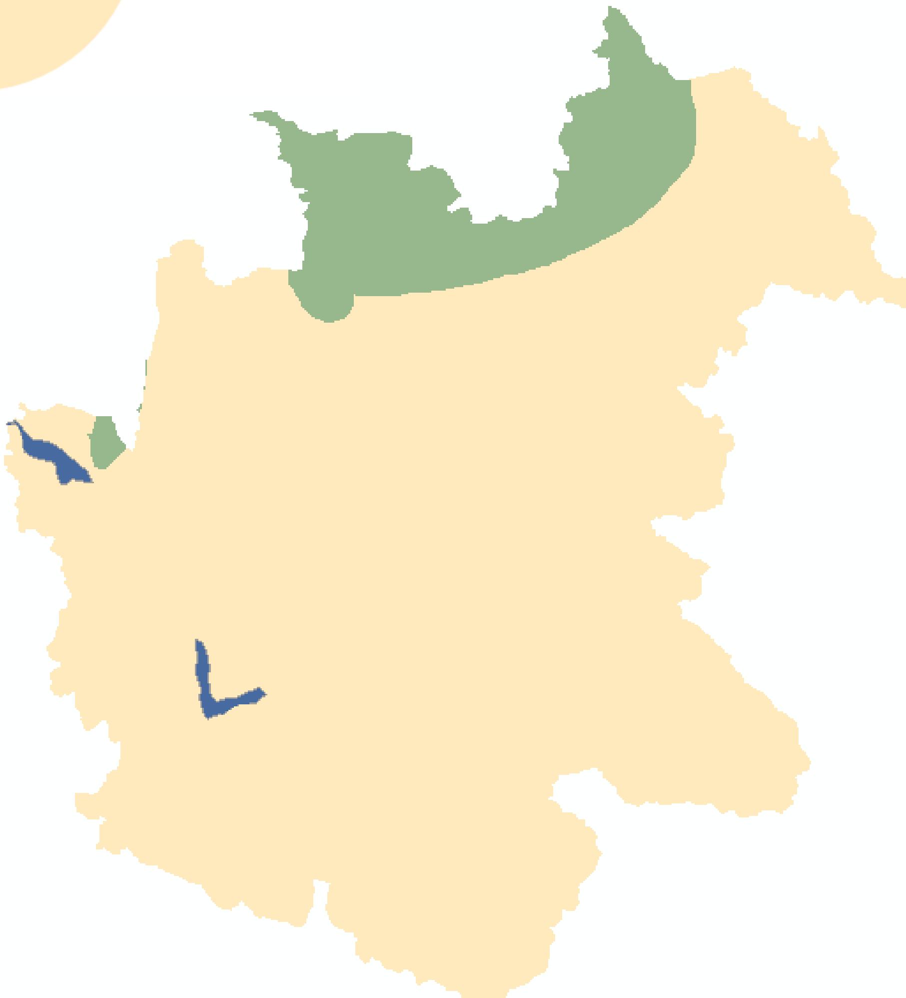
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	11.53	2.61%
Dune sand	15.51	3.51%
End moraines of coarse-textured till	178.24	40.32%
End moraines of fine-textured till	37.83	8.56%
Fine-textured glacial till	10.51	2.38%
Glacial outwash sand and gravel and postglacial alluvium	117.68	26.62%
Lacustrine sand and gravel	68.11	15.41%
Water	2.65	0.60%
Total Watershed Area	442.06	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

24, PENTWATER RIVER WATERSHED

Surficial Geology (Simplified)



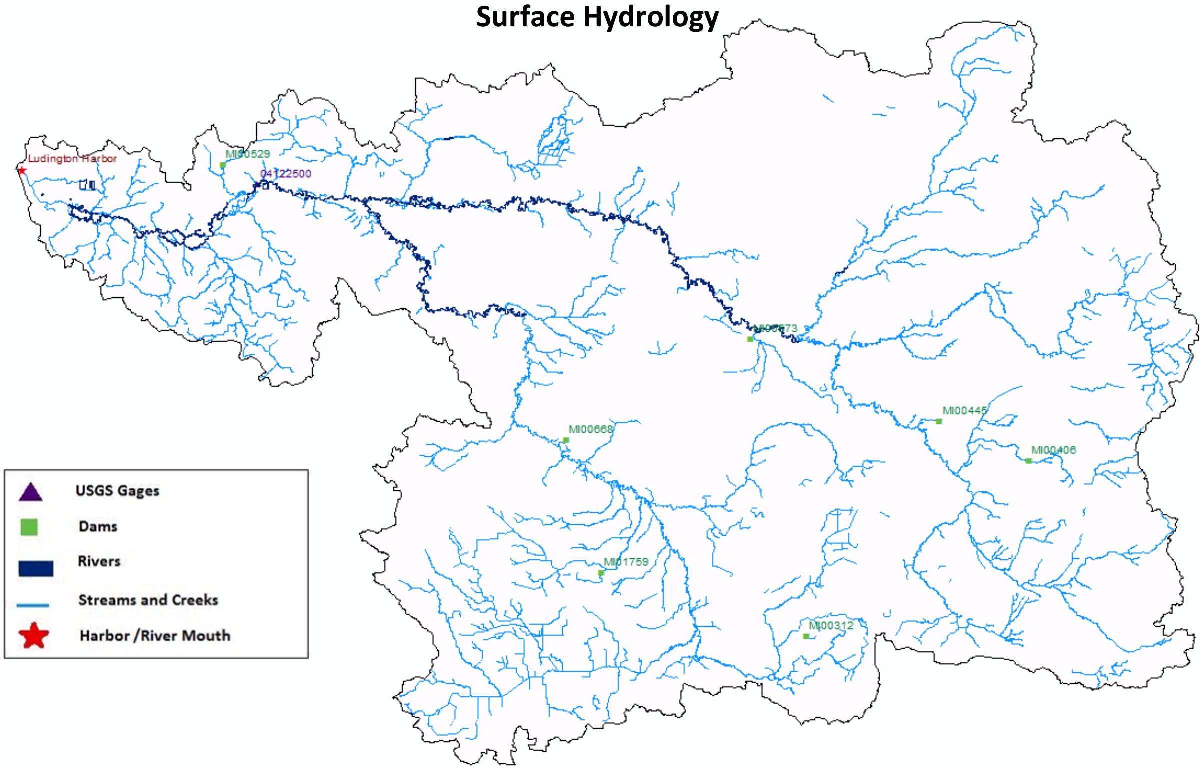


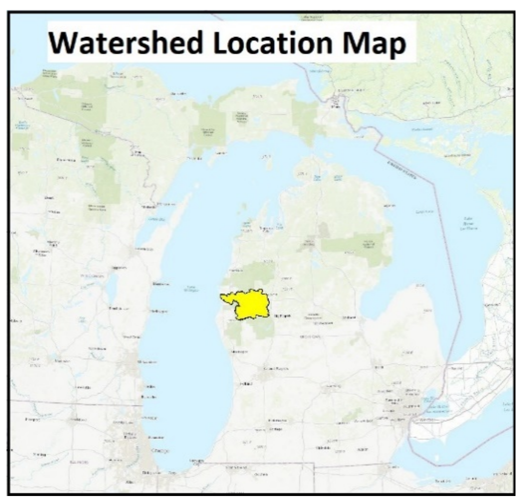
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	48.34	10.94%
Silt, Sand, and Gravel	391.06	88.46%
Water	2.65	0.60%
Total Watershed Area	442.06	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX CC. PERE MARQUETTE RIVER WATERSHED (25)

Surface Hydrology





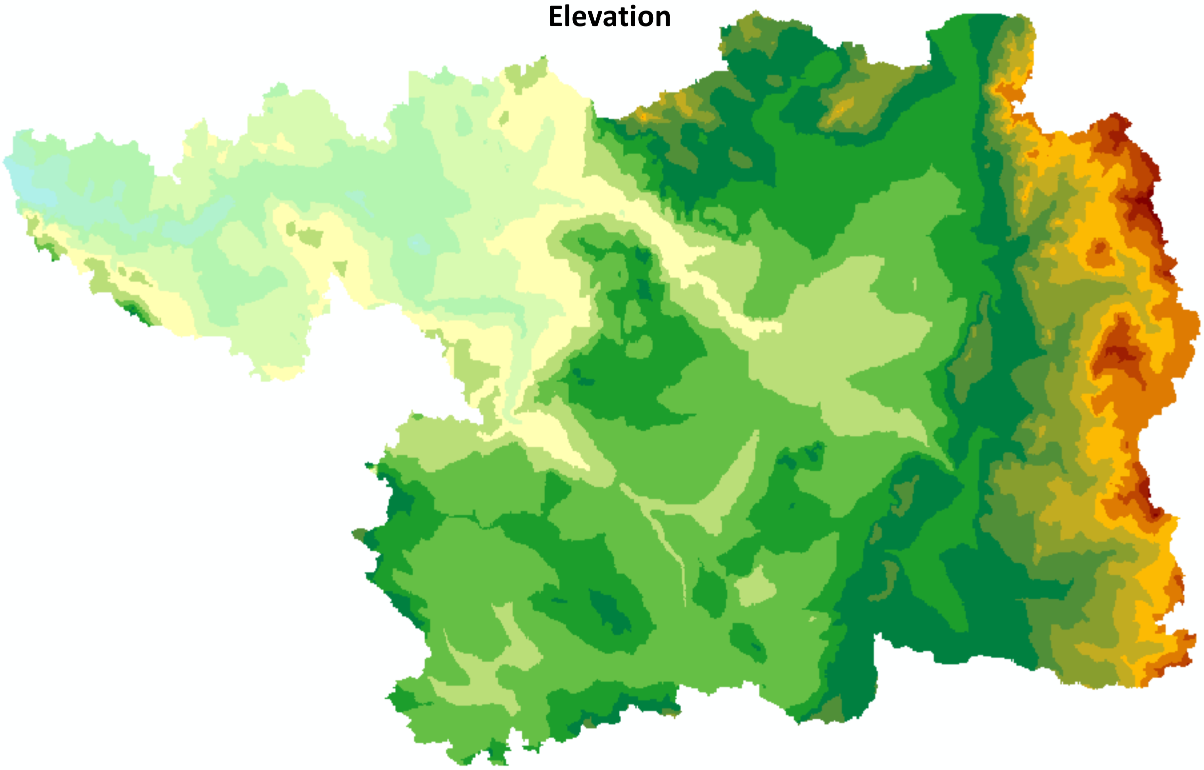
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01759	Henkin Pond Dam	-86.020550	43.734440
MI00312	Clayton Dam	-85.866670	43.700000
MI00406	Pease Creek Dam	-85.699720	43.794720
MI00445	Lake Connamara Dam	-85.766670	43.816670
MI00529	Brookside Cemetary Dam	-86.304440	43.955550
MI00573	Danaher Lake Dam	-85.908330	43.861670
MI00668	Foster Lake Dam	-86.046670	43.806670

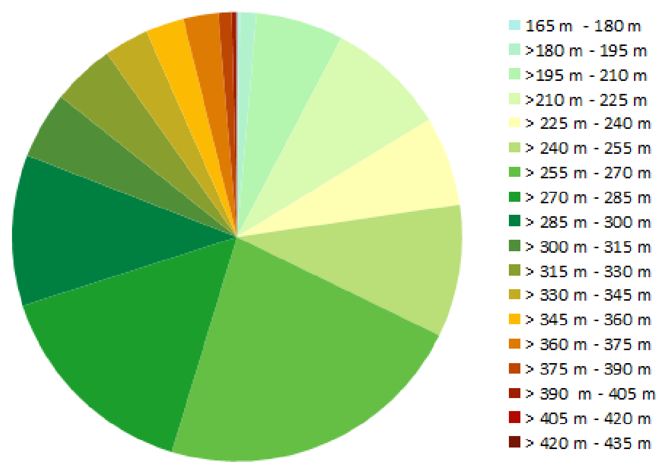
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4122500	PERE MARQUETTE RIVER AT SCOTTVILLE, MI	-86.278690	43.945006	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

25, PERE MARQUETTE RIVER WATERSHED

Elevation





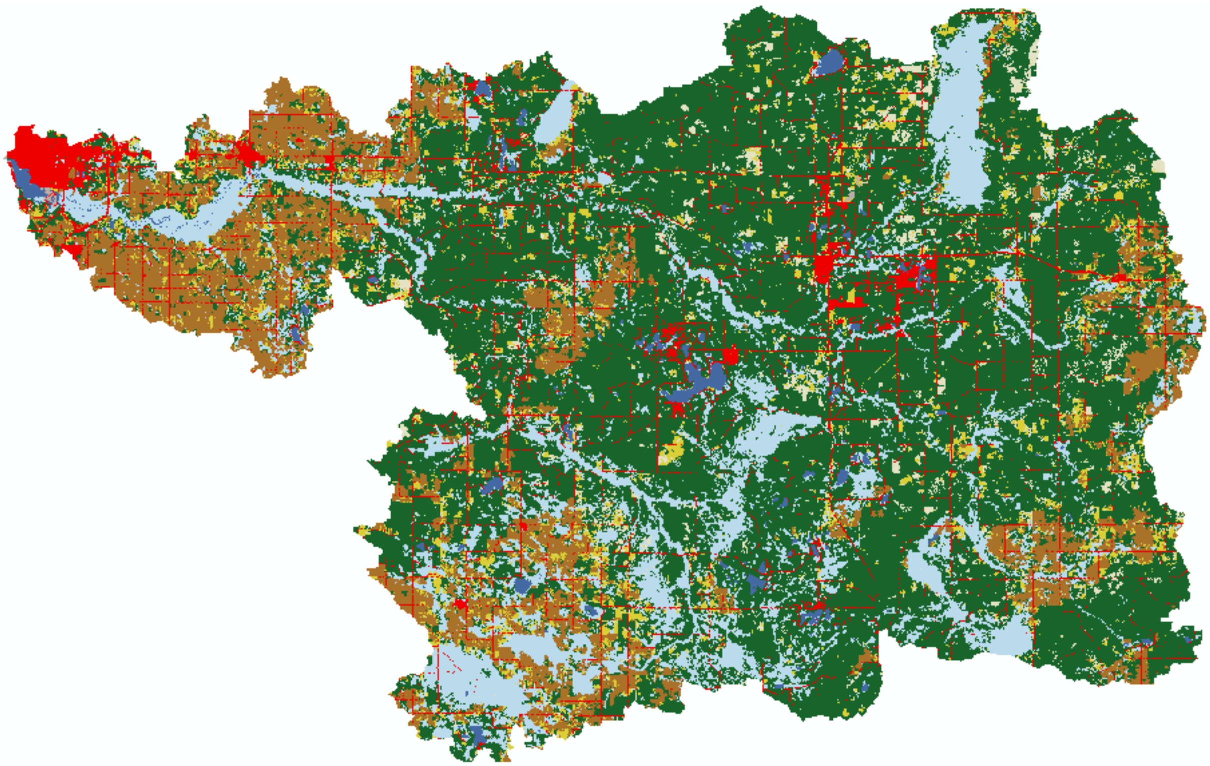
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	4.02	0.21%
>180 m - 195 m	23.19	1.19%
>195 m - 210 m	123.05	6.30%
>210 m - 225 m	167.60	8.58%
>225 m - 240 m	125.83	6.44%
>240 m - 255 m	186.00	9.52%
>255 m - 270 m	439.04	22.46%
>270 m - 285 m	300.44	15.37%
>285 m - 300 m	212.12	10.85%
>300 m - 315 m	94.15	4.82%
>315 m - 330 m	87.67	4.49%
>330 m - 345 m	62.65	3.21%
>345 m - 360 m	53.88	2.76%
>360 m - 375 m	48.98	2.51%
>375 m - 390 m	18.37	0.94%
>390 m - 405 m	6.48	0.33%
>405 m - 420 m	0.99	0.05%
>420 m - 435 m	0.06	0.00%
Size of Drainage Area	1954.52	100.00%

Pere Marquette Watershed		
Elevation Statistics		
Size of Drainage Area	**1954.52**	***km²***
Maximum	426.00	*m*
Minimum	177.00	*m*
Average	269.12	*m*
Standard Deviation	42.30	*m*

All Elevation Measurements with Respect to North American Datum 1983

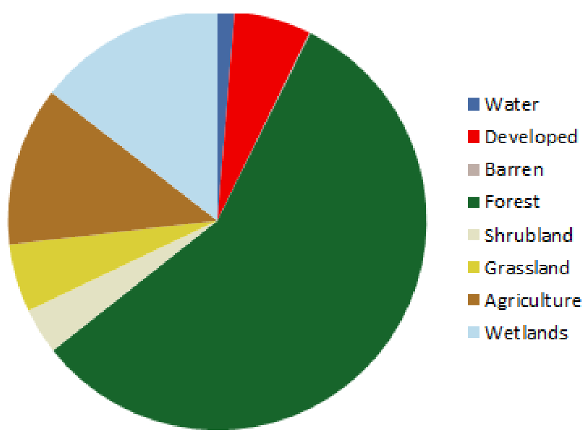
25, PERE MARQUETTE RIVER WATERSHED

Land Use



EGLE Runoff Curve Number
58.7

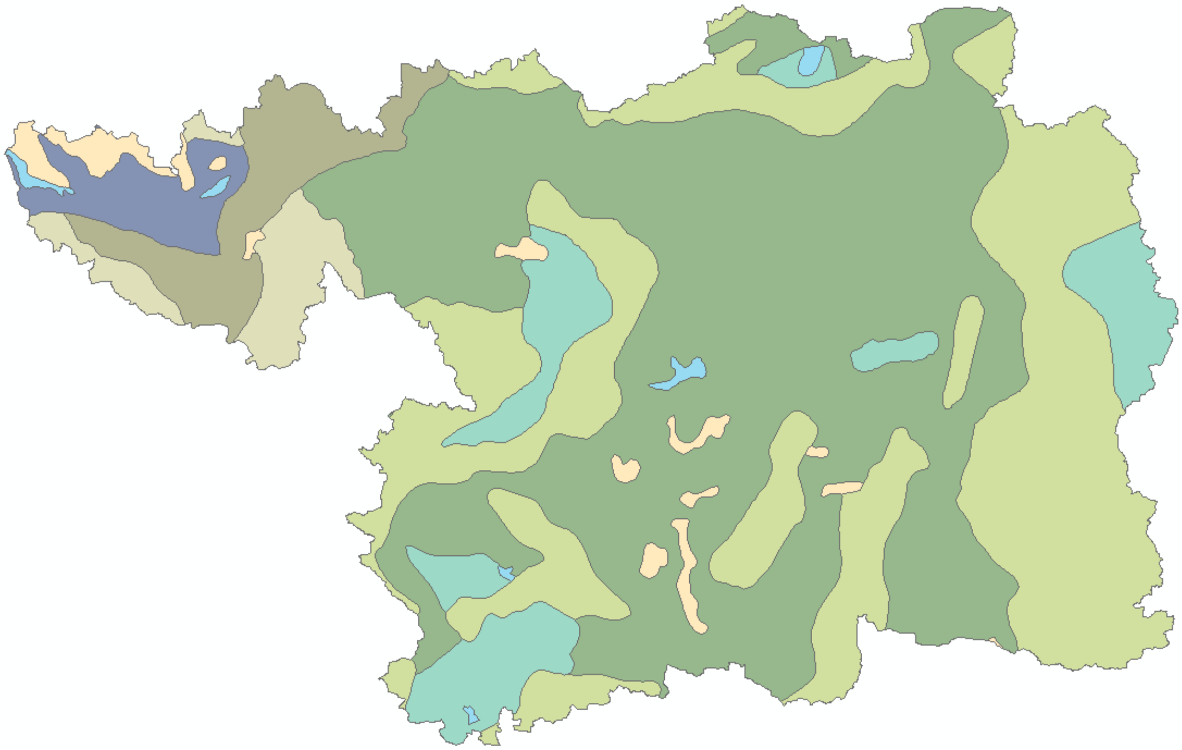
Category	Area	Percentage
Category	*km²*	*%*
Water	25.87	1.32%
Developed	116.16	5.94%
Barren	1.68	0.09%
Forest	1114.31	57.01%
Shrubland	69.81	3.57%
Grassland	102.74	5.26%
Agriculture	239.86	12.27%
Wetlands	284.09	14.53%
Total	1954.52	100.00%

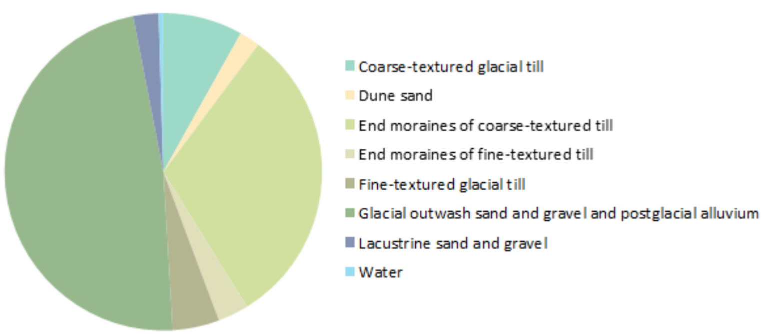


Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

25, PERE MARQUETTE RIVER WATERSHED

Surficial Geology



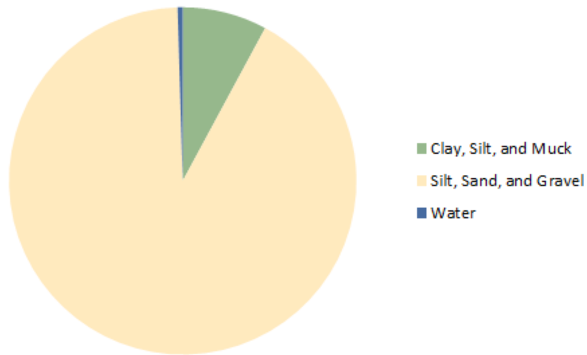


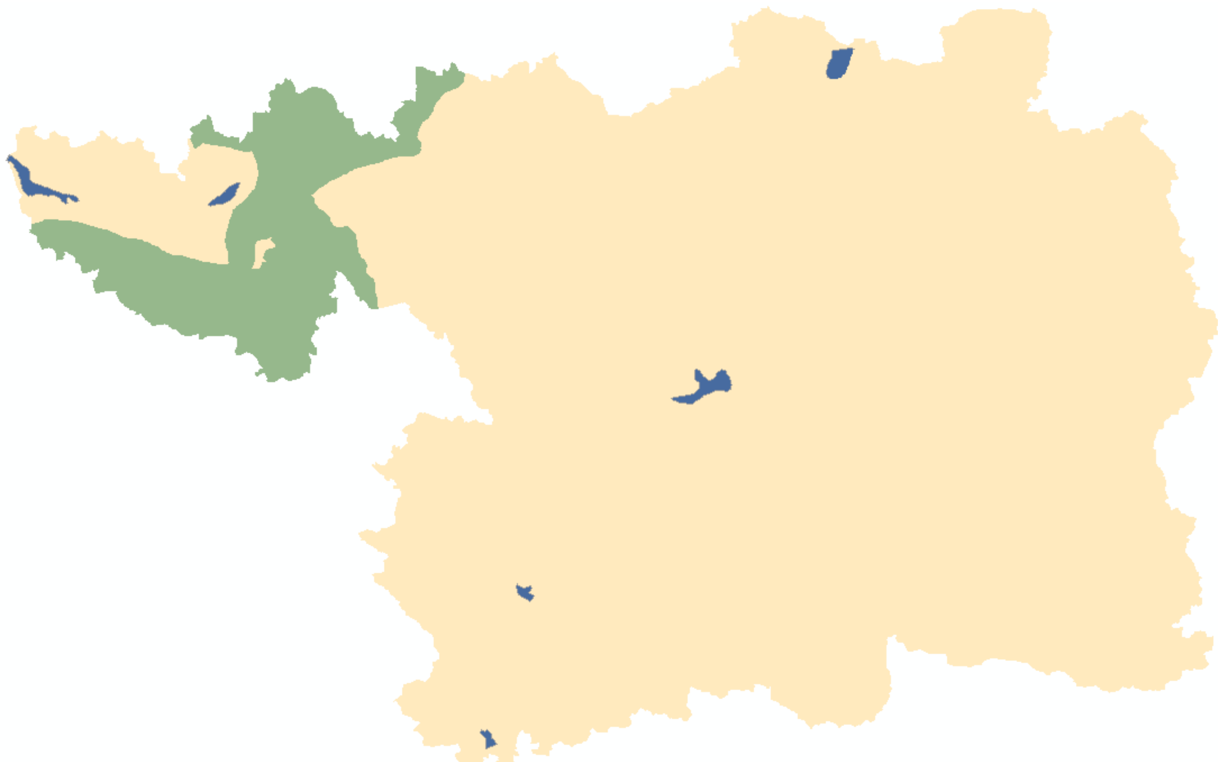
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	158.52	8.11%
Dune sand	40.84	2.09%
End moraines of coarse-textured till	605.48	30.98%
End moraines of fine-textured till	61.14	3.13%
Fine-textured glacial till	92.78	4.75%
Glacial outwash sand and gravel and postglacial alluvium	936.01	47.89%
Lacustrine sand and gravel	50.47	2.58%
Water	9.27	0.47%
Total Watershed Area	1954.52	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

25, PERE MARQUETTE RIVER WATERSHED

Surficial Geology (Simplified)



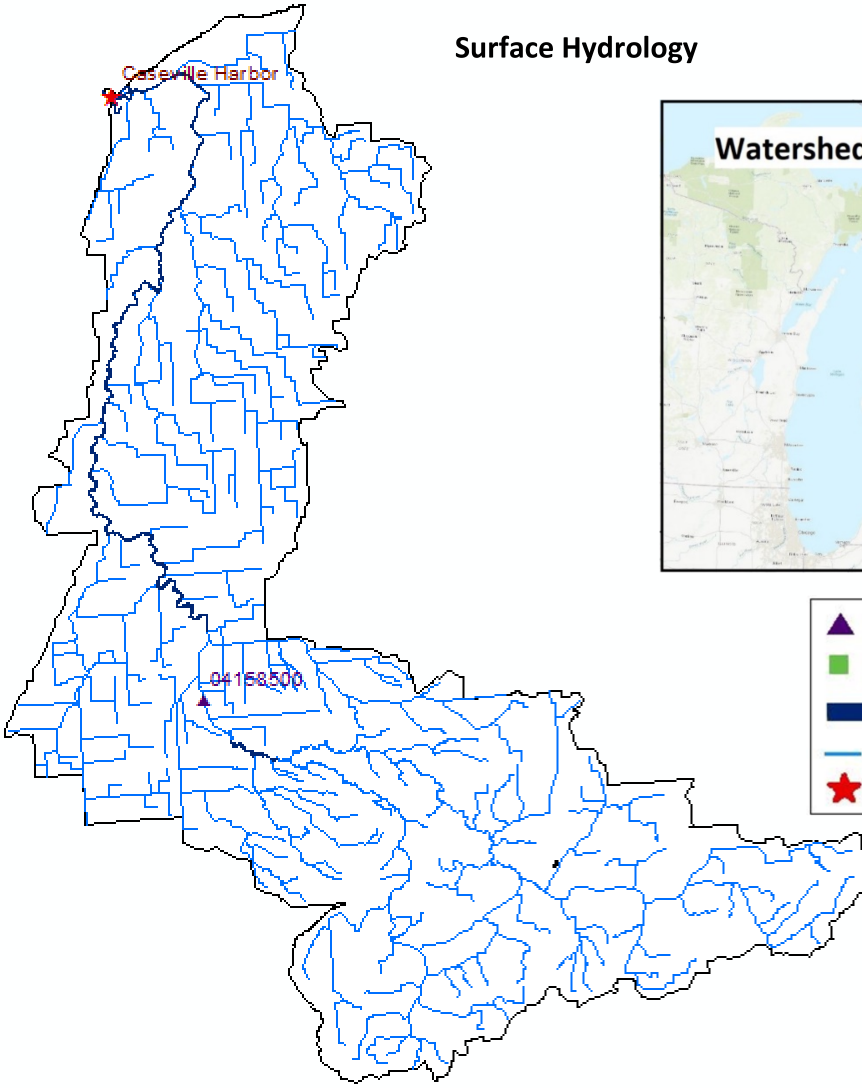


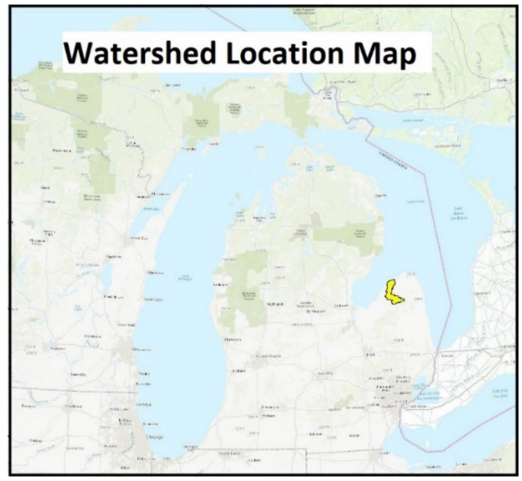
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*153.92*	7.88%
Silt, Sand, and Gravel	1791.32	91.65%
Water	9.27	0.47%
Total Watershed Area	1954.52	100.00%

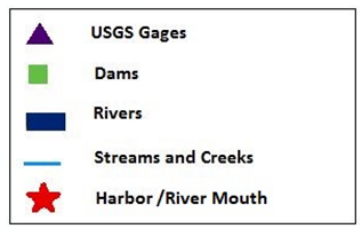
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

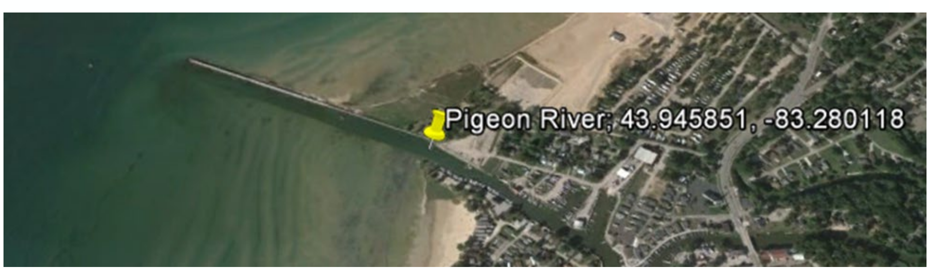
APPENDIX DD. PIGEON RIVER WATERSHED (26)

Surface Hydrology







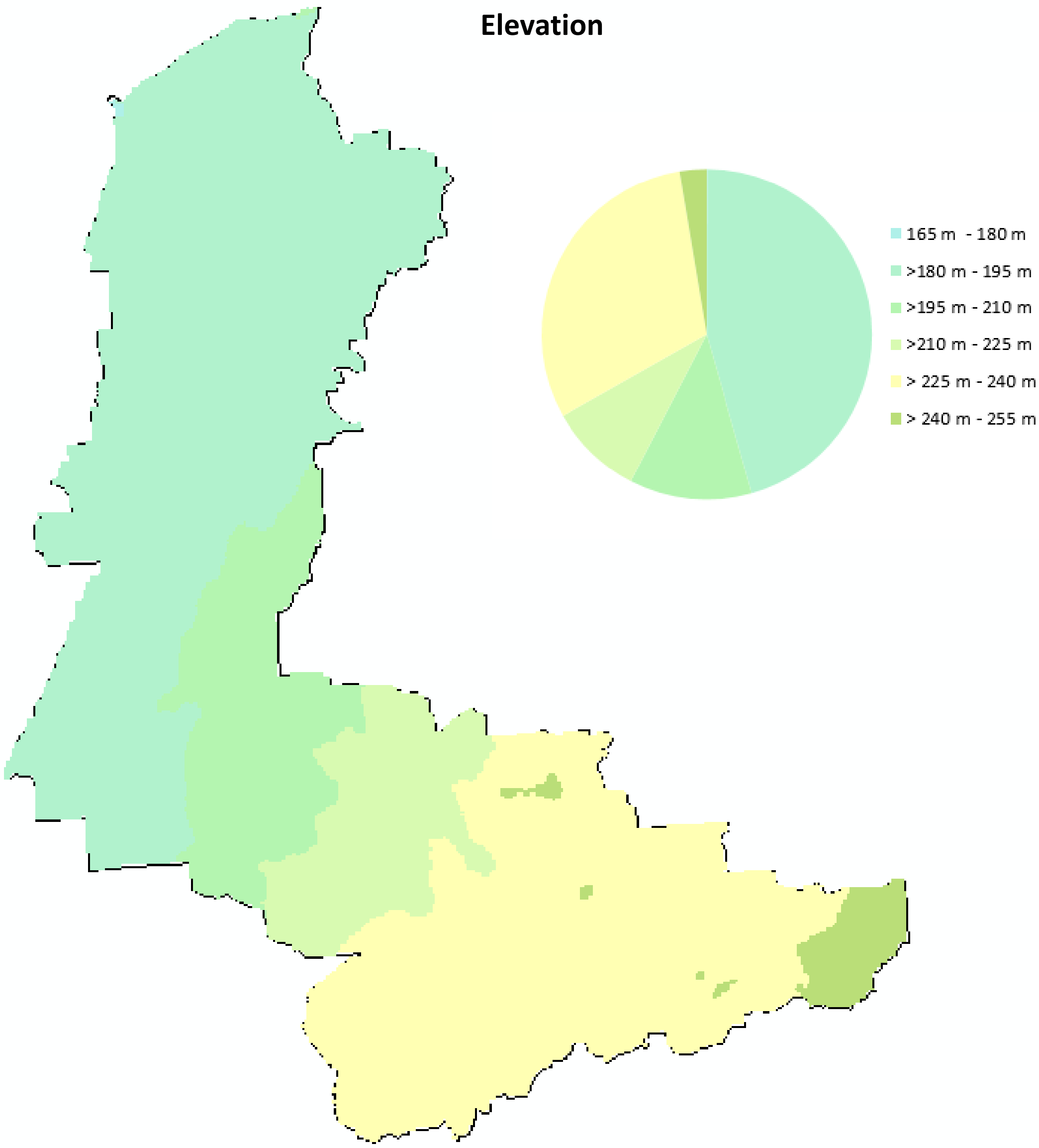


USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4158500	PIGEON RIVER NEAR OWENDALE, MI	-83.246064	43.763627	
Number of Active USGS Stream Gage's in Drainage Area (2009)				0

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

26, PIGEON RIVER WATERSHED

Elevation



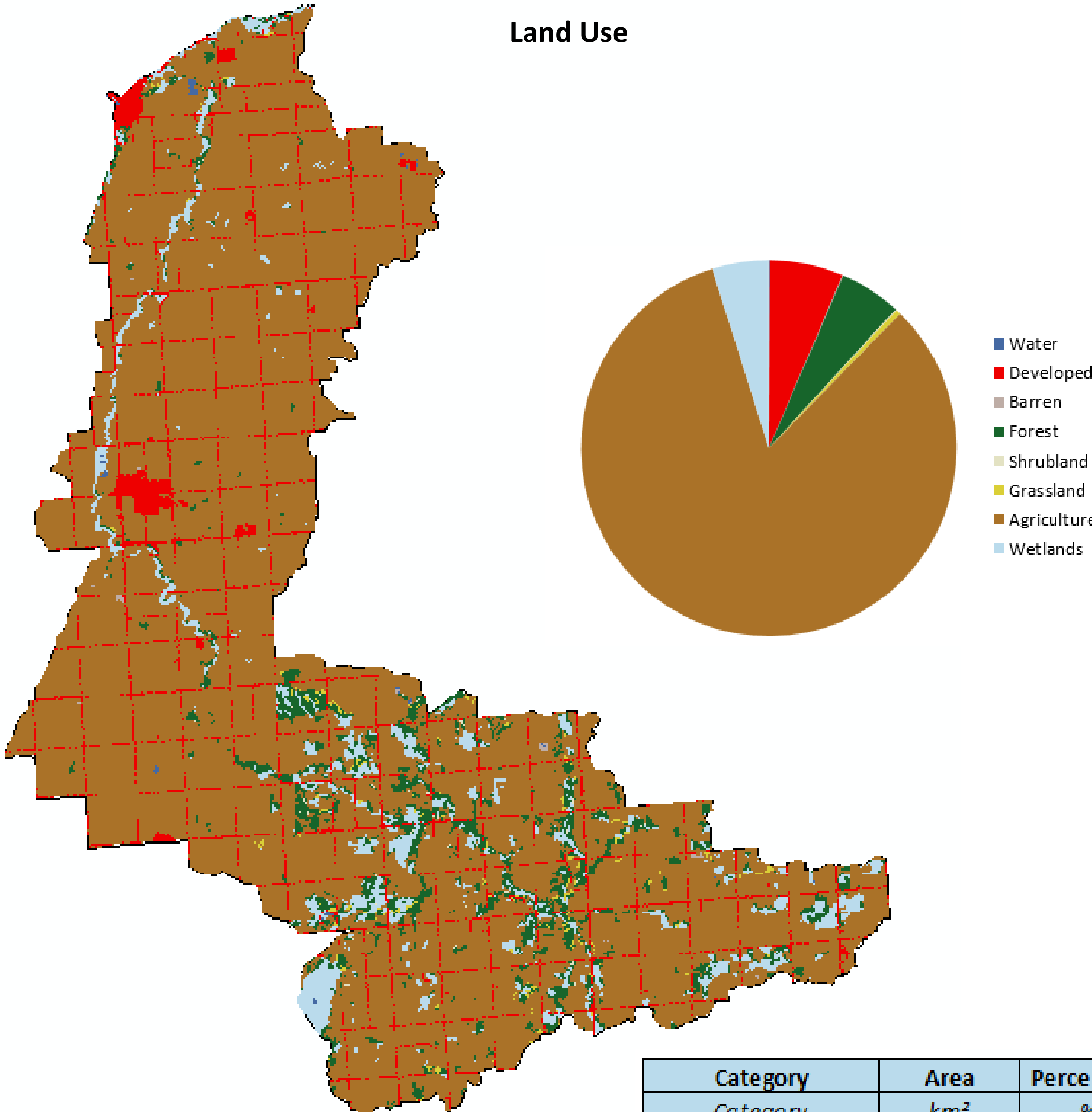
Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	0.13	0.03%
>180 m - 195 m	171.26	45.55%
>195 m - 210 m	45.14	12.01%
>210 m - 225 m	34.65	9.22%
>225 m - 240 m	114.91	30.56%
>240 m - 255 m	9.91	2.64%
Size of Drainage Area	376.00	100.00%

Pigeon Watershed		
Elevation Statistics		
Size of Drainage Area	**376.00**	***km²***
Maximum	251.00	*m*
Minimum	177.00	*m*
Average	205.67	*m*
Standard Deviation	19.43	*m*

All Elevation Measurements with Respect to North American Datum 1983

26, PIGEON RIVER WATERSHED

Land Use



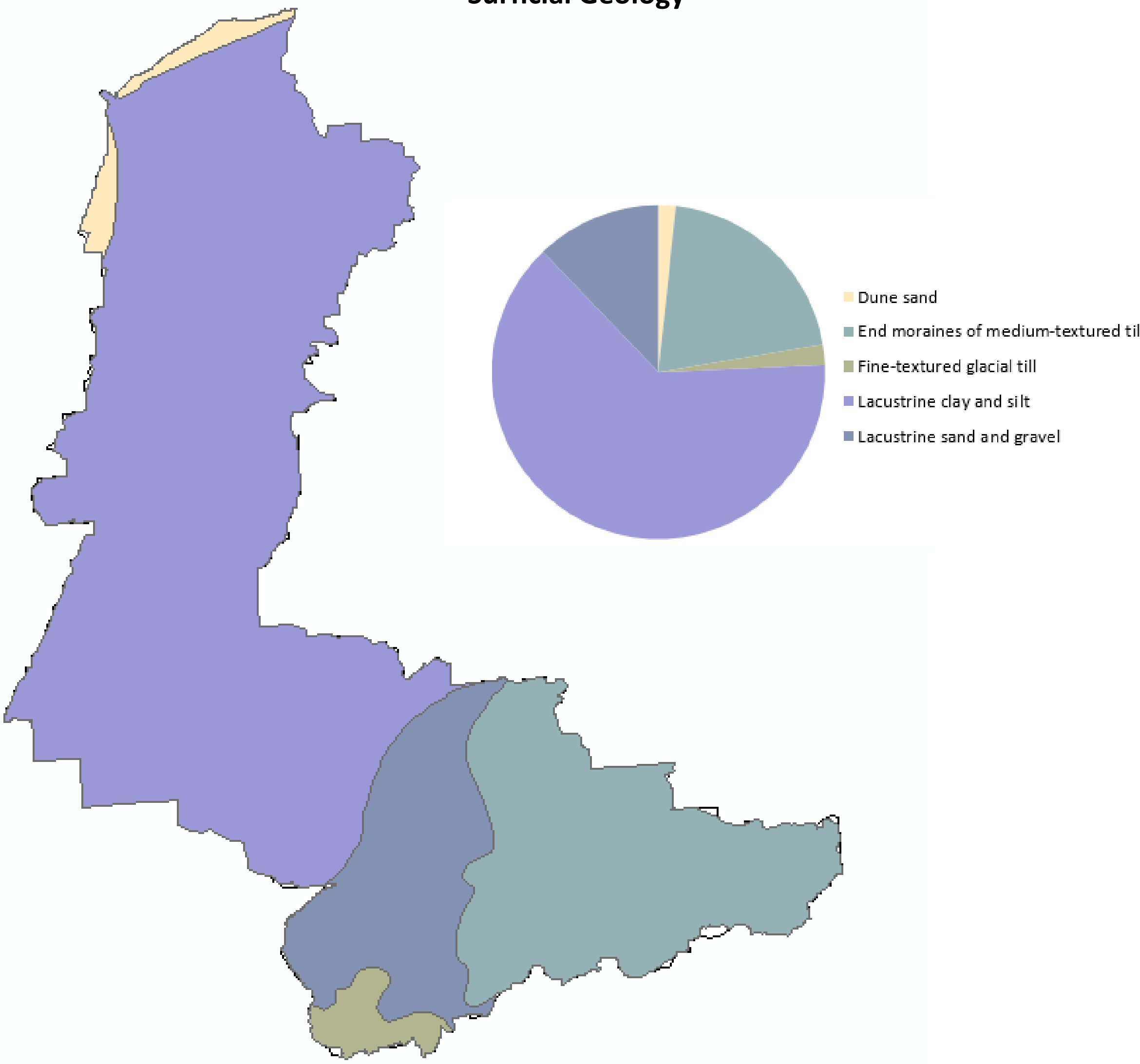
Category	Area	Percentage
Category	*km²*	*%*
Water	0.38	0.10%
Developed	23.75	6.32%
Barren	0.22	0.06%
Forest	20.02	5.33%
Shrubland	0.29	0.08%
Herbaceous	1.61	0.43%
Agriculture	311.36	82.81%
Wetlands	18.35	4.88%
Total	376.00	100.00%

MDEQ Curve Number
80.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

26, PIGEON RIVER WATERSHED

Surficial Geology

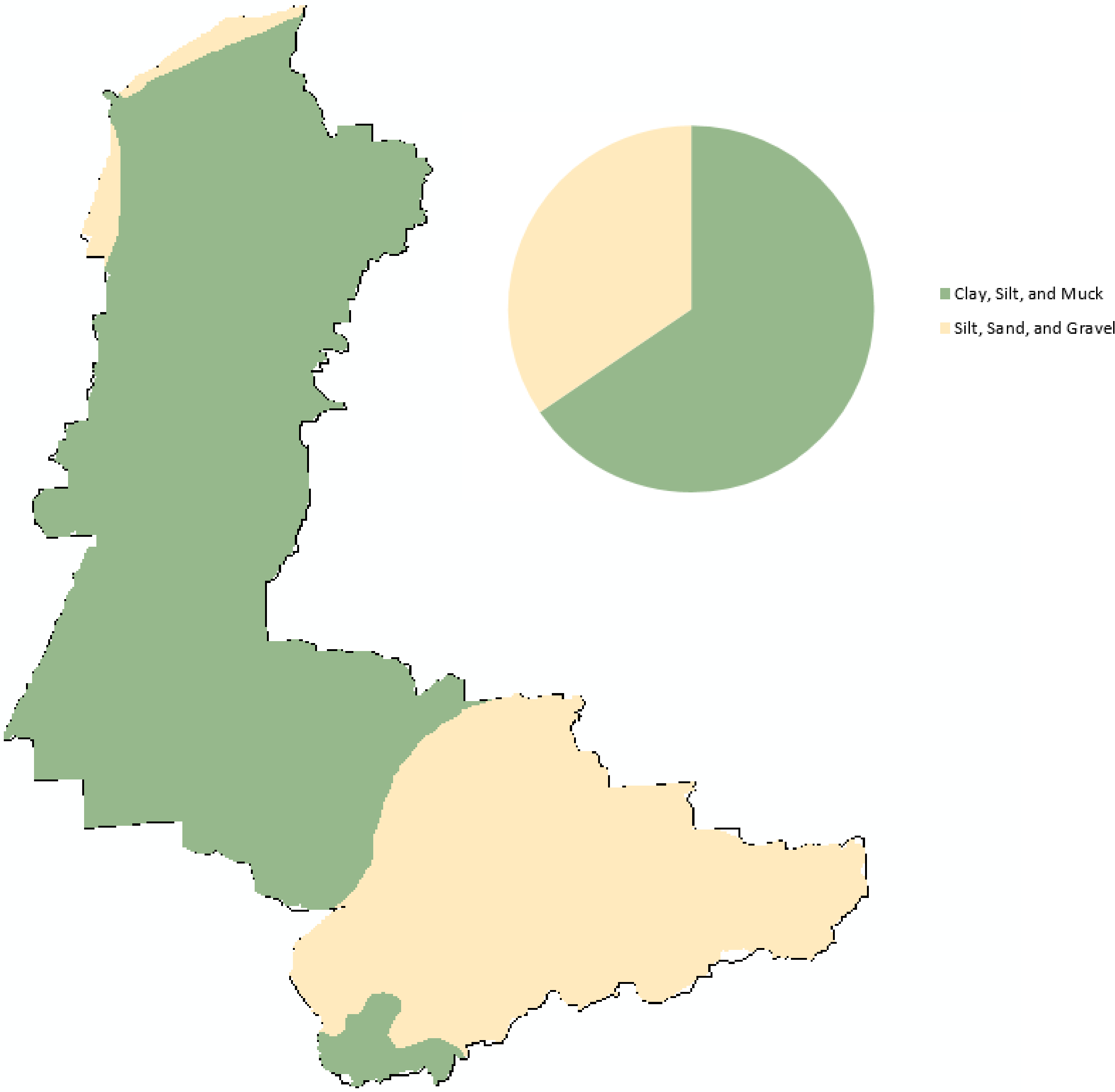


Category	Area	Percentage
Category	*km²*	*%*
Dune sand	6.30	1.67%
End moraines of medium-textured till	77.71	20.67%
Fine-textured glacial till	7.34	1.95%
Lacustrine clay and silt	238.91	63.54%
Lacustrine sand and gravel	45.74	12.17%
Total Watershed Area	376.00	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

26, PIGEON RIVER WATERSHED

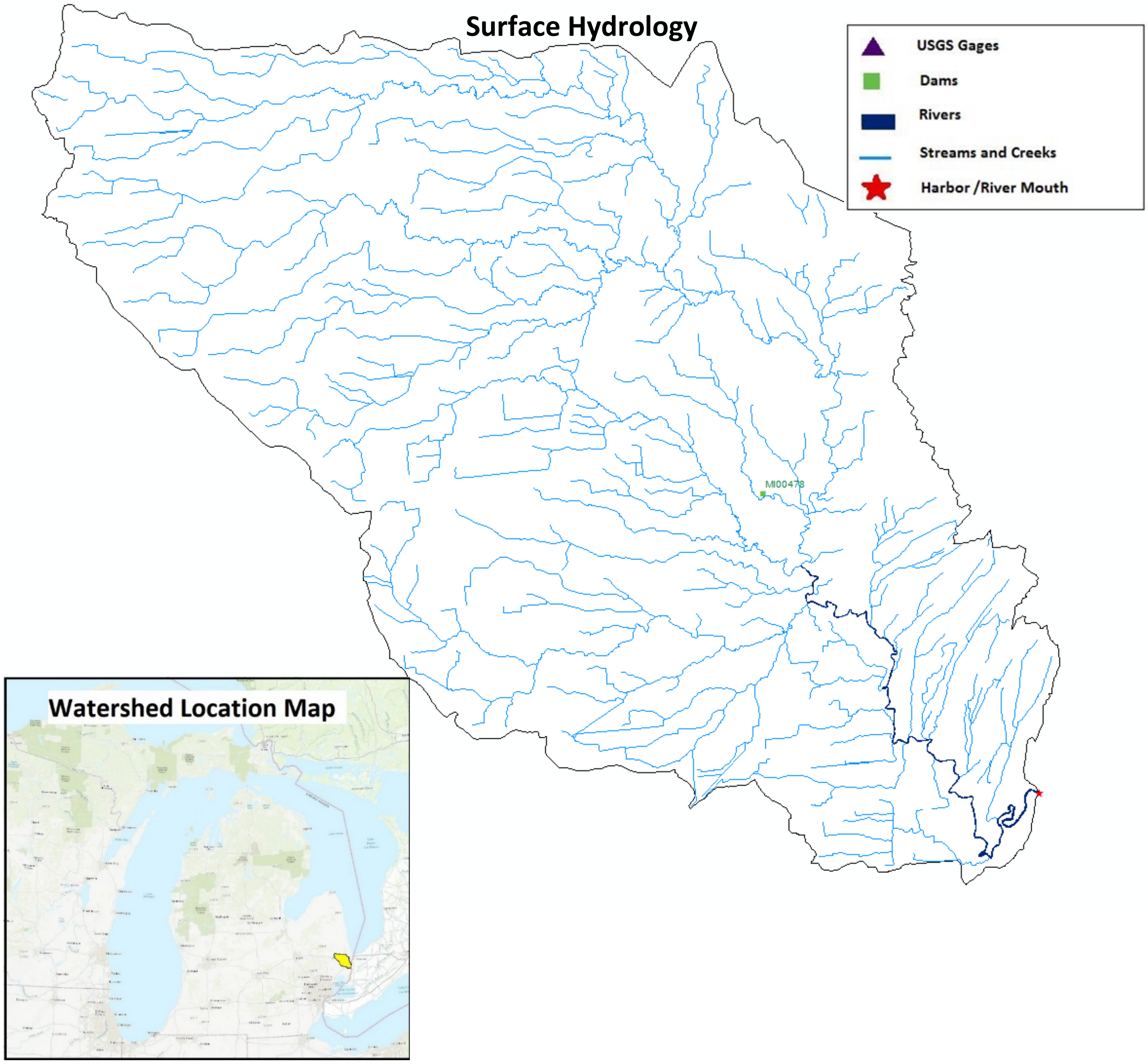
Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	246.25	65.49%
Silt, Sand, and Gravel	129.75	34.51%
Total Watershed Area	376.00	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX EE. PINE RIVER WATERSHED (27)

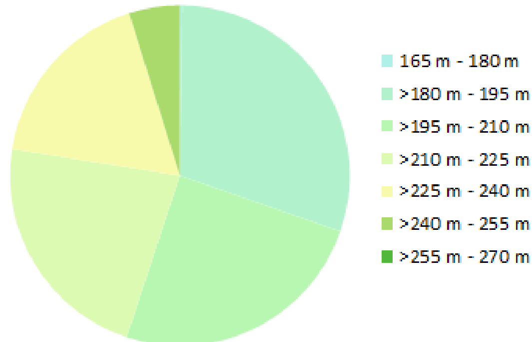


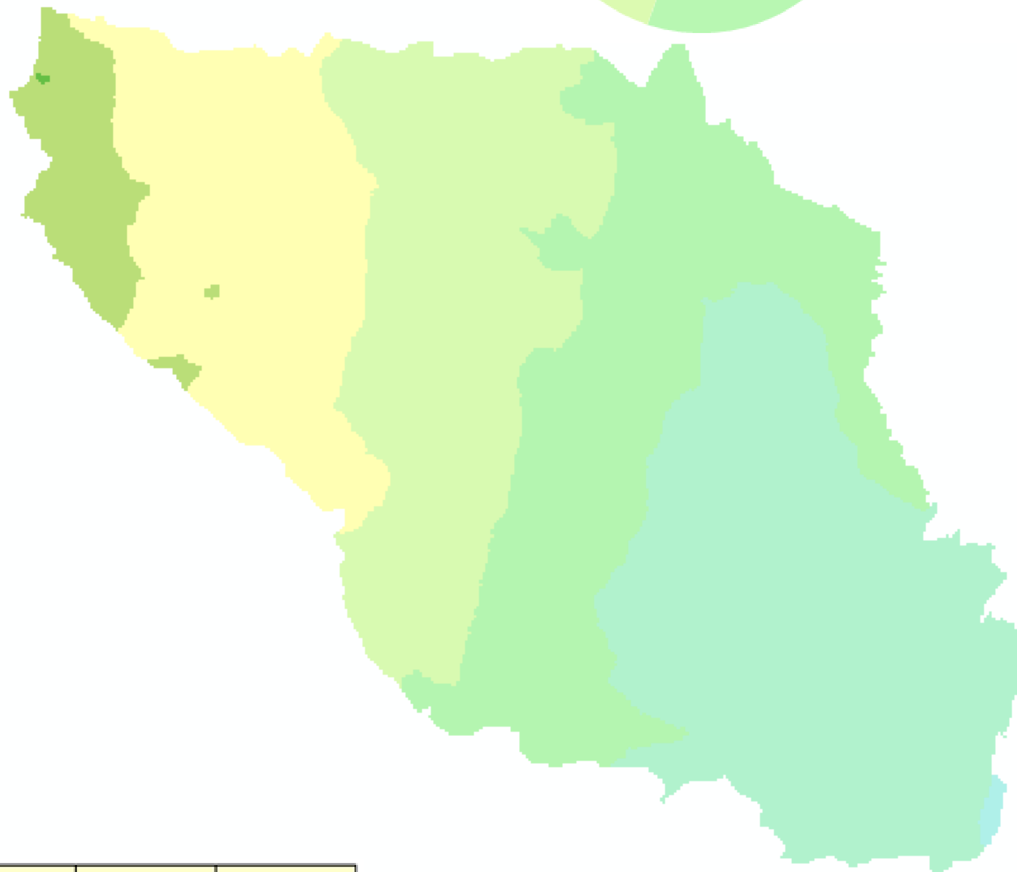
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00478	Duffy Pond Dam	-82.585000	42.906670

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

27, PINE RIVER WATERSHED

Elevation





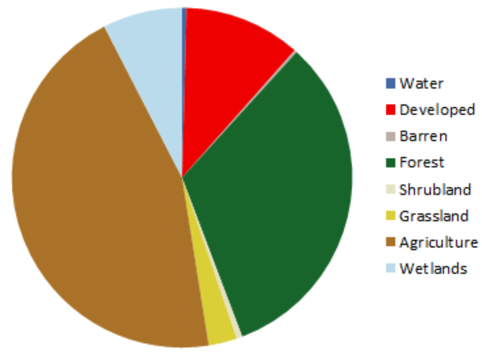
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.10	0.22%
>180 m - 195 m	151.68	30.09%
>195 m - 210 m	124.90	24.78%
>210 m - 225 m	112.98	22.41%
>225 m - 240 m	89.01	17.66%
>240 m - 255 m	24.30	4.82%
>255 m - 270 m	0.10	0.02%
Size of Drainage Area	504.07	100.00%

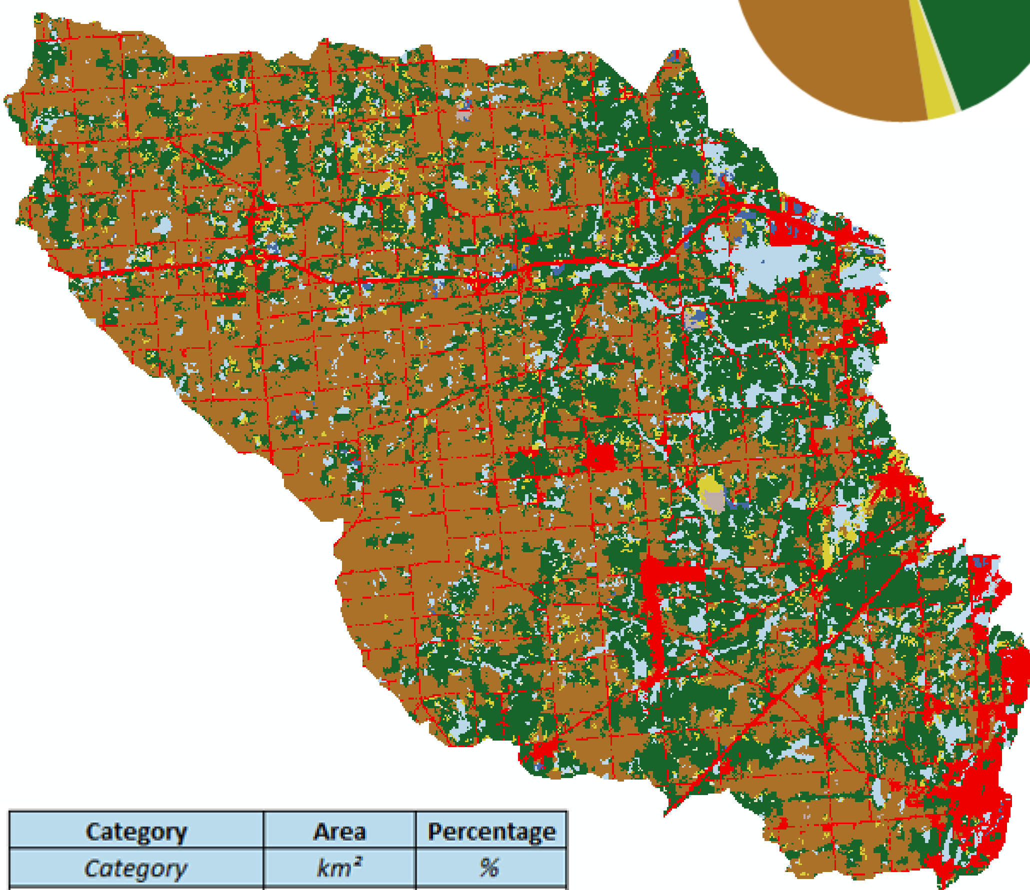
Pine Watershed		
Elevation Statistics		
Size of Drainage Area	**504.07**	***km²***
Maximum	256.00	*m*
Minimum	177.00	*m*
Average	209.51	*m*
Standard Deviation	17.87	*m*

All Elevation Measurements with Respect to North American Datum 1983

27, PINE RIVER WATERSHED

Land Use





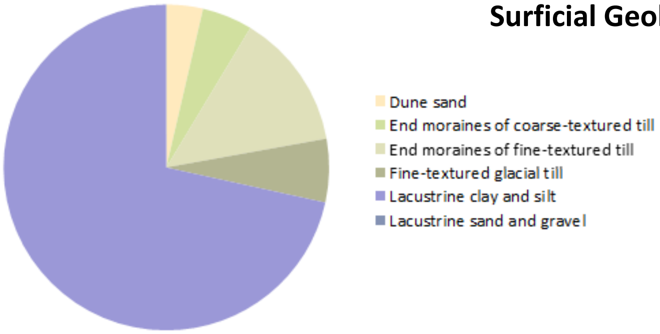
Category	Area	Percentage
Category	*km²*	*%*
Water	2.14	0.42%
Developed	55.87	11.08%
Barren	1.26	0.25%
Forest	163.77	32.49%
Shrubland	2.75	0.55%
Grassland	13.60	2.70%
Agriculture	226.63	44.96%
Wetlands	38.06	7.55%
Total	504.07	100.00%

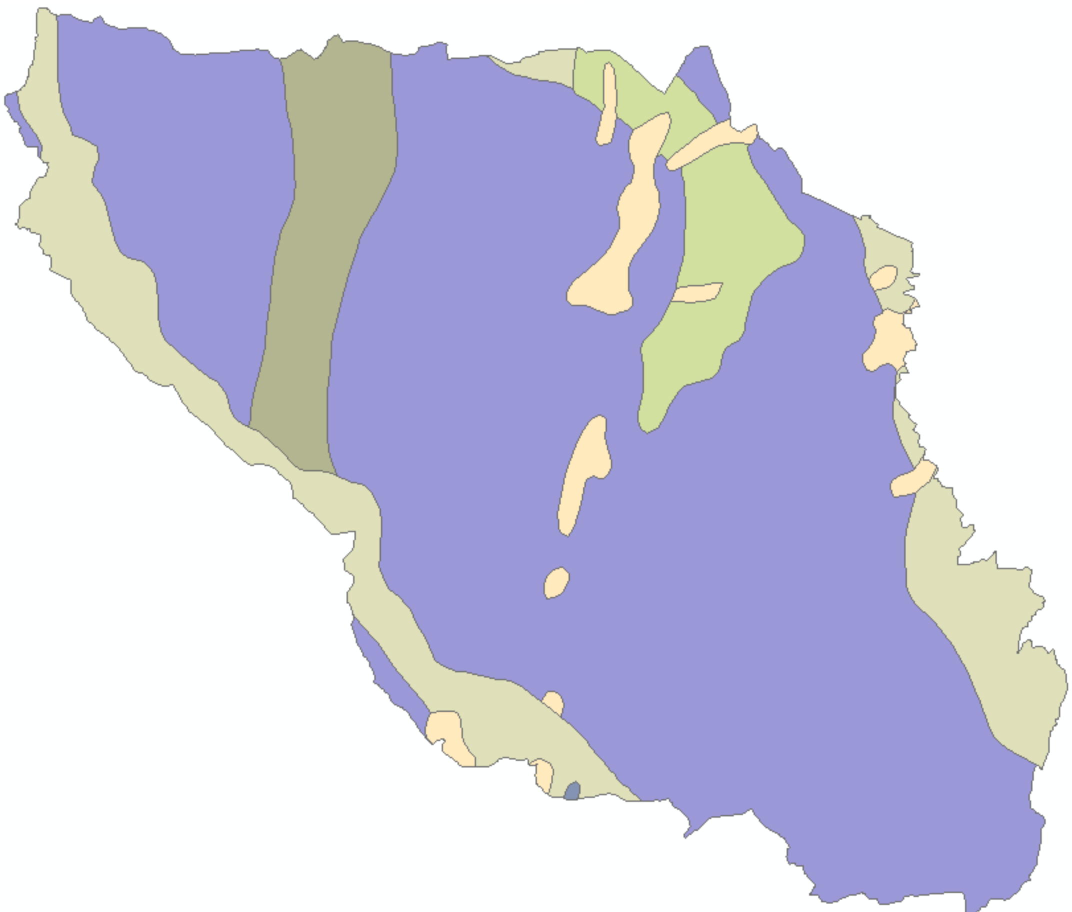
EGLE Runoff Curve Number
77.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

27, PINE RIVER WATERSHED

Surficial Geology



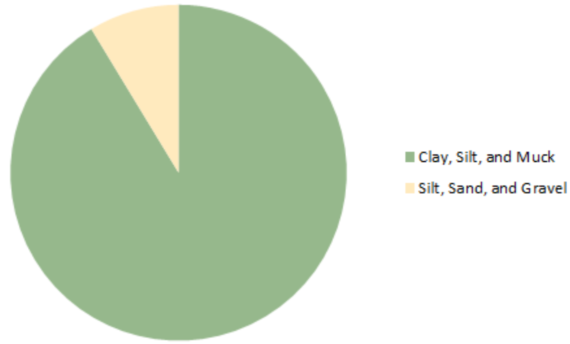


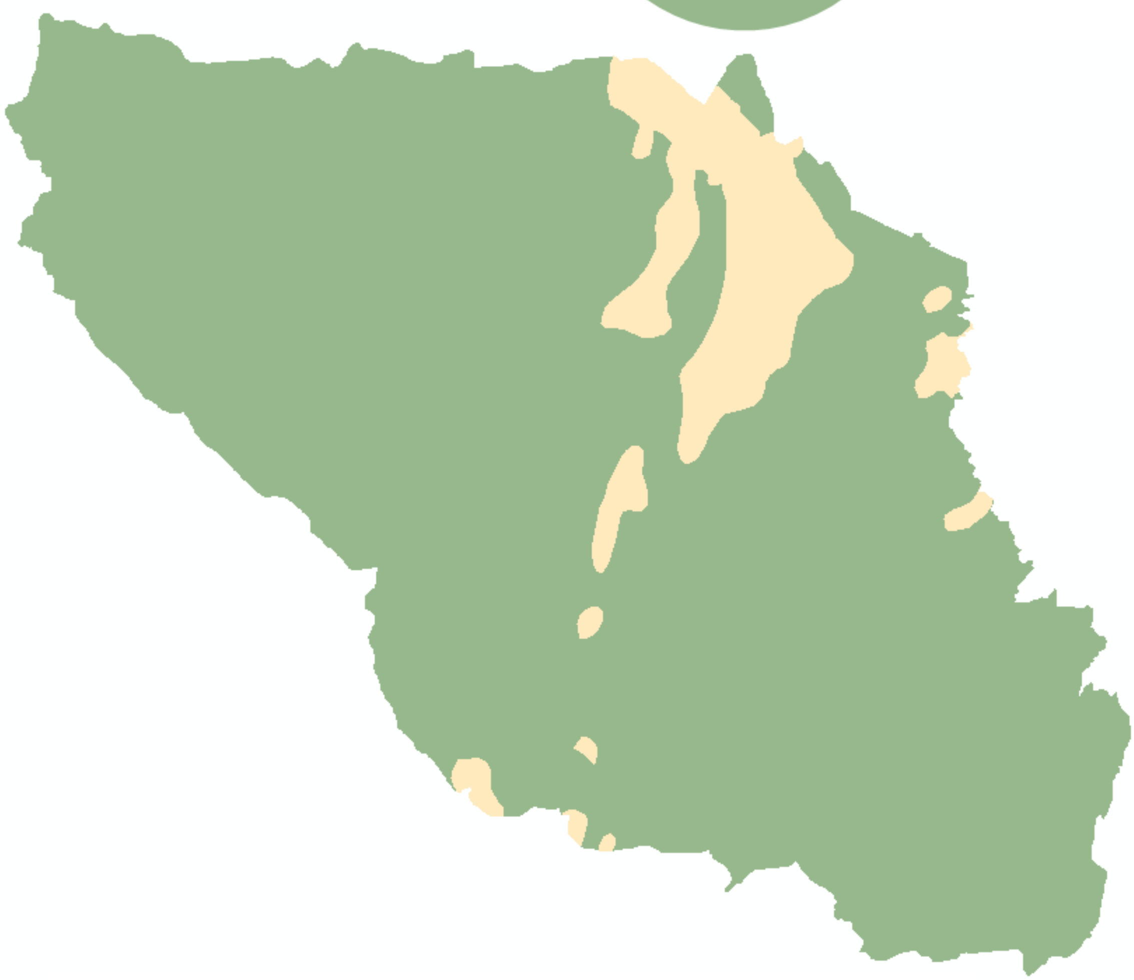
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	18.30	3.63%
End moraines of coarse-textured till	25.24	5.01%
End moraines of fine-textured till	68.19	13.53%
Fine-textured glacial till	31.70	6.29%
Lacustrine clay and silt	360.46	71.51%
Lacustrine sand and gravel	0.19	0.04%
Total Watershed Area	504.07	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

27, PINE RIVER WATERSHED

Surficial Geology (Simplified)



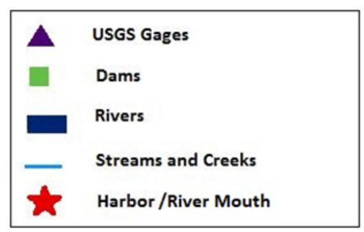


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*460.35*	91.32%
Silt, Sand, and Gravel	43.73	8.68%
Total Watershed Area	504.07	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

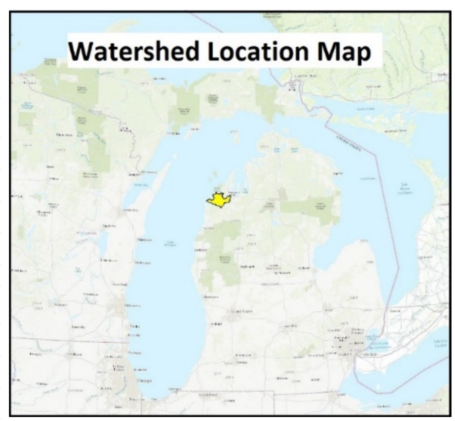
APPENDIX FF. PLATTE RIVER WATERSHED (28)

Surface Hydrology



USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00333	Little Platte Lake Control Dam	-86.056660	44.690000
MI00762	Lake Dubonnet Dam	-85.800000	44.685000

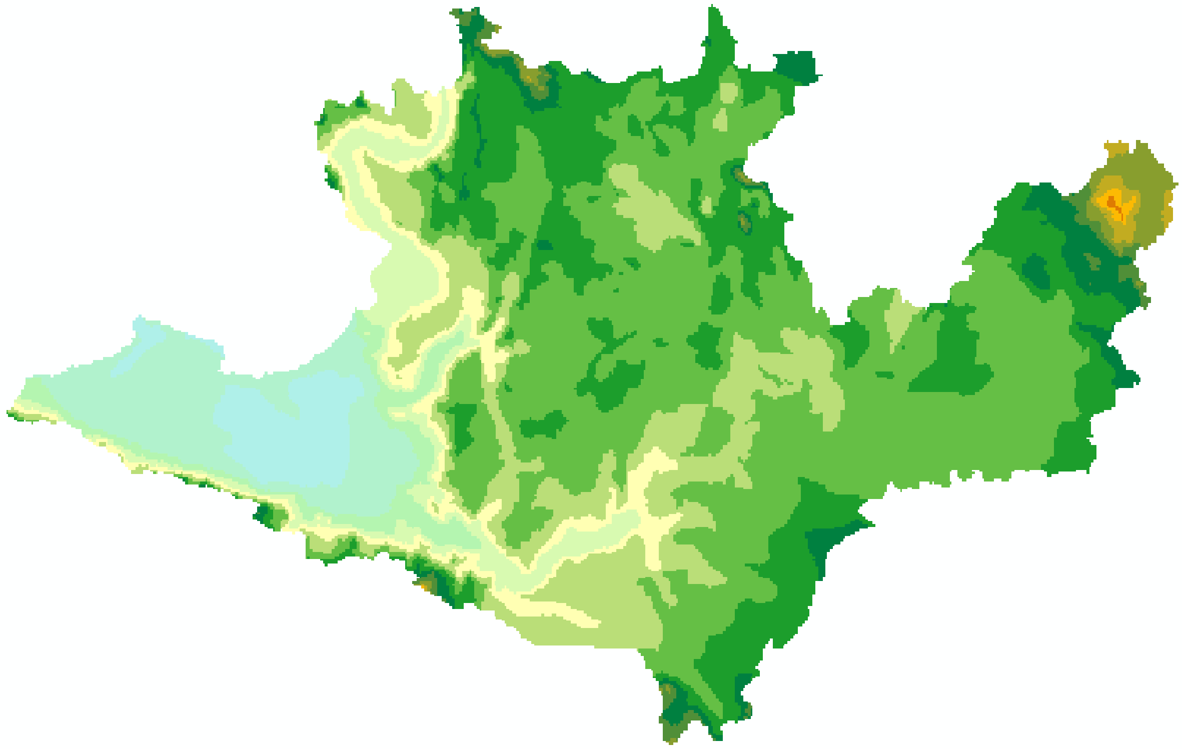
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4126740	PLATTE RIVER AT HONOR, MI	-86.034812	44.668055	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

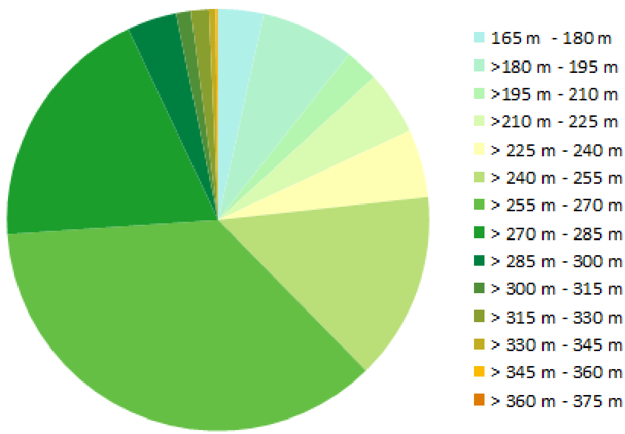


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

28, PLATTE RIVER WATERSHED

Elevation





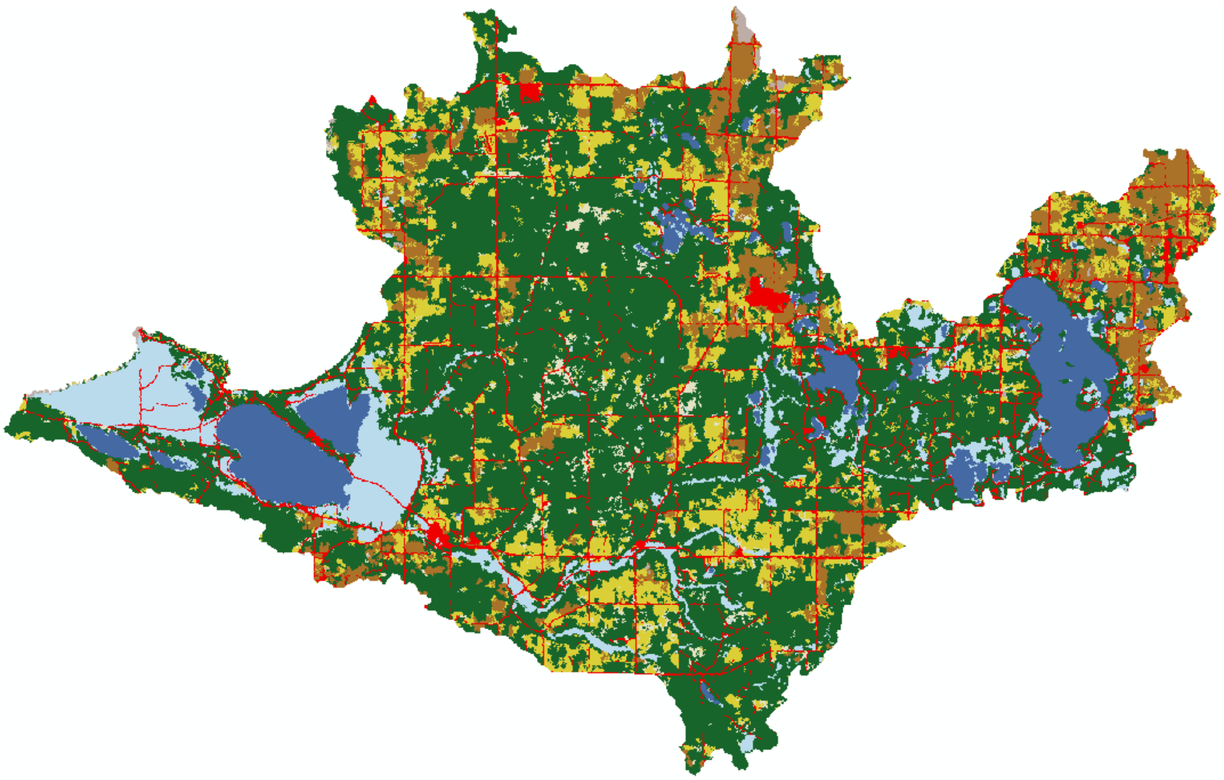
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	17.26	3.46%
>180 m - 195 m	35.72	7.17%
>195 m - 210 m	12.73	2.55%
>210 m - 225 m	24.20	4.86%
>225 m - 240 m	26.05	5.23%
>240 m - 255 m	71.74	14.40%
>255 m - 270 m	180.64	36.24%
>270 m - 285 m	95.13	19.09%
>285 m - 300 m	18.93	3.80%
>300 m - 315 m	5.61	1.13%
>315 m -330 m	6.82	1.37%
>330 m - 345 m	2.63	0.53%
>345 m - 360 m	0.75	0.15%
>360 m - 375 m	0.18	0.04%
Size of Drainage Area	498.40	100.00%

Platte Watershed		
Elevation Statistics		
Size of Drainage Area	**498.40**	***km²***
Maximum	365.00	*m*
Minimum	176.00	*m*
Average	251.16	*m*
Standard Deviation	31.33	*m*

All Elevation Measurements with Respect to North American Datum 1983

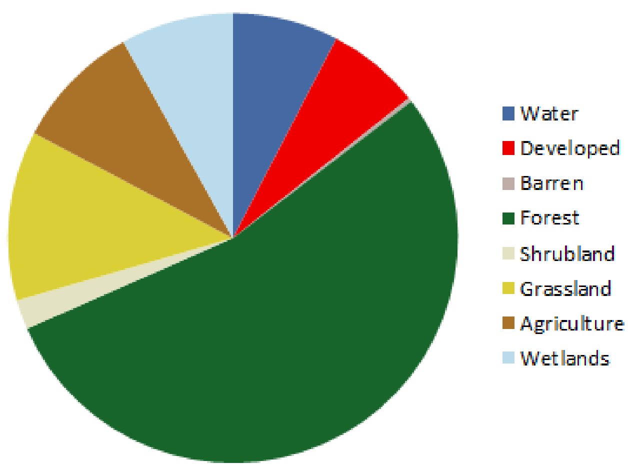
28, PLATTE RIVER WATERSHED

Land Use



EGLE Runoff Curve Number
54.1

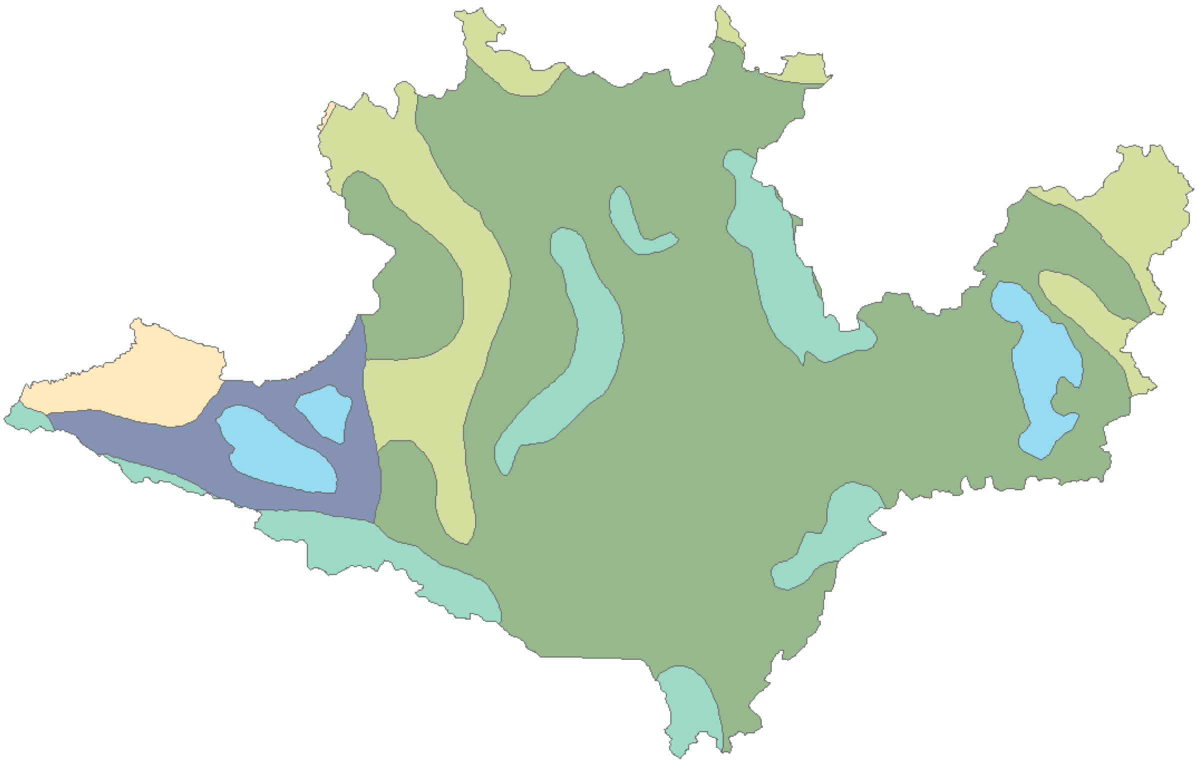
Category	Area	Percentage
Category	*km²*	*%*
Water	37.91	7.61%
Developed	33.35	6.69%
Barren	1.45	0.29%
Forest	268.23	53.82%
Shrubland	10.58	2.12%
Grassland	60.85	12.21%
Agriculture	45.69	9.17%
Wetlands	40.34	8.09%
Total	498.40	100.00%

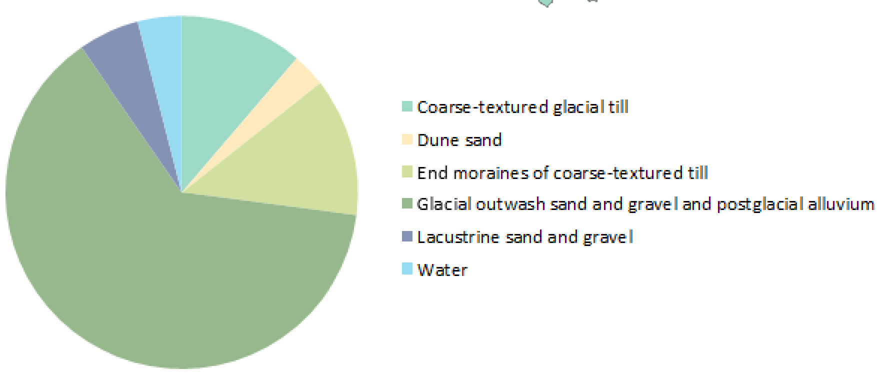


Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

28, PLATTE RIVER WATERSHED

Surficial Geology



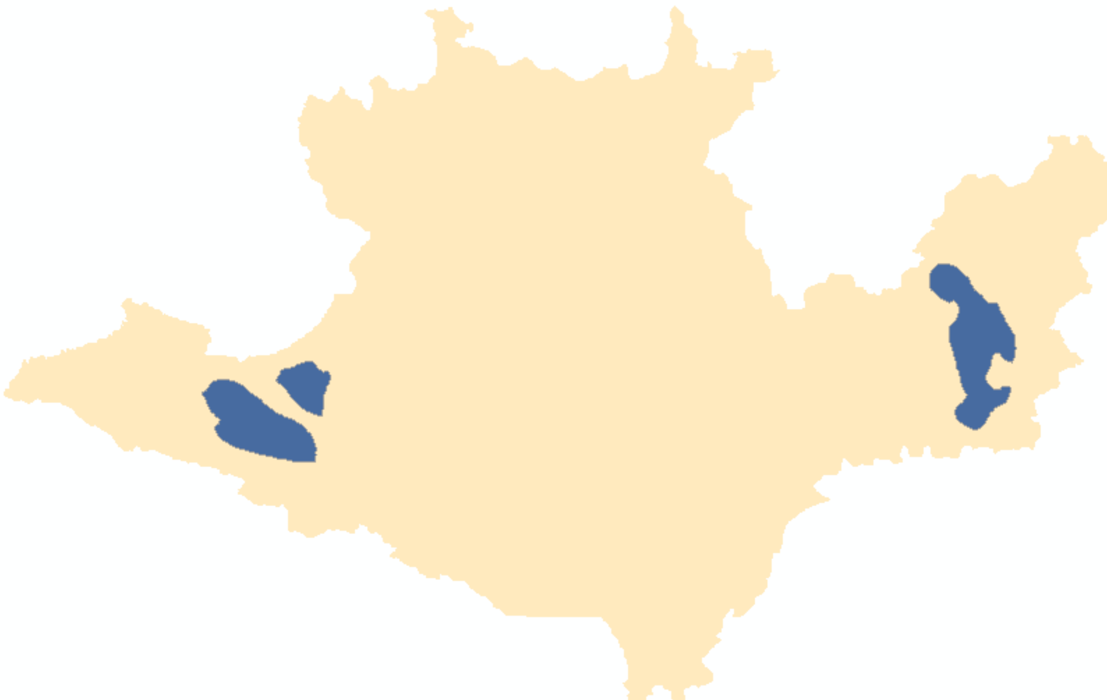


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	56.15	11.27%
Dune sand	15.34	3.08%
End moraines of coarse-textured till	63.45	12.73%
Glacial outwash sand and gravel and postglacial alluvium	315.38	63.28%
Lacustrine sand and gravel	28.02	5.62%
Water	20.05	4.02%
Total Watershed Area	498.40	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

28, PLATTE RIVER WATERSHED

Surficial Geology (Simplified)

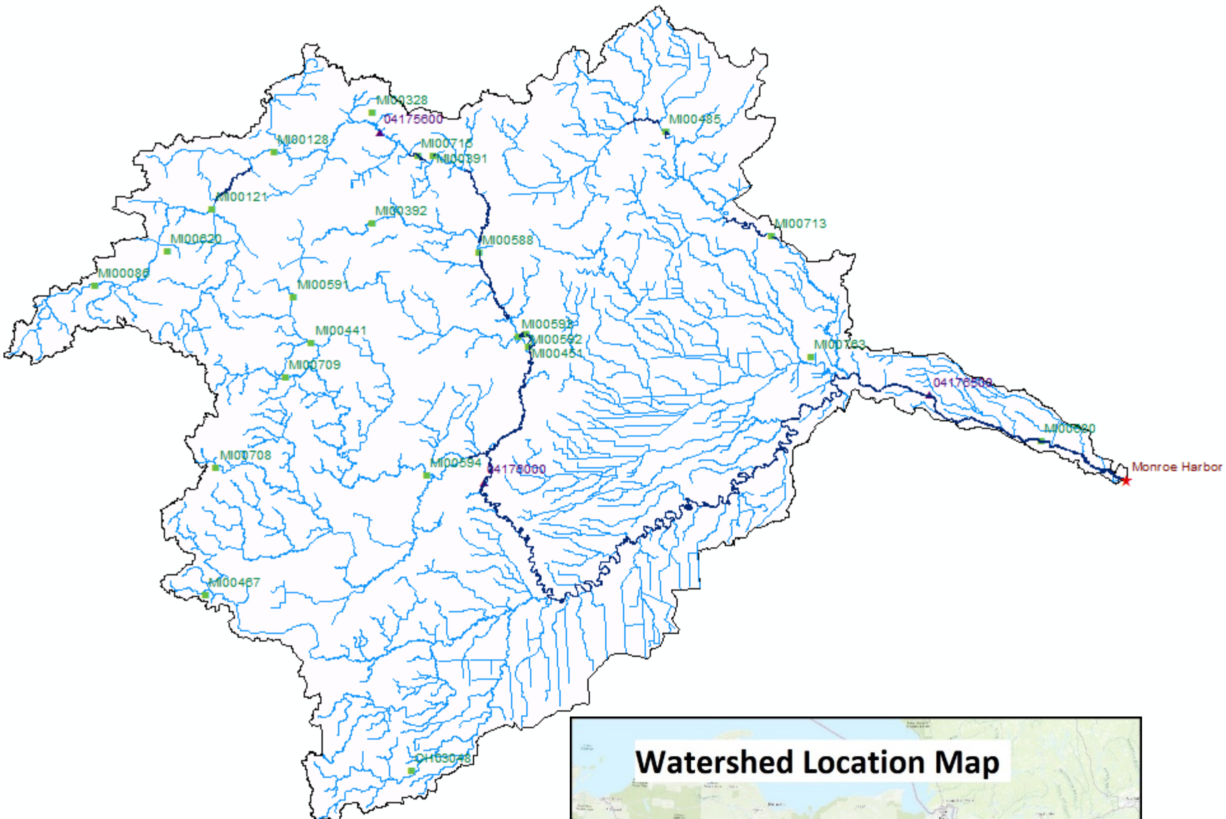


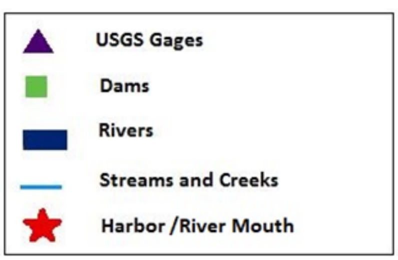
Category	Area	Percentage
Category	*km²*	*%*
Silt, Sand, and Gravel	478.34	95.98%
Water	20.05	4.02%
Total Watershed Area	498.40	100.00%

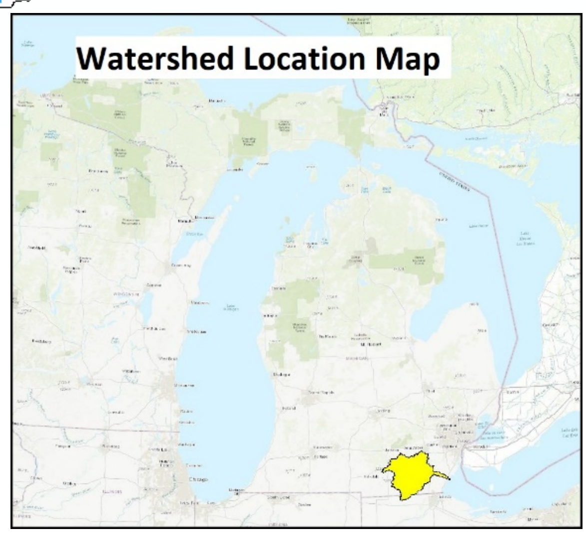
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX GG. RAISIN RIVER WATERSHED (29)

Surface Hydrology







29, RAISIN RIVER WATERSHED

Dam Information and USGS Streamgages

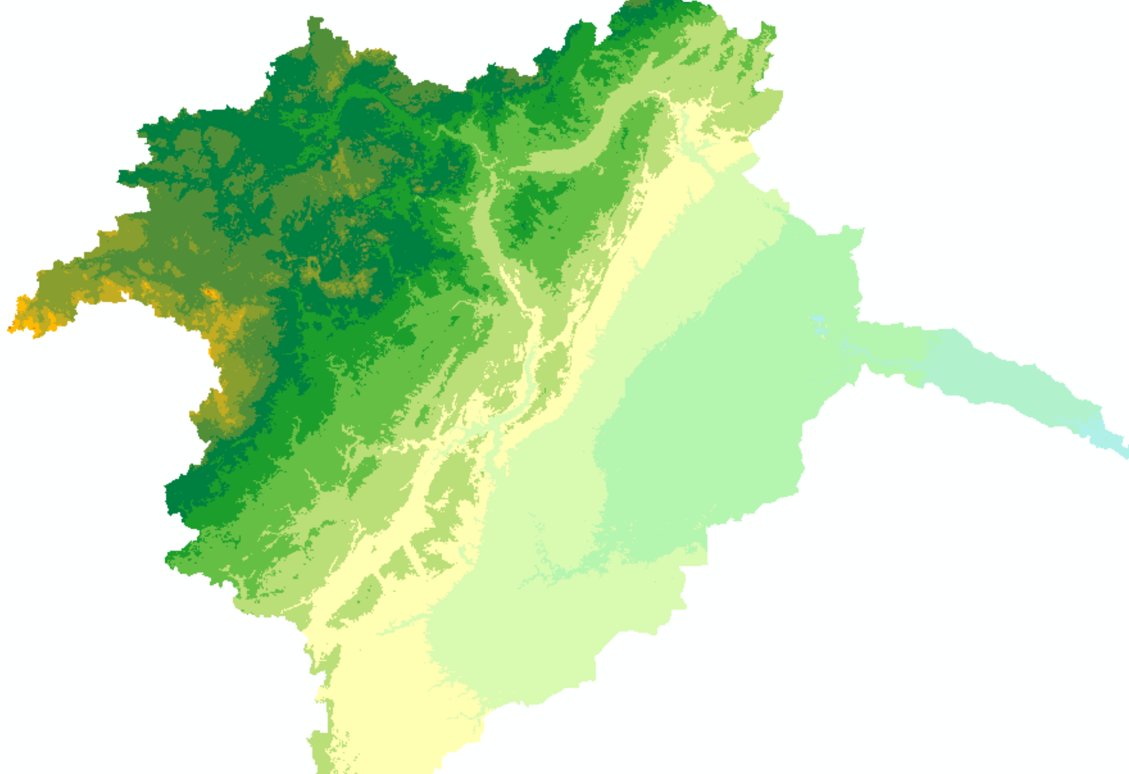
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
OH03048	LYONS WWT LAGOON	-84.060000	41.690000
MI00121	Brooklyn Dam	-84.246670	42.113330
MI00128	Norvell Dam	-84.183330	42.155000
MI00328	Sharon Mills Dam	-84.083340	42.183330
MI00391	Ford Manchester Dam	-84.023600	42.149600
MI00392	Iron Lake Dam	-84.086670	42.100000
MI00441	Loch Erin Dam	-84.150000	42.011670
MI00451	Globe Mill Dam	-83.931950	42.005000
MI00467	Lake Hudson Dam	-84.261670	41.825000
MI00485	Saline River Dam	-83.788330	42.163330
MI00588	Atles Mill Dam	-83.980000	42.076670
MI00591	Springville Mill Dam	-84.166660	42.046670
MI00592	Standish Dam	-83.933610	42.015000
MI00593	Tecumseh Dam	-83.942220	42.013330
MI00594	Lake Adrian Dam	-84.037530	41.910530
MI00620	Lake Columbia Dam	-84.292680	42.083110
MI00680	Waterloo Dam	-83.420370	41.923610
MI00708	Sparrow Dam	-84.248340	41.920000
MI00709	Fry Lake Dam	-84.176670	41.986670
MI00713	Milan Dam	-83.685000	42.083330
MI00715	Manchester Mill Dam	-84.038600	42.150100
MI00763	Macon River Dam	-83.648330	41.991660
MI00086	Lake Somerset Dam	-84.366670	42.058330

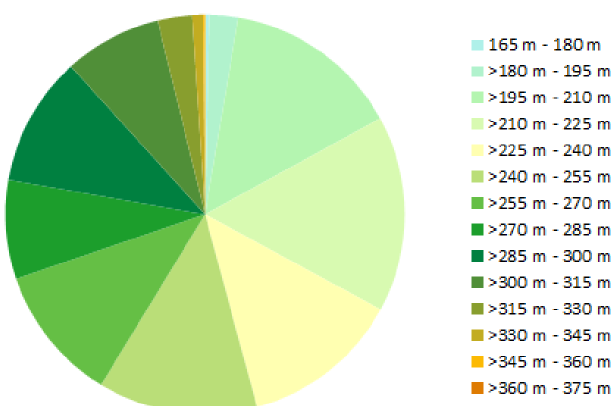
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4175600	RIVER RAISIN NEAR MANCHESTER, MI	-84.076058	42.168095	yes
4176000	RIVER RAISIN NEAR ADRIAN, MI	-83.980499	41.904214	yes
4176500	RIVER RAISIN NEAR MONROE, MI	-83.531046	41.960601	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				3

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

29, RAISIN RIVER WATERSHED

Elevation





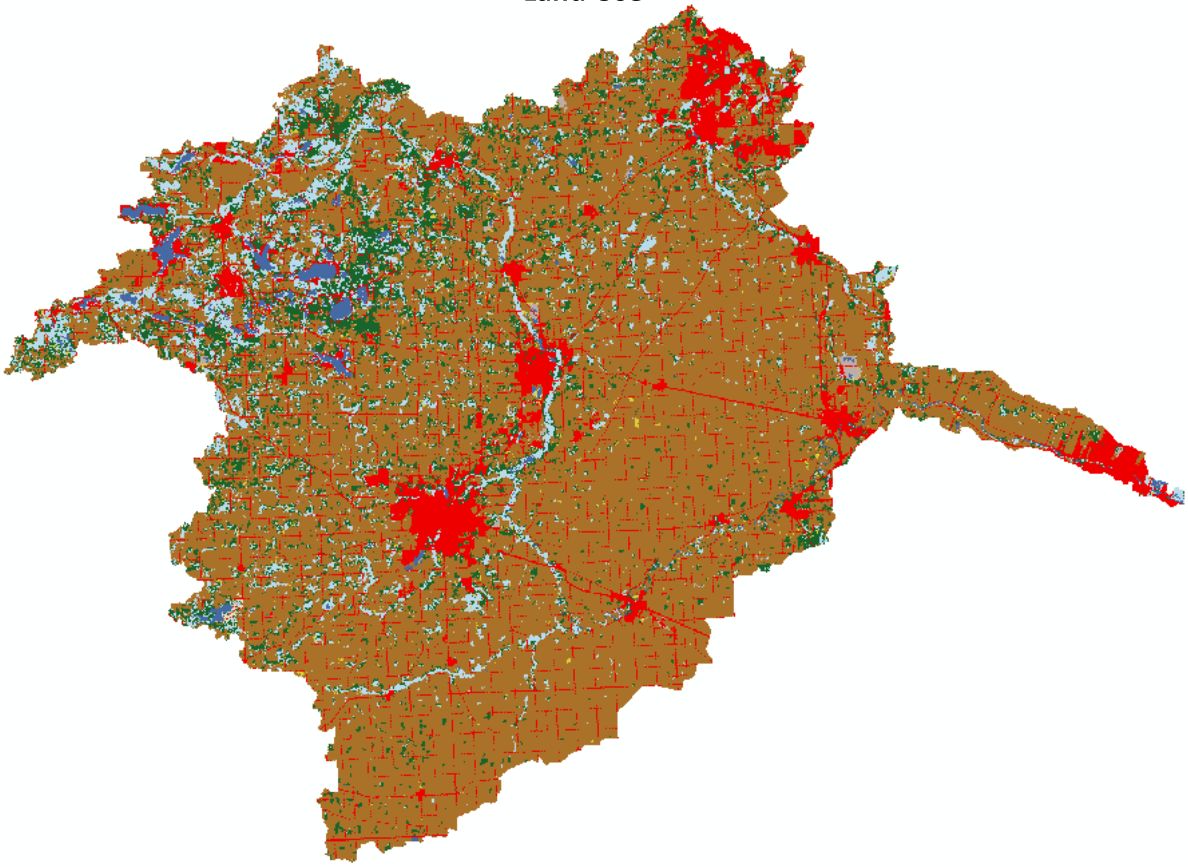
Raisin Watershed		
Elevation Statistics		
Size of Drainage Area	**2753.29**	***km²***
Maximum	373.45	*m*
Minimum	169.22	*m*
Average	249.79	*m*
Standard Deviation	37.07	*m*

Category	**Area**	**Percentage**
Category	*km²*	*%*
165 m - 180 m	9.60	0.35%
>180 m - 195 m	63.79	2.32%
>195 m - 210 m	395.26	14.36%
>210 m - 225 m	437.24	15.88%
>225 m - 240 m	355.46	12.91%
>240 m - 255 m	355.30	12.90%
>255 m - 270 m	304.47	11.06%
>270 m - 285 m	220.13	7.99%
>285 m - 300 m	289.44	10.51%
>300 m - 315 m	217.35	7.89%
>315 m - 330 m	76.91	2.79%
>330 m - 345 m	23.68	0.86%
>345 m - 360 m	4.56	0.17%
>360 m - 375 m	0.10	0.00%
Size of Drainage Area	2753.29	100.00%

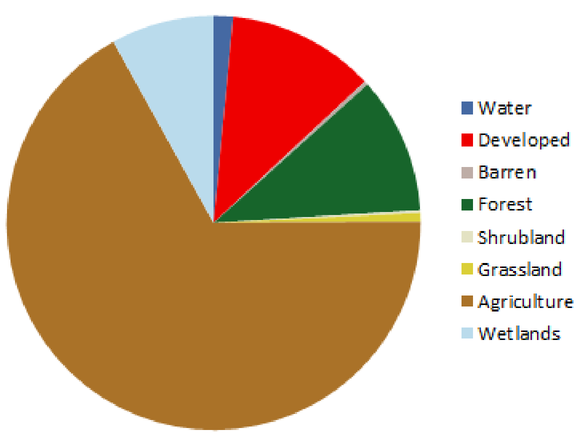
All Elevation Measurements with Respect to North American Datum 1983

29, RAISIN RIVER WATERSHED

Land Use



EGLE Runoff Curve Number
79.2

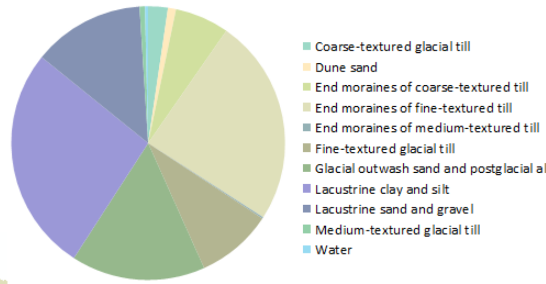


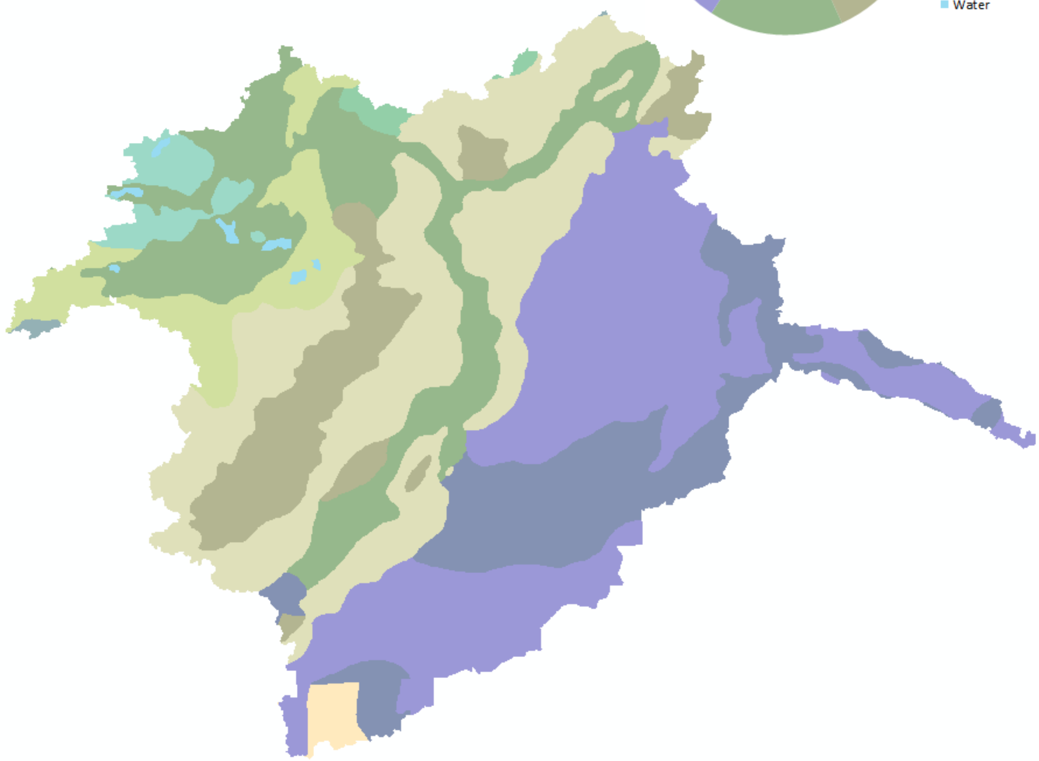
Category	Area	Percentage
Category	*km²*	*%*
Water	41.44	1.50%
Developed	317.58	11.53%
Barren	8.29	0.30%
Forest	293.97	10.68%
Shrubland	5.78	0.21%
Grassland	18.86	0.68%
Agriculture	1845.83	67.04%
Wetlands	221.55	8.05%
Total	2753.29	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

29, RAISIN RIVER WATERSHED

Surficial Geology



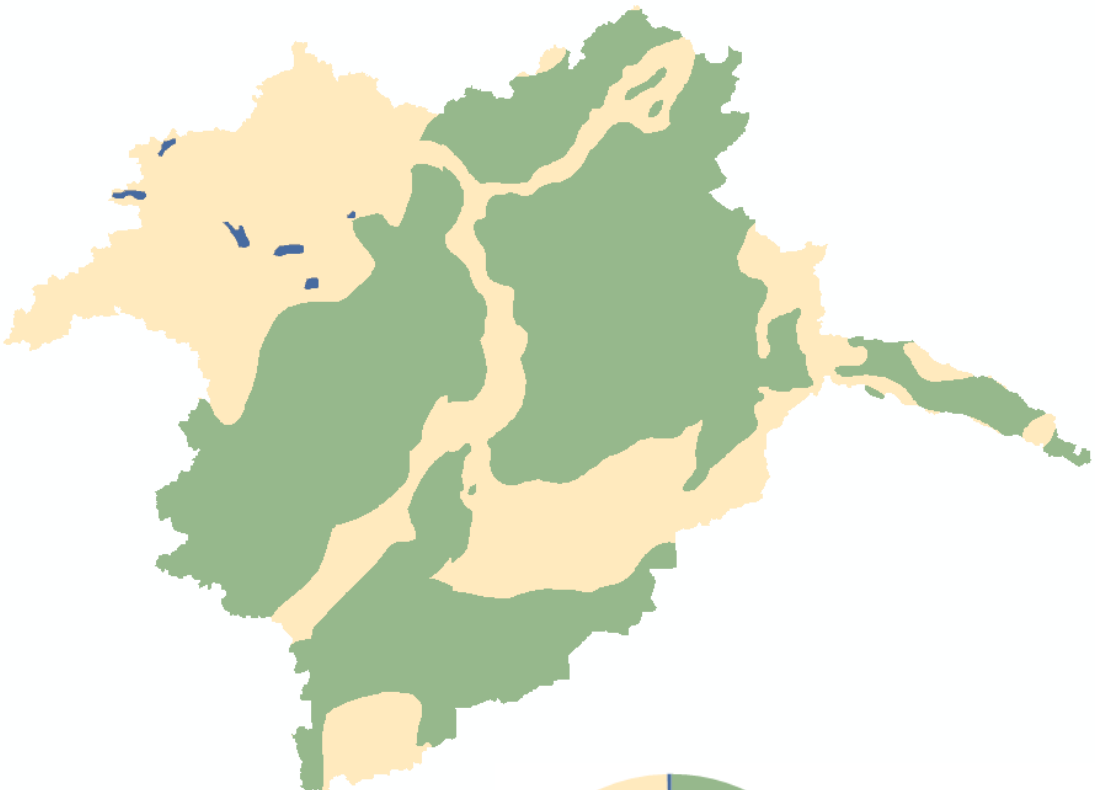


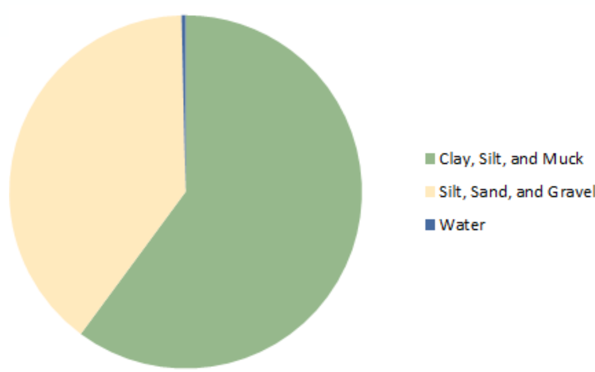
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	63.76	2.32%
Dune sand	26.46	0.96%
End moraines of coarse-textured till	175.95	6.39%
End moraines of fine-textured till	671.98	24.41%
End moraines of medium-textured till	4.57	0.17%
Fine-textured glacial till	247.66	8.99%
Glacial outwash sand and gravel and postglacial alluvium	435.60	15.82%
Lacustrine clay and silt	733.75	26.65%
Lacustrine sand and gravel	362.47	13.16%
Medium-textured glacial till	17.48	0.63%
Water	10.16	0.37%
Total Watershed Area	2753.29	99.87%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States and 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

29, RAISIN RIVER WATERSHED

Surficial Geology (Simplified)

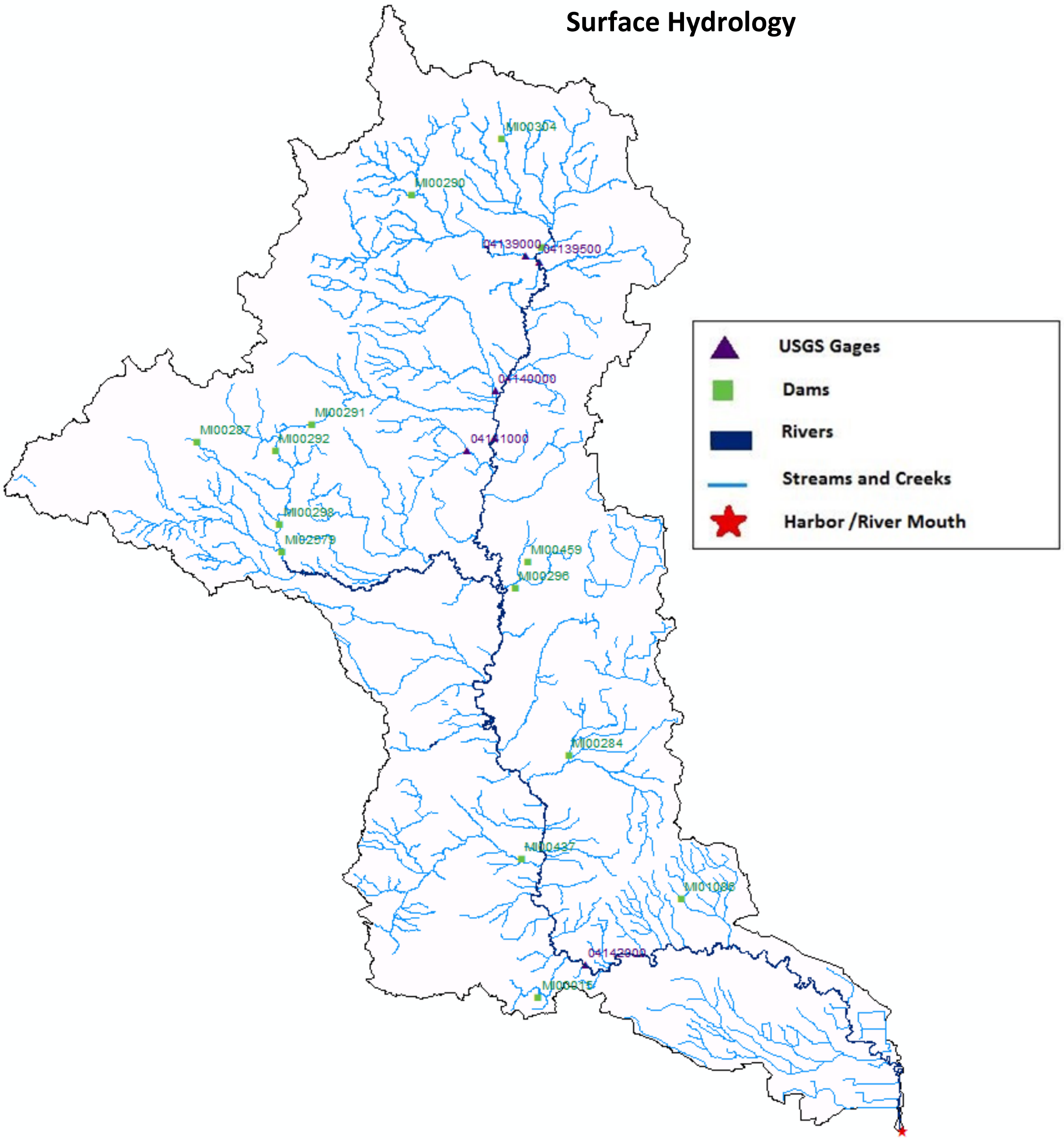




Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	1653.39	60.05%
Silt, Sand, and Gravel	1086.28	39.45%
Water	10.16	0.37%
Total Watershed Area	2753.29	99.87%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States and 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX HH. RIFLE RIVER WATERSHED (30)



30, RIFLE RIVER WATERSHED

Dam Information and USGS Streamgages

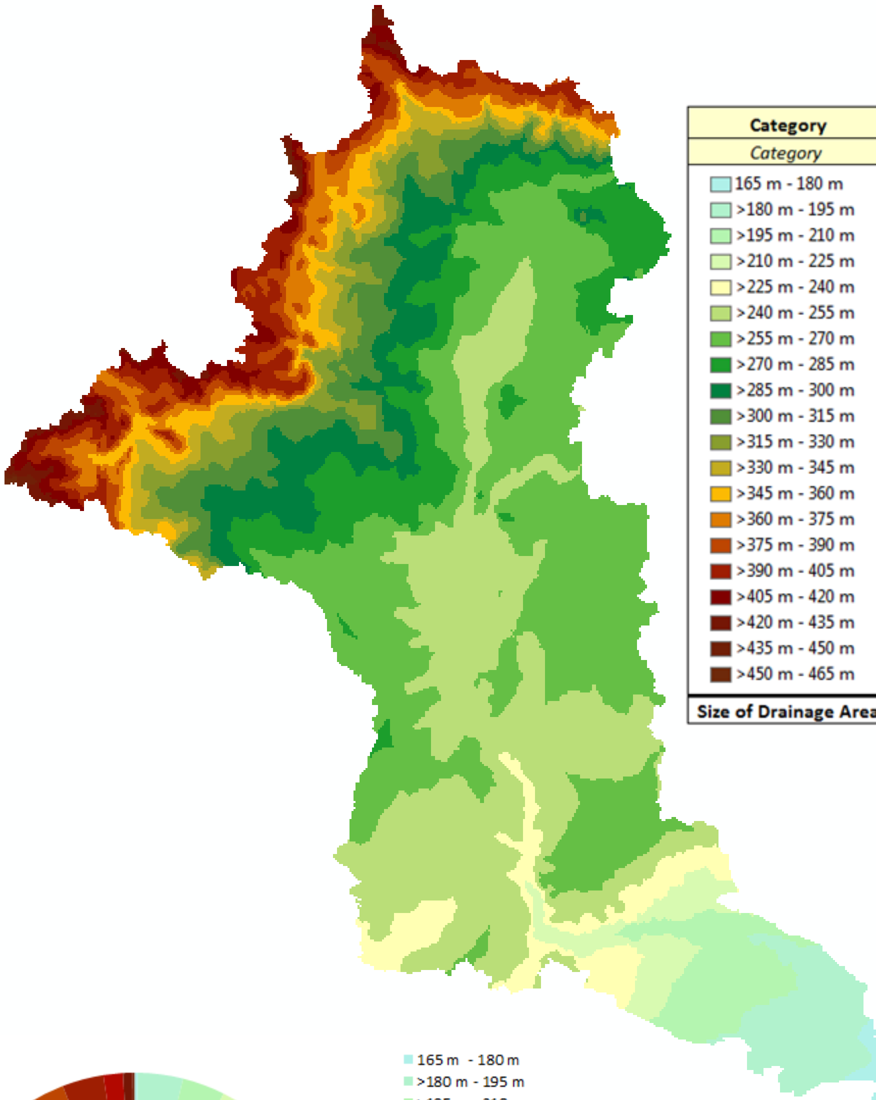
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00015	Charlyle Dam	-84.050000	44.058330
MI02579	Flowage Lake Dam	-84.205560	44.263890
MI00282	Devoe Lake Dam	-84.036670	44.400000
MI00284	Mansfield Club Dam	-84.026660	44.168330
MI00287	Heintz Lake Dam	-84.258330	44.315000
MI00290	Sanback Dam	-84.118330	44.425000
MI00291	Engle Pond Dam	-84.185000	44.321670
MI00292	Weiler Dam No 1	-84.208340	44.310000
MI00296	Lake Ogemaw Dam	-84.058330	44.245000
MI00298	Fisk Dam	-84.206670	44.276670
MI00304	Rose Valley Gun Club Dam	-84.060000	44.450000
MI00437	Forest Lake Dam	-84.058330	44.121670
MI00459	Fawn Lake Dam	-84.050000	44.256670
MI01086	HANCHET POND	-83.958300	44.101700

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4139000	HOUGHTON CREEK NEAR LUPTON, MI	-84.047219	44.395851	
4139500	RIFLE RIVER AT THE RANCH NEAR LUPTON, MI	-84.038330	44.393351	
4140000	PRIOR CREEK NEAR SELKIRK, MI	-84.068331	44.335018	
4140500	RIFLE RIVER AT STATE ROAD AT SELKIRK, MI	-84.069441	44.313352	
4141000	SOUTH BRANCH SHEPARDS CREEK NEAR SELKIRK, MI	-84.086942	44.307796	
4142000	RIFLE RIVER NEAR STERLING, MI	-84.019994	44.072520	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

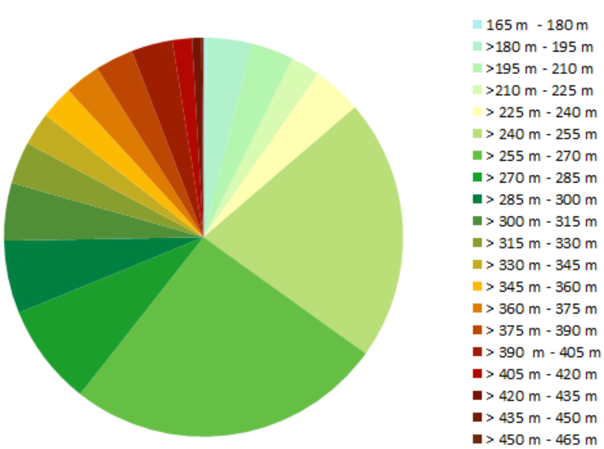
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

30, RIFLE RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	2.66	0.27%
>180 m - 195 m	36.05	3.65%
>195 m - 210 m	33.86	3.43%
>210 m - 225 m	23.50	2.38%
>225 m - 240 m	39.27	3.98%
>240 m - 255 m	209.25	21.20%
>255 m - 270 m	253.70	25.70%
>270 m - 285 m	81.07	8.21%
>285 m - 300 m	58.24	5.90%
>300 m - 315 m	46.21	4.68%
>315 m - 330 m	33.56	3.40%
>330 m - 345 m	26.51	2.69%
>345 m - 360 m	26.53	2.69%
>360 m - 375 m	28.51	2.89%
>375 m - 390 m	30.51	3.09%
>390 m - 405 m	32.99	3.34%
>405 m - 420 m	15.61	1.58%
>420 m - 435 m	7.59	0.77%
>435 m - 450 m	1.30	0.13%
>450 m - 465 m	0.28	0.03%
Size of Drainage Area	987.19	100.00%

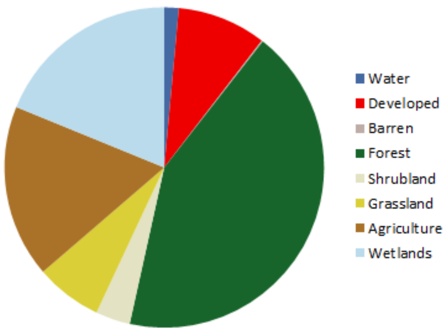


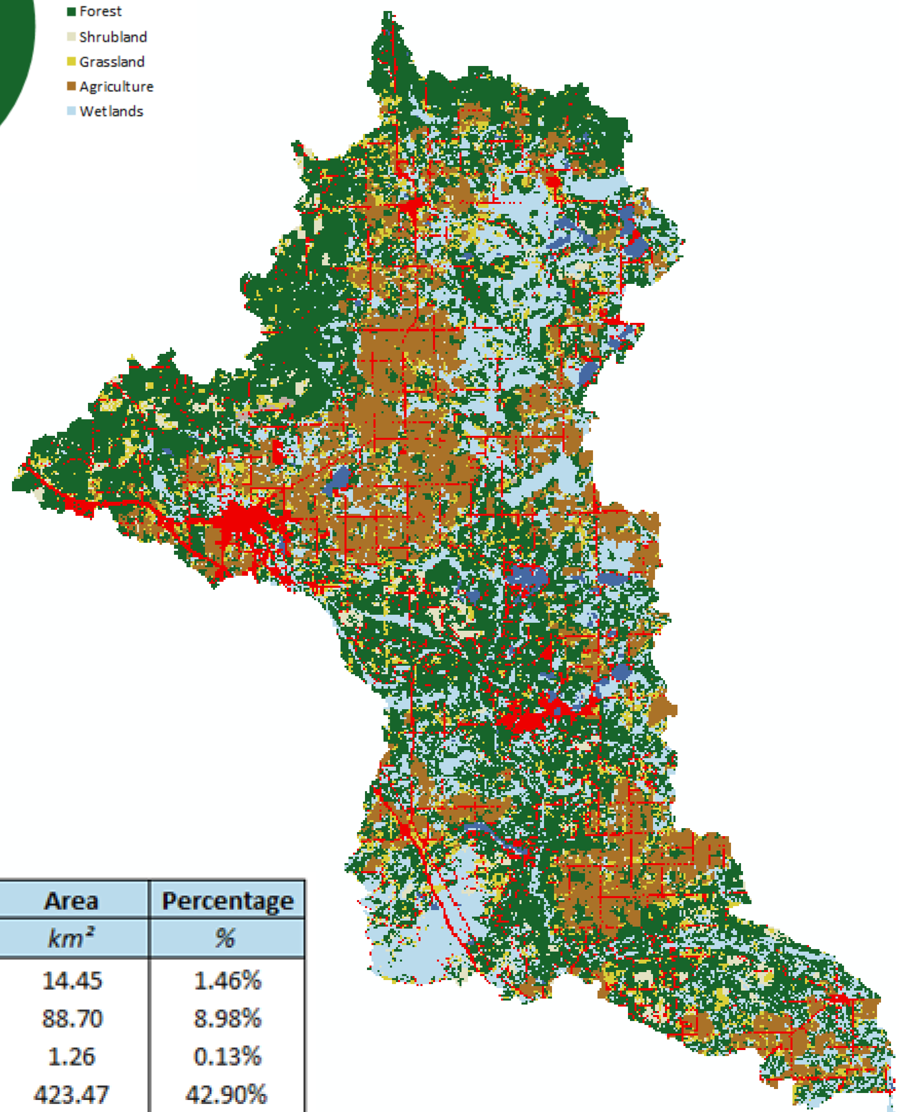
Rifle Watershed		
Elevation Statistics		
Size of Drainage Area	987.19	*km²*
Maximum	456.00	*m*
Minimum	176.00	*m*
Average	277.63	*m*
Standard Deviation	53.63	*m*

All Elevation Measurements with Respect to North American Datum 1983

30, RIFLE RIVER WATERSHED

Land Use





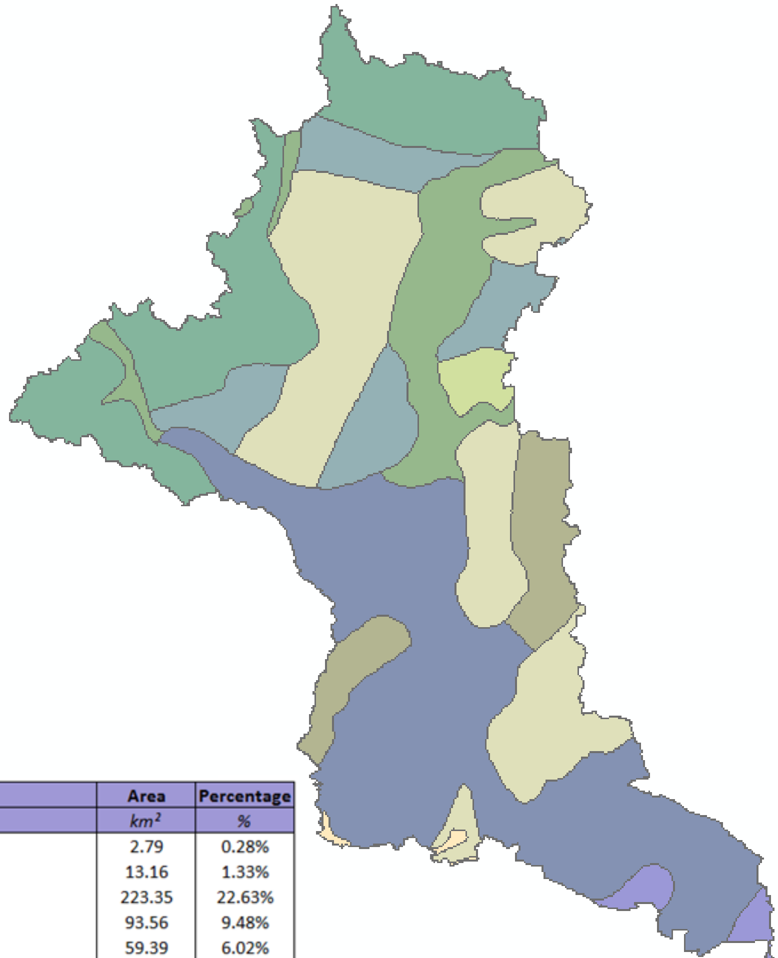
Category	Area	Percentage
Category	*km²*	*%*
Water	14.45	1.46%
Developed	88.70	8.98%
Barren	1.26	0.13%
Forest	423.47	42.90%
Shrubland	34.57	3.50%
Grassland	66.56	6.74%
Agriculture	172.21	17.44%
Wetlands	185.96	18.84%
Total	987.19	100.00%

EGLE Runoff Curve Number
67.0

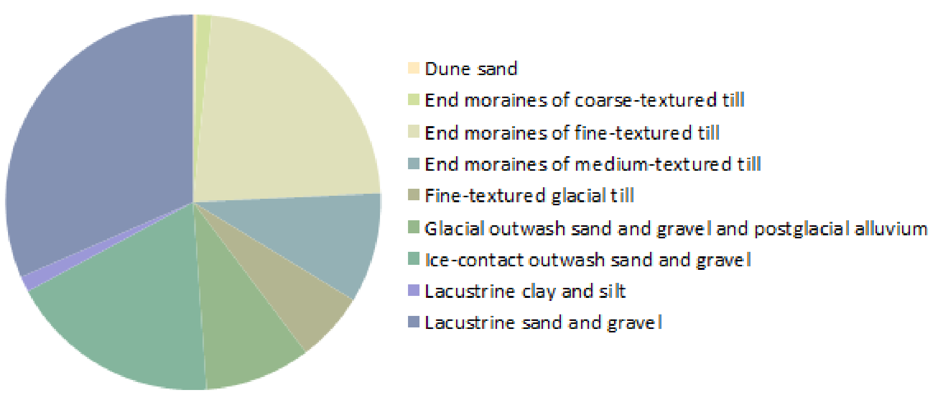
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

30, RIFLE RIVER WATERSHED

Surficial Geology



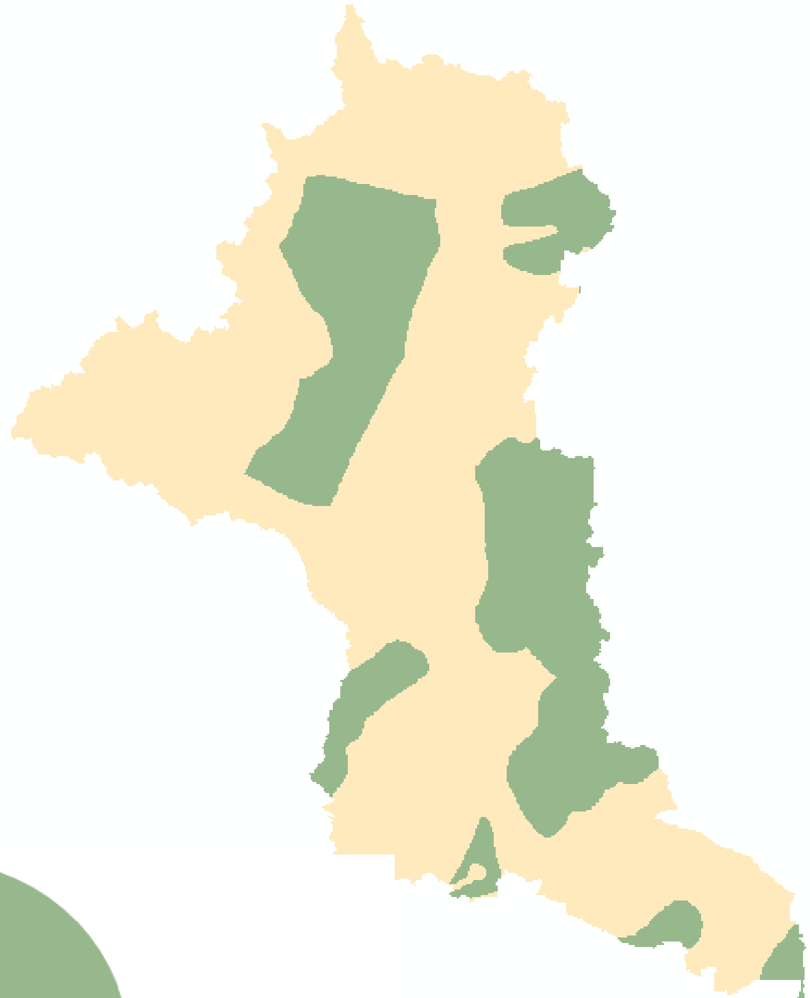
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	2.79	0.28%
End moraines of coarse-textured till	13.16	1.33%
End moraines of fine-textured till	223.35	22.63%
End moraines of medium-textured till	93.56	9.48%
Fine-textured glacial till	59.39	6.02%
Glacial outwash sand and gravel and postglacial alluvium	90.05	9.12%
Ice-contact outwash sand and gravel	180.48	18.28%
Lacustrine clay and silt	13.20	1.34%
Lacustrine sand and gravel	311.21	31.53%
Total Watershed Area	987.19	100.00%

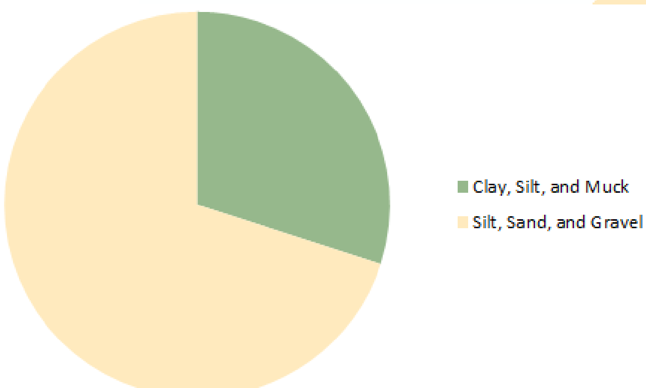


Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

30, RIFLE RIVER WATERSHED

Surficial Geology (Simplified)

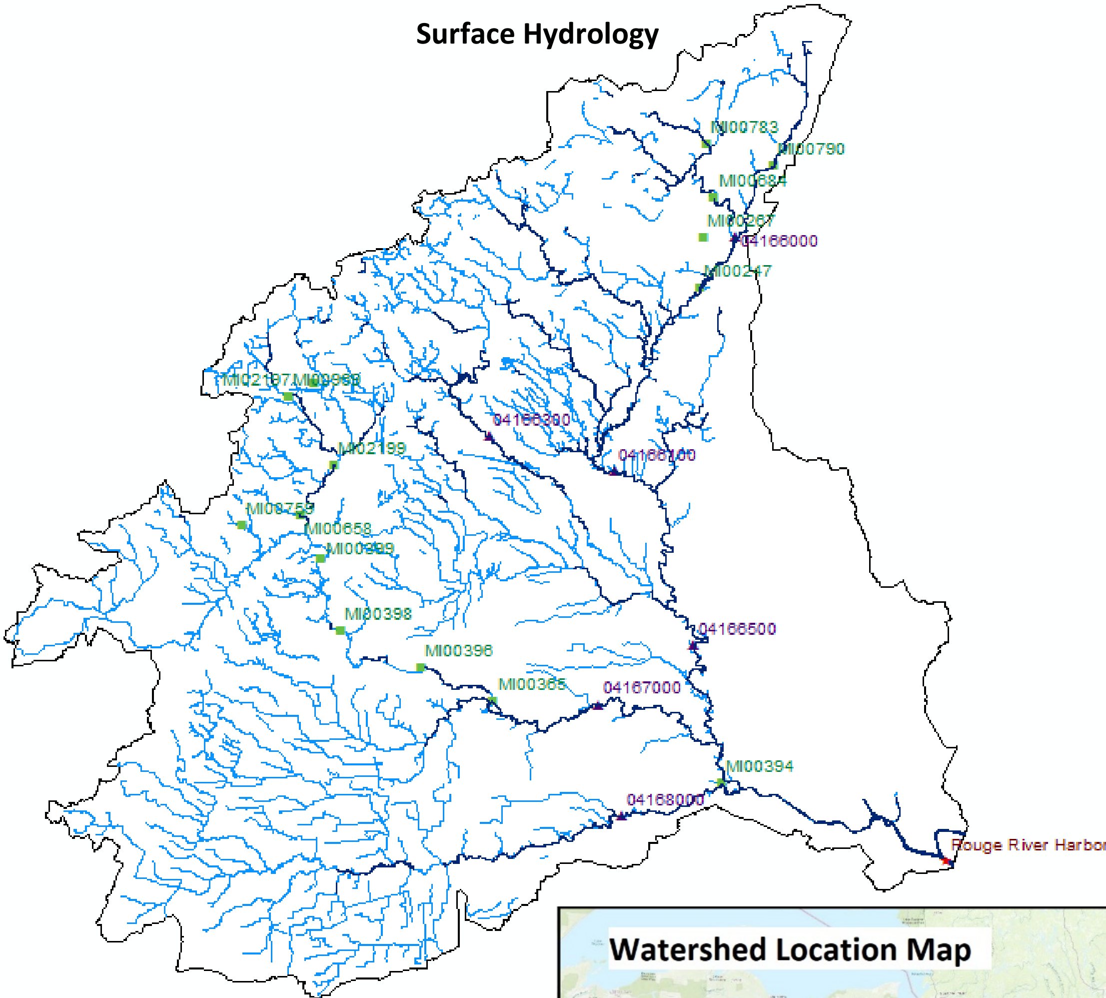


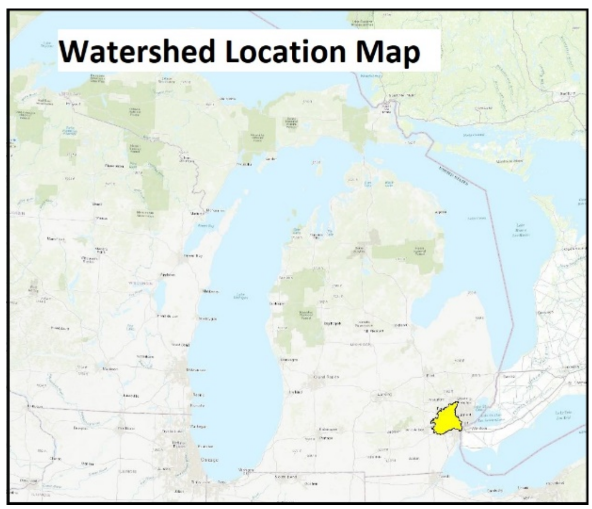


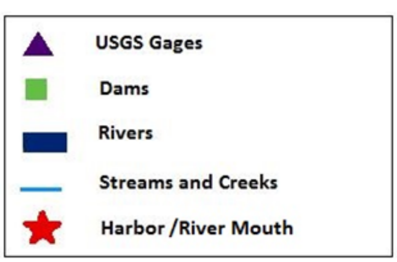
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	295.94	29.98%
Silt, Sand, and Gravel	691.25	70.02%
Total Watershed Area	987.19	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX II. ROUGE RIVER WATERSHED (31)







31, ROUGE RIVER WATERSHED

Dam Information and USGS Stream Gages

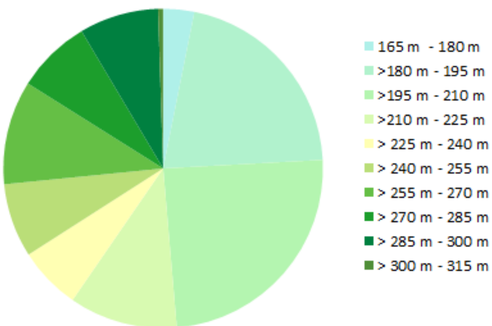
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI02197	Taft Road Regional Detention Basin	-83.484730	42.484720
MI02199	Meadowbrook Lake Dam	-83.459440	42.454170
MI00247	Erity Dam	-83.245000	42.525000
MI00267	Quarton Dam	-83.241670	42.546670
MI00365	Nankin Mill Dam	-83.371670	42.351670
MI00394	Ford Estate Dam	-83.241670	42.313330
MI00396	Newburgh Dam	-83.413330	42.366660
MI00398	Wilcox Dam	-83.458340	42.383340
MI00399	Waterford Dam	-83.468330	42.415000
MI00658	Silver Spring Lake Dam	-83.480000	42.433330
MI00681	Twelve Oaks Mall Dam	-83.470000	42.490000
MI00684	Endicott Lake Dam	-83.235000	42.563330
MI00759	Maybury Fish Pond Dam	-83.513340	42.430000
MI00783	Vhay Lake Dam	-83.238330	42.586670
MI00790	Green Lake Dam	-83.200000	42.576670
MI00969	Leavenworth Detention Pond Dam	-83.484730	42.484720

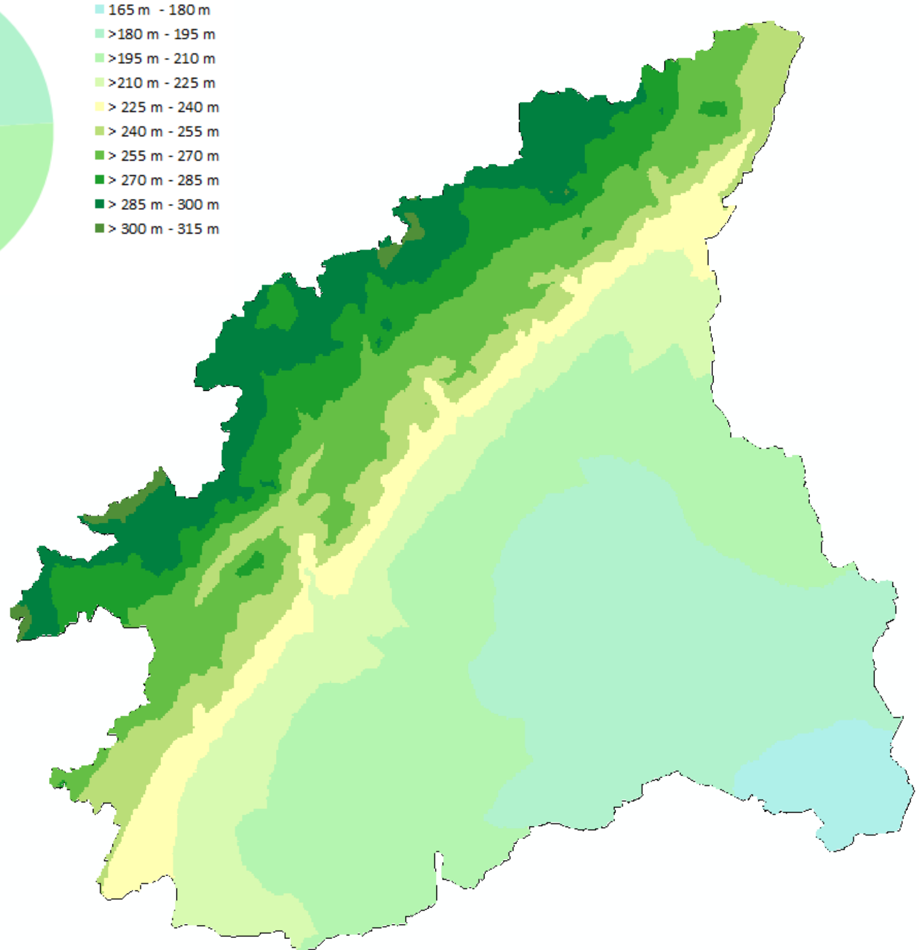
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4166000	RIVER ROUGE AT BIRMINGHAM, MI	-83.223542	42.545868	yes
4166100	RIVER ROUGE AT SOUTHFIELD, MI	-83.297709	42.447813	yes
4166300	UPPER RIVER ROUGE AT FARMINGTON, MI	-83.369655	42.464480	yes
4166500	RIVER ROUGE AT DETROIT, MI	-83.255485	42.372259	yes
4167000	MIDDLE RIVER ROUGE NEAR GARDEN CITY, MI	-83.311597	42.348093	yes
4168000	LOWER RIVER ROUGE AT INKSTER, MI	-83.300208	42.300593	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				6

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

31, ROUGE RIVER WATERSHED

Elevation





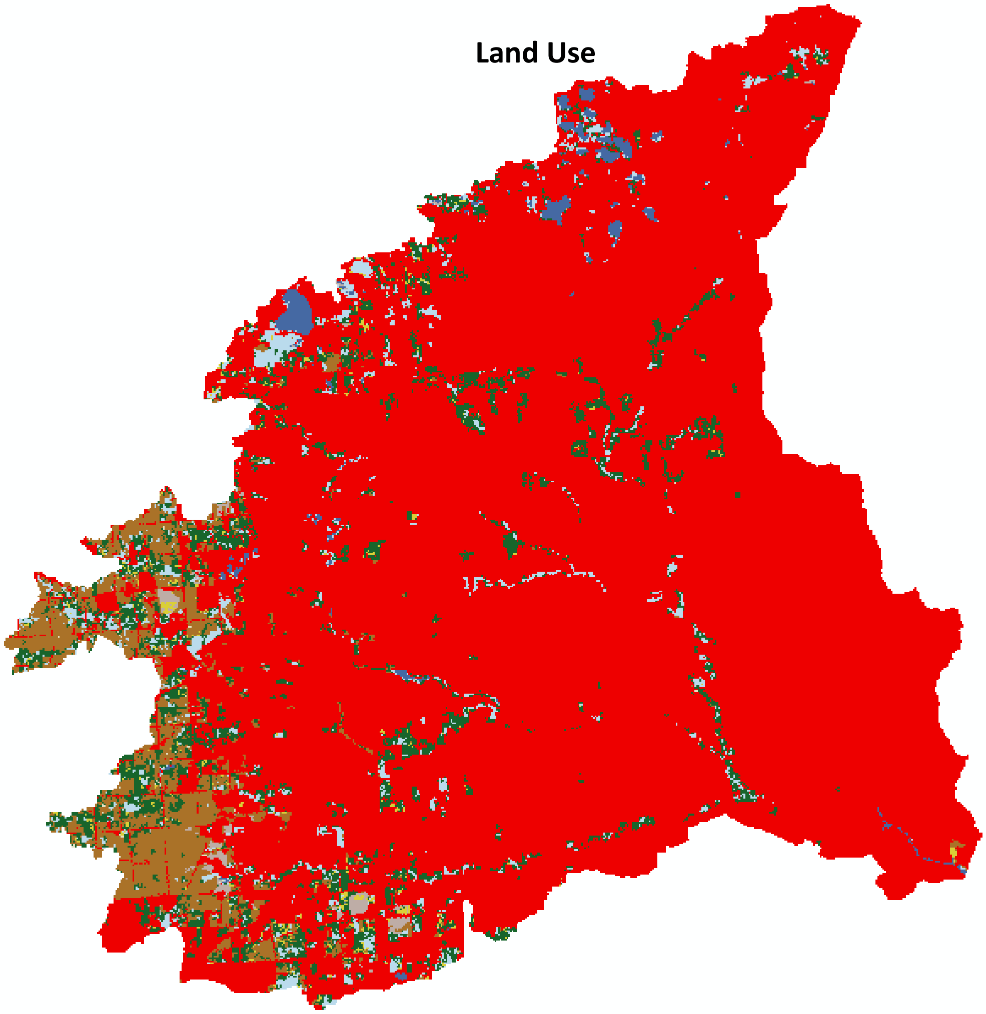
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	37.06	3.14%
>180 m - 195 m	247.98	21.00%
>195 m - 210 m	289.22	24.50%
>210 m - 225 m	129.40	10.96%
>225 m - 240 m	74.92	6.35%
>240 m - 255 m	88.35	7.48%
>255 m - 270 m	124.06	10.51%
>270 m - 285 m	88.99	7.54%
>285 m - 300 m	94.79	8.03%
>300 m - 315 m	5.96	0.50%
Size of Drainage Area	1180.72	100.00%

Rouge Watershed		
Elevation Statistics		
Size of Drainage Area	**1180.72**	***km²***
Maximum	306.00	*m*
Minimum	174.00	*m*
Average	224.09	*m*
Standard Deviation	35.36	*m*

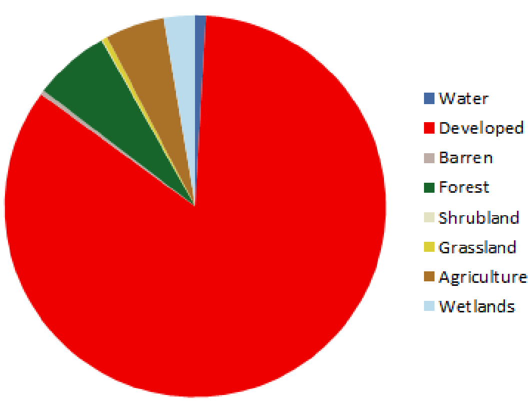
All Elevation Measurements with Respect to North American Datum 1983

31, ROUGE RIVER WATERSHED

Land Use



EGLE Runoff Curve Number
81.5

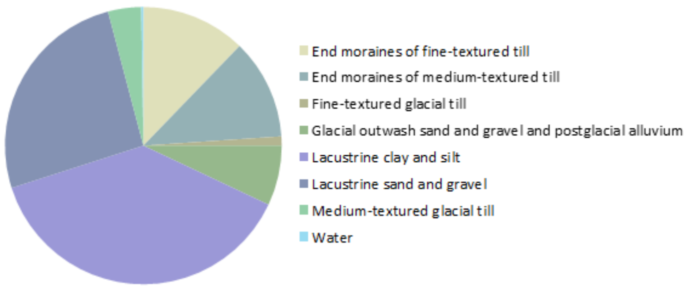


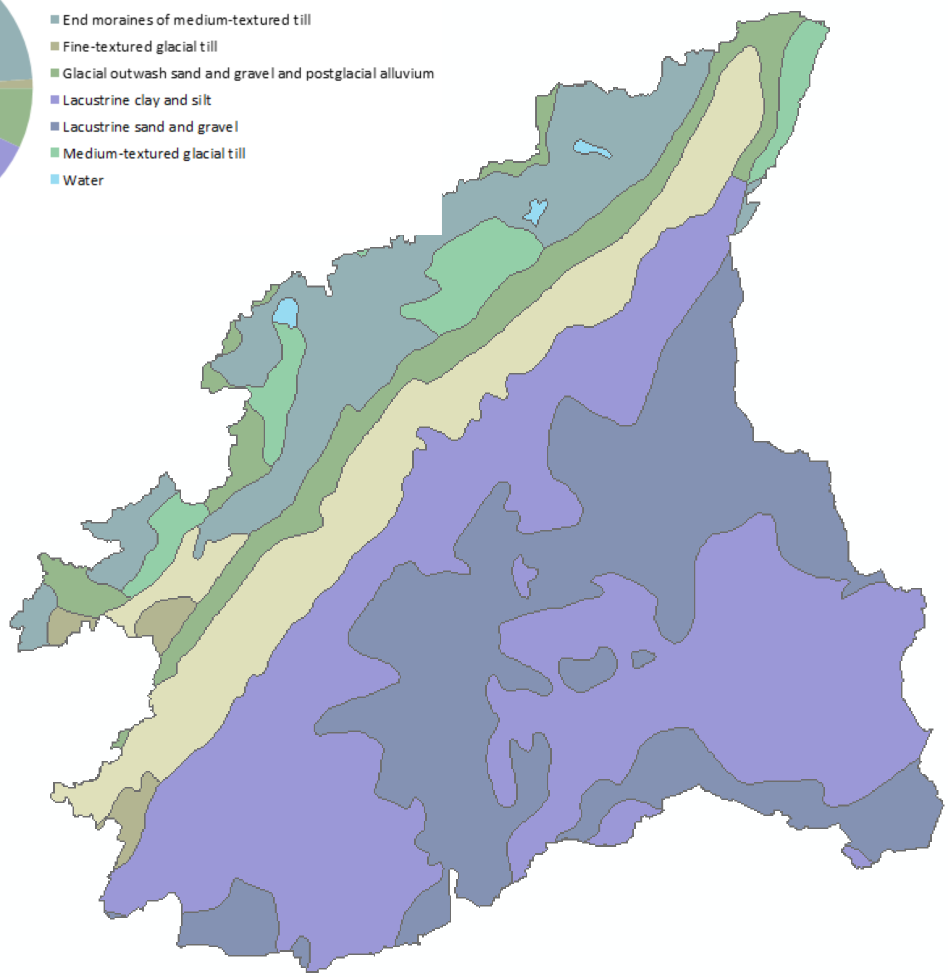
Category	Area	Percentage
Category	*km²*	*%*
Water	10.57	0.90%
Developed	993.31	84.13%
Barren	4.32	0.37%
Forest	76.11	6.45%
Shrubland	0.79	0.07%
Grassland	5.38	0.46%
Agriculture	59.07	5.00%
Wetlands	31.17	2.64%
Total	1180.72	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

31, ROUGE RIVER WATERSHED

Surficial Geology



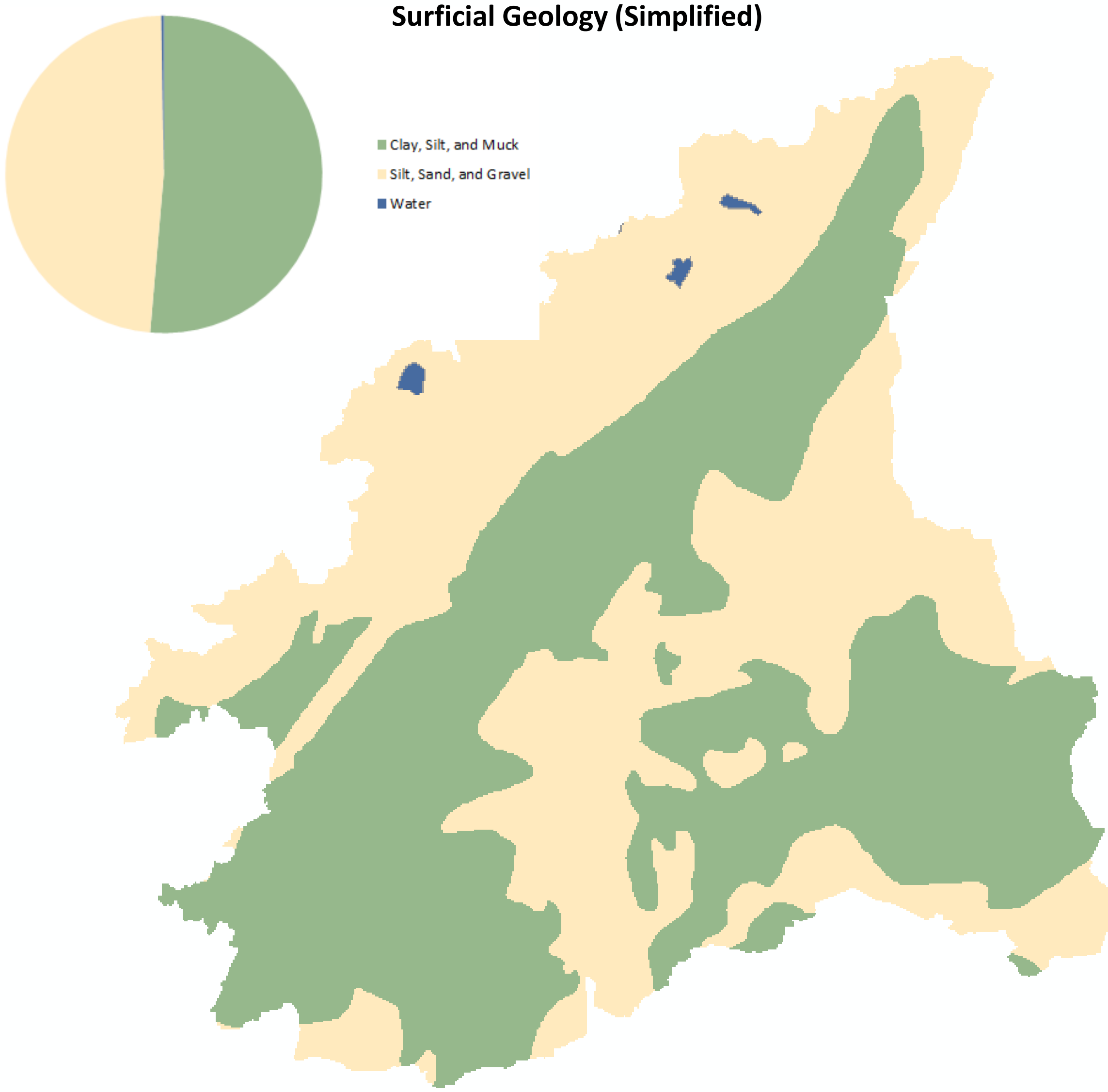


Category	Area	Percentage
Category	*km²*	*%*
End moraines of fine-textured till	144.61	12.25%
End moraines of medium-textured till	138.02	11.69%
Fine-textured glacial till	12.60	1.07%
Glacial outwash sand and gravel and postglacial alluvium	82.58	6.99%
Lacustrine clay and silt	449.50	38.07%
Lacustrine sand and gravel	304.73	25.81%
Medium-textured glacial till	45.73	3.87%
Water	2.95	0.25%
Total Watershed Area	1180.72	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

31, ROUGE RIVER WATERSHED

Surficial Geology (Simplified)

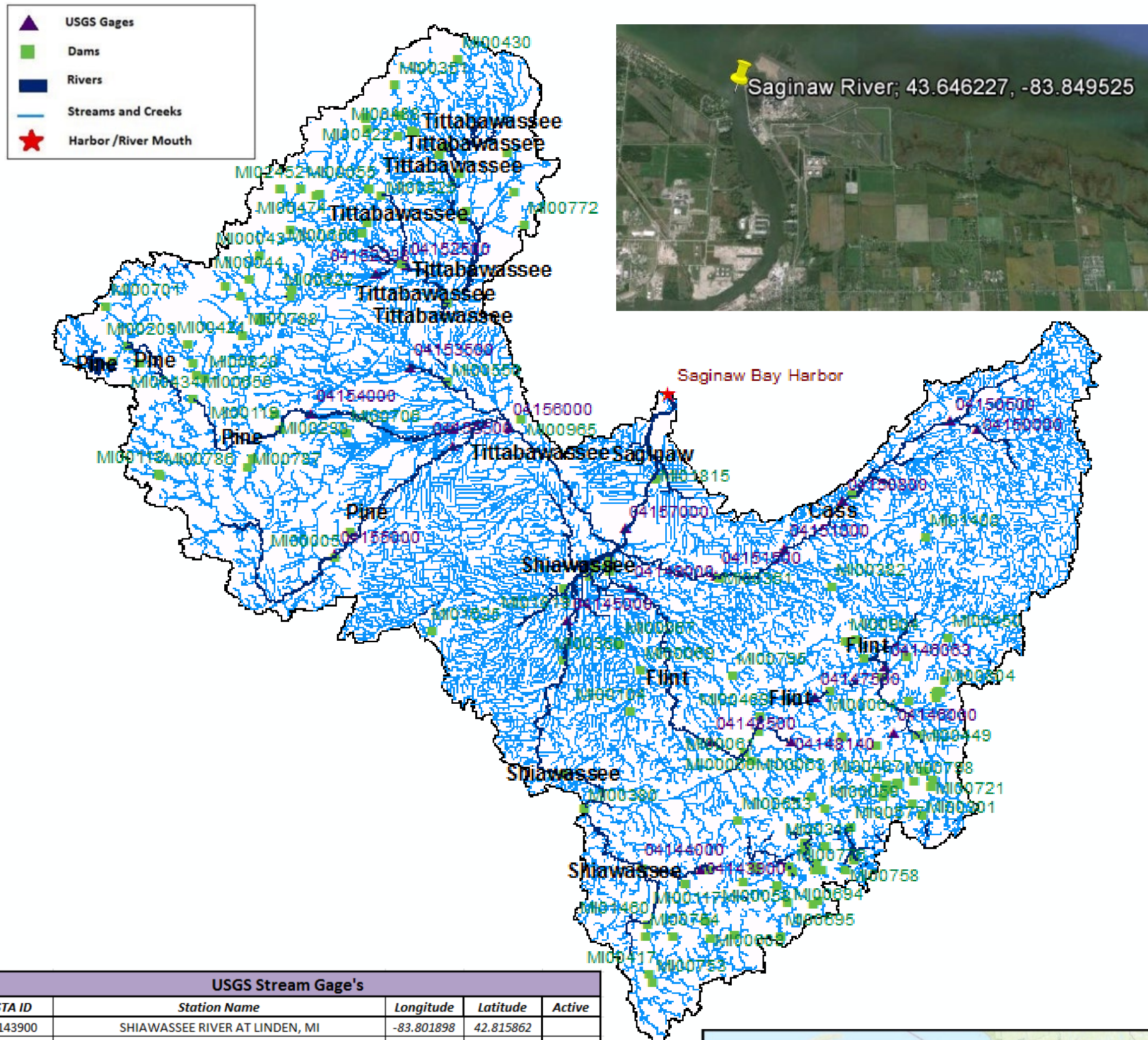


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	606.71	51.38%
Silt, Sand, and Gravel	571.06	48.37%
Water	2.95	0.25%
Total Watershed Area	1180.72	100.00%

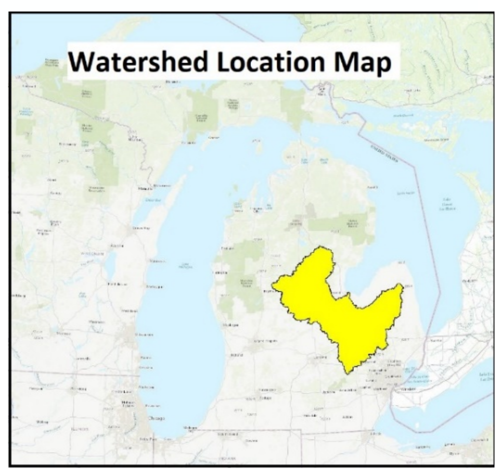
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX JJ. SAGINAW RIVER WATERSHED (32)

Surface Hydrology



USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4143900	SHIAWASSEE RIVER AT LINDEN, MI	*-83.801898*	*42.815862*	
4144000	SHIAWASSEE RIVER AT BYRON, MI	-83.945792	42.823642	
4145000	SHIAWASSEE RIVER NEAR FERGUS, MI	-84.105532	43.254748	yes
4146000	FARMERS CREEK NEAR LAPEER, MI	-83.337168	43.044749	yes
4146063	SOUTH BRANCH FLINT RIVER NEAR COLUMBIAVILLE,MI	-83.350781	43.159471	yes
4147500	FLINT RIVER NEAR OTISVILLE, MI	-83.519397	43.111137	yes
4148140	KEARSLEY CREEK NEAR DAVISON, MI	-83.581342	43.033638	yes
4148500	FLINT RIVER NEAR FLINT, MI	-83.771626	43.038916	yes
4149000	FLINT RIVER NEAR FOSTERS, MI	-83.953583	43.308359	yes
4150000	SOUTH BRANCH CASS RIVER NEAR CASS CITY, MI	-83.111889	43.566963	
4150500	CASS RIVER AT CASS CITY, MI	-83.176058	43.584185	yes
4150800	CASS RIVER AT WAHJAMEGA, MI	-83.441343	43.450577	
4151000	CASS RIVER AT VASSAR, MI	-83.581069	43.370857	
4151500	CASS RIVER AT FRANKENMUTH, MI	-83.74802	43.327802	yes
4152238	SOUTH BRANCH TOBACCO RIVER NEAR BEAVERTON, MI	-84.545289	43.866969	yes
4152500	TOBACCO RIVER AT GLIDDEN ROAD AT BEAVERTON, MI	-84.473898	43.879469	
4153500	SALT RIVER NEAR NORTH BRADLEY, MI	-84.47056	43.702806	
4154000	CHIPPEWA RIVER NEAR MOUNT PLEASANT, MI	-84.70779	43.625585	yes
4154500	CHIPPEWA RIVER NEAR MIDLAND, MI	-84.36944	43.594473	
4155000	PINE RIVER AT ALMA, MI	-84.655561	43.379475	yes
4155500	PINE RIVER NEAR MIDLAND, MI	-84.369162	43.564473	yes
4156000	TITTABAWASSEE RIVER AT MIDLAND, MI	-84.235544	43.595305	yes
4157000	SAGINAW RIVER AT SAGINAW, MI	-83.96303	43.4128	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				15



Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

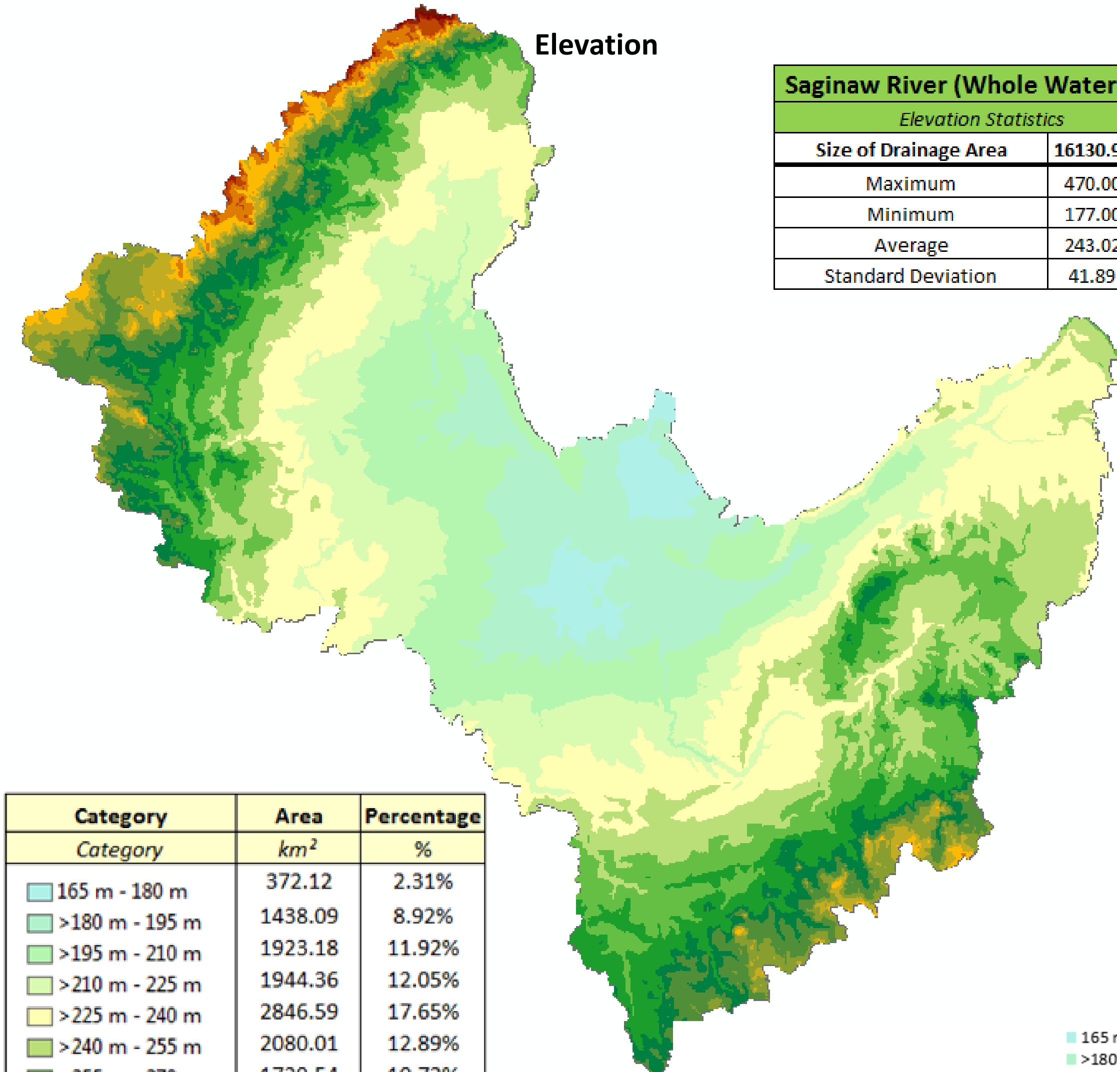
32, SAGINAW RIVER WATERSHED

Dam Information

USACE'S National Inventory of Dams (NID)							
NIDID	Dam Name	Longitude	Latitude	NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*	*National ID*	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00550	Sanford	-84.380300	43.676900	MI00253	Holly Dam	-83.623340	42.785000
MI00524	Beaverton	-84.483300	43.883300	MI00255	Lake Louise Dam	-83.436670	42.826670
MI00104	Misteguay Creek 2A	-83.958340	43.095000	MI02572	Upper Long Lake Dam	-83.231390	43.102220
MI00549	Edenville	-84.376900	43.814200	MI00264	Perrysville Dam	-83.553340	42.845000
MI00547	Secord	-84.341900	44.041100	MI02641	Hartman & Tyner Mitigation Pond 1	-83.551700	42.856000
MI00548	Smallwood	-84.336100	43.958600	MI00273	Spring Lake Dam	-83.591670	42.818330
MI00551	St Louis	-84.618600	43.416700	MI00276	Wildwood Lake Dam	-83.517780	42.808060
MI00116	Surrey Lake Dam	-84.910550	43.850150	MI00286	Upper Reed Lake Dam	-83.291660	42.958330
MI00117	Argentine Dam	-83.841670	42.791390	MI00293	Misch Lake Dam	-83.266670	42.975000
MI00118	Blanchard Pond Dam	-85.075000	43.525000	MI00294	Hemingway Lake Dam	-83.416660	43.208330
MI00119	Harris Dam	-84.783330	43.600000	MI00295	Potters Lake Dam	-83.458340	43.041670
MI00120	Russell Dam	-84.483330	44.141670	MI00300	Snoblen Dam	-83.366670	42.933330
MI01276	Blue Lake Dam	-84.560550	44.121110	MI00301	Thompson Dam	-83.275000	42.900000
MI00138	Baker Dam	-84.375000	44.085000	MI00307	Faussett Dam	-83.871670	42.700000
MI01400	Shay Lake Level Control Structure	-83.244700	43.384500	MI00314	Phipps Lake Dam	-83.508330	42.850000
MI01420	Barnes Lake Dam	-83.296670	43.176670	MI00323	Springwood Lake #1 Dam	-84.688330	44.006670
MI01423	Lapeer State Game Area Flooding #13 Dam	-83.226670	43.114170	MI00329	Hoister Lake Dam	-84.566670	44.141670
MI01425	Johnson Dam	-83.355000	42.955000	MI00330	Trout Lake Dam	-84.566670	44.138330
MI01460	Hidden Lake Dam	-83.931660	42.721670	MI00351	Priddy Lake Dam	-84.495000	44.196670
MI01587	Twin Lakes Dam	-83.208340	43.133340	MI00359	Sawdel Lake Dam	-83.361660	43.143610
MI01601	Molasses River Flooding #5 Dam	-84.210990	44.005990	MI00360	Chesaning Dam	-84.116670	43.188330
MI01625	Gratiot-Saginaw SGA Impoundment #1 Dam	-84.426670	43.241660	MI00361	Frankenmuth Dam	-83.741670	43.324810
MI01681	McGinnis Lake Dam	-83.527500	42.821110	MI00364	Winchester Dam	-85.183330	43.720000
MI01815	Crow Island Dam	-83.886670	43.500000	MI00378	Byron Dam	-83.941670	42.821670
MI01818	Pool Six Dam	-83.995000	43.348330	MI00379	Corunna Dam	-84.120000	42.986670
MI01819	Shiawassee Flats Dam	-84.113330	43.311670	MI00380	Shiawassee Town Dam	-84.076670	42.928330
MI01974	Nepessing Lake Level Control Structure	-83.376660	43.025000	MI00381	Caro Dam	-83.416660	43.461670
MI00201	Lake Contos Dam	-84.558330	44.016670	MI00382	Murphy Lake Level Control Structure	-83.471660	43.303330
MI00208	Heil Dam	-84.325000	43.975000	MI00039	Beebe Lake Dam	-84.752160	43.947210
MI00209	Barryton Dam	-85.146670	43.746670	MI00404	Lockwood Lake Dam	-83.246670	42.961670
MI00221	Peas Lake Dam	-84.850000	43.550000	MI00407	Lake Metamora Dam	-83.333340	42.958330
MI00230	Mission Creek Dam	-84.793330	43.625000	MI00041	Farwell Mill Pond Dam	-84.874600	43.831910
MI00244	Davisburg Dam	-83.538330	42.751670	MI00411	Walker Creek Dam #1	-84.991670	43.716670
MI02452	Sutherland Lake Level Control Struct	-84.775000	44.018330	MI00414	Kerswill Lake Dam	-84.564770	43.956270
MI02474	Hamlin Dam	-84.828330	43.793330	MI00417	Serene Lake Dam	-83.931660	42.636670
MI02497	Thread Creek Impoundment Dam	-83.555000	42.857780	MI00421	Walker Creek Dam #2	-85.000000	43.750000
MI00422	Lake Lochbrae Dam	-84.488330	44.106670	MI00063	Thread Lake Dam	-83.675000	43.003330
MI00425	Lake Lapeer Lake Level Control Structure	-83.380000	42.966670	MI00064	Holloway Dam	-83.485000	43.120000
MI00426	Duncan Dam	-84.825000	43.788330	MI00643	Pool One A	-83.998340	43.358330
MI00043	McKays Dam	-84.825000	43.903330	MI00644	Pool One B Dam	-83.996670	43.353330
MI00430	Morris Lake Dam	-84.340000	44.240000	MI00645	Pool Two	-84.035000	43.350000
MI00432	Big Seven Lake Dam	-83.679600	42.819510	MI00646	Pool Three	-84.006670	43.346670
MI00433	Younglove Dam	-83.295000	42.921670	MI00647	Pool Four Langshwager Tract	-84.050000	43.333330
MI00434	Lake Isabella Dam	-84.991390	43.653330	MI00648	Pool Five	-84.000000	43.340000
MI00044	Lake 13 Dam	-84.851670	43.861670	MI00653	Burroughs Reservoir Dam	-83.711940	42.900000
MI00448	Seven Lakes Addition Dam	-83.669930	42.816970	MI00655	Weidman Development Dam	-84.980000	43.696670
MI00449	Winn Lake Dam	-83.280000	43.038330	MI00656	Scottish Hills Lake Dam	-84.578320	43.938330
MI00450	Bottom Creek Dam	-83.200500	43.205900	MI00067	Misteguay Creek 4	-83.978330	43.211670
MI00463	Georgia John Farms Dam	-85.116670	43.716670	MI00068	Molasses River Flooding #2 Dam	-84.225000	44.075000
MI00466	James Bicknell III Dam	-84.750000	43.841670	MI00069	Misteguay Creek 3A	-83.933330	43.165000
MI00469	Mott Dam	-83.652410	43.080260	MI00692	Heron Dam	-83.530750	42.811040
MI00471	Lake Lancer Dam	-84.445000	44.113330	MI00693	Davisburg Trout Pond Dam	-83.524720	42.754440
MI00474	Springwood #2 Dam	-84.680000	44.008340	MI00694	Braemar Lake Dam	-83.597550	42.755600
MI00488	Lake Lancelot Dam	-84.455000	44.116660	MI00695	Knoblock Lake Dam	-83.618330	42.696670
MI00005	State Street Dam	-84.658330	43.375000	MI00697	Lapeer State Game Area Flooding #30 Dam	-83.231390	43.111670
MI00525	Chappel Dam	-84.529800	44.003440	MI00701	Siebecker Dam	-85.196660	43.816670
MI00055	Sand Lake Level Control Dam	-84.723340	44.018330	MI00706	Lake Camelot Dam	-84.625000	43.591670
MI00556	Flat Rock Dam	-83.296190	43.099890	MI00721	Beaver Lake Dam	-83.250000	42.950000
MI00057	Atlas Dam	-83.533330	42.938330	MI00753	Thompson Lake Dam	-83.923330	42.620000
MI00576	Minnawanna Dam	-83.352500	42.945560	MI00754	Oak Grove Millpond Dam	-83.936670	42.701670
MI00577	Spain-Lindsey Dam	-83.445000	42.883340	MI00758	Renchik Dam	-83.460000	42.808330
MI00058	Fenton Water Dam	-83.703330	42.793330	MI00772	Molasses River Flooding #3 Dam	-84.186670	43.948330
MI00581	Tau Beta Dam	-83.400000	43.175000	MI00776	Crystal Lake Dam	-83.586390	42.808890
MI00582	Lower Long Lake Dam	-83.233330	43.108330	MI00785	Frayer Dam	-84.388340	44.073330
MI00059	Goodrich Dam	-83.503330	42.916670	MI00786	Babcocks Pond Dam	-85.071660	43.519720
MI00060	Hamilton Dam	-83.690000	43.020000	MI00787	Schafer Dam	-84.861660	43.533330
MI00600	Tyrone Dam	-83.728390	42.700790	MI00788	Thompson Dam	-84.868330	43.763330
MI00603	Parshallville Dam	-83.785000	42.695000	MI00795	Lewis Drain Dam	-83.713330	43.153330
MI00061	Kearsley Dam	-83.656670	43.055000	MI00798	Merritt Lake Dam	-83.326670	42.955000
MI00062	Linden Mill Dam	-83.781670	42.815000	MI00804	Lapeer State Game Area Flooding #27 Dam	-83.220560	43.111110
MI00621	Shannon Lake Dam	-83.795000	42.725000	MI00820	Weidman Mill Pond Dam	-84.963060	43.688610
MI00622	Shamrock Lake Dam	-84.752940	43.830410	MI00904	Henson Dam	-83.443890	43.207500
				MI00965	Midland Storage Basin	-84.203300	43.607400

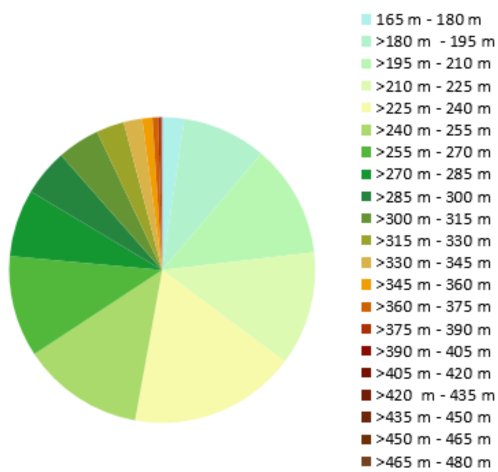
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

32, SAGINAW RIVER WATERSHED



Saginaw River (Whole Watershed)	
Elevation Statistics	
Size of Drainage Area	**16130.97 *km²***
Maximum	470.00 *m*
Minimum	177.00 *m*
Average	243.02 *m*
Standard Deviation	41.89 *m*

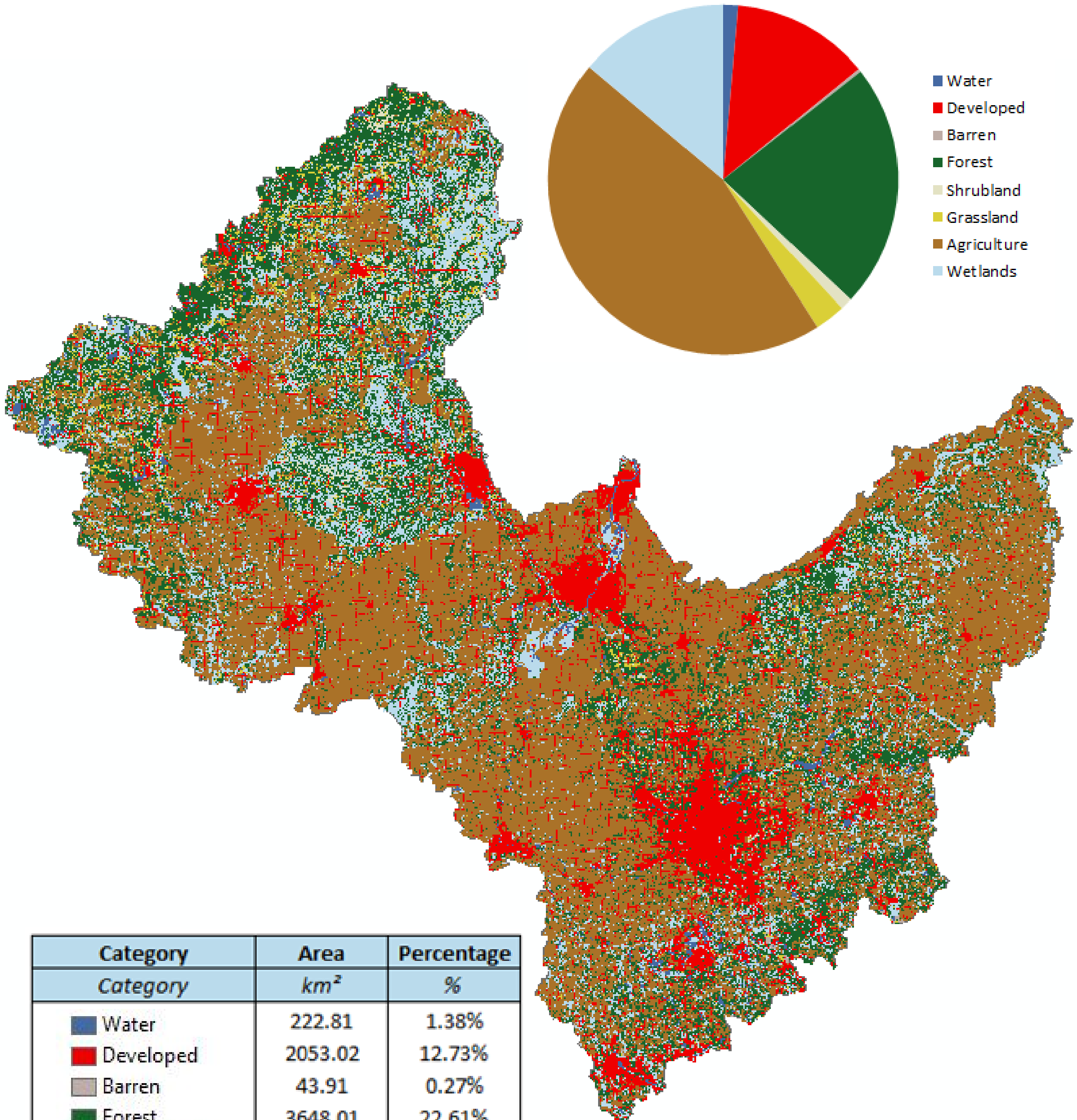
Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	372.12	2.31%
>180 m - 195 m	1438.09	8.92%
>195 m - 210 m	1923.18	11.92%
>210 m - 225 m	1944.36	12.05%
>225 m - 240 m	2846.59	17.65%
>240 m - 255 m	2080.01	12.89%
>255 m - 270 m	1729.54	10.72%
>270 m - 285 m	1149.31	7.12%
>285 m - 300 m	796.21	4.94%
>300 m - 315 m	723.63	4.49%
>315 m - 330 m	474.04	2.94%
>330 m - 345 m	316.37	1.96%
>345 m - 360 m	172.89	1.07%
>360 m - 375 m	95.88	0.59%
>375 m - 390 m	45.92	0.28%
>390 m - 405 m	12.19	0.08%
>405 m - 420 m	5.82	0.04%
>420 m - 435 m	2.67	0.02%
>435 m - 450 m	1.60	0.01%
>450 m - 465 m	0.49	0.00%
>465 m - 480 m	0.02	0.00%
Size of Drainage Area	16130.97	100.00%



All Elevation Measurements with Respect to North American Datum 1983

32, SAGINAW RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	222.81	1.38%
Developed	2053.02	12.73%
Barren	43.91	0.27%
Forest	3648.01	22.61%
Shrubland	181.78	1.13%
Grassland	456.43	2.83%
Agriculture	7289.92	45.19%
Wetlands	2235.09	13.86%
Total	16130.97	100.00%

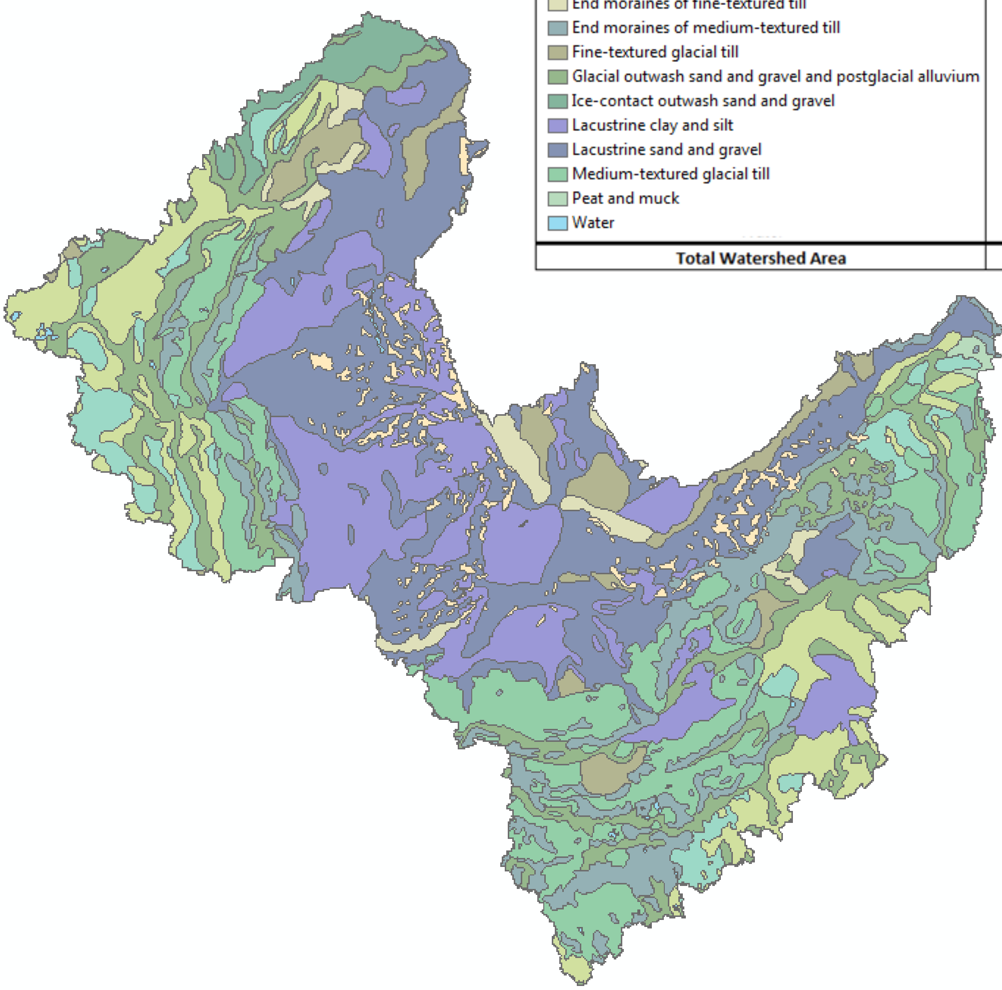
EGLE Runoff Curve Number
75.5

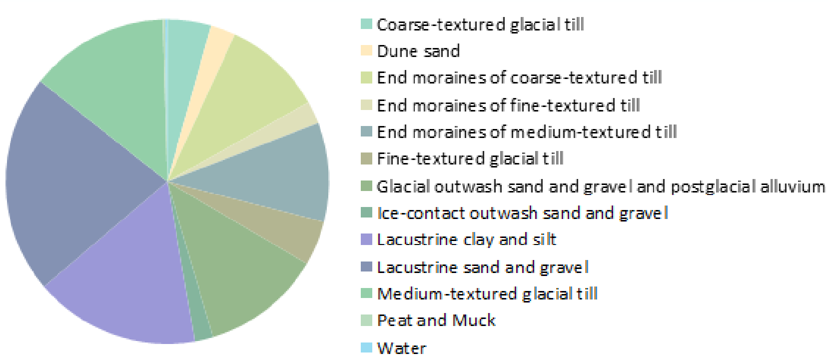
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

32, SAGINAW RIVER WATERSHED

Surficial Geology

Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	706.59	4.38%
Dune sand	400.66	2.48%
End moraines of coarse-textured till	1613.10	10.00%
End moraines of fine-textured till	361.81	2.24%
End moraines of medium-textured till	1596.01	9.89%
Fine-textured glacial till	714.94	4.43%
Glacial outwash sand and gravel and postglacial alluvium	1934.68	11.99%
Ice-contact outwash sand and gravel	297.86	1.85%
Lacustrine clay and silt	2664.29	16.52%
Lacustrine sand and gravel	3523.90	21.85%
Medium-textured glacial till	2247.80	13.93%
Peat and muck	39.23	0.24%
Water	30.09	0.19%
Total Watershed Area	16130.97	100.00%

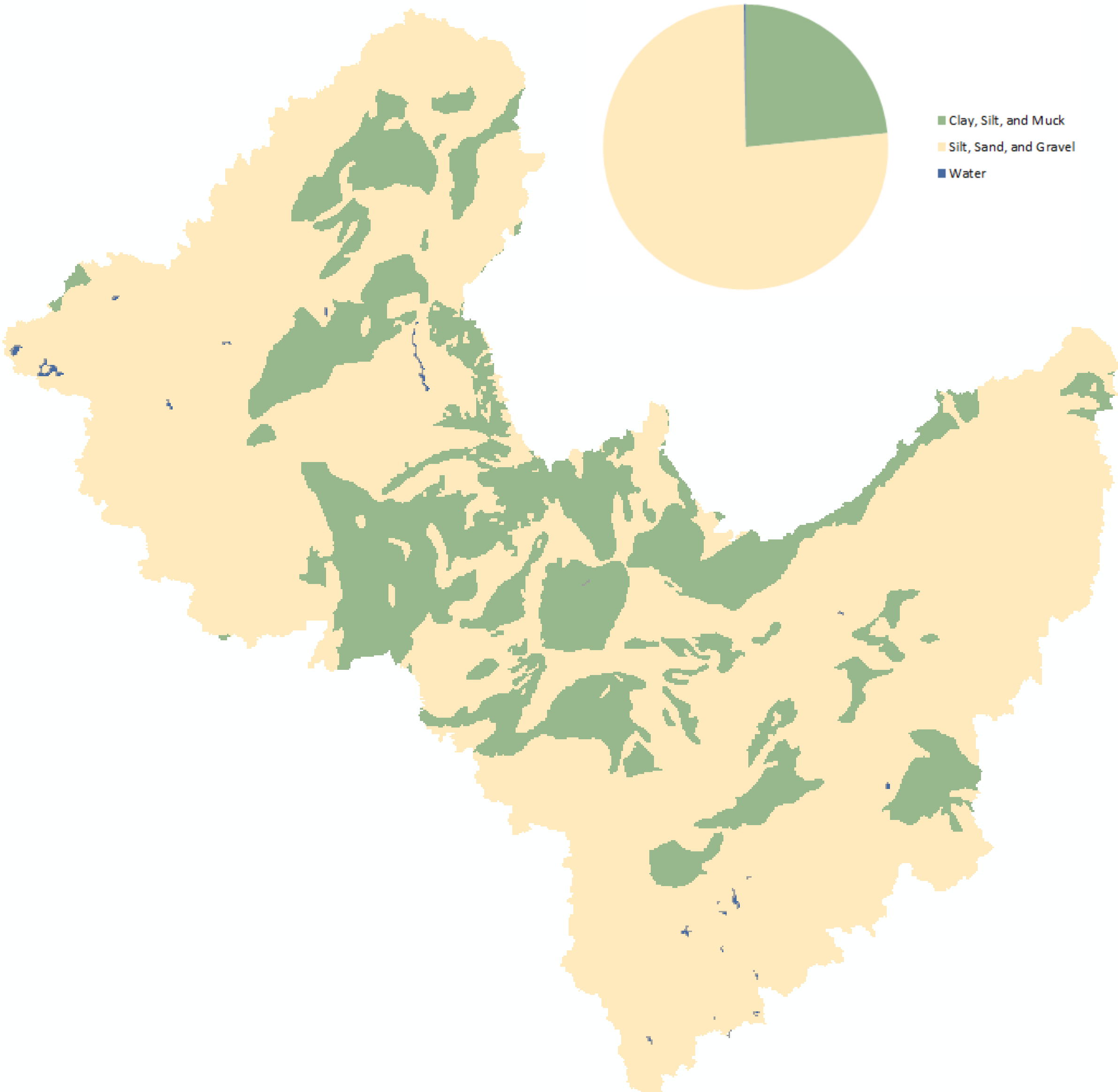




Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

32, SAGINAW RIVER WATERSHED

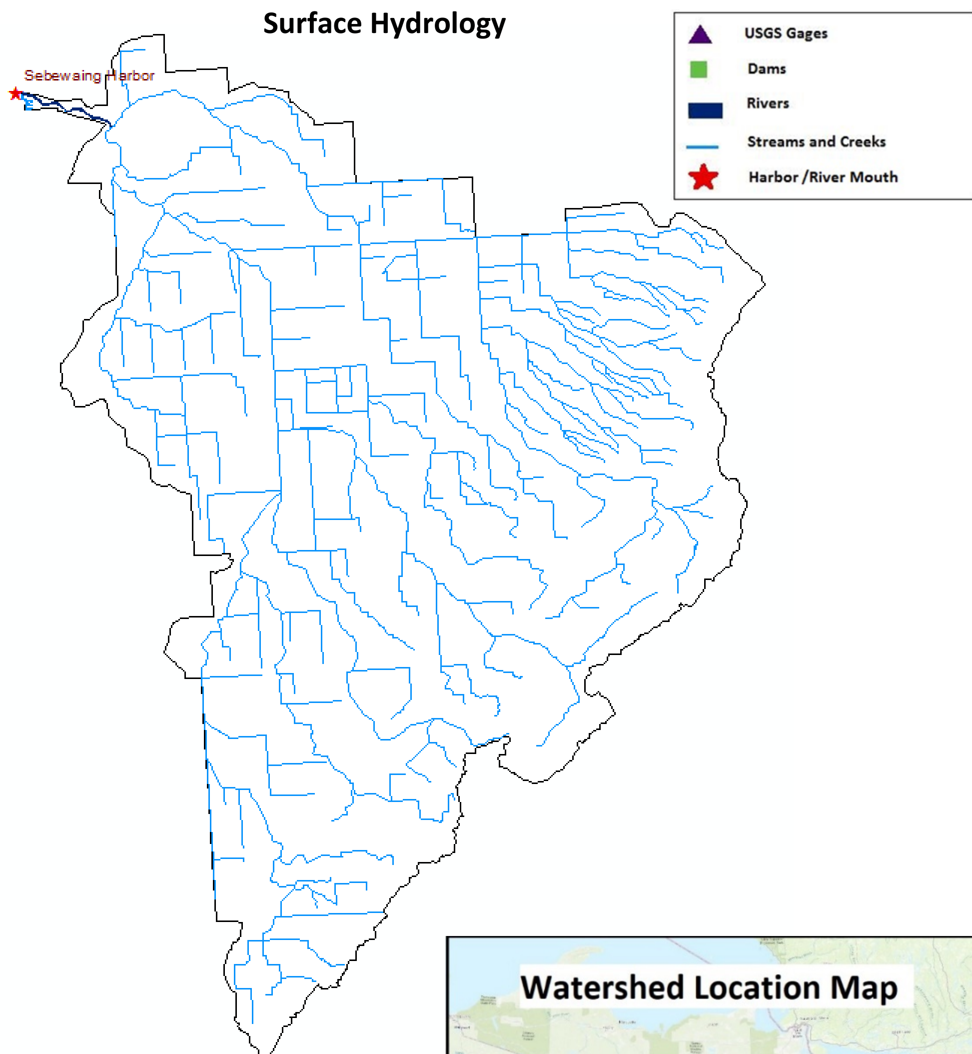
Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	3780.28	23.43%
Silt, Sand, and Gravel	12320.60	76.38%
Water	30.09	0.19%
Total Watershed Area	16130.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

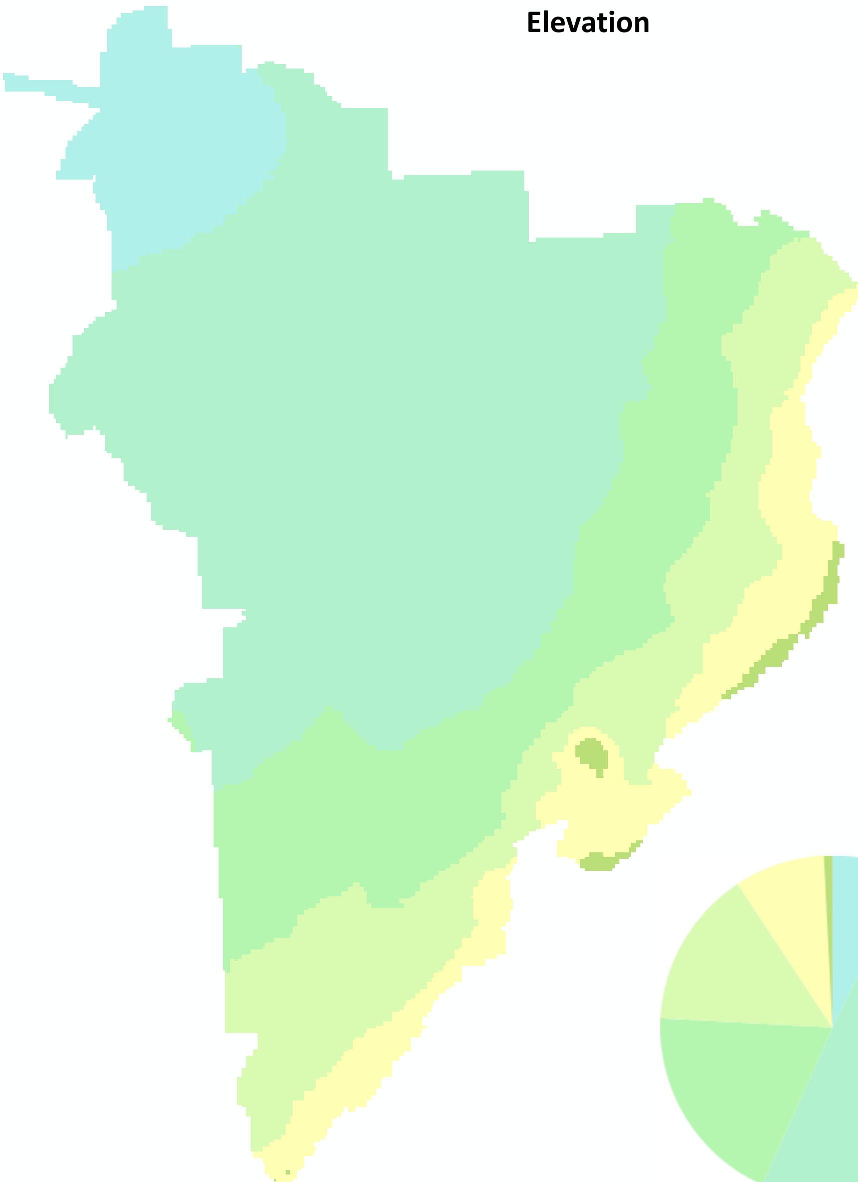
APPENDIX KK. SEBEWAING RIVER WATERSHED (33)

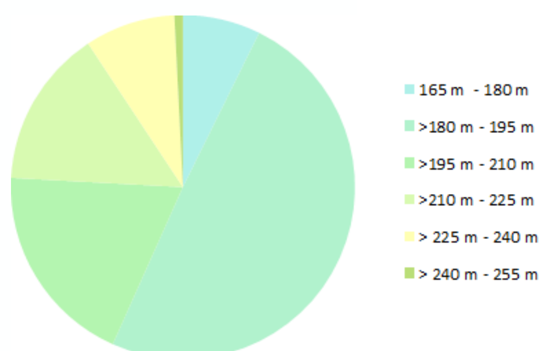


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

33, SEBEWAING RIVER WATERSHED

Elevation





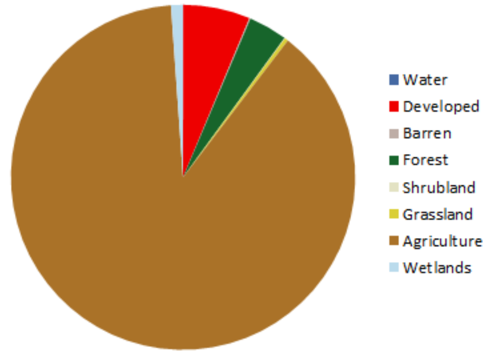
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	19.67	7.31%
>180 m - 195 m	132.79	49.37%
>195 m - 210 m	51.57	19.17%
>210 m - 225 m	39.94	14.85%
>225 m - 240 m	22.87	8.50%
>240 m - 255 m	2.13	0.79%
Size of Drainage Area	268.97	100.00%

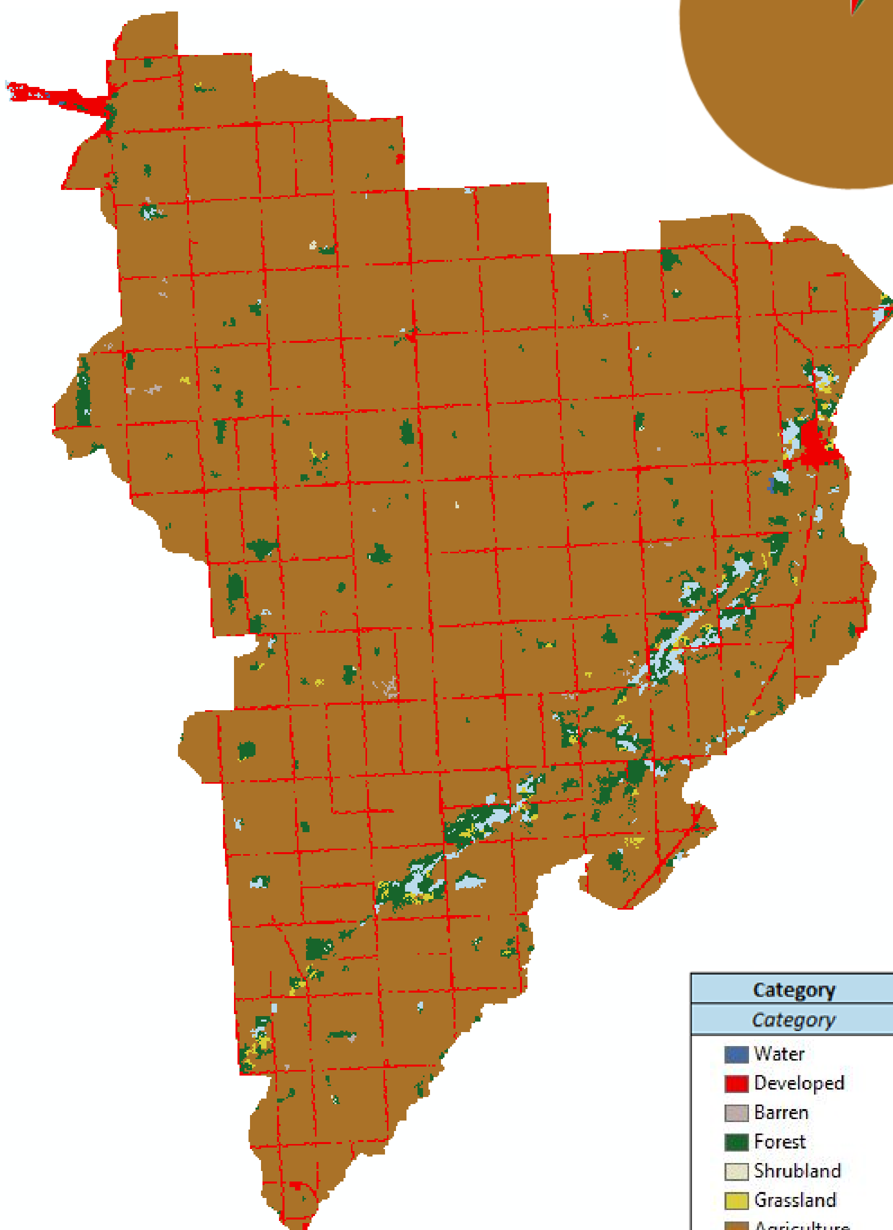
Sebewaing Watershed		
Elevation Statistics		
Size of Drainage Area	**268.97**	***km²***
Maximum	244.00	*m*
Minimum	177.00	*m*
Average	197.03	*m*
Standard Deviation	16.35	*m*

All Elevation Measurements with Respect to North American Datum 1983

33, SEBEWAING RIVER WATERSHED

Land Use





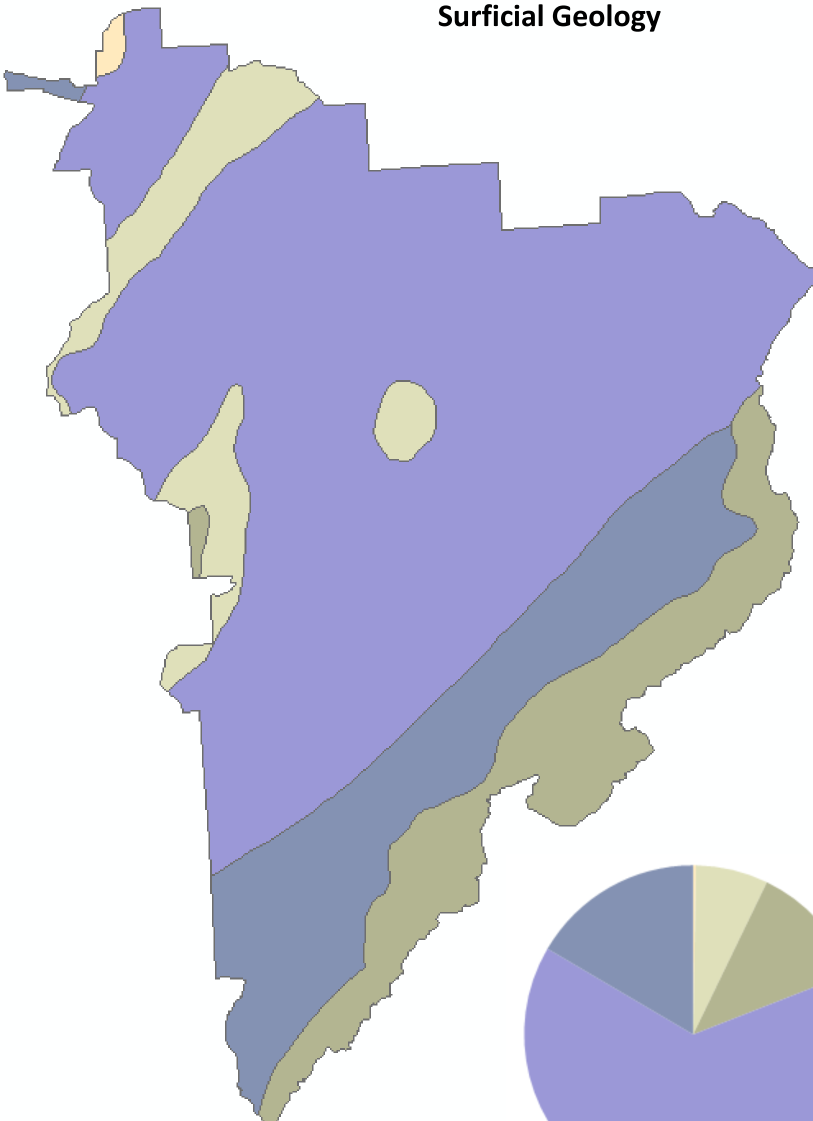
Category	Area	Percentage
Category	*km²*	*%*
Water	0.06	0.02%
Developed	16.90	6.28%
Barren	0.26	0.10%
Forest	9.78	3.64%
Shrubland	0.12	0.05%
Grassland	0.92	0.34%
Agriculture	237.89	88.45%
Wetlands	3.04	1.13%
Total	268.97	100.00%

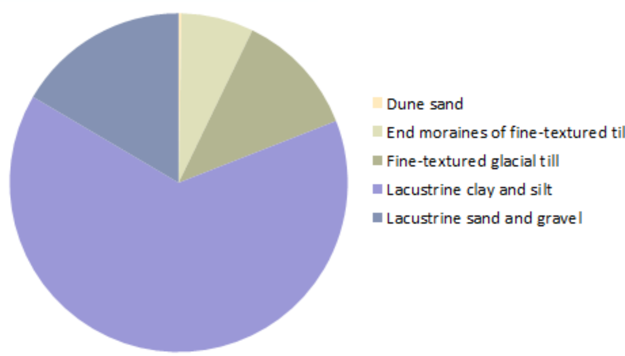
EGLE Runoff Curve Number
78.9

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

33, SEBEWAING RIVER WATERSHED

Surficial Geology



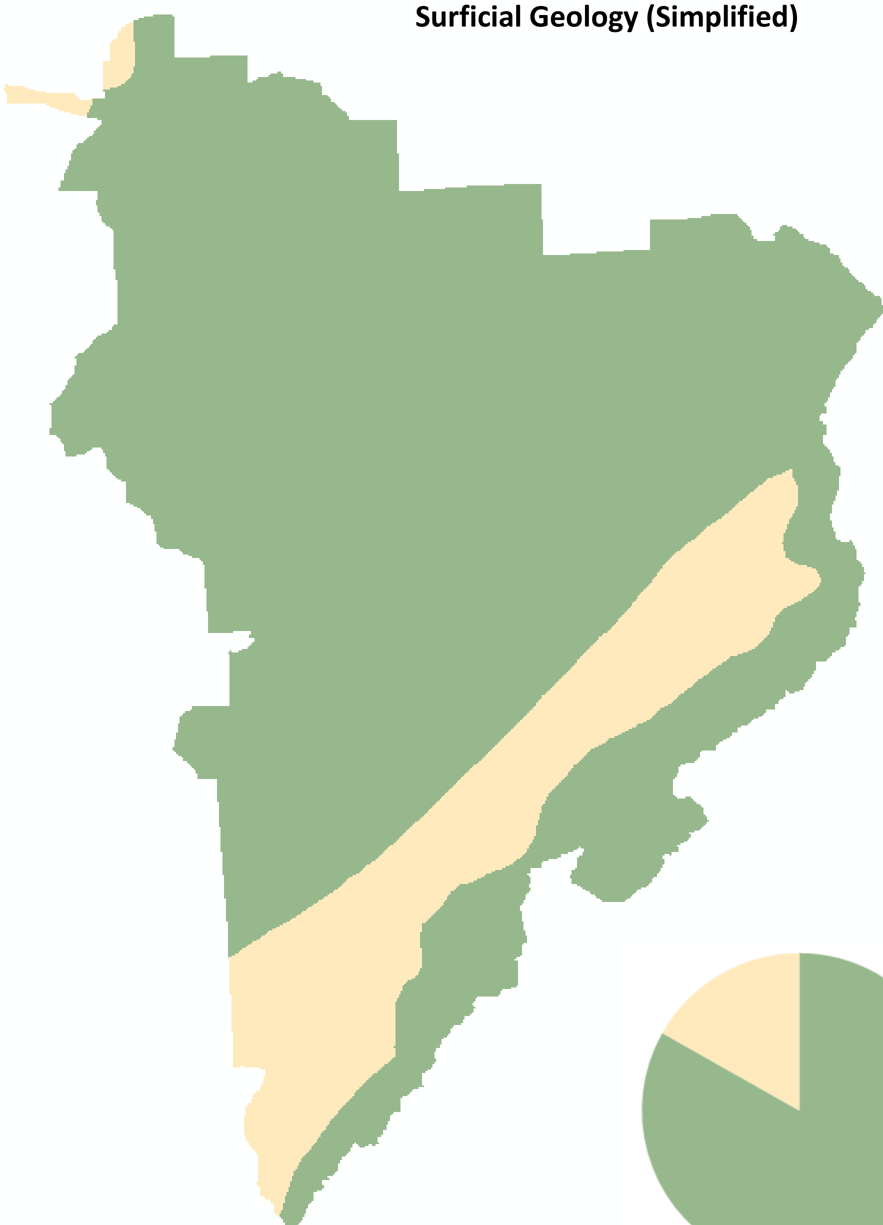


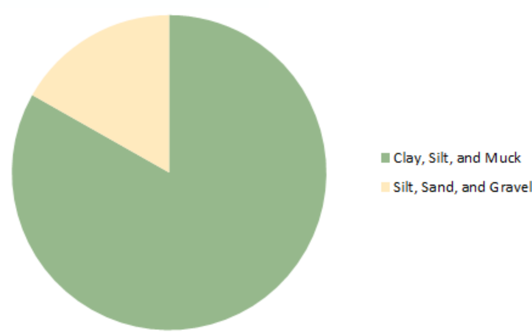
Category	Area	Percentage
Category	*km²*	*%*
Dune sand	0.72	0.27%
End moraines of fine-textured till	18.61	6.92%
Fine-textured glacial till	31.95	11.88%
Lacustrine clay and silt	173.21	64.40%
Lacustrine sand and gravel	44.49	16.54%
Total Watershed Area	268.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

33, SEBEWAING RIVER WATERSHED

Surficial Geology (Simplified)



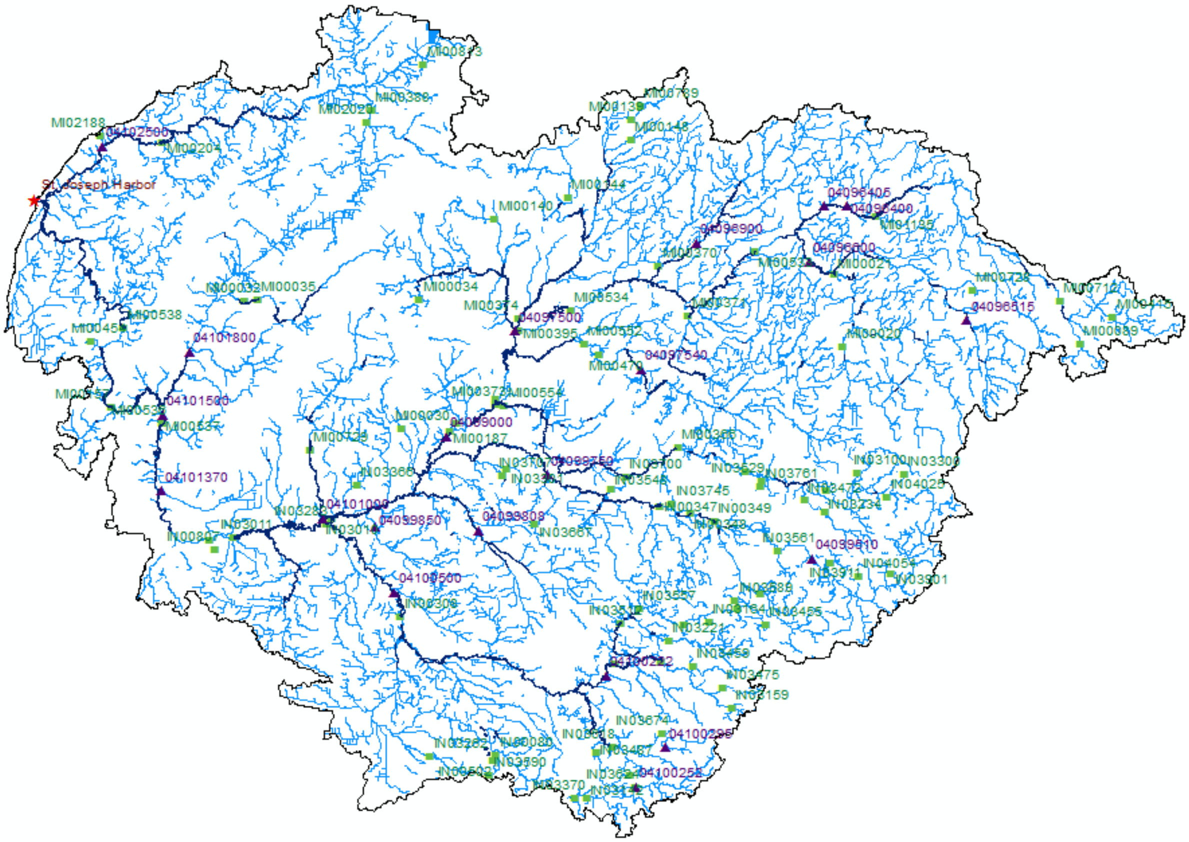


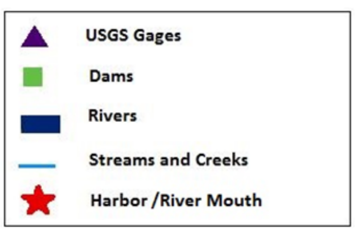
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	*223.76*	83.19%
Silt, Sand, and Gravel	45.21	16.81%
Total Watershed Area	268.97	100.00%

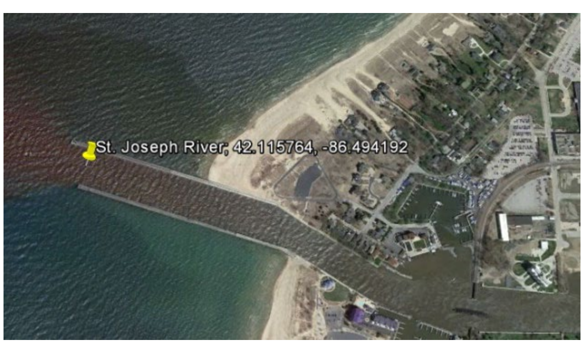
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

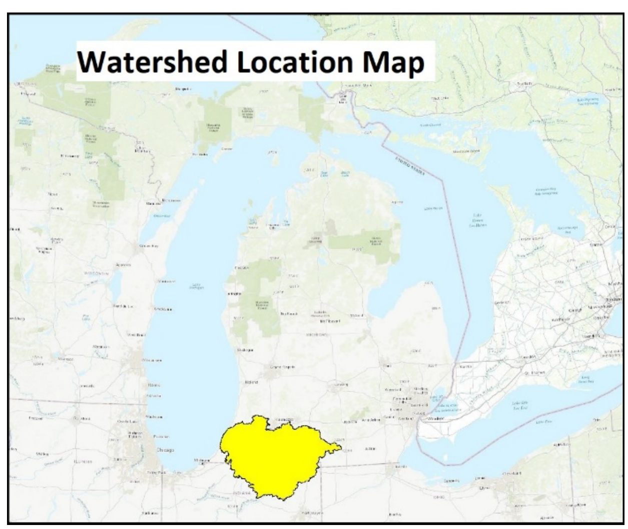
APPENDIX LL. ST. JOSEPH RIVER WATERSHED (34)

Surface Hydrology









Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

34, ST. JOSEPH RIVER WATERSHED

Dam Information and USGS Streamgages

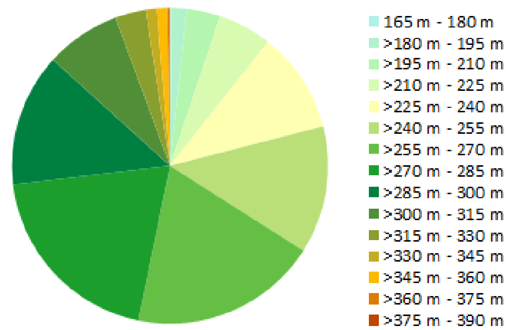
USACE's National Inventory of Dams (NID)							
NIDID	**Dam Name**	**Longitude**	**Latitude**	**NIDID**	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***	***National ID***	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
IN00080	PAPAKEECHIE LAKE	-85.670000	41.375550	IN03759	WALDRON LAKE (WEST LAKES) CONTROL STRUCTURE	-85.457220	41.497780
IN00308	GOSHEN POND DAM	-85.836660	41.560830	IN03761	WALL LAKE CONTROL STRUCTURE	-85.197220	41.731940
IN00347	ONTARIO MILLPOND DAM	-85.375830	41.706390	IN03901	GORDON T. ANDERSON EARTHEN DAM	-84.968330	41.613060
IN00348	NASBY LAKE DAM	-85.322780	41.695830	IN03911	SILVER LAKE CONTROL STRUCTURE	-85.075000	41.629170
IN00349	MONGO RESERVOIR DAM	-85.280000	41.685000	IN04025	MINIFENOKEE LAKE DAM	-84.973610	41.715000
IN00383	SYLVAN LAKE DAM	-85.376660	41.498330	IN04054	THOMAS PAPAIK LAKE DAM	-85.025000	41.609440
IN00502	FLATBELLY LAKE DAM	-85.673890	41.368330	MI00187	Mottville	-85.748300	41.806700
IN00787	LAKE BARBARA DAM	-85.432500	41.348890	MI00157	Buchanan	-86.351200	41.839100
IN00797	GREENFIELD MILLS DAM	-85.223610	41.750830	MI00534	Sturgis	-85.533300	41.966700
IN00801	JIMMERSON LAKE DAM	-85.081940	41.725000	MI00537	Niles	-86.259200	41.818100
IN00806	BALL BAND DAM (IN-CHANNEL)	-86.176940	41.663330	MI00535	Constantine	-85.666700	41.850000
IN00807	South Bend	-86.166700	41.650000	MI01135	A H Randall Milling Dam	-84.986660	42.088330
IN03010	Elkhart	-85.958300	41.691700	MI00395	Three Rivers	-85.625000	41.941700
IN03011	Twin Branch	-86.131700	41.666700	MI00139	Cooks Mill Dam	-85.421670	42.220000
IN03100	LONG BEACH LAKE DAM	-85.025830	41.747220	MI00140	Fox And Bears Dam	-85.667260	42.089880
IN03117	ADAMS LAKE CONTROL STRUCTURE	-85.336390	41.548330	MI00144	Lee Paper Company Dam	-85.536670	42.118330
IN03142	BEAR LAKE CONTROL STRUCTURE	-85.510280	41.319160	MI00148	Scotts Mill Dam	-85.422240	42.194190
IN03154	BIG LONG LAKE CONTROL STRUCTURE	-85.241390	41.568050	MI00020	Blackhawk Dam	-85.048330	41.916670
IN03157	BIG TURKEY LAKE CONTROL STRUCTURE	-85.199450	41.588050	MI02020	Briggs Dam	-85.895000	42.218330
IN03159	BIXLER LAKE CONTROL STRUCTURE	-85.252780	41.436940	MI00204	Watervliet Dam	-86.260000	42.191670
IN03164	BLACKMAN LAKE CONTROL STRUCTURE	-85.291660	41.550560	MI00021	Morrison West Chain Lake Level Control Structure	-85.061670	42.013330
IN03221	CLIFF PETTIT DAM	-85.362780	41.526940	MI02188	Welch Dam	-86.371670	42.200000
IN03234	CROOKED LAKE CONTROL STRUCTURE	-85.084720	41.696390	MI00030	Centenial Mill Dam	-85.835000	41.811670
IN03262	DEWART LAKE CONTROL STRUCTURE	-85.785840	41.374720	MI00032	Lower Mill Dam	-86.113330	41.981670
IN03283	ELKHART RIVER (IN-CHANNEL) DAM	-85.967500	41.685000	MI00034	Streater Mill Dam	-85.801670	41.983330
IN03300	FISH LAKE CONTROL STRUCTURE	-84.943050	41.745560	MI00035	Upper Mill Dam	-86.090000	41.983330
IN03301	FISH LAKE (NR. SCOTT) CONTROL STRUCTURE	-85.648610	41.756660	MI00366	Fawn River Mill Dam	-85.343330	41.783330
IN03366	HEATON LAKE CONTROL STRUCTURE	-85.914440	41.735550	MI00368	Hartenstene Dam	-85.736660	41.818330
IN03370	HIGH CONTROL STRUCTURE	-85.530560	41.318890	MI00370	Kings Mill Dam	-85.375000	42.025000
IN03455	LAKE OF THE WOODS CONTROL STRUCTURE	-85.191940	41.546390	MI00371	Lamberson Dam	-85.323330	41.958330
IN03459	LATTA LAKE CONTROL STRUCTURE	-85.320270	41.491660	MI00373	Fawn River Power Company Dam	-85.666660	41.843330
IN03472	LAKE GAGE CONTROL STRUCTURE	-85.119720	41.712780	MI00374	Portage Plant Dam	-85.625000	41.956670
IN03475	LITTLE LONG CONTROL STRUCTURE	-85.268330	41.463330	MI00388	Maple Lake Dam	-85.886670	42.235000
IN03487	LOWER LONG LAKE CONTROL STRUCTURE	-85.492500	41.378610	MI00415	Lake Bel-Air Dam	-84.566670	41.950000
IN03512	MESSICK LAKE CONTROL STRUCTURE	-85.448050	41.551110	MI00454	Trickett Dam	-86.386670	41.926670
IN03529	MUD LAKE CONTROL STRUCTURE	-85.194440	41.738330	MI00470	Lake Templene Dam	-85.483330	41.908330
IN03548	NORTH TWIN LAKE CONTROL STRUCTURE	-85.463330	41.729160	MI00533	Riley Dam	-85.203330	42.043330
IN03557	OLIVER LAKE CONTROL STRUCTURE	-85.414720	41.569160	MI00536	French Paper Company Dam	-86.260000	41.818330
IN03561	OTTER LAKE (WEST) CONTROL STRUCTURE	-85.168610	41.645000	MI00538	Berrien Springs Dam	-86.328330	41.945000
IN03589	PRETTY LAKE CONTROL STRUCTURE	-85.244160	41.579170	MI00552	Centreville Dam	-85.508330	41.921670
IN03590	PRICE LAKE	-85.681660	41.349450	MI00554	Upper Constantine Dam	-85.651660	41.841670
IN03618	RICHARD GRIEGER LAKE DAM	-85.463330	41.386670	MI00712	Jonesville Millpond Dam	-84.660000	41.973330
IN03624	RIVIR LAKE CONTROL STRUCTURE	-85.422500	41.332780	MI00728	Briskey Pond Dam	-84.816670	41.988330
IN03667	SHIPSHEWANA LAKE CONTROL STRUCTURE	-85.598340	41.683060	MI00729	Adamsville Hydroelectric Dam	-85.996670	41.783330
IN03674	SKINNER LAKE CONTROL STRUCTURE	-85.376660	41.403050	MI00789	Taylor Dam	-85.405000	42.238330
IN03700	STAR MILL DAM	-85.436670	41.745280	MI00813	Wolf Lake Fish Hatchery Dams	-85.793610	42.294720
IN03707	STONE LAKE CONTROL STRUCTURE	-85.656670	41.748610	MI00089	Hillsdale Millpond Dam	-84.625210	41.915150
IN03745	TROXEL RUN DAM	-85.355830	41.708890				

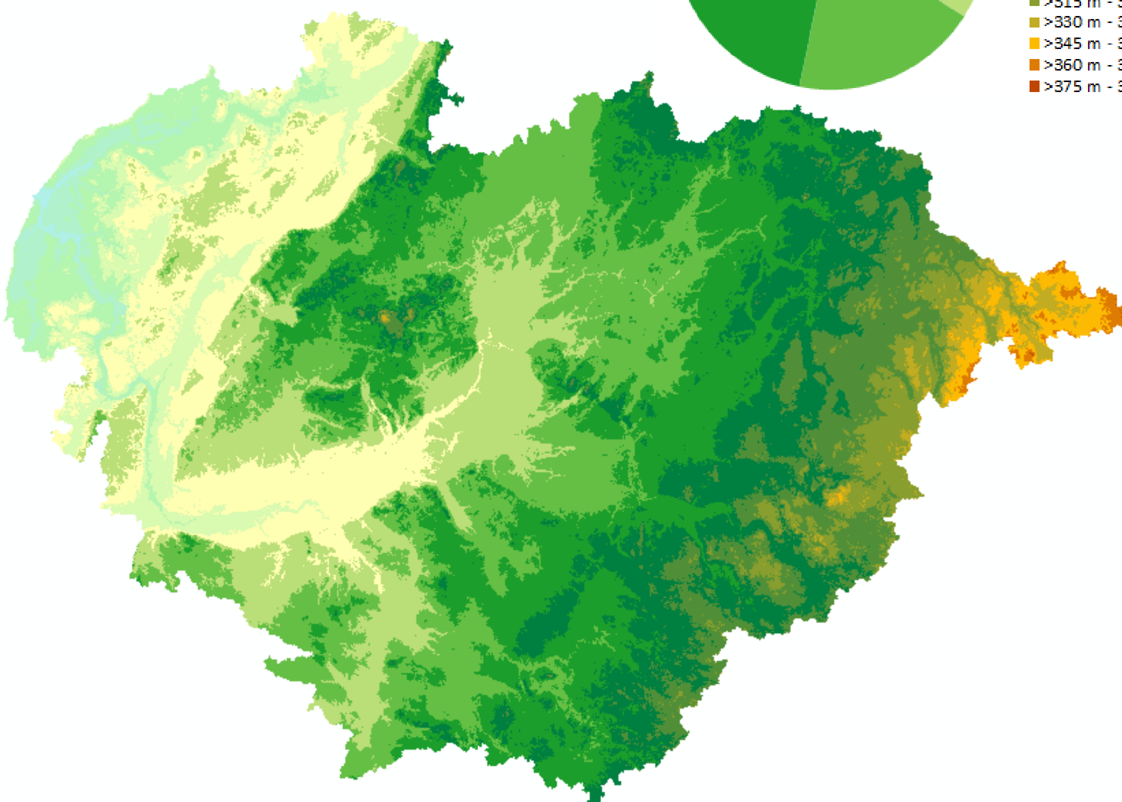
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4096400	ST. JOSEPH RIVER NEAR BURLINGTON, MI	*-85.040252*	*42.102824*	
4096405	ST. JOSEPH RIVER AT BURLINGTON, MI	-85.079976	42.103101	yes
4096515	SOUTH BRANCH HOG CREEK NEAR ALLEN, MI	-84.82774	41.948659	yes
4096600	COLDWATER RIVER NEAR HODUNK, MI	-85.106918	42.029214	
4096900	NOTTAWA CREEK NEAR ATHENS, MI	-85.308318	42.055603	
4097500	ST. JOSEPH RIVER AT THREE RIVERS, MI	-85.632771	41.940326	yes
4097540	PRAIRIE RIVER NEAR NOTTAWA, MI	-85.409428	41.888383	yes
4099000	ST. JOSEPH RIVER AT MOTTVILLE, MI	-85.756105	41.800883	yes
4099510	PIGEON CREEK NR ANGOLA, IND.	-85.109691	41.634495	yes
4099750	PIGEON RIVER NEAR SCOTT, IN	-85.576375	41.74894	yes
4099808	LITTLE ELKHART RIVER AT MIDDLEBURY, IND.	-85.700268	41.675328	
4099850	PINE CREEK NEAR ELKHART, IND.	-85.882497	41.681161	
4100222	NB ELKHART RIVER AT COSPERVILLE, IND.	-85.475537	41.481716	yes
4100252	FORKER CREEK NEAR BURR OAK, IND	-85.423591	41.332826	
4100295	RIMMELL BRANCH NEAR ALBION, IN	-85.370534	41.385327	
4100500	ELKHART RIVER AT GOSHEN, IND.	-85.848606	41.593383	yes
4101000	ST. JOSEPH RIVER AT ELKHART, IND	-85.975	41.691716	yes
4101370	JUDAY CREEK NEAR SOUTH BEND, IN	-86.262785	41.728659	yes
4101500	ST. JOSEPH RIVER AT NILES, MI	-86.259732	41.829214	yes
4101800	DOWAGIAC RIVER AT SUMNERVILLE, MI	-86.213068	41.91338	yes
4102500	PAW PAW RIVER AT RIVERSIDE, MI	-86.368357	42.186149	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				**14**

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams

34, ST. JOSEPH RIVER WATERSHED

Elevation





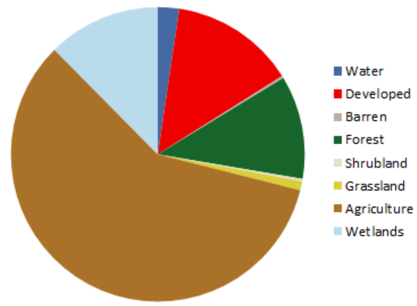
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	18.48	0.15%
>180 m - 195 m	188.89	1.55%
>195 m - 210 m	420.66	3.45%
>210 m - 225 m	670.41	5.49%
>225 m - 240 m	1261.49	10.33%
>240 m - 255 m	1593.72	13.06%
>255 m - 270 m	2341.47	19.18%
>270 m - 285 m	2427.07	19.88%
>285 m - 300 m	1663.17	13.63%
>300 m - 315 m	937.17	7.68%
>315 m -330 m	382.47	3.13%
>330 m - 345 m	138.14	1.13%
>345 m - 360 m	126.45	1.04%
>360 m - 375 m	35.86	0.29%
>375 m - 390 m	1.13	0.01%
Size of Drainage Area	12206.59	100.00%

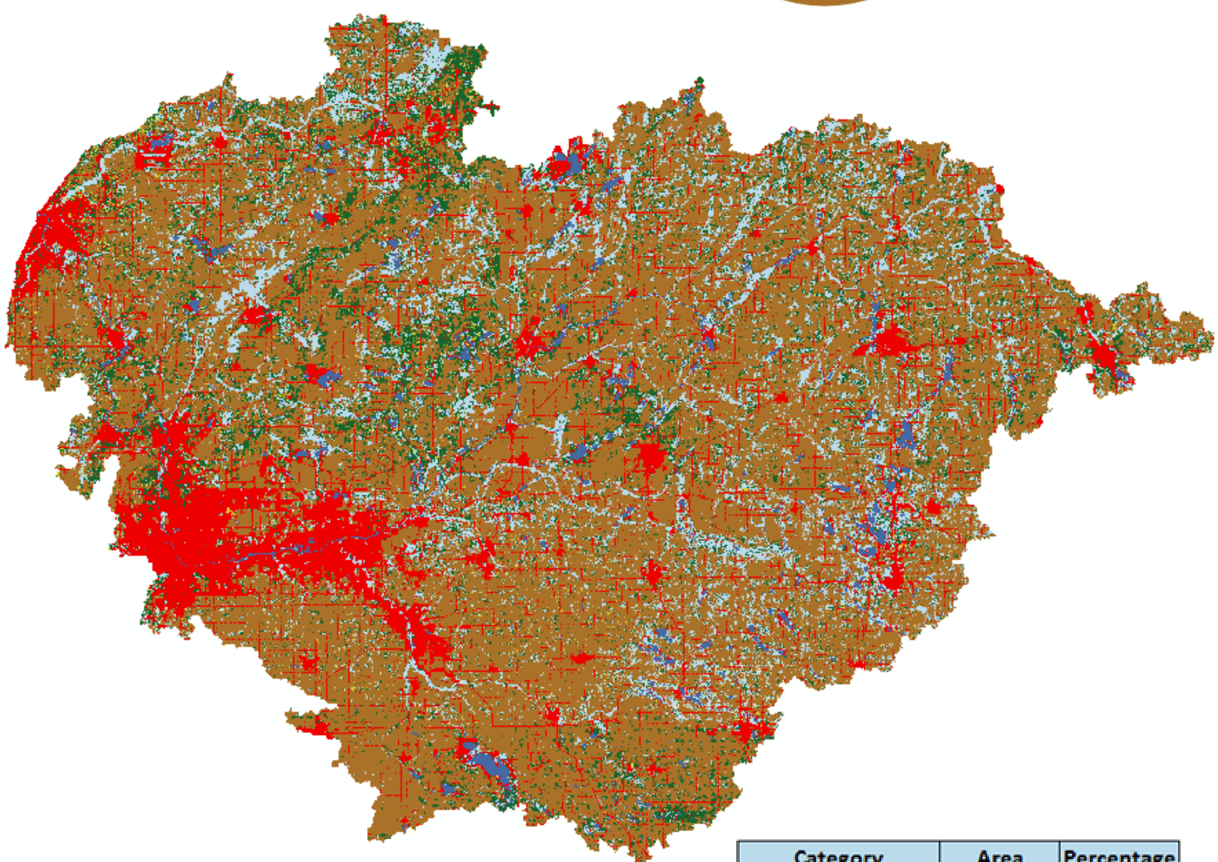
St. Joseph Watershed		
Elevation Statistics		
Size of Drainage Area	12206.59	*km²*
Maximum	389.00	*m*
Minimum	176.00	*m*
Average	266.29	*m*
Standard Deviation	32.22	*m*

All Elevation Measurements with Respect to North American Datum 1983

34, ST. JOSEPH RIVER WATERSHED

Land Use





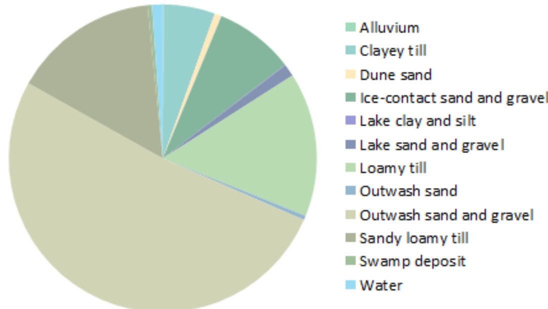
Category	Area	Percentage
Category	*km²*	*%*
Water	285.83	2.34%
Developed	1675.60	13.73%
Barren	29.48	0.24%
Forest	1386.32	11.36%
Shrubland	34.32	0.28%
Grassland	118.64	0.97%
Agriculture	7159.85	58.66%
Wetlands	1516.54	12.42%
Total	12206.59	100.00%

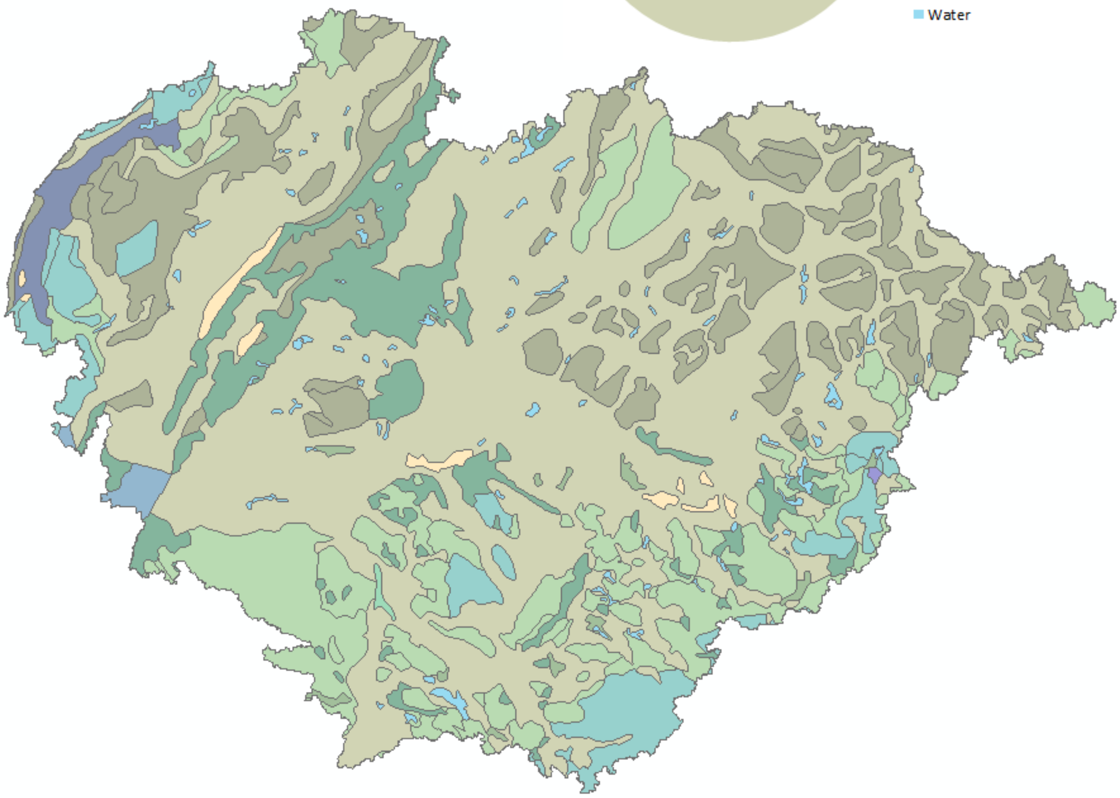
EGLE Runoff Curve Number
72.4

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

34, ST. JOSEPH RIVER WATERSHED

Surficial Geology



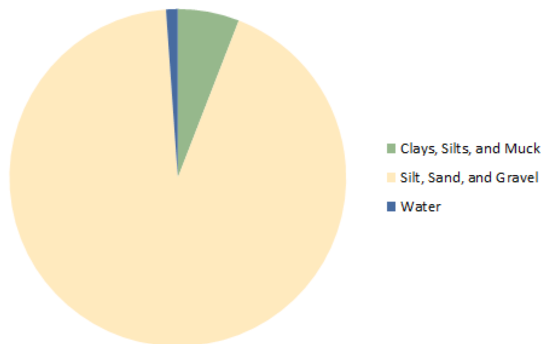


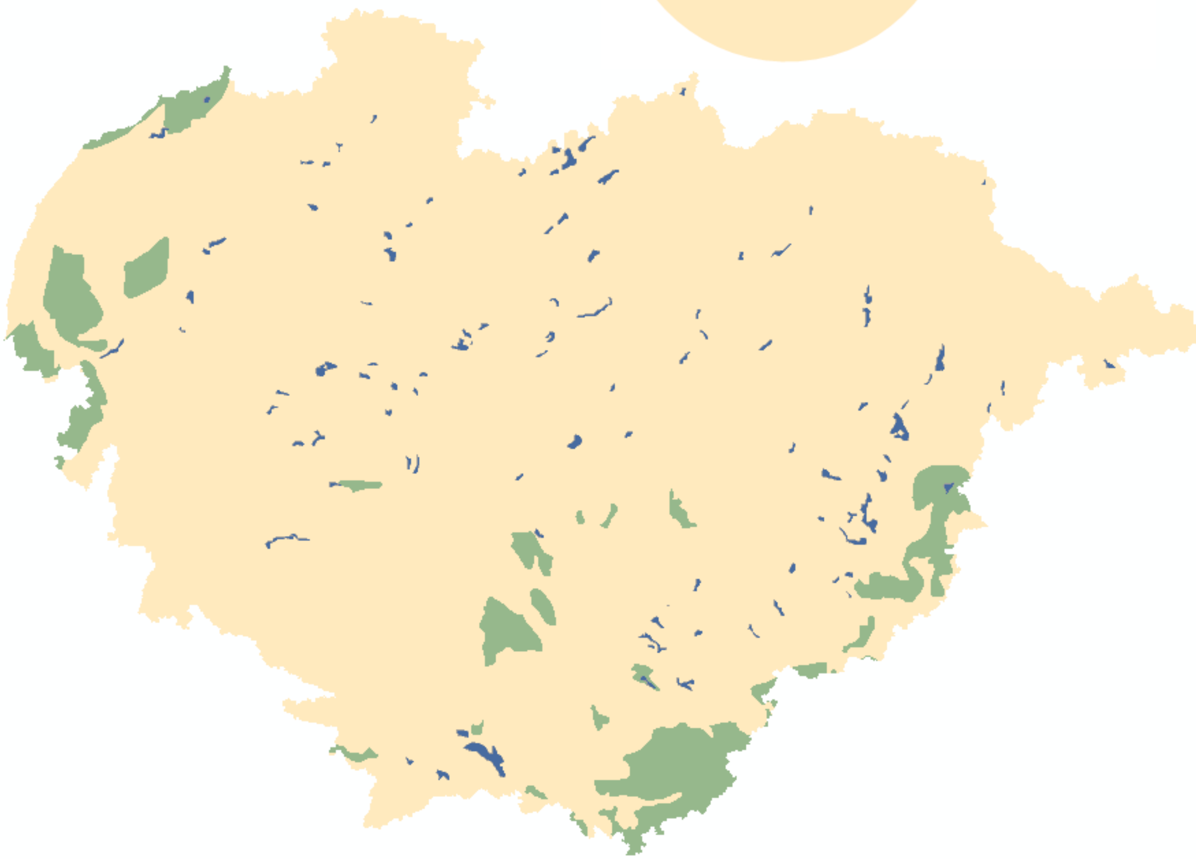
Category	Area	Percentage
Category	*km²*	*%*
Alluvium	9.67	0.08%
Clayey till	660.30	5.41%
Dune sand	90.31	0.74%
Ice-contact sand and gravel	1023.65	8.39%
Lake clay and silt	3.77	0.03%
Lake sand and gravel	159.46	1.31%
Loamy till	1849.23	15.15%
Outwash sand	54.37	0.45%
Outwash sand and gravel	6295.09	51.57%
Sandy loamy till	1867.31	15.30%
Swamp deposit	56.20	0.46%
Water	137.22	1.12%
Total Watershed Area	12206.59	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

34, ST. JOSEPH RIVER WATERSHED

Surficial Geology (Simplified)

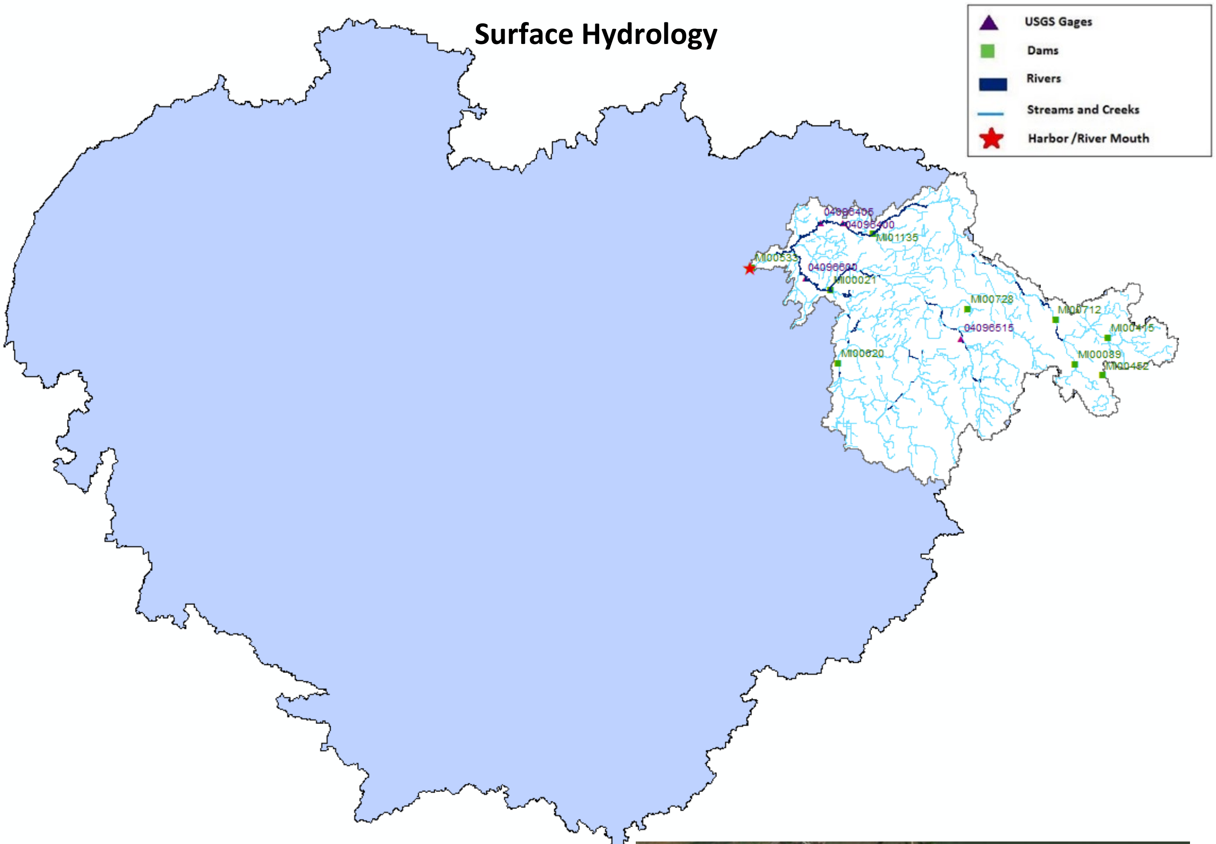




Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	720.26	5.90%
Silt, Sand, and Gravel	11349.10	92.98%
Water	137.22	1.12%
Total Watershed Area	12206.59	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX MM. ST. JOSEPH RIVER WATERSHED, RILEY DAM (34A)



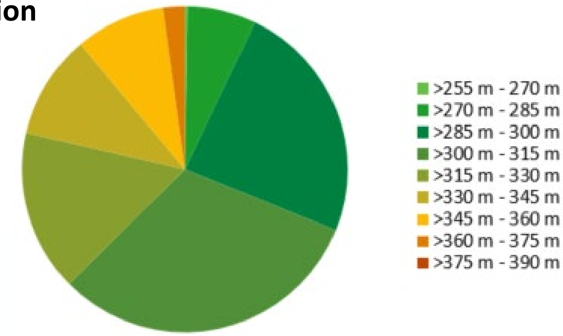
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01135	A H Randall Milling Dam	-84.986660	42.088330
MI00020	Blackhawk Dam	-85.048330	41.916670
MI00021	Morrison West Chain Lake Level Control Structure	-85.061670	42.013330
MI00415	Lake Bel-Air Dam	-84.566670	41.950000
MI00452	Weatherwood Dam	-84.575	41.9
MI00712	Jonesville Millpond Dam	-84.660000	41.973330
MI00728	Briskey Pond Dam	-84.816670	41.988330
MI00089	Hillsdale Millpond Dam	-84.625210	41.915150

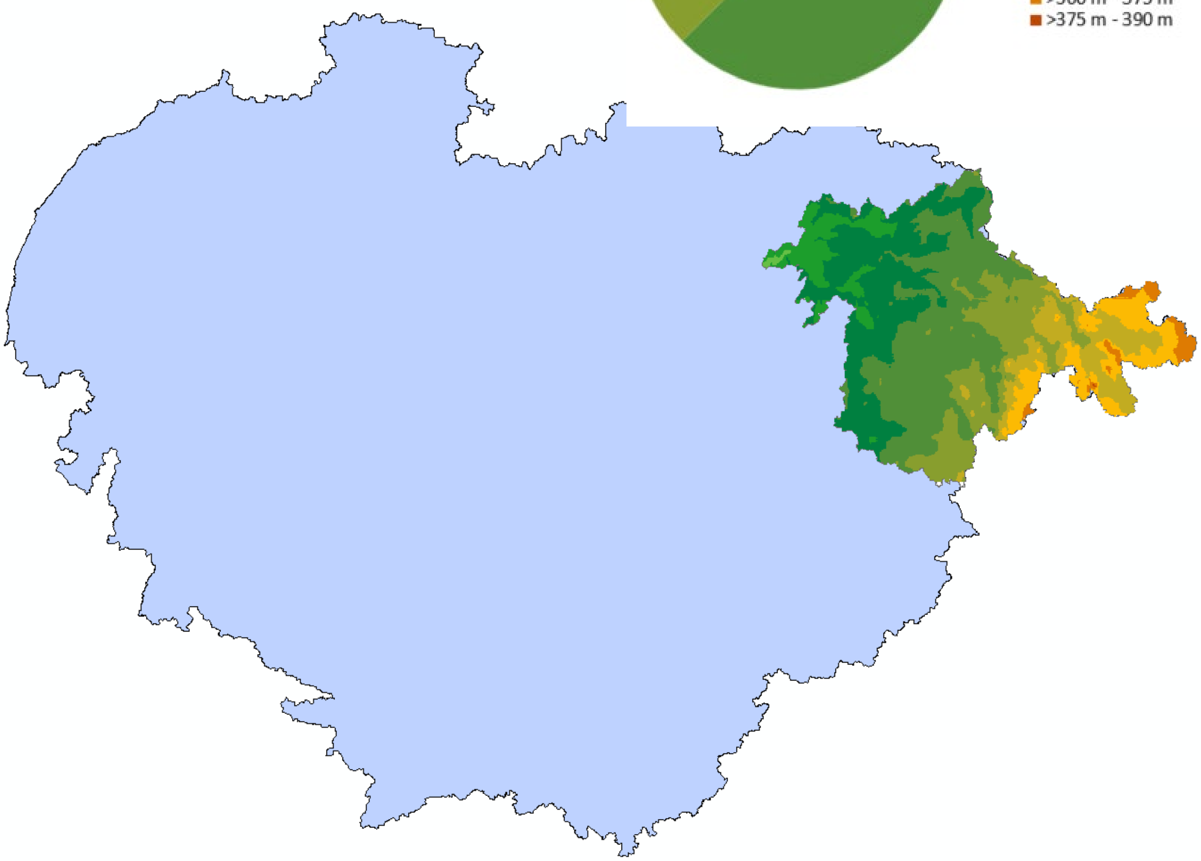
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4096400	ST. JOSEPH RIVER NEAR BURLINGTON, MI	*-85.040252*	*42.102824*	
4096405	ST. JOSEPH RIVER AT BURLINGTON, MI	-85.079976	42.103101	yes
4096515	SOUTH BRANCH HOG CREEK NEAR ALLEN, MI	-84.82774	41.948659	yes
4096600	COLDWATER RIVER NEAR HODUNK, MI	-85.106918	42.029214	
Number of Active USGS Stream Gage's in Drainage Area (2009)				2

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Stream Gages includes only active gages and gages with 20+ years of discharge records since 1950

34A, ST. JOSEPH RIVER WATERSHED, RILEY DAM

Elevation



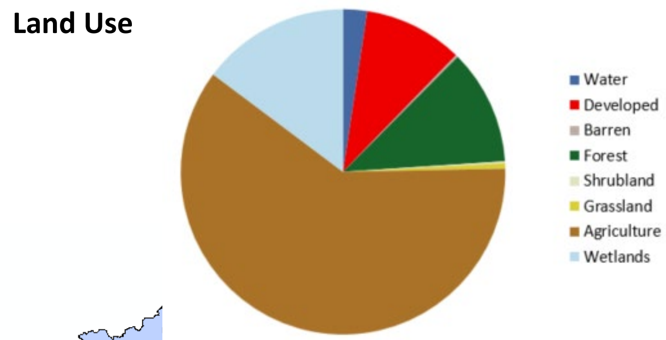


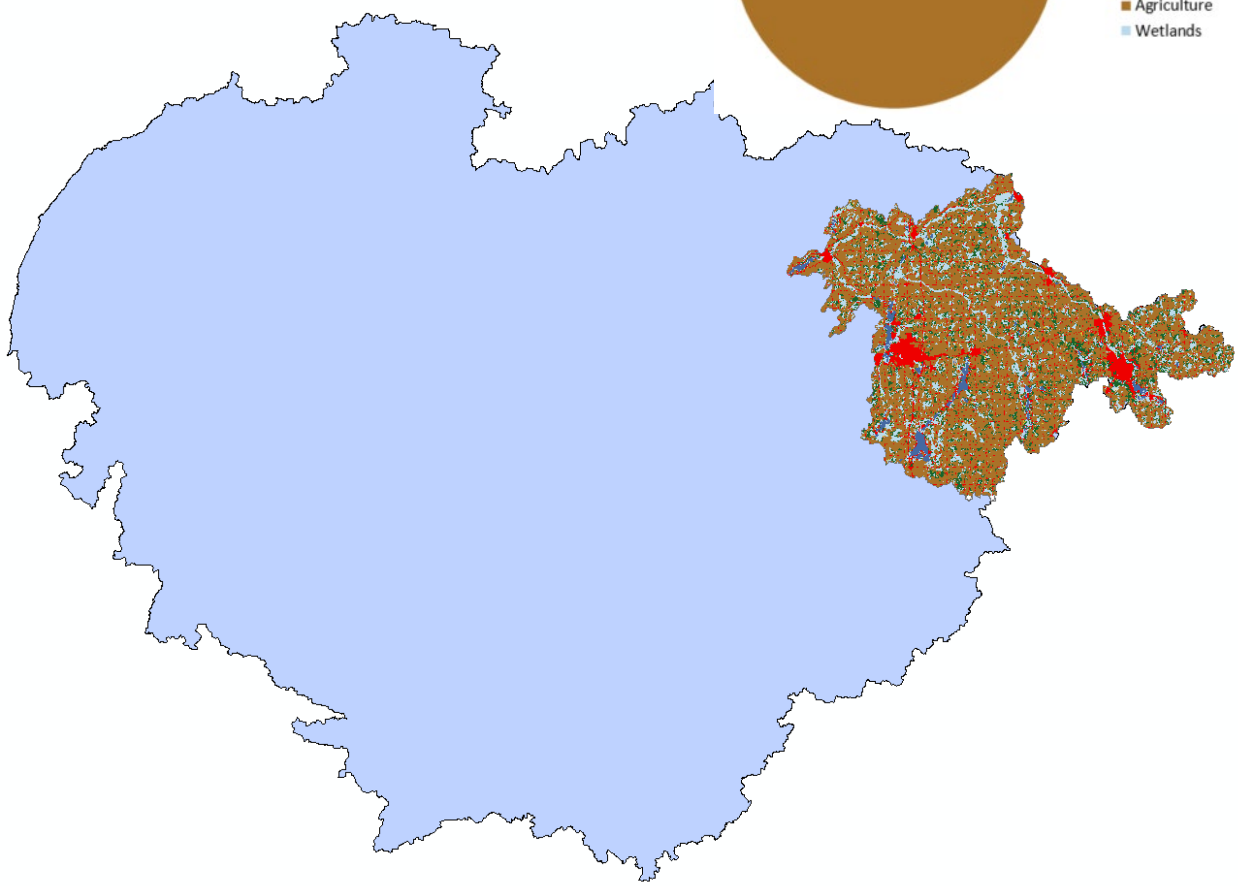
Category	Area	Percentage
Category	*km²*	*%*
>255 m - 270 m	3.64	0.27%
>270 m - 285 m	92.63	6.82%
>285 m - 300 m	326.03	24.01%
>300 m - 315 m	427.71	31.50%
>315 m - 330 m	217.17	15.99%
>330 m - 345 m	140.49	10.35%
>345 m - 360 m	120.67	8.89%
>360 m - 375 m	29.34	2.16%
>375 m - 390 m	0.15	0.01%
Size of Drainage Area	1357.83	100.00%

Riley Dam		
Elevation Statistics		
Size of Drainage Area	**1357.83**	***km²***
Maximum	380.00	*m*
Minimum	264.00	*m*
Average	310.94	*m*
Standard Deviation	21.56	*m*

All Elevation Measurements with Respect to North American Datum 1983

34A, ST. JOSEPH RIVER WATERSHED, RILEY DAM





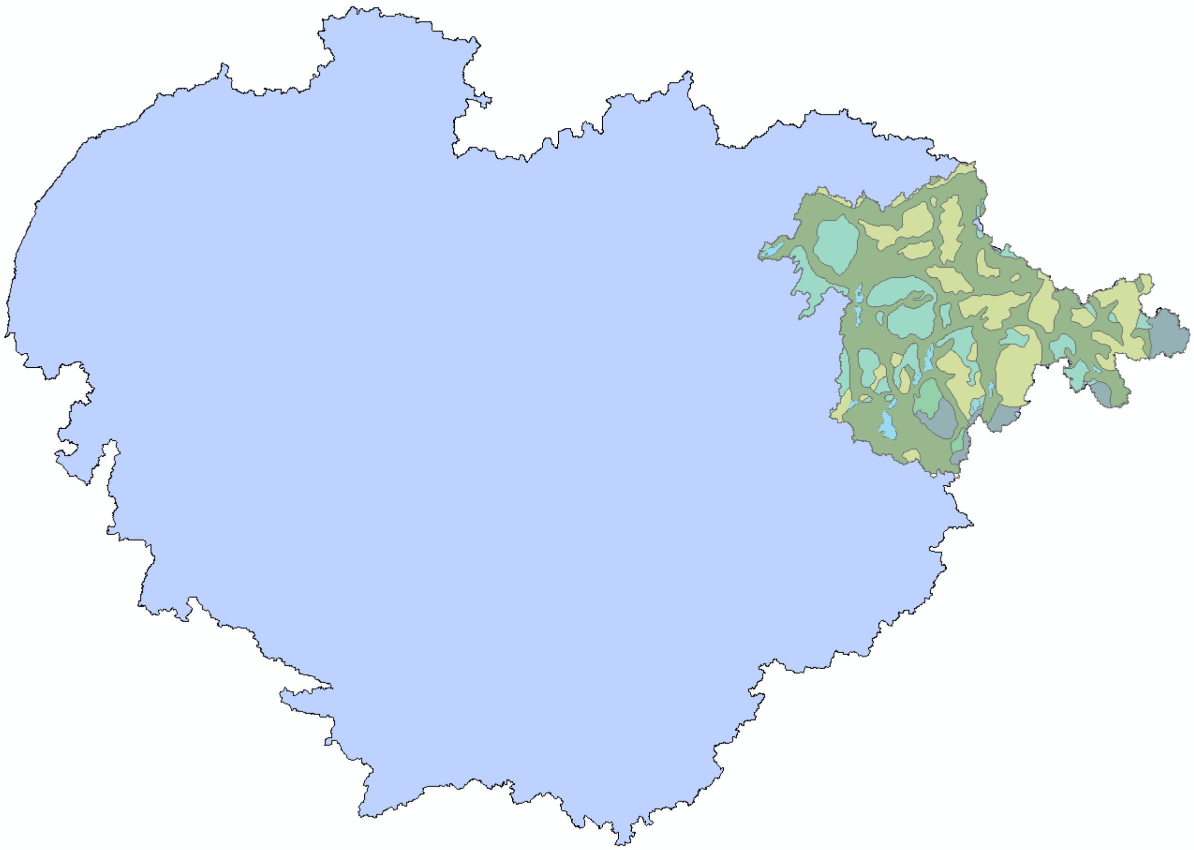
Category	Area	Percentage
Category	*km²*	*%*
Water	32.60	2.40%
Developed	133.96	9.87%
Barren	2.94	0.22%
Forest	155.75	11.47%
Shrubland	2.65	0.20%
Herbaceous	7.29	0.54%
Agriculture	822.08	60.54%
Wetlands	200.55	14.77%
Total	1357.83	100.00%

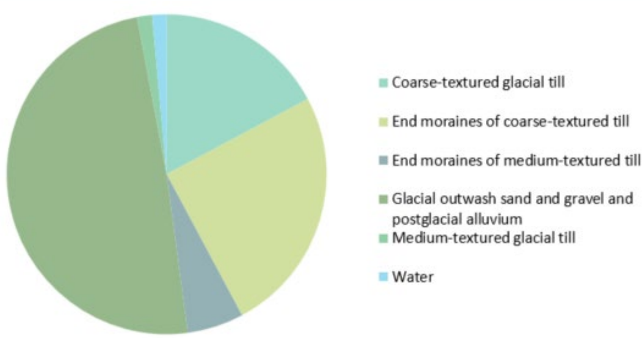
EGLE Runoff Curve Number
75.4

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

34A, ST. JOSEPH RIVER WATERSHED, RILEY DAM

Surficial Geology



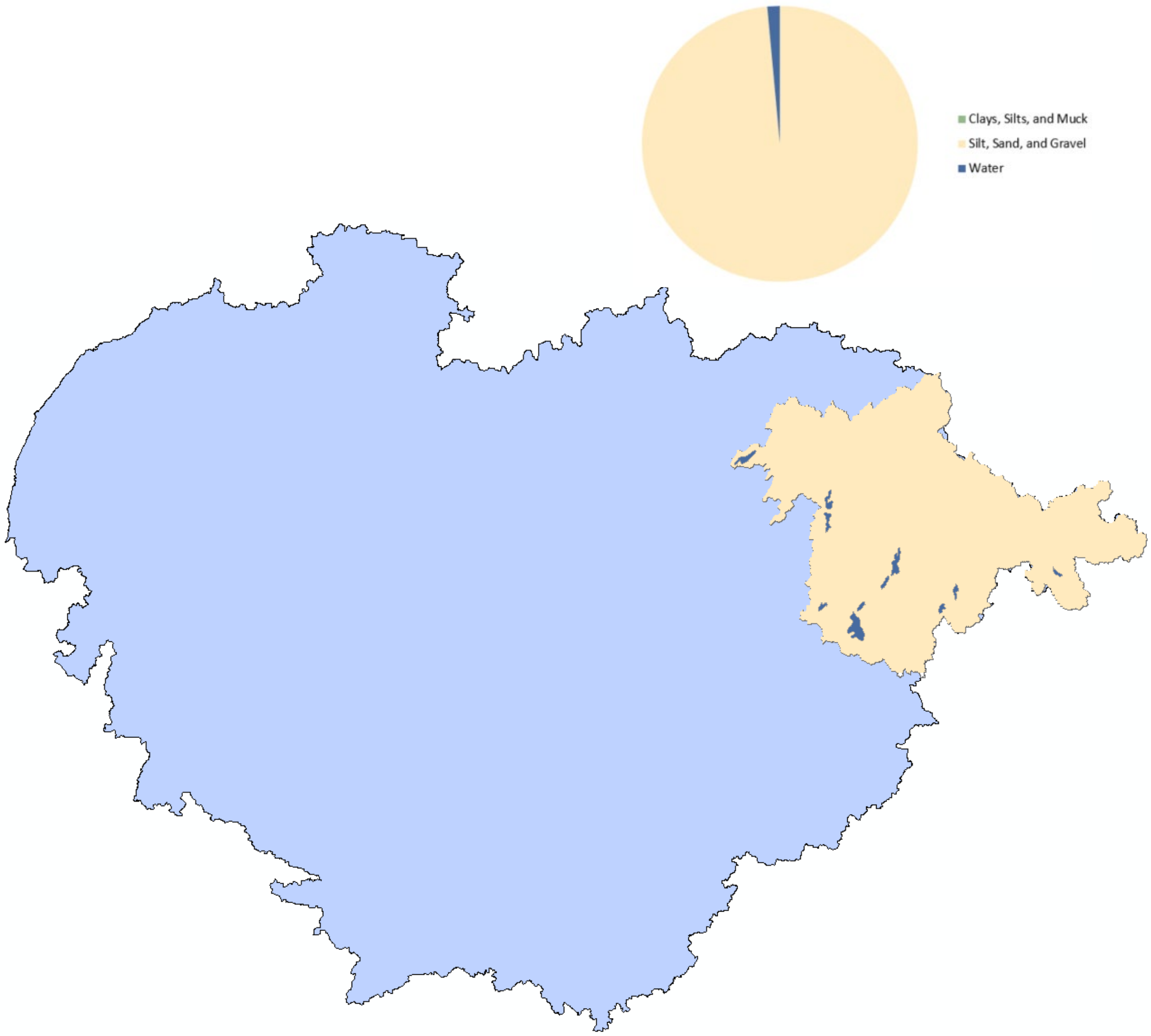


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	233.70	17.21%
End moraines of coarse-textured till	339.05	24.97%
End moraines of medium-textured till	77.54	5.71%
Glacial outwash sand and gravel and postglacial alluvium	667.14	49.13%
Medium-textured glacial till	20.49	1.51%
Water	19.91	1.47%
Total Watershed Area	1357.83	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

34A, ST. JOSEPH RIVER WATERSHED, RILEY DAM

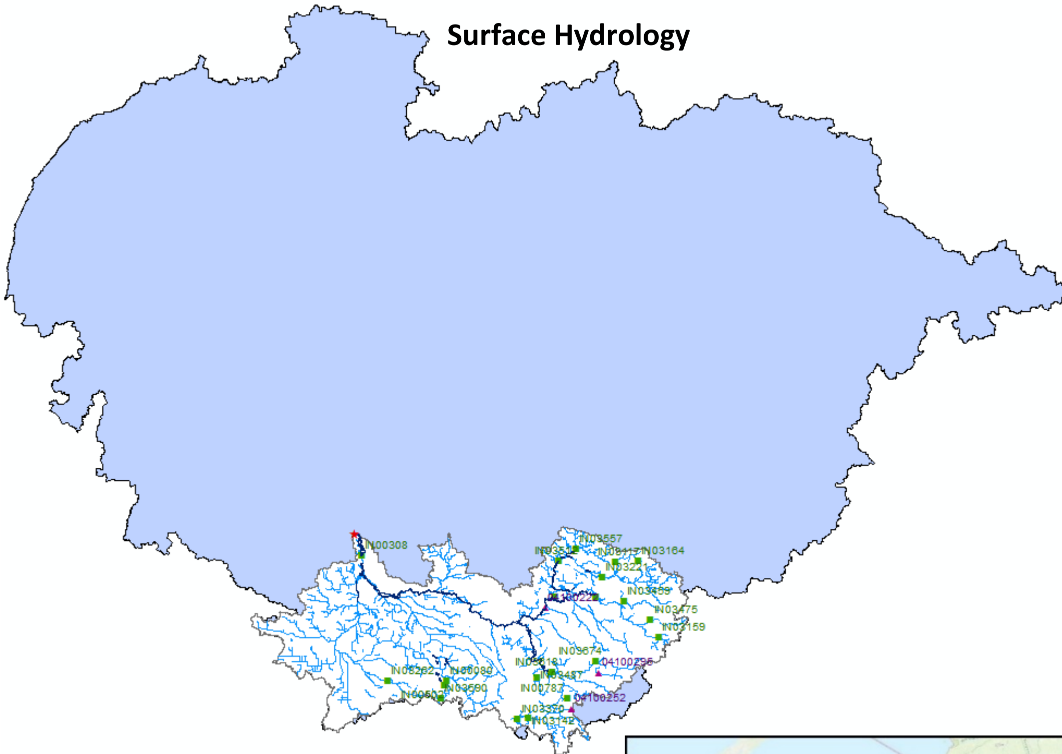
Surficial Geology (Simplified)

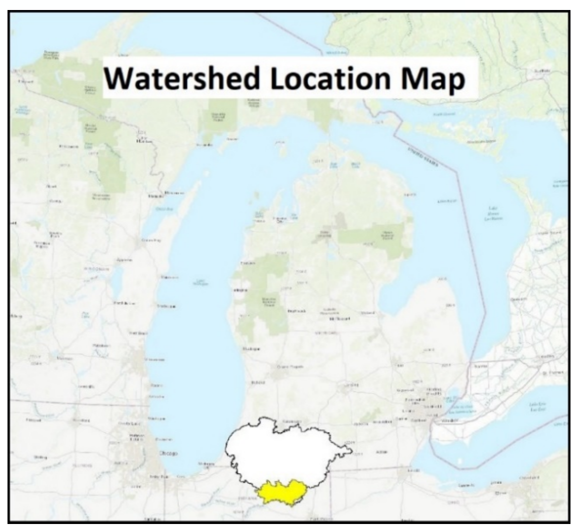


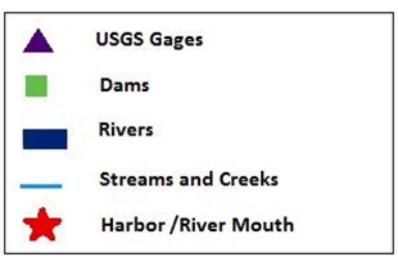
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	0.00	0.00%
Silt, Sand, and Gravel	1337.92	98.53%
Water	19.91	1.47%
Total Watershed Area	1357.83	100.00%

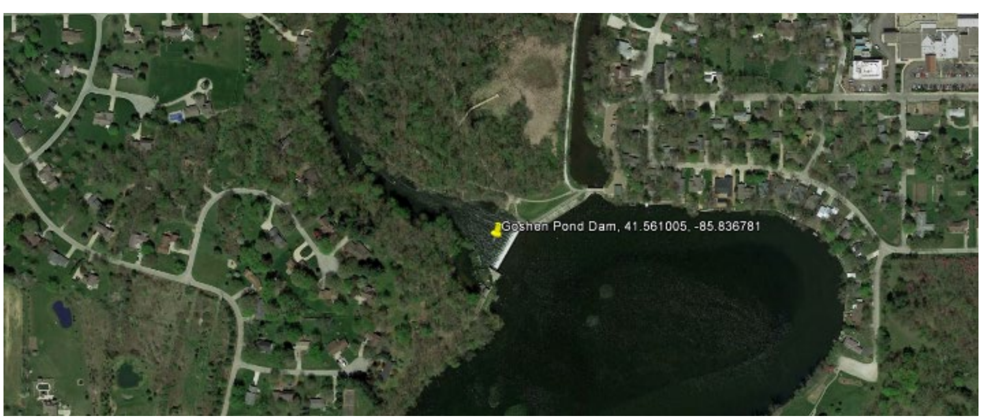
Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX NN. ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM (34B)









34B, ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM

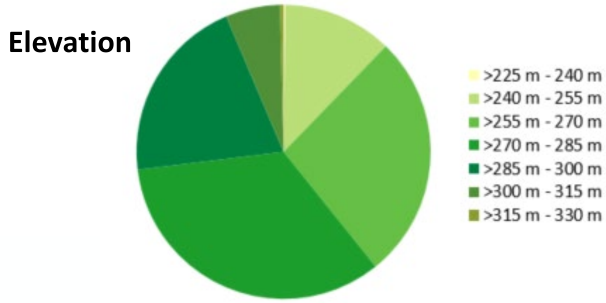
Dam Information and USGS Streamgages

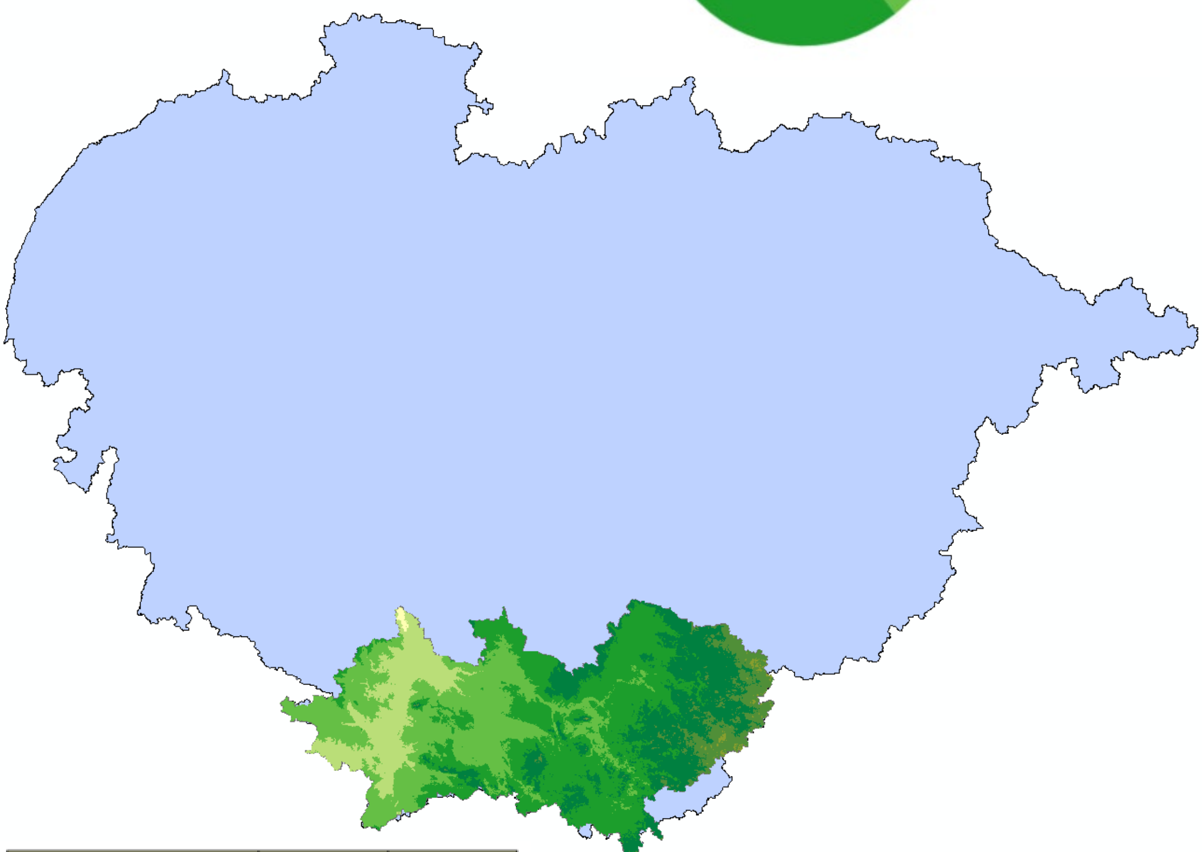
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
IN00080	PAPAKEECHIE LAKE	-85.670000	41.375550
IN00308	GOSHEN POND DAM	-85.836660	41.560830
IN00383	SYLVAN LAKE DAM	-85.376660	41.498330
IN00502	FLATBELLY LAKE DAM	-85.673890	41.368330
IN00787	LAKE BARBARA DAM	-85.432500	41.348890
IN03117	ADAMS LAKE CONTROL STRUCTURE	-85.336390	41.548330
IN03142	BEAR LAKE CONTROL STRUCTURE	-85.510280	41.319160
IN03159	BIXLER LAKE CONTROL STRUCTURE	-85.252780	41.436940
IN03164	BLACKMAN LAKE CONTROL STRUCTURE	-85.291660	41.550560
IN03221	CLIFF PETTIT DAM	-85.362780	41.526940
IN03262	DEWART LAKE CONTROL STRUCTURE	-85.785840	41.374720
IN03370	HIGH CONTROL STRUCTURE	-85.530560	41.318890
IN03459	LATTA LAKE CONTROL STRUCTURE	-85.320270	41.491660
IN03475	LITTLE LONG CONTROL STRUCTURE	-85.268330	41.463330
IN03487	LOWER LONG LAKE CONTROL STRUCTURE	-85.492500	41.378610
IN03512	MESSICK LAKE CONTROL STRUCTURE	-85.448050	41.551110
IN03557	OLIVER LAKE CONTROL STRUCTURE	-85.414720	41.569160
IN03590	PRICE LAKE	-85.681660	41.349450
IN03618	RICHARD GRIEGER LAKE DAM	-85.463330	41.386670
IN03674	SKINNER LAKE CONTROL STRUCTURE	-85.376660	41.403050
IN03759	WALDRON LAKE (WEST LAKES) CONTROL STRUCTURE	-85.457220	41.497780

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4100222	NB ELKHART RIVER AT COSPERVILLE, IND.	-85.475537	41.481716	yes
4100252	FORKER CREEK NEAR BURR OAK, IND	-85.423591	41.332826	
4100295	RIMMELL BRANCH NEAR ALBION, IN	-85.370534	41.385327	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

34B, ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM



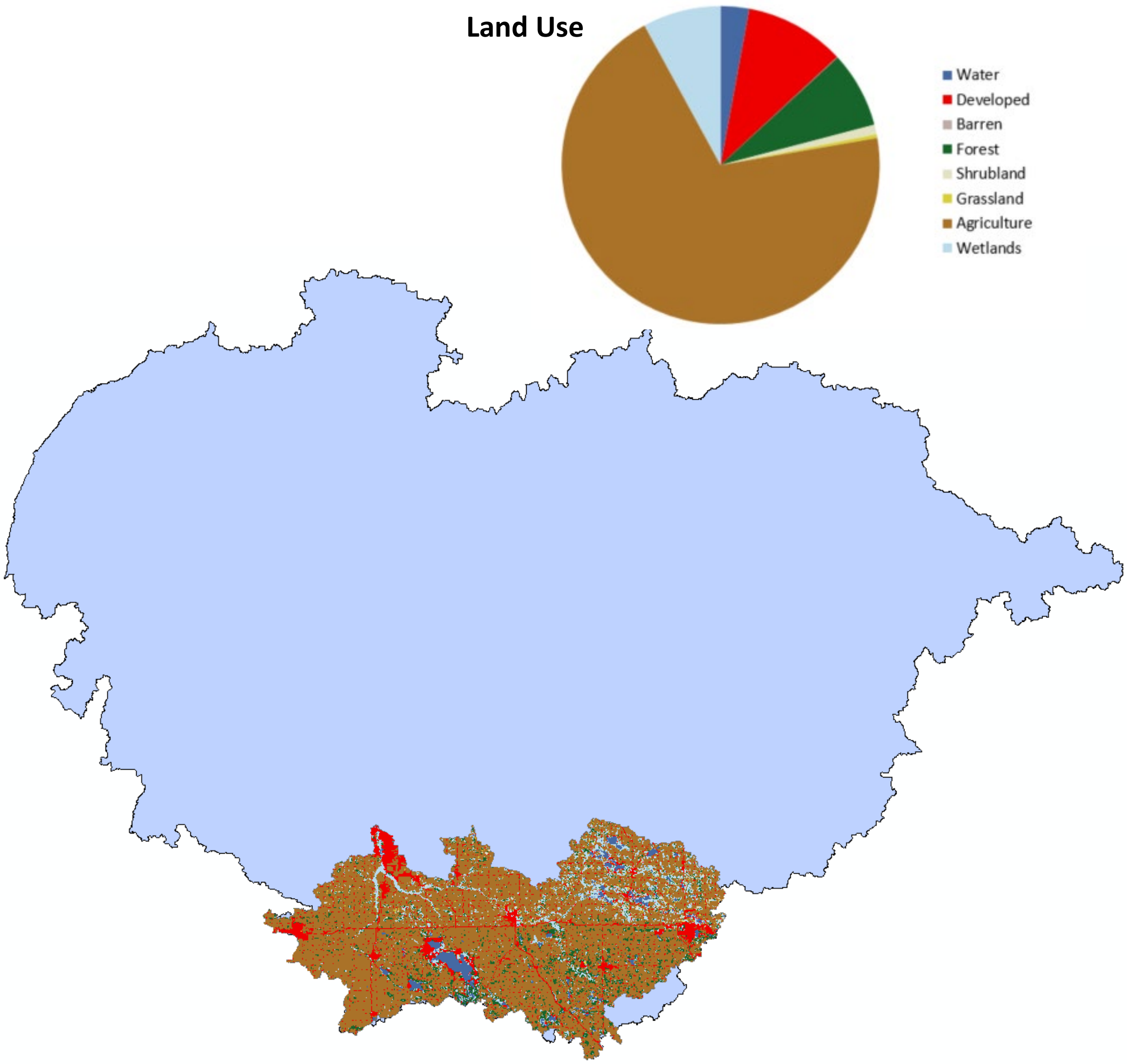


Category	Area	Percentage
Category	*km²*	*%*
>225 m - 240 m	2.84	0.19%
>240 m - 255 m	181.09	12.06%
>255 m - 270 m	405.17	26.99%
>270 m - 285 m	507.74	33.82%
>285 m - 300 m	308.62	20.56%
>300 m - 315 m	90.14	6.00%
>315 m - 330 m	5.76	0.38%
Size of Drainage Area	1501.36	100.00%

Goshen Dam Watershed		
Elevation Statistics		
Size of Drainage Area	**1501.36**	***km²***
Maximum	327.75	*m*
Minimum	235.41	*m*
Average	274.94	*m*
Standard Deviation	15.86	*m*

All Elevation Measurements with Respect to North American Datum 1983

34B, ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM

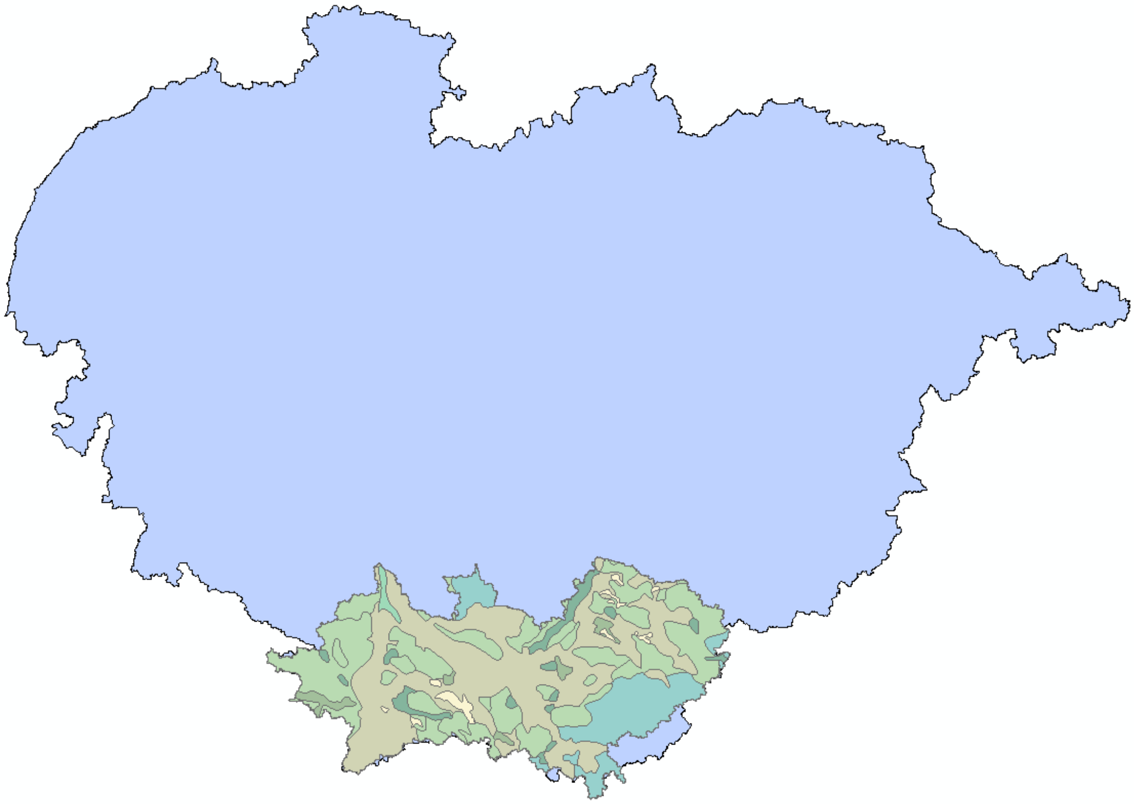


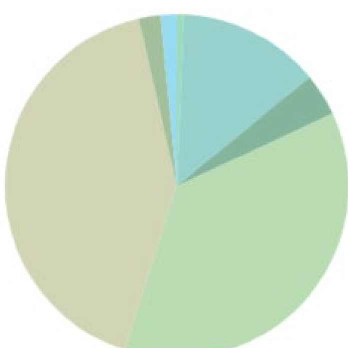
Category	Area	Percentage
Category	*km²*	*%*
Water	43.60	2.90%
Developed	153.23	10.21%
Barren	0.75	0.05%
Forest	116.38	7.75%
Shrubland	14.75	0.98%
Herbaceous	5.74	0.38%
Agriculture	1047.61	69.78%
Wetlands	119.29	7.95%
Total	1501.36	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

34B, ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM

Surficial Geology



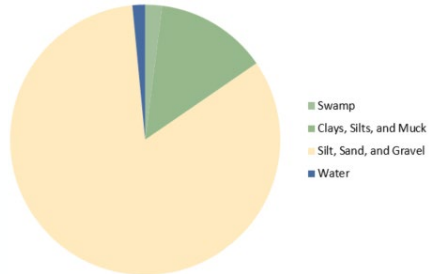


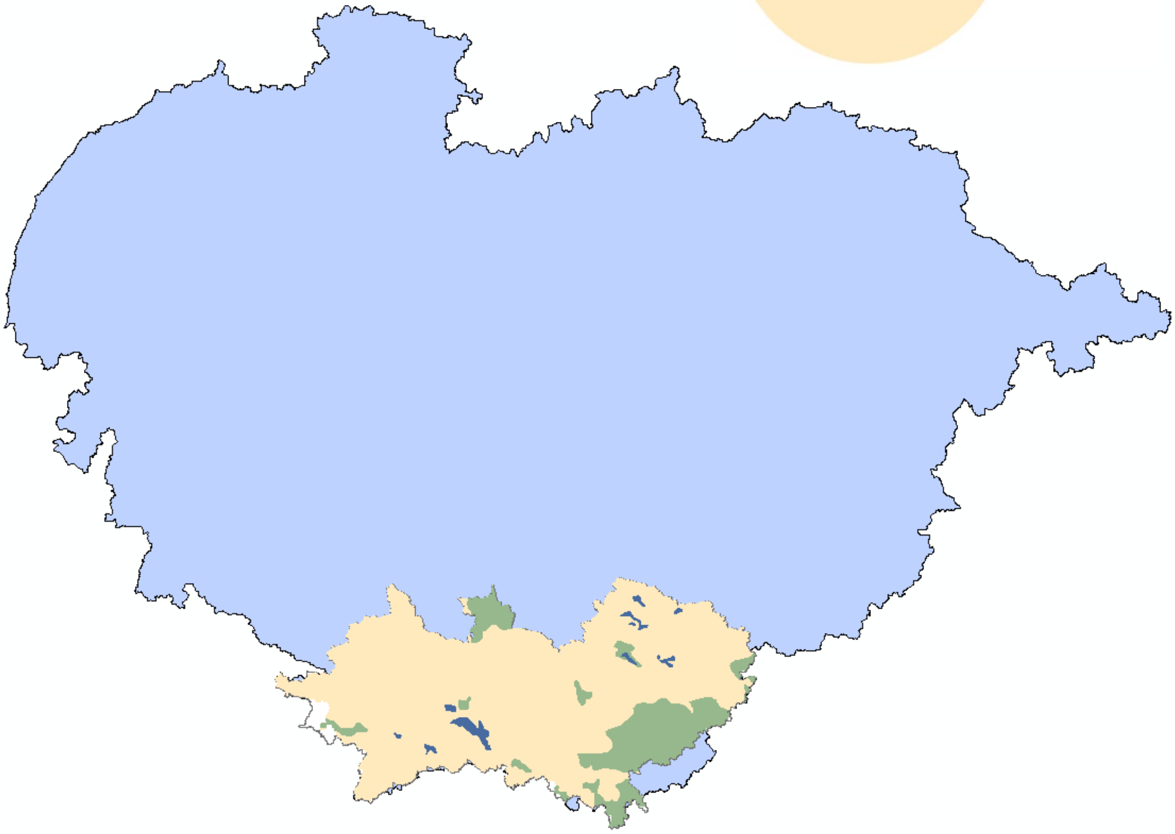
Category	Area	Percentage
Category	*km²*	*%*
Alluvium	9.62	0.64%
Clayey till	201.45	13.42%
Dune sand	0.00	0.00%
Ice-contact sand and gravel	60.21	4.01%
Lake clay and silt	0.00	0.00%
Lake sand and gravel	0.00	0.00%
Loamy till	553.20	36.85%
Outwash sand	0.00	0.00%
Outwash sand and gravel	623.91	41.56%
Sandy loamy till	0.00	0.00%
Swamp deposit	30.24	2.01%
Water	22.74	1.51%
Total Watershed Area	1501.36	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

34B, ST. JOSEPH RIVER WATERSHED, GOSHEN POND DAM

Surficial Geology (Simplified)



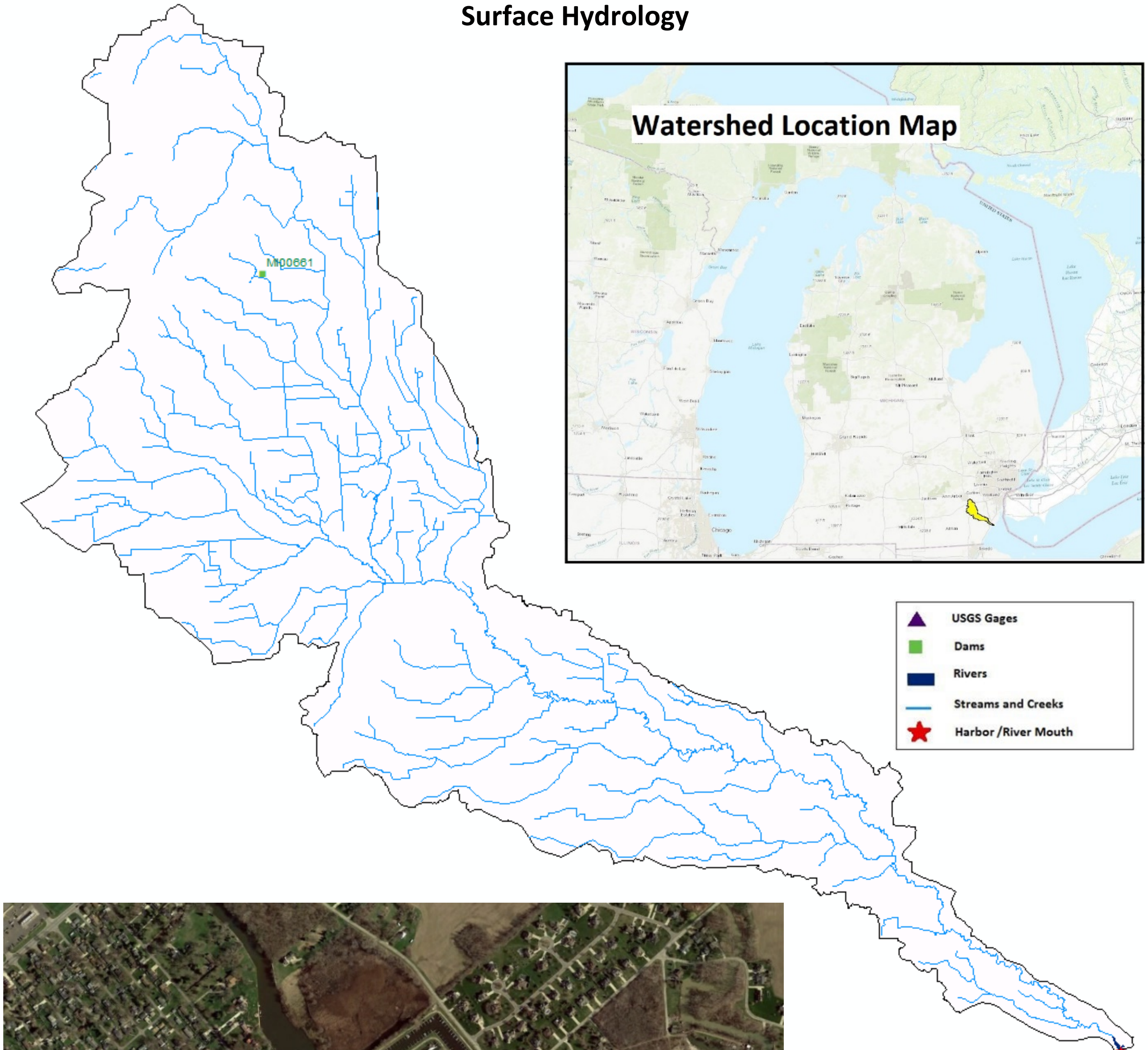


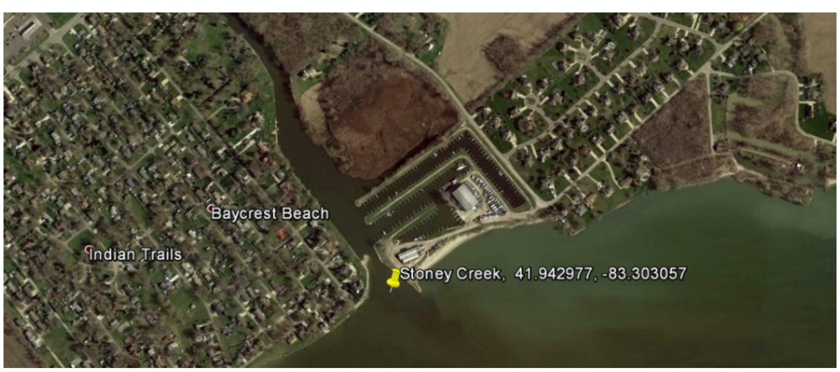
Category	Area	Percentage
Category	*km²*	*%*
Swamp	30.24	2.01%
Clay, Silt, and Muck	201.45	13.42%
Silt, Sand, and Gravel	1246.93	83.05%
Water	22.74	1.51%
Total Watershed Area	1501.36	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX OO. STONY CREEK RIVER WATERSHED (35)

Surface Hydrology



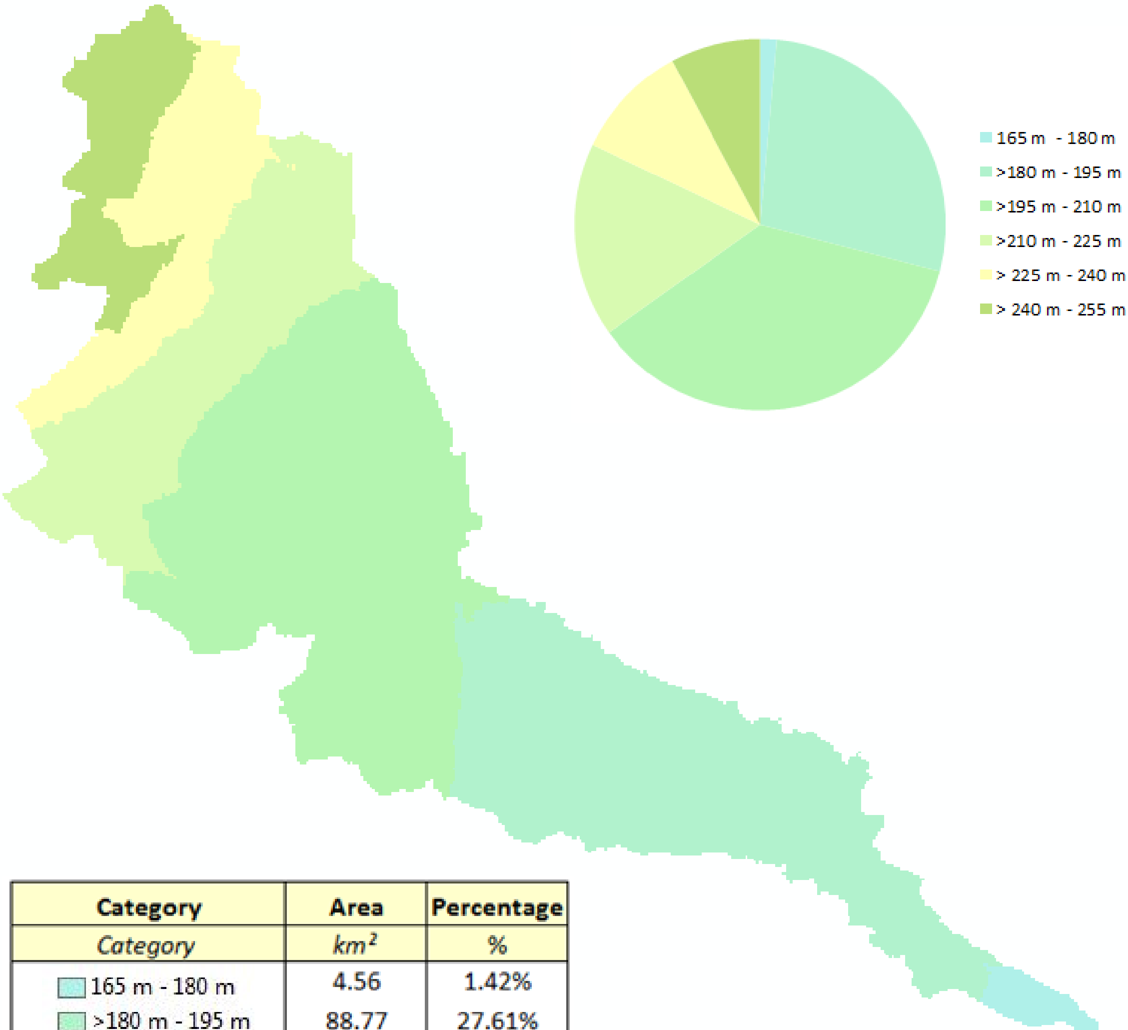


USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00661	Charles Sargent Dam	-83.626660	42.175000

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

35. STONY CREEK RIVER WATERSHED

Elevation



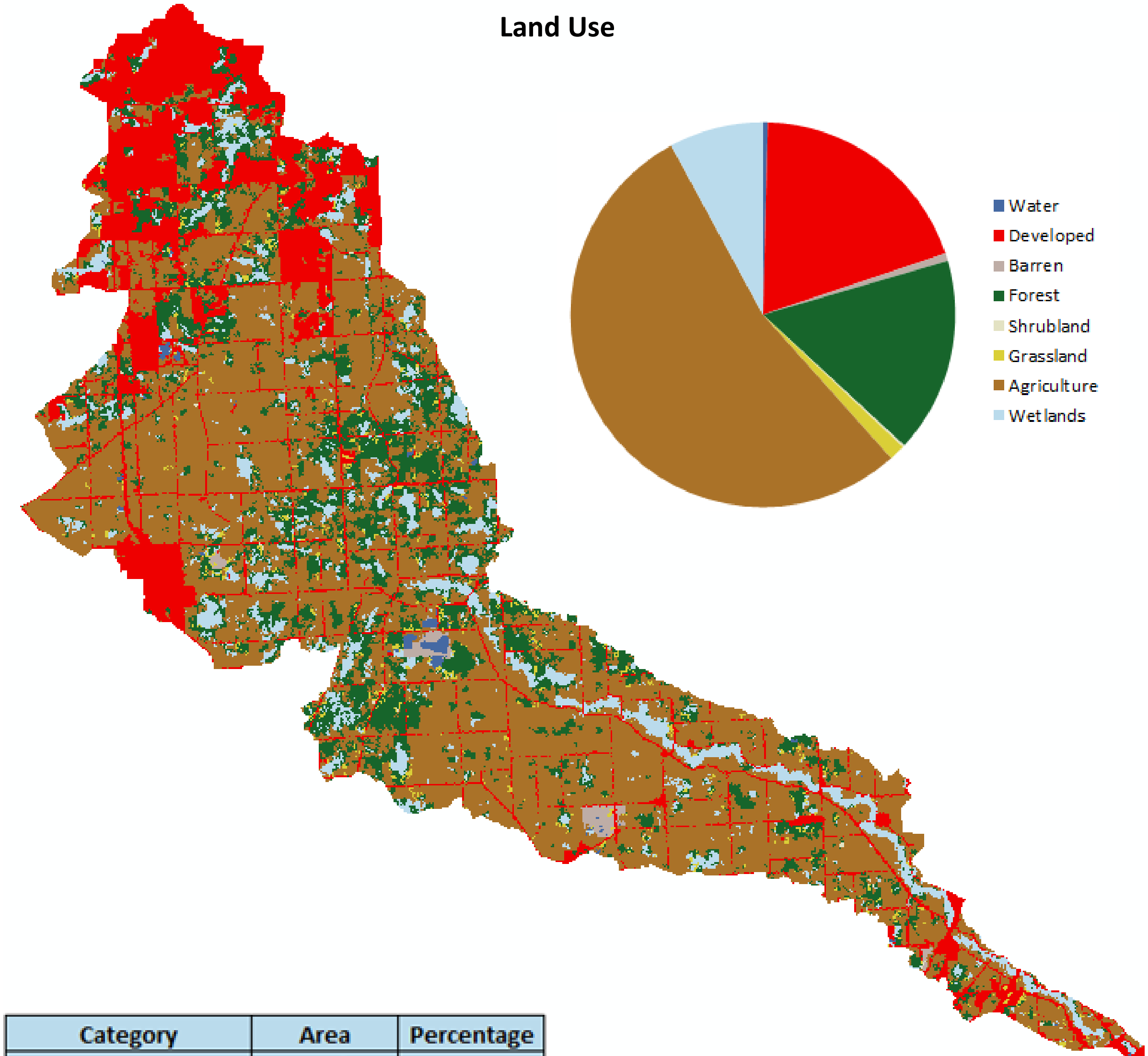
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	4.56	1.42%
>180 m - 195 m	88.77	27.61%
>195 m - 210 m	116.12	36.12%
>210 m - 225 m	54.45	16.93%
>225 m - 240 m	32.42	10.08%
>240 m - 255 m	25.20	7.84%
Size of Drainage Area	321.53	100.00%

Stony Creek Watershed		
Elevation Statistics		
Size of Drainage Area	**321.53**	***km²***
Maximum	247.00	*m*
Minimum	173.00	*m*
Average	207.49	*m*
Standard Deviation	16.94	*m*

All Elevation Measurements with Respect to North American Datum 1983

35, STONY CREEK RIVER WATERSHED

Land Use



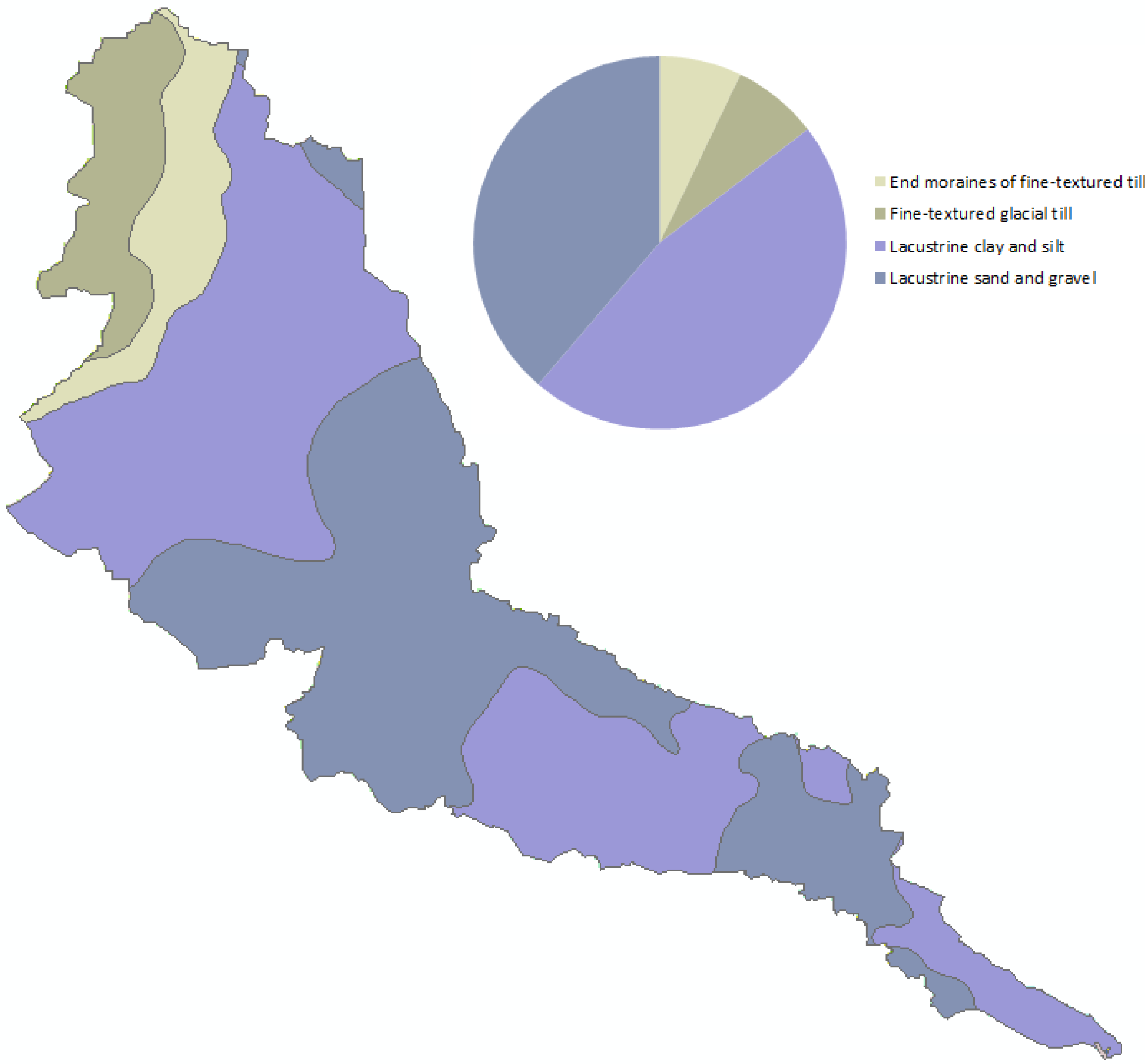
Category	Area	Percentage
Category	*km²*	*%*
Water	1.30	0.40%
Developed	62.52	19.45%
Barren	2.05	0.64%
Forest	52.72	16.40%
Shrubland	0.56	0.17%
Grassland	4.32	1.34%
Agriculture	172.64	53.70%
Wetlands	25.41	7.90%
Total	321.53	100.00%

EGLE Runoff Curve Number
75.7

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

35, STONY CREEK RIVER WATERSHED

Surficial Geology

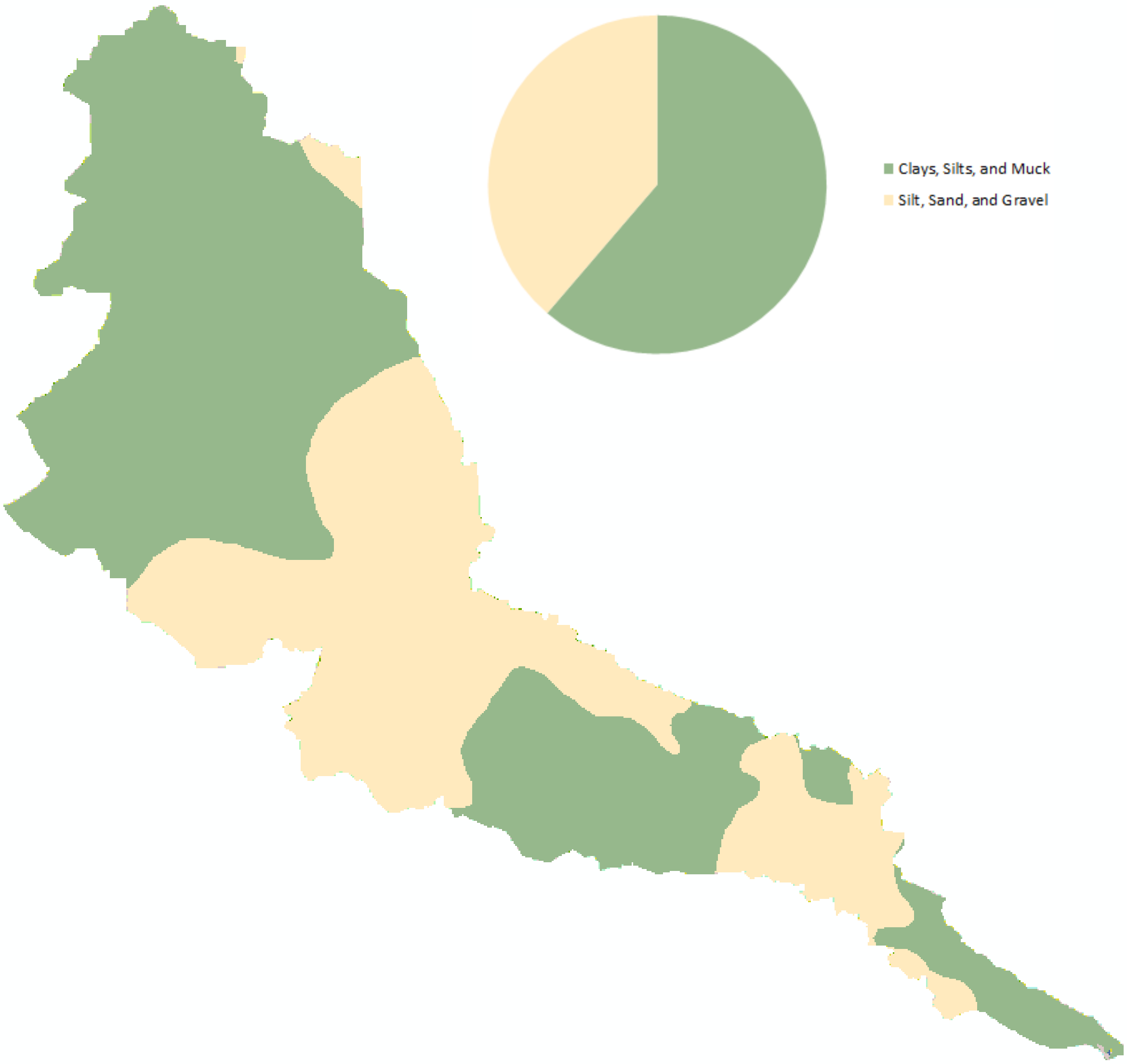


Category	Area	Percentage
Category	*km²*	*%*
End moraines of fine-textured till	22.91	7.13%
Fine-textured glacial till	24.04	7.48%
Lacustrine clay and silt	150.05	46.67%
Lacustrine sand and gravel	124.52	38.73%
Total Watershed Area	321.53	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

35, STONY CREEK RIVER WATERSHED

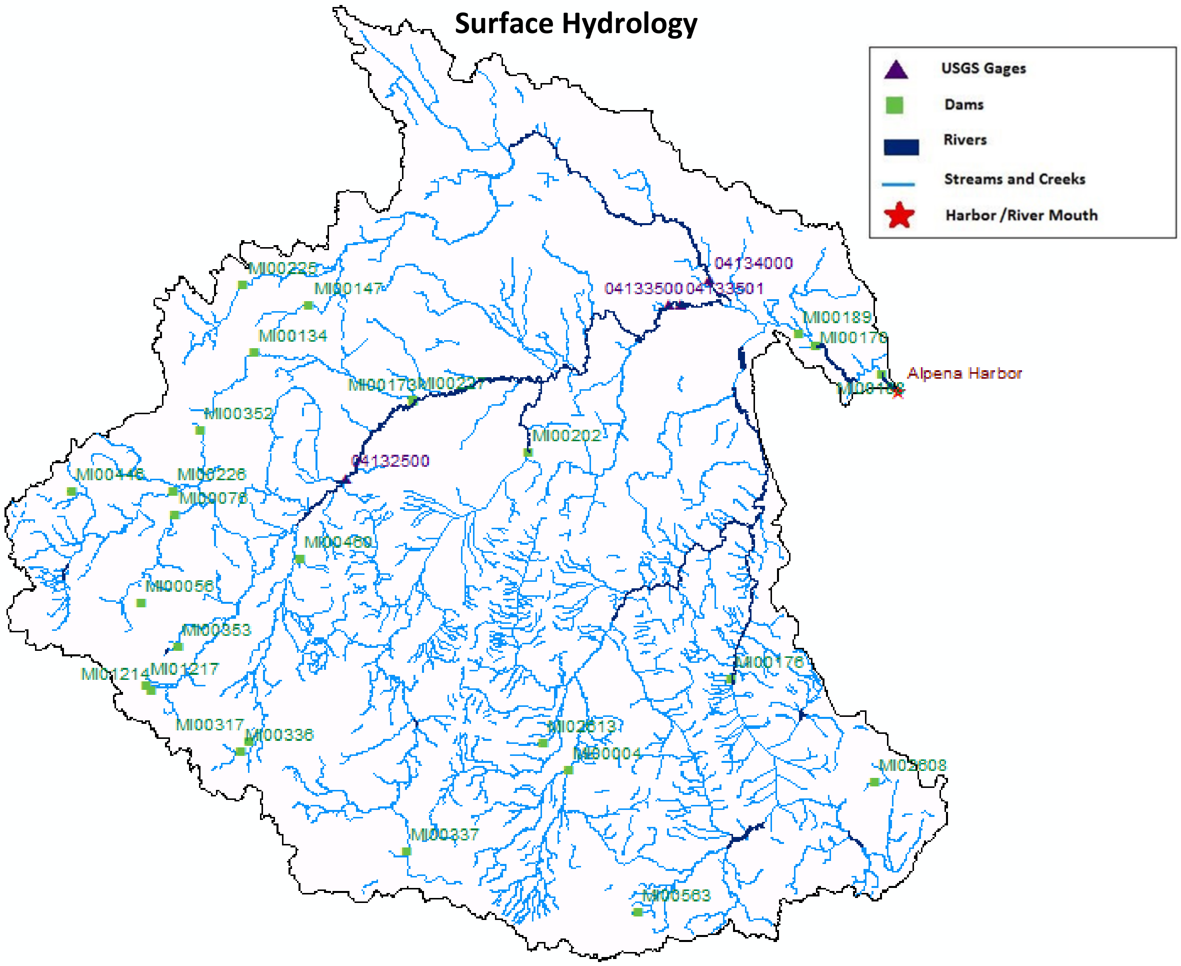
Surficial Geology (Simplified)

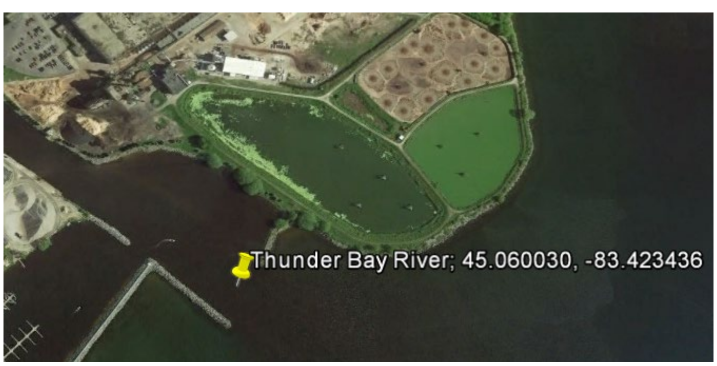


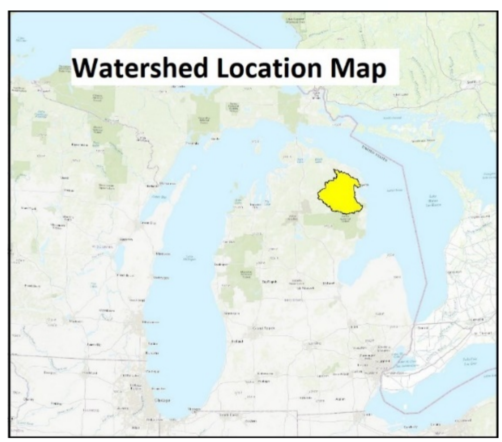
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	197.00	61.27%
Silt, Sand, and Gravel	124.52	38.73%
Total Watershed Area	321.53	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX PP. THUNDER BAY RIVER WATERSHED (36)







36, THUNDER BAY RIVER WATERSHED

Dam Information and USGS Streamgages

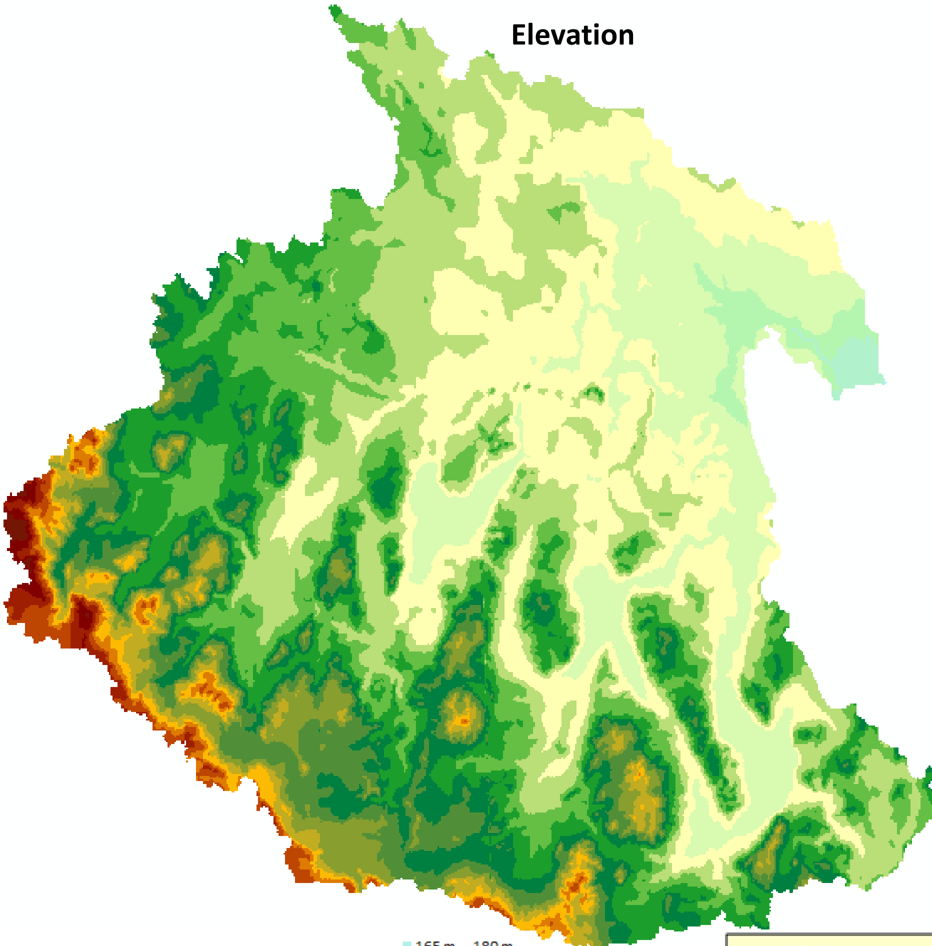
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00188	Ninth Street	-83.437100	45.071900
MI00170	Four Mile Dam	-83.502600	45.092700
MI00189	Norway Point	-83.519200	45.101900
MI00202	Upper South Dam	-83.791000	45.024000
MI00173	Hillman	-83.903100	45.061500
MI01214	East Fish Lake Dam	-84.170000	44.863330
MI01217	Fuller Creek Pond Dam	-84.175000	44.866660
MI00134	Upper Hiawatha Dam	-84.060060	45.098750
MI00147	Grass Lake Level Control Structure	-84.005000	45.131670
MI00176	Hubbard Lake Dam	-83.596660	44.860000
MI00225	Rush Lake Level Control Structure	-84.070000	45.146670
MI00226	Atlanta Dam	-84.145000	45.003330
MI00227	Brush Creek Dam	-83.903340	45.063330
MI02608	Lost Lake Woods East Dam	-83.457800	44.785100
MI02613	Birch Creek Club Dam	-83.784400	44.819600
MI00317	Rhoads Dam	-84.075000	44.825000
MI00336	Woodland Dam	-84.083340	44.818330
MI00337	Reed Ranch Dam	-83.921670	44.745000
MI00352	Atlanta Sportsmen Dam	-84.116670	45.045000
MI00353	Sage Lake Dam	-84.143330	44.893330
MI00004	Little Wolf Creek Dam	-83.760000	44.800000
MI00446	Lake Inez Dam	-84.245000	45.005000
MI00460	Robert Slivensky Dam	-84.020000	44.953330
MI00056	Avery Lake Dam	-84.178340	44.925000
MI00563	Bucks Pond Dam	-83.695000	44.698330
MI00076	Crooked Lake Level Control Structure	-84.143330	44.986670

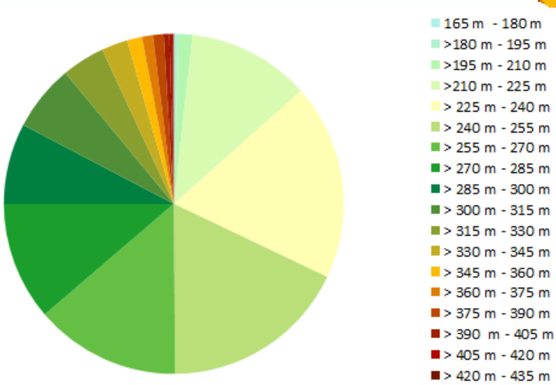
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4132500	THUNDER BAY RIVER NEAR HILLMAN, MI	-83.972498	45.008342	
4133500	THUNDER BAY RIVER NEAR BOLTON, MI	-83.647207	45.124456	
4133501	THUNDER BAY RIVER AT HERRON ROAD NEAR BOLTON, MI	-83.635540	45.124179	yes
4134000	NORTH BRANCH THUNDER BAY RIVER NR BOLTON, MI	-83.605817	45.141679	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

36, THUNDER BAY RIVER WATERSHED

Elevation





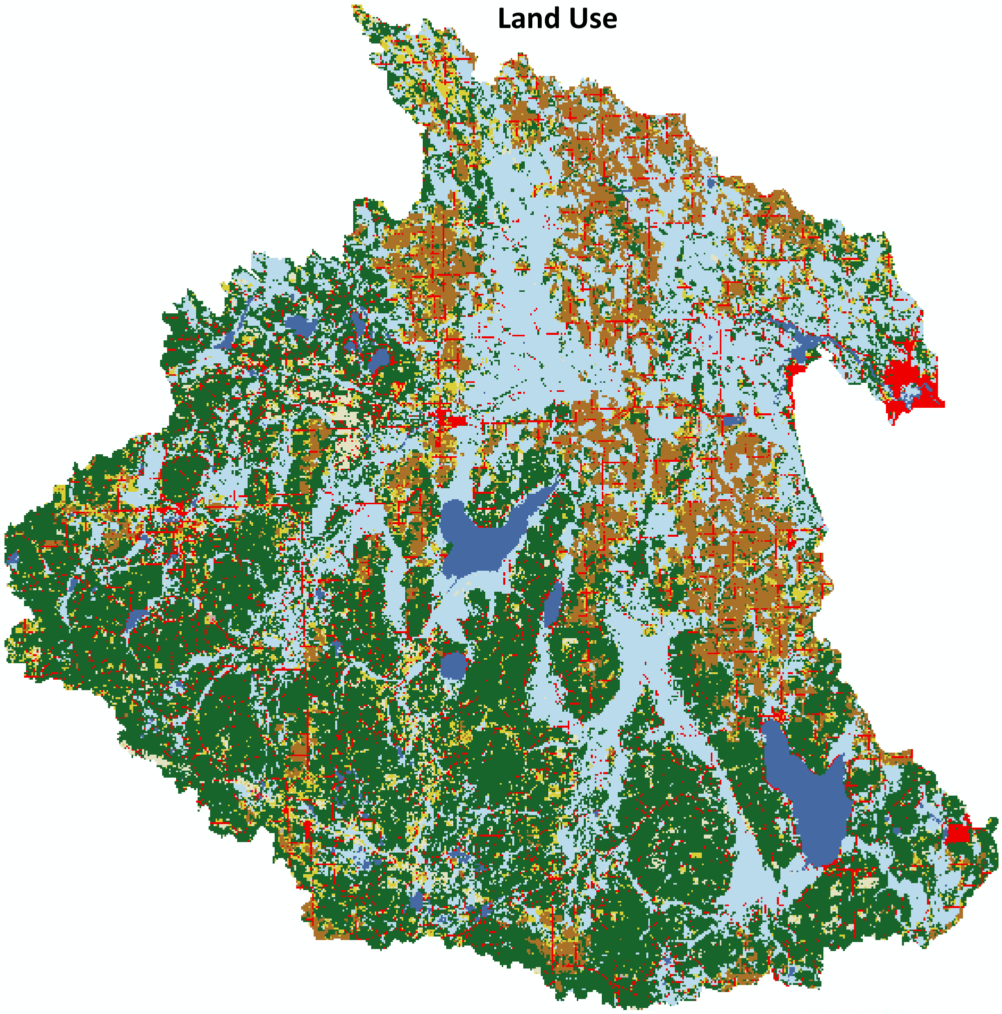
Thunder Bay Watershed		
Elevation Statistics		
Size of Drainage Area	3238.04	*km²*
Maximum	433.00	*m*
Minimum	176.00	*m*
Average	263.18	*m*
Standard Deviation	39.52	*m*

Category	Area	Percentage
Category	*km²*	%
165 m - 180 m	0.10	0.00%
>180 m - 195 m	14.65	0.45%
>195 m - 210 m	42.30	1.31%
>210 m - 225 m	377.77	11.67%
>225 m - 240 m	603.69	18.64%
>240 m - 255 m	576.68	17.81%
>255 m - 270 m	448.35	13.85%
>270 m - 285 m	364.58	11.26%
>285 m - 300 m	248.92	7.69%
>300 m - 315 m	204.38	6.31%
>315 m -330 m	132.37	4.09%
>330 m - 345 m	81.04	2.50%
>345 m - 360 m	45.73	1.41%
>360 m - 375 m	33.22	1.03%
>375 m - 390 m	33.22	1.03%
>390 m - 405 m	17.61	0.54%
>405 m - 420 m	9.61	0.30%
>420 m - 435 m	3.83	0.12%
Size of Drainage Area	3238.04	100.00%

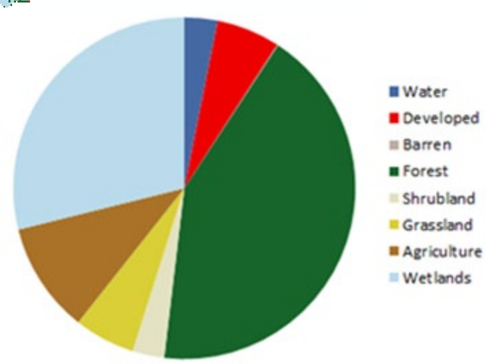
All Elevation Measurements with Respect to North American Datum 1983

36, THUNDER BAY RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	101.29	3.13%
Developed	194.68	6.01%
Barren	2.81	0.09%
Forest	1381.14	42.65%
Shrubland	97.59	3.01%
Grassland	186.32	5.75%
Agriculture	338.44	10.45%
Wetlands	935.76	28.90%
Total	3238.04	100.00%

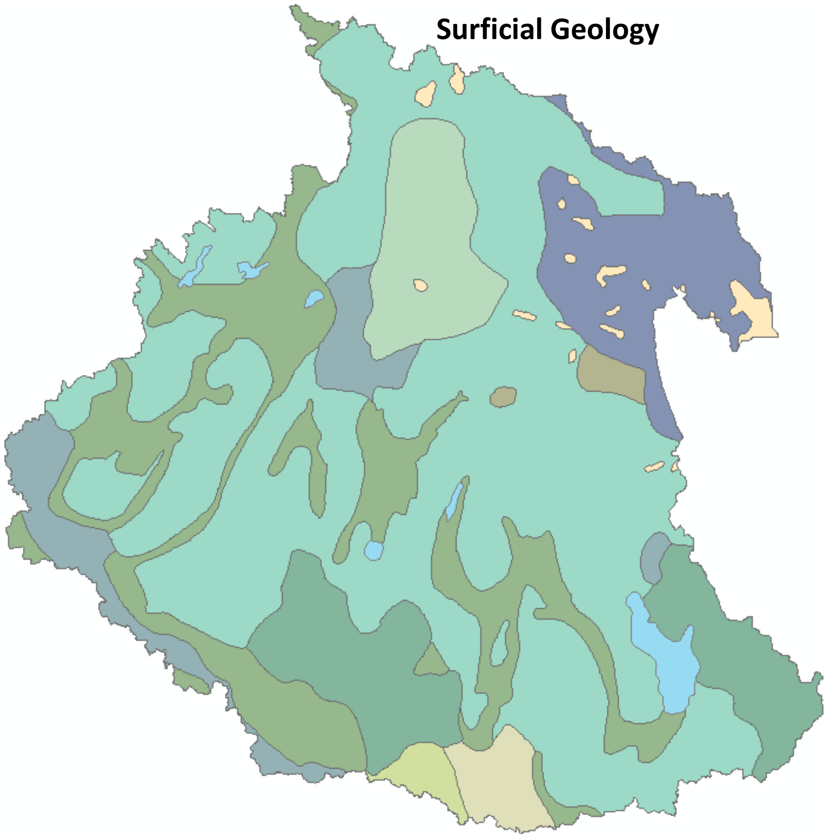


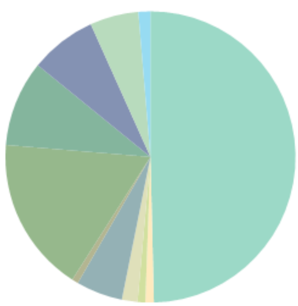
EGLE Runoff Curve Number
66.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

36, THUNDER BAY RIVER WATERSHED

Surficial Geology



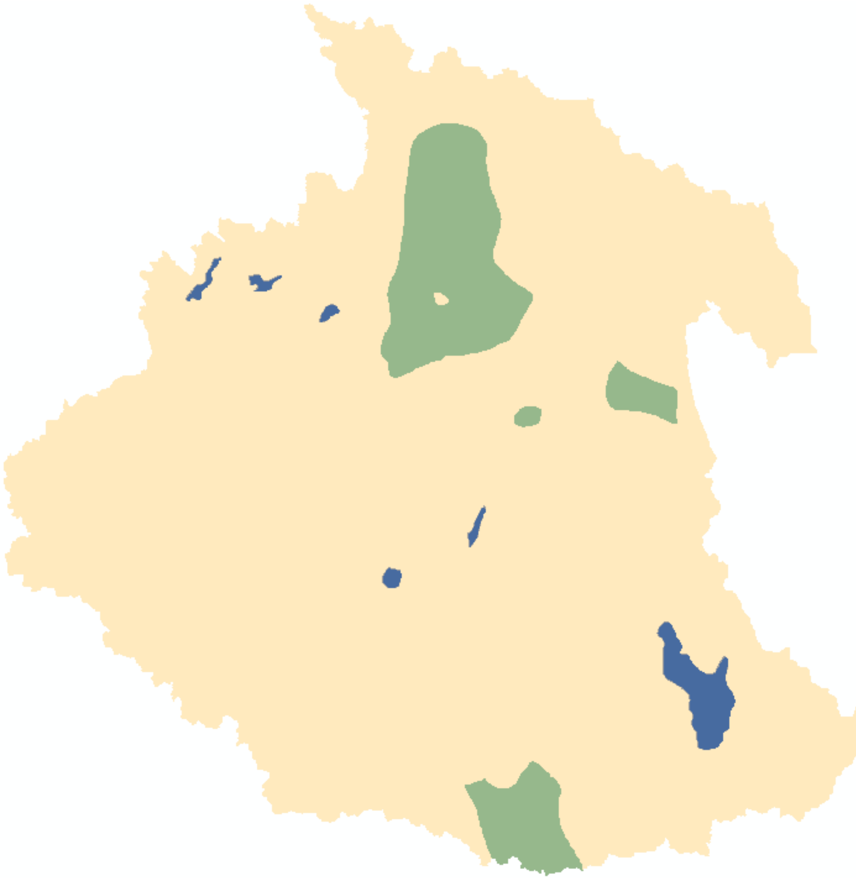


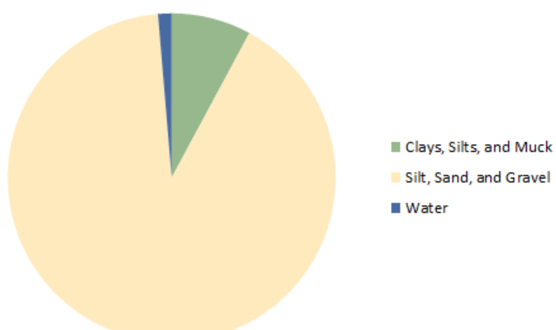
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	1606.91	49.63%
Dune sand	30.30	0.94%
End moraines of coarse-textured till	28.08	0.87%
End moraines of fine-textured till	56.31	1.74%
End moraines of medium-textured till	167.76	5.18%
Fine-textured glacial till	23.01	0.71%
Glacial outwash sand and gravel and postglacial alluvium	558.81	17.26%
Ice-contact outwash sand and gravel	308.42	9.52%
Lacustrine sand and gravel	239.97	7.41%
Peat and muck	175.31	5.41%
Water	43.17	1.33%
Total Watershed Area	3238.04	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

36, THUNDER BAY RIVER WATERSHED

Surficial Geology (Simplified)

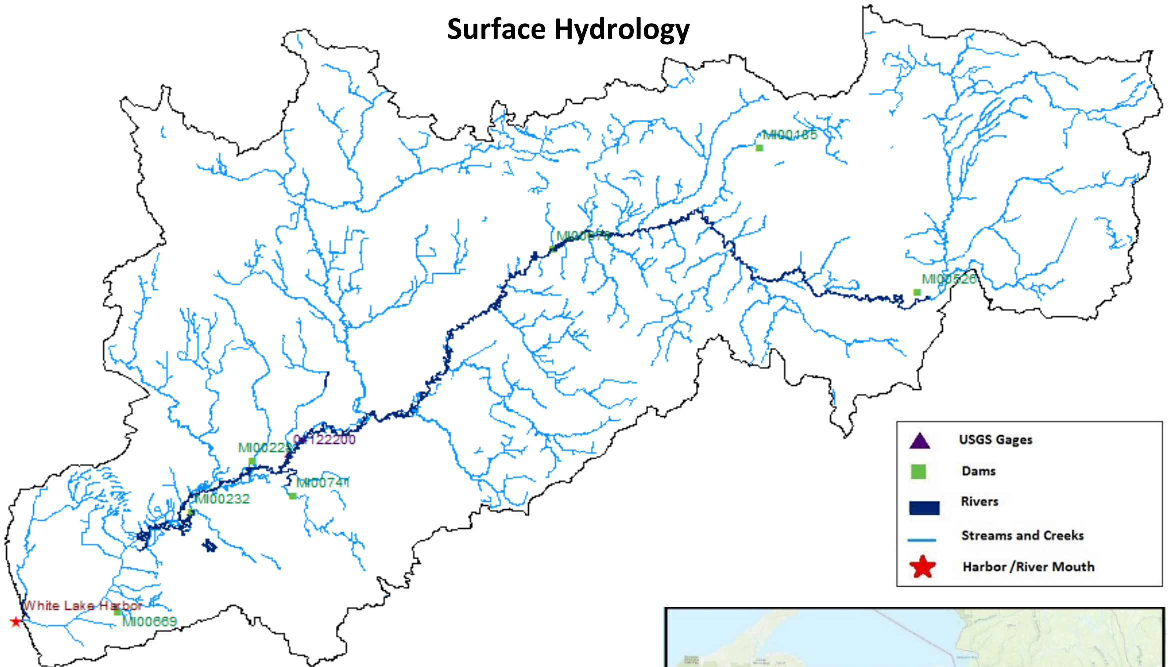




Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	254.62	7.86%
Silt, Sand, and Gravel	2940.24	90.80%
Water	43.17	1.33%
Total Watershed Area	3238.04	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX QQ. WHITE RIVER WATERSHED (37)



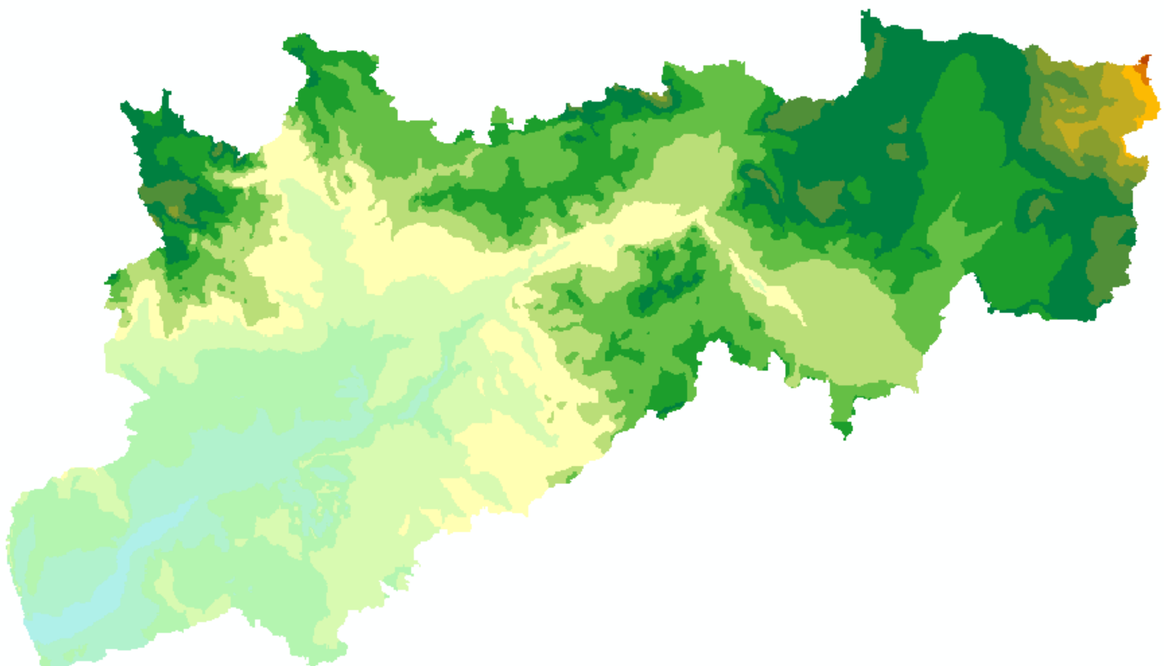
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00185	Minnie Lake Dam	-85.890000	43.626670
MI00228	Browns Pond Dam	-86.259450	43.460280
MI00232	Silver Creek Pond Dam	-86.303340	43.433330
MI00526	White Cloud Dam	-85.775000	43.550000
MI00669	Whitehall Millpond Dam	-86.356670	43.380000
MI00678	Hesperia Dam	-86.040680	43.572780
MI00741	Cleveland Lake Dam	-86.230000	43.441670

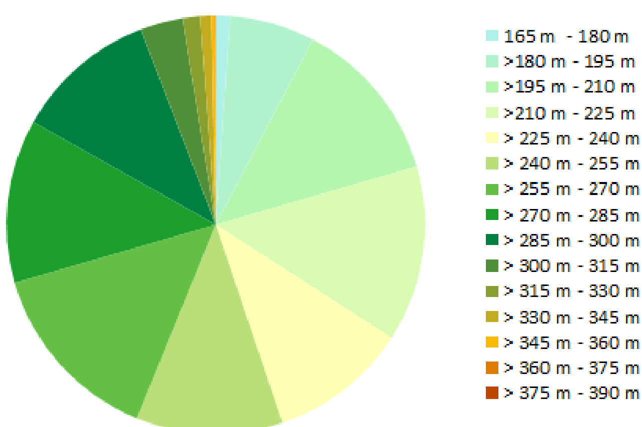
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4122200	WHITE RIVER NEAR WHITEHALL, MI	-86.232567	43.464179	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

37, WHITE RIVER WATERSHED

Elevation





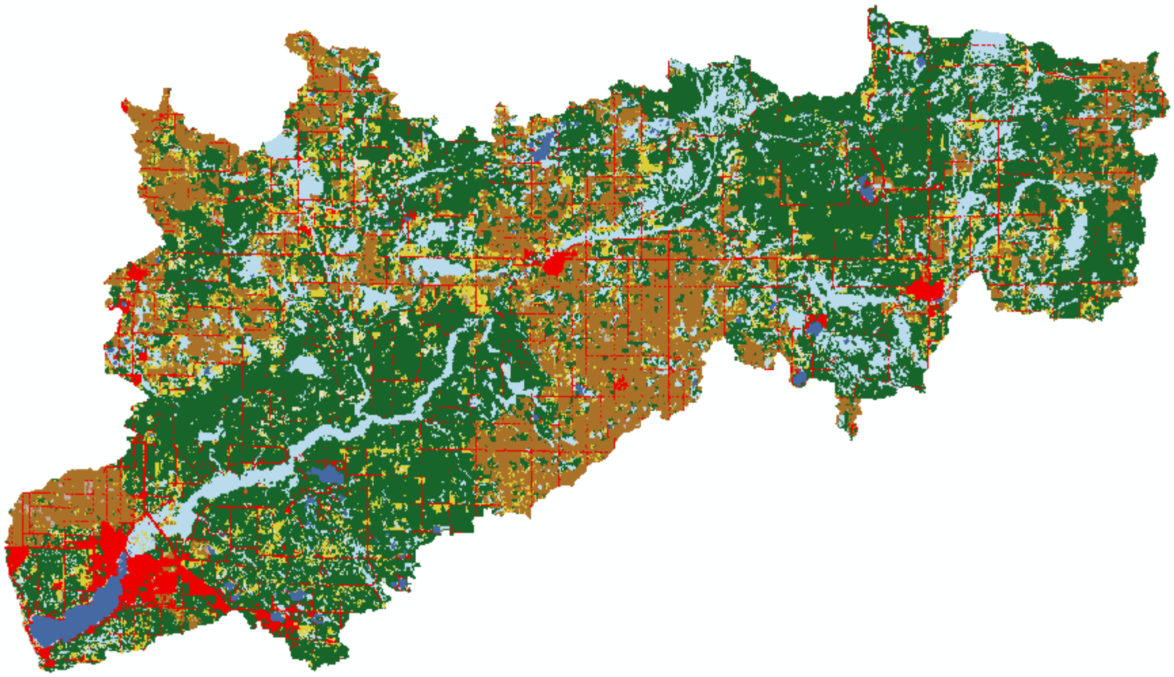
White Watershed		
Elevation Statistics		
Size of Drainage Area	**1392.97**	***km²***
Maximum	381.00	*m*
Minimum	177.00	*m*
Average	245.18	*m*
Standard Deviation	36.96	*m*

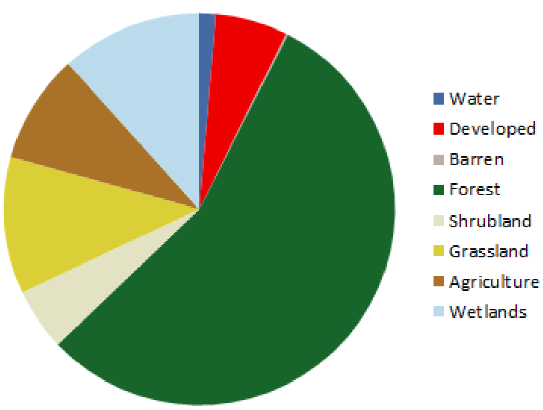
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	15.40	1.11%
>180 m - 195 m	91.82	6.59%
>195 m - 210 m	178.62	12.82%
>210 m - 225 m	189.24	13.59%
>225 m - 240 m	149.41	10.73%
>240 m - 255 m	157.61	11.31%
>255 m - 270 m	200.12	14.37%
>270 m - 285 m	176.24	12.65%
>285 m - 300 m	153.34	11.01%
>300 m - 315 m	45.84	3.29%
>315 m -330 m	18.80	1.35%
>330 m - 345 m	12.05	0.87%
>345 m - 360 m	3.53	0.25%
>360 m - 375 m	0.72	0.05%
>375 m - 390 m	0.23	0.02%
Size of Drainage Area	1392.97	100.00%

All Elevation Measurements with Respect to North American Datum 1983

37, WHITE RIVER WATERSHED

Land Use





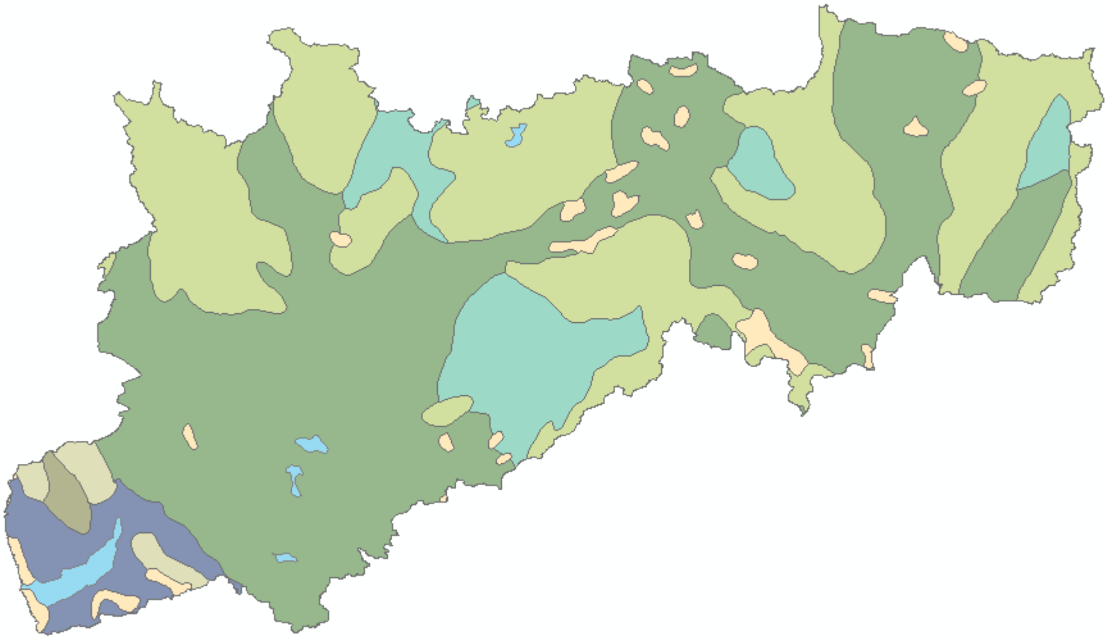
Category	Area	Percentage
Category	*km²*	*%*
Water	18.85	1.35%
Developed	83.35	5.98%
Barren	2.15	0.15%
Forest	771.50	55.39%
Shrubland	71.72	5.15%
Grassland	157.35	11.30%
Agriculture	125.57	9.01%
Wetlands	162.49	11.67%
Total	1392.97	100.00%

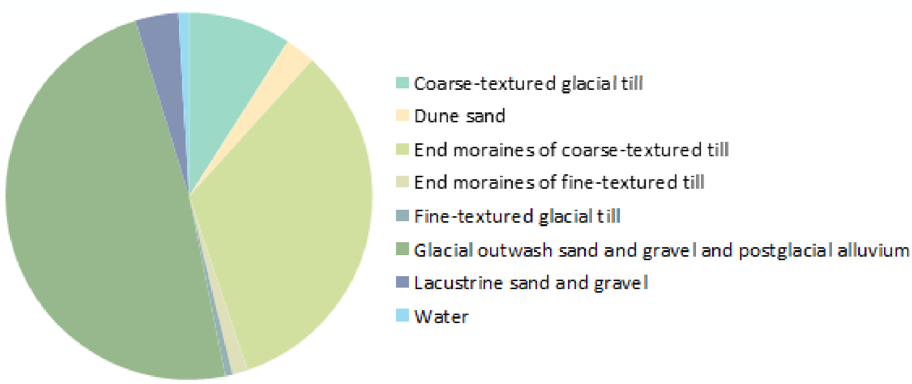
EGLE Runoff Curve Number
60.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

37, WHITE RIVER WATERSHED

Surficial Geology



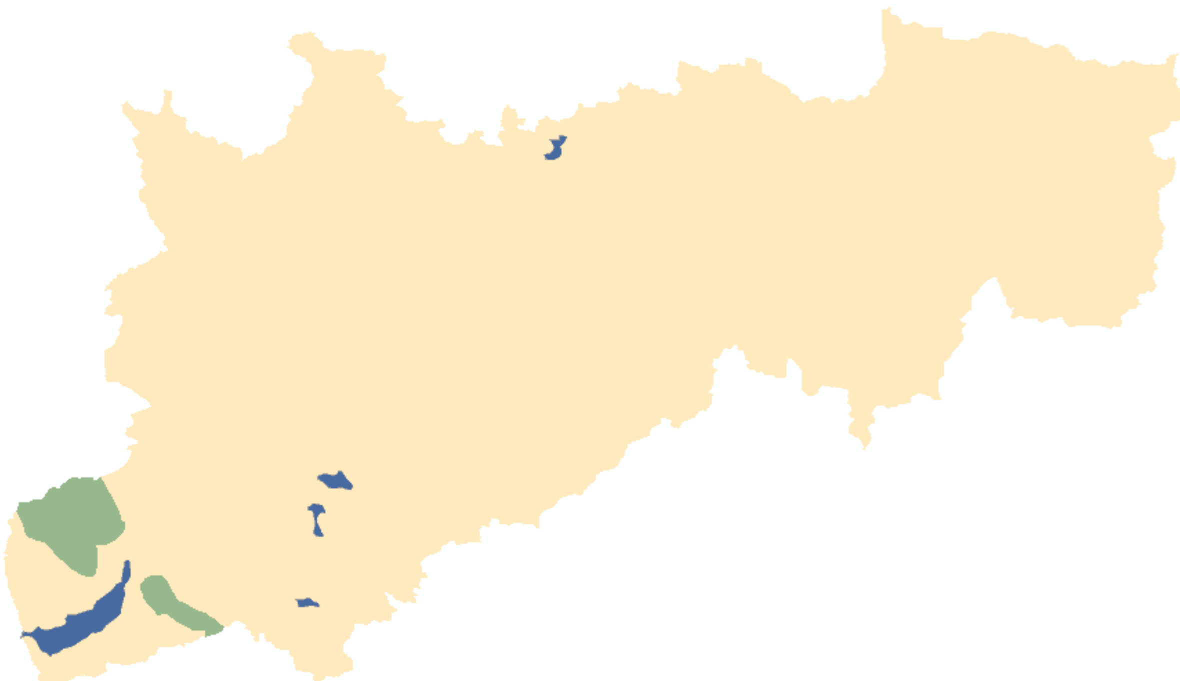


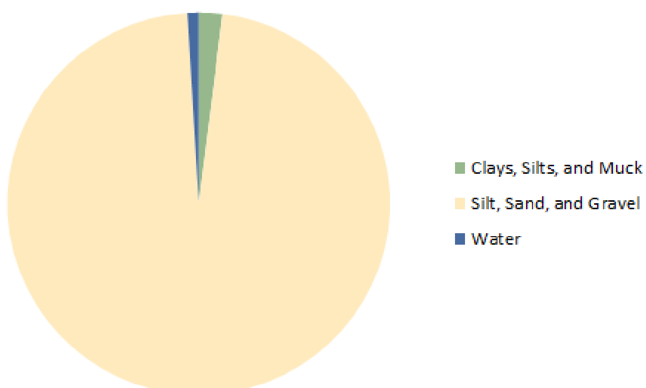
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	125.97	9.04%
Dune sand	37.04	2.66%
End moraines of coarse-textured till	461.30	33.12%
End moraines of fine-textured till	18.98	1.36%
Fine-textured glacial till	8.86	0.64%
Glacial outwash sand and gravel and postglacial alluvium	675.07	48.46%
Lacustrine sand and gravel	52.78	3.79%
Water	12.98	0.93%
Total Watershed Area	1392.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

37, WHITE RIVER WATERSHED

Surficial Geology (Simplified)



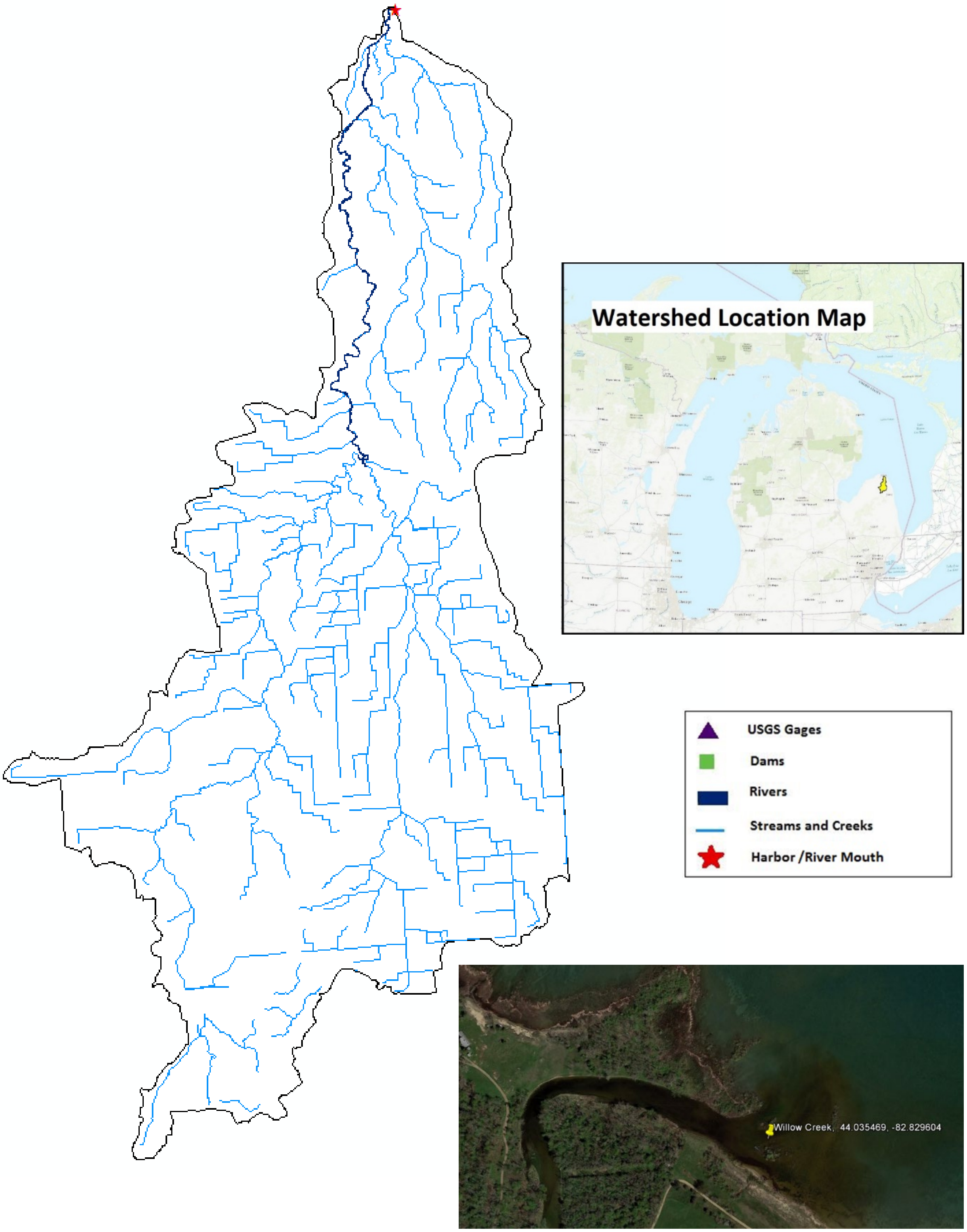


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	27.85	2.00%
Silt, Sand, and Gravel	1352.15	97.07%
Water	12.98	0.93%
Total Watershed Area	1392.97	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX RR. WILLOW CREEK WATERSHED (38)

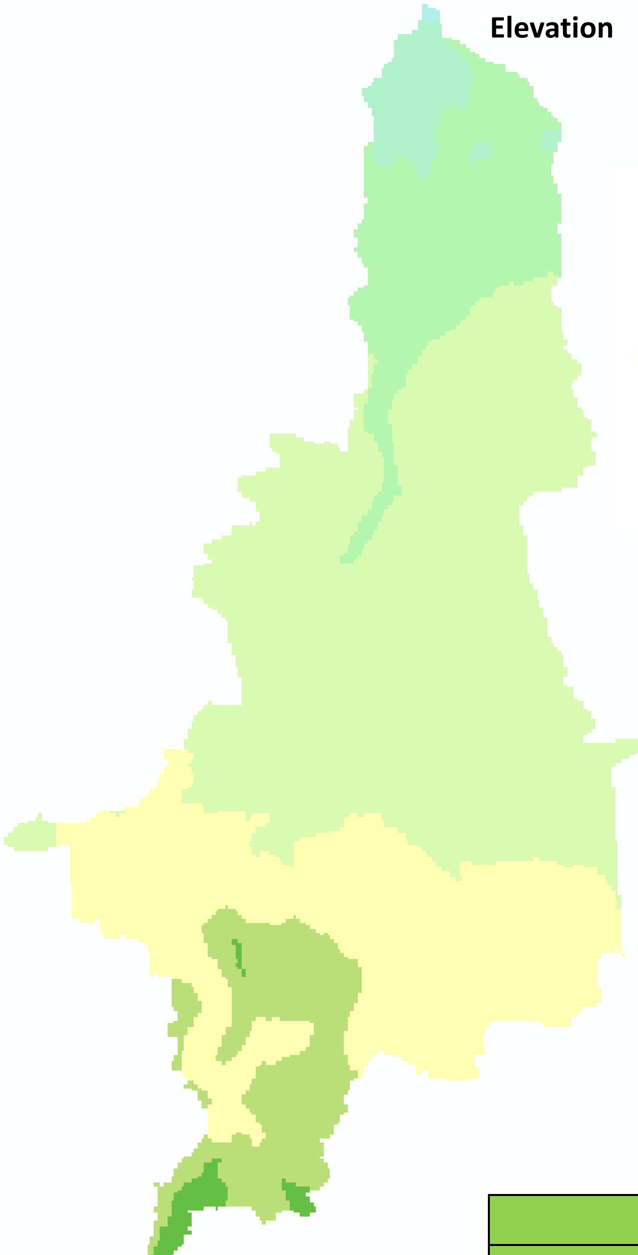
Surface Hydrology

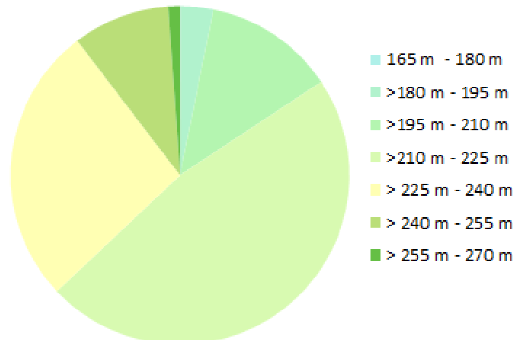


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

38, WILLOW CREEK WATERSHED

Elevation





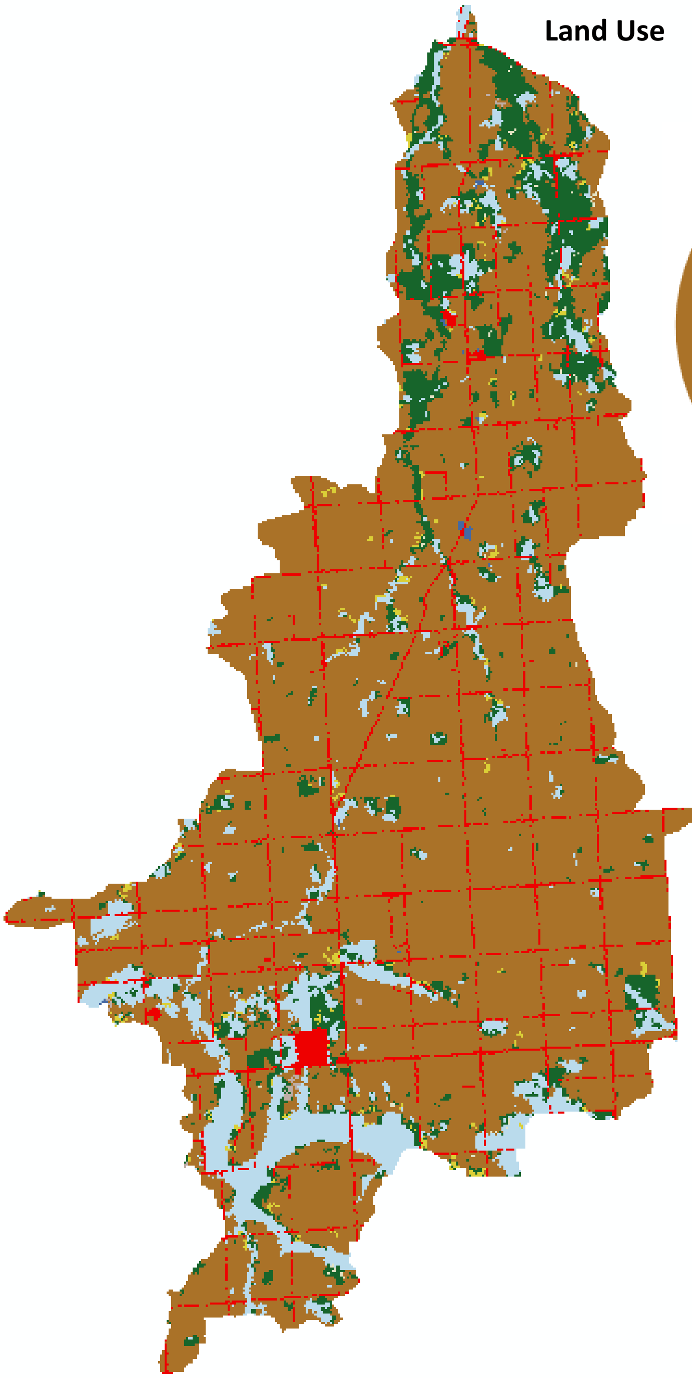
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.19	0.08%
>180 m - 195 m	7.64	3.09%
>195 m - 210 m	30.96	12.53%
>210 m - 225 m	116.78	47.26%
>225 m - 240 m	65.90	26.67%
>240 m - 255 m	22.92	9.27%
>255 m - 270 m	2.72	1.10%
Size of Drainage Area	247.11	100.00%

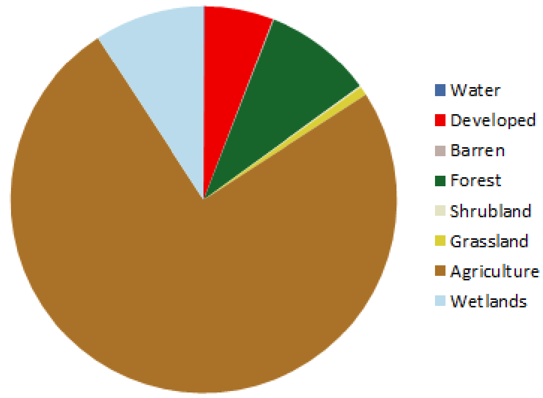
Willow Watershed		
Elevation Statistics		
Size of Drainage Area	**247.11**	***km²***
Maximum	259.00	*m*
Minimum	176.00	*m*
Average	221.33	*m*
Standard Deviation	13.65	*m*

All Elevation Measurements with Respect to North American Datum 1983

38, WILLOW CREEK WATERSHED

Land Use





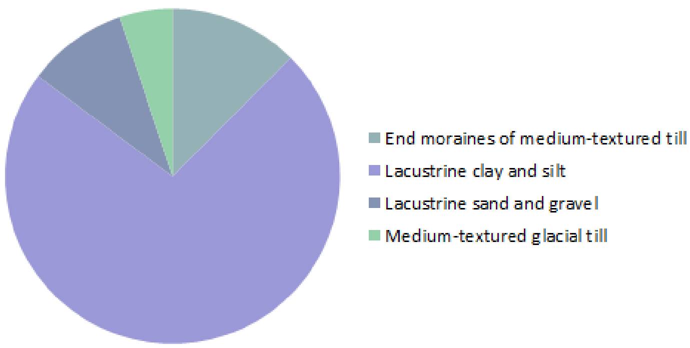
Category	Area	Percentage
Category	*km²*	*%*
Water	0.21	0.08%
Developed	14.21	5.75%
Barren	0.19	0.08%
Forest	22.49	9.10%
Shrubland	0.29	0.12%
Grassland	1.82	0.74%
Agriculture	185.13	74.92%
Wetlands	22.77	9.22%
Total	247.11	100.00%

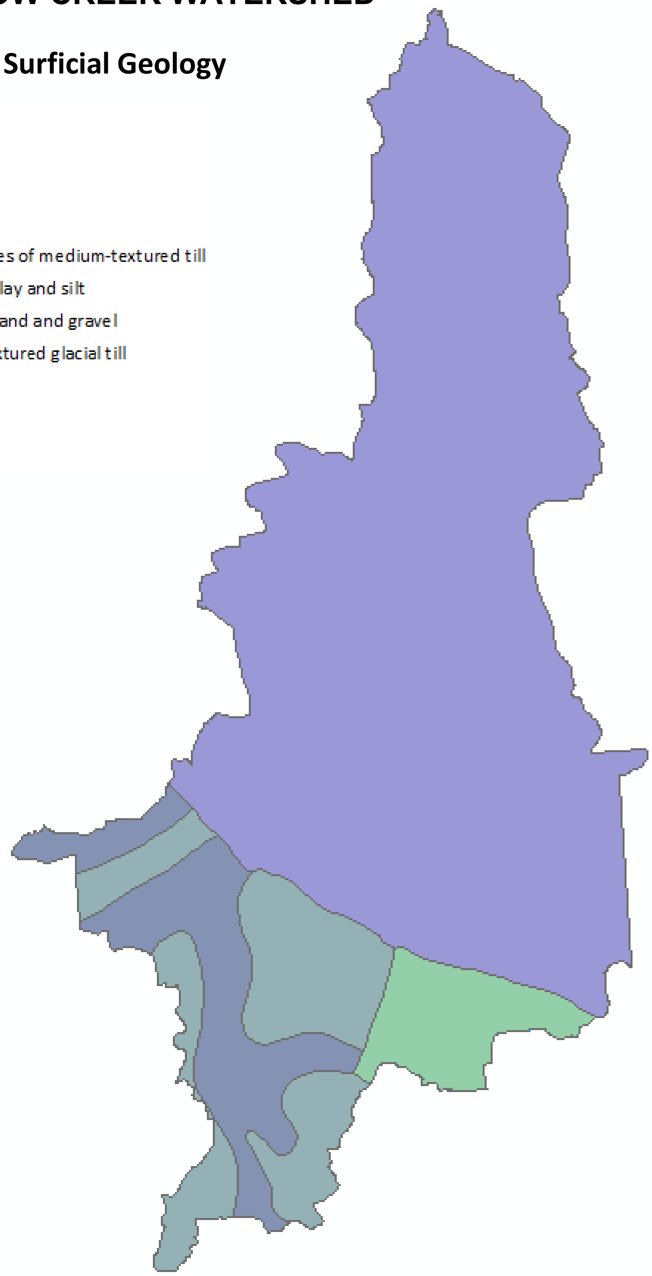
EGLE Runoff Curve Number
79.0

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

38, WILLOW CREEK WATERSHED

Surficial Geology



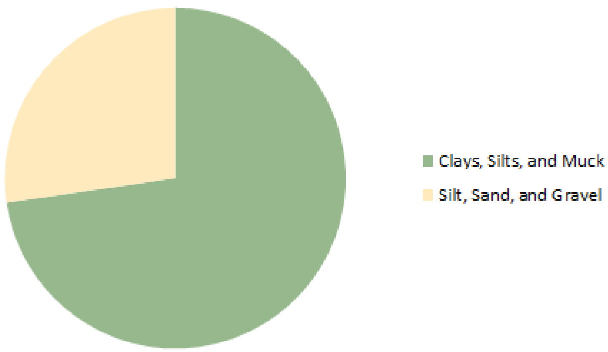


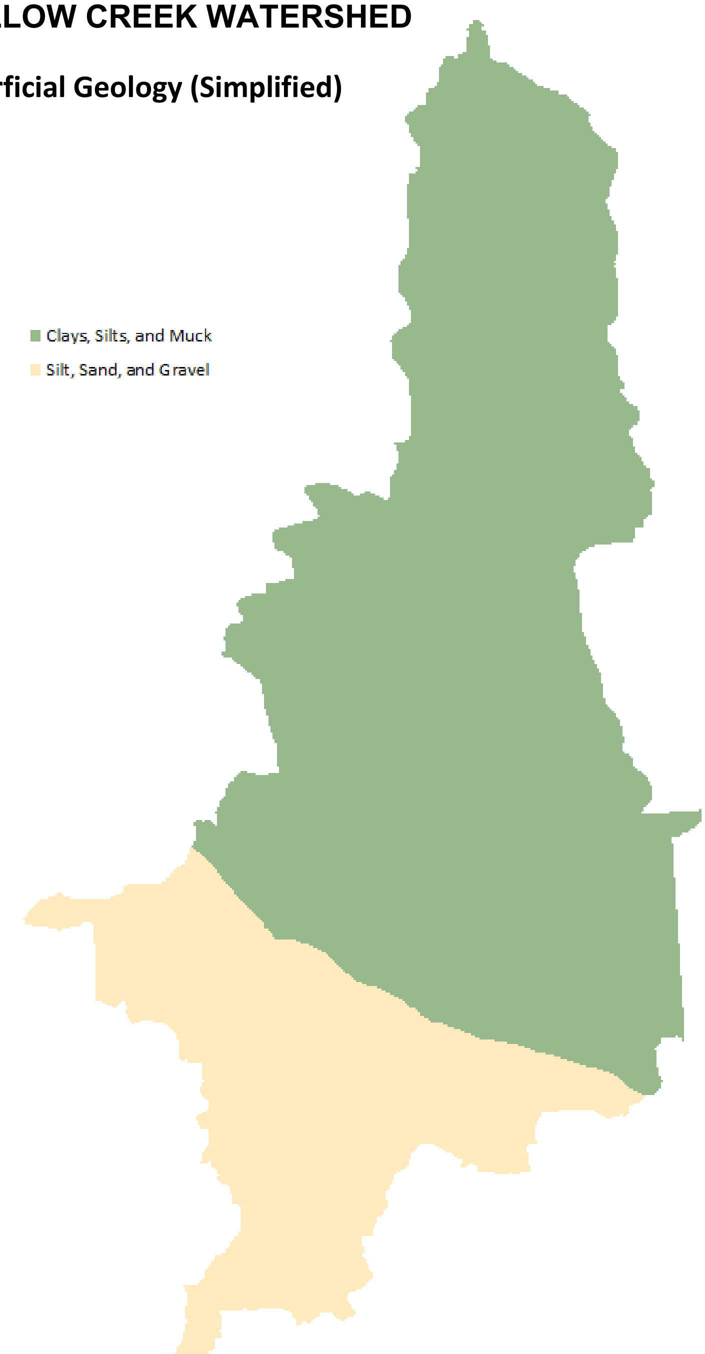
Category	Area	Percentage
Category	*km²*	*%*
End moraines of medium-textured till	30.86	12.49%
Lacustrine clay and silt	179.66	72.70%
Lacustrine sand and gravel	24.04	9.73%
Medium-textured glacial till	12.56	5.08%
Total Watershed Area	247.11	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

38, WILLOW CREEK WATERSHED

Surficial Geology (Simplified)

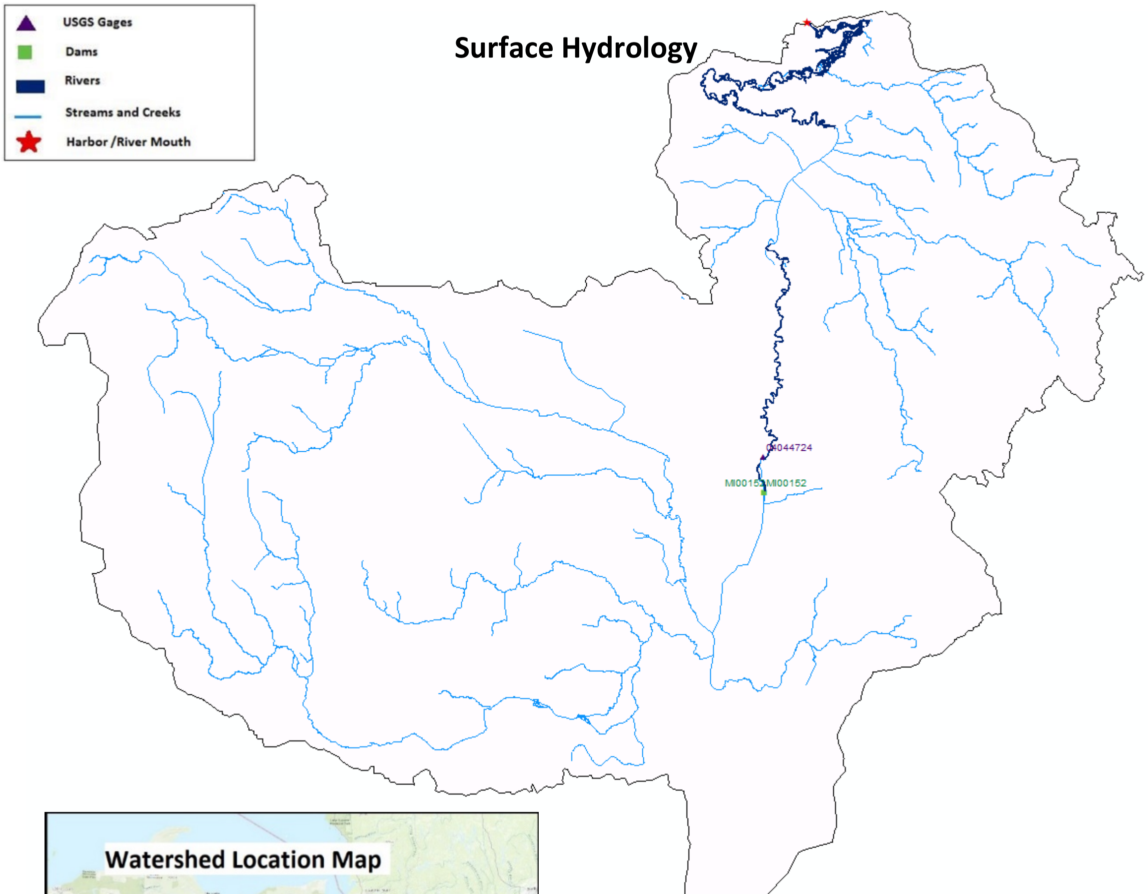


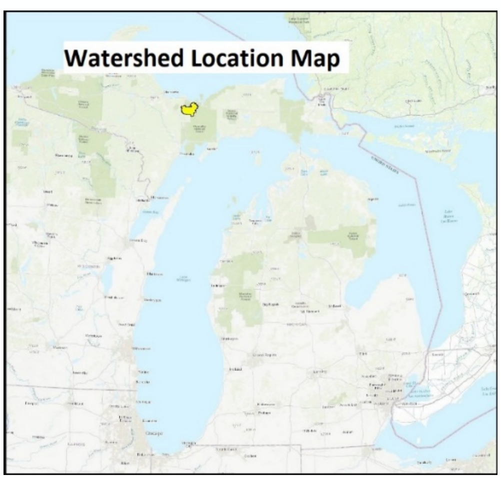


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	179.66	72.70%
Silt, Sand, and Gravel	67.45	27.30%
Total Watershed Area	247.11	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX SS. AU TRAIN WATERSHED (39)





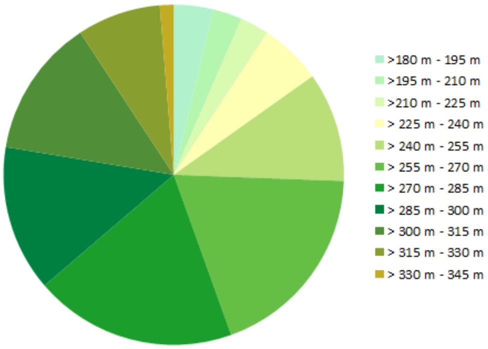
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4044724	AU TRAIN RIVER AT FOREST LAKE, MI	-86.850150	46.340780	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

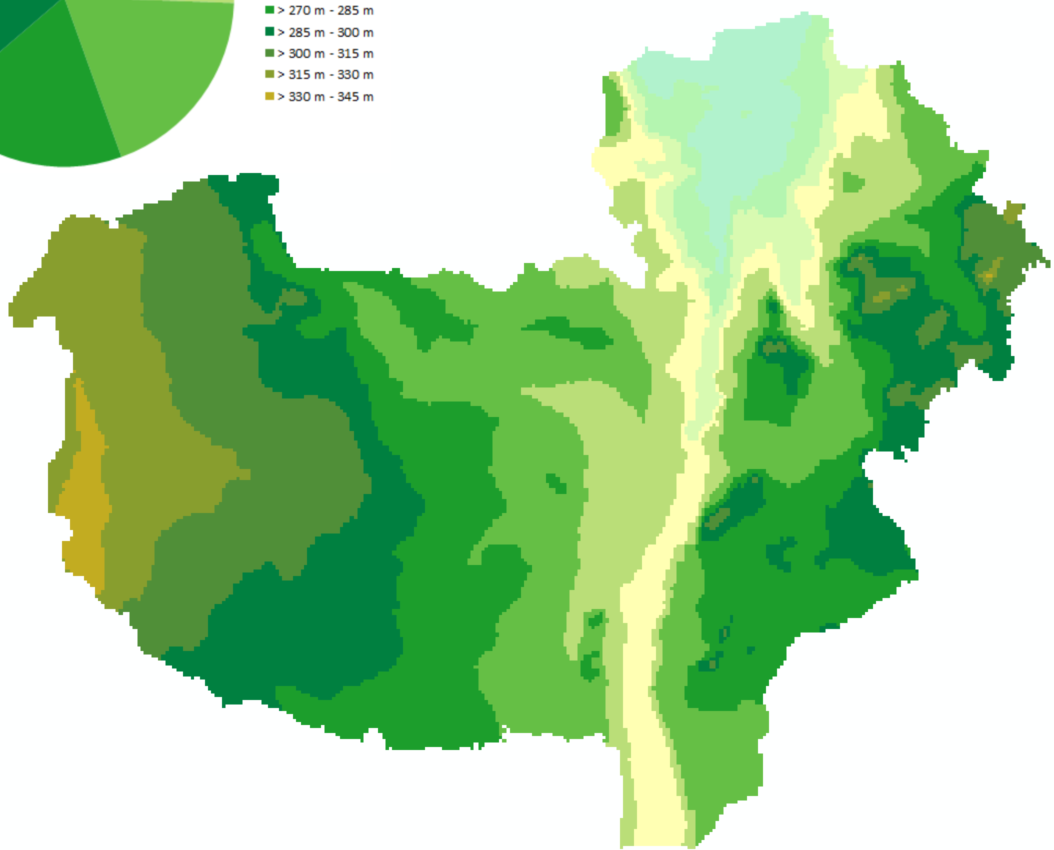
USACE's National Inventory of Dams (NID)			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00152	Au Train	-86.850000	46.333300
MI00152	Au Train South Levee	-86.850000	46.333300

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

39, AU TRAIN WATERSHED

Elevation





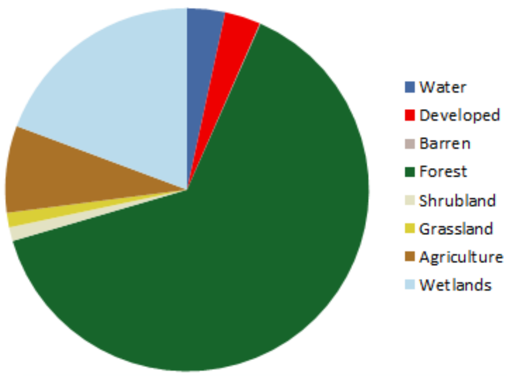
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	11.61	3.76%
>195 m - 210 m	8.47	2.74%
>210 m - 225 m	8.49	2.75%
>225 m - 240 m	18.23	5.91%
>240 m - 255 m	32.15	10.42%
>255 m - 270 m	58.43	18.94%
>270 m - 285 m	59.23	19.20%
>285 m - 300 m	42.87	13.89%
>300 m - 315 m	40.54	13.14%
>315 m -330 m	24.52	7.95%
>330 m - 345 m	4.02	1.30%
Size of Drainage Area	308.55	100.00%

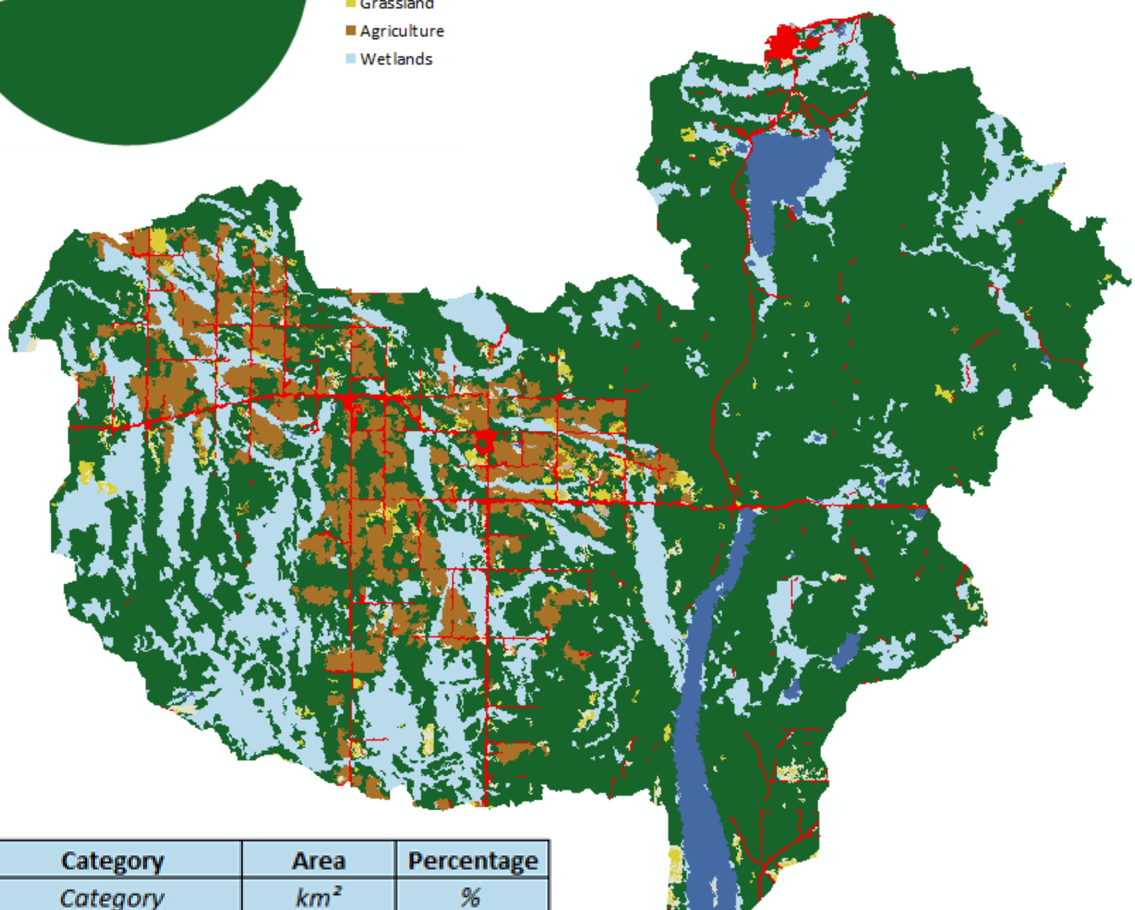
Au Train Watershed		
Elevation Statistics		
Size of Drainage Area	**308.55**	***km²***
Maximum	335.00	*m*
Minimum	185.00	*m*
Average	271.72	*m*
Standard Deviation	33.77	*m*

All Elevation Measurements with Respect to North American Datum 1983

39, AU TRAIN WATERSHED

Land Use





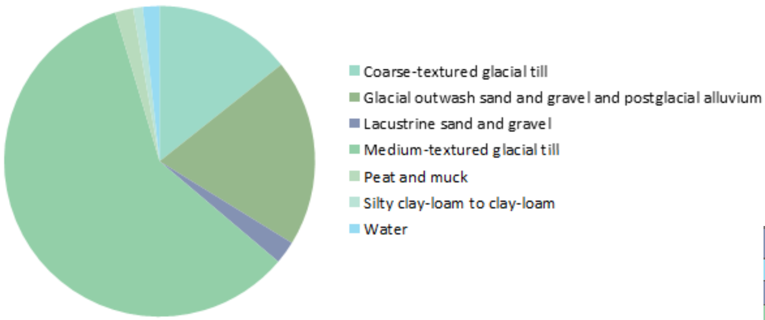
Category	Area	Percentage
Category	*km²*	*%*
Water	10.42	3.38%
Developed	9.85	3.19%
Barren	0.18	0.06%
Forest	196.91	63.82%
Shrubland	3.79	1.23%
Grassland	4.00	1.30%
Agriculture	23.87	7.74%
Wetlands	59.54	19.30%
Total	308.55	100.00%

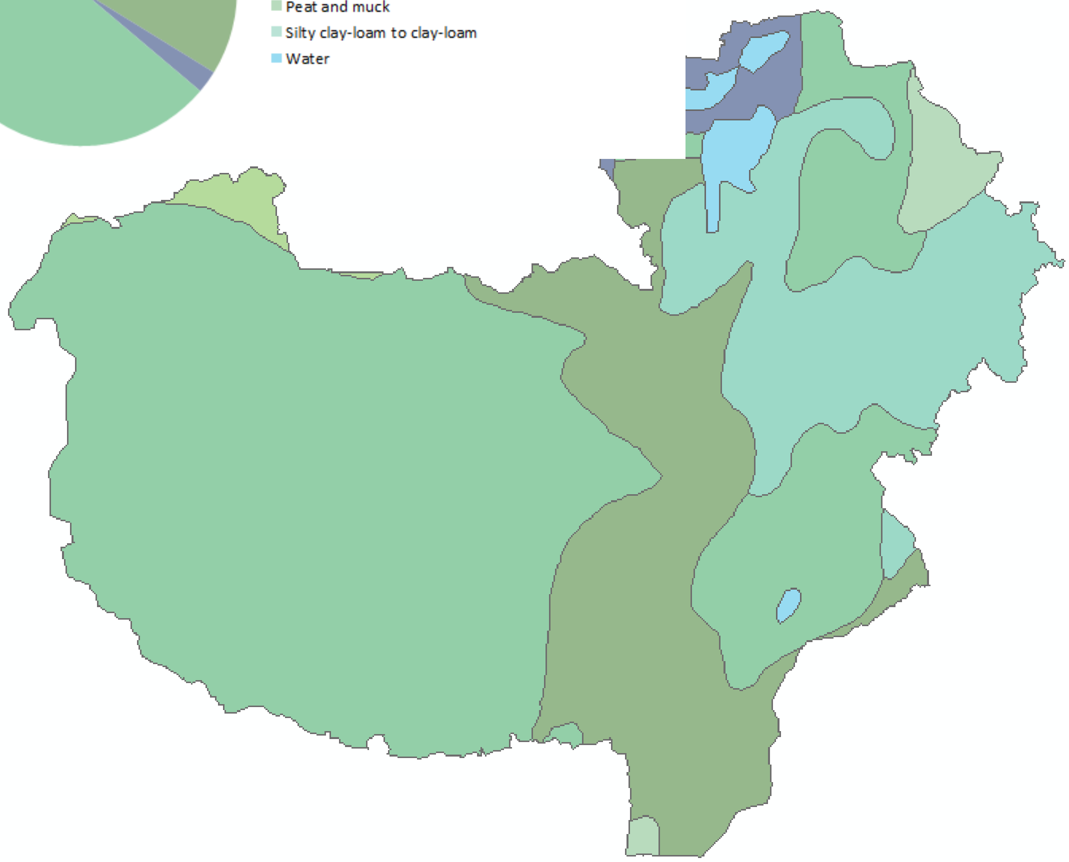
EGLE Runoff Curve Number
67.4

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

39, AU TRAIN WATERSHED

Surficial Geology



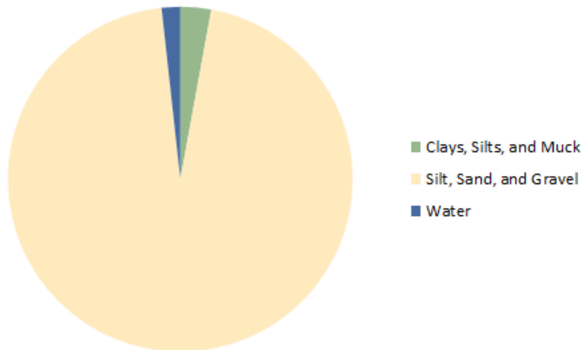


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	44.16	14.31%
Glacial outwash sand and gravel and postglacial alluvium	60.12	19.49%
Lacustrine sand and gravel	7.31	2.37%
Medium-textured glacial till	182.71	59.22%
Peat and muck	5.81	1.88%
Thin to discontinuous glacial till over bedrock	3.07	1.00%
Water	5.36	1.74%
Total Watershed Area	308.55	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

39, AU TRAIN WATERSHED

Surficial Geology (Simplified)

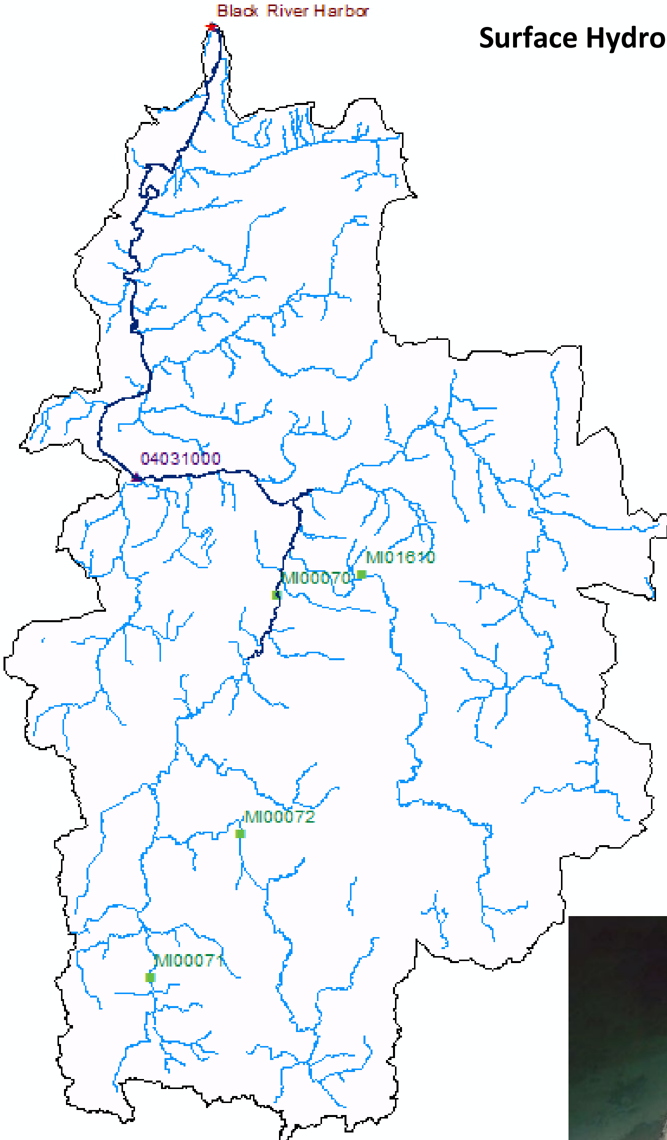


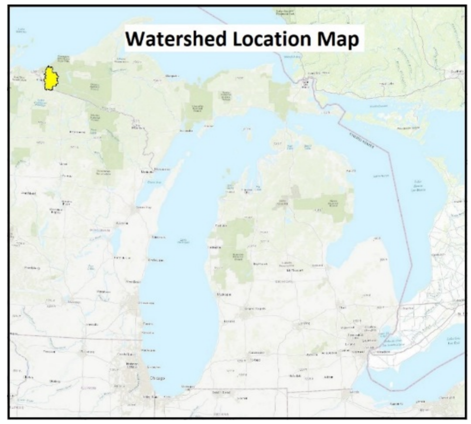
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	8.88	2.88%
Silt, Sand, and Gravel	294.31	95.38%
Water	5.36	1.74%
Total Watershed Area	308.55	100.00%

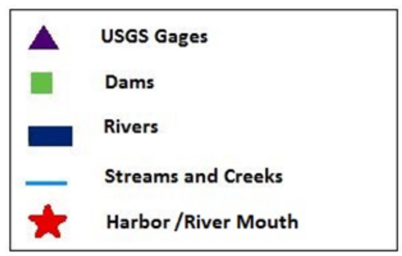
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX TT. BLACK RIVER (GOGEBIC) WATERSHED (40)

Surface Hydrology







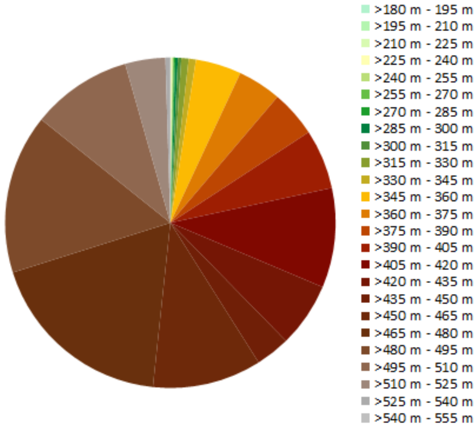
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4031000	BLACK RIVER NEAR BESSEMER, MI	-90.074618	46.511336	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

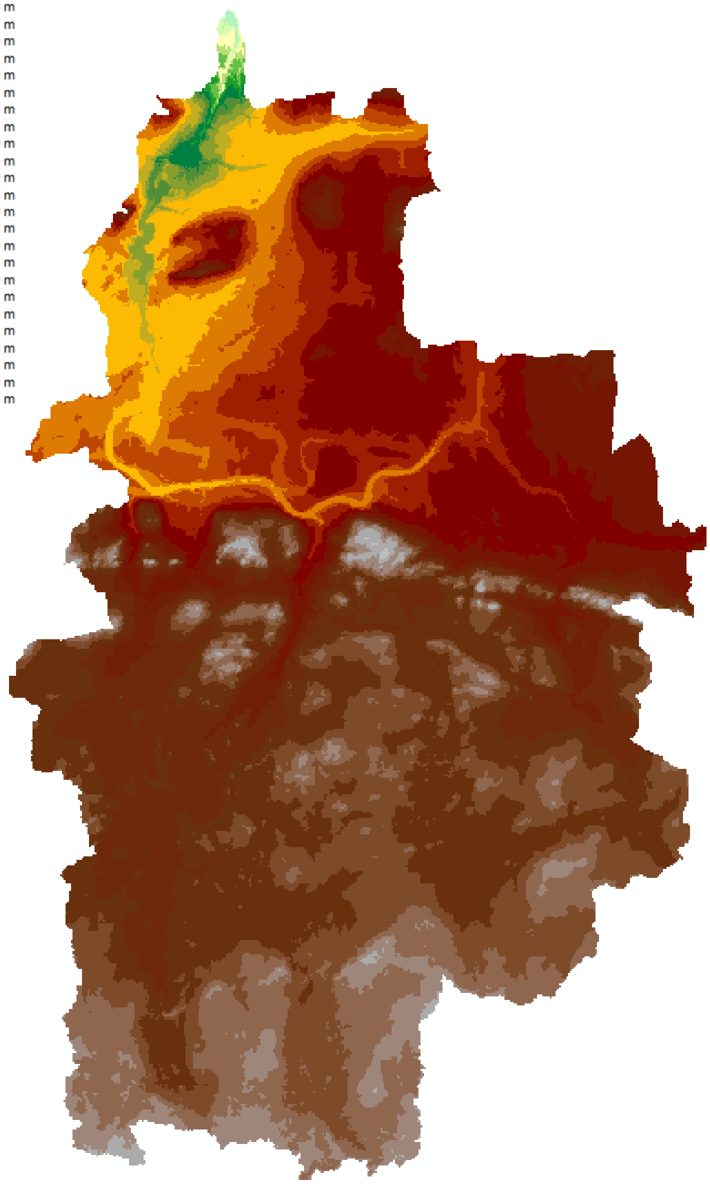
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01610	Sunday Lake Dam	-89.960000	46.481670
MI00070	Bessemer Township Park Dam	-90.001660	46.473330
MI00071	Black River Dam	-90.055000	46.340000
MI00072	McDonald Lake Dam	-90.013890	46.390560

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

40, BLACK RIVER (GOGEBIC) WATERSHED

Elevation





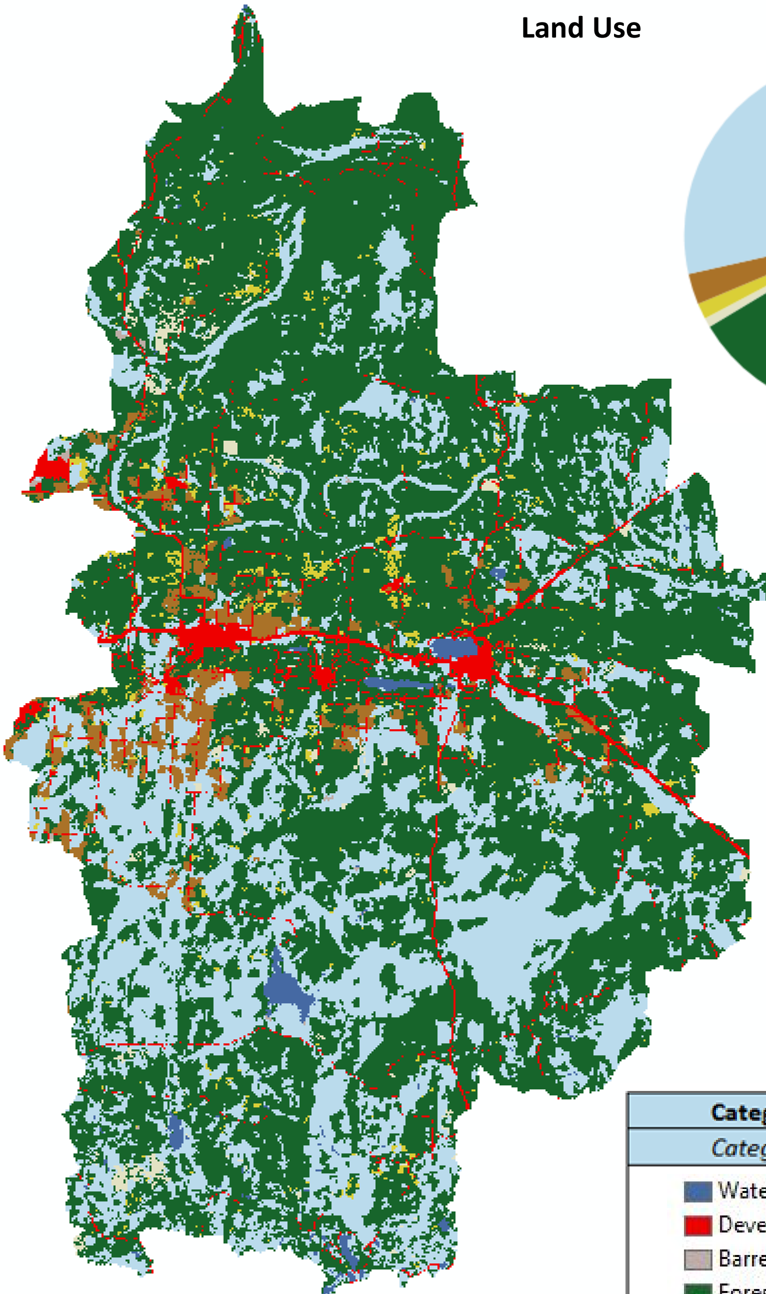
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	0.09	0.01%
>195 m - 210 m	0.16	0.02%
>210 m - 225 m	0.45	0.07%
>225 m - 240 m	0.51	0.08%
>240 m - 255 m	0.54	0.08%
>255 m - 270 m	0.62	0.09%
>270 m - 285 m	0.79	0.12%
>285 m - 300 m	1.63	0.25%
>300 m - 315 m	2.22	0.34%
>315 m - 330 m	4.68	0.71%
>330 m - 345 m	4.68	0.71%
>345 m - 360 m	29.55	4.48%
>360 m - 375 m	28.10	4.26%
>375 m - 390 m	30.05	4.55%
>390 m - 405 m	38.53	5.84%
>405 m - 420 m	64.41	9.76%
>420 m - 435 m	41.68	6.32%
>435 m - 450 m	22.12	3.35%
>450 m - 465 m	70.38	10.66%
>465 m - 480 m	121.73	18.44%
>480 m - 495 m	102.99	15.61%
>495 m - 510 m	64.92	9.84%
>510 m - 525 m	26.04	3.95%
>525 m - 540 m	3.00	0.46%
>540 m - 555 m	0.14	0.02%
Size of Drainage Area	659.99	100.00%

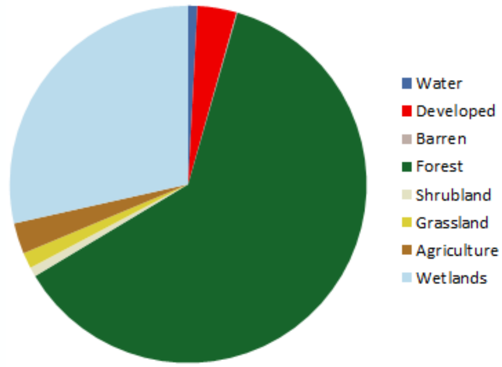
Black (U.P.) Watershed		
Elevation Statistics		
Size of Drainage Area	**659.99**	***km²***
Maximum	549.38	*m*
Minimum	182.96	*m*
Average	446.83	*m*
Standard Deviation	50.57	*m*

All Elevation Measurements with Respect to North American Datum 1983

40, BLACK RIVER (GOGEBIC) WATERSHED

Land Use





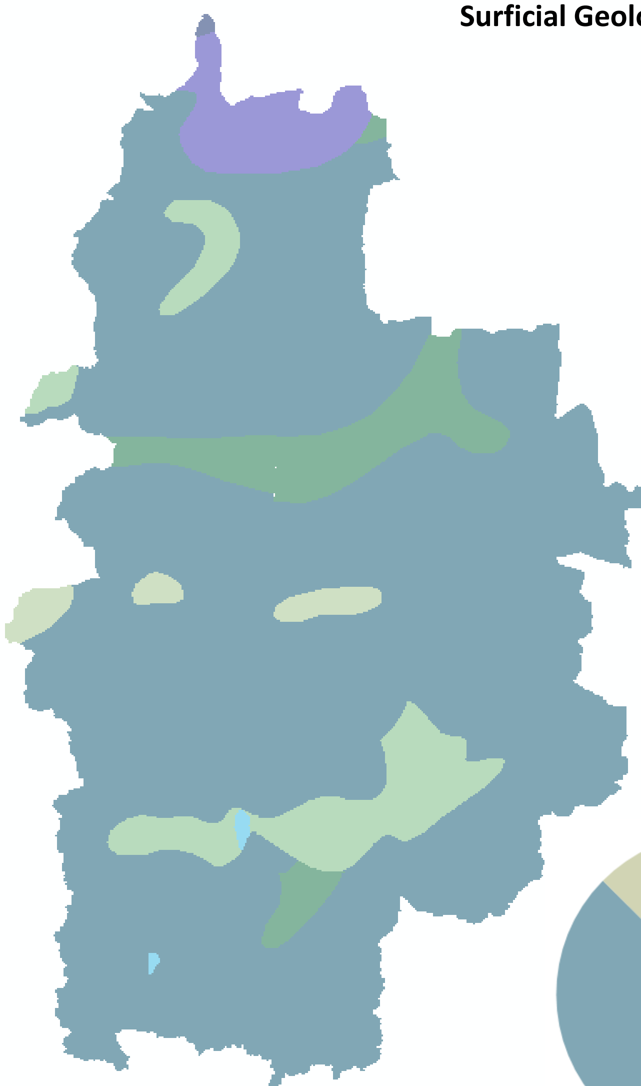
Category	Area	Percentage
Category	*km²*	*%*
Water	5.51	0.83%
Developed	23.35	3.54%
Barren	0.54	0.08%
Forest	408.91	61.96%
Shrubland	5.62	0.85%
Grassland	9.45	1.43%
Agriculture	18.40	2.79%
Wetlands	188.22	28.52%
Total	659.99	100.00%

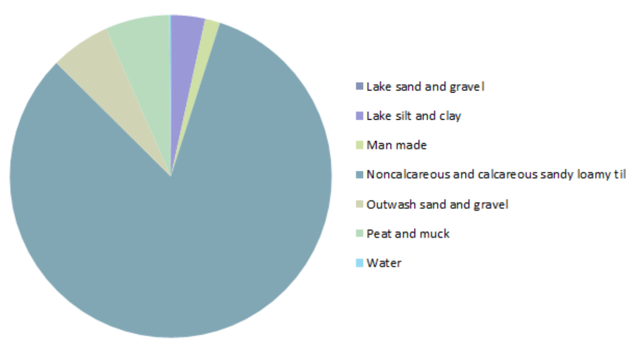
EGLE Runoff Curve Number
77.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

40, BLACK RIVER (GOGEBIC) WATERSHED

Surficial Geology



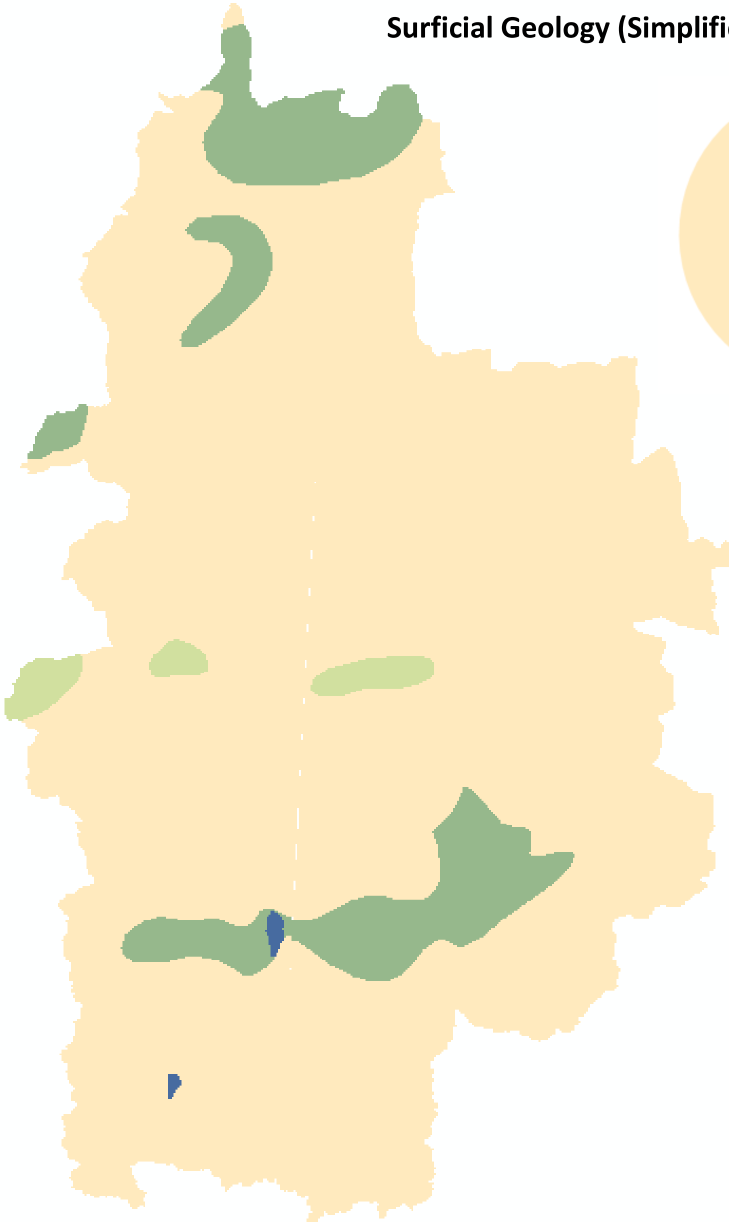


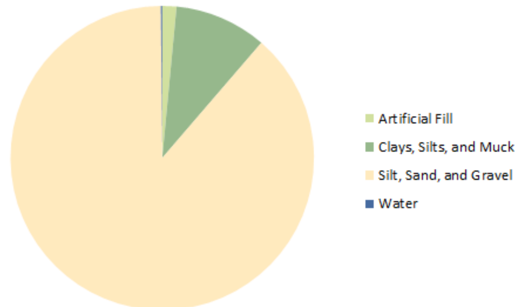
Category	Area	Percentage
Category	*km²*	*%*
Lake sand and gravel	0.48	0.07%
Lake silt and clay	22.24	3.37%
Man made	9.98	1.51%
Noncalcareous and calcareous sandy loamy till	544.26	82.46%
Outwash sand and gravel	39.54	5.99%
Peat and muck	42.56	6.45%
Water	0.94	0.14%
Total Watershed Area	659.99	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

40, BLACK RIVER (GOGEBIC) WATERSHED

Surficial Geology (Simplified)



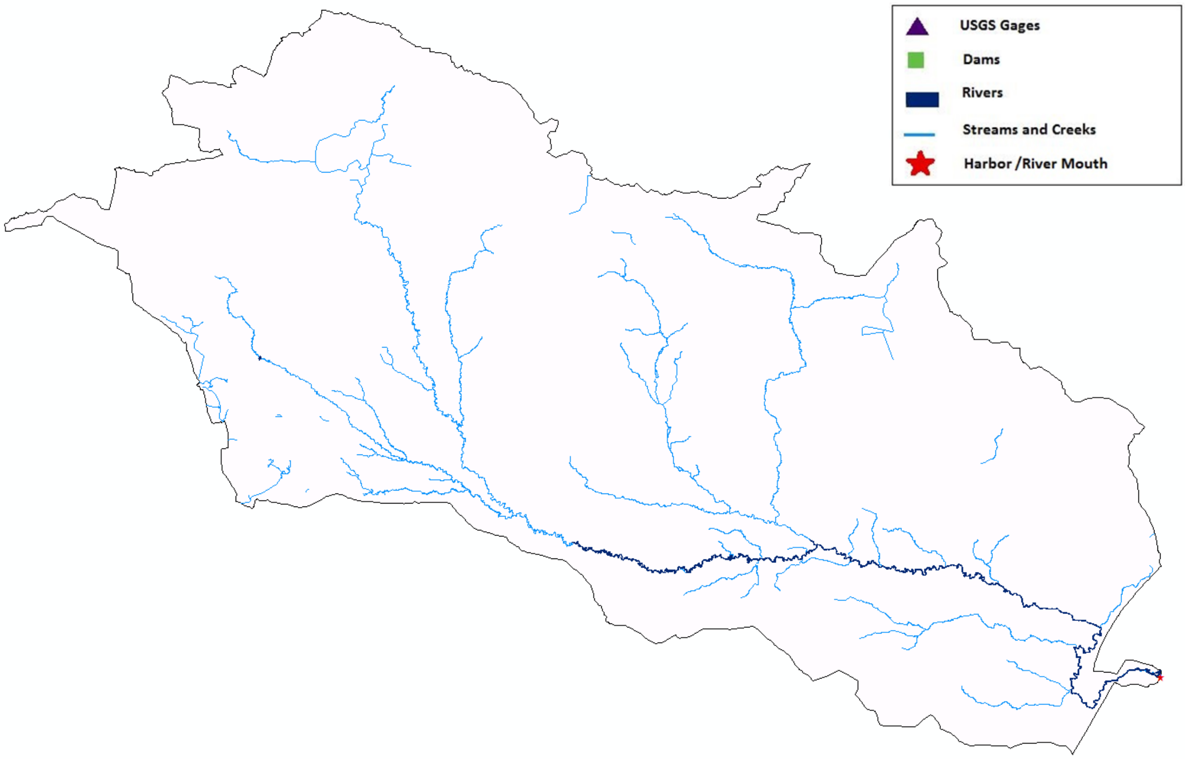


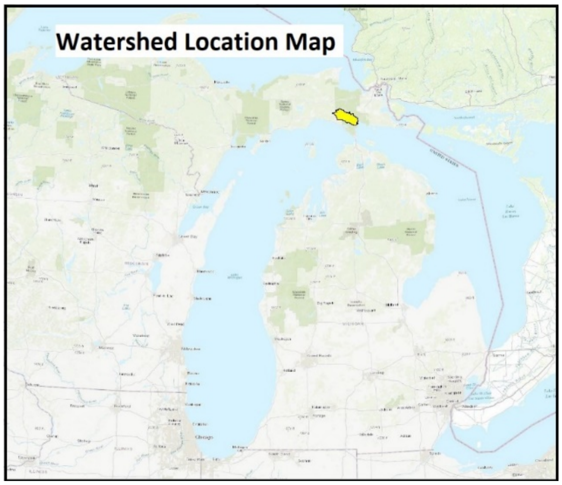
Category	Area	Percentage
Category	*km²*	*%*
Artificial fill	9.98	1.51%
Clay, Silt, and Muck	64.79	9.82%
Silt, Sand, and Gravel	584.28	88.53%
Water	0.94	0.14%
Total Watershed Area	659.99	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX UU. CARP RIVER WATERSHED (41)

Surface Hydrology

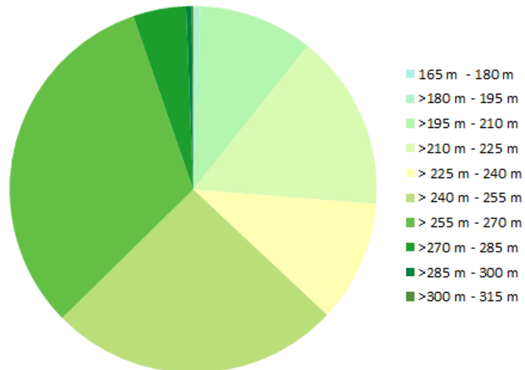


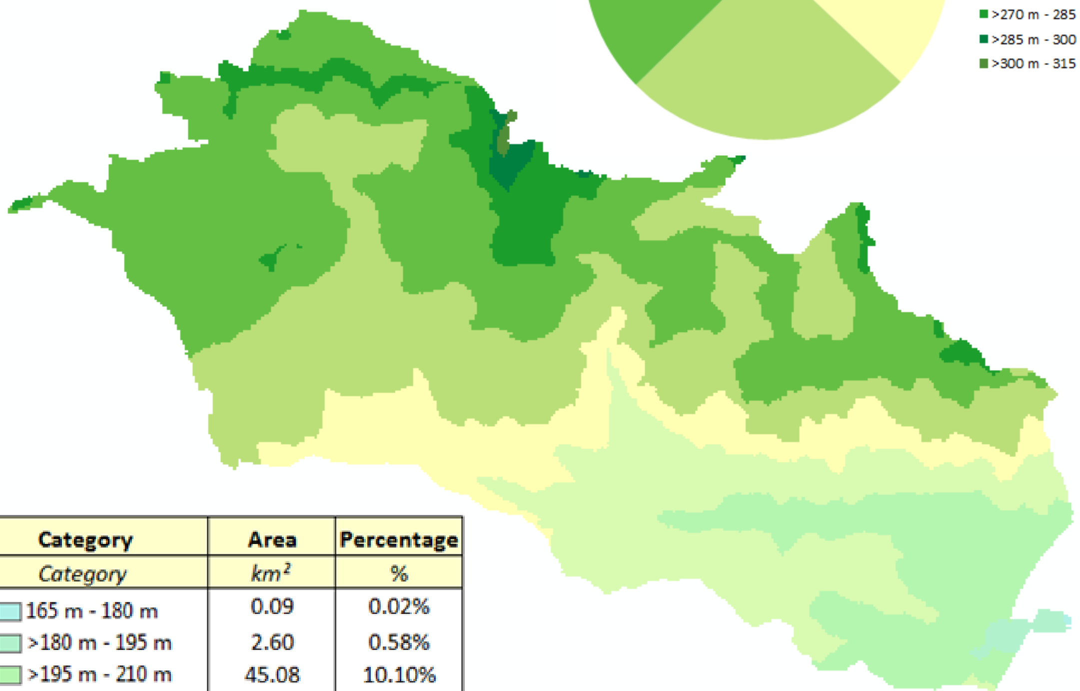


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

41, CARP RIVER WATERSHED

Elevation





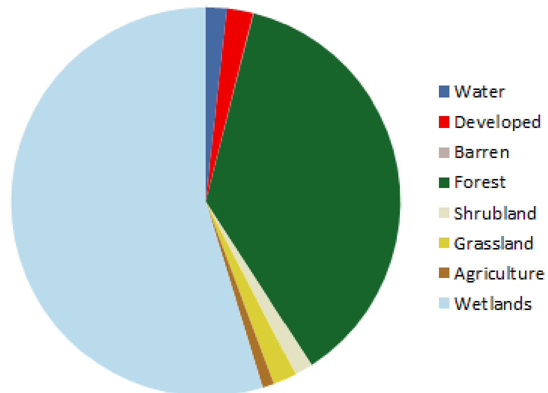
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.09	0.02%
>180 m - 195 m	2.60	0.58%
>195 m - 210 m	45.08	10.10%
>210 m - 225 m	69.43	15.56%
>225 m - 240 m	47.86	10.72%
>240 m - 255 m	114.55	25.67%
>255 m - 270 m	143.08	32.06%
>270 m - 285 m	20.84	4.67%
>285 m - 300 m	2.22	0.50%
>300 m - 315 m	0.54	0.12%
Size of Drainage Area	446.28	100.00%

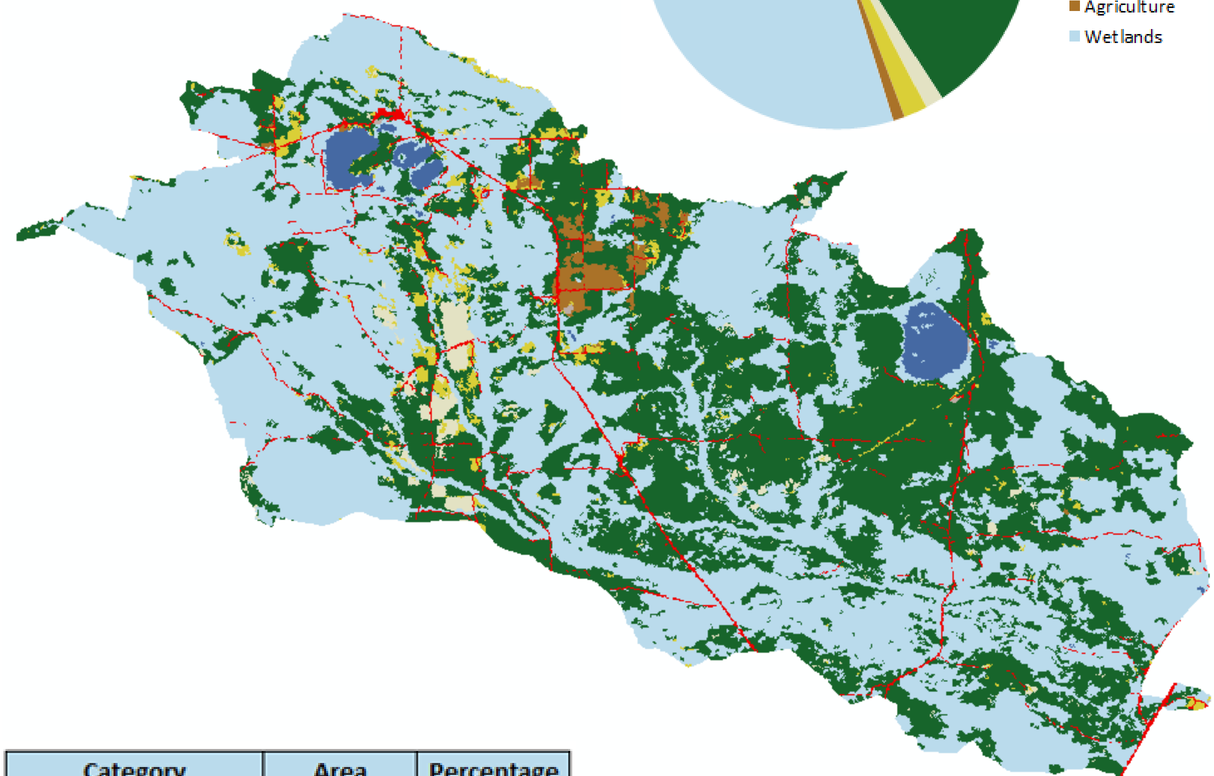
Carp Watershed		
Elevation Statistics		
Size of Drainage Area	**446.28**	***km²***
Maximum	304.00	*m*
Minimum	176.00	*m*
Average	242.08	*m*
Standard Deviation	21.95	*m*

All Elevation Measurements with Respect to North American Datum 1983

41, CARP RIVER WATERSHED

Land Use





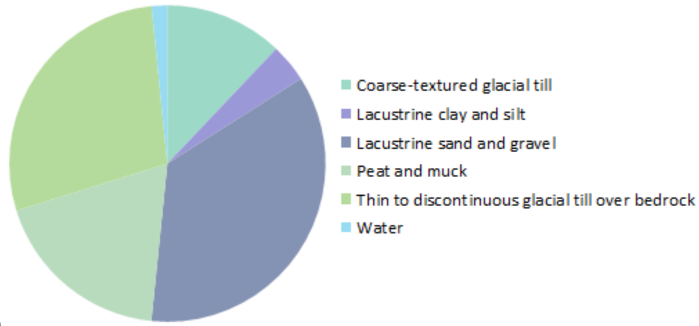
Category	Area	Percentage
Category	*km²*	*%*
Water	7.76	1.74%
Developed	9.78	2.19%
Barren	0.19	0.04%
Forest	164.59	36.88%
Shrubland	6.75	1.51%
Grassland	8.60	1.93%
Agriculture	4.32	0.97%
Wetlands	244.30	54.74%
Total	446.28	100.00%

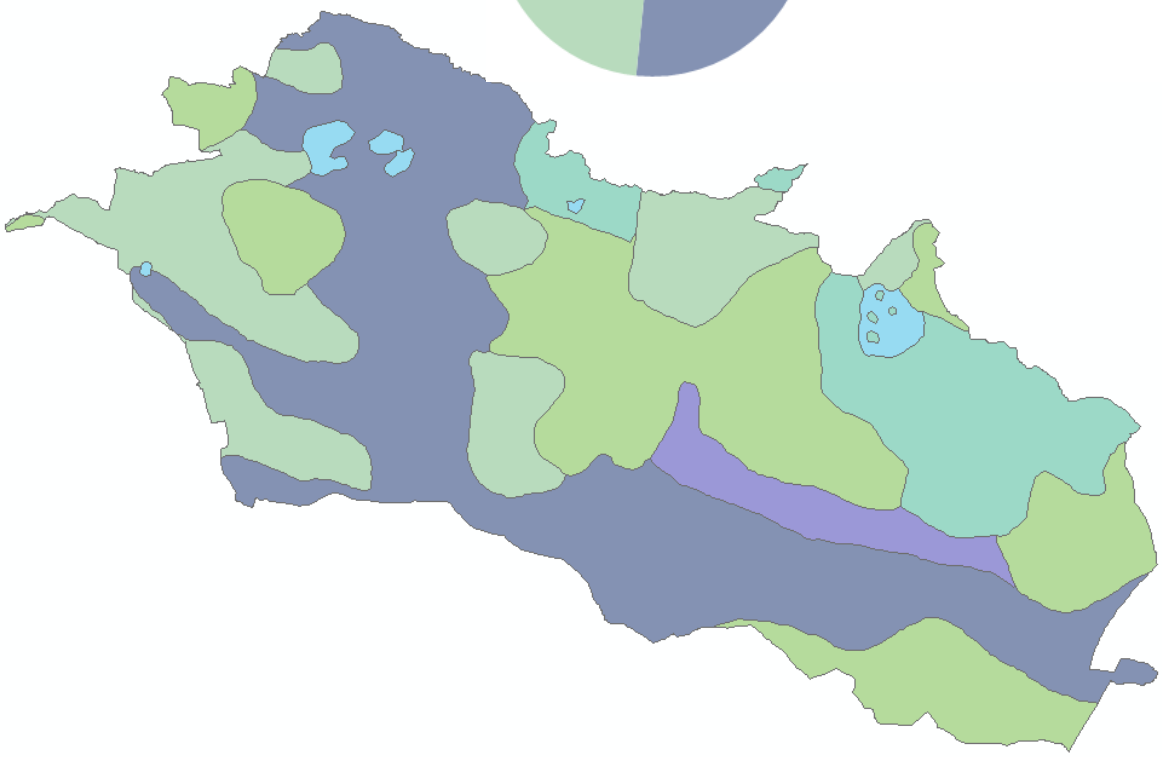
EGLE Runoff Curve Number
72.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

41, CARP RIVER WATERSHED

Surficial Geology



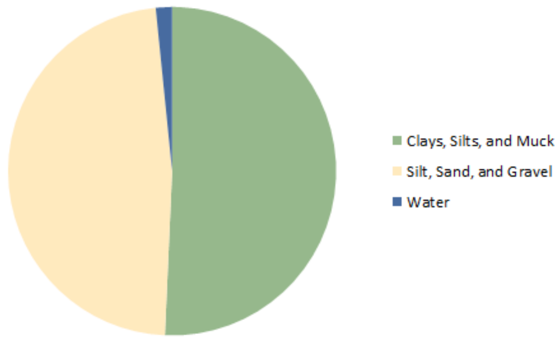


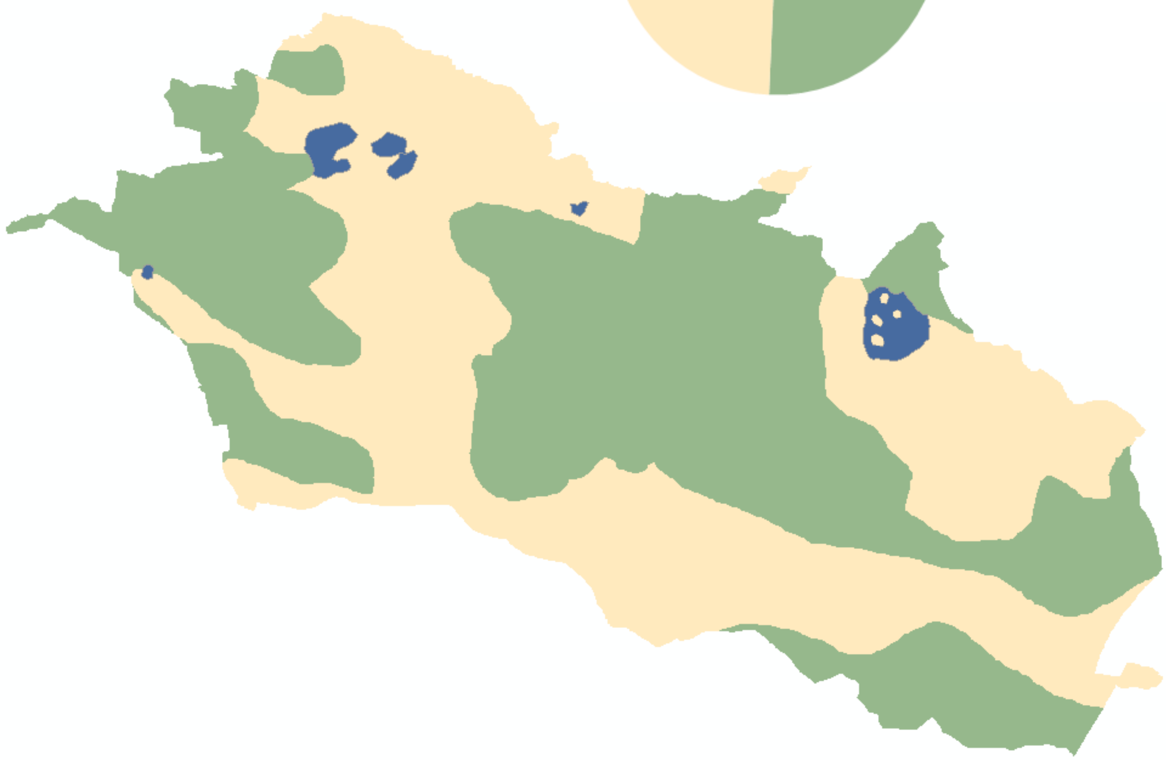
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	53.89	12.08%
Lacustrine clay and silt	17.52	3.93%
Lacustrine sand and gravel	158.96	35.62%
Peat and muck	82.83	18.56%
Thin to discontinuous glacial till over bedrock	125.92	28.22%
Water	7.16	1.60%
Total Watershed Area	446.28	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

41, CARP RIVER WATERSHED

Surficial Geology (Simplified)



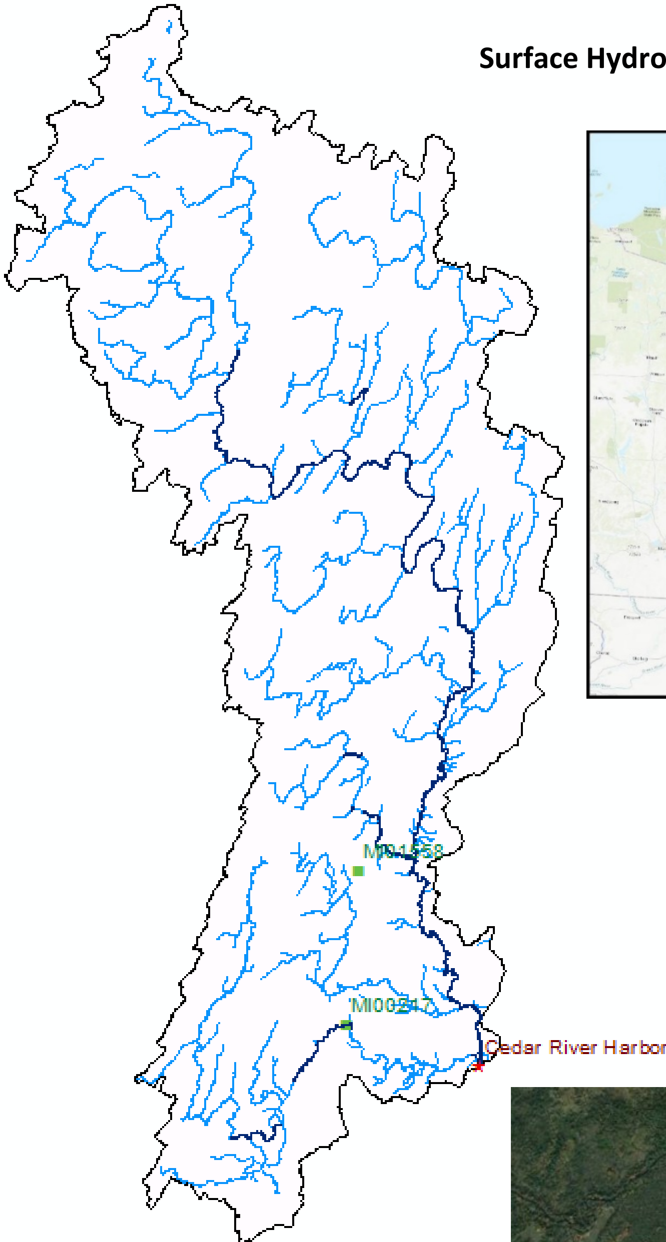


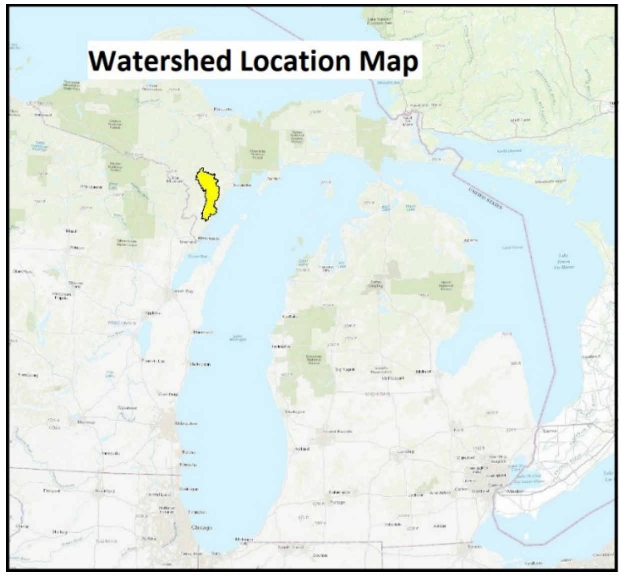
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	226.27	50.70%
Silt, Sand, and Gravel	212.85	47.69%
Water	7.16	1.60%
Total Watershed Area	446.28	100.00%

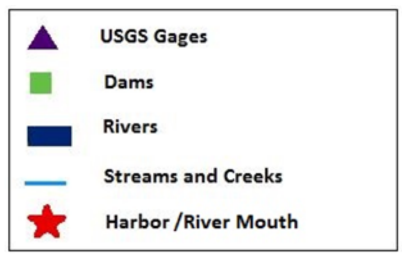
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

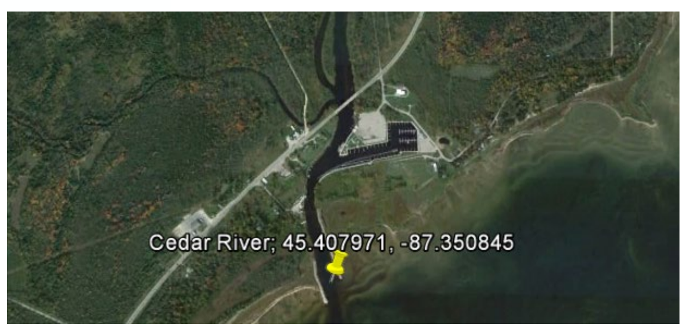
APPENDIX VV. CEDAR RIVER WATERSHED (42)

Surface Hydrology







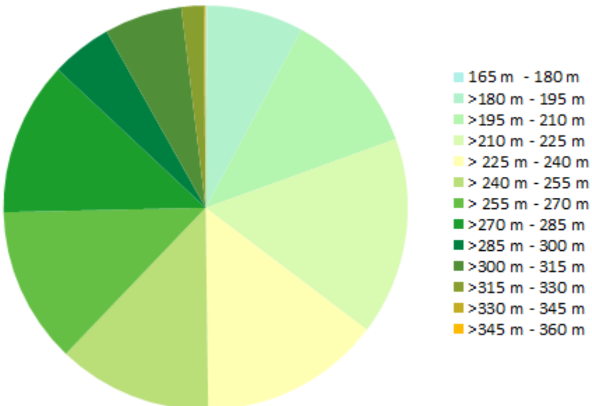


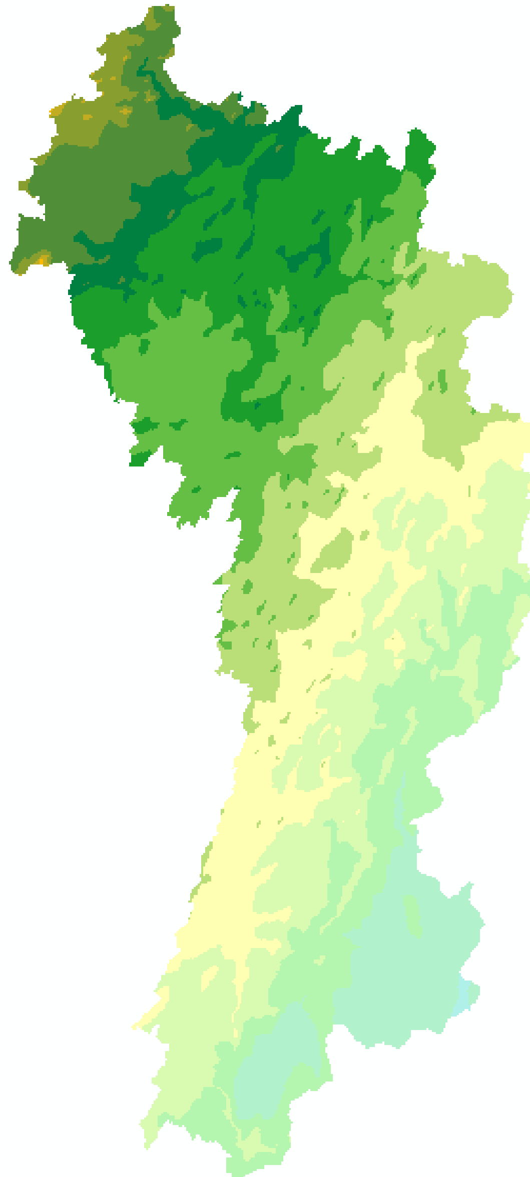
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI01558	Peterson Pond Dam	-87.434600	45.501760
MI00217	Hayward Lake Dam	-87.440760	45.428360

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

42, CEDAR RIVER WATERSHED

Elevation





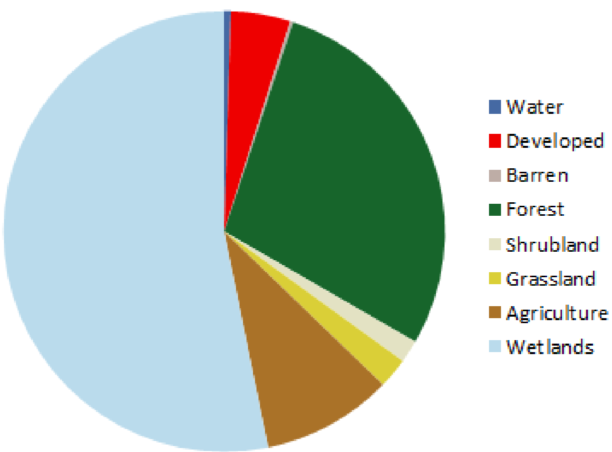
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.35	0.14%
>180 m - 195 m	75.38	7.71%
>195 m - 210 m	113.57	11.62%
>210 m - 225 m	154.73	15.83%
>225 m - 240 m	141.64	14.49%
>240 m - 255 m	120.61	12.34%
>255 m - 270 m	122.06	12.49%
>270 m - 285 m	120.58	12.34%
>285 m - 300 m	47.65	4.88%
>300 m - 315 m	60.75	6.22%
>315 m - 330 m	17.55	1.80%
>330 m - 345 m	1.20	0.12%
>345 m - 360 m	0.12	0.01%
Size of Drainage Area	977.18	100.00%

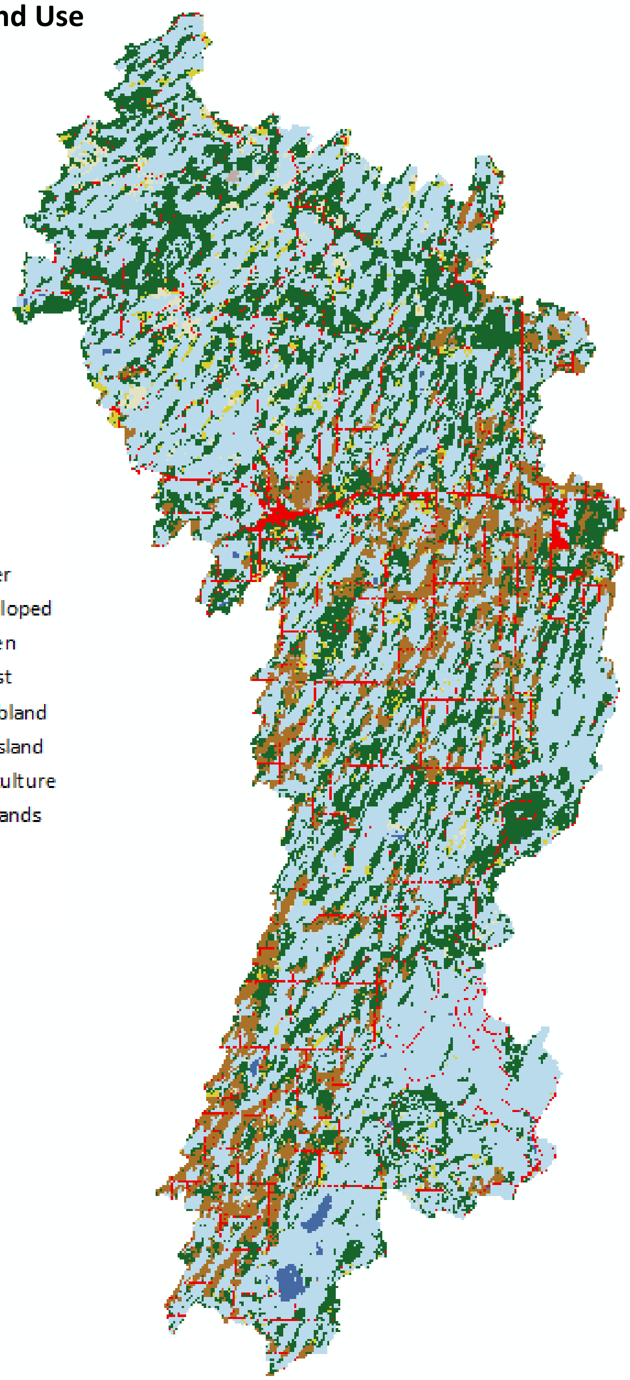
Cedar Watershed		
Elevation Statistics		
Size of Drainage Area	**977.18**	***km²***
Maximum	350.00	*m*
Minimum	176.00	*m*
Average	242.61	*m*
Standard Deviation	34.75	*m*

All Elevation Measurements with Respect to North American Datum 1983

42, CEDAR RIVER WATERSHED

Land Use





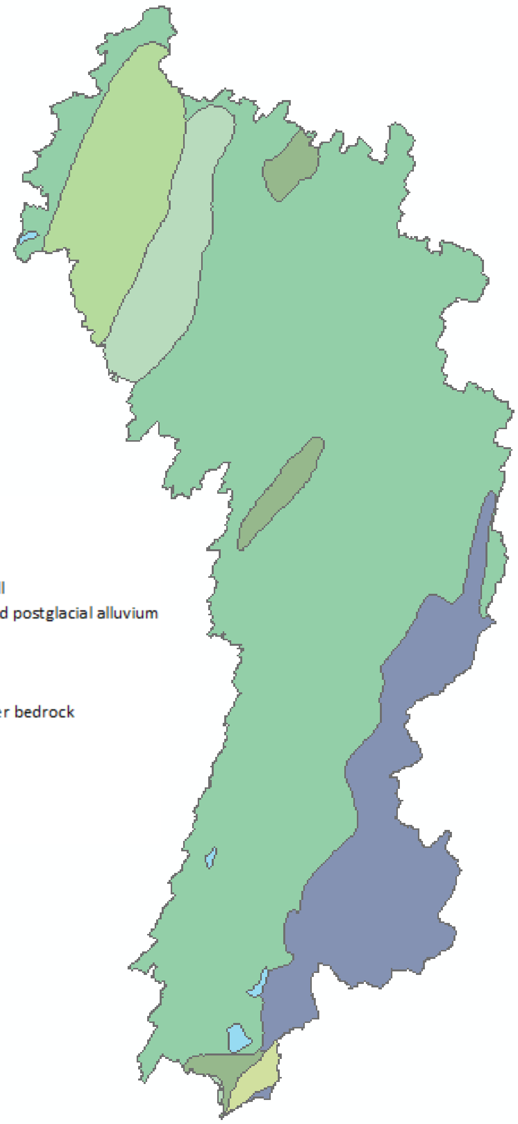
Category	Area	Percentage
Category	*km²*	*%*
Water	4.76	0.49%
Developed	42.56	4.36%
Barren	2.21	0.23%
Forest	276.30	28.27%
Shrubland	16.17	1.65%
Grassland	21.76	2.23%
Agriculture	93.64	9.58%
Wetlands	519.80	53.19%
Total	977.18	100.00%

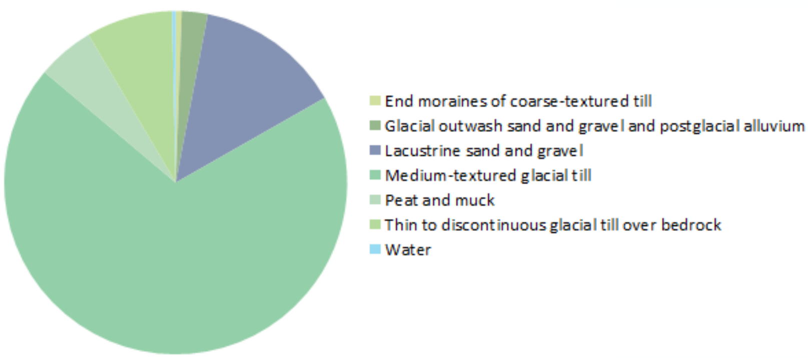
EGLE Runoff Curve Number
76.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

42, CEDAR RIVER WATERSHED

Surficial Geology



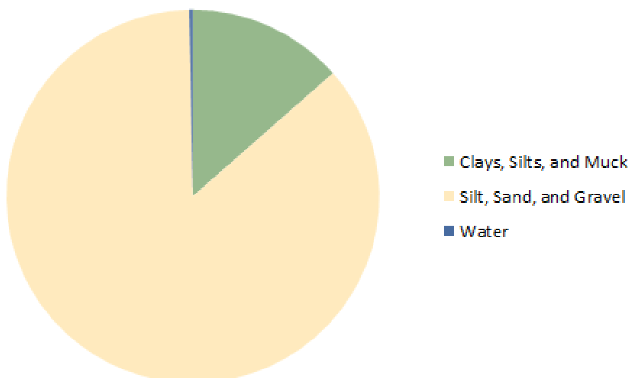


Category	Area	Percentage
Category	*km²*	*%*
End moraines of coarse-textured till	5.53	0.57%
Glacial outwash sand and gravel and postglacial alluvium	23.85	2.44%
Lacustrine sand and gravel	134.55	13.77%
Medium-textured glacial till	677.86	69.37%
Peat and muck	52.48	5.37%
Thin to discontinuous glacial till over bedrock	79.71	8.16%
Water	3.20	0.33%
Total Watershed Area	977.18	99.67%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

42, CEDAR RIVER WATERSHED

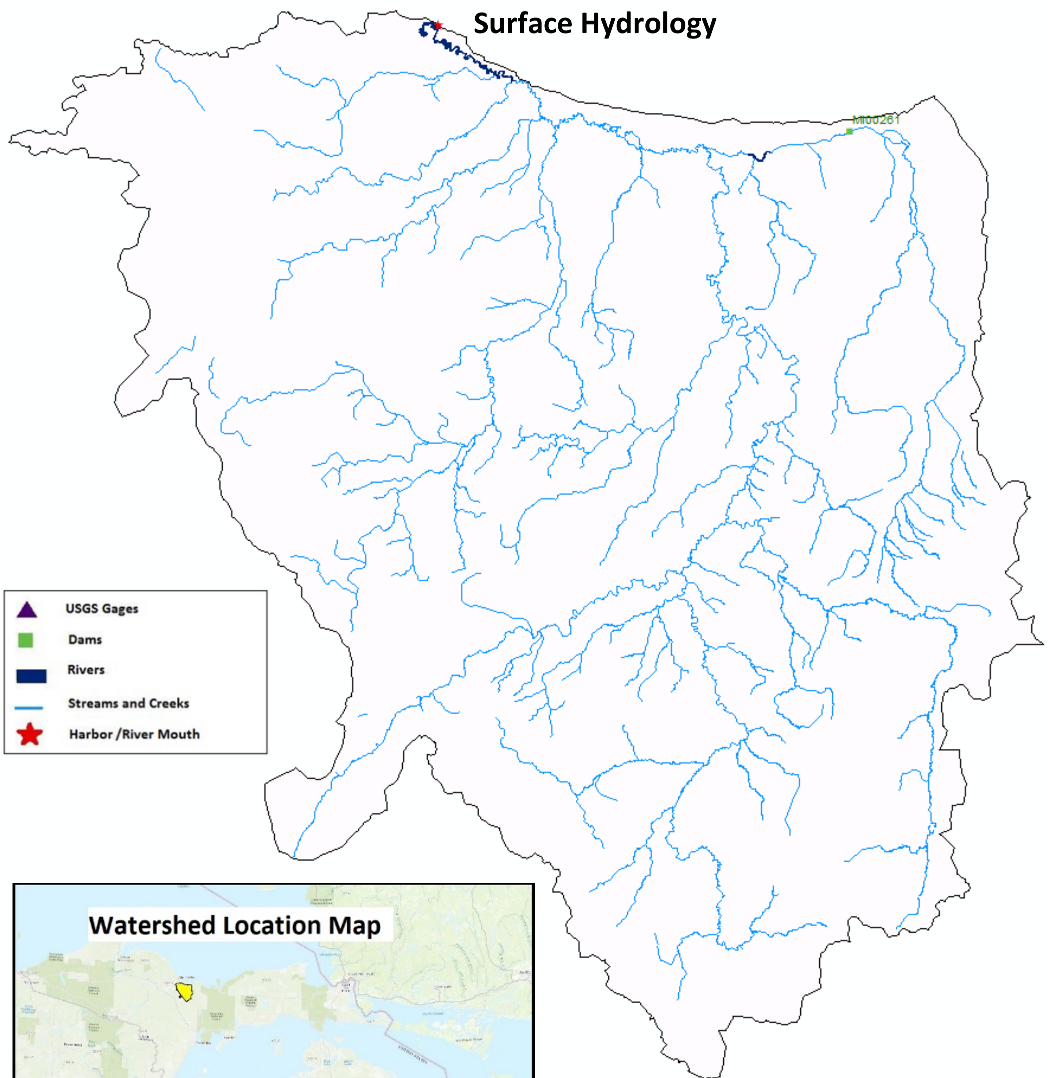
Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	132.20	13.53%
Silt, Sand, and Gravel	841.79	86.14%
Water	3.20	0.33%
Total Watershed Area	977.18	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX WW. CHOCOLAY RIVER WATERSHED (43)

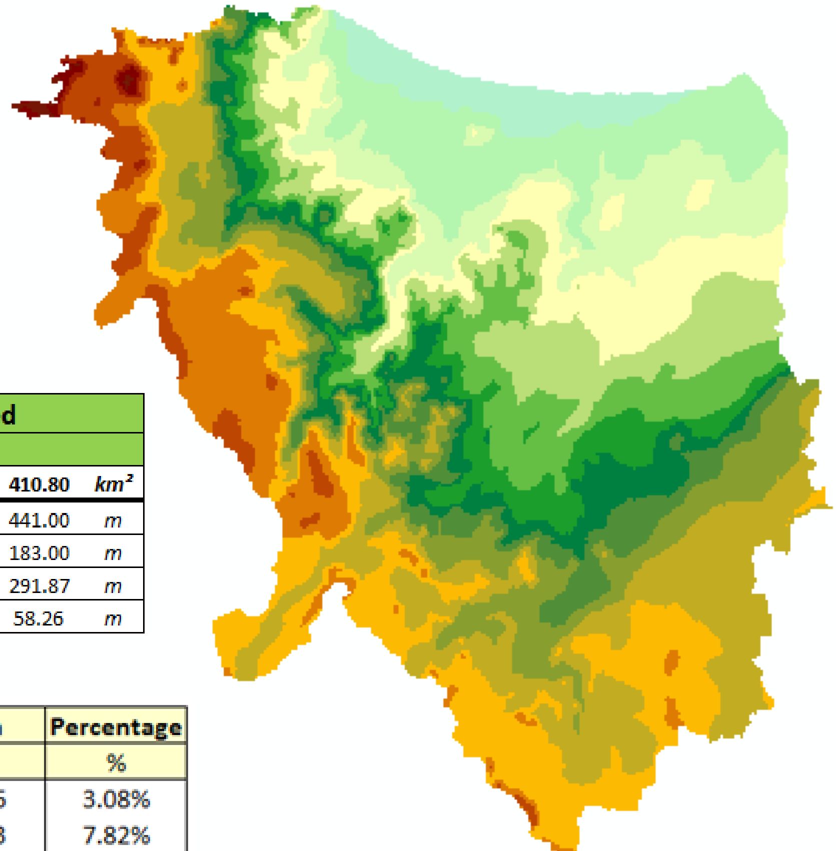


USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00261	Lake Le Vasseur Dam	-87.216670	46.478330

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

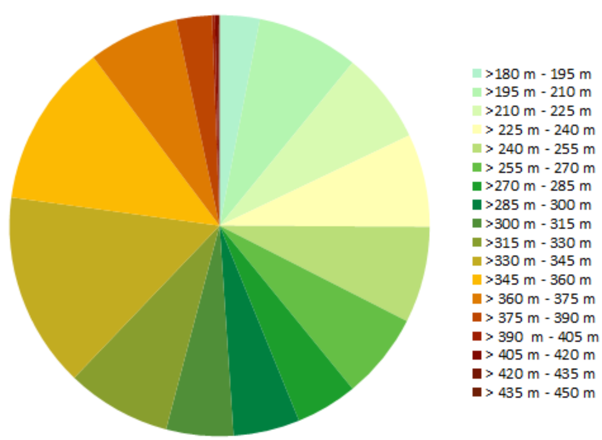
43, CHOCOLAY RIVER WATERSHED

Elevation



Chocolay Watershed		
Elevation Statistics		
Size of Drainage Area	**410.80**	***km²***
Maximum	441.00	*m*
Minimum	183.00	*m*
Average	291.87	*m*
Standard Deviation	58.26	*m*

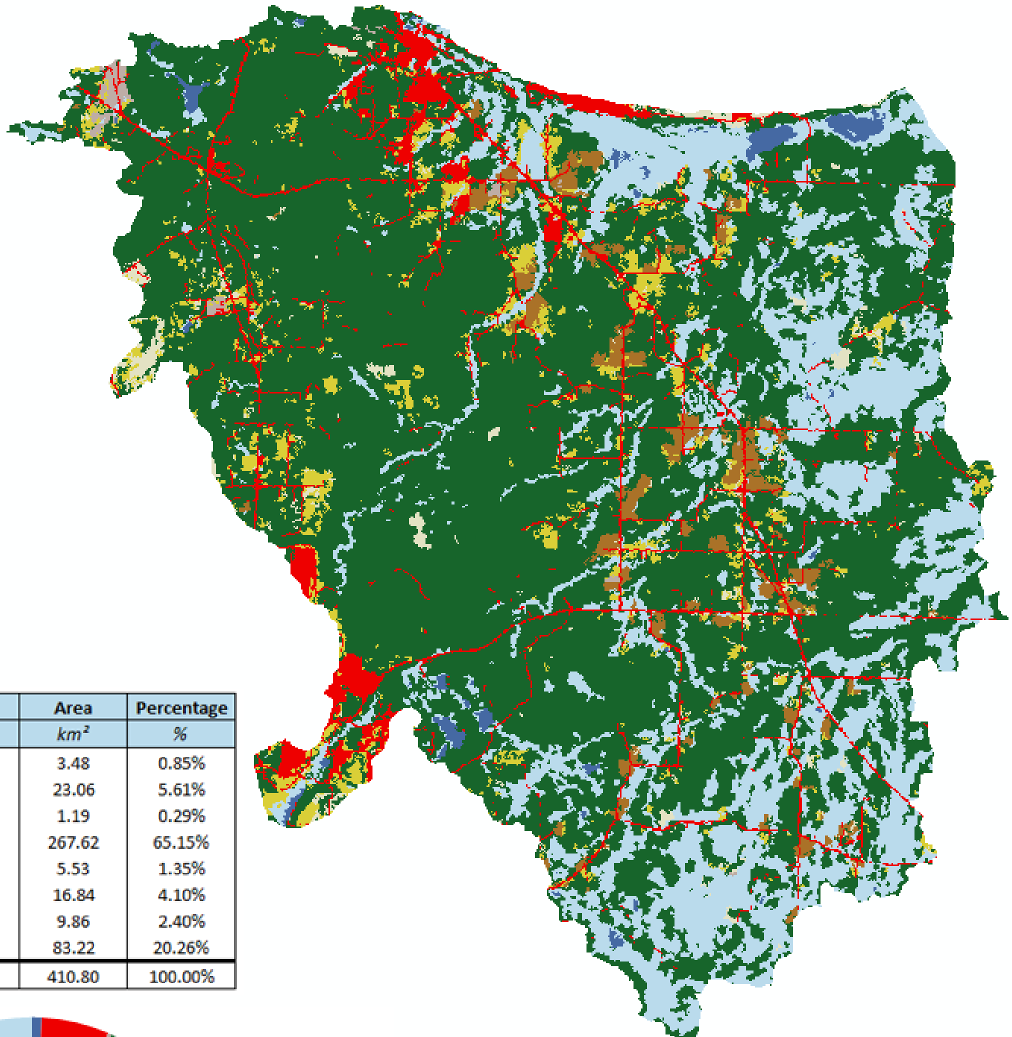
Category	Area	Percentage
Category	*km²*	%
>180 m - 195 m	12.66	3.08%
>195 m - 210 m	32.13	7.82%
>210 m - 225 m	28.89	7.03%
>225 m - 240 m	29.36	7.15%
>240 m - 255 m	30.40	7.40%
>255 m - 270 m	27.13	6.60%
>270 m - 285 m	19.48	4.74%
>285 m - 300 m	20.96	5.10%
>300 m - 315 m	21.22	5.17%
>315 m - 330 m	33.09	8.05%
>330 m - 345 m	61.60	15.00%
>345 m - 360 m	51.73	12.59%
>360 m - 375 m	28.55	6.95%
>375 m - 390 m	11.21	2.73%
>390 m - 405 m	0.93	0.23%
>405 m - 420 m	0.92	0.22%
>420 m - 435 m	0.52	0.13%
>435 m - 450 m	0.01	0.00%
Size of Drainage Area	410.80	100.00%



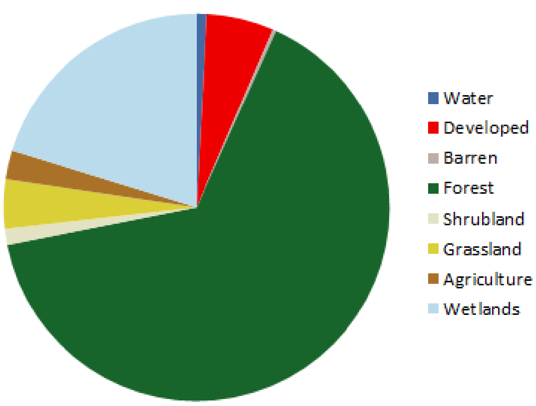
All Elevation Measurements with Respect to North American Datum 1983

43, CHOCOLAY RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	3.48	0.85%
Developed	23.06	5.61%
Barren	1.19	0.29%
Forest	267.62	65.15%
Shrubland	5.53	1.35%
Grassland	16.84	4.10%
Agriculture	9.86	2.40%
Wetlands	83.22	20.26%
Total	410.80	100.00%

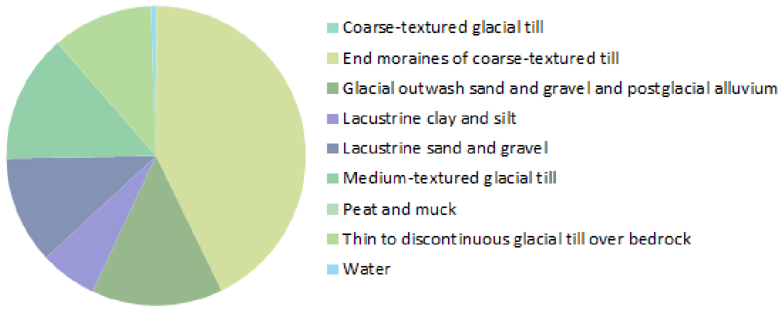


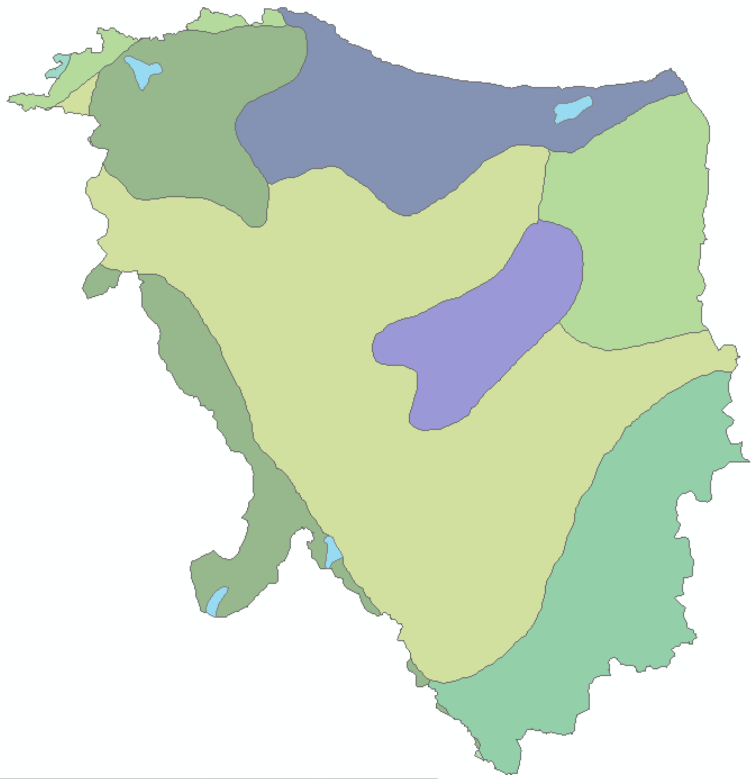
EGLE Runoff Curve Number
63.5

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

43, CHOCOLAY RIVER WATERSHED

Surficial Geology



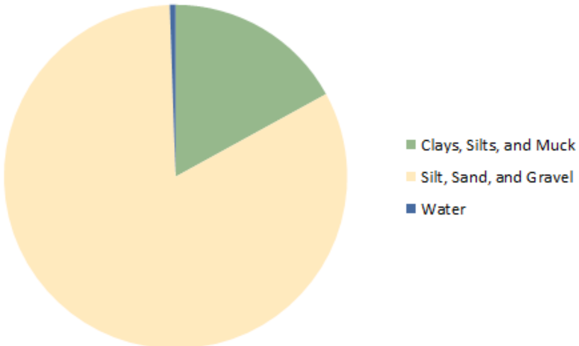


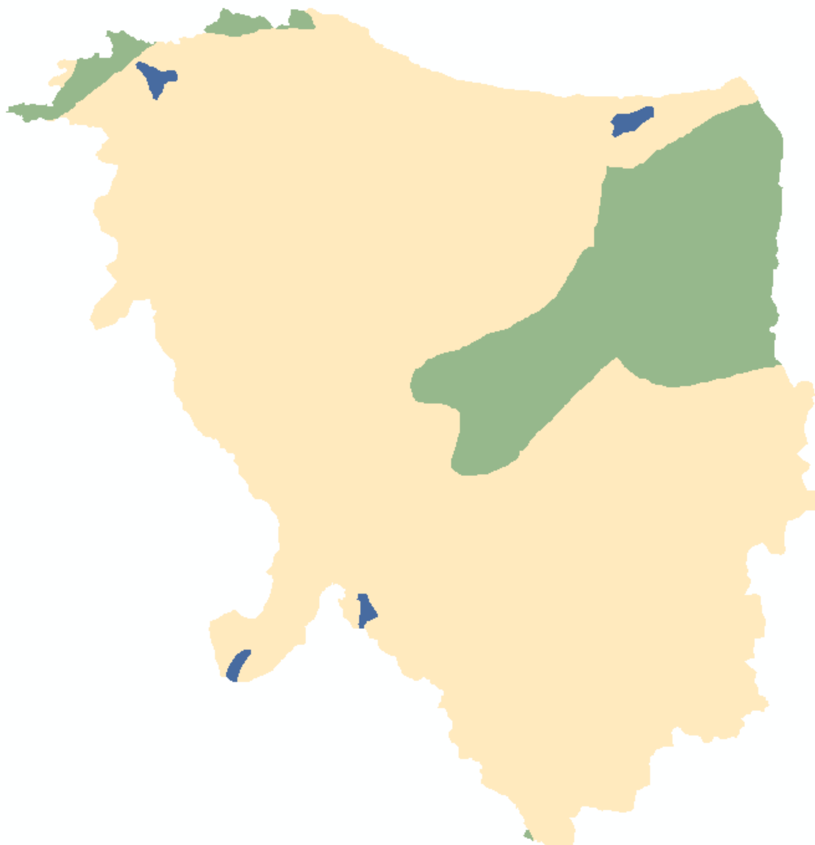
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	0.38	0.09%
End moraines of coarse-textured till	175.44	42.71%
Glacial outwash sand and gravel and postglacial alluvium	58.23	14.18%
Lacustrine clay and silt	25.23	6.14%
Lacustrine sand and gravel	47.70	11.61%
Medium-textured glacial till	56.91	13.85%
Peat and muck	0.05	0.01%
Thin to discontinuous glacial till over bedrock	44.64	10.87%
Water	2.22	0.54%
Total Watershed Area	410.80	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

43, CHOCOLAY RIVER WATERSHED

Surficial Geology (Simplified)



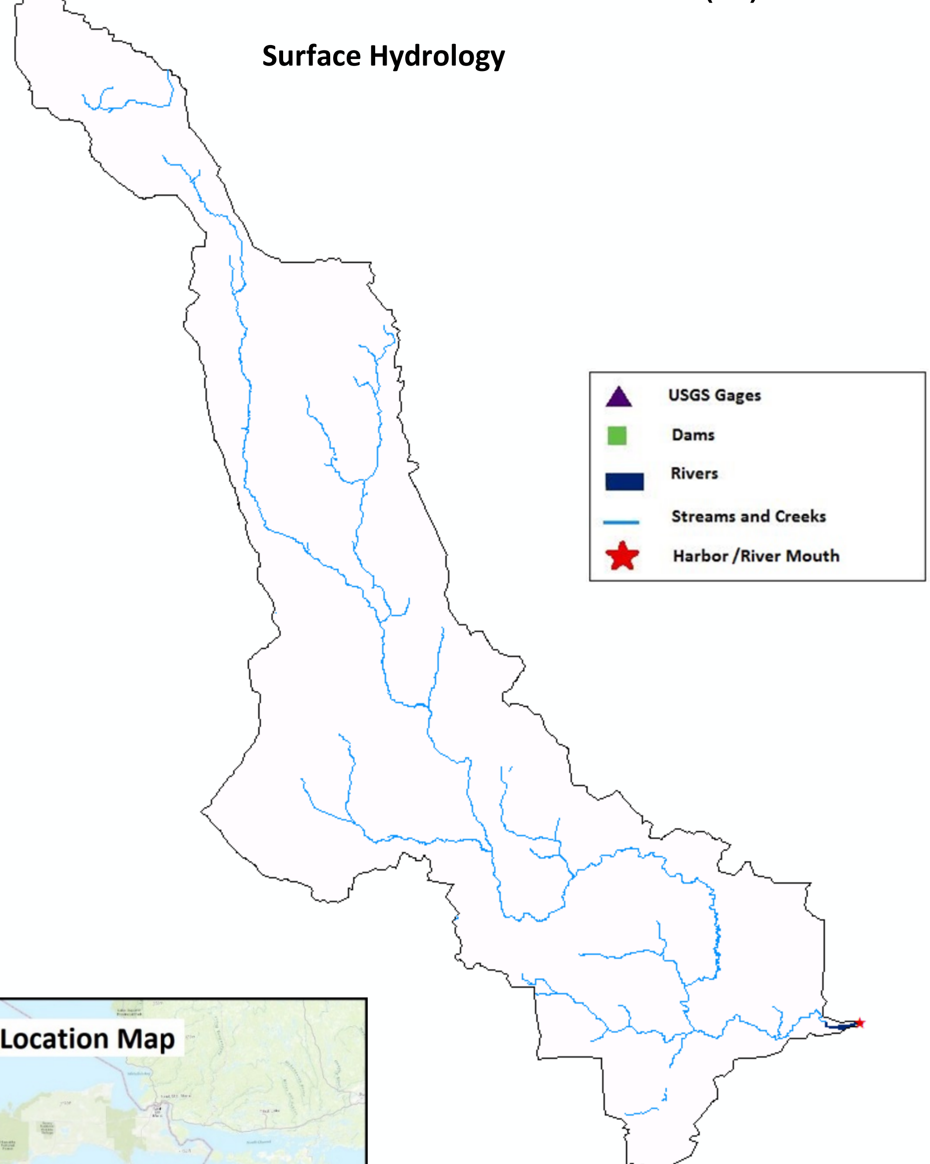


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	69.92	17.02%
Silt, Sand, and Gravel	338.66	82.44%
Water	2.22	0.54%
Total Watershed Area	410.80	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX XX. DAYS RIVER WATERSHED (44)

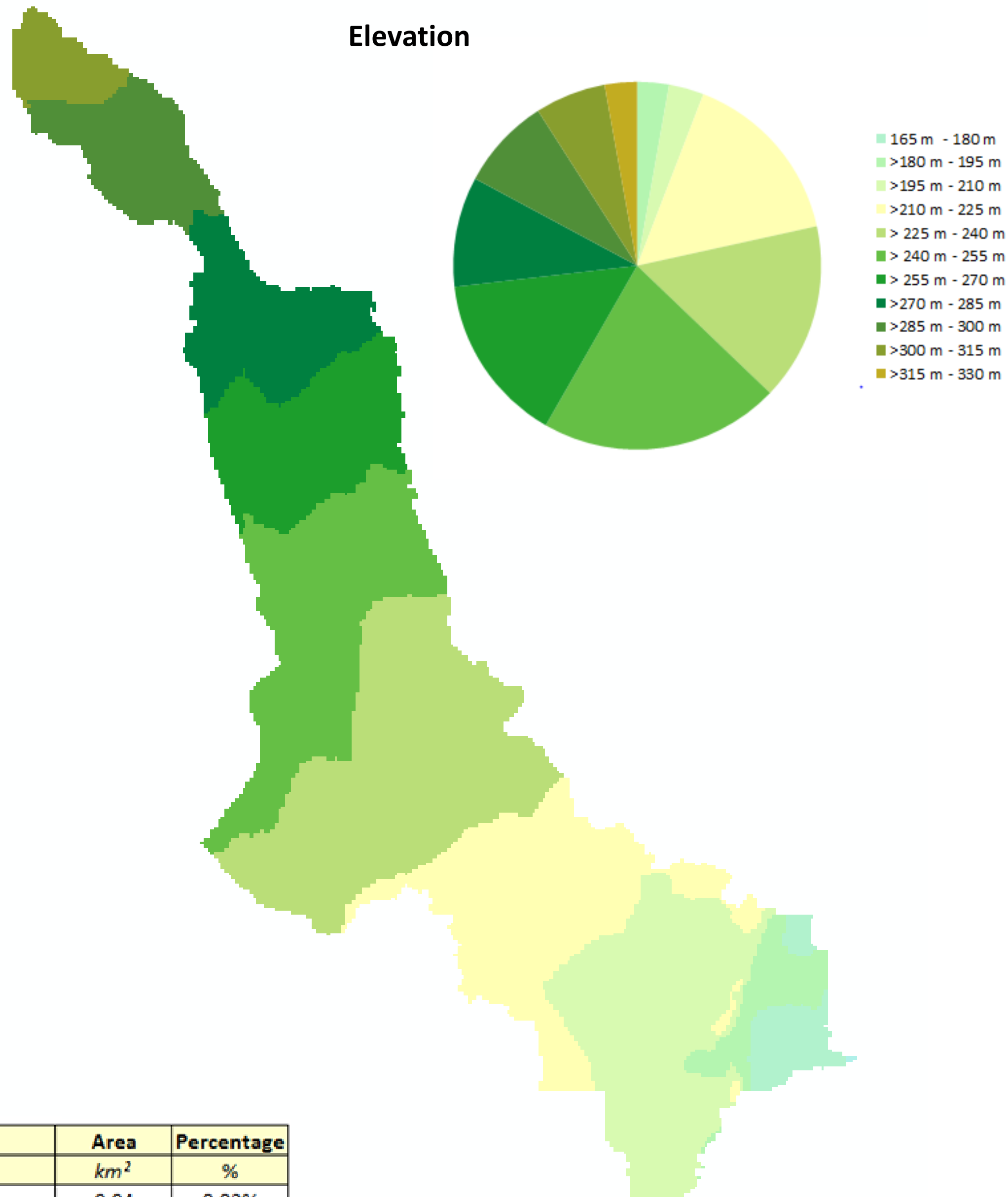
Surface Hydrology



Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

44, DAYS RIVER WATERSHED

Elevation



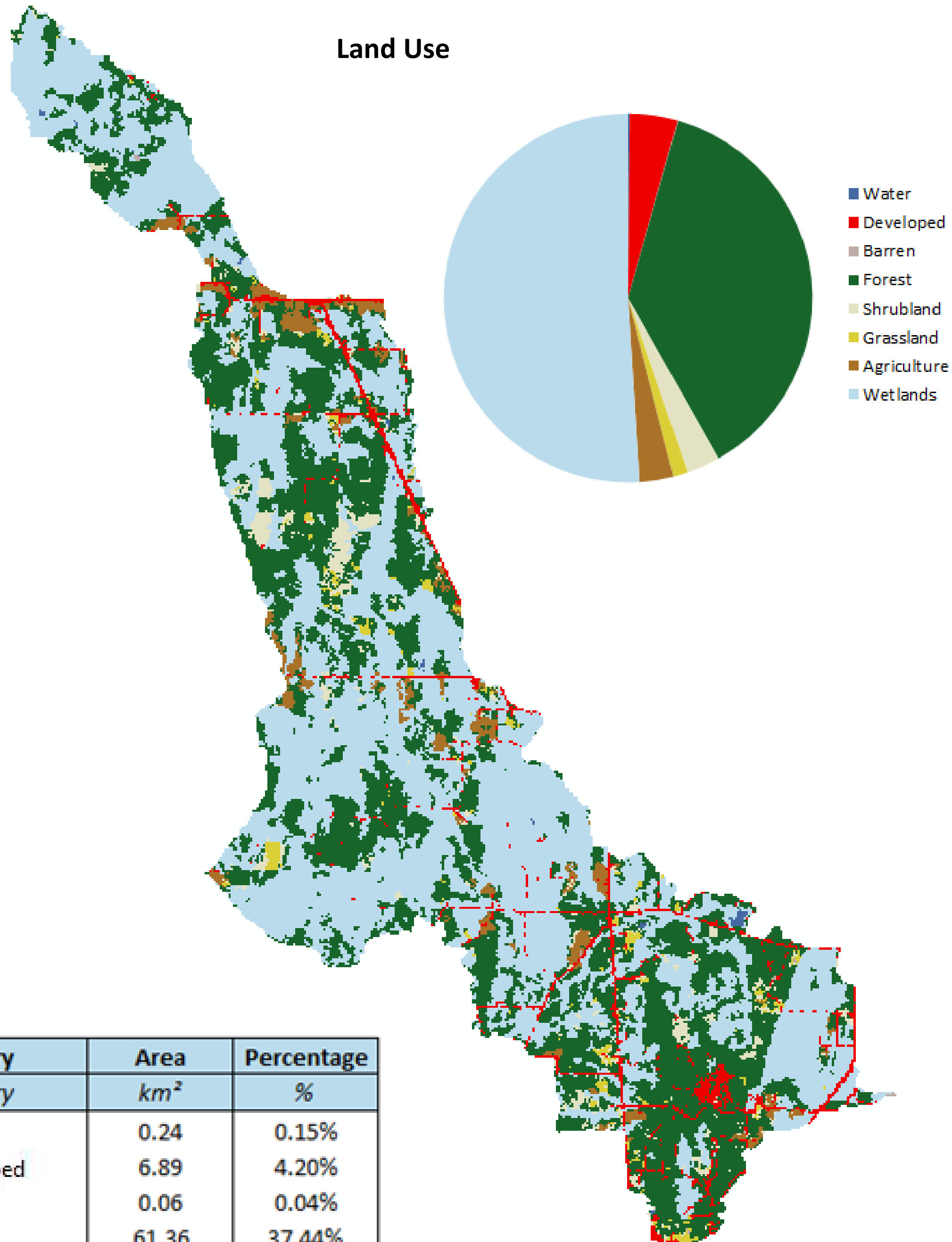
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.04	0.02%
>180 m - 195 m	4.53	2.76%
>195 m - 210 m	5.04	3.07%
>210 m - 225 m	25.72	15.69%
>225 m - 240 m	25.57	15.60%
>240 m - 255 m	34.62	21.12%
>255 m - 270 m	24.39	14.88%
>270 m - 285 m	15.87	9.68%
>285 m - 300 m	13.27	8.10%
>300 m - 315 m	10.19	6.22%
>315 m - 330 m	4.66	2.84%
Size of Drainage Area	163.89	100.00%

Days Watershed		
Elevation Statistics		
Size of Drainage Area	**163.89**	***km²***
Maximum	322.00	*m*
Minimum	176.00	*m*
Average	252.51	*m*
Standard Deviation	31.15	*m*

All Elevation Measurements with Respect to North American Datum 1983

44, DAYS RIVER WATERSHED

Land Use



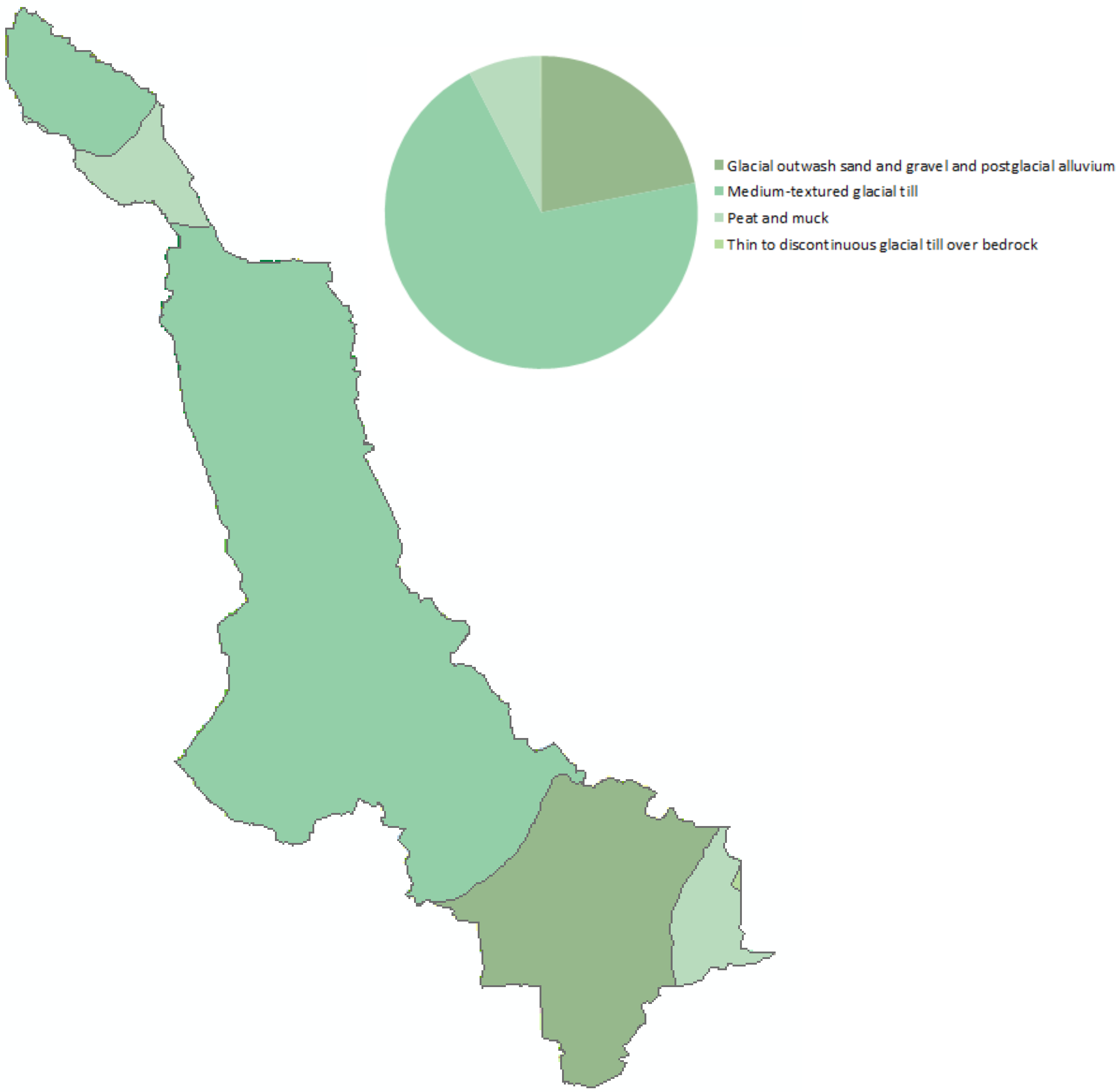
Category	Area	Percentage
Category	*km²*	*%*
Water	0.24	0.15%
Developed	6.89	4.20%
Barren	0.06	0.04%
Forest	61.36	37.44%
Shrubland	4.79	2.92%
Grassland	2.11	1.29%
Agriculture	4.87	2.97%
Wetlands	83.58	51.00%
Total	163.89	100.00%

EGLE Runoff Curve Number
69.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

44, DAYS RIVER WATERSHED

Surficial Geology

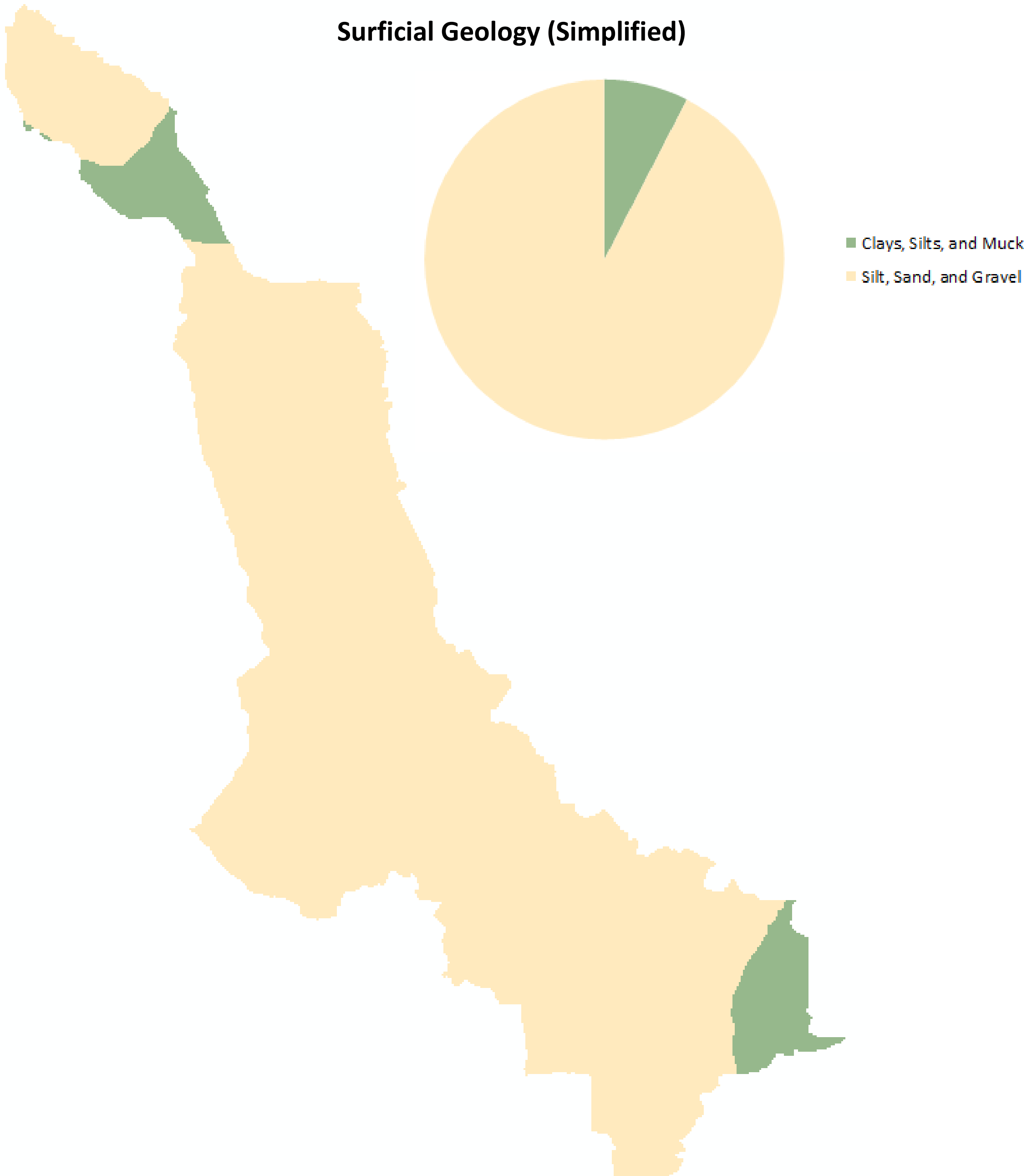


Category	Area	Percentage
Category	*km²*	*%*
Glacial outwash sand and gravel and postglacial alluvium	36.03	21.98%
Medium-textured glacial till	115.44	70.44%
Peat and muck	12.30	7.50%
Thin to discontinuous glacial till over bedrock	0.12	0.08%
Total Watershed Area	163.89	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

44, DAYS RIVER WATERSHED

Surficial Geology (Simplified)

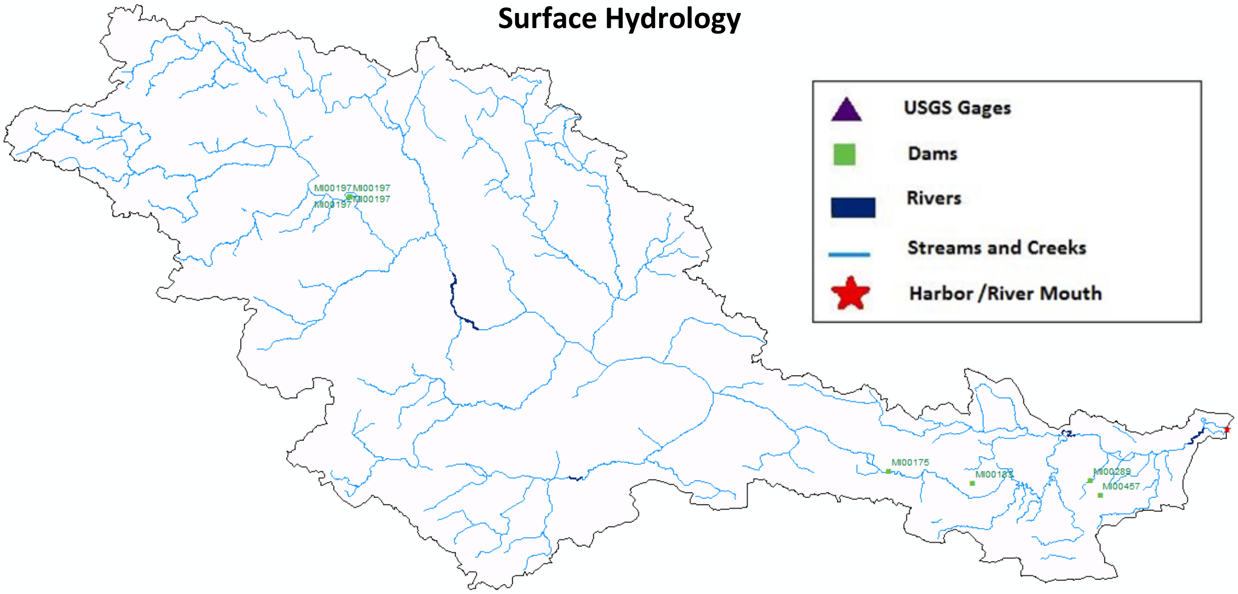


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	12.42	7.58%
Silt, Sand, and Gravel	151.47	92.42%
Total Watershed Area	163.89	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX YY. DEAD RIVER WATERSHED (45)

Surface Hydrology

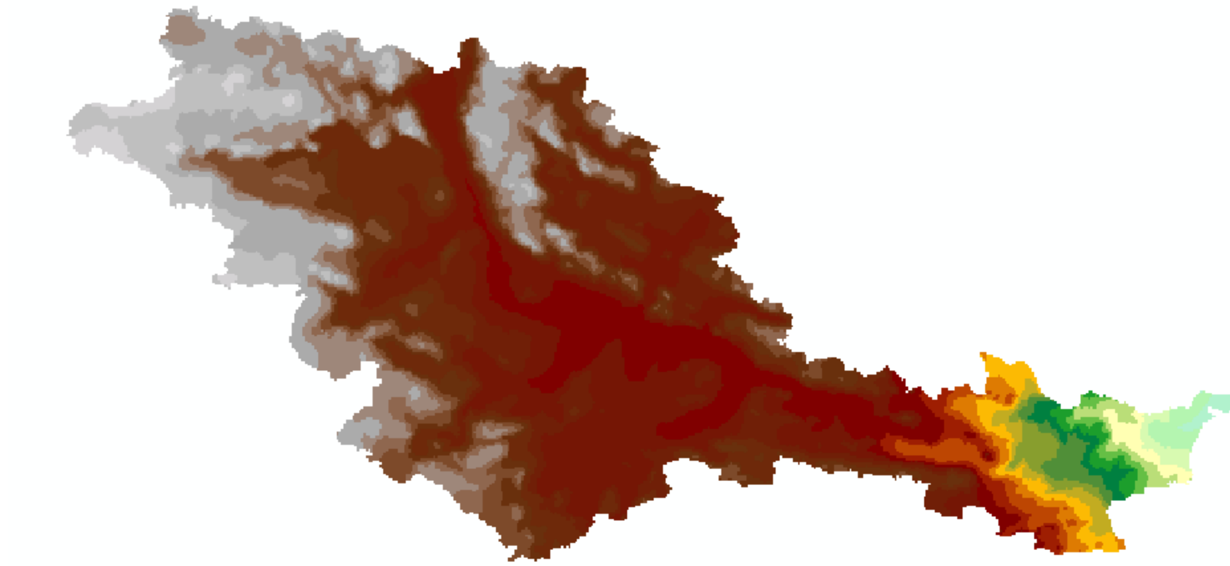


USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00197	Silver Lake	-87.830000	46.650000
MI00197	Silver Lake Dike 1	-87.830000	46.650000
MI00197	Silver Lake Dike 3	-87.830000	46.650000
MI00197	Silver Lake Dike 4	-87.830000	46.650000
MI00175	Hoist	-87.560000	46.560000
MI00183	McClure Dam	-87.518330	46.556670
MI00289	Brebner Dam	-87.460000	46.558330
MI00457	Bancroft Dairy Dam	-87.455000	46.553330

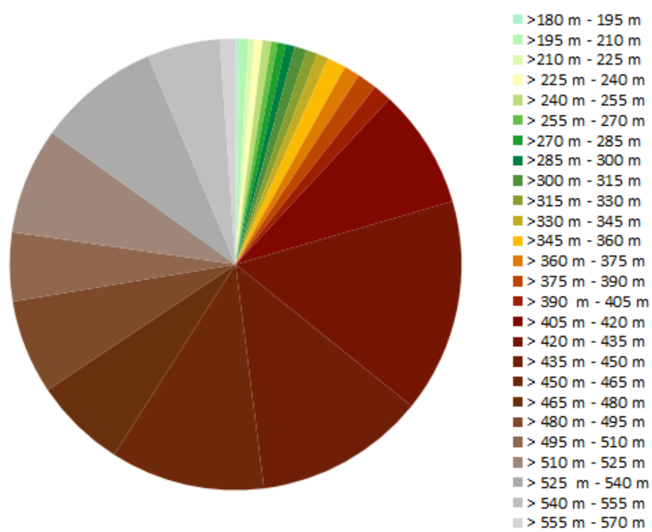
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

45, DEAD RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	1.15	0.27%
>195 m - 210 m	2.69	0.63%
>210 m - 225 m	1.79	0.42%
>225 m - 240 m	2.53	0.60%
>240 m - 255 m	2.65	0.62%
>255 m - 270 m	1.95	0.46%
>270 m - 285 m	2.46	0.58%
>285 m - 300 m	2.74	0.65%
>300 m - 315 m	3.65	0.86%
>315 m - 330 m	3.44	0.81%
>330 m - 345 m	3.52	0.83%
>345 m - 360 m	5.68	1.34%
>360 m - 375 m	4.85	1.14%
>375 m - 390 m	5.96	1.40%
>390 m - 405 m	5.56	1.31%
>405 m - 420 m	36.43	8.57%
>420 m - 435 m	65.04	15.31%
>435 m - 450 m	51.83	12.20%
>450 m - 465 m	46.93	11.05%
>465 m - 480 m	27.92	6.57%
>480 m - 495 m	28.70	6.75%
>495 m - 510 m	20.95	4.93%
>510 m - 525 m	32.37	7.62%
>525 m - 540 m	37.19	8.75%
>540 m - 555 m	22.16	5.22%
>555 m - 570 m	4.76	1.12%
Size of Drainage Area	424.91	100.00%

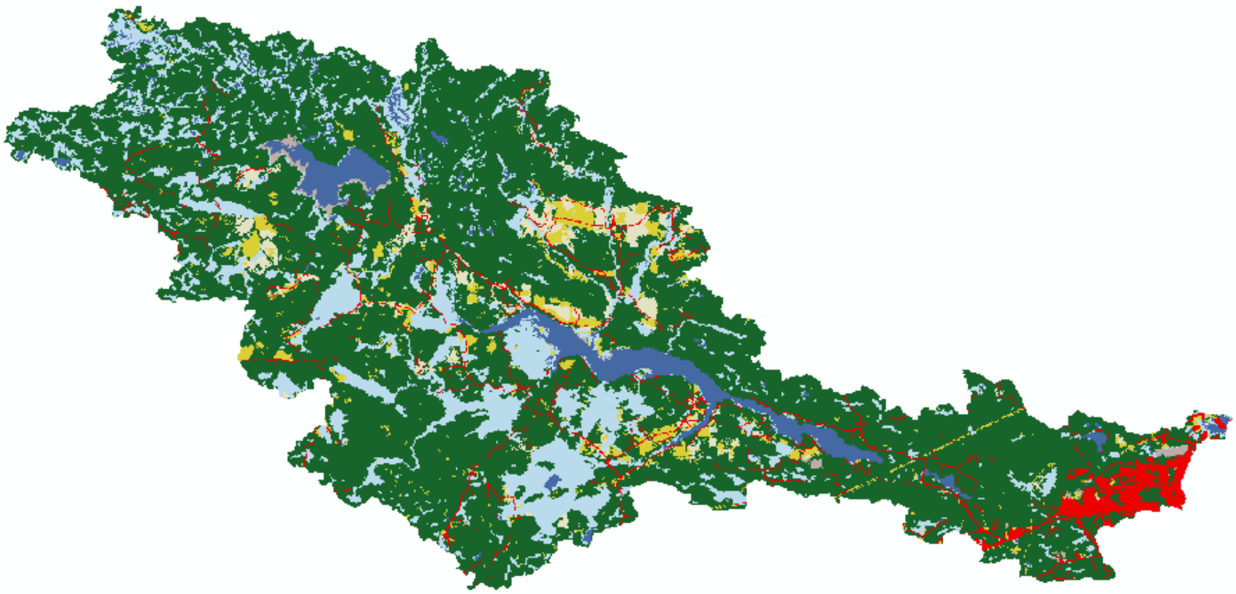


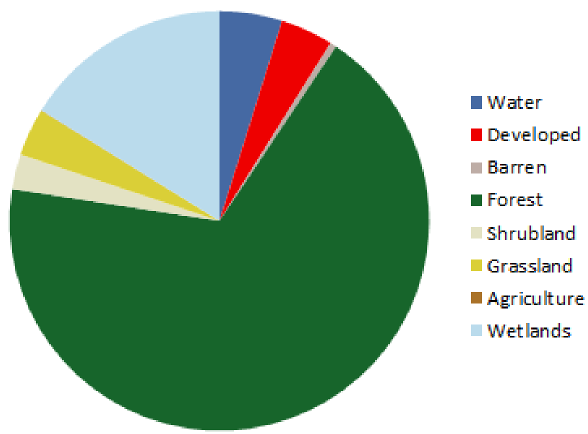
Dead Watershed		
Elevation Statistics		
Size of Drainage Area	**424.91**	***km²***
Maximum	565.00	*m*
Minimum	184.00	*m*
Average	452.68	*m*
Standard Deviation	68.08	*m*

All Elevation Measurements with Respect to North American Datum 1983

45, DEAD RIVER WATERSHED

Land Use





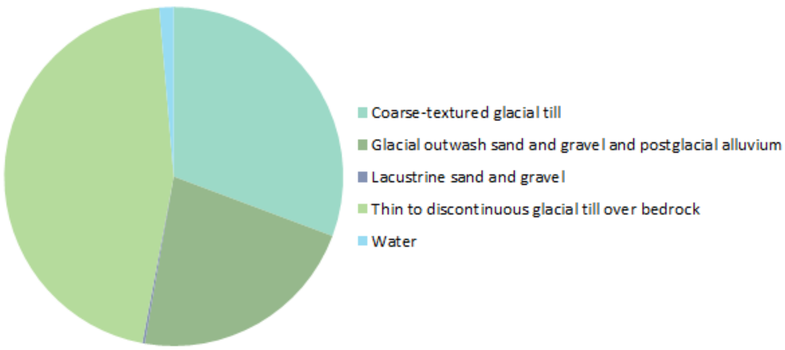
Category	Area	Percentage
Category	*km²*	*%*
Water	20.50	4.83%
Developed	17.26	4.06%
Barren	2.08	0.49%
Forest	289.20	68.06%
Shrubland	11.48	2.70%
Grassland	15.67	3.69%
Agriculture	0.09	0.02%
Wetlands	68.63	16.15%
Total	424.91	100.00%

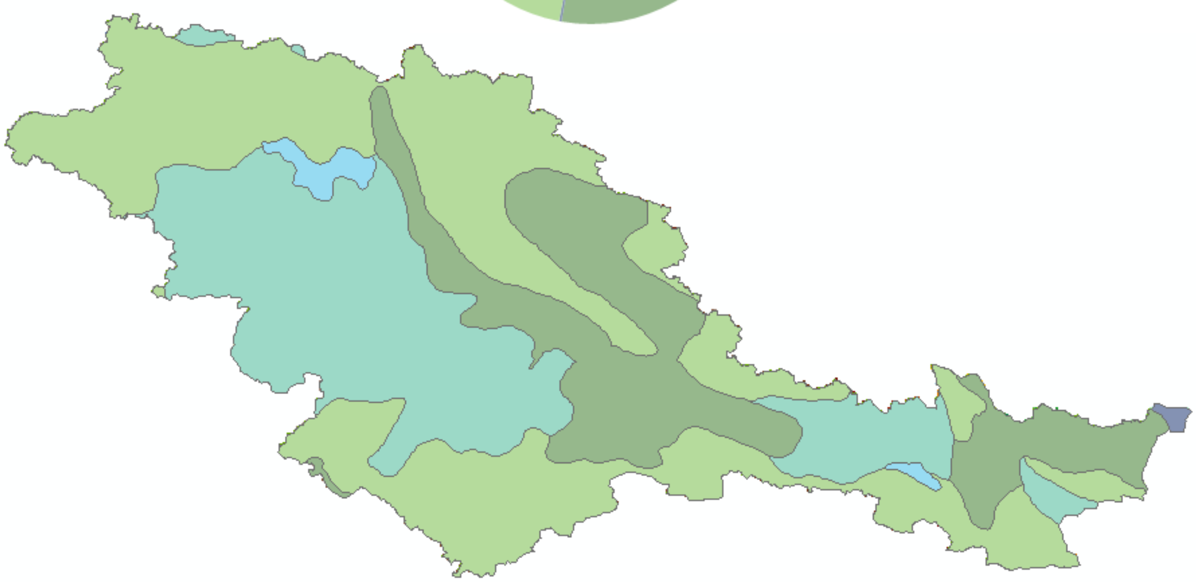
EGLE Runoff Curve Number
65.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

45, DEAD RIVER WATERSHED

Surficial Geology



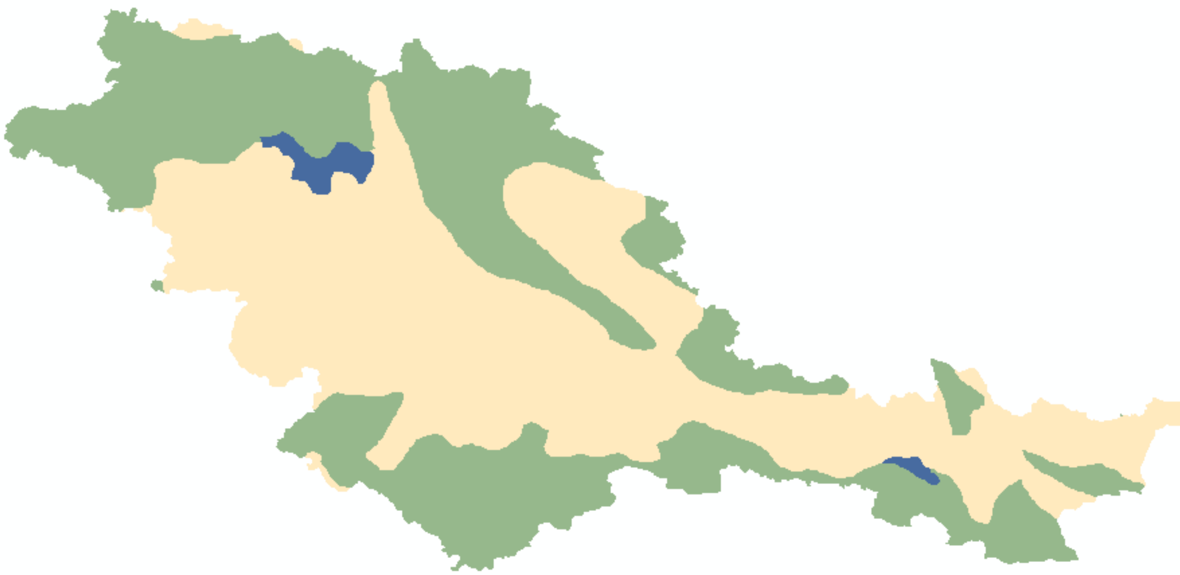


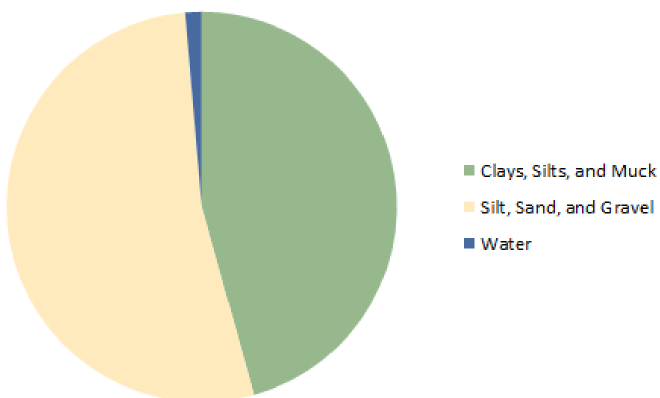
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	130.47	30.71%
Glacial outwash sand and gravel and postglacial alluvium	93.62	22.03%
Lacustrine sand and gravel	0.94	0.22%
Thin to discontinuous glacial till over bedrock	194.07	45.67%
Water	5.80	1.37%
Total Watershed Area	424.91	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

45, DEAD RIVER WATERSHED

Surficial Geology (Simplified)

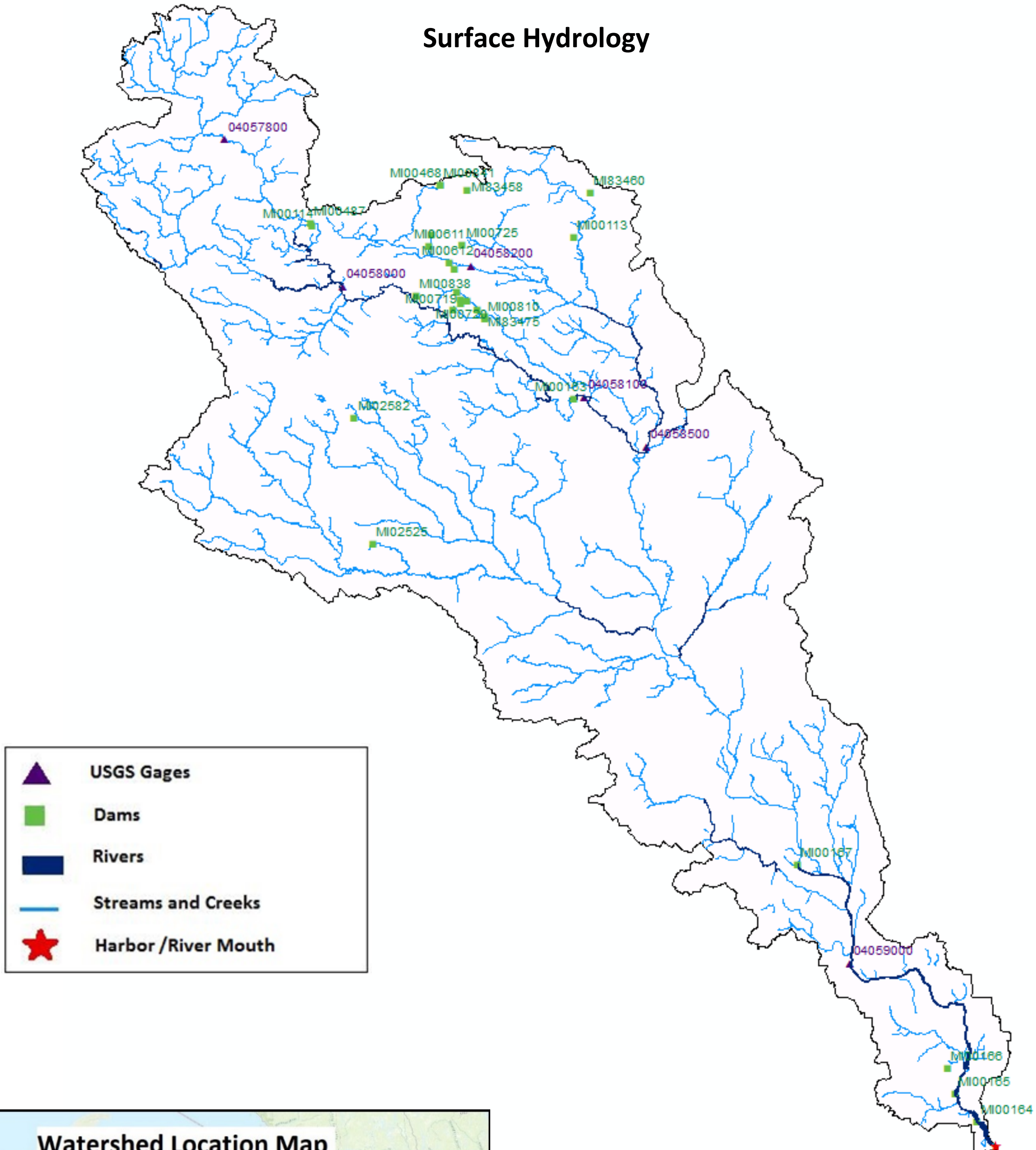




Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	194.07	45.67%
Silt, Sand, and Gravel	225.03	52.96%
Water	5.80	1.37%
Total Watershed Area	424.91	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX ZZ. ESCANABA RIVER WATERSHED (46)



46, ESCANABA RIVER WATERSHED

Dam Information and USGS Streamgages

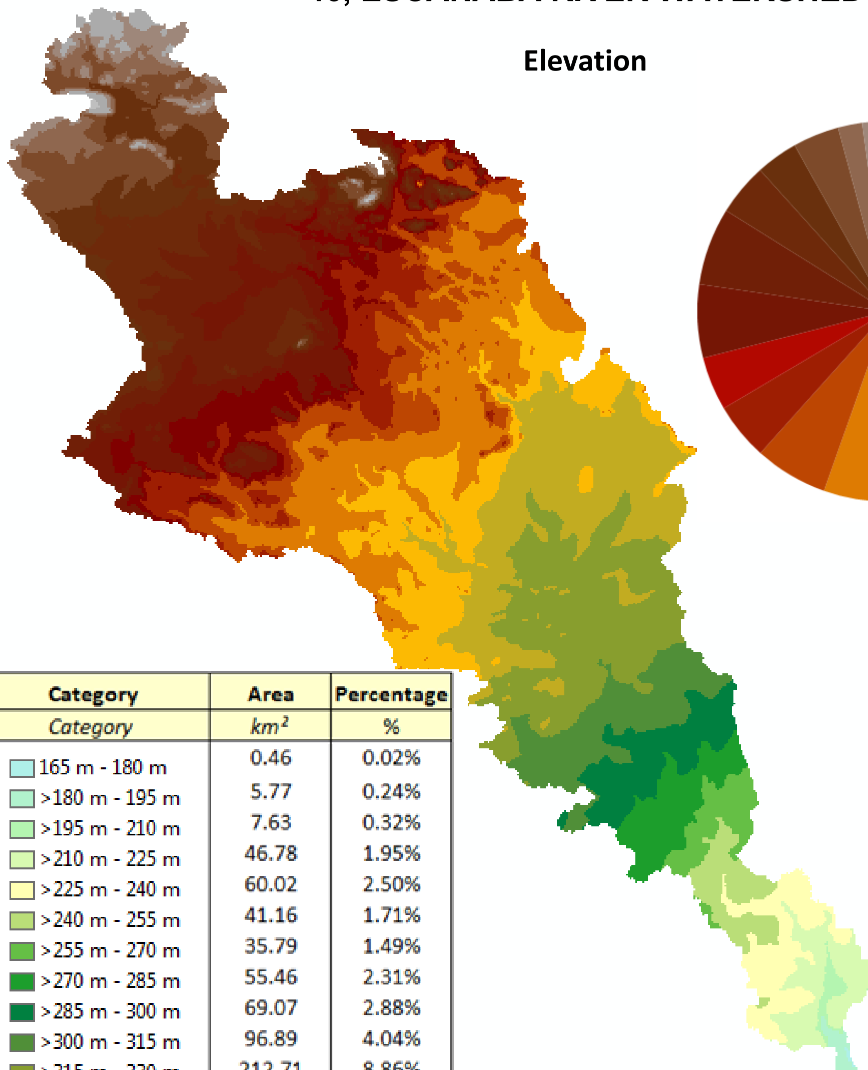
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00166	Escanaba No 3	-87.110000	45.833300
MI00167	Escanaba No 4 Boney Falls	-87.270000	45.980000
MI00101	Empire Mine Tertiary Pond Dam	-87.627780	46.386110
MI00163	Cataract Hydroelectric	-87.512700	46.316000
MI00113	Gribben North Tailings Basin Dam	-87.516670	46.433330
MI00114	Greenwood Afterbay Dam	-87.791660	46.438330
MI00164	Escanaba No 1 Dam	-87.078330	45.795000
MI00165	Escanaba No 2 Dam	-87.101670	45.815000
MI83458	OGDEN DAM	-87.629170	46.466670
MI83460	HOOVER DAM	-87.500000	46.466670
MI83476	TILDEN RECIRCULATION BASIN DAM	-87.666660	46.433330
MI83465	EMPIRE MINE SECONDARY POND DAM	-87.641670	46.379170
MI83466	EMPIRE MINE TERTIARY POND DAM	-87.616670	46.379170
MI83473	EMPIRE MINE TAILINGS BASIN DAM	-87.637500	46.391670
MI83474	SCHWEITZER DAM	-87.641670	46.408330
MI83475	EMPIRE MINE EXPANDED TERTIARY DAM	-87.608330	46.375000
MI02525	Gunnel Dam	-87.720830	46.207780
MI02582	Trout Lake Dam	-87.743060	46.298610
MI00468	Lake Sally Dam	-87.658330	46.470000
MI00487	Greenwood Reservoir Dam	-87.793330	46.440000
MI00611	Tilden Recirculation Basin	-87.668330	46.425000
MI00612	Schweitzer Dam	-87.646670	46.413330
MI00719	Empire Mine Tailings Basin Dam	-87.633330	46.386670
MI00720	Empire Mine Secondary Pond Dam	-87.633330	46.383340
MI00725	Hoover Pond Dam	-87.633330	46.426670
MI00810	Empire Mine Expanded Tertiary Dam	-87.608330	46.372780
MI00838	ETB Waterway Dams	-87.681390	46.388610
MI00841	Ogden Lake Dam	-87.658330	46.470000

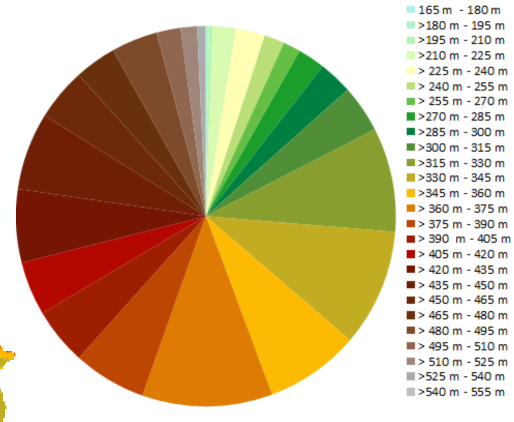
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4057800	MIDDLE BRANCH ESCANABA RIVER AT HUMBOLDT, MI	-87.886524	46.499103	yes
4058000	M BR ESCANABA RIVER NR ISHPEMING, MI	-87.758468	46.394384	
4058100	MIDDLE BRANCH ESCANABA RIVER NR PRINCETON, MI	-87.502082	46.317165	yes
4058200	SCHWEITZER CREEK NEAR PALMER, MI	-87.624303	46.411050	yes
4058500	EAST BRANCH ESCANABA RIVER AT GWINN, MI	-87.435416	46.282167	
4059000	ESCANABA RIVER AT CORNELL, MI	-87.213748	45.908573	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				4

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

46, ESCANABA RIVER WATERSHED

Elevation





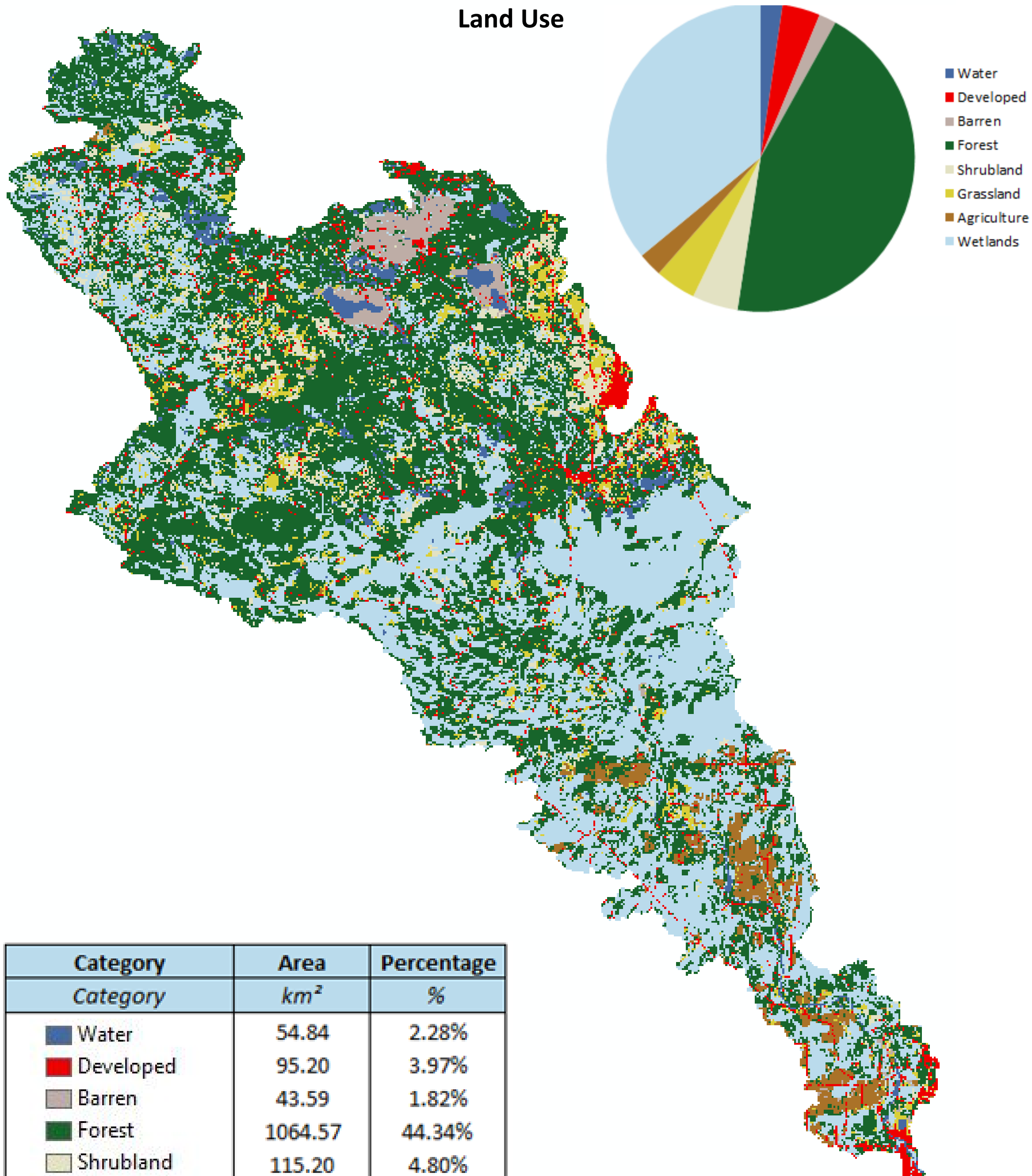
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.46	0.02%
>180 m - 195 m	5.77	0.24%
>195 m - 210 m	7.63	0.32%
>210 m - 225 m	46.78	1.95%
>225 m - 240 m	60.02	2.50%
>240 m - 255 m	41.16	1.71%
>255 m - 270 m	35.79	1.49%
>270 m - 285 m	55.46	2.31%
>285 m - 300 m	69.07	2.88%
>300 m - 315 m	96.89	4.04%
>315 m - 330 m	212.71	8.86%
>330 m - 345 m	239.47	9.97%
>345 m - 360 m	192.95	8.04%
>360 m - 375 m	266.58	11.10%
>375 m - 390 m	149.28	6.22%
>390 m - 405 m	116.51	4.85%
>405 m - 420 m	109.64	4.57%
>420 m - 435 m	149.48	6.23%
>435 m - 450 m	158.23	6.59%
>450 m - 465 m	106.47	4.43%
>465 m - 480 m	85.51	3.56%
>480 m - 495 m	94.36	3.93%
>495 m - 510 m	49.35	2.06%
>510 m - 525 m	33.61	1.40%
>525 m - 540 m	17.04	0.71%
>540 m - 555 m	0.65	0.03%
Size of Drainage Area	2400.85	100.00%

Escanaba Watershed		
Elevation Statistics		
Size of Drainage Area	**2400.85**	**km²**
Maximum	549.00	*m*
Minimum	177.00	*m*
Average	373.37	*m*
Standard Deviation	71.67	*m*

All Elevation Measurements with Respect to North American Datum 1983

46, ESCANABA RIVER WATERSHED

Land Use



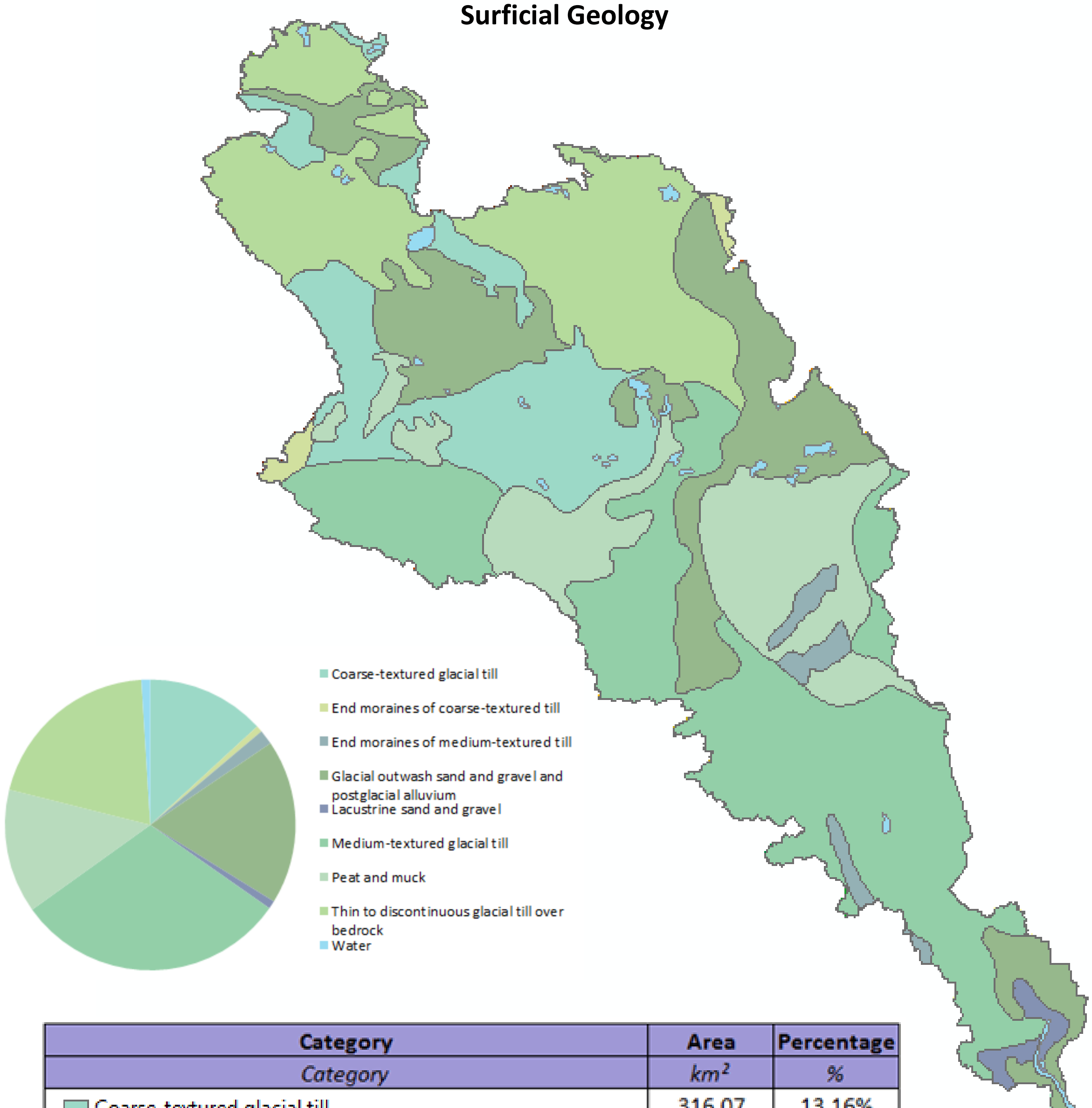
Category	Area	Percentage
Category	*km²*	*%*
Water	54.84	2.28%
Developed	95.20	3.97%
Barren	43.59	1.82%
Forest	1064.57	44.34%
Shrubland	115.20	4.80%
Grassland	102.86	4.28%
Agriculture	60.91	2.54%
Wetlands	863.67	35.97%
Total	2400.85	100.00%

EGLE Runoff Curve Number
65.1

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

46, ESCANABA RIVER WATERSHED

Surficial Geology

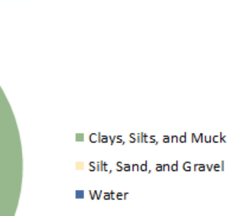


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	316.07	13.16%
End moraines of coarse-textured till	16.95	0.71%
End moraines of medium-textured till	39.17	1.63%
Glacial outwash sand and gravel and postglacial alluvium	439.71	18.31%
Lacustrine sand and gravel	21.39	0.89%
Medium-textured glacial till	729.62	30.39%
Peat and muck	331.60	13.81%
Thin to discontinuous glacial till over bedrock	482.86	20.11%
Water	23.49	0.98%
Total Watershed Area	2400.85	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

46, ESCANABA RIVER WATERSHED

Surficial Geology (Simplified)

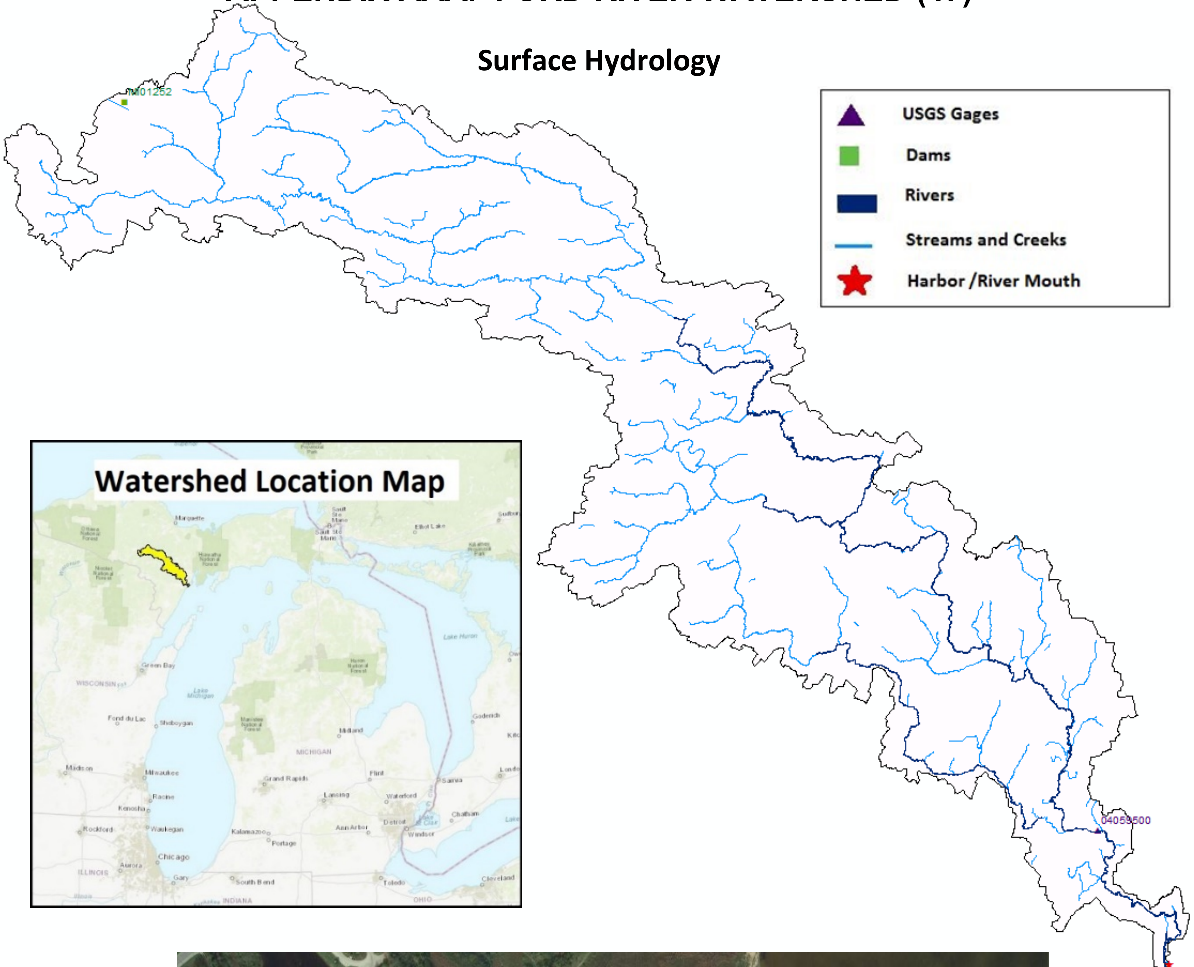


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	814.46	33.92%
Silt, Sand, and Gravel	1562.90	65.10%
Water	23.49	0.98%
Total Watershed Area	2400.85	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX AAA. FORD RIVER WATERSHED (47)

Surface Hydrology



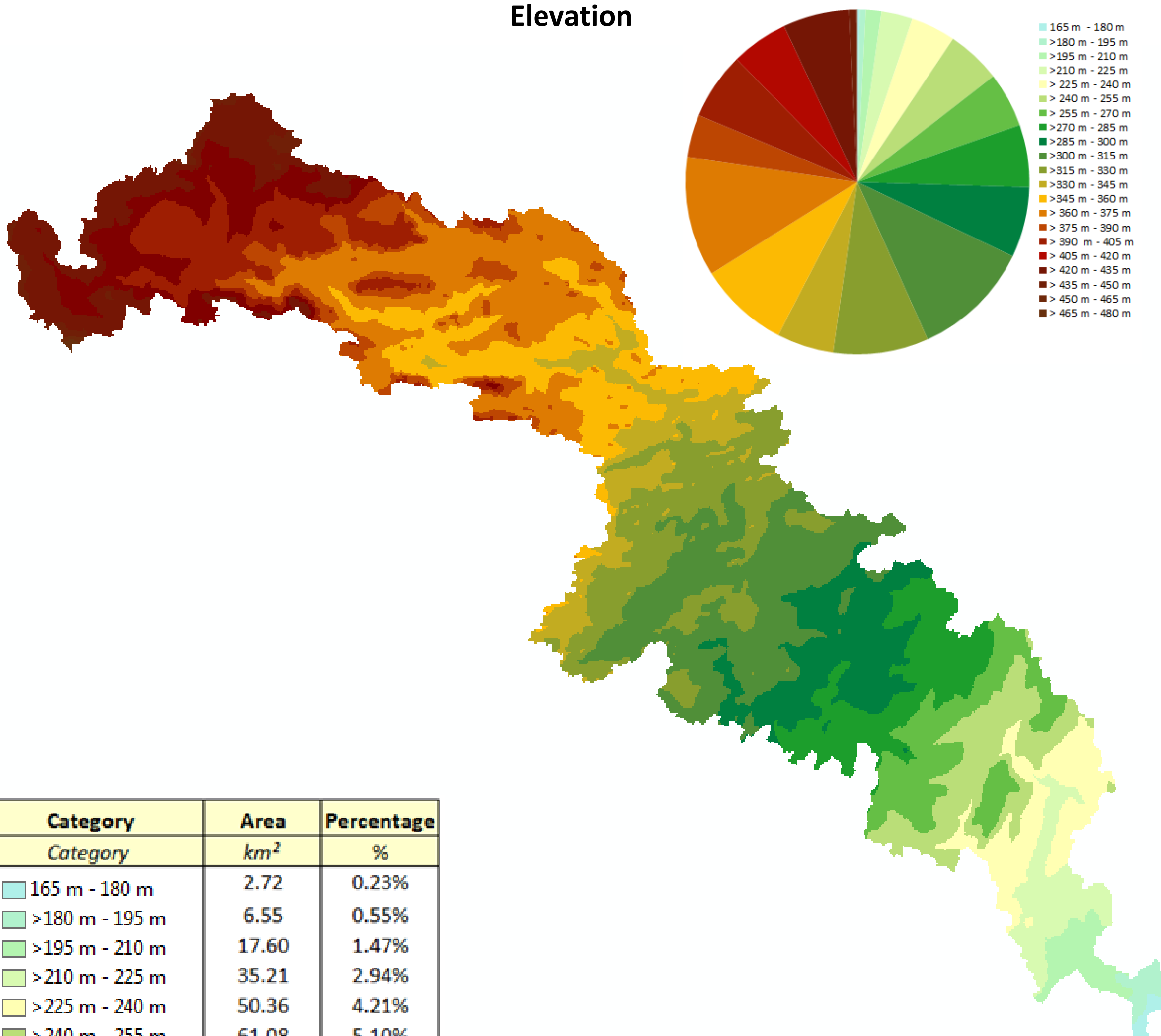
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4059500	FORD RIVER NEAR HYDE, MI	-87.201524	45.755523	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI01252	Sawyer Lake Dam	-88.055000	46.183330

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

47, FORD RIVER WATERSHED

Elevation



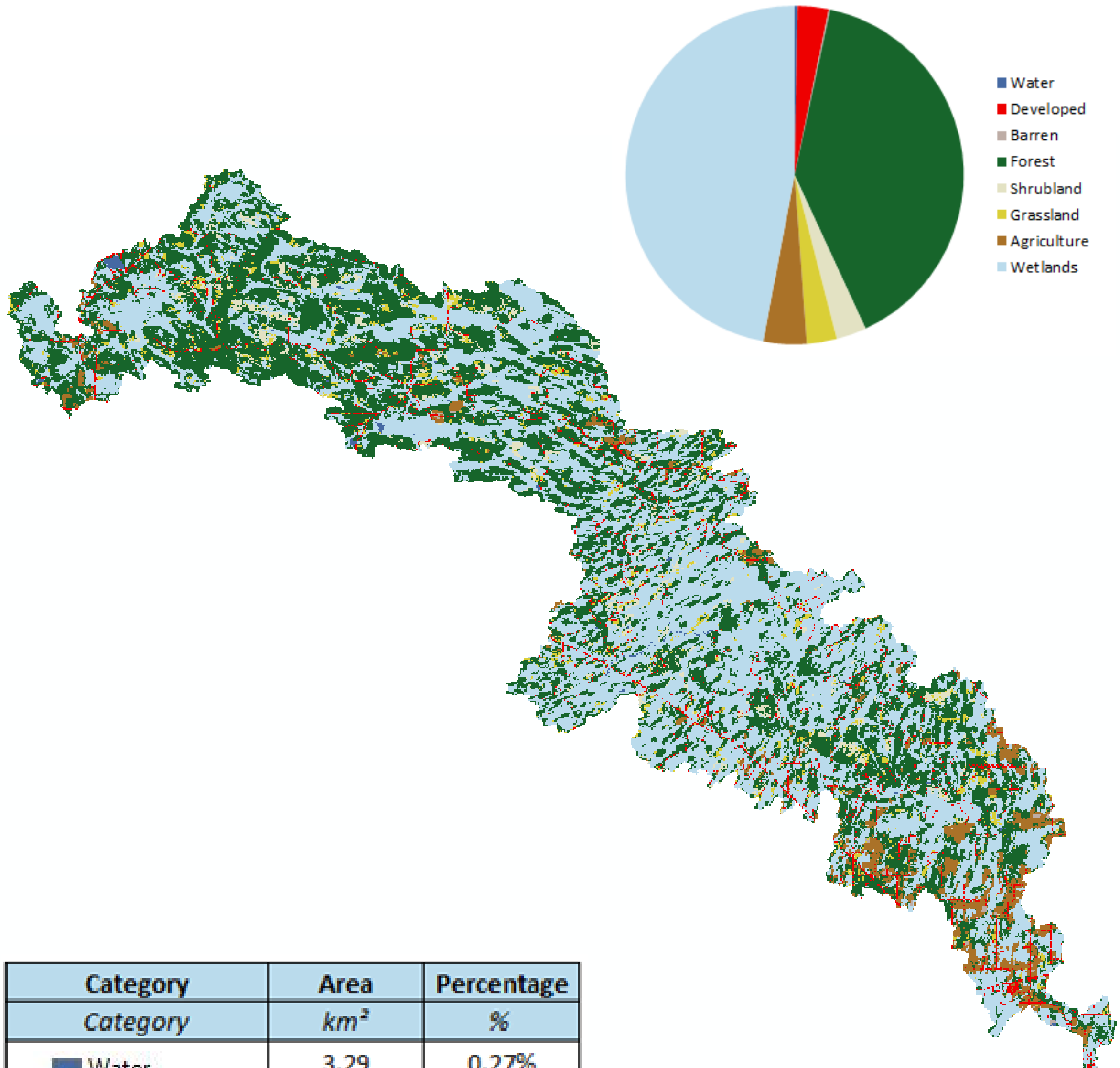
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	2.72	0.23%
>180 m - 195 m	6.55	0.55%
>195 m - 210 m	17.60	1.47%
>210 m - 225 m	35.21	2.94%
>225 m - 240 m	50.36	4.21%
>240 m - 255 m	61.08	5.10%
>255 m - 270 m	61.53	5.14%
>270 m - 285 m	69.90	5.84%
>285 m - 300 m	78.97	6.60%
>300 m - 315 m	134.23	11.21%
>315 m - 330 m	107.37	8.97%
>330 m - 345 m	64.09	5.35%
>345 m - 360 m	101.53	8.48%
>360 m - 375 m	134.49	11.24%
>375 m - 390 m	47.98	4.01%
>390 m - 405 m	75.25	6.29%
>405 m - 420 m	64.30	5.37%
>420 m - 435 m	74.41	6.22%
>435 m - 450 m	8.57	0.72%
>450 m - 465 m	0.45	0.04%
>465 m - 480 m	0.43	0.04%
Size of Drainage Area	1197.04	100.00%

Ford Watershed		
Elevation Statistics		
Size of Drainage Area	**1197.04**	***km²***
Maximum	472.00	*m*
Minimum	176.00	*m*
Average	326.66	*m*
Standard Deviation	60.75	*m*

All Elevation Measurements with Respect to North American Datum 1983

47, FORD RIVER WATERSHED

Land Use



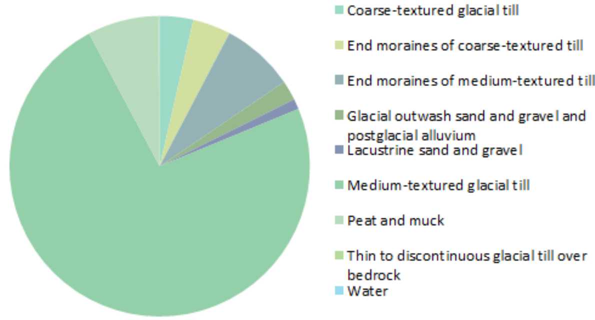
Category	Area	Percentage
Category	*km²*	*%*
Water	3.29	0.27%
Developed	35.54	2.97%
Barren	1.54	0.13%
Forest	475.61	39.73%
Shrubland	34.61	2.89%
Grassland	34.26	2.86%
Agriculture	49.36	4.12%
Wetlands	562.83	47.02%
Total	1197.04	100.00%

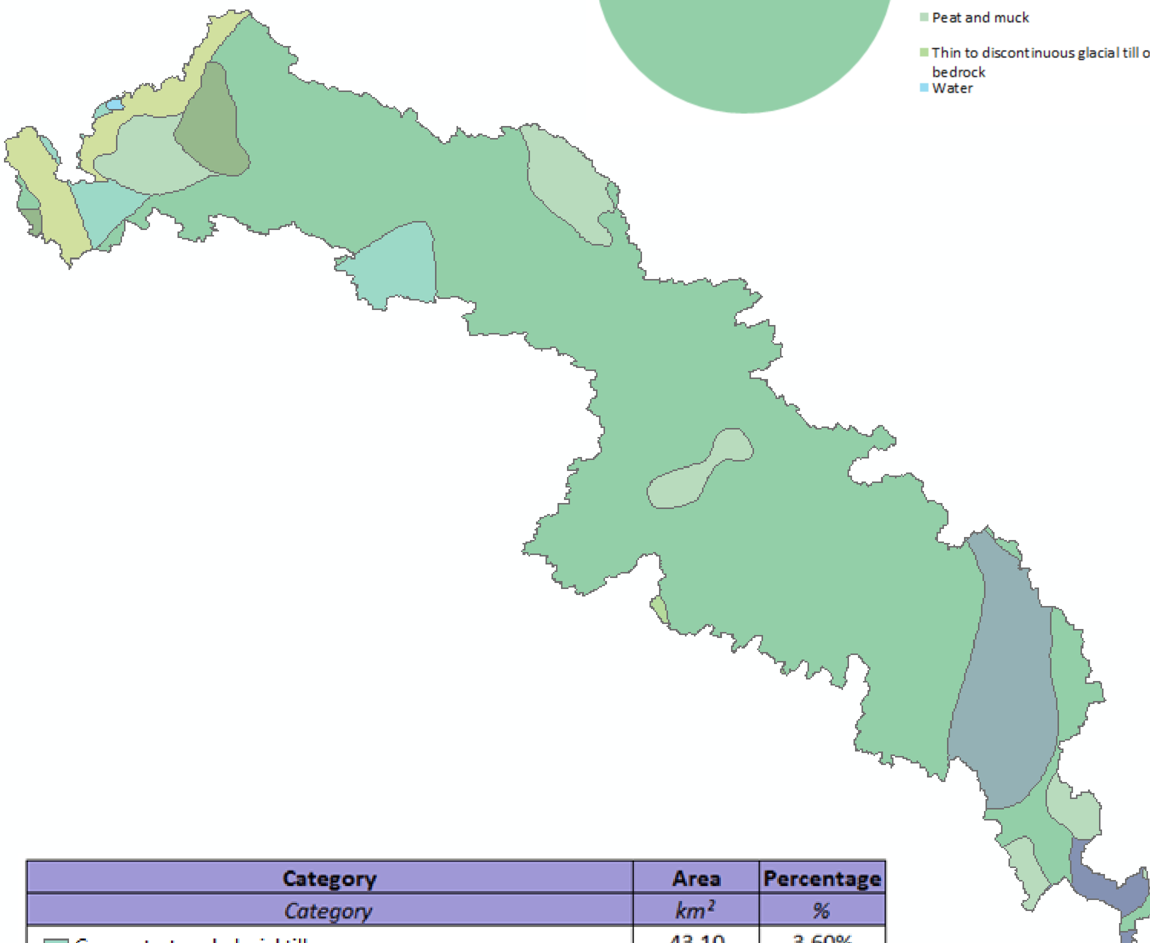
EGLE Runoff Curve Number
70.2

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

47, FORD RIVER WATERSHED

Surficial Geology



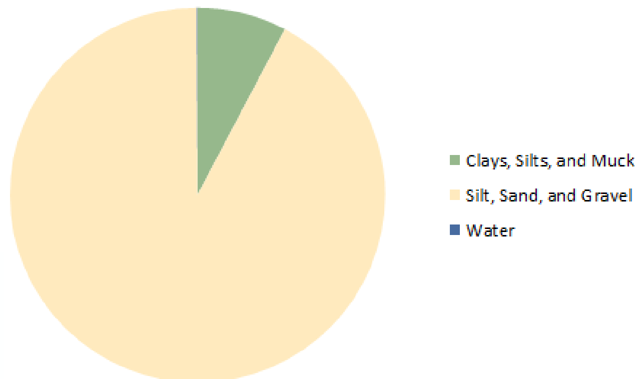


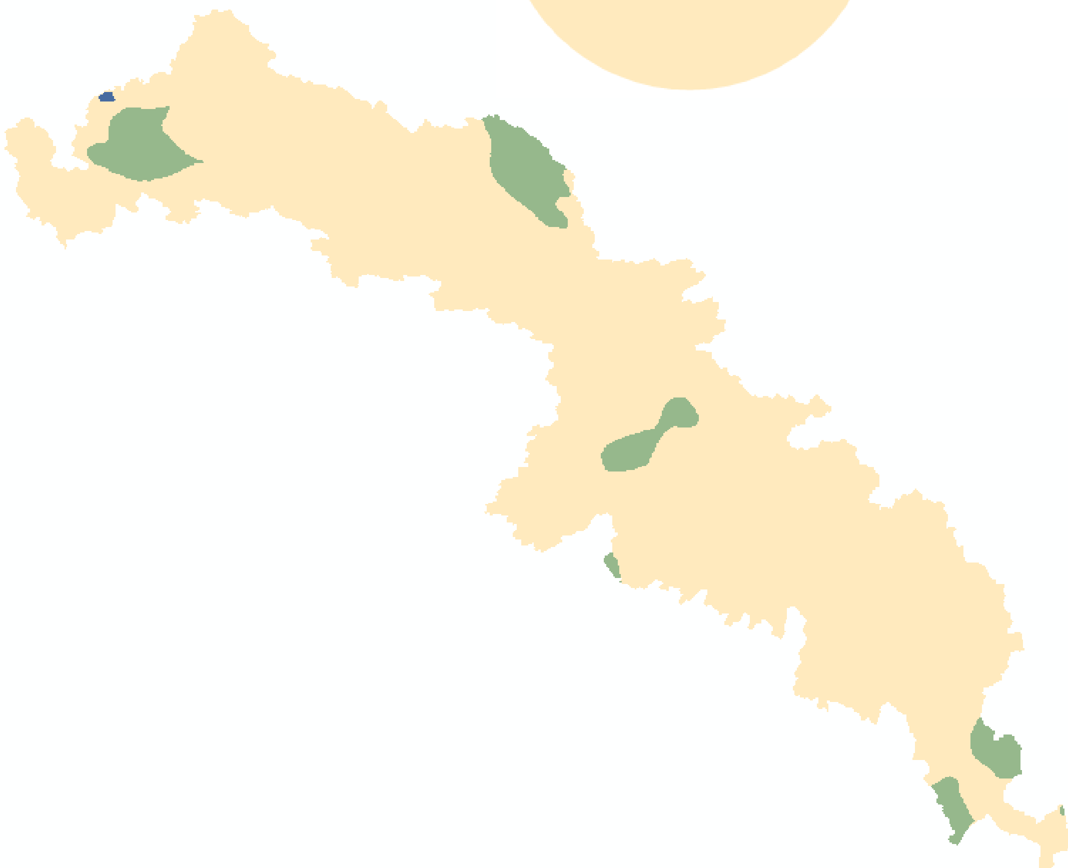
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	43.10	3.60%
End moraines of coarse-textured till	49.06	4.10%
End moraines of medium-textured till	93.76	7.83%
Glacial outwash sand and gravel and postglacial alluvium	25.49	2.13%
Lacustrine sand and gravel	13.32	1.11%
Medium-textured glacial till	879.15	73.44%
Peat and muck	91.02	7.60%
Thin to discontinuous glacial till over bedrock	1.42	0.12%
Water	0.72	0.06%
Total Watershed Area	1197.04	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

47, FORD RIVER WATERSHED

Surficial Geology (Simplified)



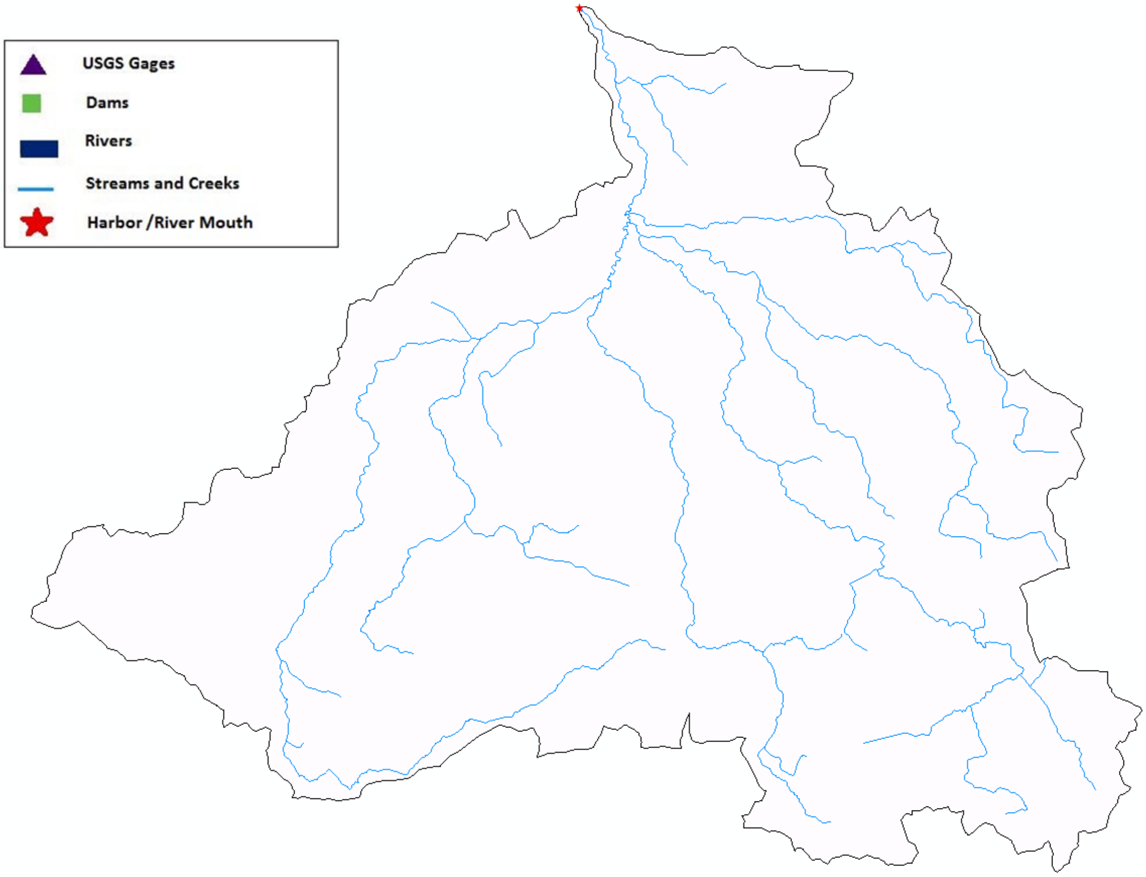


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	92.44	7.72%
Silt, Sand, and Gravel	1103.88	92.22%
Water	0.72	0.06%
Total Watershed Area	1197.04	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX BBB. FALLS RIVER WATERSHED (48)

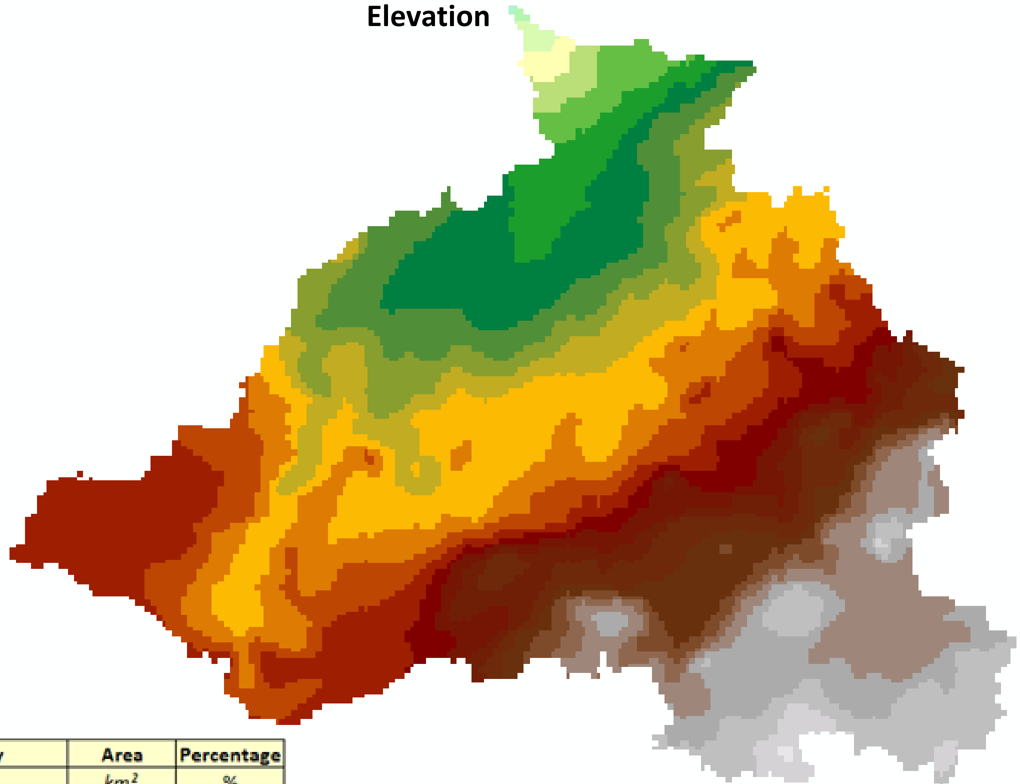
Surface Hydrology



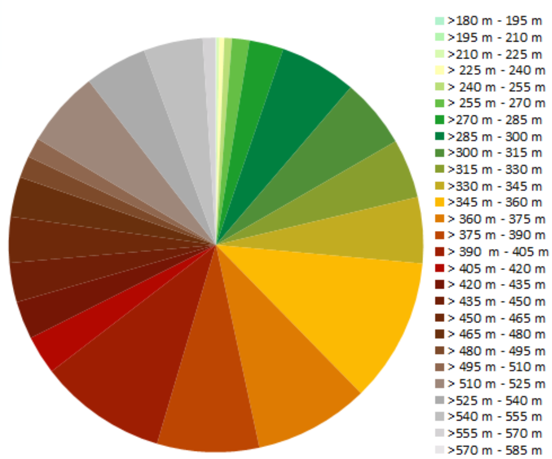
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

48, FALLS RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	0.02	0.02%
>195 m - 210 m	0.04	0.03%
>210 m - 225 m	0.25	0.20%
>225 m - 240 m	0.47	0.39%
>240 m - 255 m	0.71	0.59%
>255 m - 270 m	1.65	1.36%
>270 m - 285 m	3.24	2.67%
>285 m - 300 m	7.29	6.00%
>300 m - 315 m	6.57	5.41%
>315 m - 330 m	5.60	4.61%
>330 m - 345 m	6.26	5.15%
>345 m - 360 m	13.68	11.26%
>360 m - 375 m	10.89	8.96%
>375 m - 390 m	9.67	7.95%
>390 m - 405 m	12.12	9.97%
>405 m - 420 m	3.68	3.03%
>420 m - 435 m	3.59	2.96%
>435 m - 450 m	3.72	3.06%
>450 m - 465 m	4.35	3.58%
>465 m - 480 m	3.79	3.12%
>480 m - 495 m	2.06	1.70%
>495 m - 510 m	1.88	1.54%
>510 m - 525 m	7.24	5.95%
>525 m - 540 m	5.91	4.87%
>540 m - 555 m	5.58	4.59%
>555 m - 570 m	1.20	0.98%
>570 m - 585 m	0.06	0.05%
Size of Drainage Area	121.54	100.00%

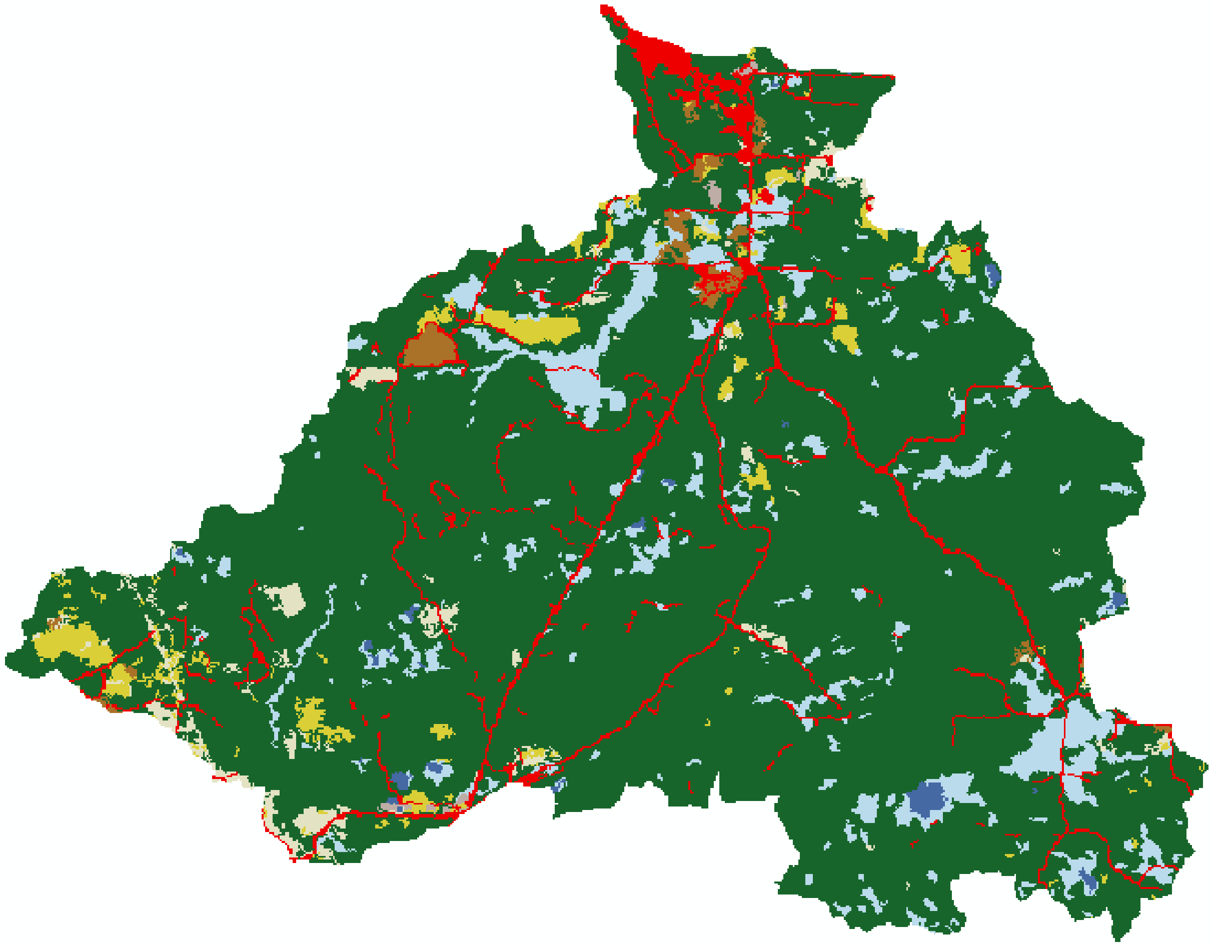


Falls Watershed		
Elevation Statistics		
Size of Drainage Area	**121.54**	***km²***
Maximum	576.00	*m*
Minimum	191.00	*m*
Average	396.11	*m*
Standard Deviation	81.41	*m*

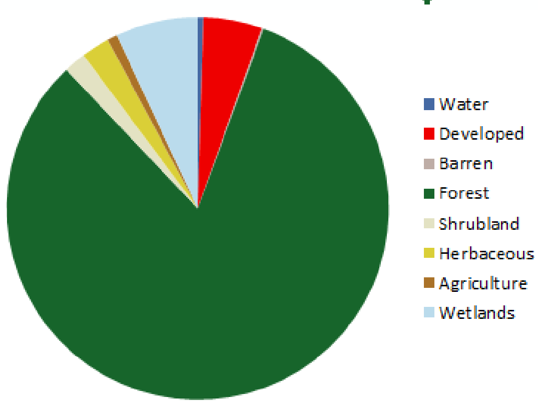
All Elevation Measurements with Respect to North American Datum 1983

48, FALLS RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	0.58	0.47%
Developed	6.05	4.98%
Barren	0.19	0.15%
Forest	100.04	82.31%
Shrubland	2.28	1.87%
Grassland	2.90	2.39%
Agriculture	1.03	0.85%
Wetlands	8.47	6.97%
Total	121.54	100.00%

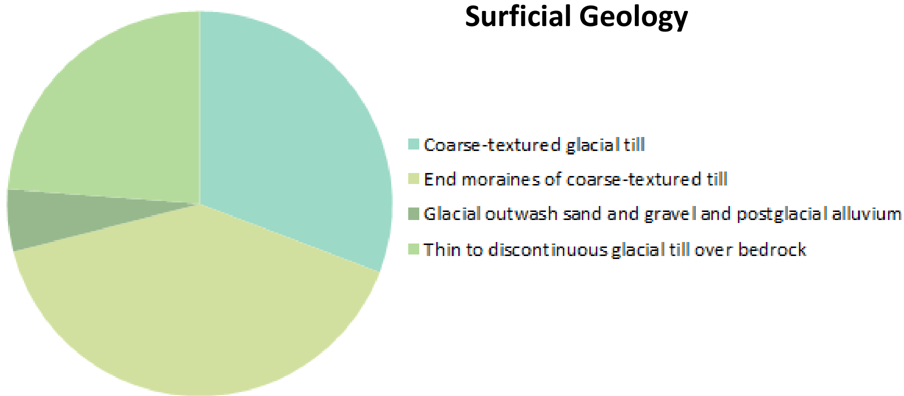


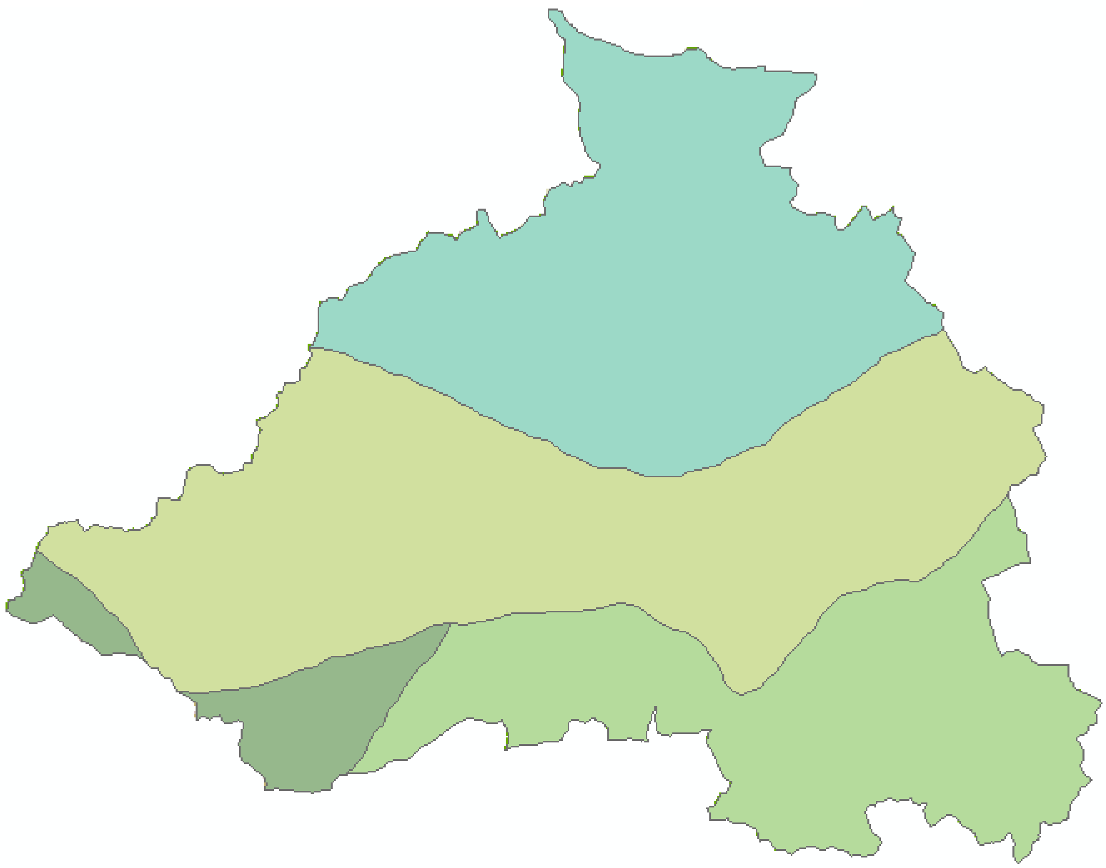
EGLE Runoff Curve Number
60.9

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

48, FALLS RIVER WATERSHED

Surficial Geology



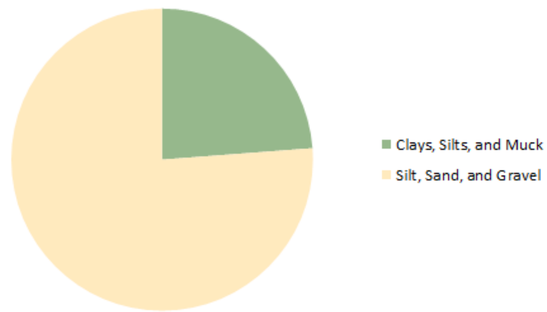


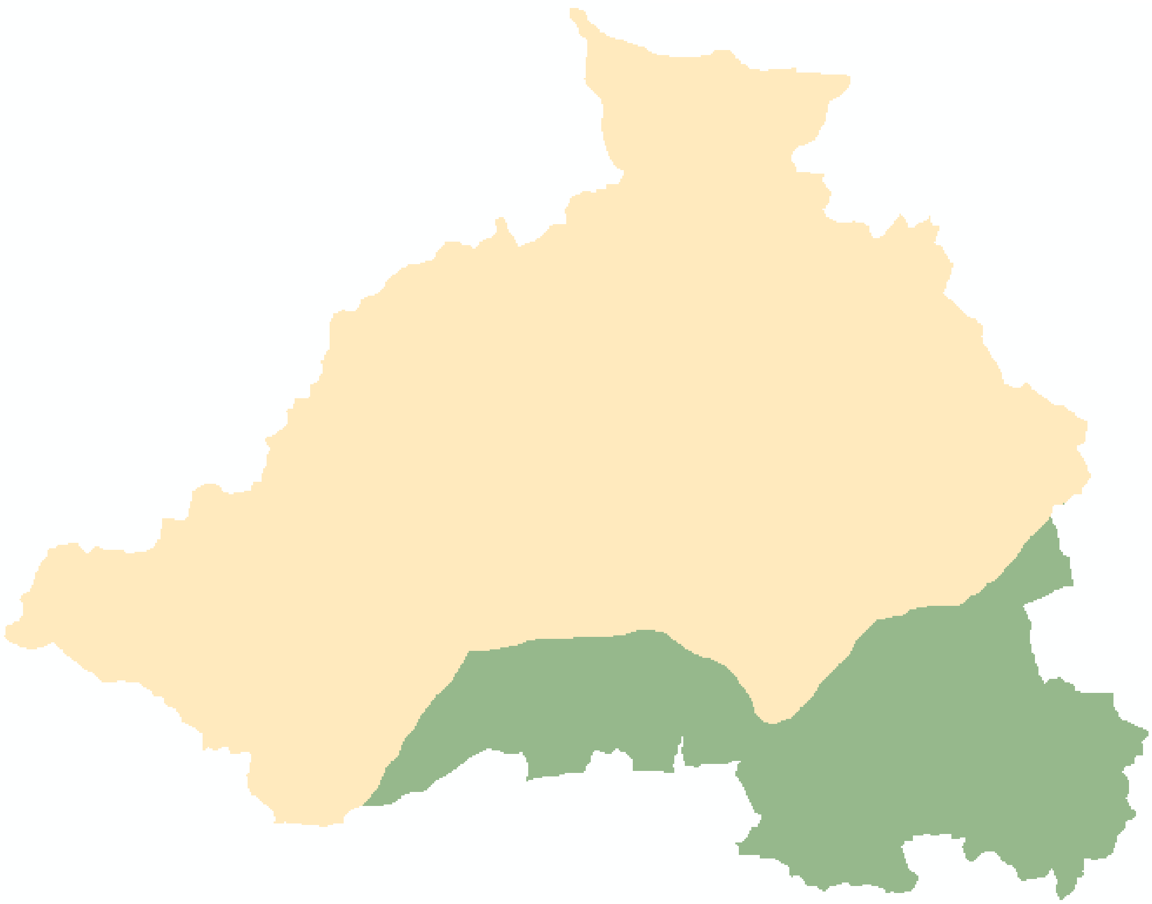
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	37.42	30.79%
End moraines of coarse-textured till	48.86	40.20%
Glacial outwash sand and gravel and postglacial alluvium	6.35	5.23%
Thin to discontinuous glacial till over bedrock	28.91	23.79%
Total Watershed Area	121.54	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

48, FALLS RIVER WATERSHED

Surficial Geology (Simplified)



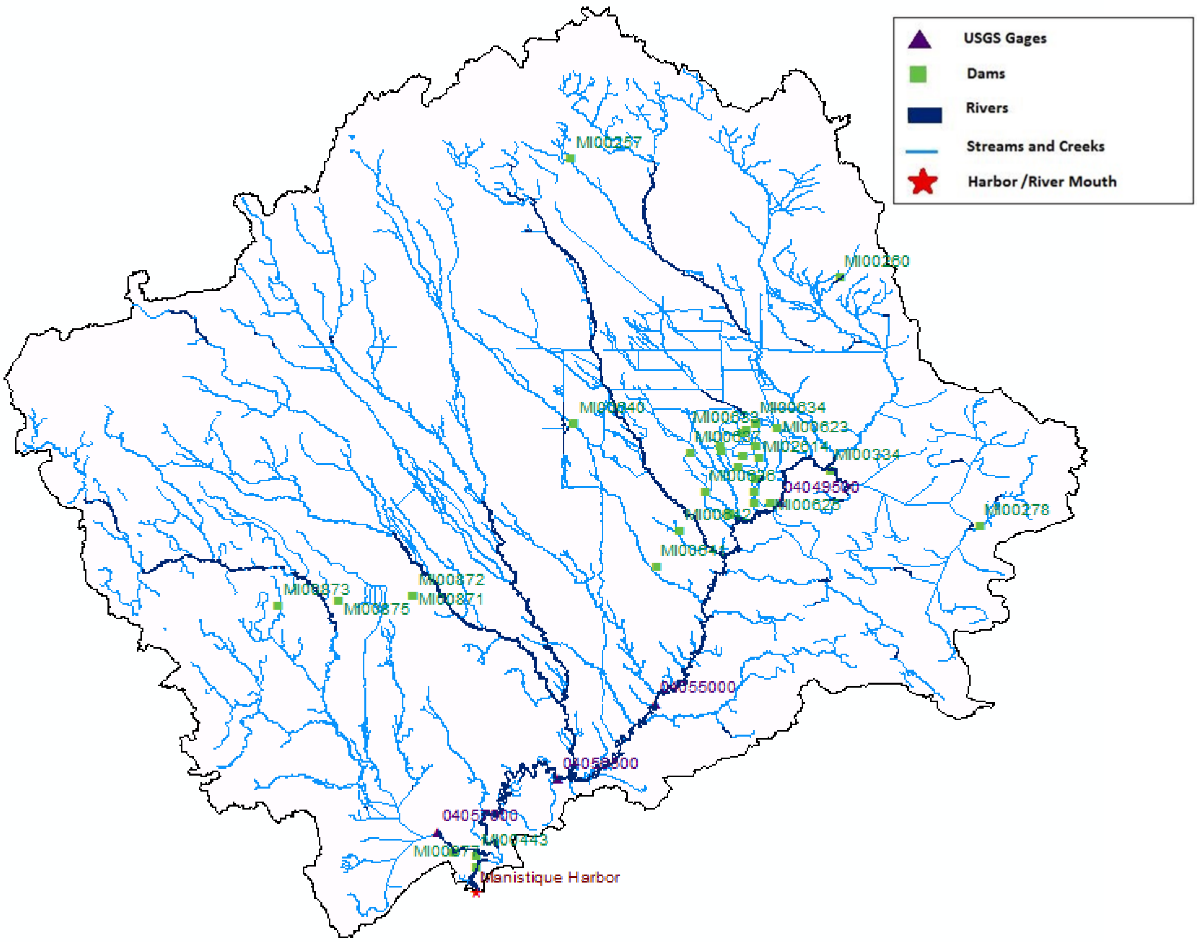


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	28.91	23.79%
Silt, Sand, and Gravel	92.63	76.21%
Total Watershed Area	121.54	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX CCC. MANISTIQUE RIVER WATERSHED (49)

Surface Hydrology



49, MANISTIQUE RIVER WATERSHED

Dam Information and USGS Streamgages

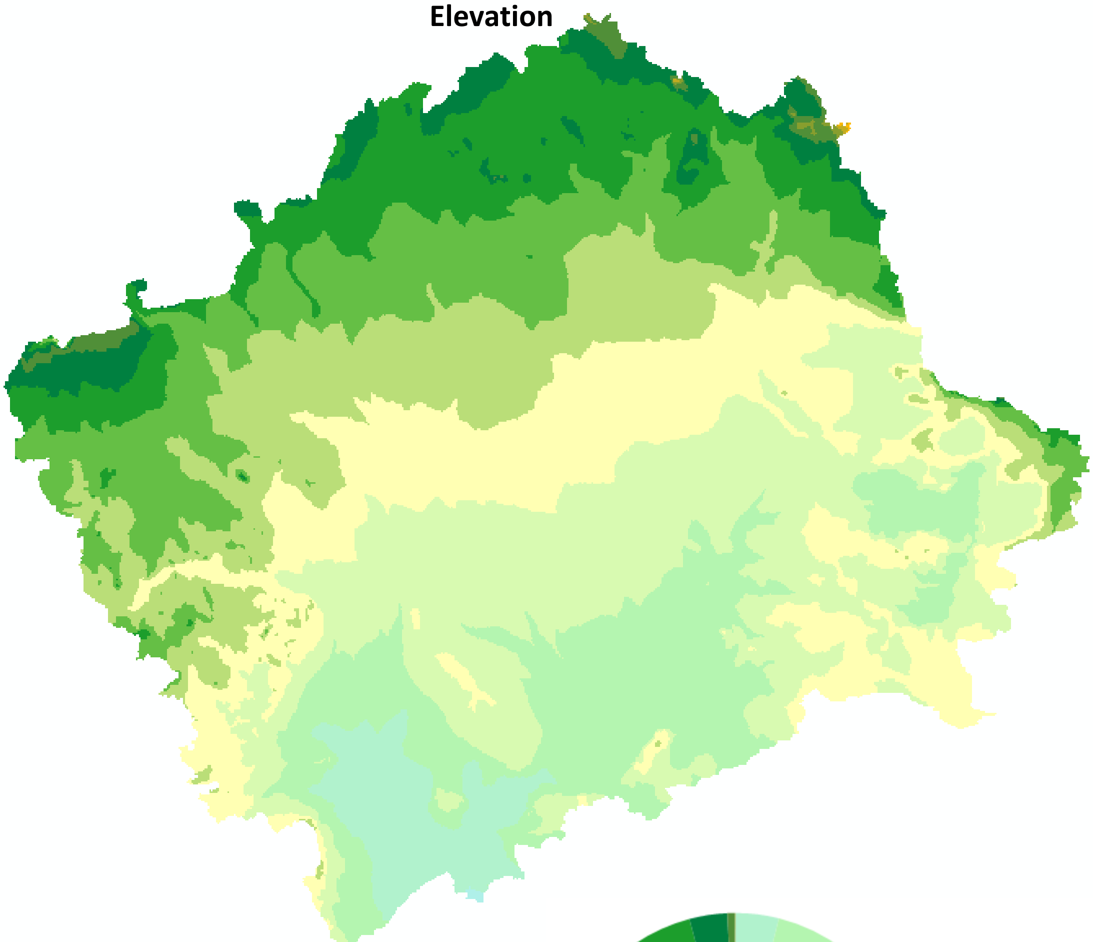
USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00871	SCOTTS MARSH DIKE 1	-86.314300	46.164600
MI00872	SCOTTS MARSH DIKE 2 & 3	-86.314300	46.164600
MI00875	MUDDY GRIMES DAM	-86.393000	46.161500
MI00257	Stanley Lake Dam	-86.148620	46.485400
MI00260	Spring CreekTrout Pond Dam	-85.863330	46.398330
MI02614	Grays Creek Raised Grade Dam	-85.950000	46.266700
MI00271	Carpenter Dam (Indian Lake Dam)	-86.271760	45.977300
MI00274	Grays Creek Dam	-85.955560	46.233610
MI00278	Black Creek Dam	-85.716670	46.216670
MI00334	Manistique Lake Dam	-85.875000	46.256670
MI00377	Manistique Papers Dam	-86.246670	45.966670
MI00443	Intake Park Dam	-86.246670	45.975000
MI00623	Show Pool Dam	-85.930000	46.288330
MI00624	Upper Goose Pen Dam	-85.955000	46.241660
MI00625	Lower Goose Pen Dam	-85.938330	46.233330
MI00626	A-1 Pool	-85.953330	46.251670
MI00627	B-1 Pool Dam	-85.971660	46.260000
MI00628	C-1 Pool Dam	-85.966670	46.268330
MI00629	D-1 Pool	-85.988330	46.271670
MI00630	E-1 Pool Dam	-85.953330	46.275000
MI00631	F-1 Pool	-85.963330	46.286670
MI00632	G-1 Pool	-85.991670	46.275000
MI00633	H-1 Pool Dam	-85.966670	46.285000
MI00634	I-1 Pool Dam	-85.953330	46.291670
MI00636	M-2 Pool Dam	-86.006390	46.241660
MI00637	C-2 Pool	-86.021670	46.270000
MI00638	T-2 Pool	-85.980000	46.225000
MI00640	C-3 Pool	-86.145000	46.291670
MI00641	Marsh Creek Pool	-86.058330	46.186670
MI00642	Delta Creek Pool Dam	-86.033330	46.213330
MI00873	Little Bass Lake Dam	-86.456130	46.156980

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4049500	MANISTIQUE RIVER AT GERMFASK, MI	-85.927908	46.233313	
4055000	MANISTIQUE RIVER AT COOKSON BRIDGE NEAR BLANEY, MI	-86.059577	46.086087	
4056500	MANISTIQUE RIVER NEAR MANISTIQUE, MI	-86.161249	46.030529	yes
4057000	INDIAN RIVER NEAR MANISTIQUE, MI	-86.287645	45.991638	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

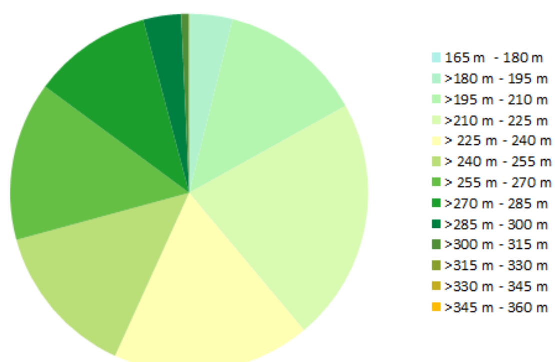
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

49, MANISTIQUE RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.21	0.03%
>180 m - 195 m	147.76	3.88%
>195 m - 210 m	495.17	13.01%
>210 m - 225 m	837.52	22.00%
>225 m - 240 m	680.76	17.88%
>240 m - 255 m	531.92	13.97%
>255 m - 270 m	546.06	14.34%
>270 m - 285 m	409.24	10.75%
>285 m - 300 m	130.17	3.42%
>300 m - 315 m	24.45	0.64%
>315 m - 330 m	2.17	0.06%
>330 m - 345 m	0.49	0.01%
>345 m - 360 m	0.25	0.01%
Size of Drainage Area	3807.20	100.00%

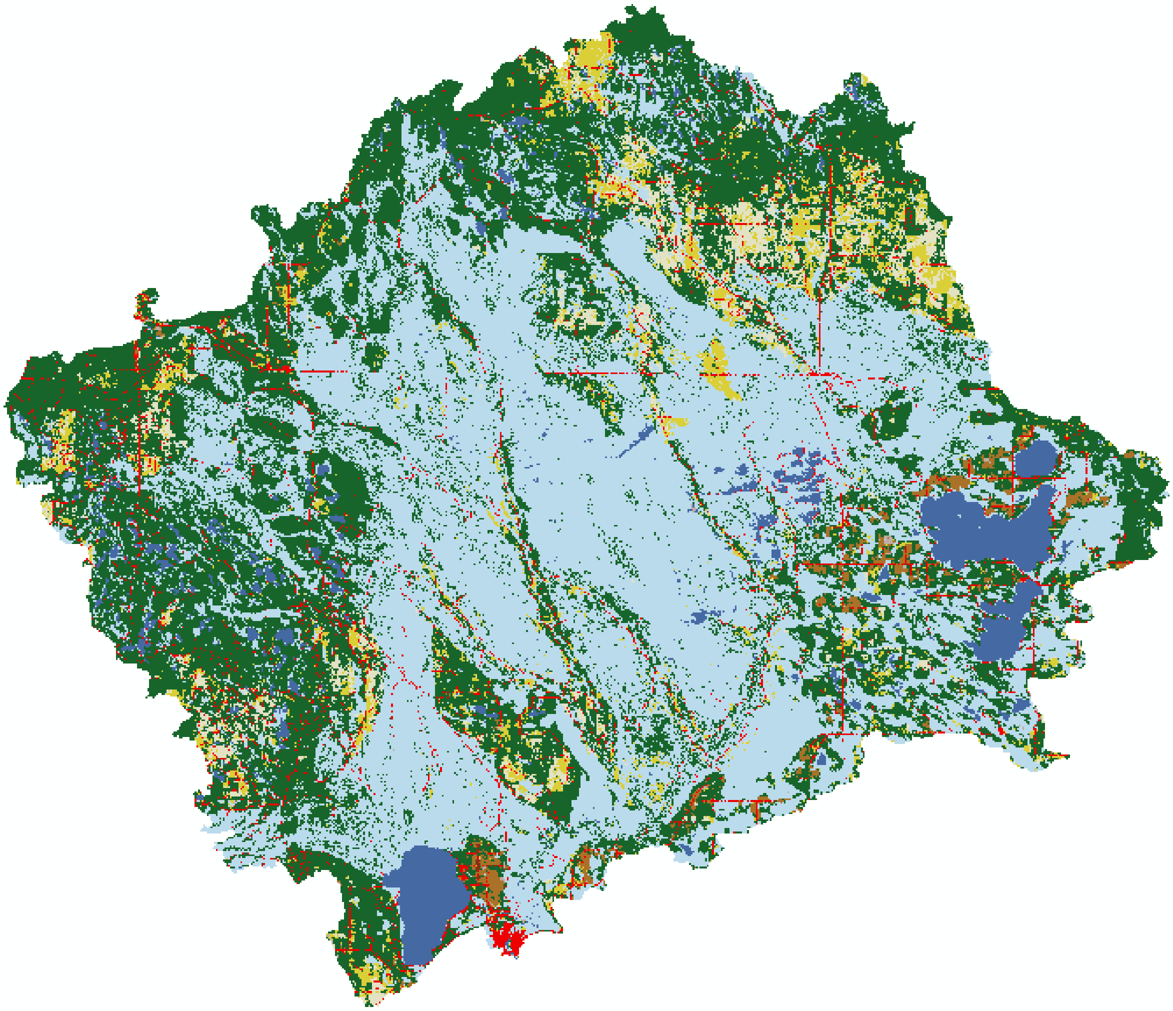


Manistique Watershed		
Elevation Statistics		
Size of Drainage Area	3807.20	*km²*
Maximum	472.00	*m*
Minimum	176.00	*m*
Average	326.66	*m*
Standard Deviation	60.75	*m*

All Elevation Measurements with Respect to North American Datum 1983

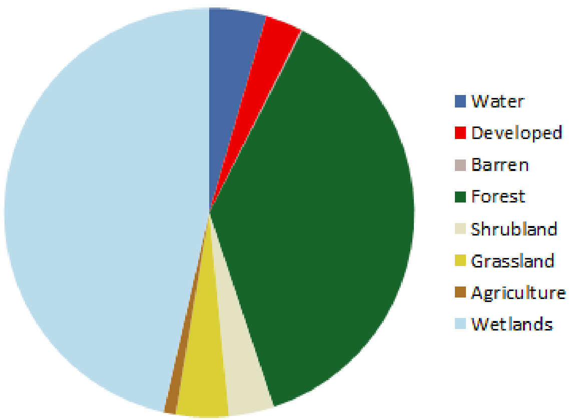
49, MANISTIQUE RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	170.98	4.49%
Developed	111.35	2.92%
Barren	4.18	0.11%
Forest	1422.88	37.37%
Shrubland	135.47	3.56%
Grassland	158.64	4.17%
Agriculture	36.61	0.96%
Wetlands	1767.08	46.41%
Total	3807.20	100.00%

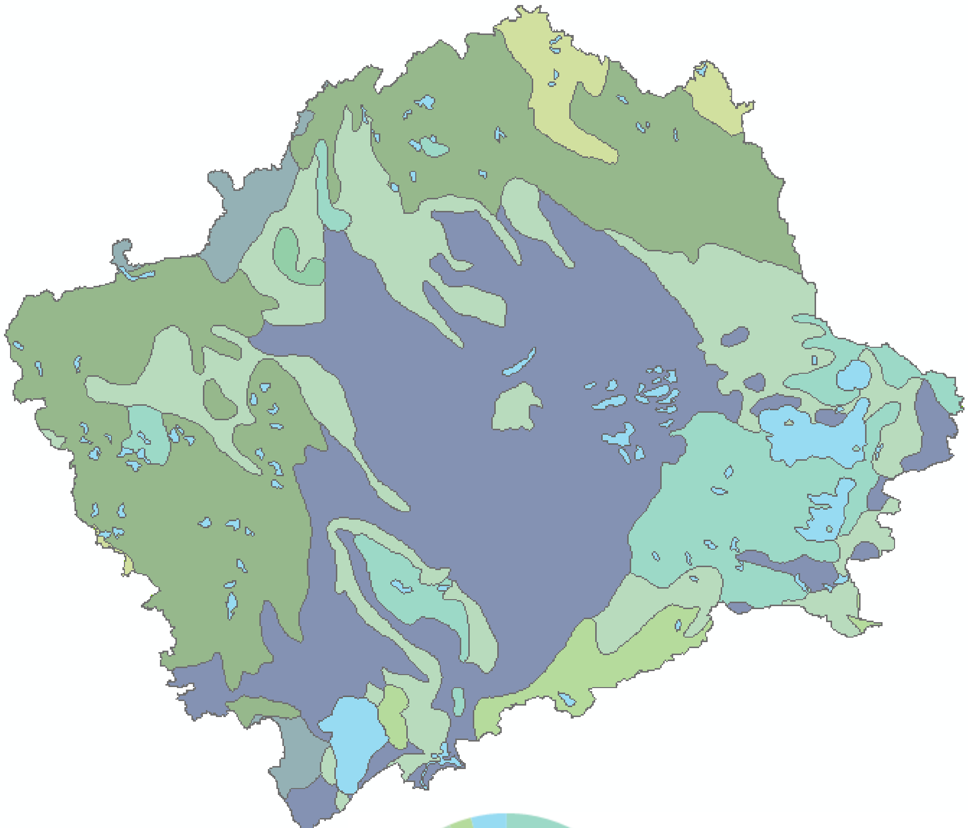
EGLE Runoff Curve Number
67.7

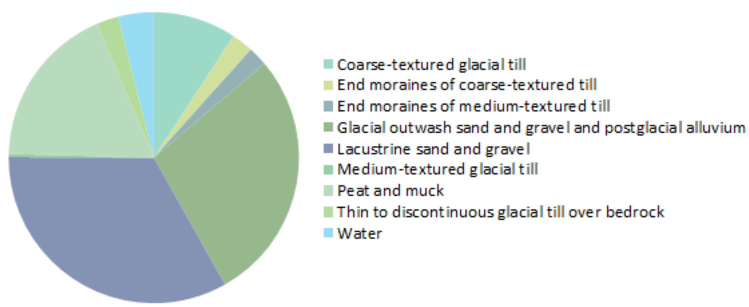


Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

49, MANISTIQUE RIVER WATERSHED

Surficial Geology



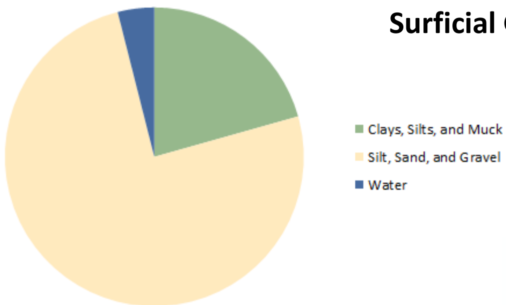


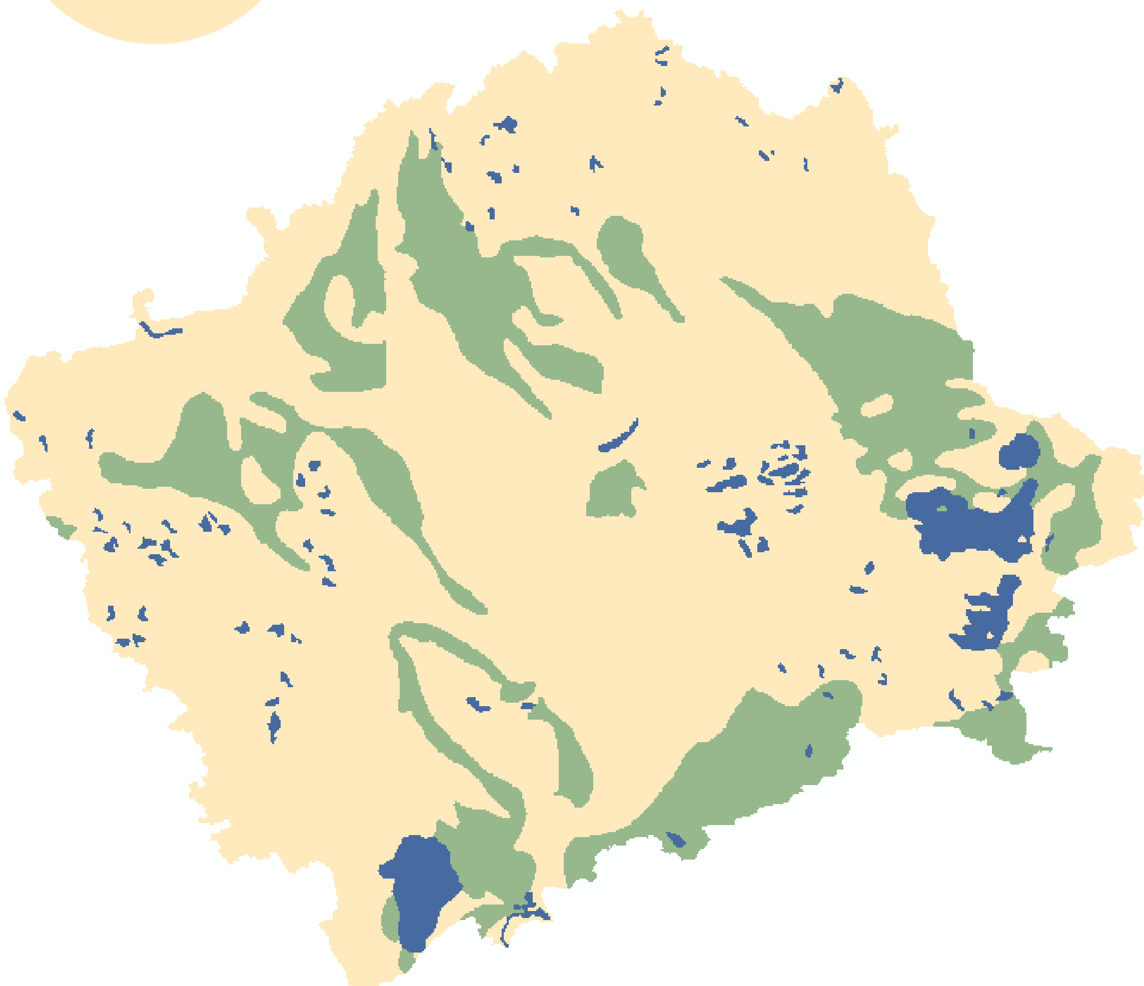
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	351.68	9.24%
End moraines of coarse-textured till	92.01	2.42%
End moraines of medium-textured till	80.96	2.13%
Glacial outwash sand and gravel and postglacial alluvium	1068.33	28.06%
Lacustrine sand and gravel	1264.97	33.23%
Medium-textured glacial till	13.38	0.35%
Peat and muck	691.90	18.17%
Thin to discontinuous glacial till over bedrock	93.73	2.46%
Water	150.26	3.95%
Total Watershed Area	3807.20	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

49, MANISTIQUE RIVER WATERSHED

Surficial Geology (Simplified)



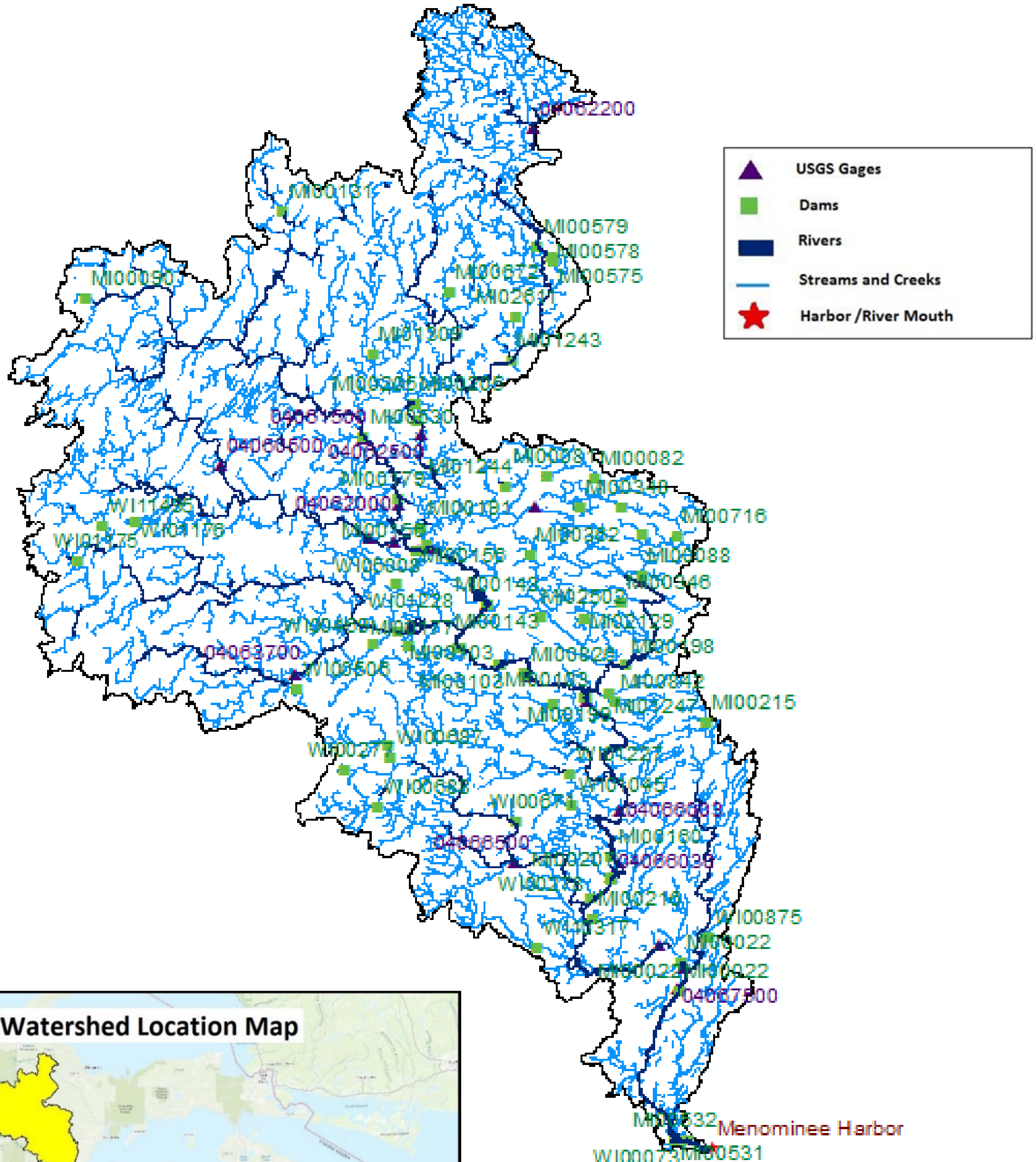


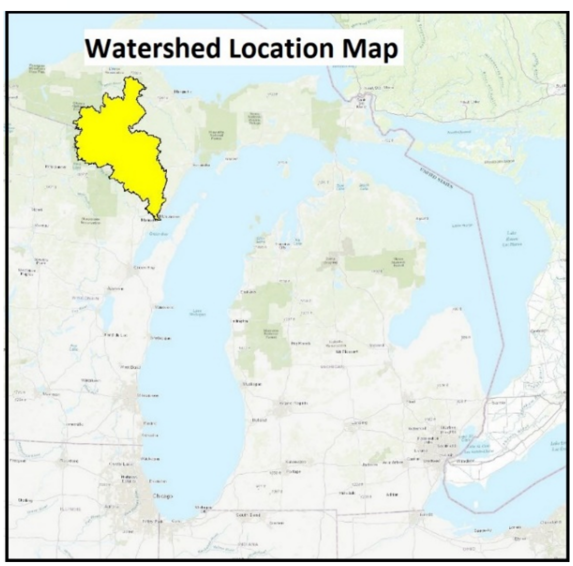
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	785.63	20.64%
Silt, Sand, and Gravel	2871.31	75.42%
Water	150.26	3.95%
Total Watershed Area	3807.20	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX DDD. MENOMINEE RIVER WATERSHED (50)

Surface Hydrology





50, MENOMINEE RIVER WATERSHED

Dam Identification and USGS Streamgages

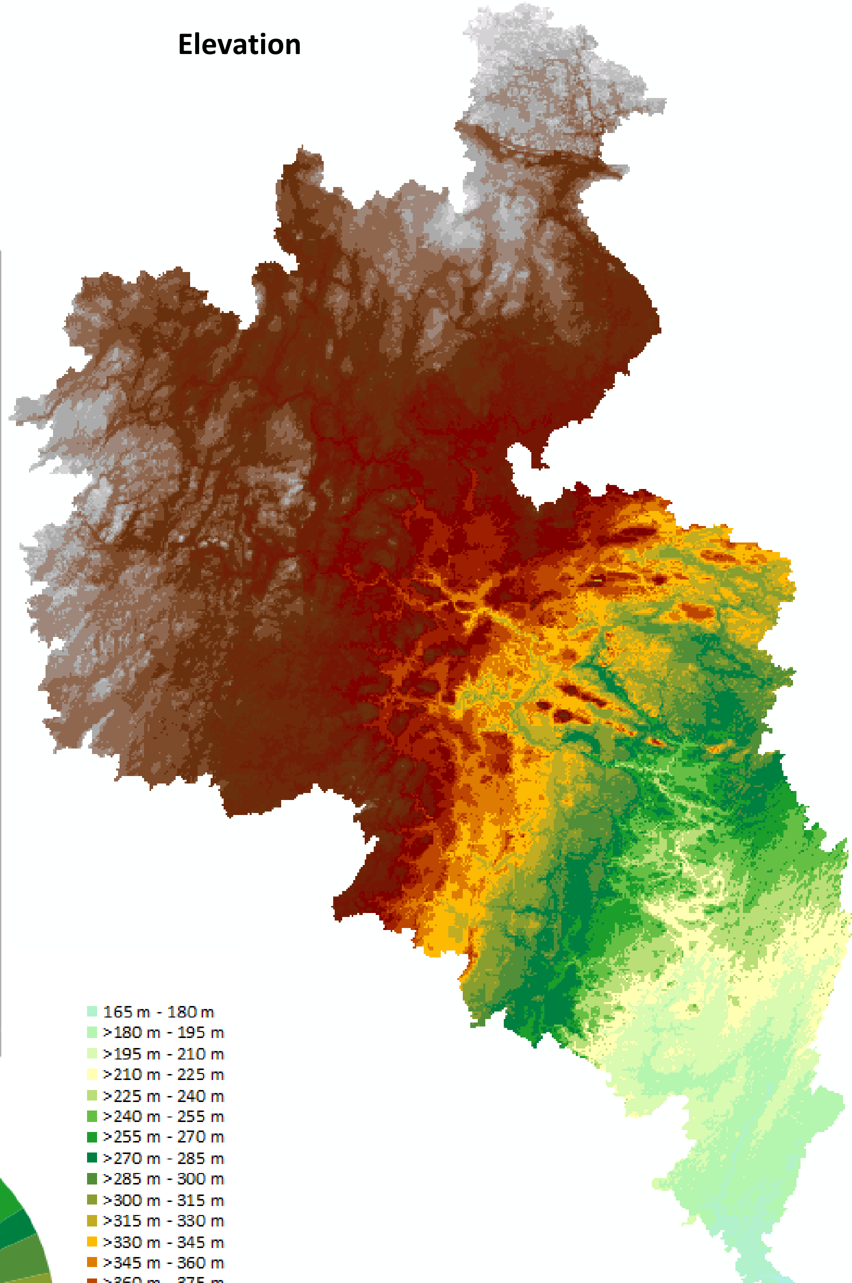
USACE's National Inventory of Dams (NID)							
NIDID	Dam Name	Longitude	Latitude	NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*	*National ID*	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
WI00073	THIRD MARINETTE	-87.660040	45.107540	MI00207	White Rapids Left Causeway	-87.803300	45.480000
WI00275	HATCHERY	-88.267520	45.664680	MI00160	Chalk Hill	-87.801800	45.513700
WI00277	GOODMAN	-88.356570	45.628850	MI00156	Brule	-88.218700	45.947400
WI00278	SQUAW CREEK	-87.844440	45.452550	MI00156	Brule Remote Dike	-88.216700	45.946700
WI00460	PANIS,JOE JR.	-87.931270	45.731910	MI00022	Grand Rapids	-87.656200	45.362400
WI00469	HALLS CREEK WILDLIFE FLOWAGE	-88.300910	45.810340	MI00022	Grand Rapids Detached Dike No 2	-87.660000	45.321700
WI00475	LINDOW	-88.230710	45.807940	MI00022	Grand Rapids Detached Dike No 3	-87.660000	45.321700
WI00506	MUD CREEK	-88.457890	45.740650	MI00198	Sturgeon	-87.782700	45.789900
WI00671	BEECHER LAKE	-88.001190	45.559580	MI00199	Sturgeon Falls	-87.863500	45.741600
WI00687	KIRTON	-88.260850	45.648450	MI00531	Park Mill	-87.660000	45.107500
WI00688	BROCK	-88.284270	45.574330	MI00530	Crystal Falls	-88.334500	46.106600
WI00738	Pine	-88.253300	45.828300	MI00191	Peavy Falls	-88.210000	45.980000
WI00755	Little Quinnesec Falls	-87.989000	45.774000	MI00143	Twin Falls	-88.070000	45.871700
WI00875	Menominee	-87.600000	45.400000	MI00143	Twin Falls Auxilliary Spillway	-88.070000	45.871700
WI01045	MISCAUNO POND	-87.887540	45.585680	MI00143	Twin Falls Auxiliary Dike	-88.070000	45.871700
WI01175	BRISS LAKE DAM	-88.916700	45.916700	MI01242	Coppo Dam	-87.800000	46.016670
WI01176	WEST ALLEN CREEK DAM	-88.802300	45.974700	MI01243	Floodwood Lakes Dam	-88.033330	46.225000
WI01227	SWELSTAD, JACK	-87.889970	45.630380	MI01244	Kimberly-Clark Dam	-88.038330	46.043330
WI01228	VERLEY, RAY	-88.258410	45.897100	MI01246	Carlson Dam	-87.754720	45.978330
WI05001	GRAND RAPIDS	-87.656000	45.362240	MI01247	Mary Lake Dam	-87.817020	45.748540
WI05002	BIG QUINNESEC FALLS	-88.040490	45.787130	MI01309	Gagnon Dam	-88.320000	46.226670
WI05006	FORD	-88.125520	45.807640	MI00131	Net River Dam	-88.516670	46.428330
WI05008	BRULE	-88.219070	45.947570	MI02129	Vigo Dam	-87.870550	45.854440
WI05010	CHALK HILLS	-87.802130	45.513760	MI00215	Hermansville Dam	-87.613330	45.708330
WI05011	STURGEON FALLS	-87.864940	45.742250	MI00216	Shakey Lakes Dam	-87.838330	45.421670
WI05012	WHITE RAPIDS	-87.802620	45.482390	MI02502	Richard J Trepanier Dam	-87.960830	45.855000
WI05016	TWIN FALLS	-88.069710	45.872710	MI02611	Nico Lake Dam	-88.028000	46.285600
WI10317	WAUSAUKEE	-87.952540	45.379580	MI00346	Blomgren s Marsh Dam	-87.793330	45.878330
WI11495	ALVIN CREEK DAM	-88.866700	45.966700	MI00348	Felch Mountain Dam	-87.885000	46.013330
MI00205	Way	-88.233300	46.158300	MI00362	Groveland Dam #8	-87.985000	45.945000
MI00205	Way Dike B-C	-88.233300	46.158300	MI00532	Lower Menominee River Dam	-87.636670	45.106670
MI00205	Way Dike D	-88.233300	46.158300	MI00568	Republic Mine Tailings Pond Dam B	-87.953330	46.371670
MI00205	Way Dike E	-88.233300	46.158300	MI00575	Republic Mine Tailings Pond Dam Tertiary	-87.953330	46.368330
MI00205	Way Dike F	-88.233300	46.158300	MI00578	Republic Mine Tailings Pond Dams	-87.958340	46.373330
MI00205	Way Dike G	-88.233300	46.158300	MI00579	Republic Dam	-87.985000	46.388330
MI00103	Big Quinnesec Falls	-88.041700	45.786700	MI00672	Robert Minerick Dam	-88.166660	46.318890
MI00103	Big Quinnesec Falls Dike "A"	-88.041700	45.786700	MI00716	Hardwood Dam	-87.683330	45.976670
MI00103	Big Quinnesec Falls Dike "B"	-88.041700	45.786700	MI00081	Warren s Walleye Pond Dam	-87.955000	46.058330
MI00179	Lower Paint	-88.261700	46.020000	MI00082	Gene s Pond Dam	-87.856670	46.056670
MI00184	Michigamme Falls	-88.196700	45.955000	MI00826	Little Quinnesec Falls Dam	-87.987500	45.770830
MI00172	Hemlock Falls	-88.225000	46.133300	MI00842	Red Dam Lake Dam	-87.802220	45.736950
MI00177	Kingsford	-88.126700	45.808300	MI00088	Hancock Creek Dam	-87.751660	45.918330
MI00207	White Rapids	-87.803300	45.480000	MI00090	Bear Trap Dam	-88.920000	46.295000

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4060500	IRON RIVER AT COUNTY HWY-424 AT CASPIAN, MI	-88.627354	46.058566	yes
4060993	BRULE RIVER AT US HIGHWAY 2 NEAR FLORENCE, WI	-88.315966	45.960787	yes
4061000	BRULE RIVER NR FLORENCE, WI	-88.265967	45.958564	
4061500	PAINT RIVER AT CRYSTAL FALLS, MI	-88.334858	46.105784	
4062000	PAINT RIVER NR ALPHA, MI	-88.258468	46.011064	yes
4062011	BRULE RIVER NEAR COMMONWEALTH, WI	-88.215411	45.947453	yes
4062200	PESHEKEE RIVER NEAR CHAMPION, MI	-88.002634	46.556879	yes
4062500	MICHIGAMME RIVER NEAR CRYSTAL FALLS, MI	-88.215969	46.113838	yes
4063000	MENOMINEE RIVER NEAR FLORENCE, WI	-88.187077	45.951064	yes
4063500	MENOMINEE RIVER AT TWIN FALLS NEAR IRON MT, MI	-88.070129	45.871343	yes
4063700	POPPLE RIVER NEAR FENCE, WI	-88.463178	45.763570	yes
4064500	PINE RIVER BELOW PINE R POWERPLANT NR FLORENCE, WI	-88.225407	45.837177	yes
4065106	MENOMINEE RIVER AT NIAGARA, WI	-87.980680	45.767735	yes
04065300	WEST BRANCH STURGEON RIVER NEAR RANDVILLE, MI	-87.978188	46.012451	
4065500	STURGEON RIVER NEAR FOSTER CITY, MI	-87.754296	45.908289	
4065722	MENOMINEE RIVER NEAR VULCAN, MI	-87.863457	45.736627	yes
4066003	MENOMINEE RIVER BELOW PEMENE CREEK NEAR PEMBINE,WI	-87.787063	45.579410	yes
4066030	MENOMINEE RIVER AT WHITE RAPIDS DAM NEAR BANAT, MI	-87.802338	45.481913	yes
4066500	PIKE RIVER AT AMBERG, WI	-88.000115	45.499965	yes
4066800	MENOMINEE RIVER AT KOSS, MI	-87.702059	45.387195	yes
4067000	MENOMINEE RIVER NEAR KOSS, MI	-87.648725	45.354419	
4067500	MENOMINEE RIVER NEAR MC ALLISTER, WI	-87.663446	45.325809	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				17

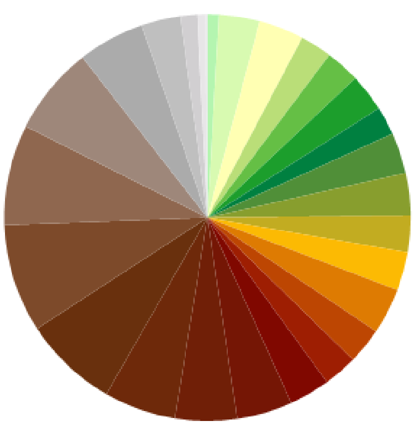
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

50, MENOMINEE RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	1.14	0.01%
>180 m - 195 m	94.82	0.90%
>195 m - 210 m	340.77	3.23%
>210 m - 225 m	376.67	3.58%
>225 m - 240 m	265.42	2.52%
>240 m - 255 m	287.75	2.73%
>255 m - 270 m	315.54	3.00%
>270 m - 285 m	237.77	2.26%
>285 m - 300 m	341.21	3.24%
>300 m - 315 m	353.33	3.35%
>315 m - 330 m	306.05	2.91%
>330 m - 345 m	323.71	3.07%
>345 m - 360 m	383.67	3.64%
>360 m - 375 m	300.99	2.86%
>375 m - 390 m	284.41	2.70%
>390 m - 405 m	341.39	3.24%
>405 m - 420 m	466.23	4.43%
>420 m - 435 m	517.06	4.91%
>435 m - 450 m	602.76	5.72%
>450 m - 465 m	792.71	7.52%
>465 m - 480 m	907.13	8.61%
>480 m - 495 m	840.42	7.98%
>495 m - 510 m	743.06	7.05%
>510 m - 525 m	557.94	5.30%
>525 m - 540 m	327.55	3.11%
>540 m - 555 m	141.64	1.34%
>555 m - 570 m	66.40	0.63%
>570 m - 585 m	16.01	0.15%
>585 m	1.44	0.01%
Size of Drainage Area	10534.97	100.00%



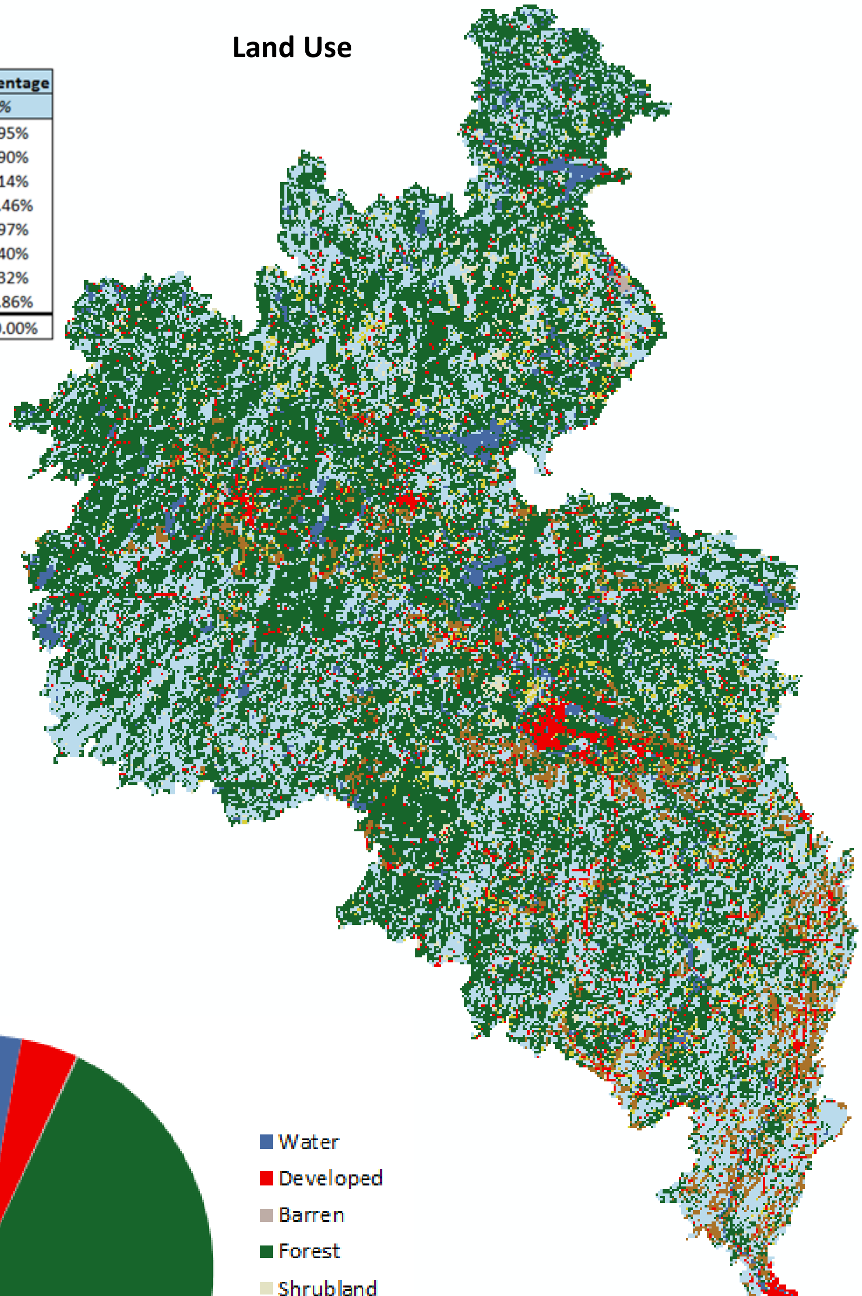
Menominee Watershed		
Elevation Statistics		
Size of Drainage Area	10534.97	*km²*
Maximum	601.46	*m*
Minimum	176.76	*m*
Average	399.86	*m*
Standard Deviation	101.44	*m*

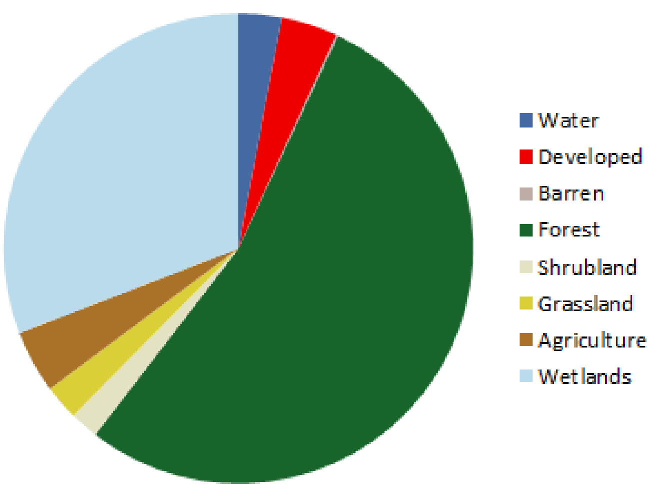
All Elevation Measurements with Respect to North American Datum 1983

50, MENOMINEE RIVER WATERSHED

Land Use

Category	Area	Percentage
Category	km^2	%
Water	310.86	2.95%
Developed	410.72	3.90%
Barren	14.54	0.14%
Forest	5631.97	53.46%
Shrubland	207.38	1.97%
Grassland	253.16	2.40%
Agriculture	455.47	4.32%
Wetlands	3250.85	30.86%
Total	10534.97	100.00%



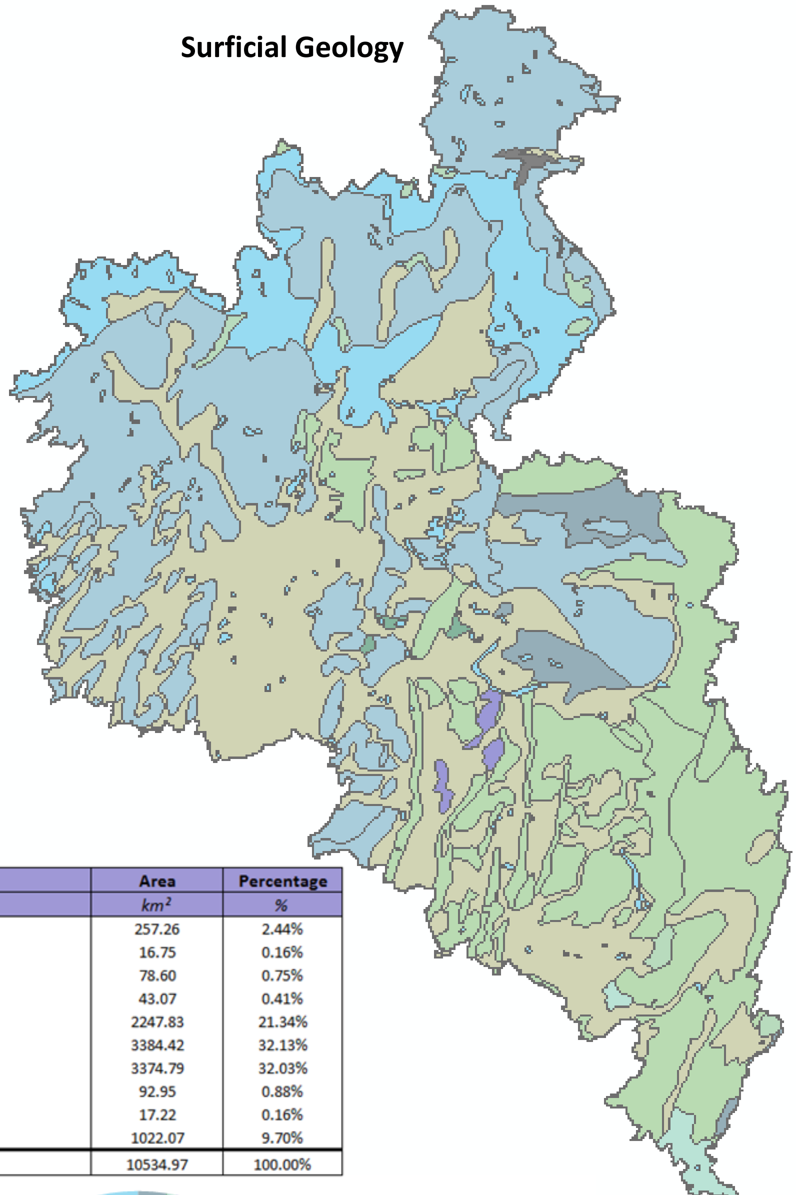


EGLE Runoff Curve Number
68.7

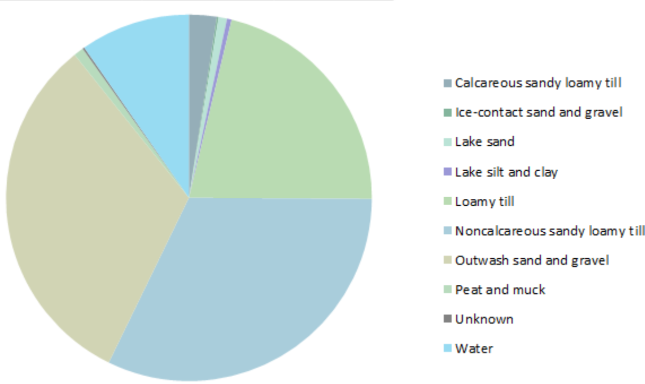
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

50, MENOMINEE RIVER WATERSHED

Surficial Geology



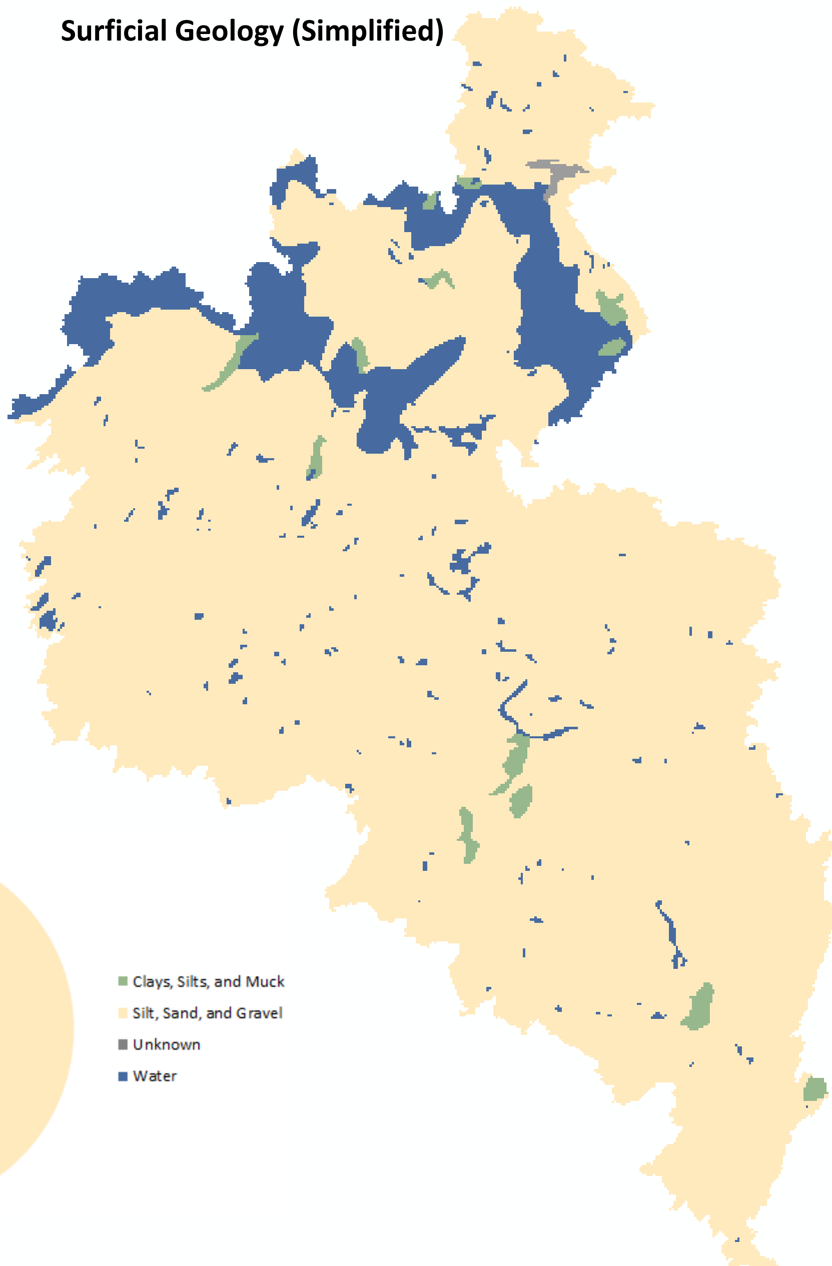
Category	Area	Percentage
Category	*km²*	*%*
Calcareous sandy loamy till	257.26	2.44%
Ice-contact sand and gravel	16.75	0.16%
Lake sand	78.60	0.75%
Lake silt and clay	43.07	0.41%
Loamy till	2247.83	21.34%
Noncalcareous sandy loamy till	3384.42	32.13%
Outwash sand and gravel	3374.79	32.03%
Peat and muck	92.95	0.88%
Unknown	17.22	0.16%
Water	1022.07	9.70%
Total Watershed Area	10534.97	100.00%

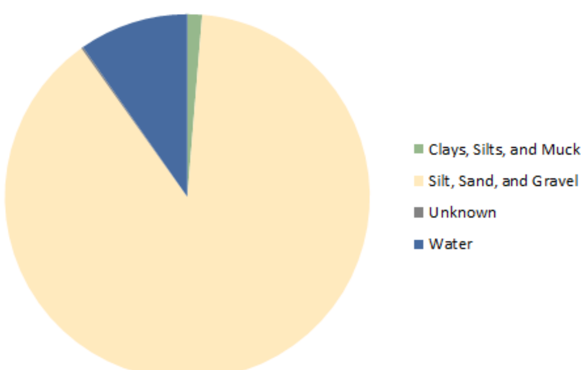


Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

50, MENOMINEE RIVER WATERSHED

Surficial Geology (Simplified)



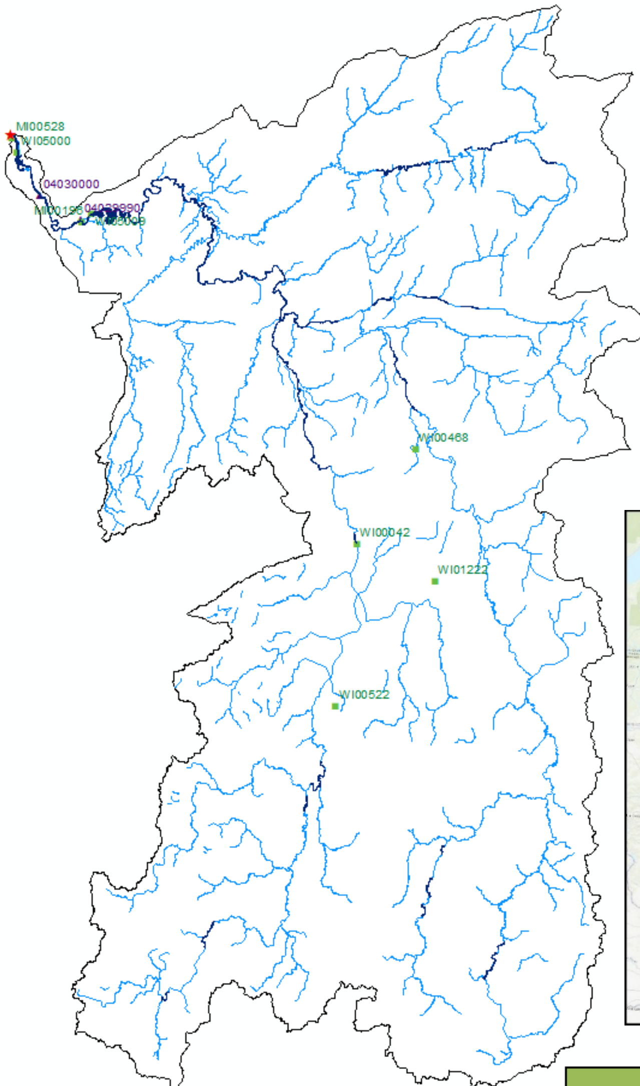


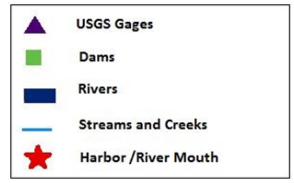
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	136.02	1.29%
Silt, Sand, and Gravel	9359.65	88.84%
Unknown	17.22	0.16%
Water	1022.07	9.70%
Total Watershed Area	10534.97	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX EEE. MONTREAL RIVER WATERSHED (51)

Surface Hydrology





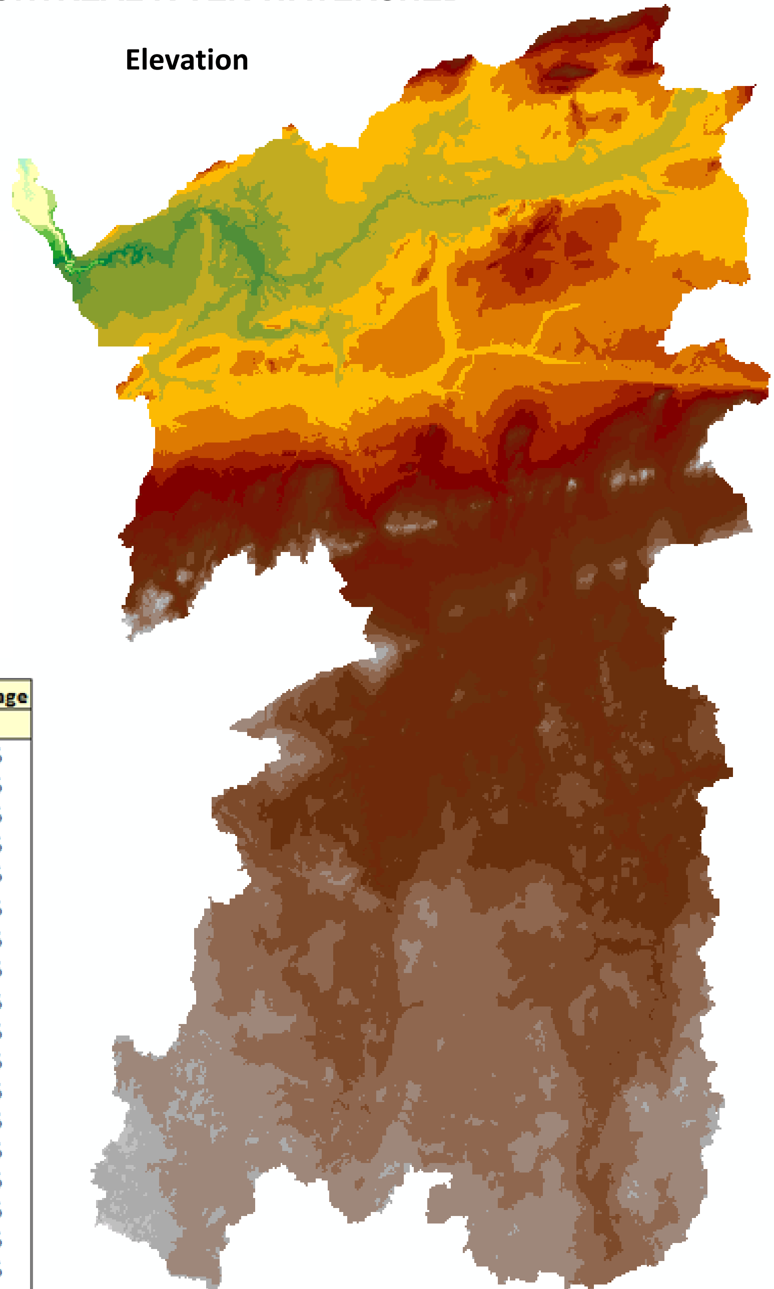
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
WI00042	GILE RESERVOIR	-90.226770	46.425650
WI00468	LA BLONDE	-90.198660	46.460870
WI00522	JOHNSON SPRINGS	-90.233300	46.366700
WI01222	GILE FLOWAGE SUB-IMPOUNDMENT	-90.184940	46.413390
WI05000	SUPERIOR FALLS	-90.414920	46.559750
WI05009	SAXON	-90.374230	46.539170
MI00528	Superior Falls	-90.417800	46.565100
MI00196	Saxon Falls	-90.379000	46.536200

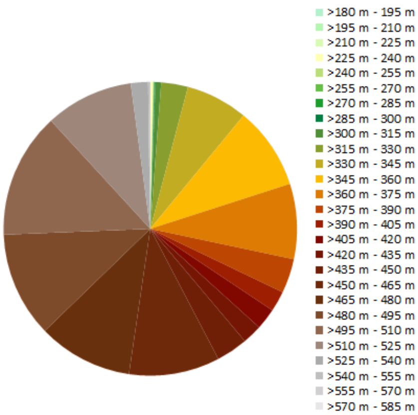
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4029990	MONTREAL RIVER AT SAXON FALLS NEAR SAXON, WI	-90.379902	46.536891	yes
4030000	MONTREAL RIVER NEAR SAXON, WI	-90.401847	46.544669	
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

51, MONTREAL RIVER WATERSHED

Elevation





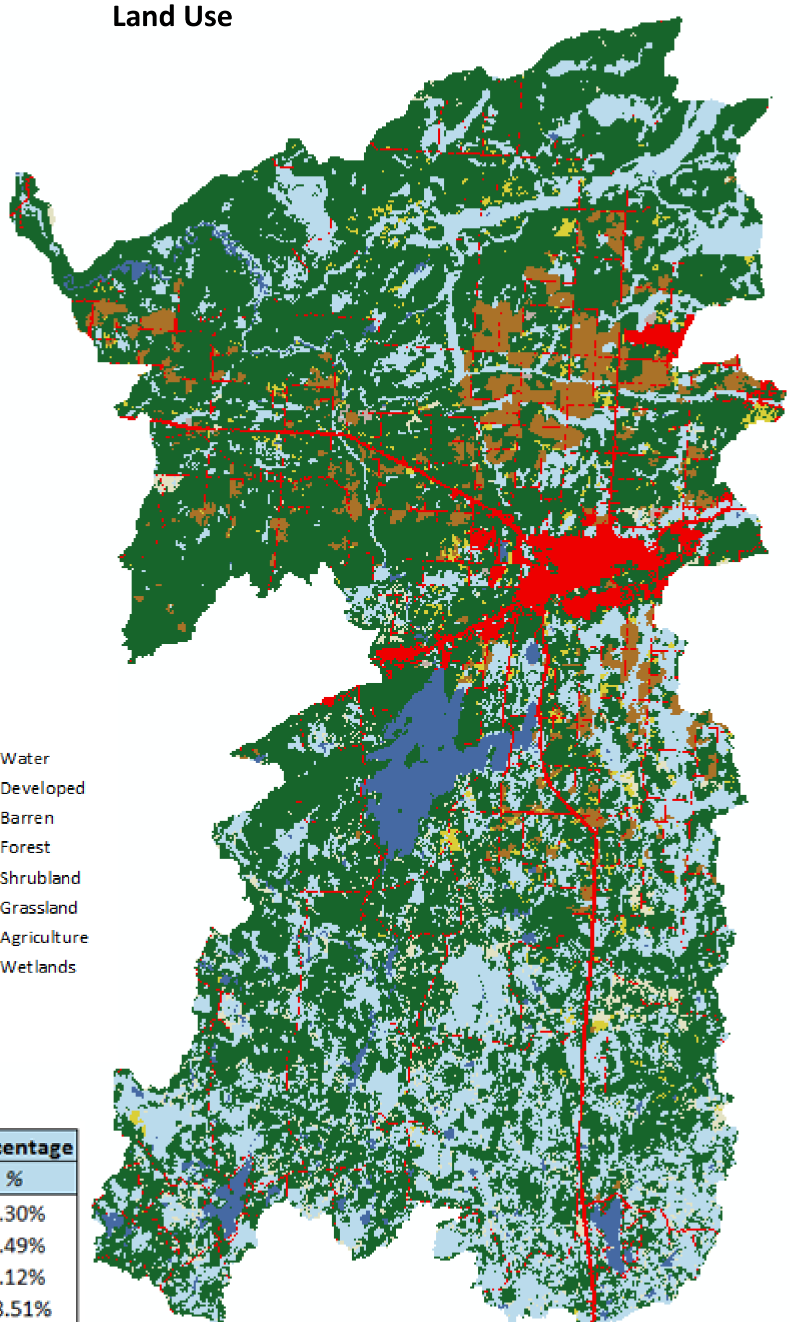
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	0.05	0.01%
>195 m - 210 m	0.03	0.00%
>210 m - 225 m	0.30	0.04%
>225 m - 240 m	1.68	0.24%
>240 m - 255 m	0.55	0.08%
>255 m - 270 m	0.43	0.06%
>270 m - 285 m	0.31	0.04%
>285 m - 300 m	0.57	0.08%
>300 m - 315 m	4.38	0.63%
>315 m - 330 m	20.65	2.95%
>330 m - 345 m	47.80	6.83%
>345 m - 360 m	63.54	9.08%
>360 m - 375 m	57.96	8.28%
>375 m - 390 m	26.45	3.78%
>390 m - 405 m	15.85	2.26%
>405 m- 420 m	16.27	2.33%
>420 m - 435 m	15.12	2.16%
>435 m - 450 m	24.28	3.47%
>450 m - 465 m	70.03	10.01%
>465 m - 480 m	73.06	10.44%
>480 m - 495 m	81.13	11.59%
>495 m - 510 m	96.60	13.80%
>510 m - 525 m	67.92	9.70%
>525 m - 540 m	13.29	1.90%
>540 m - 555 m	1.58	0.23%
>555 m - 570 m	0.06	0.01%
>570 m - 585 m	0.00	0.00%
Size of Drainage Area	699.89	100.00%

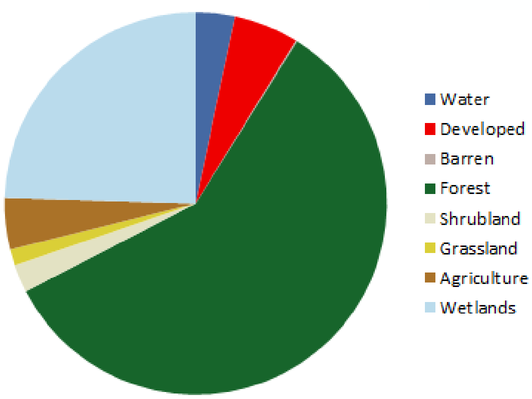
Montreal Watershed		
Elevation Statistics		
Size of Drainage Area	**699.89**	***km²***
Maximum	570.59	*m*
Minimum	183.48	*m*
Average	439.41	*m*
Standard Deviation	66.79	*m*

All Elevation Measurements with Respect to North American Datum 1983

51, MONTREAL RIVER WATERSHED

Land Use





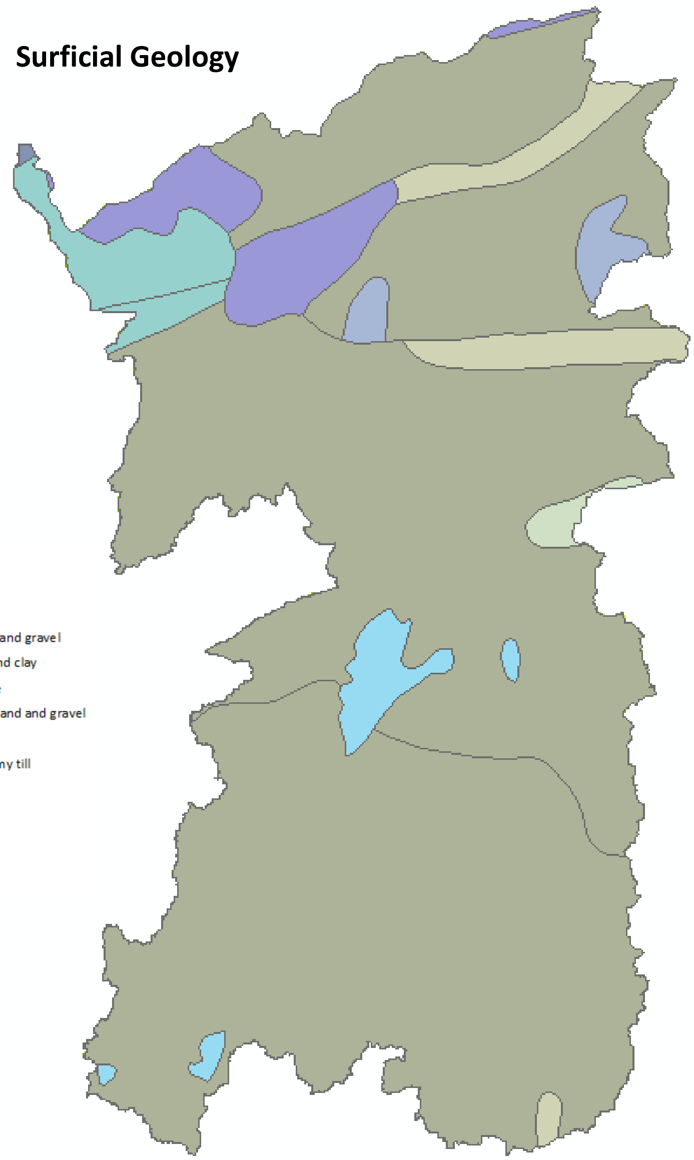
Category	Area	Percentage
Category	*km²*	*%*
Water	23.09	3.30%
Developed	38.41	5.49%
Barren	0.81	0.12%
Forest	409.49	58.51%
Shrubland	16.52	2.36%
Grassland	9.59	1.37%
Agriculture	30.40	4.34%
Wetlands	171.58	24.52%
Total	699.89	100.00%

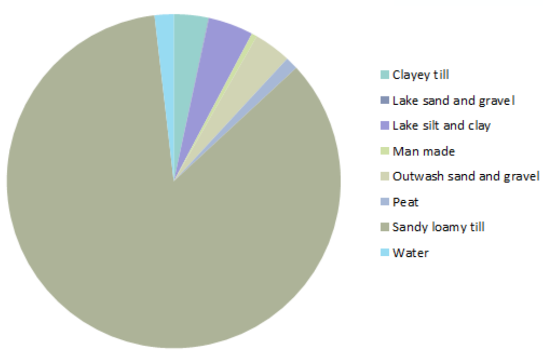
EGLE Runoff Curve Number
76.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

51, MONTREAL RIVER WATERSHED

Surficial Geology



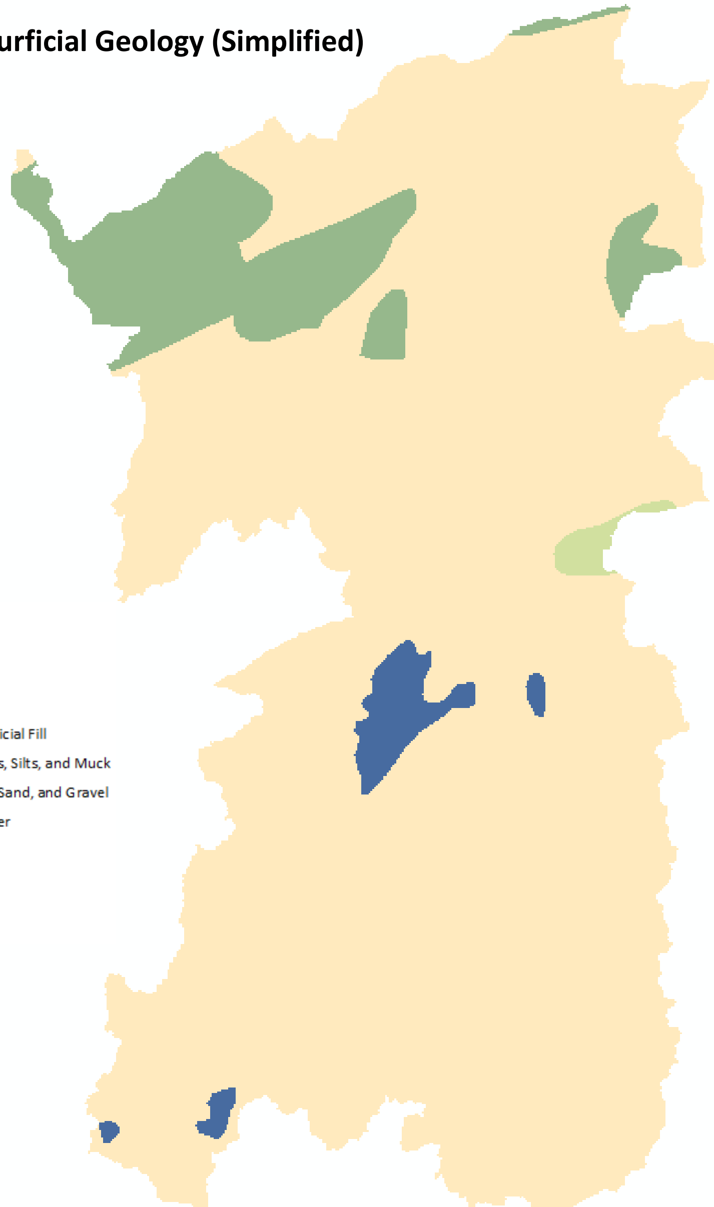


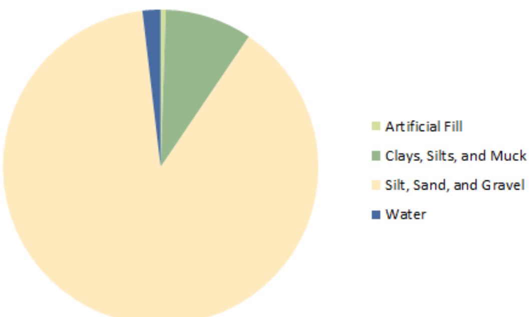
Category	Area	Percentage
Category	*km²*	*%*
Clayey till	23.37	3.34%
Lake sand and gravel	0.39	0.06%
Lake silt and clay	30.56	4.37%
Man made	3.72	0.53%
Outwash sand and gravel	25.19	3.60%
Peat	8.59	1.23%
Sandy loamy till	595.16	85.04%
Water	12.92	1.85%
Total Watershed Area	699.89	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

51, MONTREAL RIVER WATERSHED

Surficial Geology (Simplified)

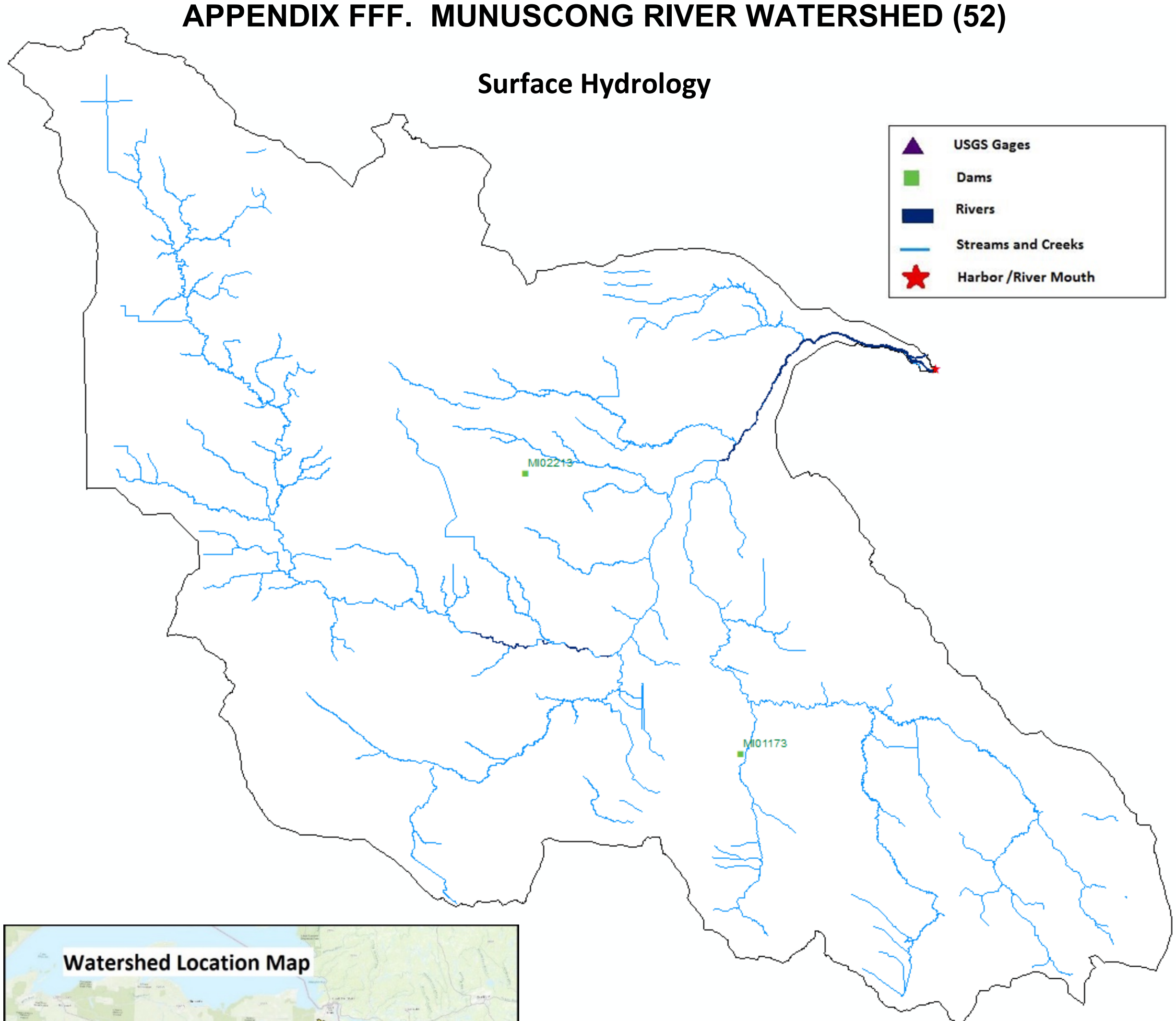


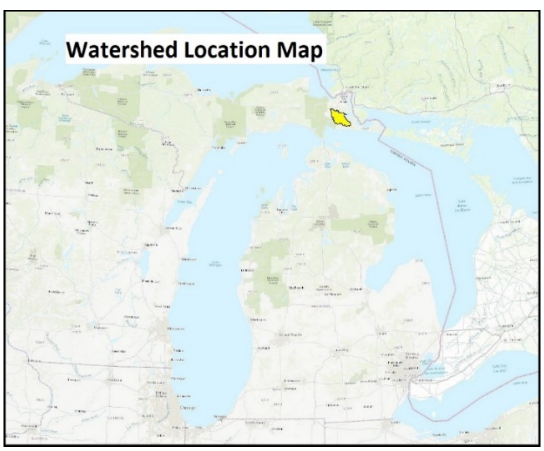


Category	Area	Percentage
Category	*km²*	*%*
Artificial fill	3.72	0.53%
Clay, Silt, and Muck	62.51	8.93%
Silt, Sand, and Gravel	620.73	88.69%
Water	12.92	1.85%
Total Watershed Area	699.89	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX FFF. MUNUSCONG RIVER WATERSHED (52)



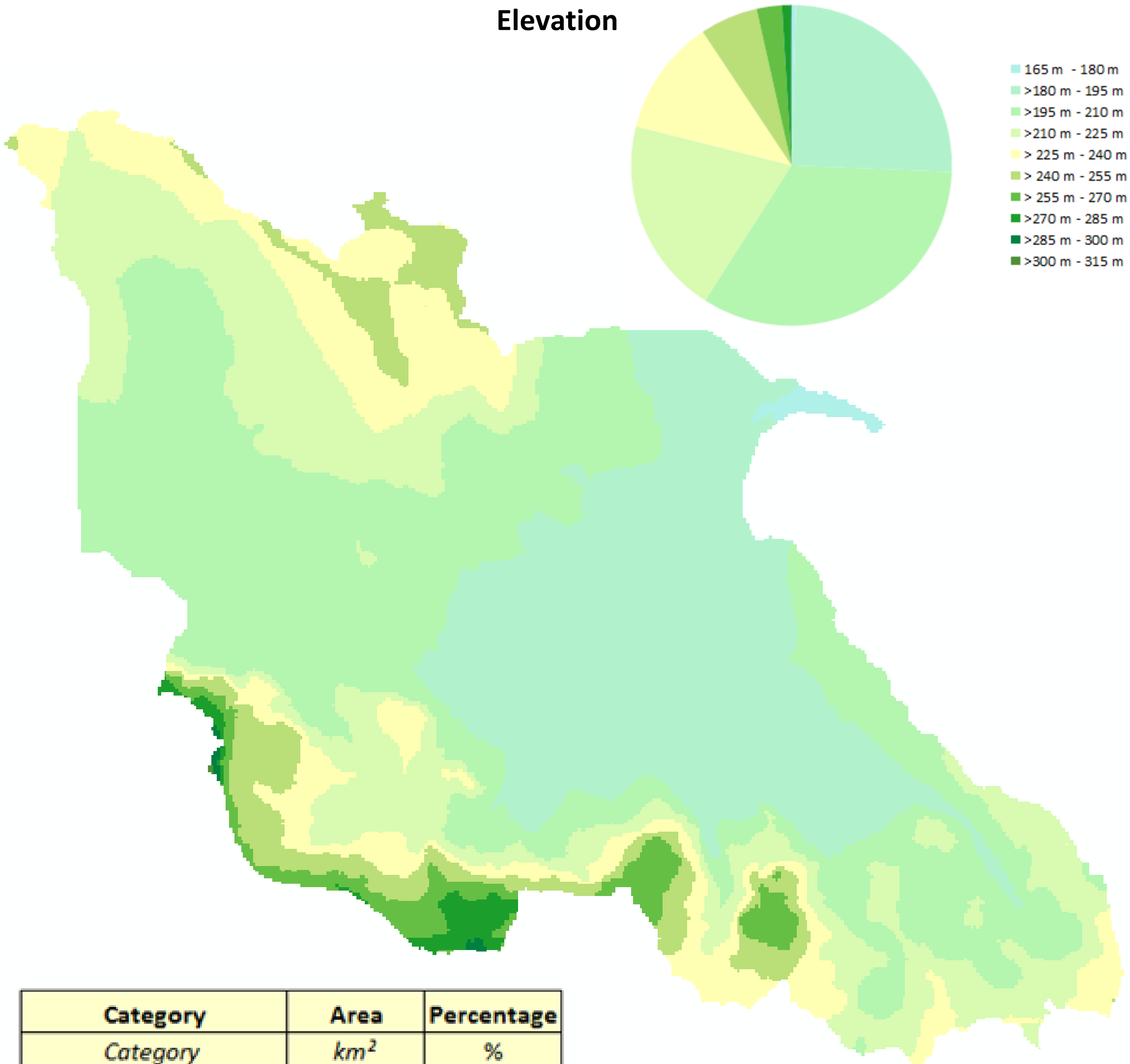


USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI02213	SYLVESTER CREEK DAM	-84.405800	46.181400
MI01173	Christian Service Brigade Camp Dam	-84.326670	46.106670

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

52, MUNUSCONG RIVER WATERSHED

Elevation



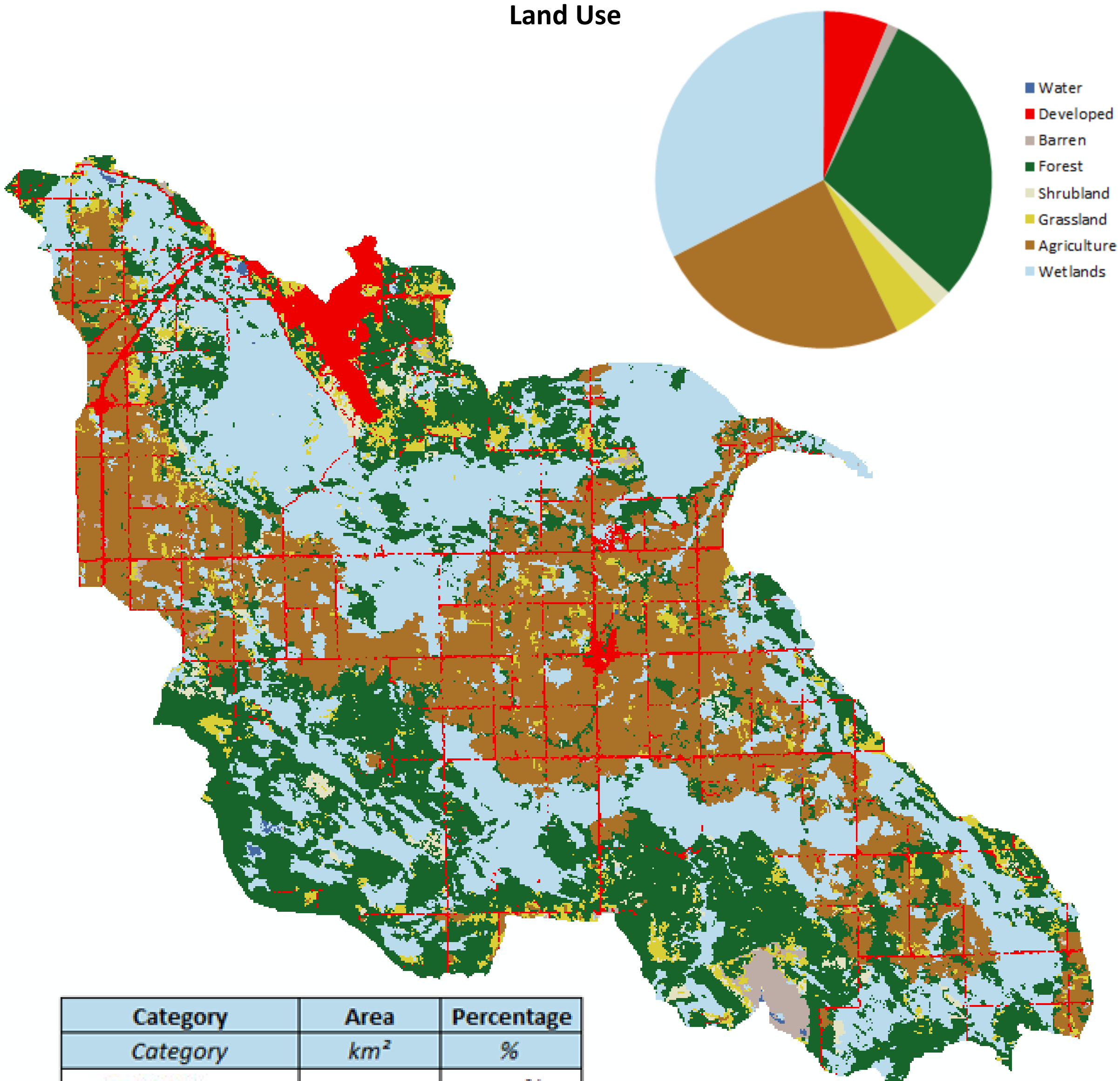
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	2.17	0.45%
>180 m - 195 m	122.38	25.22%
>195 m - 210 m	162.03	33.39%
>210 m - 225 m	96.34	19.85%
>225 m - 240 m	57.03	11.75%
>240 m - 255 m	28.33	5.84%
>255 m - 270 m	12.33	2.54%
>270 m - 285 m	4.19	0.86%
>285 m - 300 m	0.42	0.09%
>300 m - 315 m	0.04	0.01%
Size of Drainage Area	485.27	100.00%

Munuscong Watershed		
Elevation Statistics		
Size of Drainage Area	**485.27**	***km²***
Maximum	312.00	*m*
Minimum	176.00	*m*
Average	209.67	*m*
Standard Deviation	19.54	*m*

All Elevation Measurements with Respect to North American Datum 1983

52, MUNUSCONG RIVER WATERSHED

Land Use



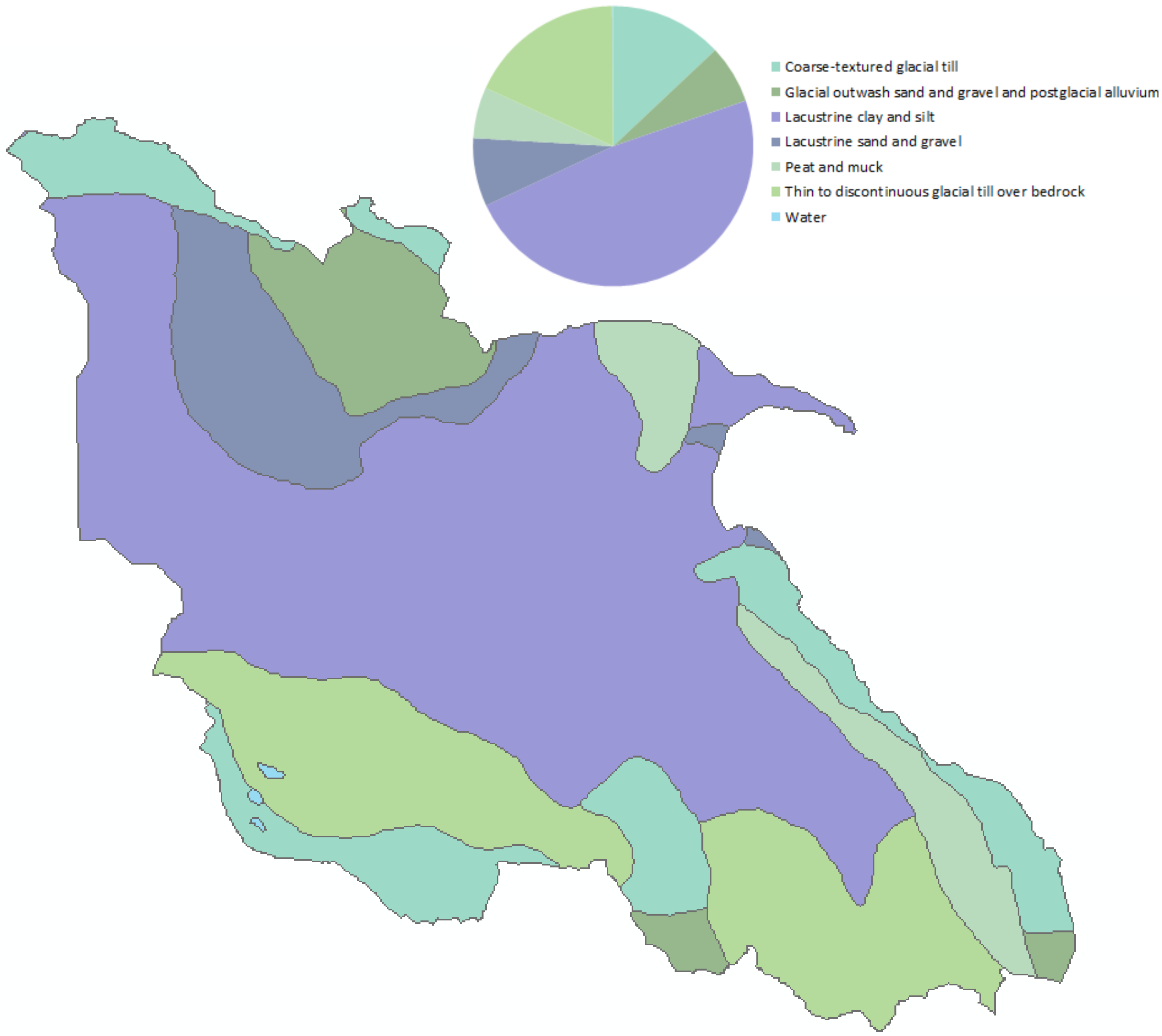
Category	Area	Percentage
Category	*km²*	*%*
Water	0.59	0.12%
Developed	29.70	6.12%
Barren	5.19	1.07%
Forest	142.48	29.36%
Shrubland	8.06	1.66%
Grassland	21.56	4.44%
Agriculture	119.92	24.71%
Wetlands	157.78	32.51%
Total	485.27	100.00%

EGLE Runoff Curve Number
75.7

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

52, MUNUSCONG RIVER WATERSHED

Surficial Geology



Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	62.98	12.98%
Glacial outwash sand and gravel and postglacial alluvium	32.78	6.76%
Lacustrine clay and silt	234.46	48.31%
Lacustrine sand and gravel	38.18	7.87%
Peat and muck	28.60	5.89%
Thin to discontinuous glacial till over bedrock	87.77	18.09%
Water	0.50	0.10%
Total Watershed Area	485.27	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

52, MUNUSCONG RIVER WATERSHED

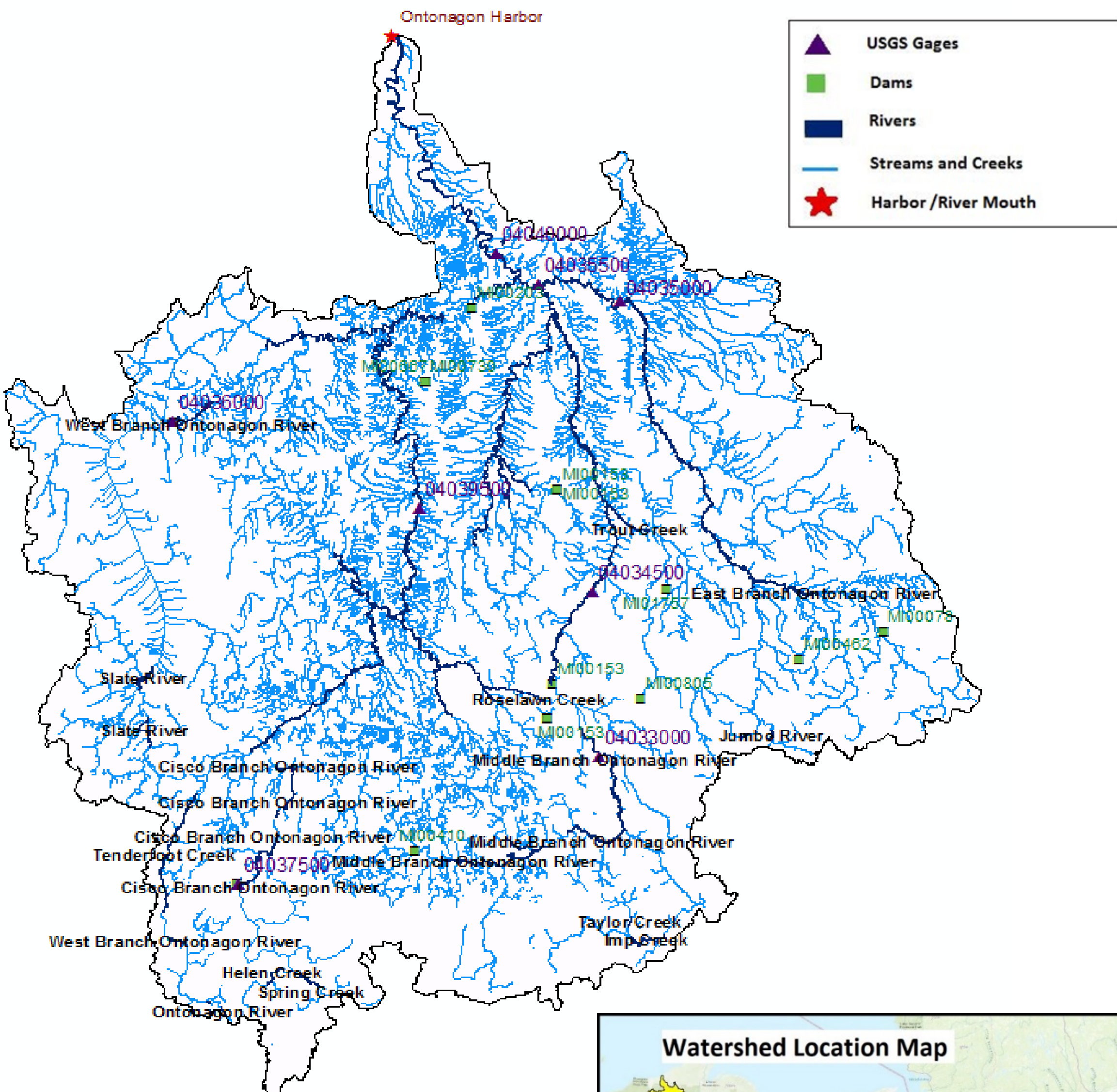
Surficial Geology (Simplified)

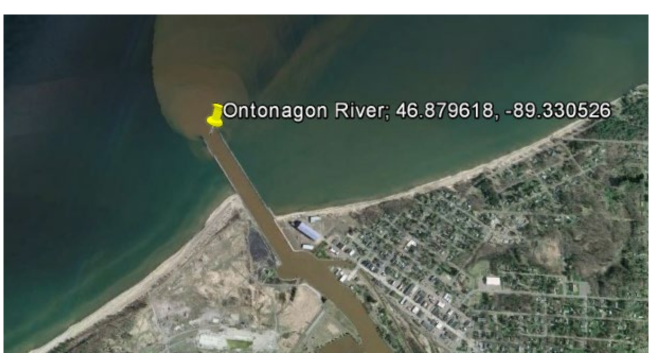
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	350.83	72.30%
Silt, Sand, and Gravel	133.95	27.60%
Water	0.50	0.10%
Total Watershed Area	485.27	100.00%

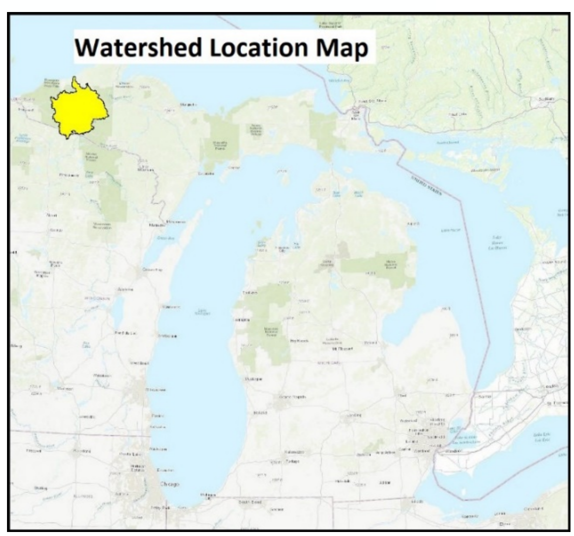
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX GGG. ONTONAGON RIVER WATERSHED (53)

Surface Hydrology







53, ONTONAGON RIVER WATERSHED

Dam Information and USGS Streamgages

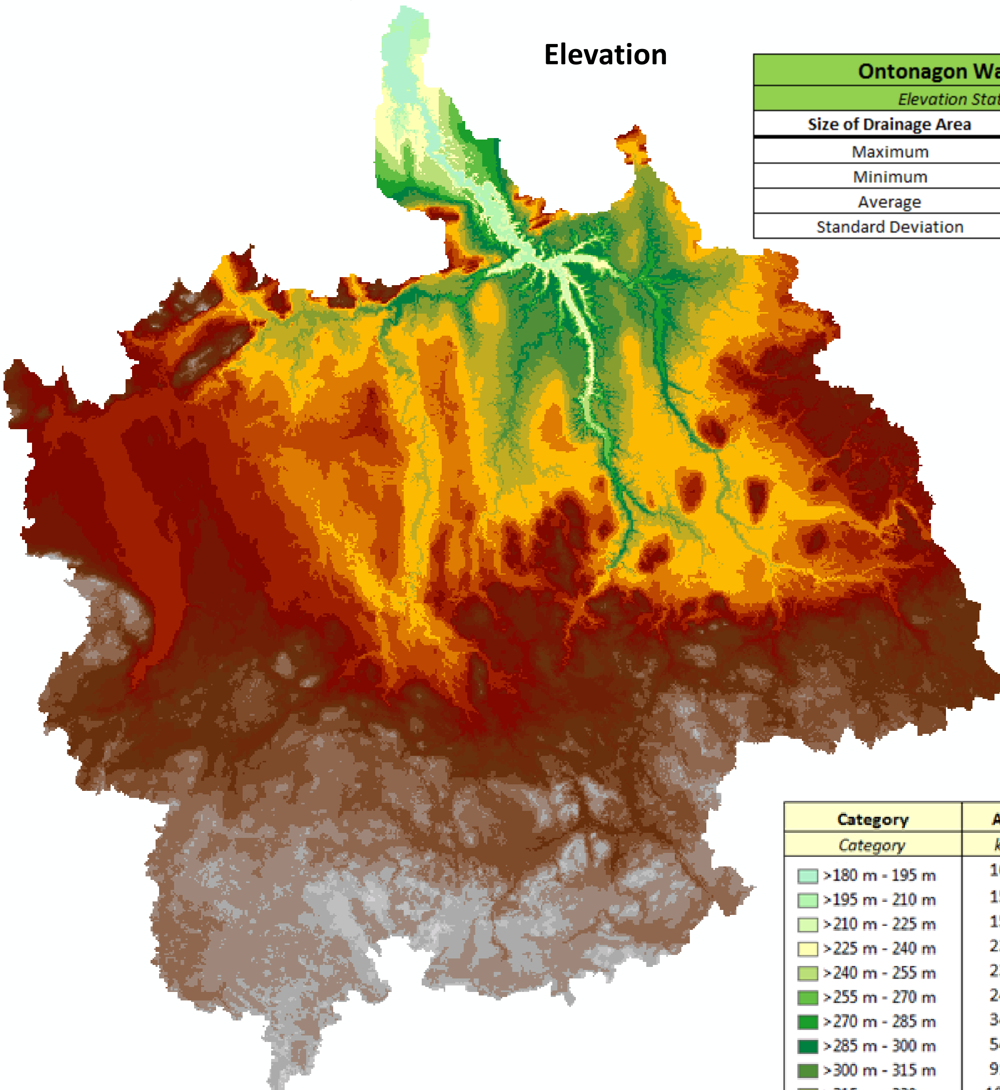
USACE's National Inventory of Dams (NID)			
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI00153	Bond Falls Main Dam	-89.129200	46.408000
MI00153	Bond Falls Auxiliary Dike	-89.133300	46.550000
MI00153	Bond Falls Control Dam	-89.133300	46.383300
MI00153	Bond Falls Sand Lake Dike	-89.133300	46.383300
MI00153	Bond Falls South Auxiliary Dike	-89.133300	46.550000
MI00203	Victoria	-89.230000	46.680000
MI00052	Cisco	-89.452100	46.253100
MI01757	Trout Creek Dam	-89.013340	46.480000
MI00028	Bergland Dam	-89.541660	46.586670
MI00410	Wolf Lake Dam	-89.266670	46.283330
MI00462	Nordine Dam	-88.871670	46.433330
MI00667	Kitchin Dam	-89.275000	46.625000
MI00730	Dills Dam	-89.277660	46.624250
MI00078	Lower Dam	-88.783330	46.455000
MI00805	Calderwood Walleye Pond Dam	-89.035840	46.400000

USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4033000	MIDDLE BRANCH ONTONAGON RIVER NEAR PAULDING, MI	*-89.077362*	*46.356892*	yes
4034500	MIDDLE BRANCH ONTONAGON RIVER NR TROUT CREEK, MI	-89.090419	46.477722	yes
4035000	EAST BR ONTONAGON RIVER NEAR MASS, MI	-89.073473	46.68994	
4035500	MIDDLE BRANCH ONTONAGON RIVER NEAR ROCKLAND, MI	-89.160141	46.699107	yes
4036000	WEST BRANCH ONTONAGON RIVER NEAR BERGLAND, MI	-89.54182	46.587447	yes
4037500	CISCO BRANCH ONTONAGON R AT CISCO LAKE OUTLET, MI	-89.451536	46.253282	yes
4039500	SOUTH BRANCH ONTONAGON RIVER AT EWEN, MI	-89.277089	46.532722	
4040000	ONTONAGON RIVER NEAR ROCKLAND, MI	-89.207086	46.720774	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				6

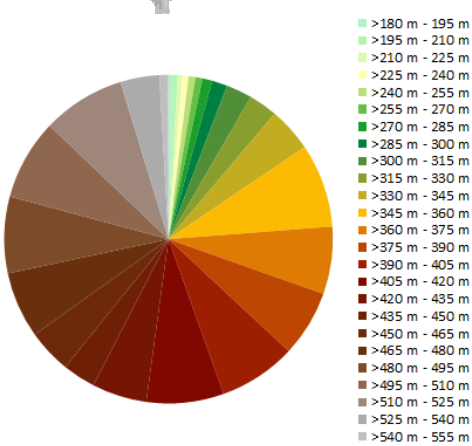
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

53, ONTONAGON RIVER WATERSHED

Elevation



Ontonagon Watershed		
Elevation Statistics		
Size of Drainage Area	**3595.60**	***km²***
Maximum	566.00	*m*
Minimum	182.00	*m*
Average	419.10	*m*
Standard Deviation	75.99	*m*

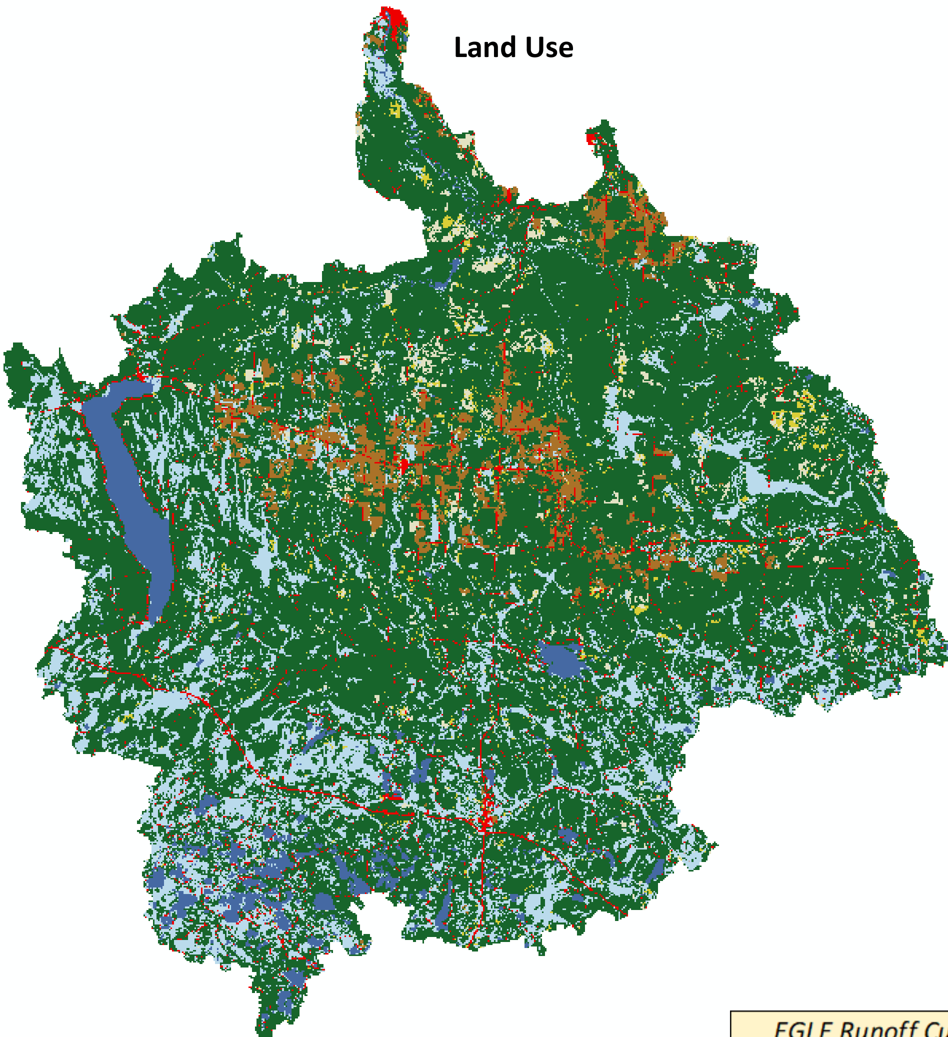


Category	**Area**	**Percentage**
Category	*km²*	*%*
>180 m - 195 m	16.96	0.47%
>195 m - 210 m	15.16	0.42%
>210 m - 225 m	15.21	0.42%
>225 m - 240 m	23.62	0.66%
>240 m - 255 m	23.81	0.66%
>255 m - 270 m	24.61	0.68%
>270 m - 285 m	34.88	0.97%
>285 m - 300 m	54.72	1.52%
>300 m - 315 m	91.34	2.54%
>315 m - 330 m	101.21	2.81%
>330 m - 345 m	157.31	4.37%
>345 m - 360 m	295.93	8.23%
>360 m - 375 m	238.47	6.63%
>375 m - 390 m	234.61	6.52%
>390 m - 405 m	274.08	7.62%
>405 m - 420 m	273.99	7.62%
>420 m - 435 m	193.69	5.39%
>435 m - 450 m	117.07	3.26%
>450 m - 465 m	155.30	4.32%
>465 m - 480 m	234.31	6.52%
>480 m - 495 m	270.59	7.53%
>495 m - 510 m	285.95	7.95%
>510 m - 525 m	293.17	8.15%
>525 m - 540 m	137.59	3.83%
>540 m - 555 m	30.82	0.86%
>555 m - 570 m	1.20	0.03%
Size of Drainage Area	3595.60	100.00%

All Elevation Measurements with Respect to North American Datum 1983

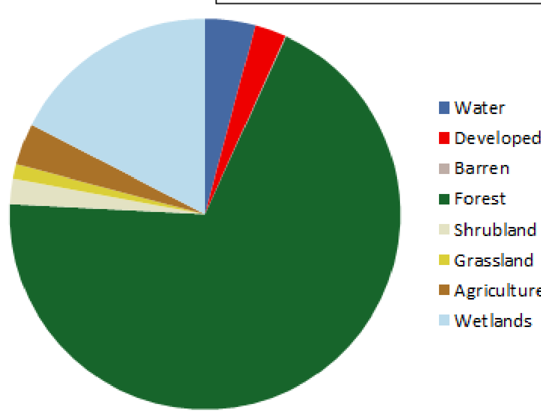
53, ONTONAGON RIVER WATERSHED

Land Use



Category	Area	Percentage
Category	*km²*	*%*
Water	149.41	4.16%
Developed	93.52	2.60%
Barren	2.53	0.07%
Forest	2481.00	69.00%
Shrubland	75.88	2.11%
Grassland	42.87	1.19%
Agriculture	123.92	3.45%
Wetlands	626.46	17.42%
Total	3595.60	100.00%

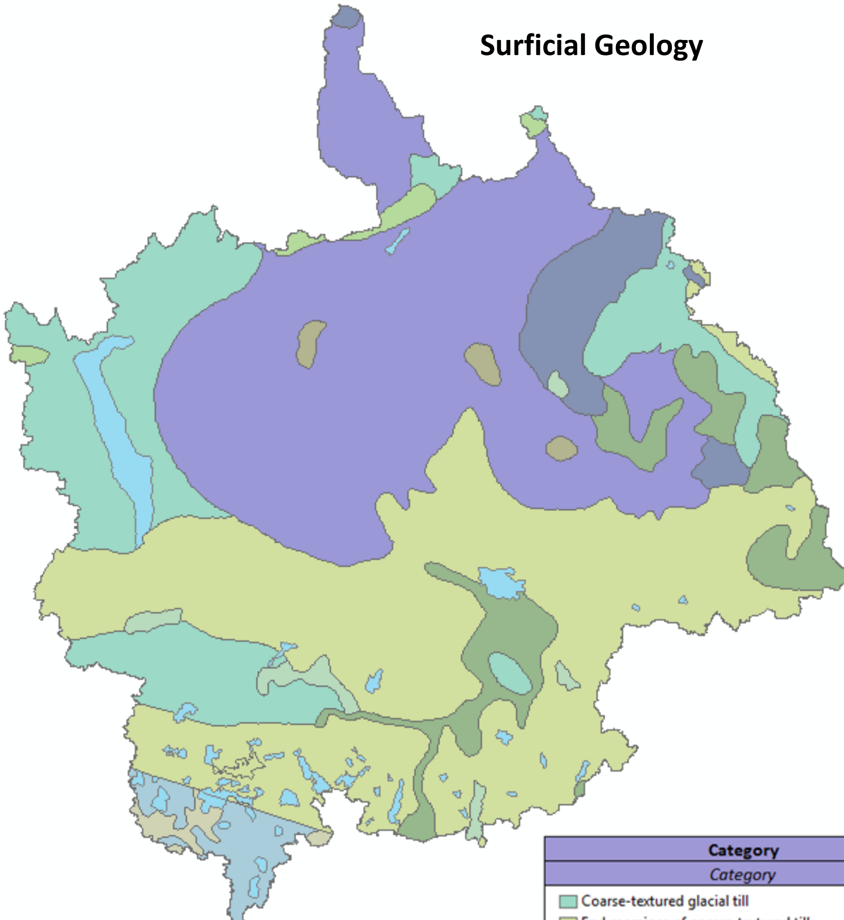
EGLE Runoff Curve Number
71.4



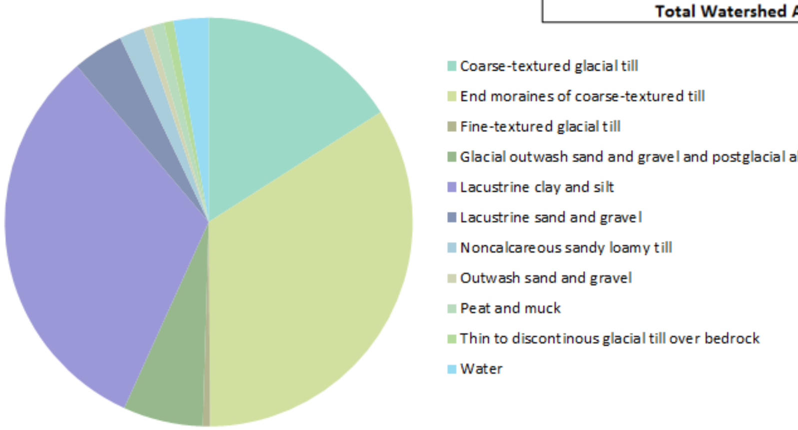
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

53, ONTONAGON RIVER WATERSHED

Surficial Geology



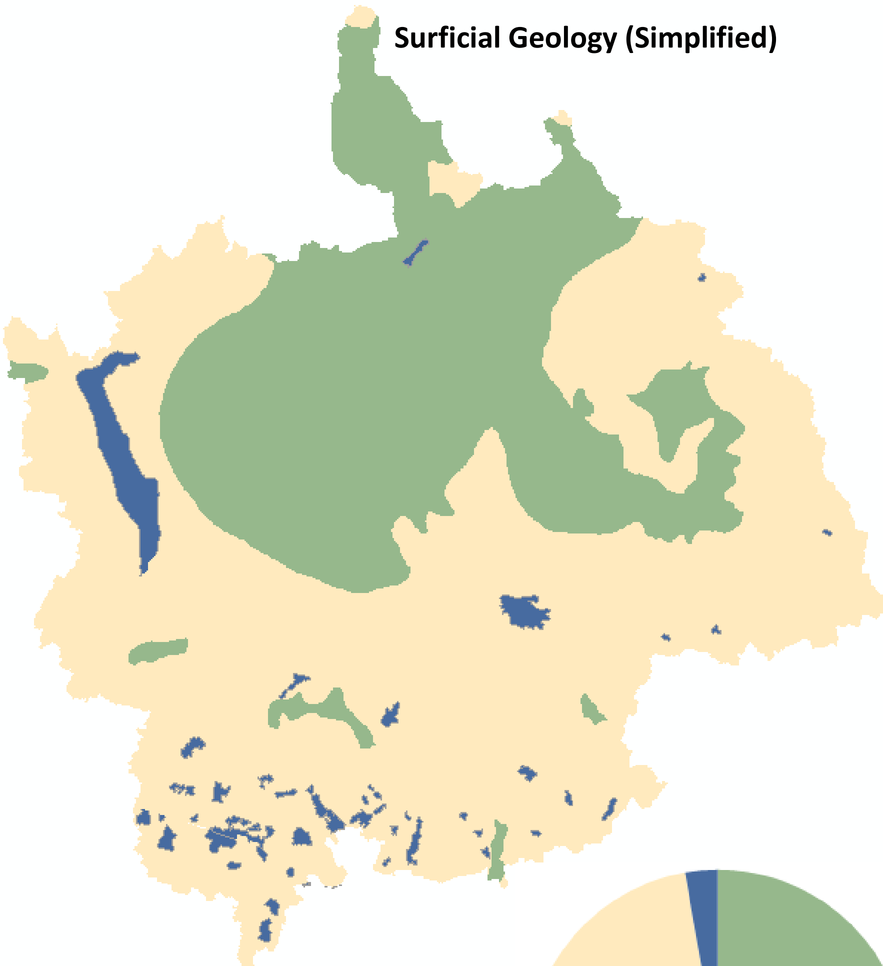
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	574.24	15.97%
End moraines of coarse-textured till	1219.55	33.92%
Fine-textured glacial till	20.72	0.58%
Glacial outwash sand and gravel and postglacial al	227.81	6.34%
Lacustrine clay and silt	1151.06	32.01%
Lacustrine sand and gravel	145.54	4.05%
Noncalcareous sandy loamy till	70.29	1.95%
Outwash sand and gravel	22.37	0.62%
Peat and muck	36.61	1.02%
Thin to discontinuous glacial till over bedrock	27.80	0.77%
Water	99.61	2.77%
Total Watershed Area	3595.60	100.00%

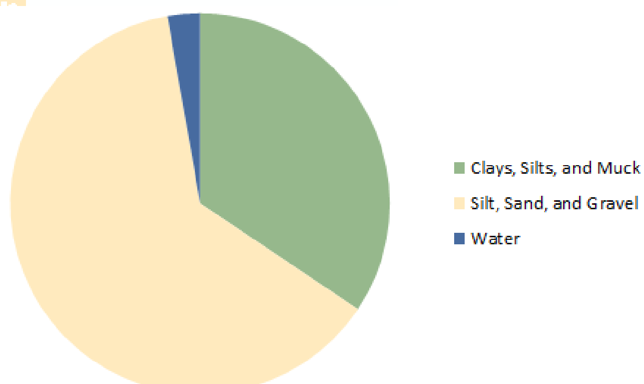


Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States and 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

53, ONTONAGON RIVER WATERSHED

Surficial Geology (Simplified)

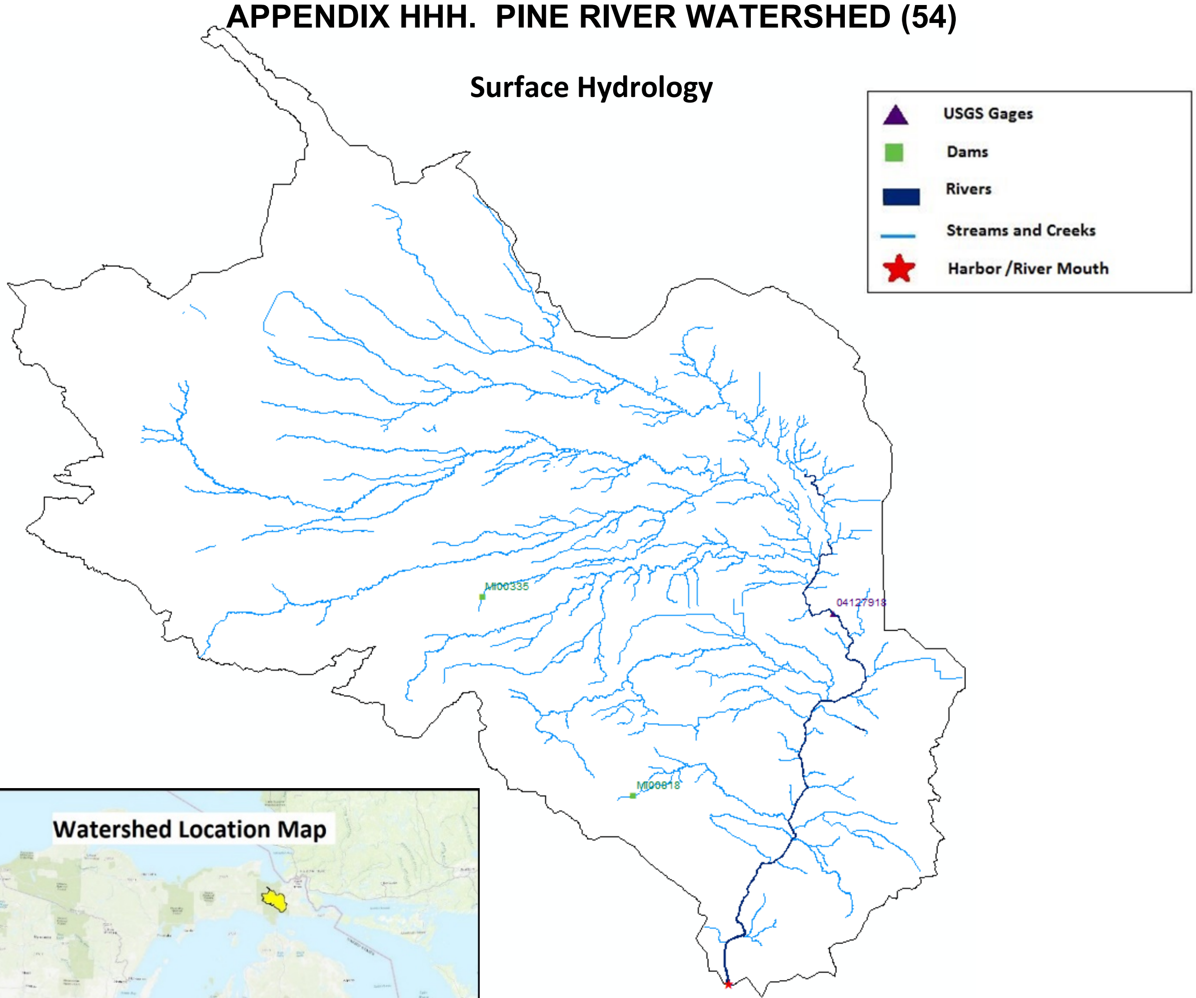


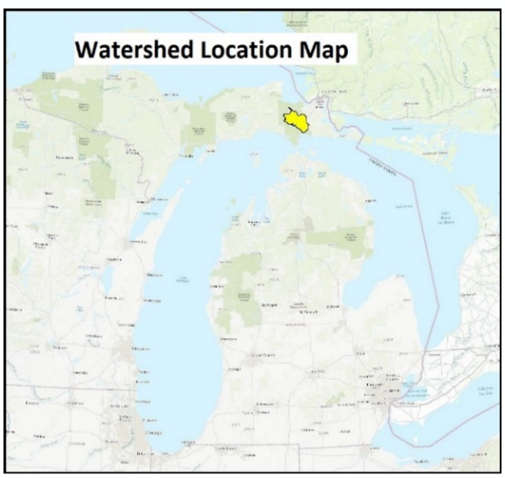


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	1236.20	34.38%
Silt, Sand, and Gravel	2259.80	62.85%
Water	99.61	2.77%
Total Watershed Area	3595.60	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States and 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX HHH. PINE RIVER WATERSHED (54)





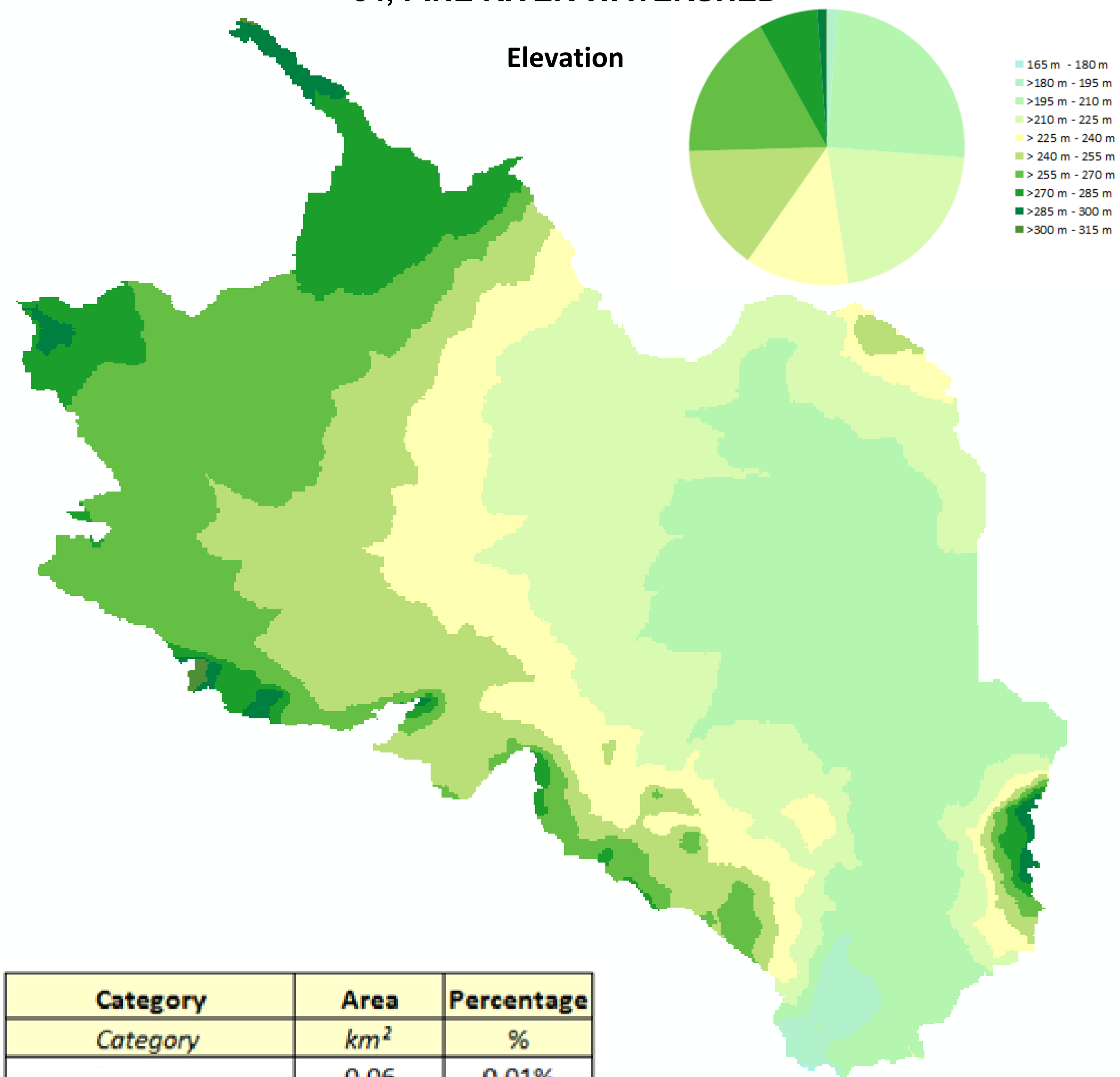
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00335	Trout Brook Pond Dam	-84.780690	46.194030
MI00818	Elmhirst Creek Dam	-84.703610	46.121110

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4127918	PINE RIVER NEAR RUDYARD, MI	-84.597826	46.185851	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

54, PINE RIVER WATERSHED

Elevation



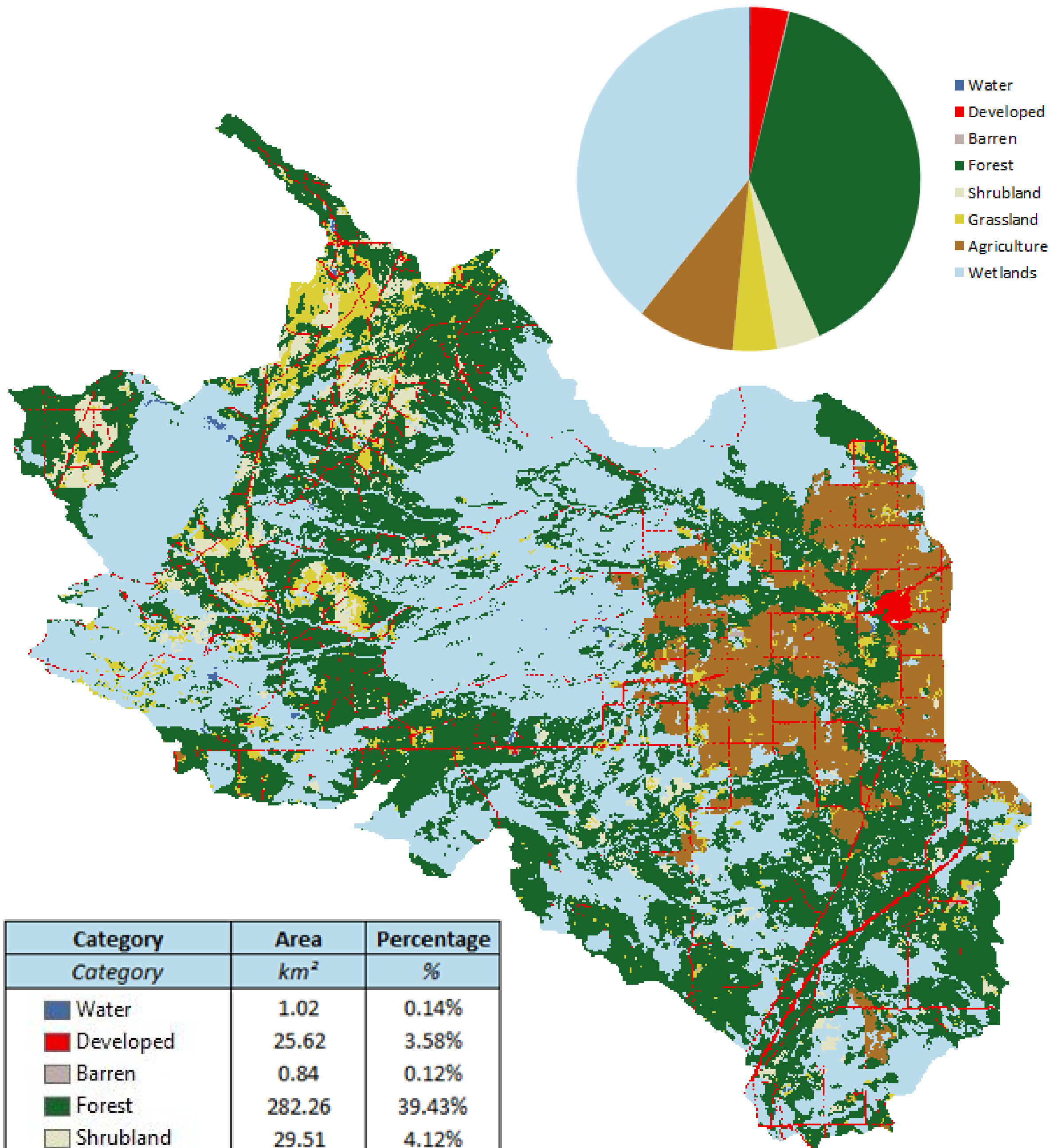
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	0.06	0.01%
>180 m - 195 m	8.81	1.23%
>195 m - 210 m	178.84	24.98%
>210 m - 225 m	152.18	21.26%
>225 m - 240 m	87.70	12.25%
>240 m - 255 m	106.11	14.82%
>255 m - 270 m	124.60	17.40%
>270 m - 285 m	49.37	6.90%
>285 m - 300 m	7.57	1.06%
>300 m - 315 m	0.65	0.09%
Size of Drainage Area	715.88	100.00%

Pine (U.P.) Watershed		
Elevation Statistics		
Size of Drainage Area	**715.88**	***km²***
Maximum	304.00	*m*
Minimum	178.00	*m*
Average	232.28	*m*
Standard Deviation	26.06	*m*

All Elevation Measurements with Respect to North American Datum 1983

54, PINE RIVER WATERSHED

Land Use



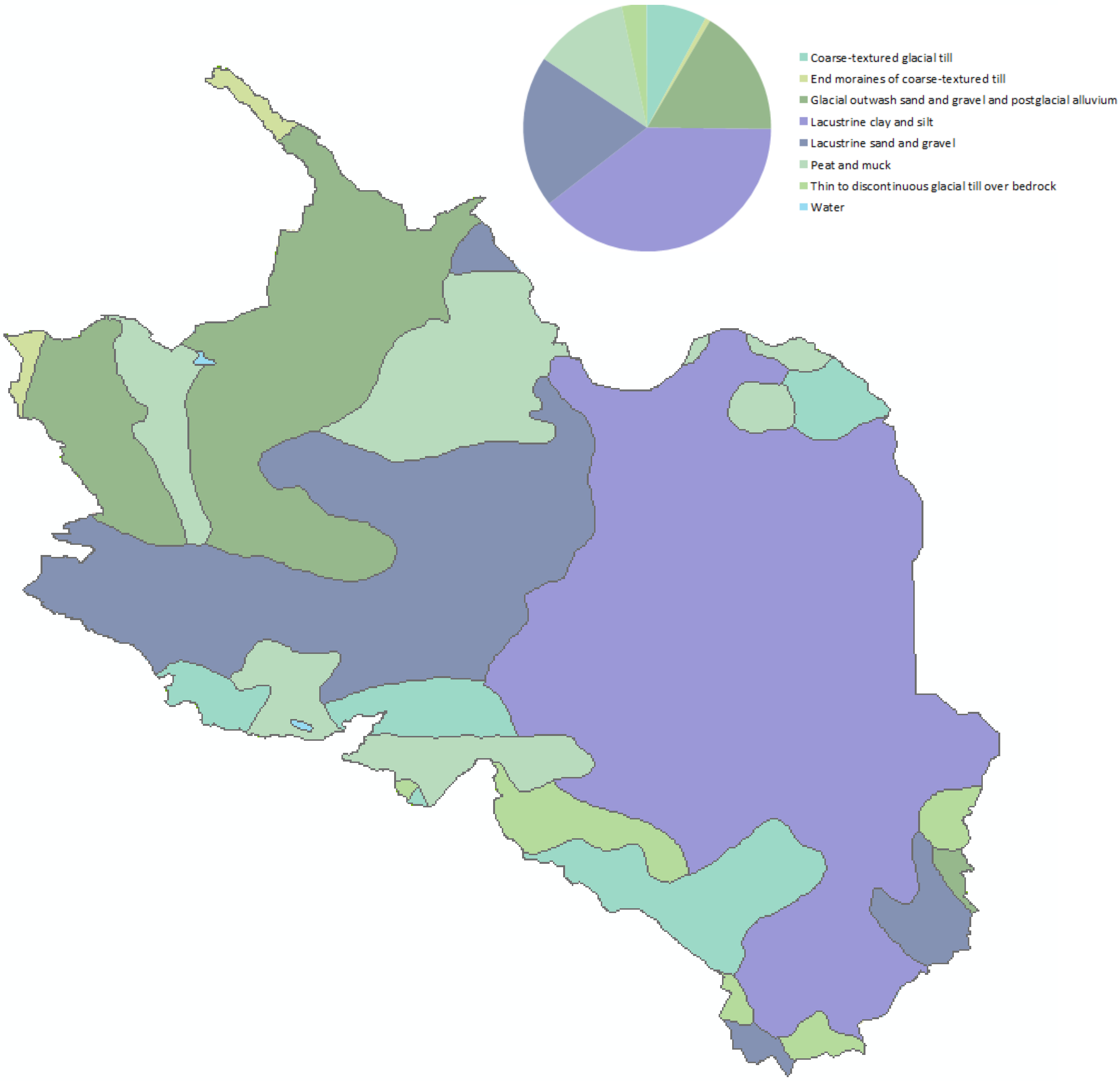
Category	Area	Percentage
Category	*km²*	*%*
Water	1.02	0.14%
Developed	25.62	3.58%
Barren	0.84	0.12%
Forest	282.26	39.43%
Shrubland	29.51	4.12%
Grassland	29.69	4.15%
Agriculture	65.88	9.20%
Wetlands	281.06	39.26%
Total	715.88	100.00%

EGLE Runoff Curve Number
71.1

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

54, PINE RIVER WATERSHED

Surficial Geology

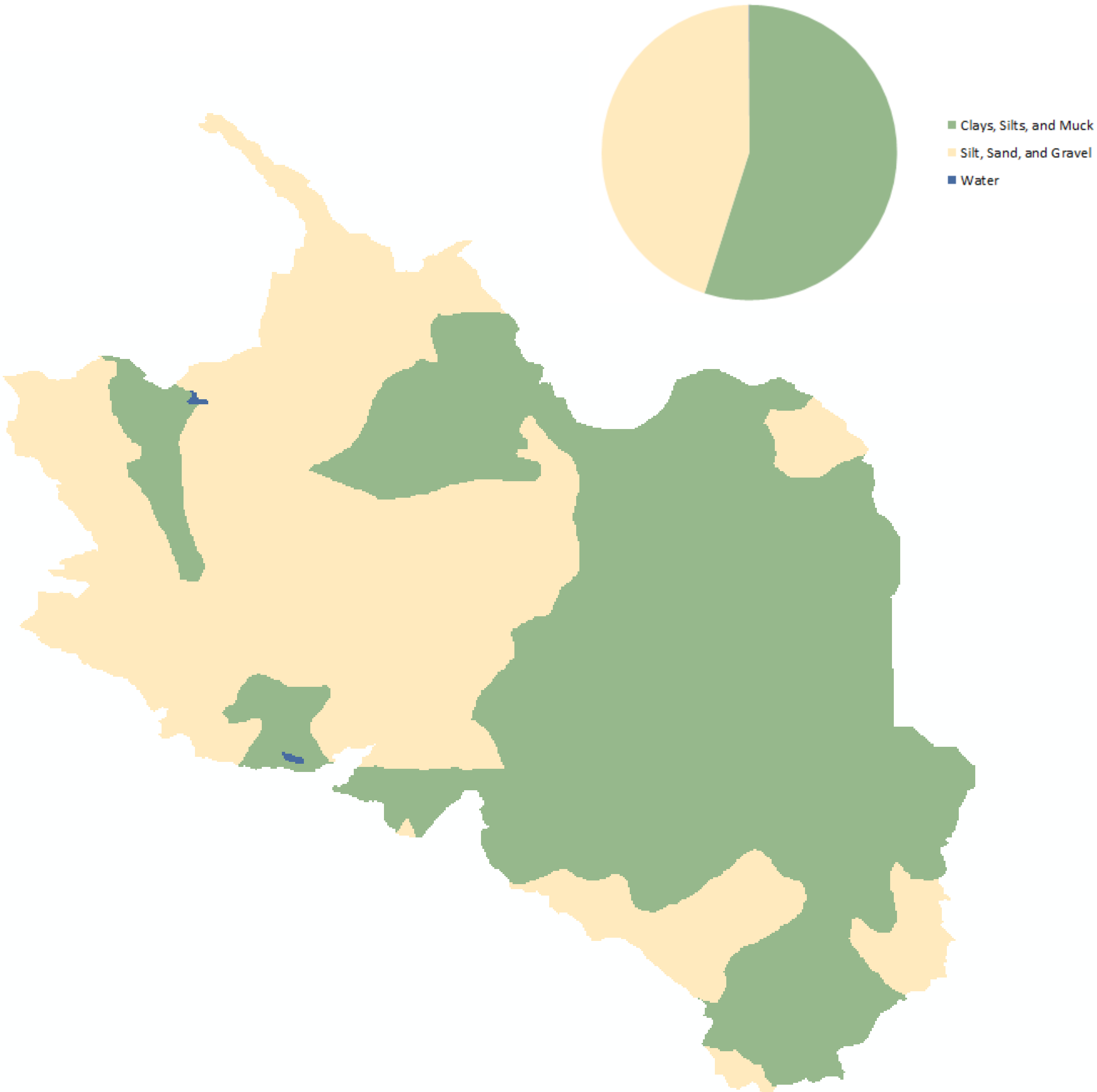


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	55.87	7.80%
End moraines of coarse-textured till	4.79	0.67%
Glacial outwash sand and gravel and postglacial alluvium	119.56	16.70%
Lacustrine clay and silt	281.62	39.34%
Lacustrine sand and gravel	142.13	19.85%
Peat and muck	88.29	12.33%
Thin to discontinuous glacial till over bedrock	23.16	3.23%
Water	0.46	0.06%
Total Watershed Area	715.88	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

54, PINE RIVER WATERSHED

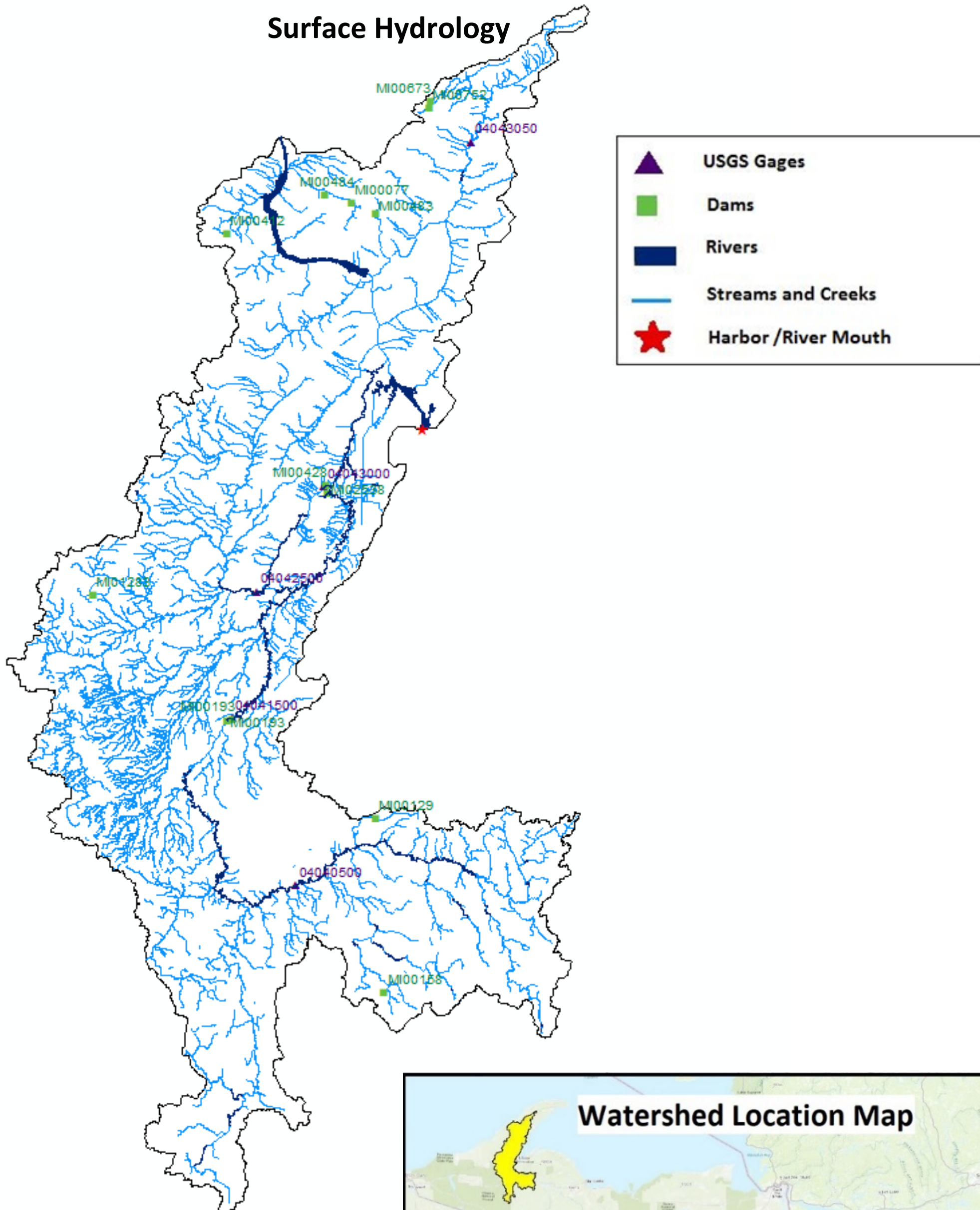
Surficial Geology (Simplified)

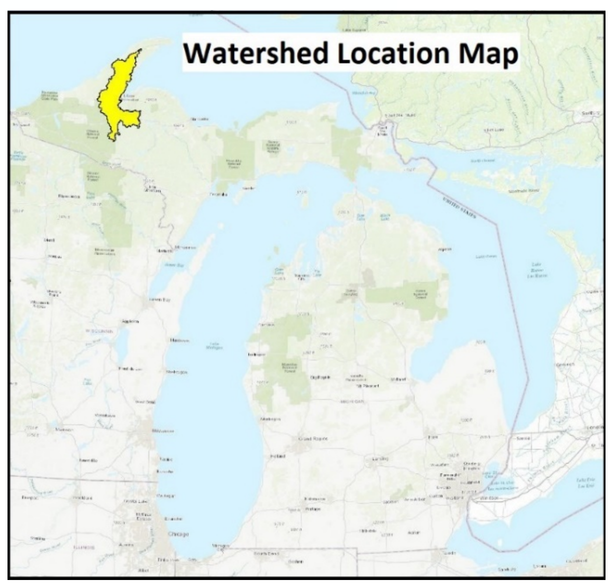


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	393.07	54.91%
Silt, Sand, and Gravel	322.36	45.03%
Water	0.46	0.06%
Total Watershed Area	715.88	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX III. PORTAGE RIVER WATERSHED (55)





55, PORTAGE RIVER WATERSHED

Dam Information and USGS Streamgages

USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00193	Prickett	-88.668300	46.724400
MI00193	Prickett Intake & Powerhouse	-88.662300	46.726000
MI01283	Pike Lake Dam	-88.841110	46.828940
MI00129	Ford Dam	-88.479110	46.644620
MI00158	Carp Intake Dam	-88.461130	46.494910
MI02538	Otter Lake Diversion Dam	-88.551670	46.923050
MI00412	Kissam Dam	-88.689100	47.143400
MI00428	Otter Lake Dam	-88.553610	46.929720
MI00483	Gooseneck Creek Dam	-88.503330	47.165000
MI00484	Vitton Dam	-88.566670	47.180000
MI00673	Homestake Copper Dam	-88.438330	47.263330
MI00752	Calumet Dam	-88.440000	47.256670
MI00077	Boston Pond Dam	-88.533330	47.173330

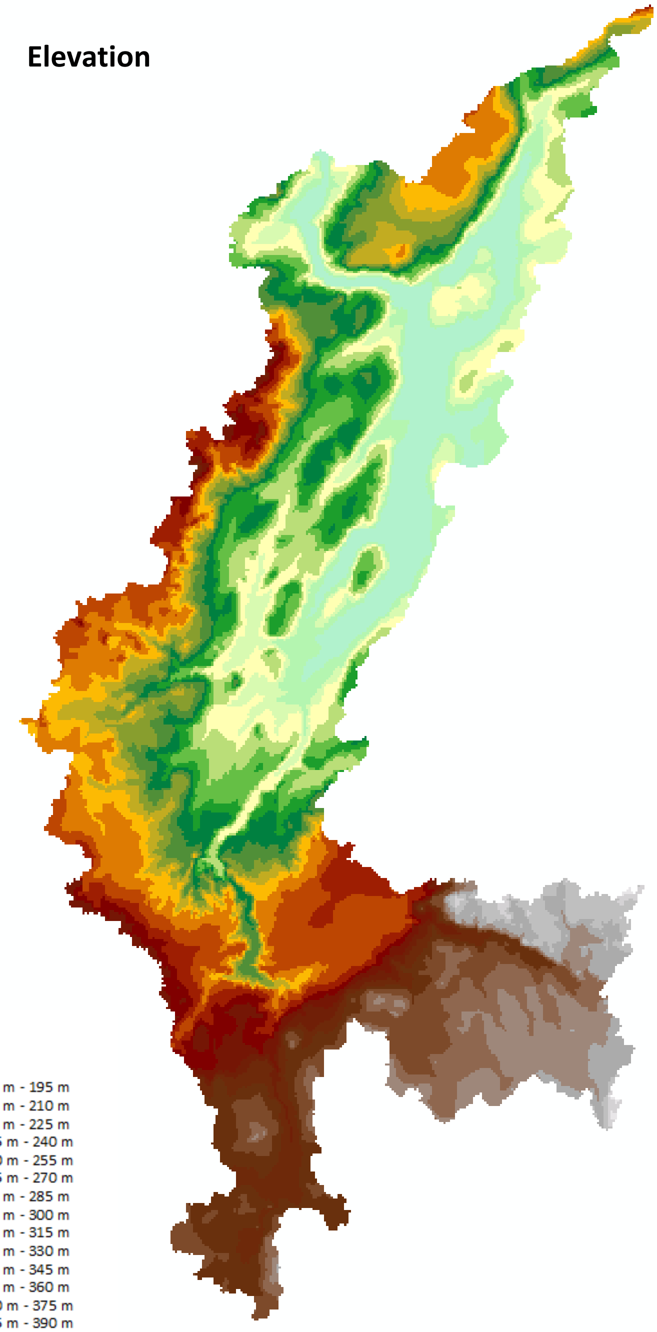
USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4040500	STURGEON RIVER NEAR SIDNAW, MI	-88.575970	46.584106	yes
4041500	STURGEON RIVER NEAR ALSTON, MI	-88.662079	46.726323	yes
4042500	OTTER RIVER NR ELO, MI	-88.636798	46.835765	
4043000	STURGEON RIVER NR ARNHEIM, MI	-88.556517	46.928263	
4043050	TRAP ROCK RIVER NEAR LAKE LINDEN, MI	-88.385393	47.228536	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				3

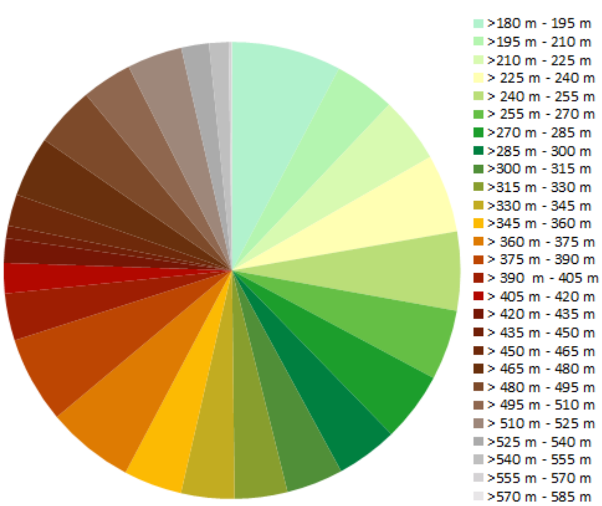
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

55, PORTAGE RIVER WATERSHED

Elevation

Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	199.14	7.75%
>195 m - 210 m	111.02	4.32%
>210 m - 225 m	119.34	4.64%
>225 m - 240 m	142.40	5.54%
>240 m - 255 m	143.25	5.58%
>255 m - 270 m	127.60	4.97%
>270 m - 285 m	126.18	4.91%
>285 m - 300 m	112.17	4.37%
>300 m - 315 m	103.08	4.01%
>315 m - 330 m	96.09	3.74%
>330 m - 345 m	96.81	3.77%
>345 m - 360 m	106.07	4.13%
>360 m - 375 m	159.10	6.19%
>375 m - 390 m	157.43	6.13%
>390 m - 405 m	85.68	3.33%
>405 m - 420 m	55.28	2.15%
>420 m - 435 m	44.38	1.73%
>435 m - 450 m	22.77	0.89%
>450 m - 465 m	57.65	2.24%
>465 m - 480 m	110.19	4.29%
>480 m - 495 m	110.25	4.29%
>495 m - 510 m	91.35	3.56%
>510 m - 525 m	100.15	3.90%
>525 m - 540 m	50.52	1.97%
>540 m - 555 m	35.34	1.38%
>555 m - 570 m	5.02	0.20%
>570 m - 585 m	1.05	0.04%
Size of Drainage Area	2569.30	100.00%



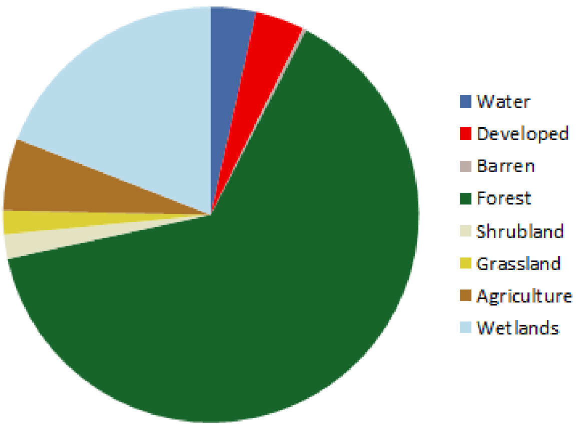


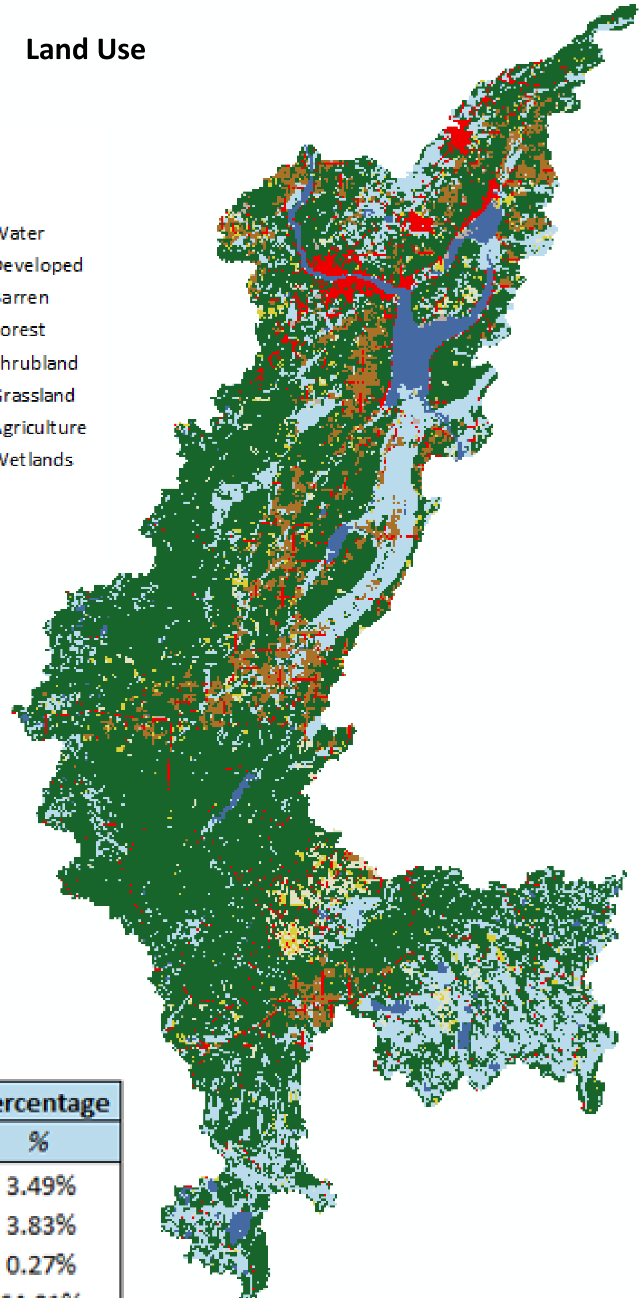
Portage Watershed		
Elevation Statistics		
Size of Drainage Area	2569.30	*km²*
Maximum	579.00	*m*
Minimum	183.00	*m*
Average	339.22	*m*
Standard Deviation	106.42	*m*

All Elevation Measurements with Respect to North American Datum 1983

55, PORTAGE RIVER WATERSHED

Land Use





Category	Area	Percentage
Category	*km²*	*%*
Water	89.67	3.49%
Developed	98.37	3.83%
Barren	6.95	0.27%
Forest	1644.53	64.01%
Shrubland	48.55	1.89%
Grassland	47.57	1.85%
Agriculture	144.11	5.61%
Wetlands	489.55	19.05%
Total	2569.30	100.00%

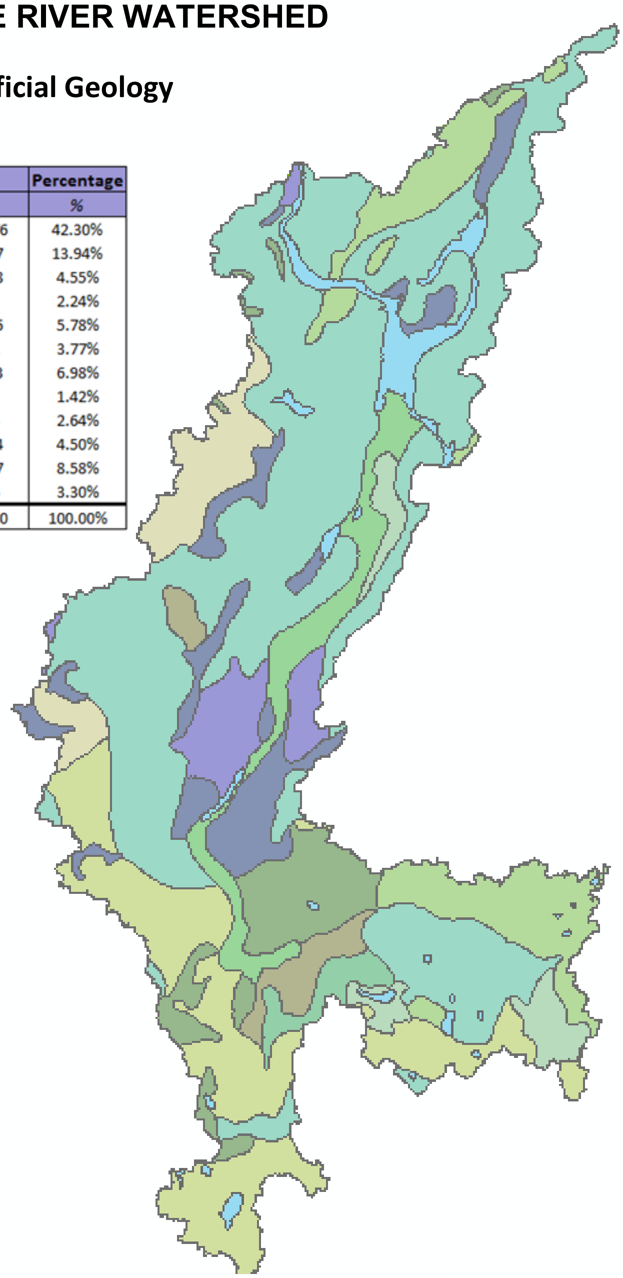
EGLE Runoff Curve Number
72.8

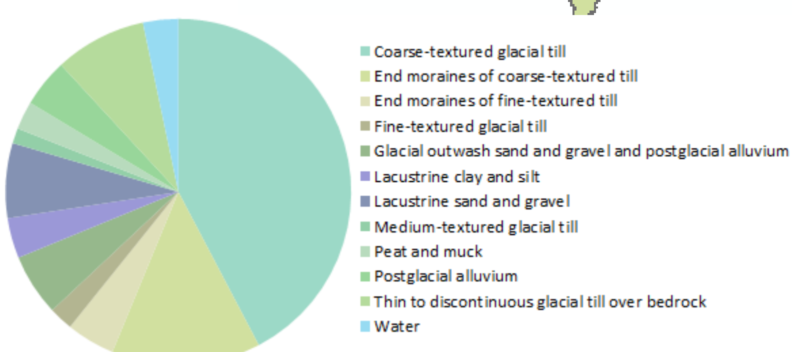
Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

55, PORTAGE RIVER WATERSHED

Surficial Geology

Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	1086.76	42.30%
End moraines of coarse-textured till	358.17	13.94%
End moraines of fine-textured till	116.88	4.55%
Fine-textured glacial till	57.53	2.24%
Glacial outwash sand and gravel and postglacial alluvium	148.46	5.78%
Lacustrine clay and silt	96.81	3.77%
Lacustrine sand and gravel	179.43	6.98%
Medium-textured glacial till	36.43	1.42%
Peat and muck	67.85	2.64%
Postglacial alluvium	115.64	4.50%
Thin to discontinuous glacial till over bedrock	220.47	8.58%
Water	84.86	3.30%
Total Watershed Area	2569.30	100.00%

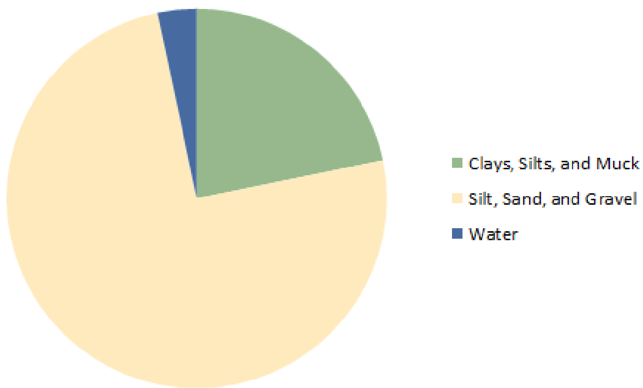


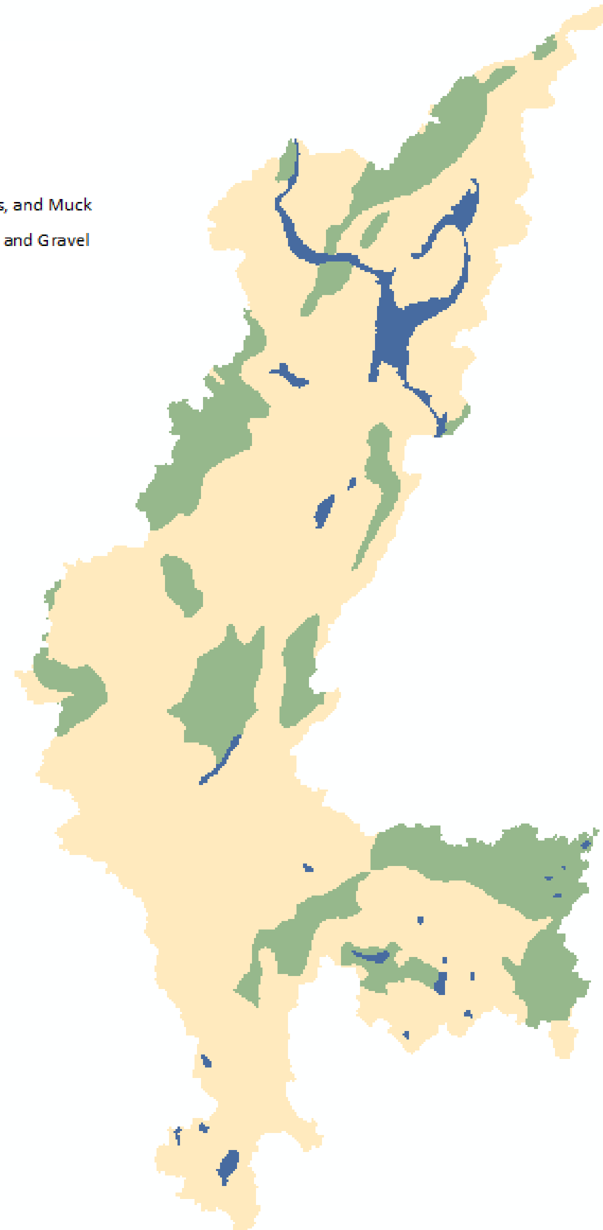


Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

55, PORTAGE RIVER WATERSHED

Surficial Geology (Simplified)



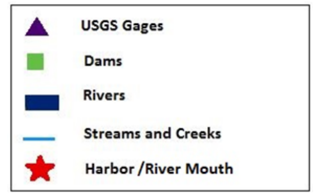


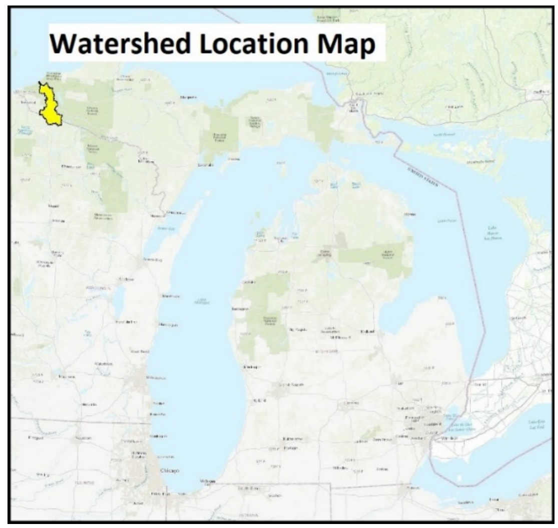
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	559.54	21.78%
Silt, Sand, and Gravel	1924.90	74.92%
Water	84.86	3.30%
Total Watershed Area	2569.30	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX JJJ. PRESQUE ISLE RIVER WATERSHED (56)

Surface Hydrology



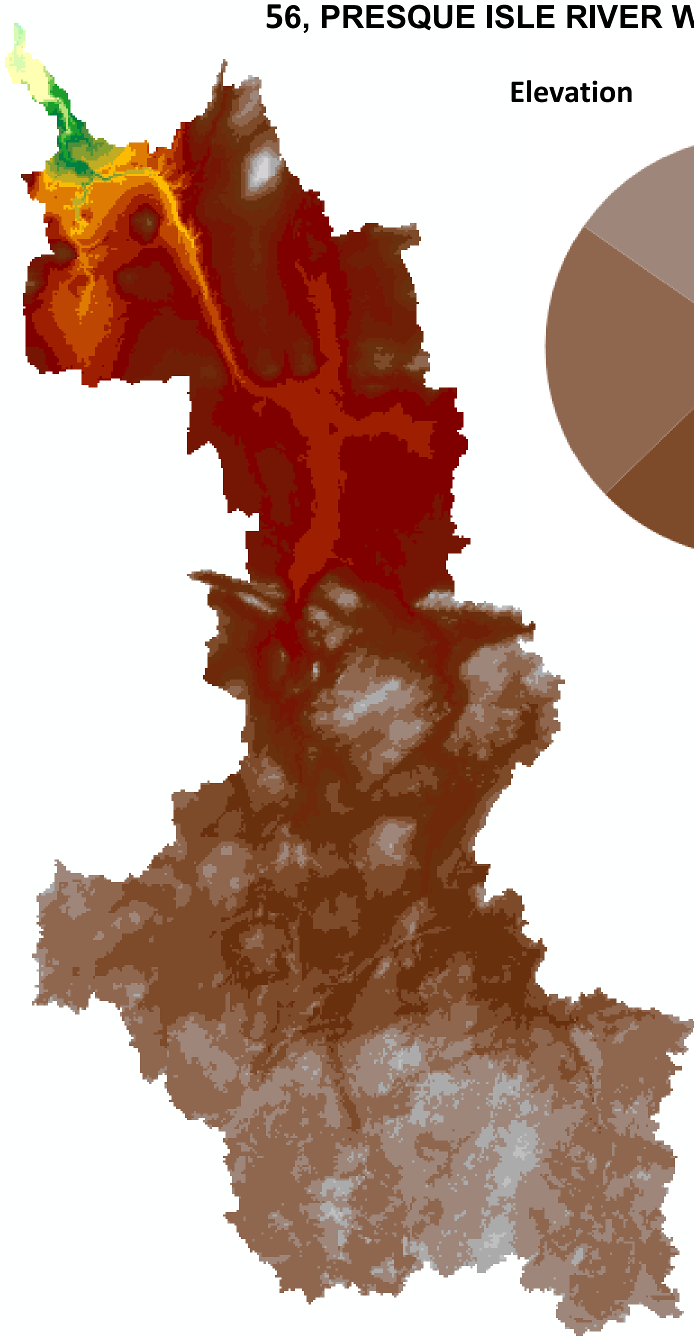


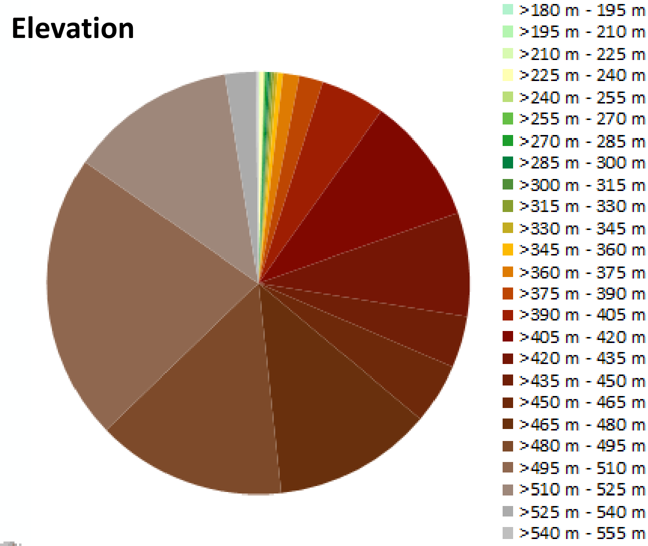
USACE's National Inventory of Dams (NID)			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
WI00433	MCFADYEN	-89.927360	46.295670
MI00192	Presque Isle Wildlife Dam	-89.728330	46.345000

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4031500	PRESQUE ISLE RIVER AT MARENISCO, MI	-89.692379	46.372170	
4032000	PRESQUE ISLE RIVER NEAR TULA, MI	-89.777385	46.546892	
Number of Active USGS Stream Gage's in Drainage Area (2009)				0

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

56, PRESQUE ISLE RIVER WATERSHED





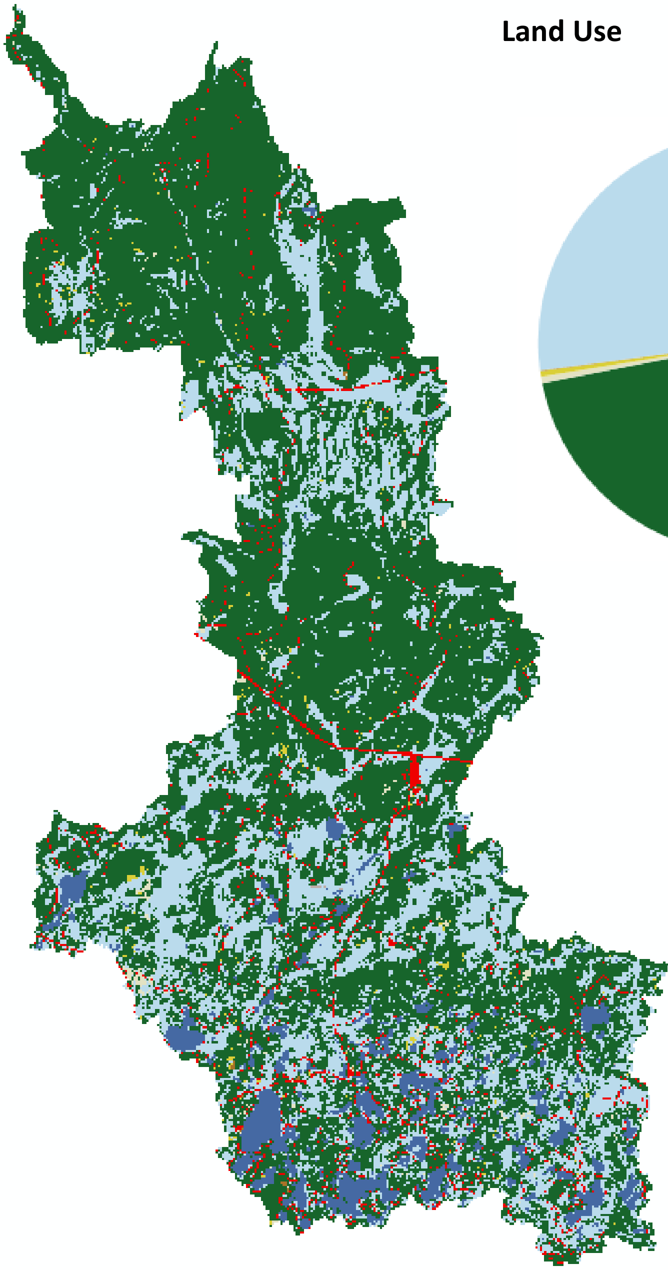
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	0.05	0.01%
>195 m - 210 m	0.08	0.01%
>210 m - 225 m	1.08	0.11%
>225 m - 240 m	2.48	0.26%
>240 m - 255 m	0.54	0.06%
>255 m - 270 m	0.60	0.06%
>270 m - 285 m	1.47	0.16%
>285 m - 300 m	1.52	0.16%
>300 m - 315 m	1.45	0.15%
>315 m - 330 m	1.86	0.20%
>330 m - 345 m	2.56	0.27%
>345 m - 360 m	3.93	0.42%
>360 m - 375 m	11.82	1.25%
>375 m - 390 m	17.20	1.82%
>390 m - 405 m	46.30	4.91%
>405 m - 420 m	91.89	9.75%
>420 m - 435 m	74.63	7.92%
>435 m - 450 m	37.38	3.97%
>450 m - 465 m	43.39	4.60%
>465 m - 480 m	114.73	12.17%
>480 m - 495 m	136.58	14.49%
>495 m - 510 m	206.85	21.95%
>510 m - 525 m	120.18	12.75%
>525 m - 540 m	21.92	2.33%
>540 m - 555 m	1.53	0.16%
>555 m - 570 m	0.40	0.04%
Size of Drainage Area	942.42	100.00%

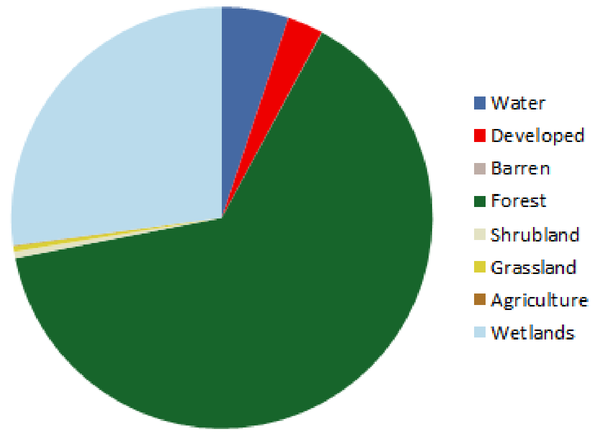
Presque Isle Watershed		
Elevation Statistics		
Size of Drainage Area	**942.42**	***km²***
Maximum	570.29	*m*
Minimum	183.94	*m*
Average	468.15	*m*
Standard Deviation	47.69	*m*

All Elevation Measurements with Respect to North American Datum 1983

56, PRESQUE ISLE RIVER WATERSHED

Land Use



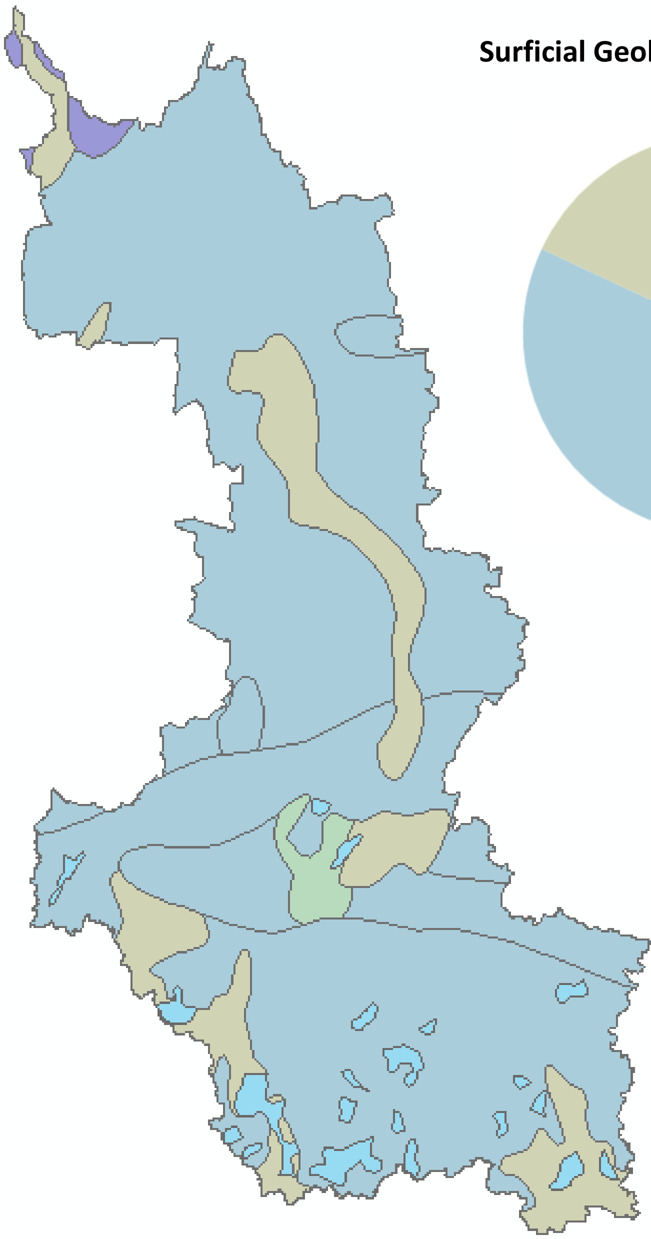


Category	Area	Percentage
Category	*km²*	*%*
Water	48.35	5.13%
Developed	25.83	2.74%
Barren	0.30	0.03%
Forest	603.38	64.02%
Shrubland	4.76	0.51%
Grassland	3.99	0.42%
Agriculture	0.43	0.05%
Wetlands	255.39	27.10%
Total	942.42	100.00%

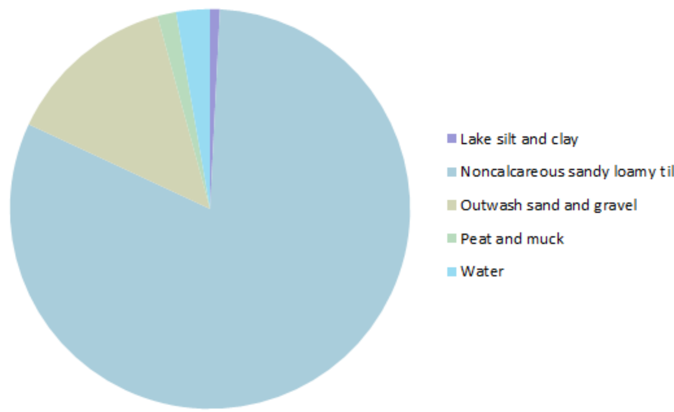
EGLE Runoff Curve Number
76.0

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

56, PRESQUE ISLE RIVER WATERSHED



Surficial Geology

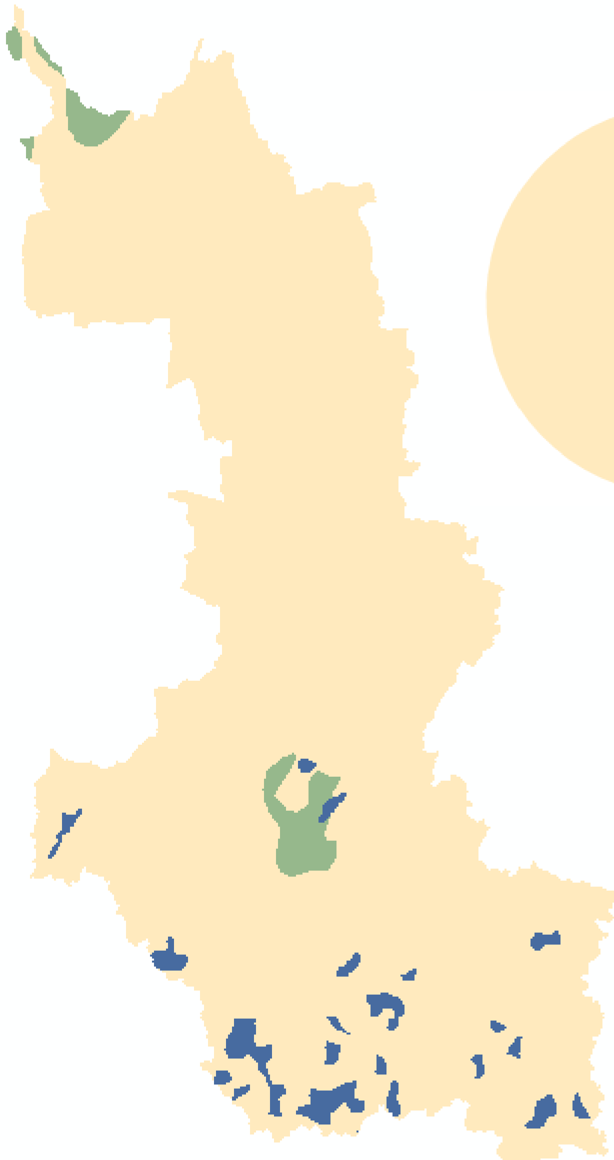


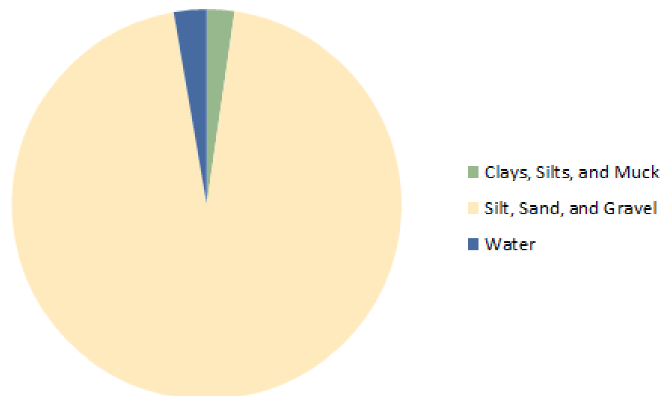
Category	Area	Percentage
Category	*km²*	*%*
Lake silt and clay	7.47	0.79%
Noncalcareous sandy loamy till	764.87	81.16%
Outwash sand and gravel	130.20	13.82%
Peat and muck	14.19	1.51%
Water	25.69	2.73%
Total Watershed Area	942.42	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

56, PRESQUE ISLE RIVER WATERSHED

Surficial Geology (Simplified)



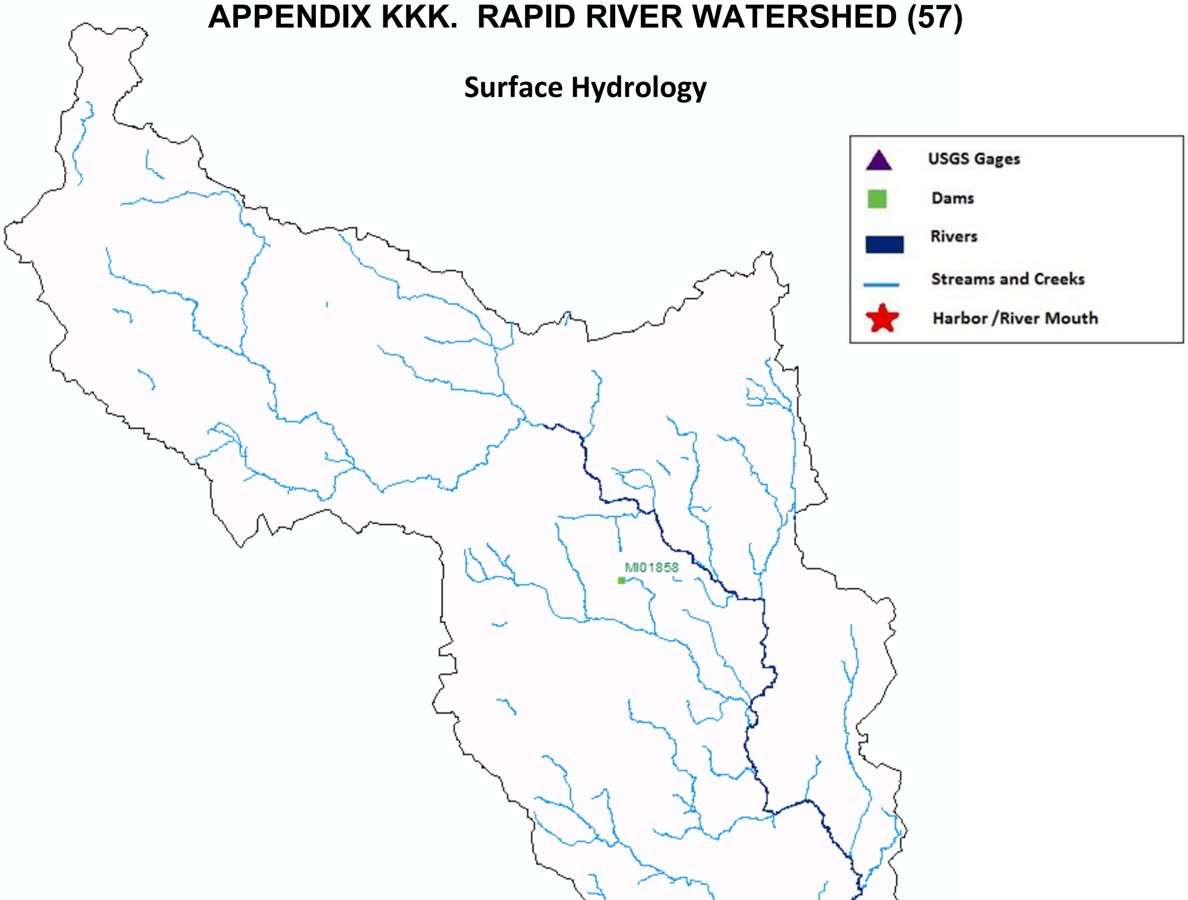


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	21.66	2.30%
Silt, Sand, and Gravel	895.08	94.98%
Water	25.69	2.73%
Total Watershed Area	942.42	100.00%

Data Obtained from United States Geological Survey Surficial Geology Map of the Conterminous United States

APPENDIX KKK. RAPID RIVER WATERSHED (57)

Surface Hydrology

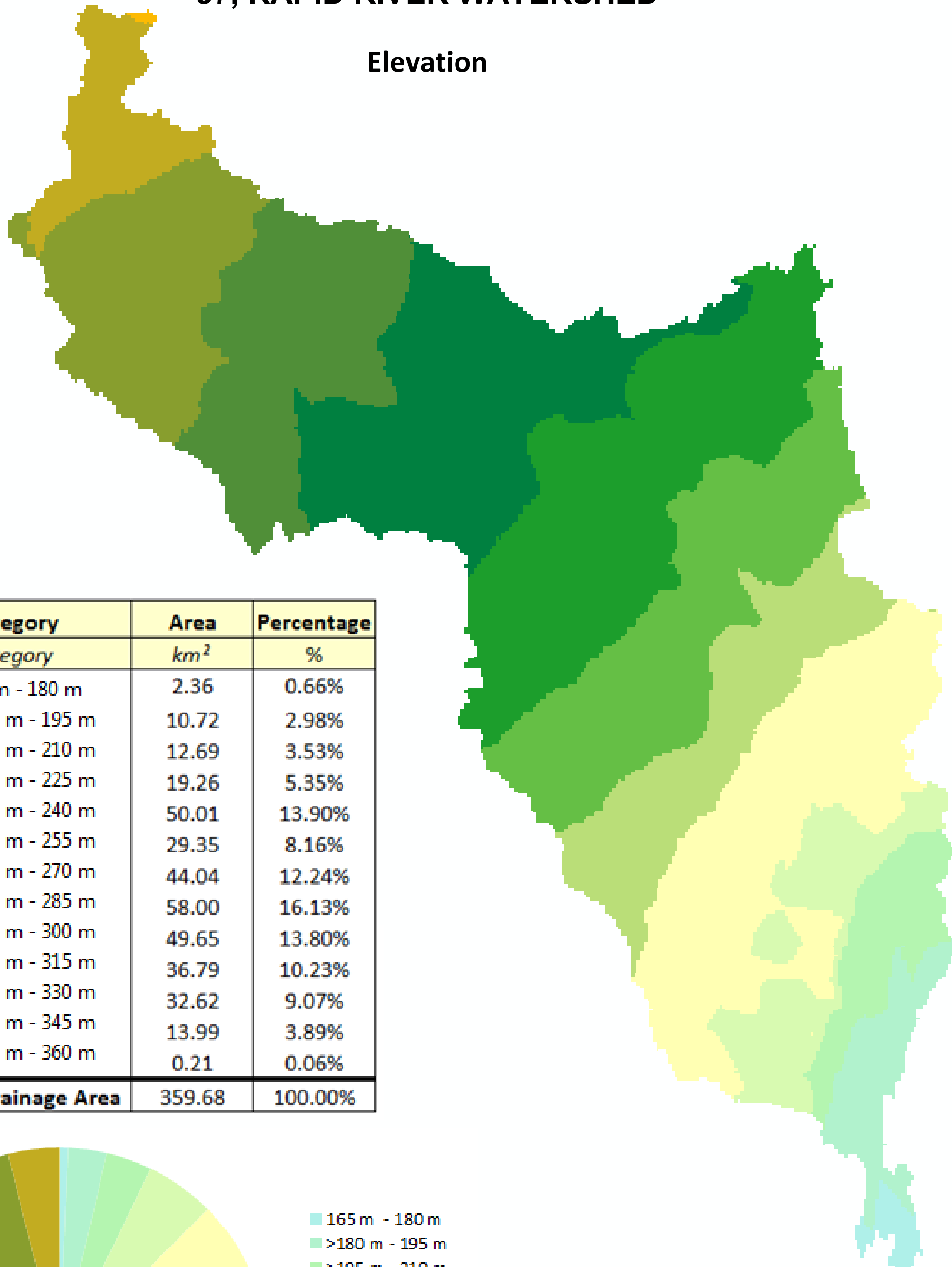


USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI01858	Friday Flooding	-87.047230	46.082220

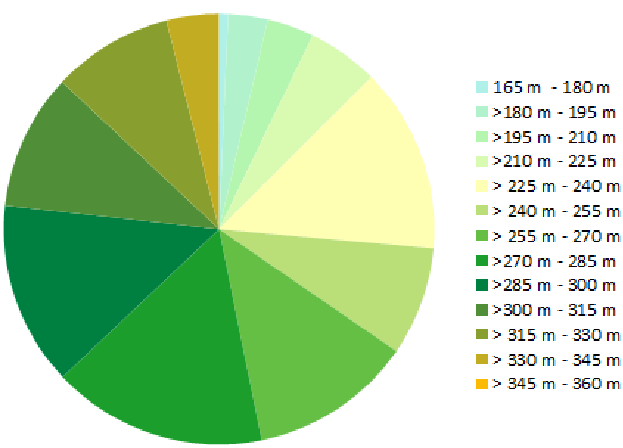
Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

57, RAPID RIVER WATERSHED

Elevation



Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	2.36	0.66%
>180 m - 195 m	10.72	2.98%
>195 m - 210 m	12.69	3.53%
>210 m - 225 m	19.26	5.35%
>225 m - 240 m	50.01	13.90%
>240 m - 255 m	29.35	8.16%
>255 m - 270 m	44.04	12.24%
>270 m - 285 m	58.00	16.13%
>285 m - 300 m	49.65	13.80%
>300 m - 315 m	36.79	10.23%
>315 m - 330 m	32.62	9.07%
>330 m - 345 m	13.99	3.89%
>345 m - 360 m	0.21	0.06%
Size of Drainage Area	359.68	100.00%

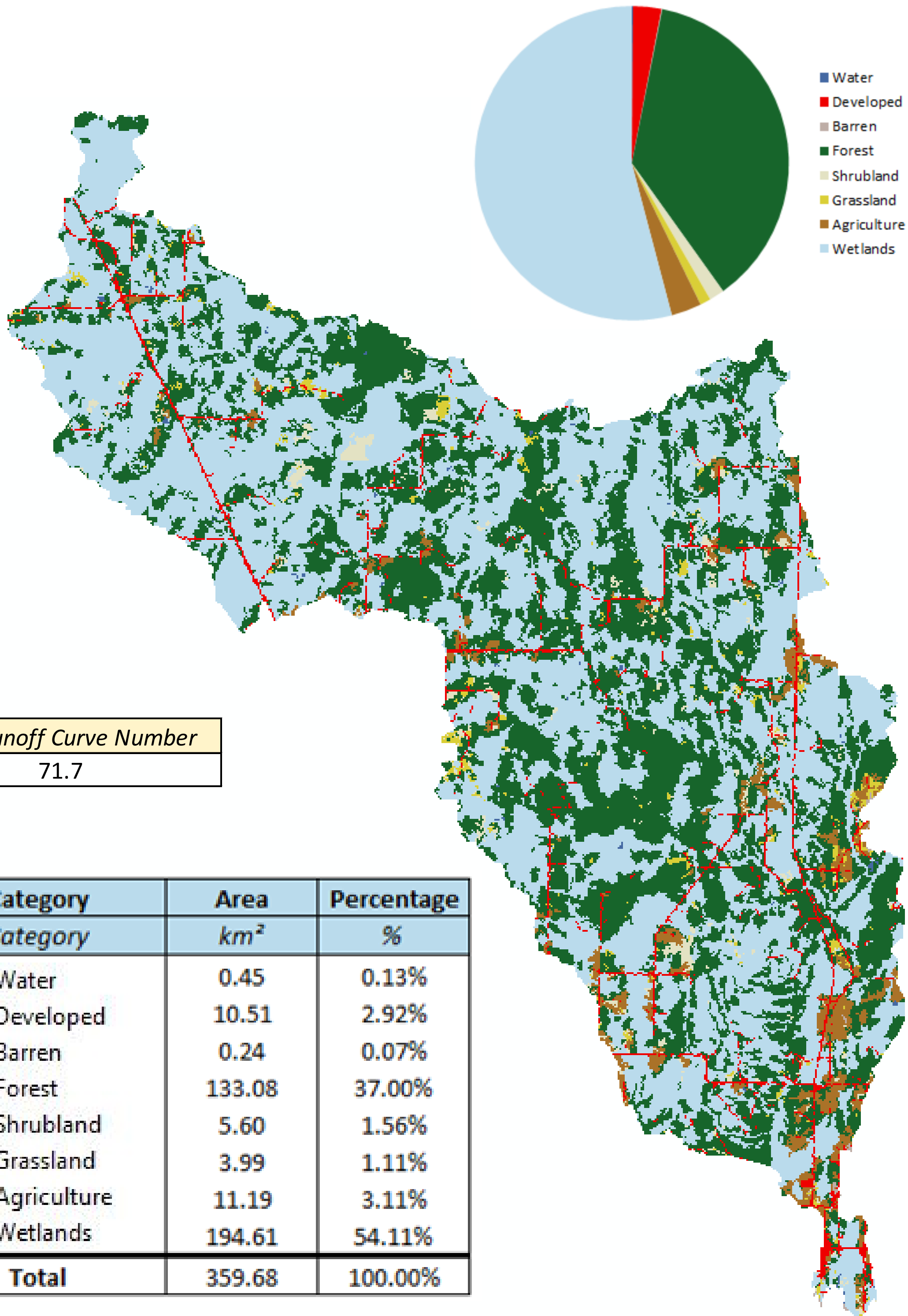


Rapid Watershed		
Elevation Statistics		
Size of Drainage Area	359.68	*km²*
Maximum	350.00	*m*
Minimum	176.00	*m*
Average	269.69	*m*
Standard Deviation	38.44	*m*

All Elevation Measurements with Respect to North American Datum 1983

57, RAPID RIVER WATERSHED

Land Use



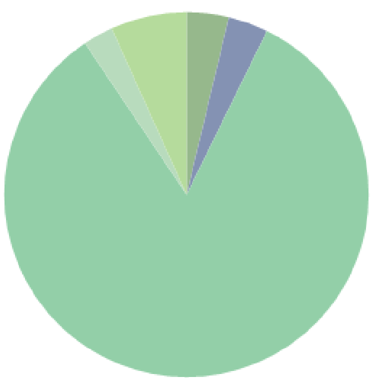
EGLE Runoff Curve Number
71.7

Category	Area	Percentage
Category	*km²*	*%*
Water	0.45	0.13%
Developed	10.51	2.92%
Barren	0.24	0.07%
Forest	133.08	37.00%
Shrubland	5.60	1.56%
Grassland	3.99	1.11%
Agriculture	11.19	3.11%
Wetlands	194.61	54.11%
Total	359.68	100.00%

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

57, RAPID RIVER WATERSHED

Surficial Geology

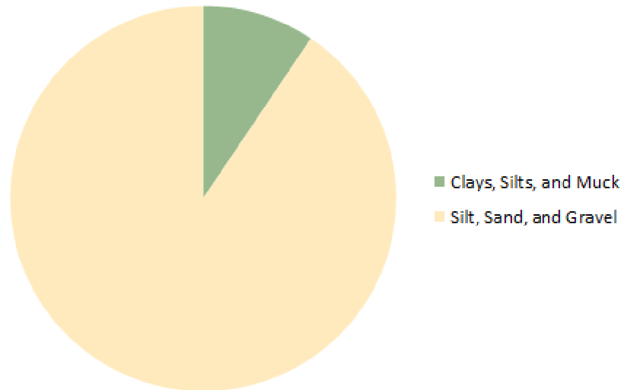


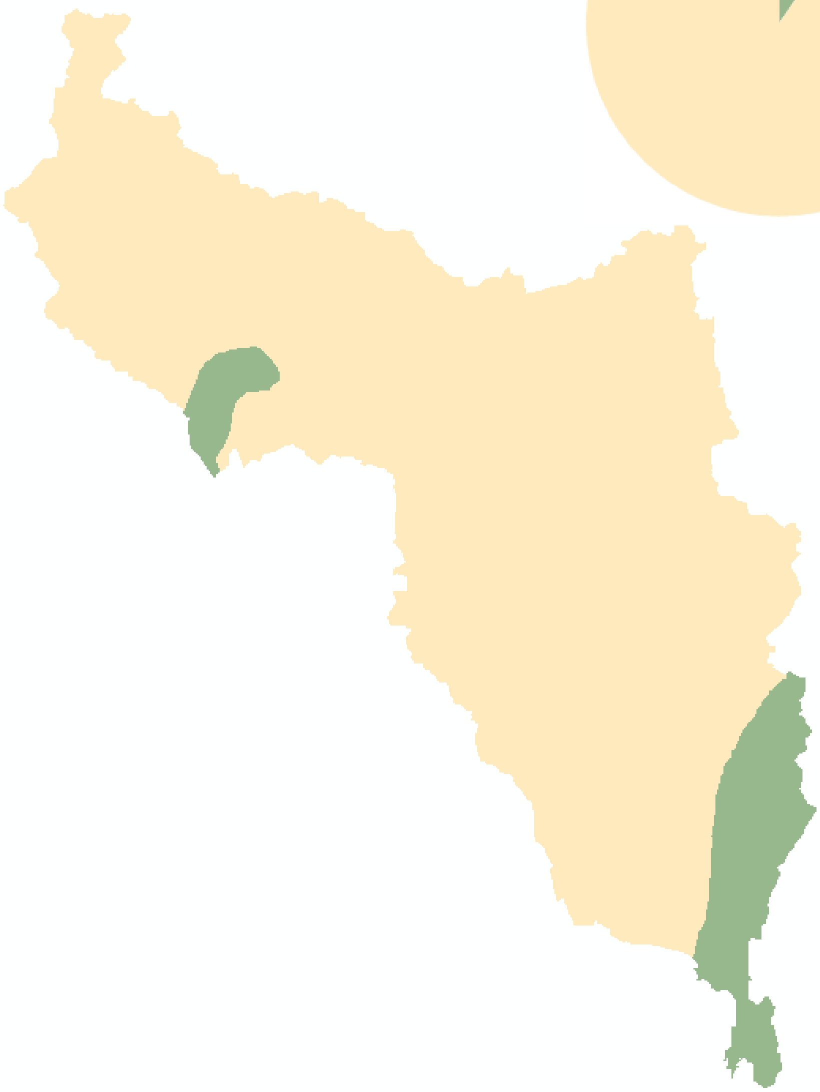
Category	Area	Percentage
Category	*km²*	*%*
Glacial outwash sand and gravel and postglacial alluvium	13.40	3.73%
Lacustrine sand and gravel	12.74	3.54%
Medium-textured glacial till	299.66	83.31%
Peat and muck	9.61	2.67%
Thin to discontinuous glacial till over bedrock	24.26	6.74%
Total Watershed Area	359.68	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

57, RAPID RIVER WATERSHED

Surficial Geology (Simplified)



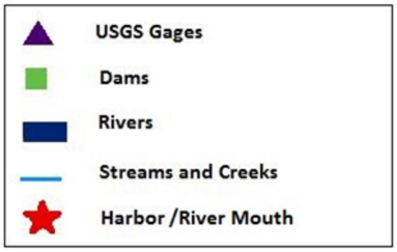


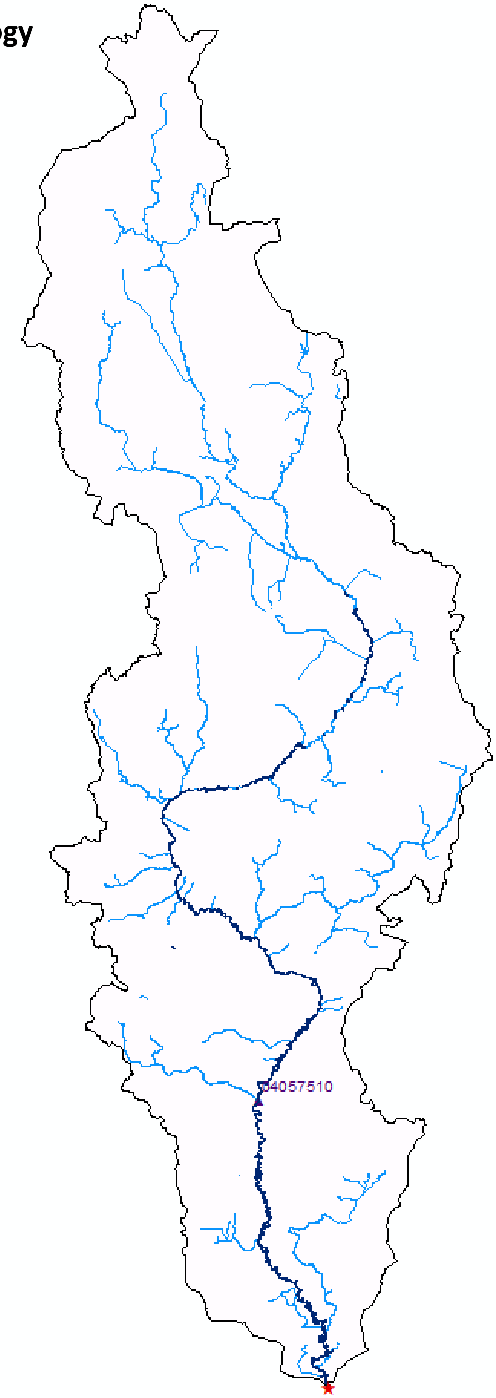
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	33.87	9.42%
Silt, Sand, and Gravel	325.81	90.58%
Total Watershed Area	359.68	100.00%

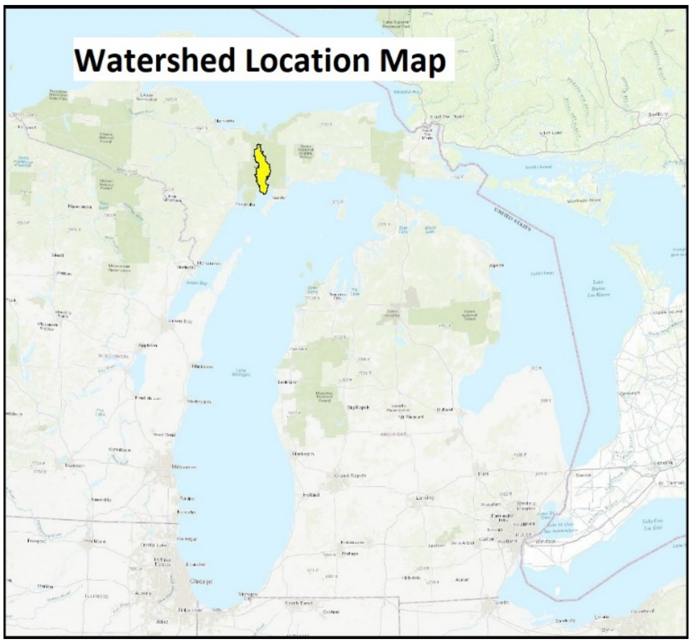
Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX LLL. STURGEON RIVER WATERSHED (58)

Surface Hydrology



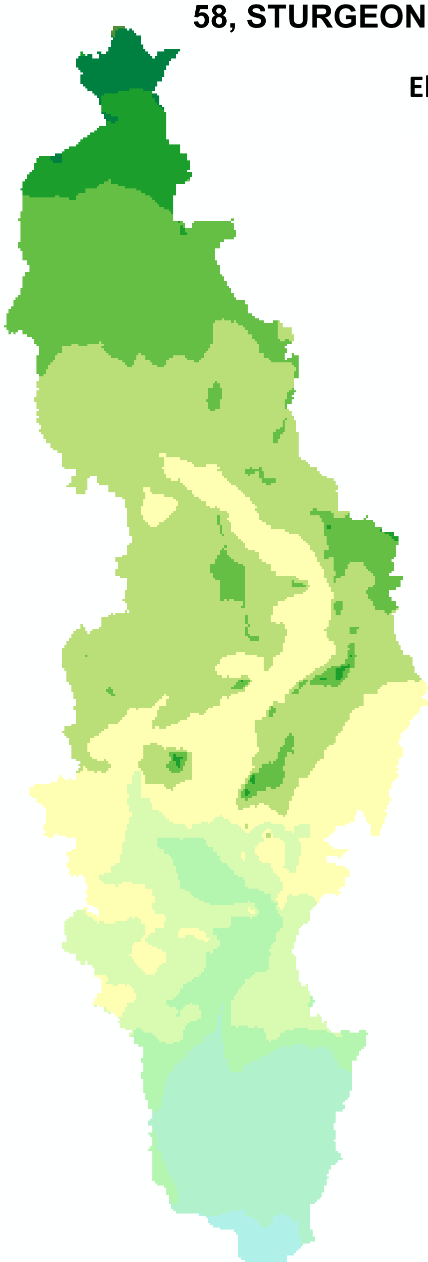




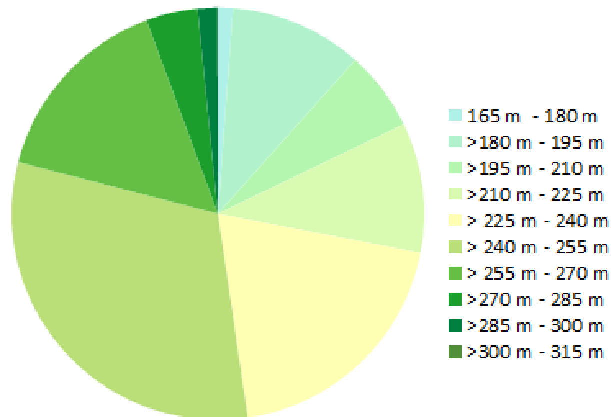
USGS Stream Gage's				
STA ID	***Station Name***	***Longitude***	***Latitude***	***Active***
4057510	STURGEON RIVER NEAR NAHMA JUNCTION, MI	-86.705700	45.943024	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

58, STURGEON RIVER WATERSHED



Elevation



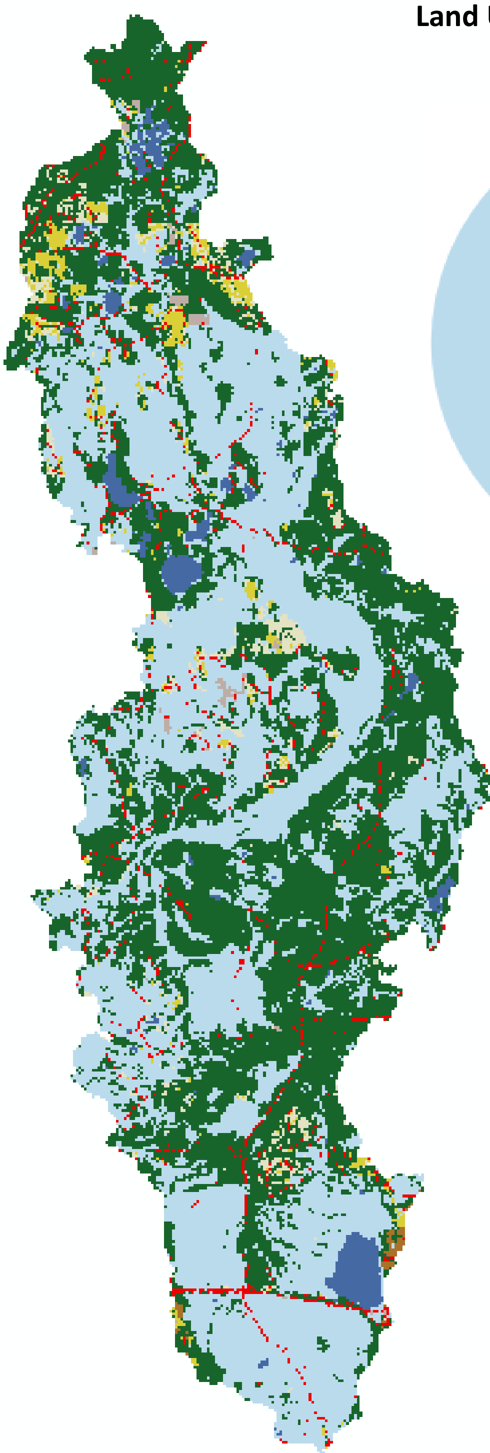
Category	Area	Percentage
Category	*km²*	*%*
165 m - 180 m	6.62	1.17%
>180 m - 195 m	59.22	10.43%
>195 m - 210 m	35.52	6.26%
>210 m - 225 m	57.78	10.18%
>225 m - 240 m	111.63	19.66%
>240 m - 255 m	177.93	31.34%
>255 m - 270 m	87.12	15.34%
>270 m - 285 m	23.01	4.05%
>285 m - 300 m	8.81	1.55%
>300 m - 315 m	0.14	0.02%
Size of Drainage Area	567.79	100.00%

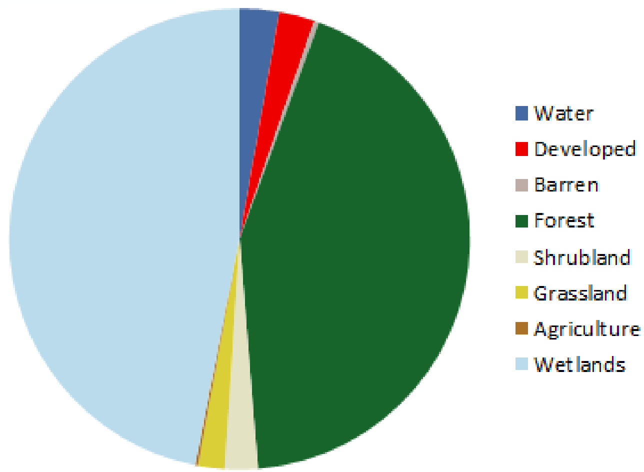
Sturgeon Watershed		
Elevation Statistics		
Size of Drainage Area	**567.79**	***km²***
Maximum	304.00	*m*
Minimum	176.00	*m*
Average	234.56	*m*
Standard Deviation	25.28	*m*

All Elevation Measurements with Respect to North American Datum 1983

58, STURGEON RIVER WATERSHED

Land Use



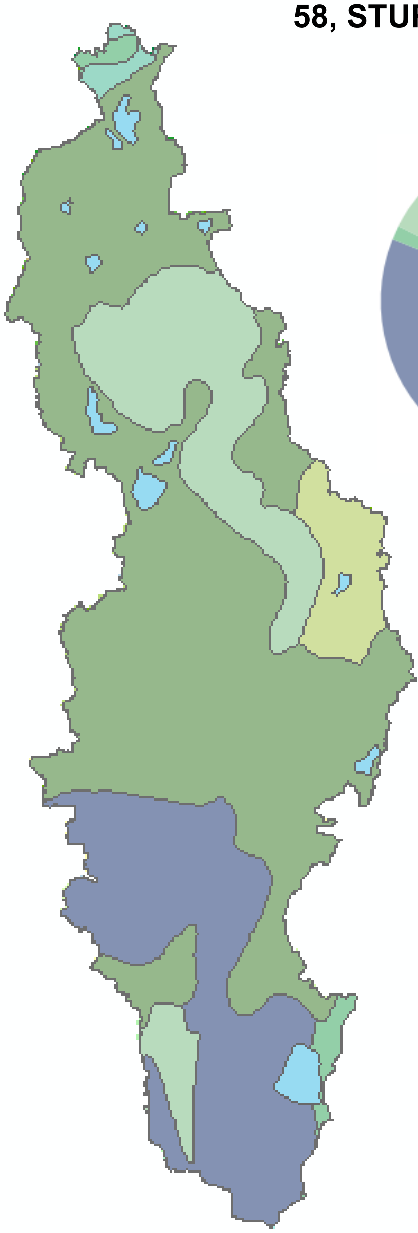


Category	Area	Percentage
Category	*km²*	*%*
Water	15.74	2.77%
Developed	14.12	2.49%
Barren	1.94	0.34%
Forest	244.86	43.12%
Shrubland	12.98	2.29%
Grassland	10.69	1.88%
Agriculture	1.07	0.19%
Wetlands	266.40	46.92%
Total	567.79	100.00%

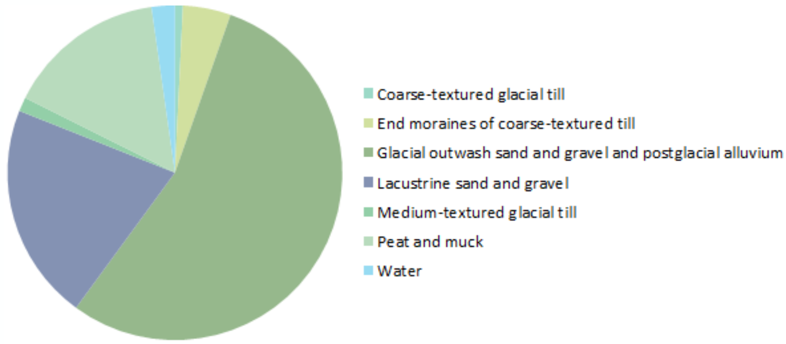
EGLE Runoff Curve Number
63.4

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

58, STURGEON RIVER WATERSHED



Surficial Geology

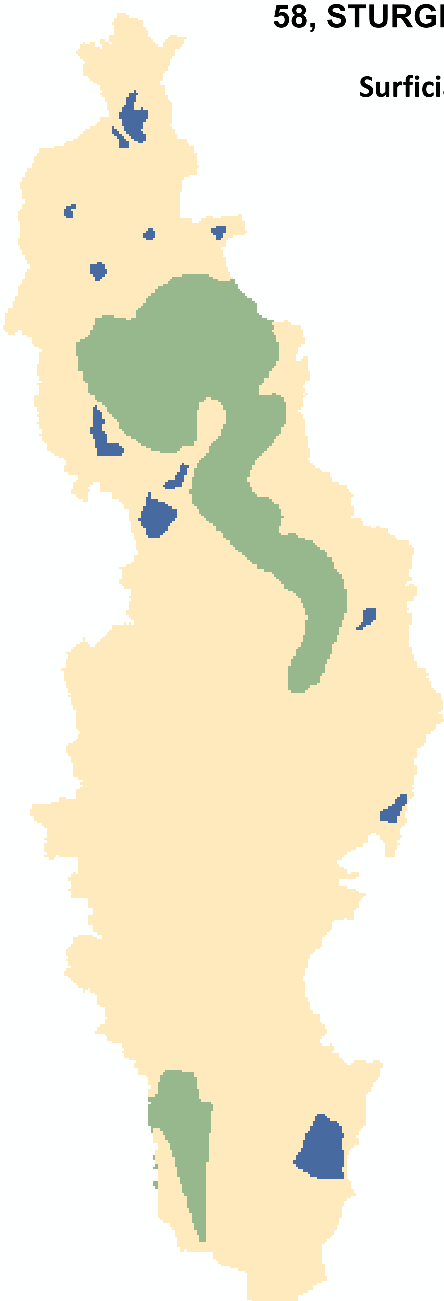


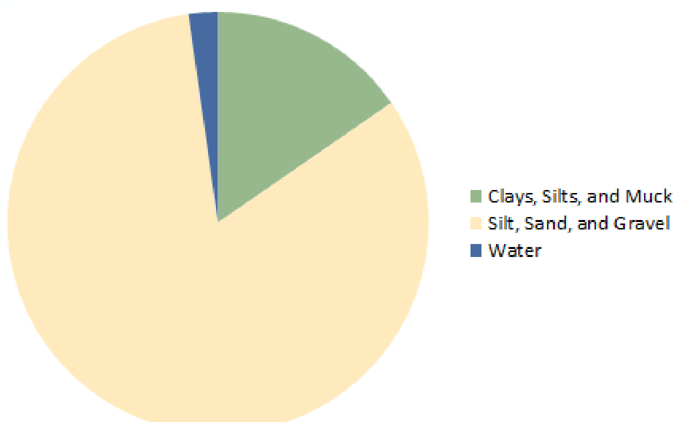
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	4.37	0.77%
End moraines of coarse-textured till	26.30	4.63%
Glacial outwash sand and gravel and postglacial alluvium	310.31	54.65%
Lacustrine sand and gravel	119.06	20.97%
Medium-textured glacial till	7.66	1.35%
Peat and muck	87.34	15.38%
Water	12.75	2.25%
Total Watershed Area	567.79	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

58, STURGEON RIVER WATERSHED

Surficial Geology (Simplified)

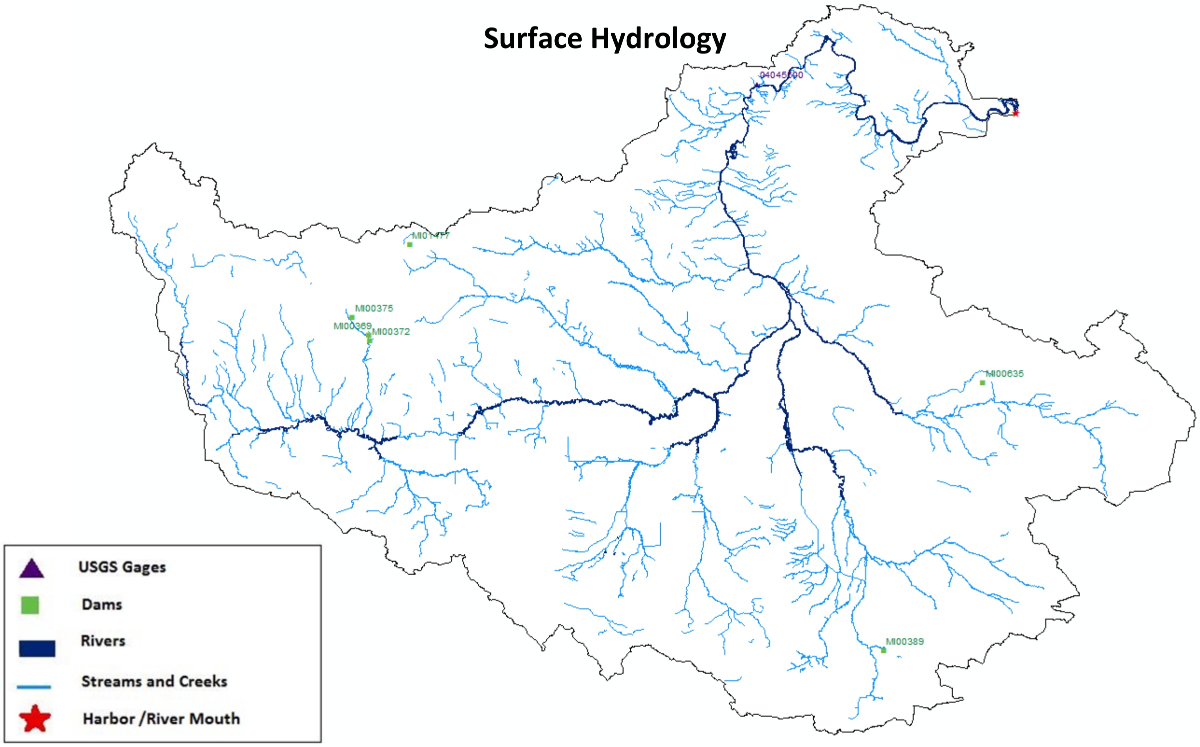


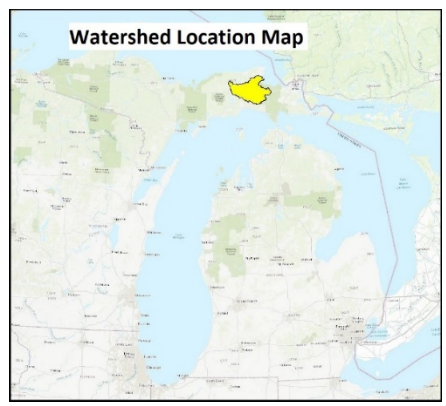


Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	87.34	15.38%
Silt, Sand, and Gravel	467.70	82.37%
Water	12.75	2.25%
Total Watershed Area	567.79	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX MMM. TAHQUAMENON RIVER WATERSHED (60)



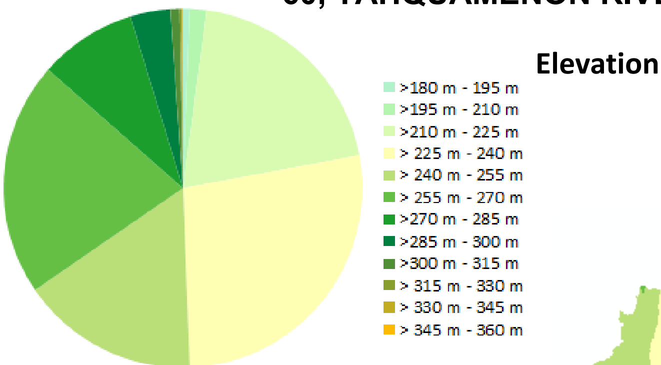


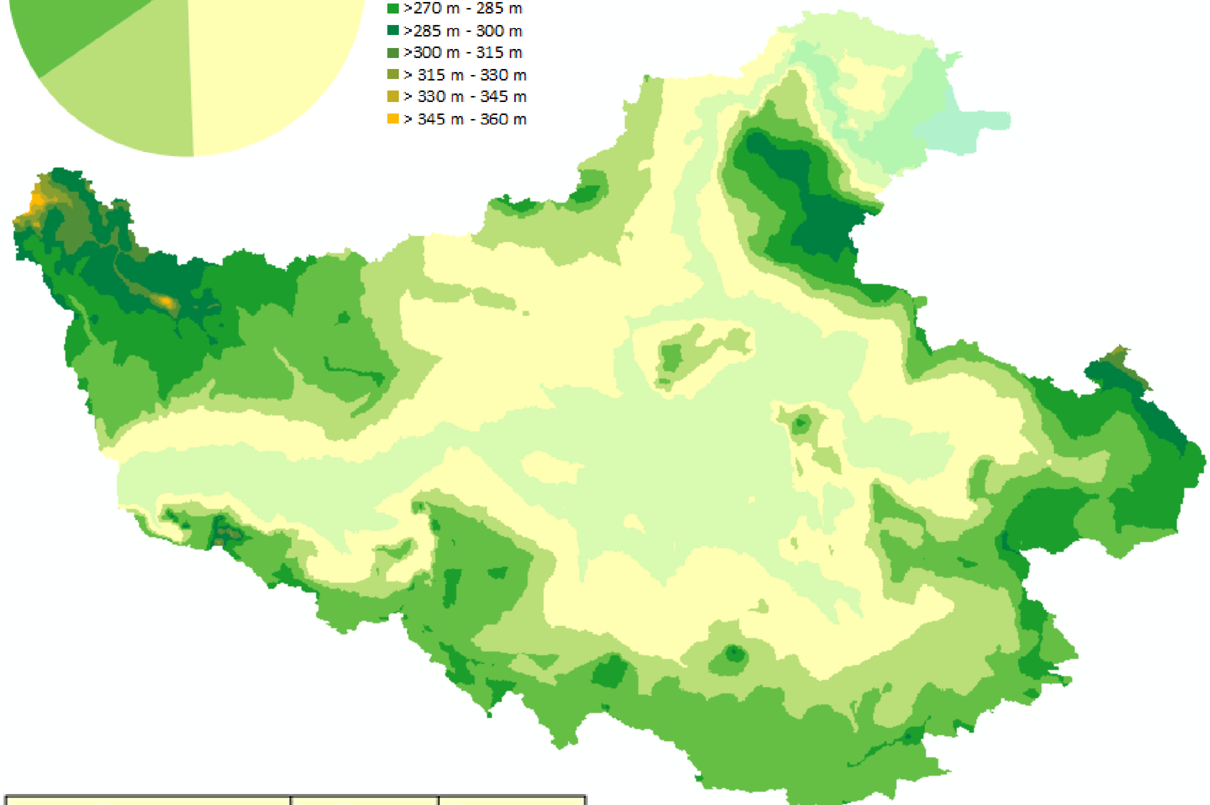
USACE's National Inventory of Dams			
NIDID	Dam Name	Longitude	Latitude
National ID	*Official Name*	*Decimal Degrees*	*Decimal Degrees*
MI00635	SENEY A-2 POOL DAM	-85.063890	46.383340
MI01477	Halfway Lake Dam	-85.591670	46.475000
MI00369	Brockies Pond Dam	-85.629930	46.417260
MI00372	Buckies Pond Dam	-85.629040	46.413760
MI00375	Silver Creek Trout Pond Dam	-85.645000	46.428330
MI00389	Fibron Trout Pond Dam	-85.158330	46.213330

USGS Stream Gage's				
STA ID	*Station Name*	*Longitude*	*Latitude*	*Active*
4045500	TAHQUAMENON RIVER NEAR PARADISE, MI	-85.269555	46.575015	yes
Number of Active USGS Stream Gage's in Drainage Area (2009)				1

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

60, TAHQUAMENON RIVER WATERSHED





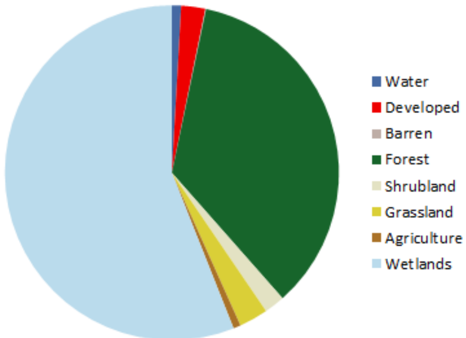
Category	Area	Percentage
Category	*km²*	%
>180 m - 195 m	12.63	0.60%
>195 m - 210 m	31.80	1.52%
>210 m - 225 m	418.14	19.94%
>225 m - 240 m	573.33	27.34%
>240 m - 255 m	335.92	16.02%
>255 m - 270 m	441.81	21.07%
>270 m - 285 m	184.22	8.78%
>285 m - 300 m	75.72	3.61%
>300 m - 315 m	17.36	0.83%
>315 m - 330 m	3.84	0.18%
>330 m - 345 m	1.63	0.08%
>345 m - 360 m	0.74	0.04%
Size of Drainage Area	2097.14	100.00%

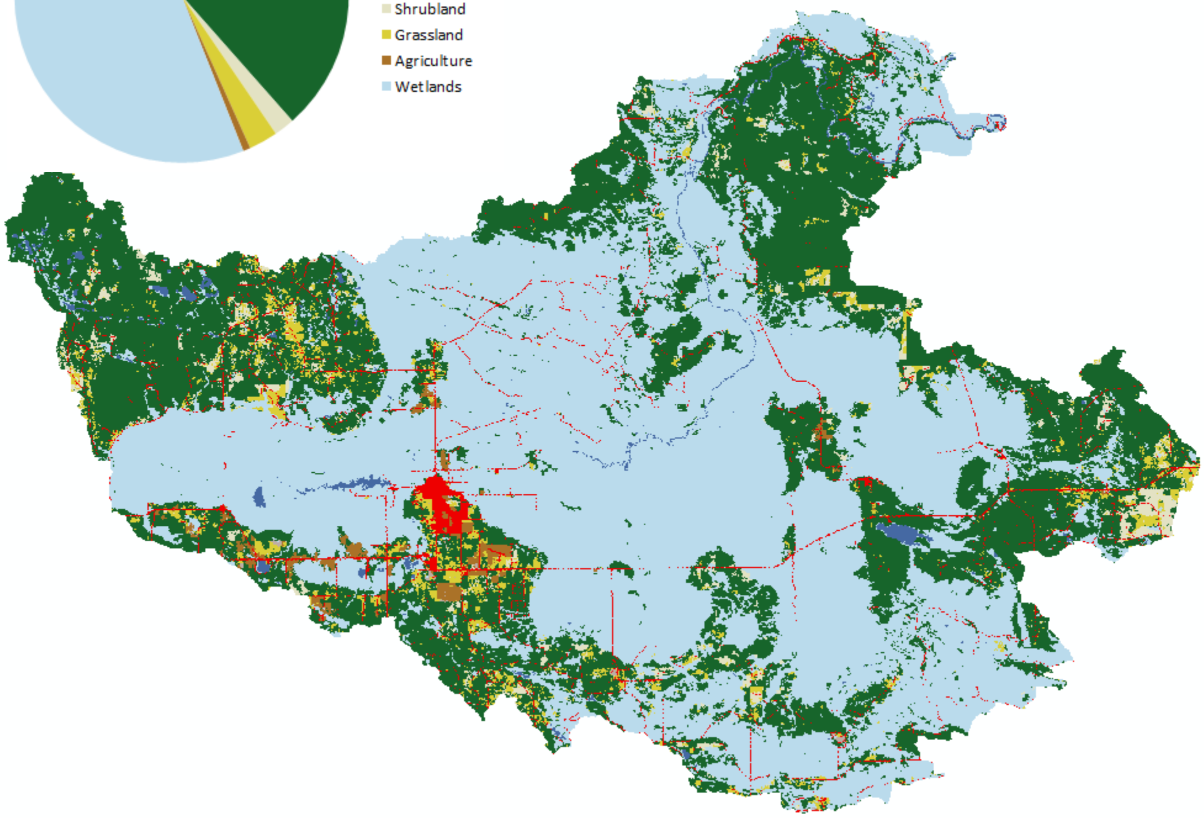
Tahquamenon Watershed		
Elevation Statistics		
Size of Drainage Area	**2097.14**	***km²***
Maximum	354.00	*m*
Minimum	183.00	*m*
Average	244.44	*m*
Standard Deviation	22.13	*m*

All Elevation Measurements with Respect to North American Datum 1983

60, TAHQUAMENON RIVER WATERSHED

Land Use



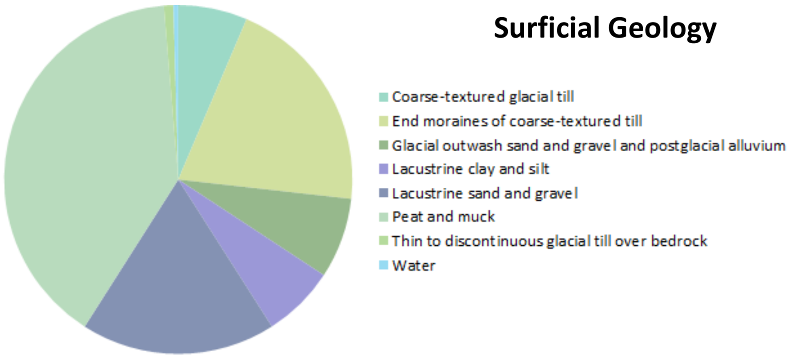


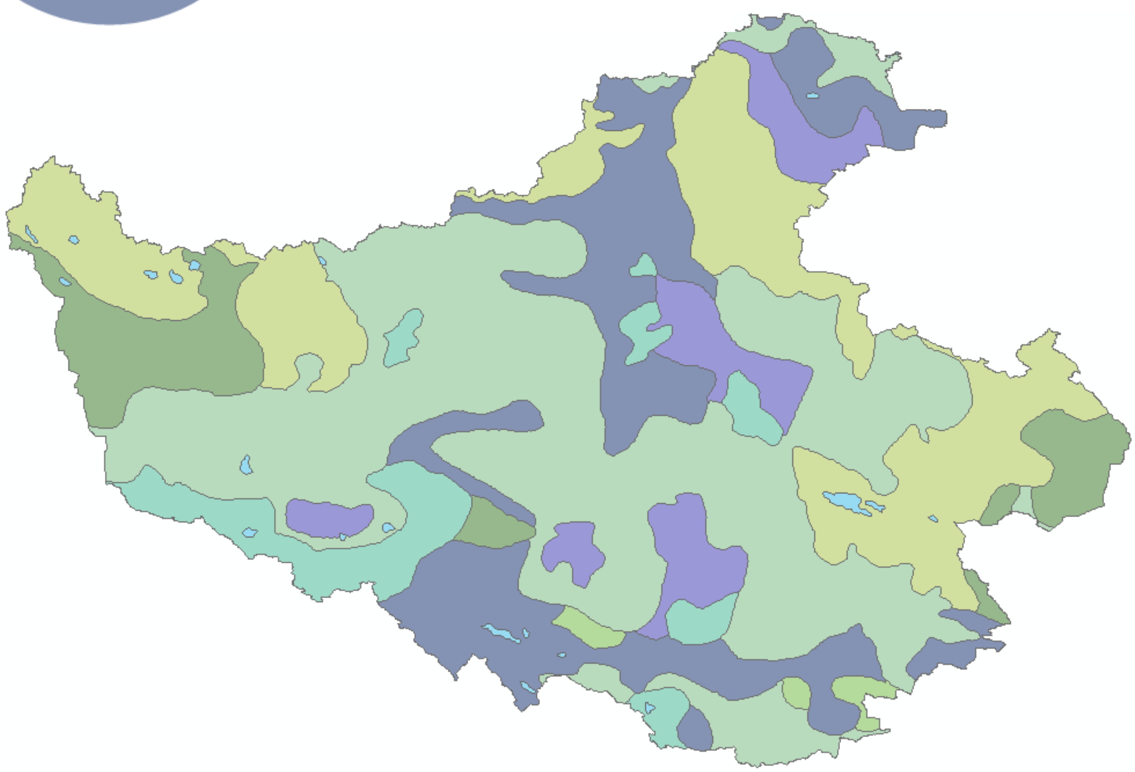
Category	Area	Percentage
Category	*km²*	*%*
Water	18.64	0.89%
Developed	48.91	2.33%
Barren	1.50	0.07%
Forest	737.91	35.19%
Shrubland	41.79	1.99%
Grassland	58.58	2.79%
Agriculture	15.00	0.72%
Wetlands	1174.81	56.02%
Total	2097.14	100.00%

EGLE Runoff Curve Number
68.3

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

60, TAHQUAMENON RIVER WATERSHED



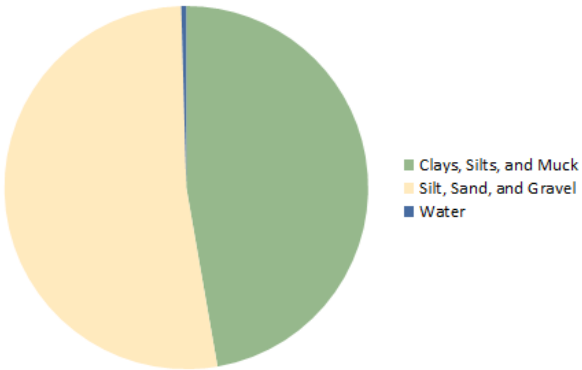


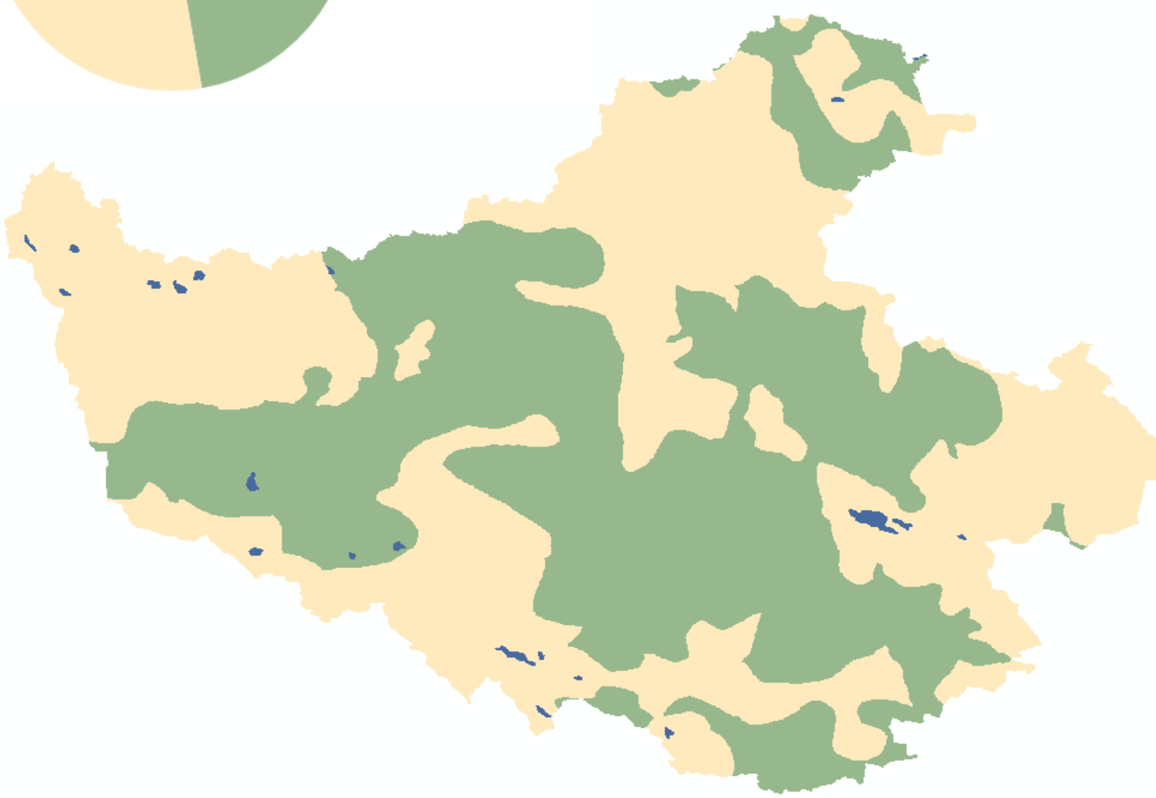
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	134.72	6.42%
End moraines of coarse-textured till	426.78	20.35%
Glacial outwash sand and gravel and postglacial alluvium	156.50	7.46%
Lacustrine clay and silt	140.97	6.72%
Lacustrine sand and gravel	378.99	18.07%
Peat and muck	831.47	39.65%
Thin to discontinuous glacial till over bedrock	18.49	0.88%
Water	9.22	0.44%
Total Watershed Area	2097.14	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

60, TAHQUAMENON RIVER WATERSHED

Surficial Geology (Simplified)



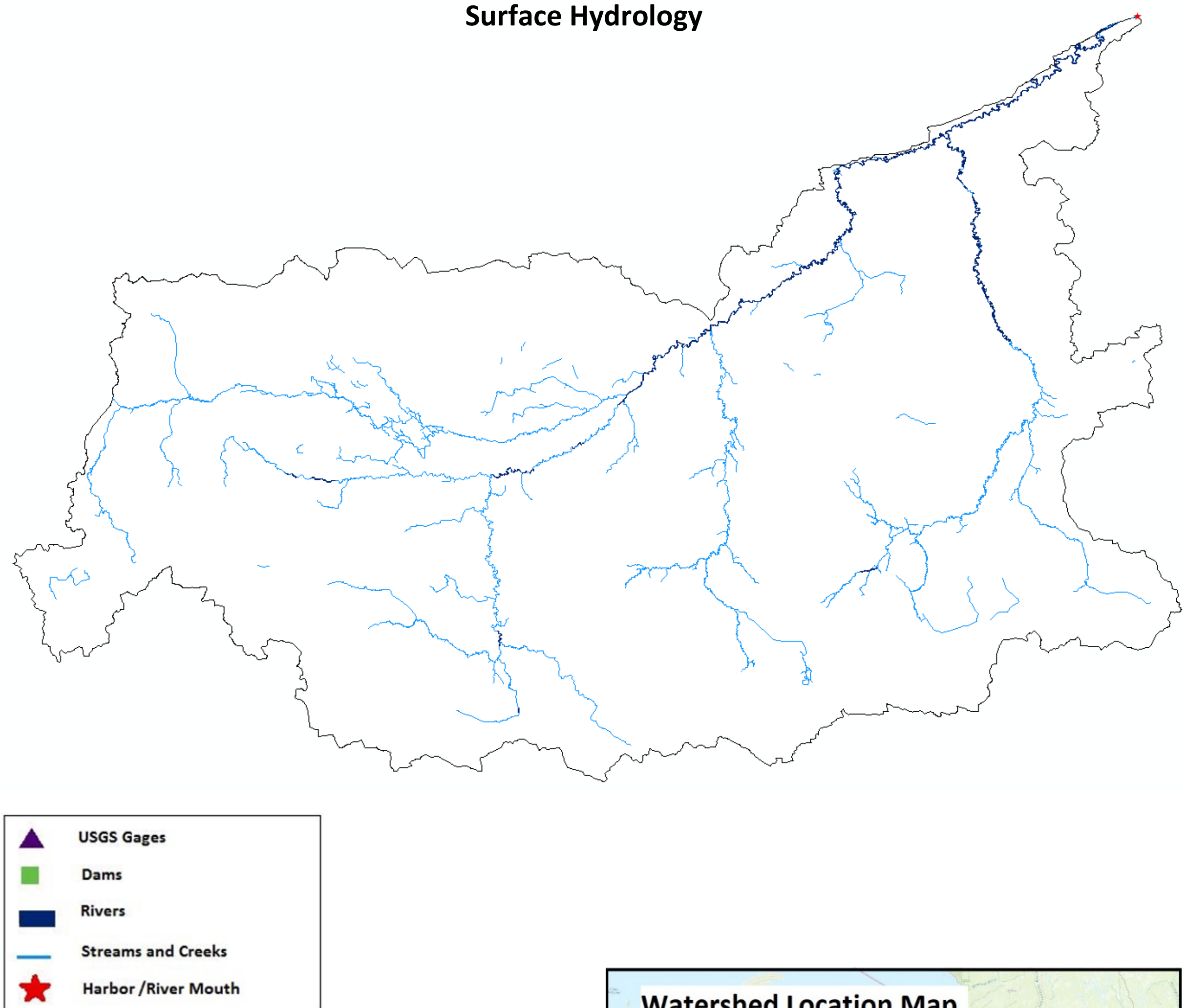


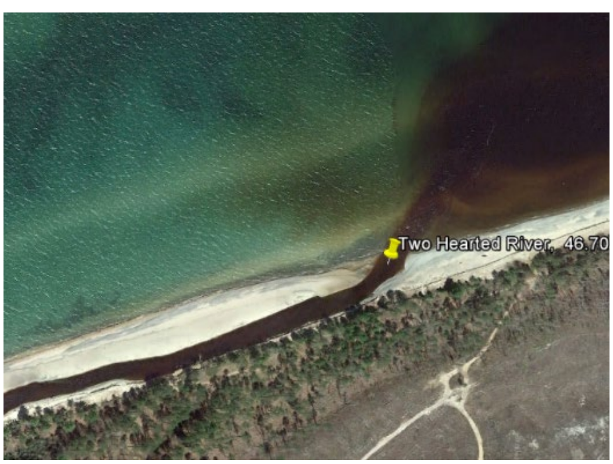
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	990.93	47.25%
Silt, Sand, and Gravel	1096.99	52.31%
Water	9.22	0.44%
Total Watershed Area	2097.14	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX NNN. TWO HEARTED RIVER WATERSHED (61)

Surface Hydrology

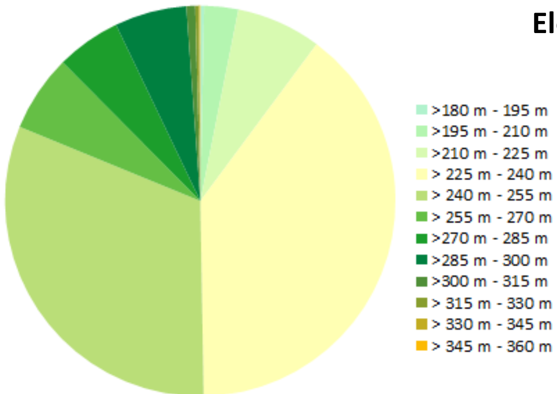


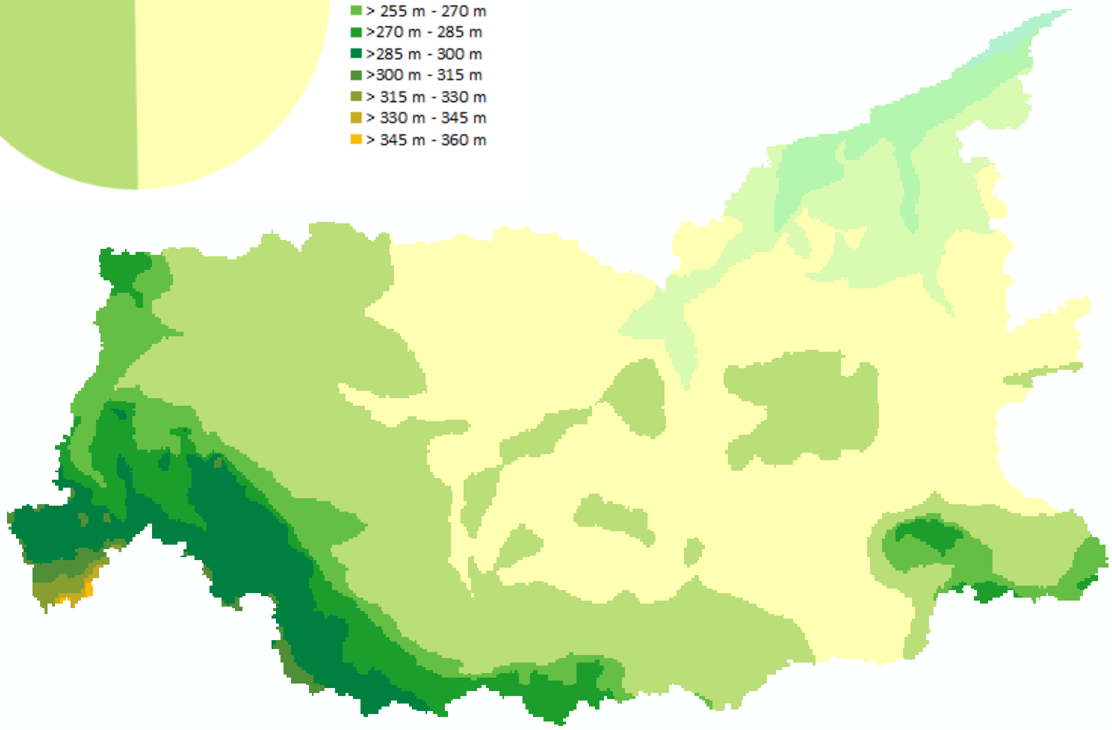


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages include only active gages and gages with 20+ years of discharge records since 1950

61, TWO HEARTED RIVER WATERSHED

Elevation



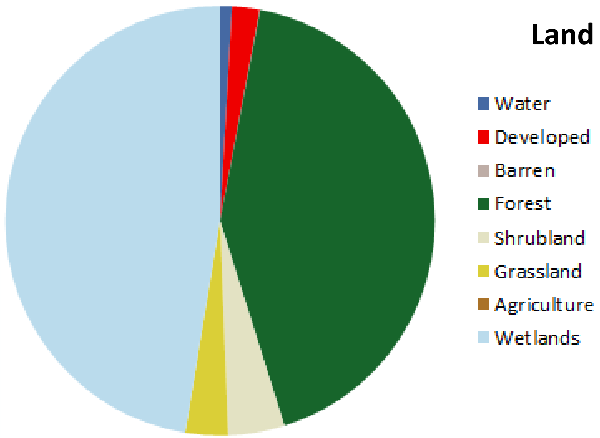


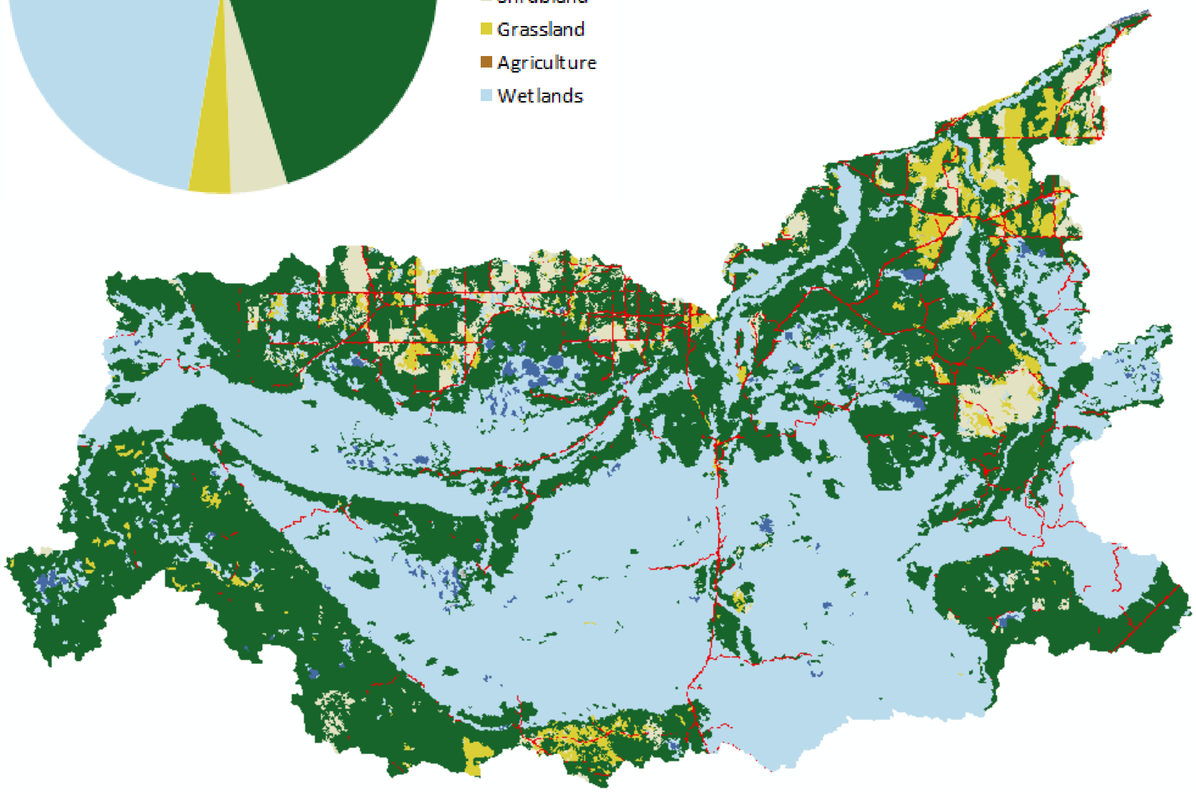
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	1.68	0.31%
>195 m - 210 m	15.11	2.82%
>210 m - 225 m	37.69	7.03%
>225 m - 240 m	212.13	39.57%
>240 m - 255 m	168.76	31.48%
>255 m - 270 m	34.08	6.36%
>270 m - 285 m	28.62	5.34%
>285 m - 300 m	31.93	5.96%
>300 m - 315 m	3.91	0.73%
>315 m - 330 m	1.56	0.29%
>330 m - 345 m	0.51	0.10%
>345 m - 360 m	0.16	0.03%
Size of Drainage Area	536.15	100.00%

Two Hearted Watershed		
Elevation Statistics		
Size of Drainage Area	536.15	*km²*
Maximum	350.00	*m*
Minimum	183.00	*m*
Average	244.07	*m*
Standard Deviation	20.28	*m*

All Elevation Measurements with Respect to North American Datum 1983

61, TWO HEARTED RIVER WATERSHED





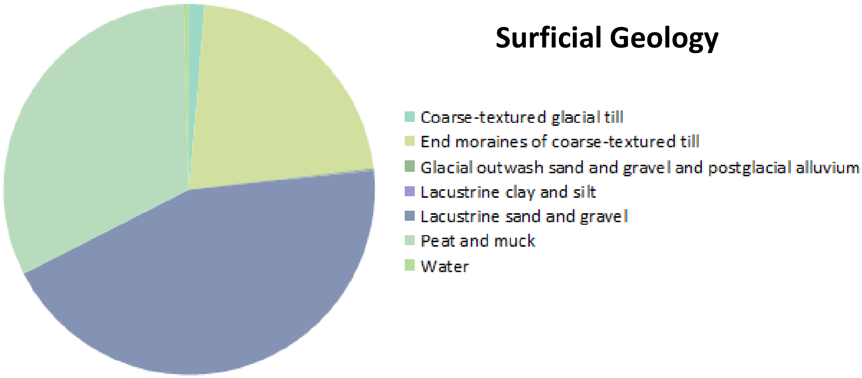
Category	Area	Percentage
Category	*km²*	*%*
Water	4.74	0.88%
Developed	11.13	2.08%
Barren	0.14	0.03%
Forest	226.13	42.18%
Shrubland	22.74	4.24%
Grassland	17.16	3.20%
Agriculture	0.00	0.00%
Wetlands	254.10	47.39%
Total	536.15	100.00%

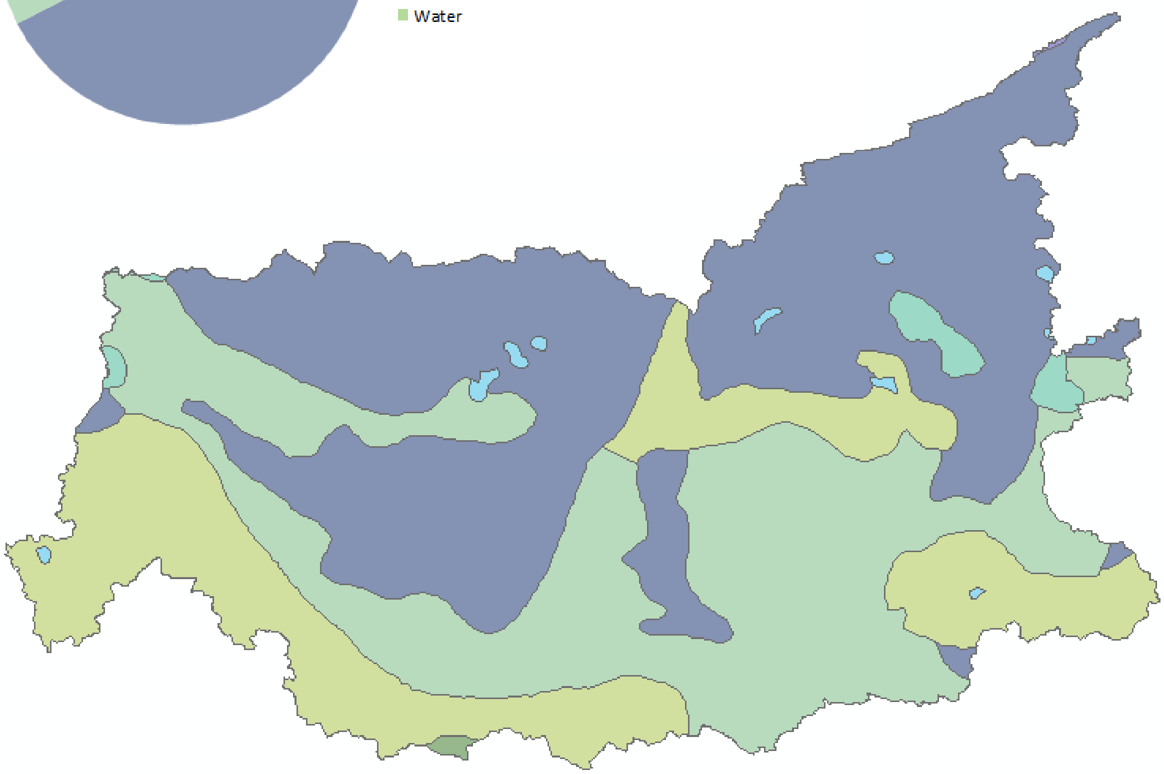
EGLE Runoff Curve Number
66.8

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

61, TWO HEARTED RIVER WATERSHED

Surficial Geology



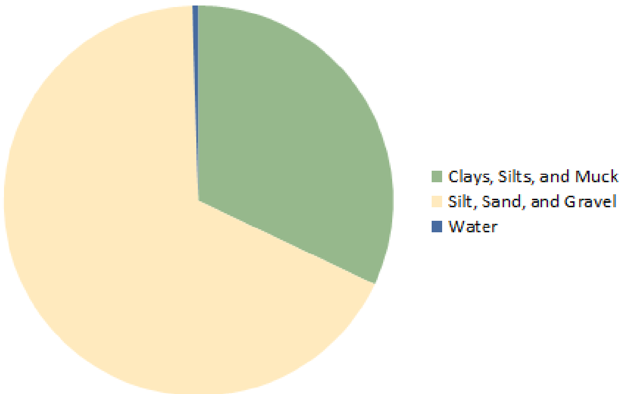


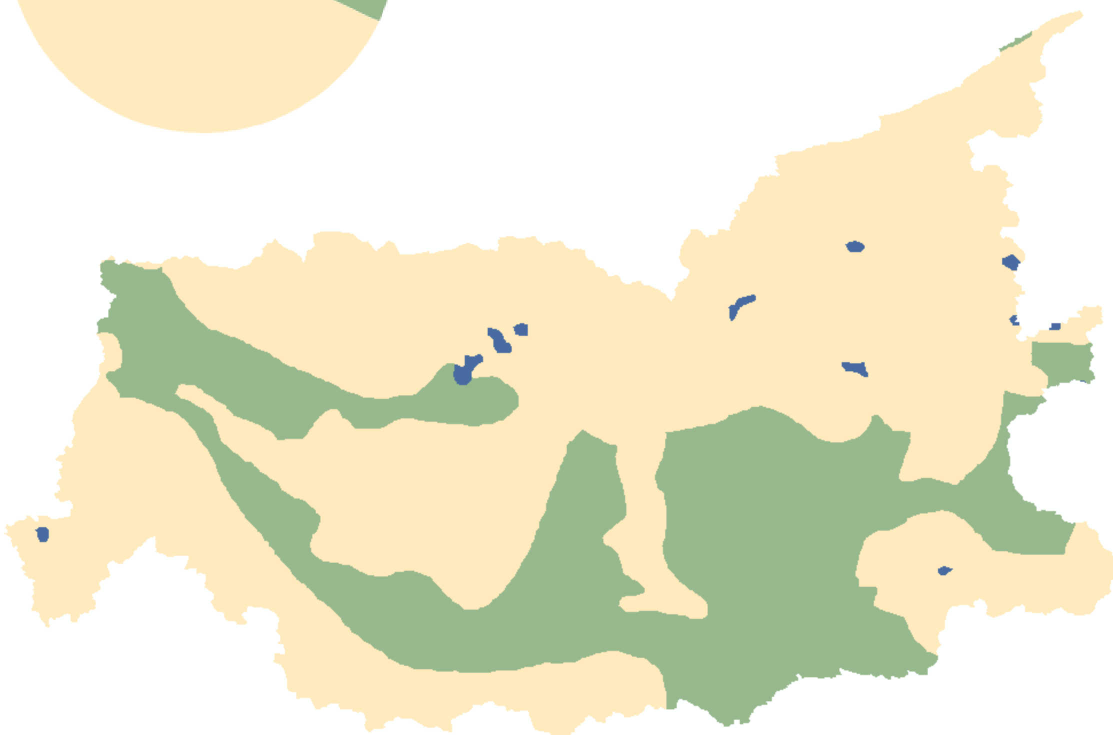
Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	7.29	1.36%
End moraines of coarse-textured till	116.96	21.82%
Glacial outwash sand and gravel and postglacial alluvium	0.82	0.15%
Lacustrine clay and silt	0.16	0.03%
Lacustrine sand and gravel	236.66	44.14%
Peat and muck	171.55	32.00%
Water	2.70	0.50%
Total Watershed Area	536.15	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

61, TWO HEARTED RIVER WATERSHED

Surficial Geology (Simplified)



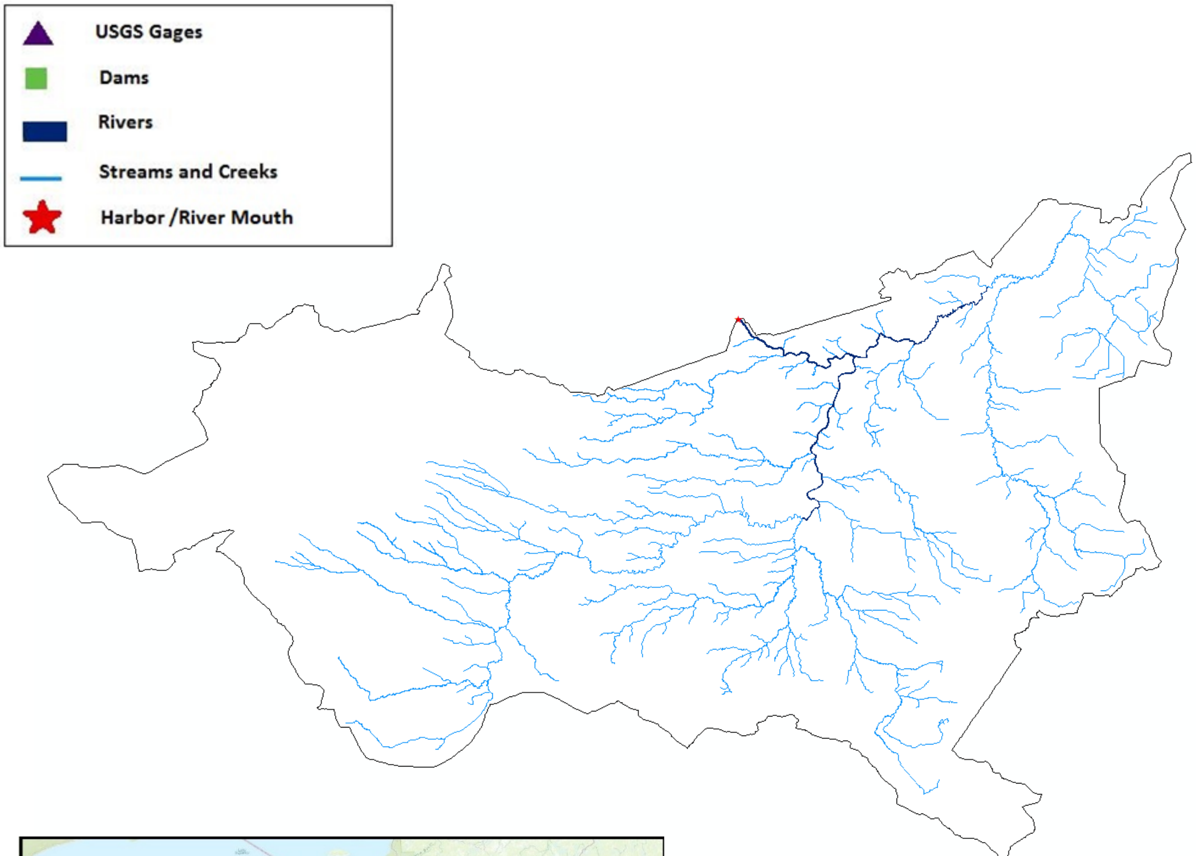


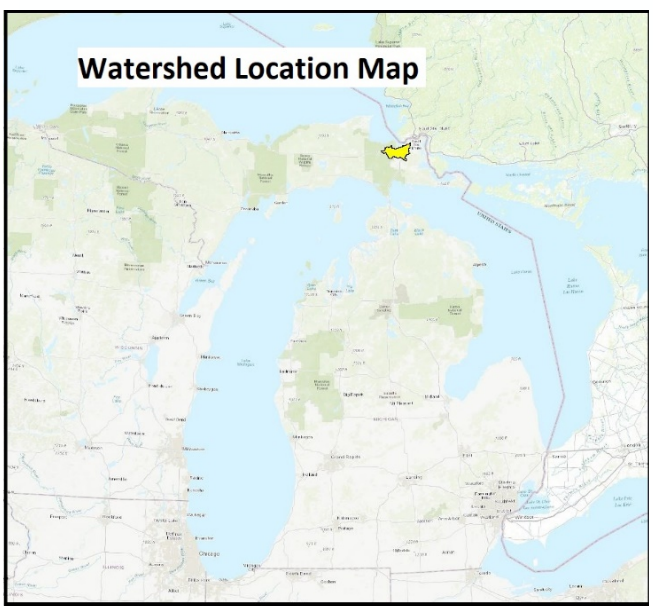
Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	171.72	32.03%
Silt, Sand, and Gravel	361.73	67.47%
Water	2.70	0.50%
Total Watershed Area	536.15	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX OOO. WAISKA RIVER WATERSHED (62)

Surface Hydrology

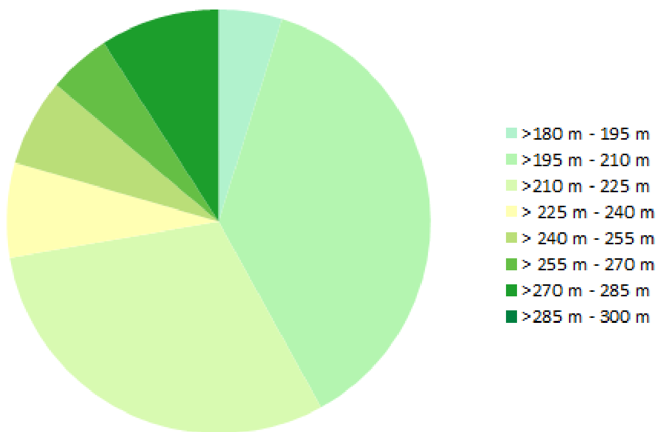


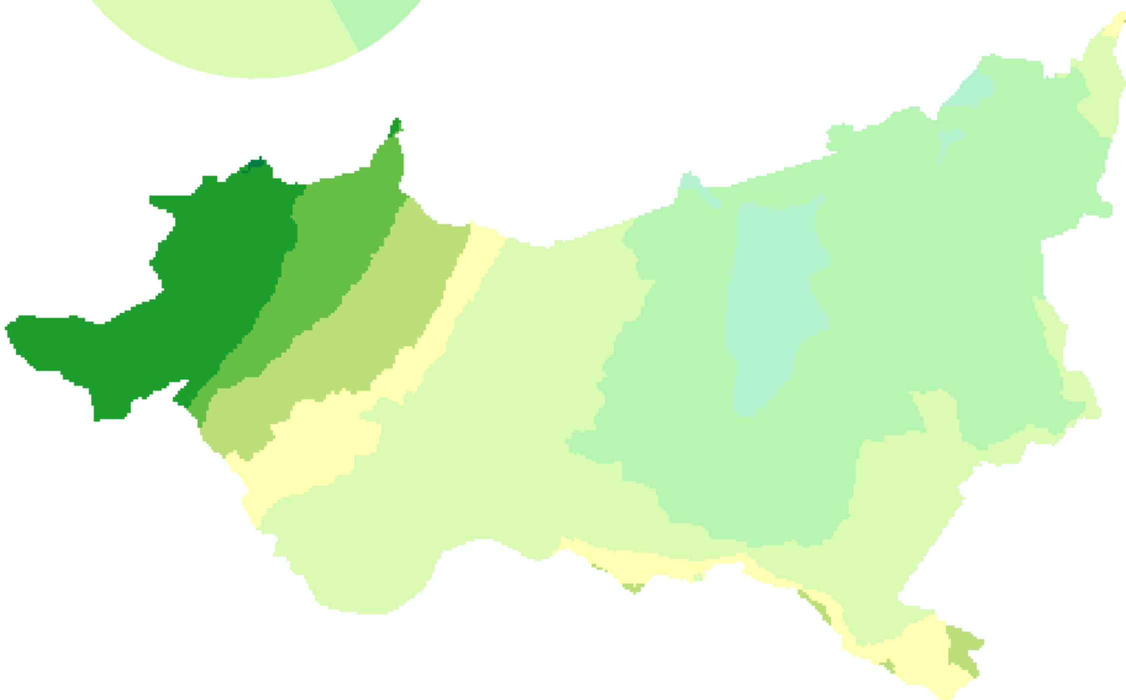


Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

62, WAISKA RIVER WATERSHED

Elevation



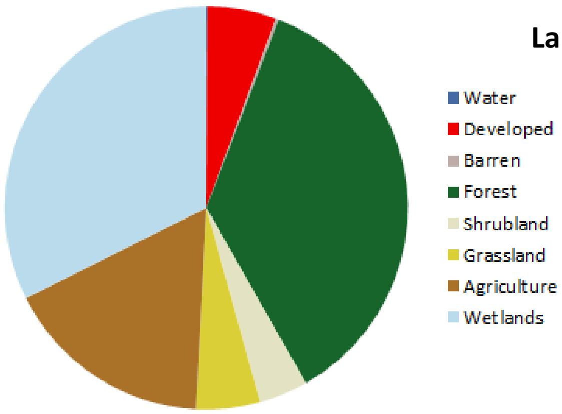


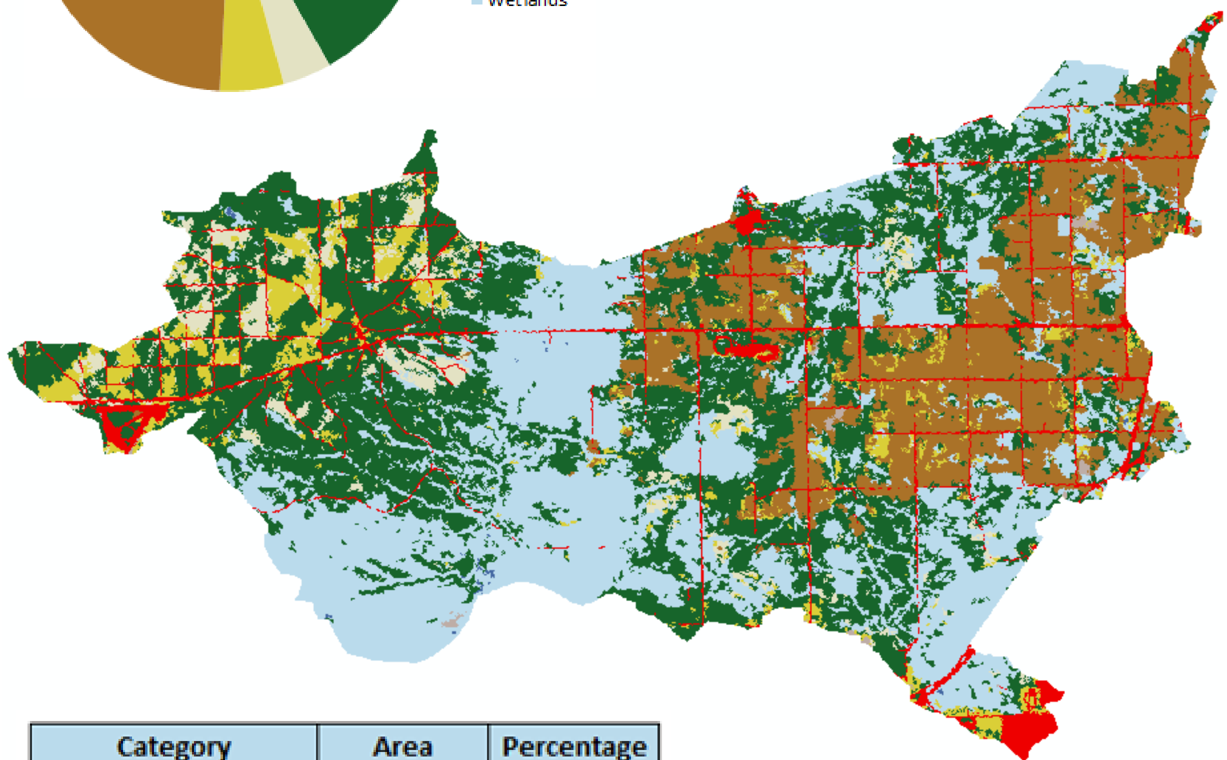
Category	Area	Percentage
Category	*km²*	*%*
>180 m - 195 m	18.64	4.85%
>195 m - 210 m	142.65	37.12%
>210 m - 225 m	116.47	30.30%
>225 m - 240 m	27.72	7.21%
>240 m - 255 m	25.54	6.65%
>255 m - 270 m	18.35	4.77%
>270 m - 285 m	34.80	9.06%
>285 m - 300 m	0.16	0.04%
Size of Drainage Area	384.33	100.00%

Waiska Watershed		
Elevation Statistics		
Size of Drainage Area	384.33	*km²*
Maximum	288.00	*m*
Minimum	183.00	*m*
Average	220.22	*m*
Standard Deviation	24.79	*m*

All Elevation Measurements with Respect to North American Datum 1983

62, WAISKA RIVER WATERSHED





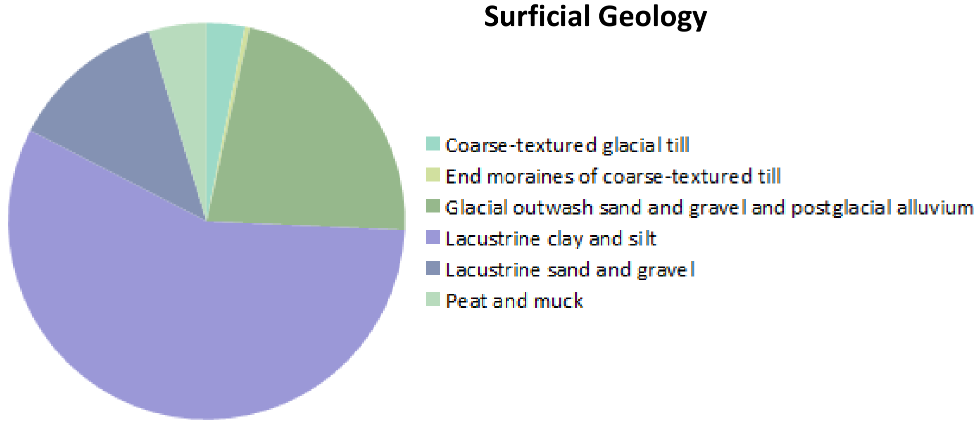
Category	Area	Percentage
Category	*km²*	*%*
Water	0.39	0.10%
Developed	21.17	5.51%
Barren	0.95	0.25%
Forest	138.03	35.92%
Shrubland	15.09	3.93%
Grassland	19.63	5.11%
Agriculture	64.58	16.80%
Wetlands	124.47	32.39%
Total	384.33	100.00%

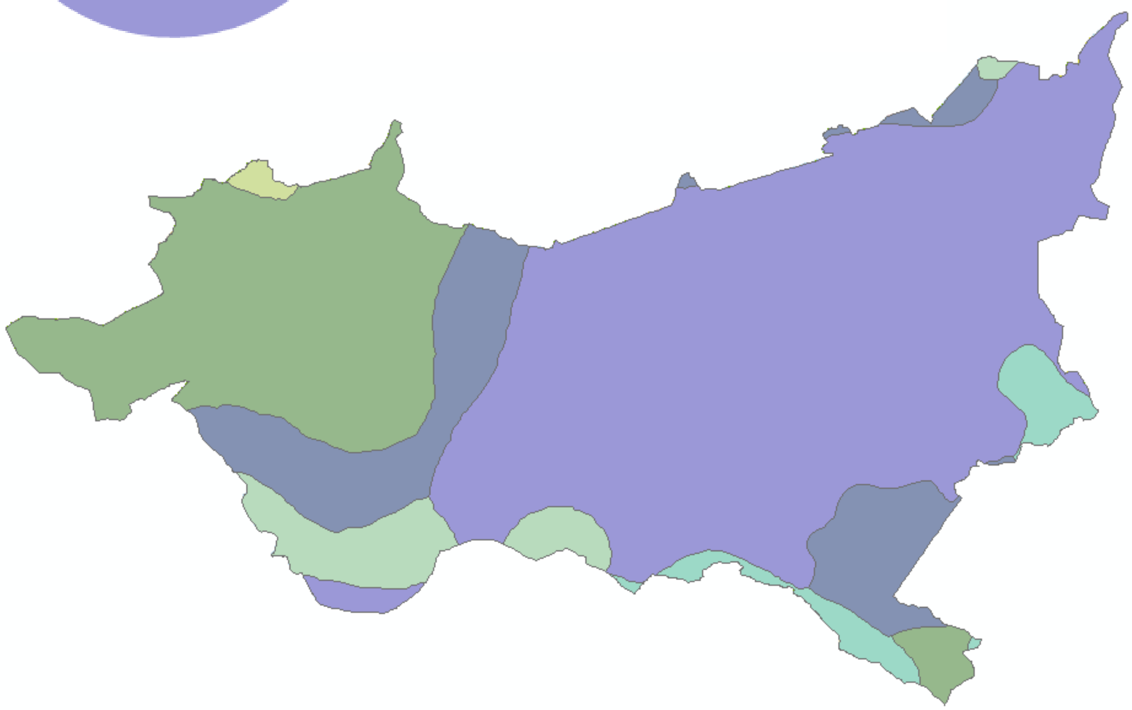
EGLE Runoff Curve Number
72.6

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

62, WAISKA RIVER WATERSHED

Surficial Geology



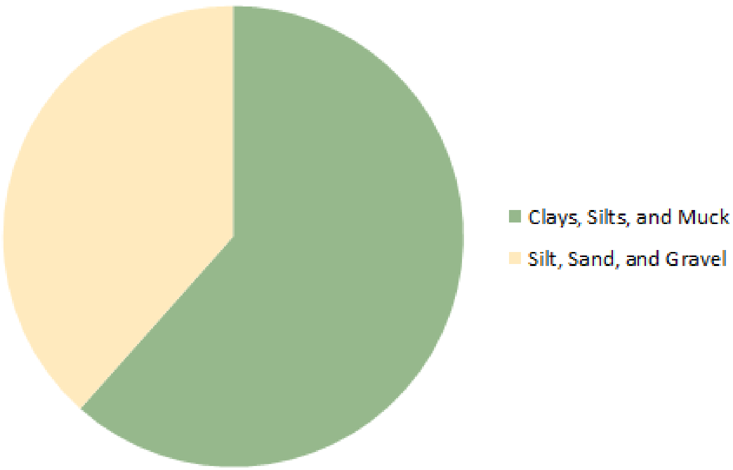


Category	Area	Percentage
Category	*km²*	*%*
Coarse-textured glacial till	11.95	3.11%
End moraines of coarse-textured till	1.57	0.41%
Glacial outwash sand and gravel and postglacial alluvium	85.28	22.19%
Lacustrine clay and silt	218.55	56.87%
Lacustrine sand and gravel	48.91	12.73%
Peat and muck	18.07	4.70%
Total Watershed Area	384.33	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

62, WAISKA RIVER WATERSHED

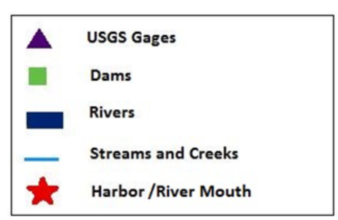
Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	236.63	61.57%
Silt, Sand, and Gravel	147.70	38.43%
Total Watershed Area	384.33	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

APPENDIX PPP. WHITEFISH RIVER WATERSHED (63)

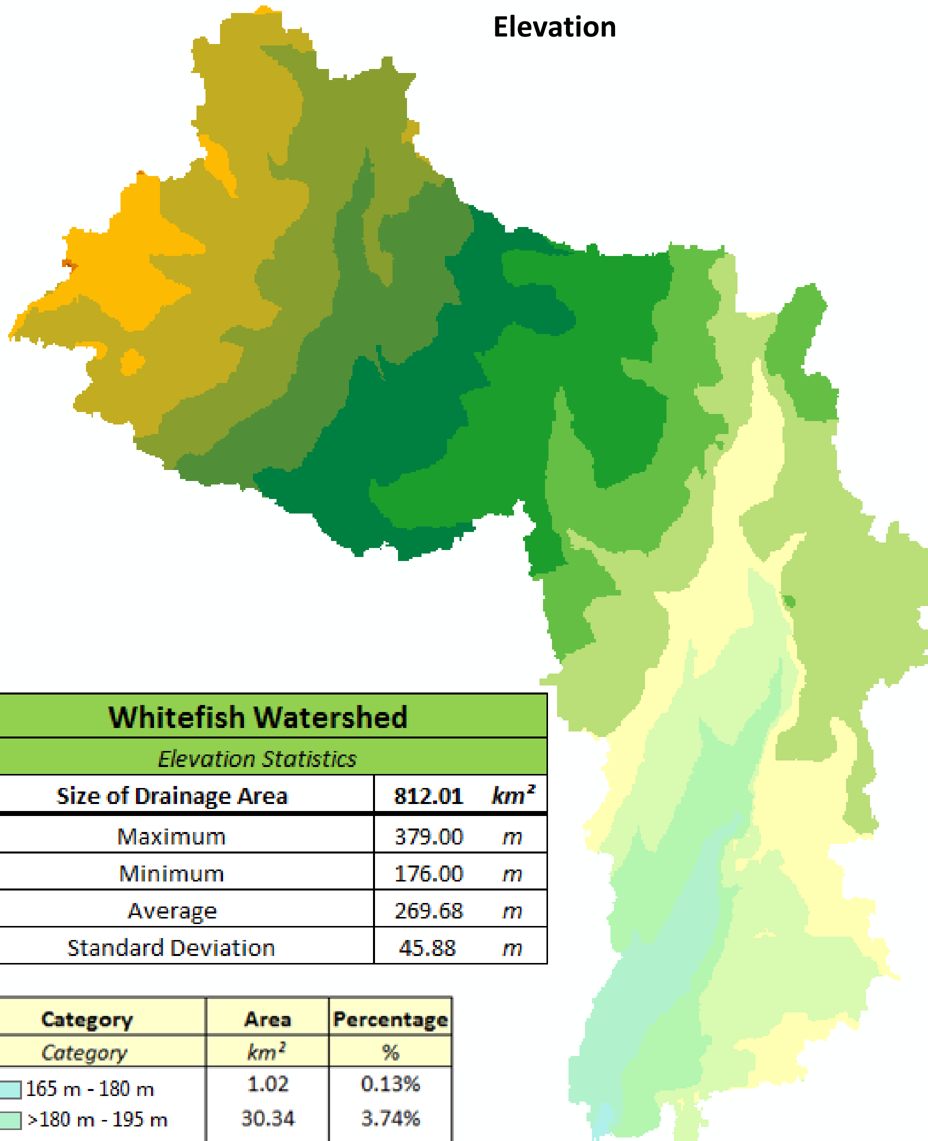


USACE's National Inventory of Dams			
NIDID	**Dam Name**	**Longitude**	**Latitude**
National ID	***Official Name***	***Decimal Degrees***	***Decimal Degrees***
MI01234	Hamilton Marsh Dam	-86.805000	46.043330

Data Obtained from USGS National Hydrography Dataset and National Inventory of Dams
USGS Streamgages includes only active gages and gages with 20+ years of discharge records since 1950

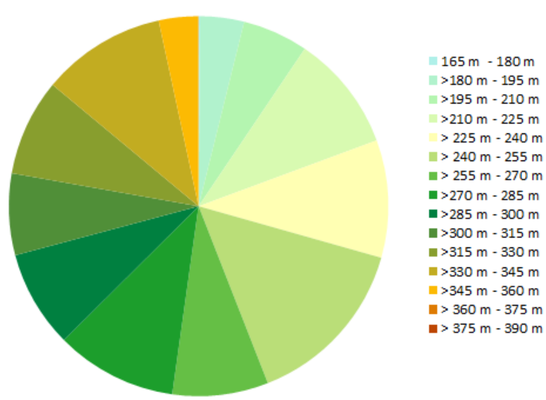
63, WHITEFISH RIVER WATERSHED

Elevation



Whitefish Watershed		
Elevation Statistics		
Size of Drainage Area	**812.01**	***km²***
Maximum	379.00	*m*
Minimum	176.00	*m*
Average	269.68	*m*
Standard Deviation	45.88	*m*

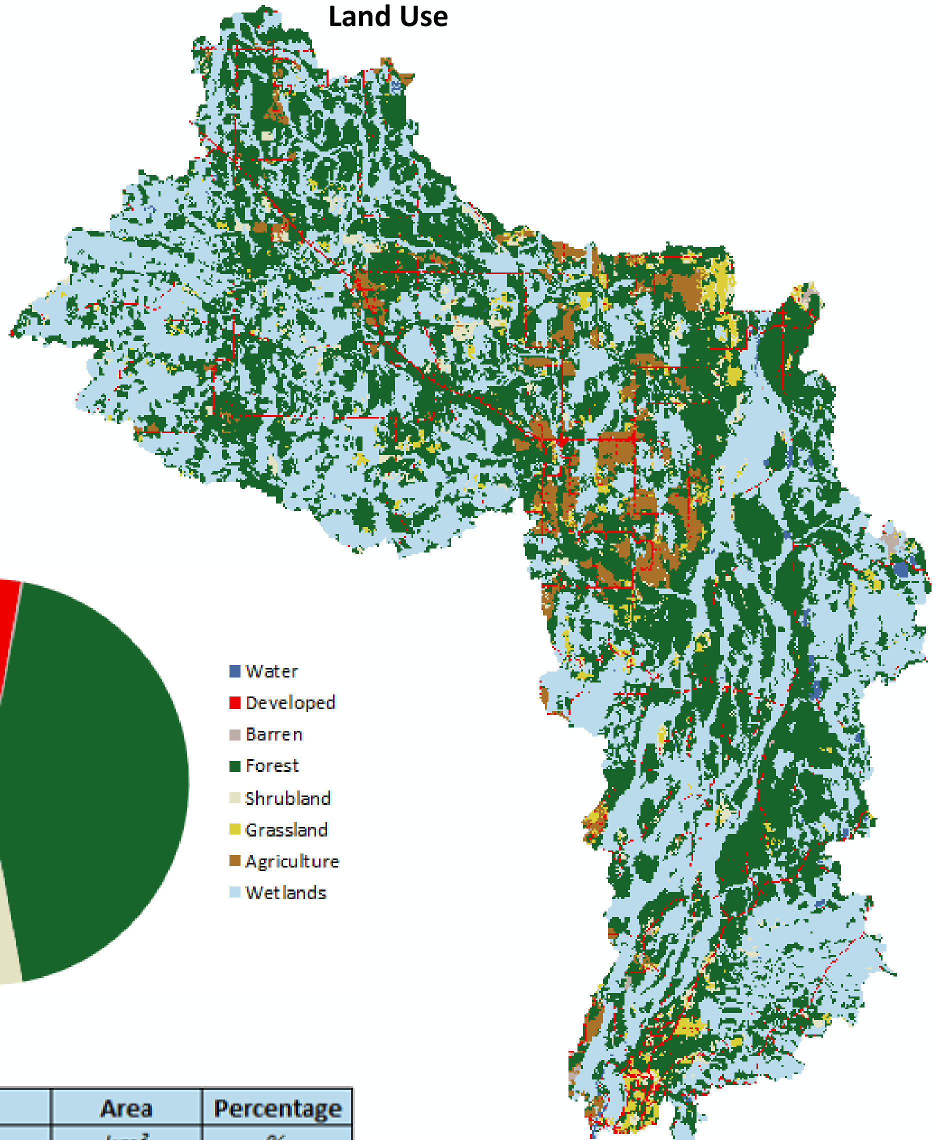
Category	**Area**	**Percentage**
Category	*km²*	*%*
165 m - 180 m	1.02	0.13%
>180 m - 195 m	30.34	3.74%
>195 m - 210 m	45.40	5.59%
>210 m - 225 m	80.49	9.91%
>225 m - 240 m	81.31	10.01%
>240 m - 255 m	119.17	14.68%
>255 m - 270 m	66.34	8.17%
>270 m - 285 m	83.90	10.33%
>285 m - 300 m	67.28	8.29%
>300 m - 315 m	56.34	6.94%
>315 m - 330 m	66.96	8.25%
>330 m - 345 m	86.00	10.59%
>345 m - 360 m	27.22	3.35%
>360 m - 375 m	0.21	0.03%
>375 m - 390 m	0.03	0.00%
Size of Drainage Area	812.01	100.00%

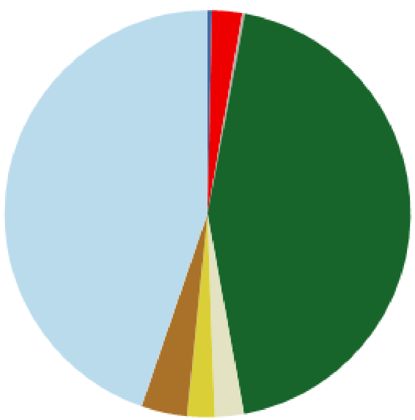


All Elevation Measurements with Respect to North American Datum 1983

63, WHITEFISH RIVER WATERSHED

Land Use





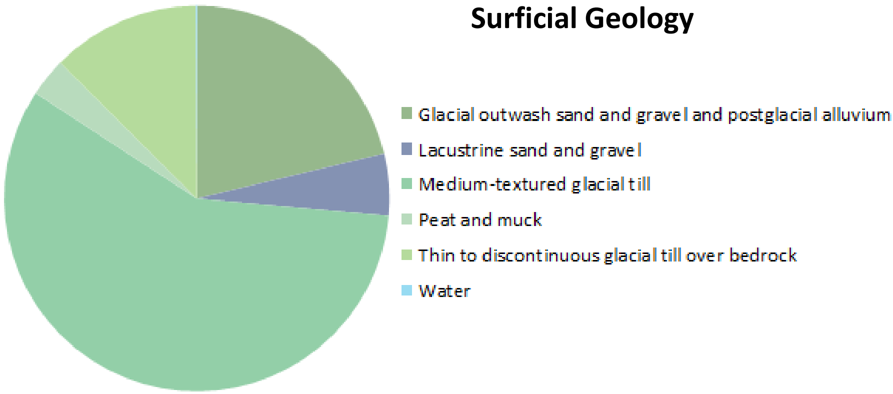
Category	Area	Percentage
Category	*km²*	*%*
Water	2.96	0.36%
Developed	19.27	2.37%
Barren	1.86	0.23%
Forest	358.44	44.14%
Shrubland	19.01	2.34%
Grassland	17.58	2.16%
Agriculture	29.59	3.64%
Wetlands	363.30	44.74%
Total	812.01	100.00%

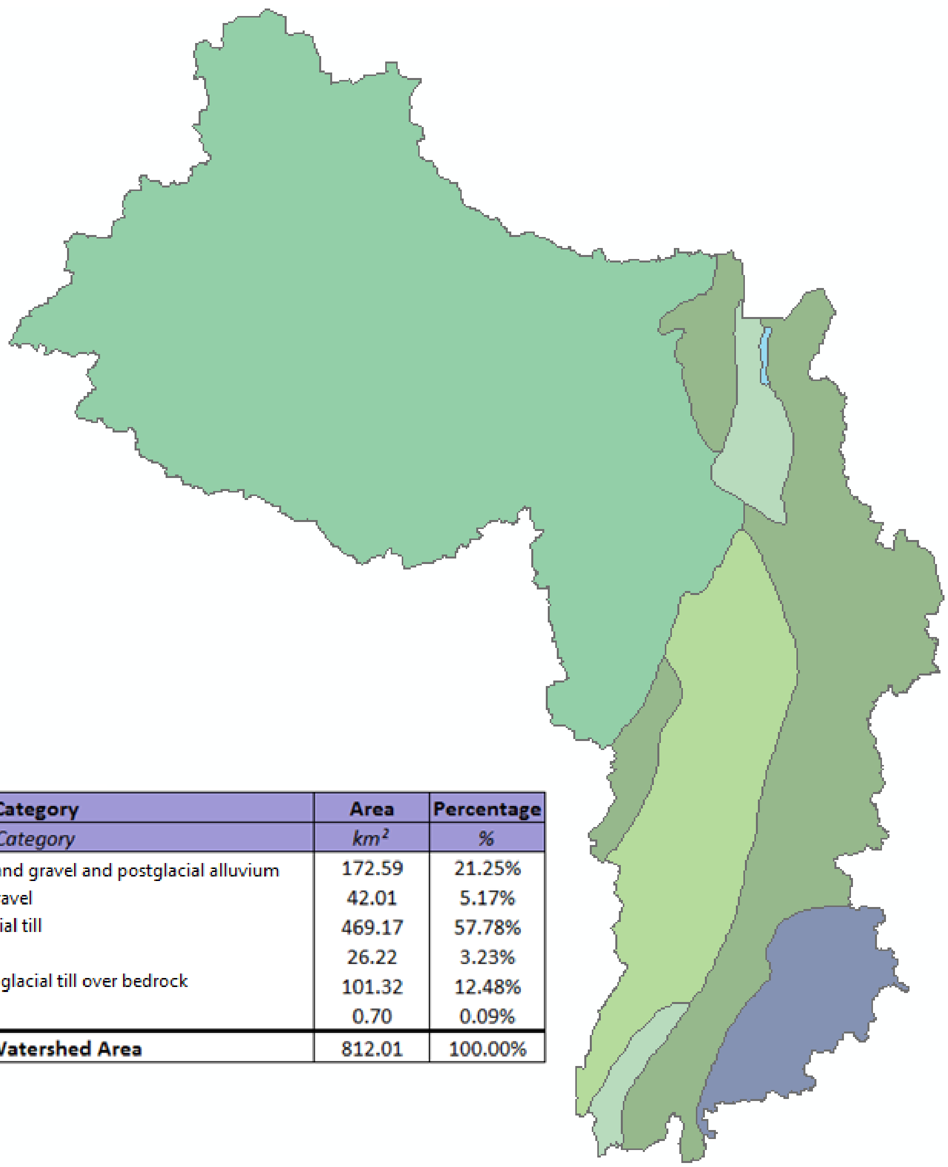
EGLE Runoff Curve Number
69.9

Data Obtained from National Land Cover Database 2011 (NLCD2011) for the Conterminous United States
Classifications Aggregated into 9 Land Use Categories in Accordance with Modified Anderson Land Use System
Legend Color Scheme Adapted from NLCD 2011 Land Cover Classification Legend

63, WHITEFISH RIVER WATERSHED

Surficial Geology



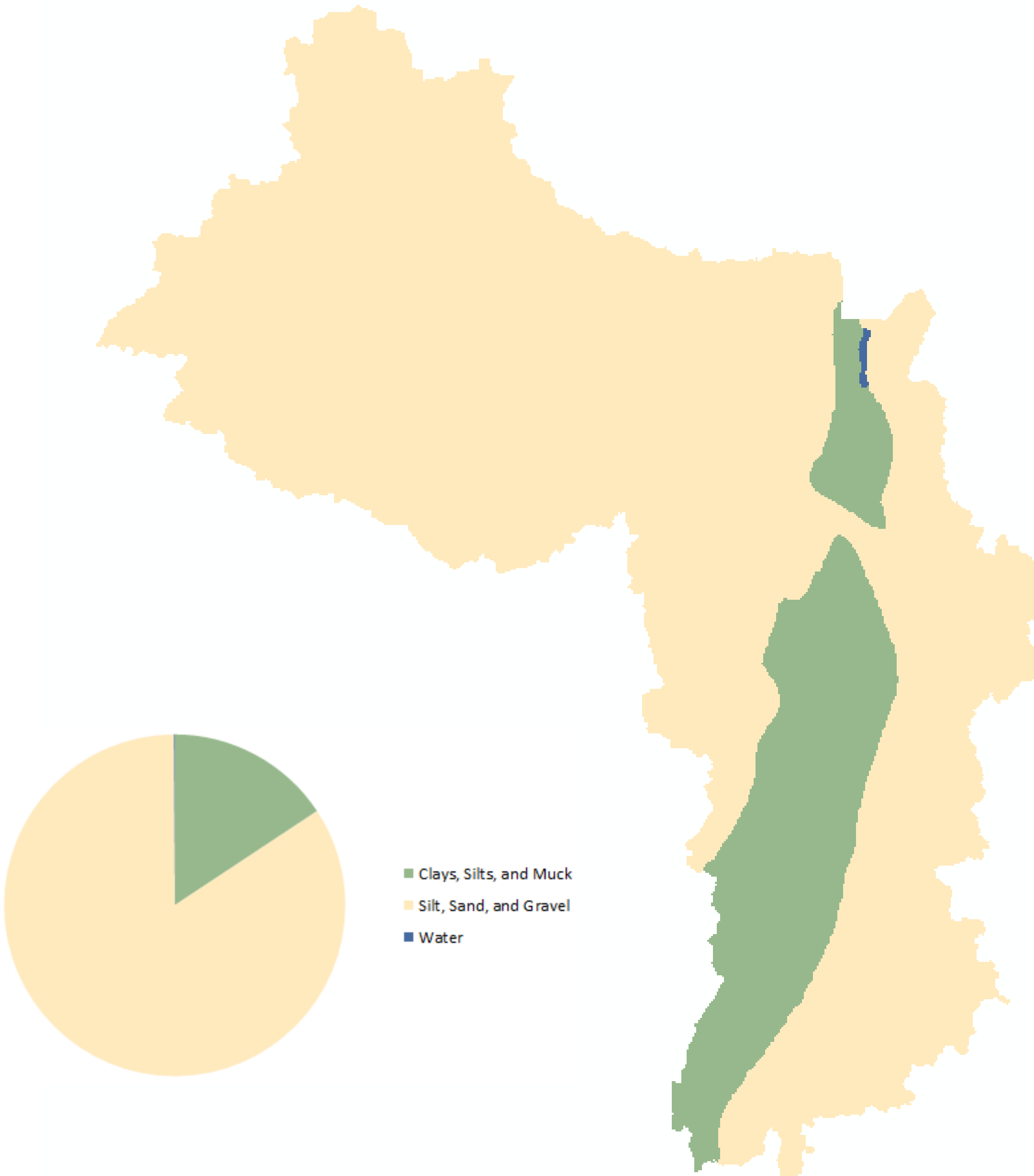


Category	Area	Percentage
Category	*km²*	*%*
Glacial outwash sand and gravel and postglacial alluvium	172.59	21.25%
Lacustrine sand and gravel	42.01	5.17%
Medium-textured glacial till	469.17	57.78%
Peat and muck	26.22	3.23%
Thin to discontinuous glacial till over bedrock	101.32	12.48%
Water	0.70	0.09%
Total Watershed Area	812.01	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

63, WHITEFISH RIVER WATERSHED

Surficial Geology (Simplified)



Category	Area	Percentage
Category	*km²*	*%*
Clay, Silt, and Muck	127.54	15.71%
Silt, Sand, and Gravel	683.77	84.21%
Water	0.70	0.09%
Total Watershed Area	812.01	100.00%

Data Obtained by 1982 Quaternary Geology map of Michigan published by Michigan Department of Natural Resources

REFERENCES

Ackers P and White WR. 1973. Sediment transport: New approach and analysis. American Society of Civil Engineers, Journal of the Hydraulics Division, Volume 99 (HY11).

Alighalehbabakhani F, Miller CJ. Baskaran M, Selegean JP, Barkach JH, Sadatiyan SMA., Dahl T. 2017a. Forecasting the remaining reservoir capacity in the Laurentian Great Lakes watershed. Journal of Hydrology 555: 926-937.

Alighalehbabakhani, F, Miller, CJ, Selegean, JP, Barkach, J, Sadatiyan SMA, Dahl, T., Baskaran, M. 2017b. Estimate of sediment trapping rates for two reservoirs in the Lake Erie watershed: Past and present scenarios. Journal of Hydrology 544: 147-155.

American Society of Civil Engineers (ASCE). 1982. Relationships between morphology of small streams and sediment yields. ASCE Task Committee on Relations between Morphology of Small Streams and Sediment Yield of the Committee on Sedimentation of the Hydraulics Division. Journal of the Hydraulics Division, Volume 108 (HY11).

Armijos E, Merten GH, Groten JT, Ellison CA, and Lisiecki LU. 2021. Performance of Bedload Sediment Transport Formulas Applied to the Lower Minnesota River. Journal of Hydrologic Engineering, Volume 26(7): 05021014

Bagnold RA. 1956. The Flow of Cohesionless Grains in Fluids. Philosophical Transactions of the Royal Society of London, Series A, Volume 249 (964).

Baskaran, M, Nix J, Kuyper C, and Karunakara N. 2014. Problems with the dating of sediment core using excess 210Pbxs in a freshwater system impacted by large scale watershed changes. J. Environ. Radioact. Volume 138, pages 355-363.

Baskaran M and Naidu AS. 1995. 210Pb-derived chronology and the fluxes of 210Pb and 137Cs isotopes into continental shelf sediments, East Chukchi Sea, Alaskan Arctic. Geochim. Cosmochim. Acta, Volume 59, pages 4435-4448.

Baskaran M., Miller CJ, Kumar A, Andersen E, Hui J, Selegean JP, Creech CT and Barkach JH. 2015. Sediment accumulation rates and sediment dynamics using five different methods in a well-constrained impoundment: Case study from Union Lake, Michigan. Journal of Great Lakes Research Volume 41, pages 607-617.

Beaver M. 2013. Aerial photograph of the Grand River at Lake Michigan taken by Marge Beaver, Photography-Plus, on April 23, 2013. Permission to use the photograph was provided by Photography-Plus, Muskegon, MI. http://photography-plus.com/.

Bent PC. 1970. A proposed stream flow data program for Michigan. USGS, Lansing, Michigan. Open file report, pages 1-44.

Bent PC. 1971. Influence of surface glacial deposits on streamflow characteristics. USGS, Lansing, Michigan. Open file report, pages 1-37.

Biedenharn DS, Watson CC, and Thorne CR. 2008. Fundamentals of Fluvial Geomorphology. IN: Chapter 6, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Borah DK, Drug EC, and Yoder D. 2008. Watershed Sediment Yield. IN: Chapter 17, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Brooks KN, Folliott PF, and Magner JA. 2013. Hydrology and the management of watersheds. John Wiley & Sons, Inc., New York.

Brown CB. 1943. Discussion of Sedimentation in Reservoirs. American Society of Civil Engineers, Volume 69, pages 793-815.

Brune GM. 1953. Trap Efficiency of Reservoirs. American Geophysical Union. Volume 34(3).

Charlton R. 2008. Fundamentals of Fluvial Geomorphology. Routledge, New York, New York.

Churchill MA. 1948. Discussion of the Analyses and Use of Reservoir Sedimentation Data by LC Gottschalk. In Proceedings of the Federal Interagency Sedimentation Conference, Denver Colorado. USGS, Washington D.C.

Cohen S, Kettner AJ, Syvitski, JP, Fekete BM. 2011. WBMsed, a distributed global-scale riverine sediment flux model: Model description and validation. Computers and Geosciences. Volume 53, pages 80-93.

Cohen S, Kettner AJ, Syvitski, JP. 2014. Global suspended sediment and water discharge dynamics between 1960 and 2010: Continental trends and intra-basin sensitivity. Global and Planetary Change; Volume 115, pages 44-58.

Creech C, Selegean J, and Dahl T. 2010. Historic and Modern Sediment Yield from a Forested Watershed and its Impact on Navigation. Conference Proceedings: 2nd Joint Federal Interagency Conference, Las Vegas, NV, June 27 - July 1, 2010.

Dendy FE. 1974. Sediment trap efficiency of small reservoirs. Transactions of the ASAE, Volume 17, pages 898-908.

Environment, Great Lakes, and Energy (EGLE). 2020. Personal communication with Susan Greiner, P.E. Michigan Department of Environment, Great Lakes, and Energy, Water Resources Division, Lansing, Michigan. Date: October 16, 2020.

Einstein HA. 1950. The Bedload Function for Sediment Transportation in Open Channel Flows. USDA Soil Conservation Service, Washington D.C.Technical Bulletin No 1026.

Farrand WR and Bell DL. 1982. Quaternary Geology of Michigan. Michigan Department of Natural Resources, Lansing, Michigan. https://www.michigan.gov/documents/deq/1982_Quaternary_Geology_Map_301467_7.pdf

Flint RF. 1971. Glacial and Quaternary Geology. John Wiley and Sons, Inc., New York, New York.

Federal Emergency Management Agency (FEMA). 2020. Online Map Service Center: Flood Insurance Studies (FIS) and Flood Insurance Rate Maps (FIRMs). FEMA, Washington D.C. https://msc.fema.gov/portal/.

Federal Interagency Stream Restoration Work Group (FISRWG). 1998. Stream Corridor Restoration, Principals, Processes, and Practices. Fifteen Federal Agencies. GPO Item Number: 0120-A. ISBN-0-934213-59-3.

Ferguson R. and Church M. 2004. A Simple Universal Equation for Grain Settling Velocity. Journal of Sedimentary Research, Volume 74, pages 933–937.

Foster GR, Lane LJ, Nowlin JD, Laflen JM, and Young RA. 1981. Estimating Erosion and Sediment Yield on Field-sized Areas. Transactions, American Society of Agricultural Engineers, Volume 24(5), pages 1253-1262.

Garcia MH. 2008. Sediment Transport and Morphodynamics. IN: Chapter 2, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Garg V and Jothiprakash V. 2008. Estimation of Useful Life of a Reservoir Using Sediment Trap Efficiency. Journal of Spatial Hydrology Vol.8, No.2. Date: Fall 2008.

Gill MA. 1979. Sedimentation and Useful Life of Reservoirs. Journal of Hydrology. Volume 44, pages 89-95.

Gomez B and Church M. 1989. An Assessment of Bed Load Sediment Transport Formulae for Gravel Bed Rivers. Water Resources Research, Volume 25(6).

Google Earth Pro. 2021. Version 7.3.3.7786. Figure references follow.

Figure 1. Hearted River (61). 46.705781, -85.409216, eye elevation 4,776 feet. Accessed June 15, 2021, Image USDA Farm Service Agency, May 8, 2021.

Figure 12. Mio Dam, Michigan. 44.678163, -84.220963, eye altitude 34,449 feet. Accessed May 27, 2021. Image USDA Farm Service Agency, July 25, 2010.

Figure 13. Brown Bridge Dam, Michigan. 44.647144, -85.498959, eye altitude 5,567 feet. Accessed May 27, 2021. Image USDA Farm Service Agency, July 25, 2010.

Figure 14. Webber Dam, Michigan. 42.940964, -84.893928, eye altitude 13,030 feet. Accessed May 27, 2021. Image USDA Farm Service Agency, July 25, 2010.

Figure 15. Ford Lake Dam, Michigan. 42.231659, -83.590882, eye altitude 16,792 feet. Accessed May 27, 2021. Image USDA Farm Service Agency, July 25, 2010.

Figure 16. Riley Dam, Michigan. 42.054023, -83.182336, eye altitude 14,278 feet. Accessed May 27, 2021. Image USDA Farm Service Agency, July 25, 2010.

Figure 17. St. Joseph Harbor and Navigation Channel, St. Joseph River (34). 42.114207, -86.485725, eye altitude 3,925 feet. Accessed June 12, 2021. Google Earth Pro Imagery, March 25, 2019.

Figure 18. Holland Harbor, Macatawa River (8). 42.772691, -86.208198, eye altitude 3,589 feet. Accessed May 30, 2021. Google Earth Pro Imagery, March 18, 2021.

Figure 25. Portage River (55), Dam and Reservoir MI00673, 47.264463, -88.434508, eye elevation 1,607 feet. Accessed June 12, 2021. Google Earth Imagery June 6, 2017.

Figure 25. Au Gres River (1), Dam and Reservoir MI01729, 44.204442, -83.947972, eye elevation 3,782. Accessed June 14, 2021. Google Earth Imagery June 10, 2018.

Figure 25. Clinton River (12), Dam and Reservoir MI00670, 42.630827, -82.970333, eye elevation 5,135 feet. Accessed June 14, 2021. Google Earth, 2021 Maxar Technology Imagery May 5, 2020.

Figure 25. Saginaw River (32), Dam and Reservoir MI3004, 43.059805, -83.306811, eye elevation 737 feet. Accessed June 10, 2021. Google Earth Imagery March 24, 2019.

Figure 28. Cedar River Dam, MI00516, 44.977740, -85.190115, eye altitude 2,166 feet. Accessed June 10, 2021. Google Earth Imagery, May 8, 2016.

Figure 44. Loud Dam, MI00178, 44.4639, -83.7217, eye elevation 15,818 feet. Accessed June 19, 2021. Google Earth Pro, Earth Point Software USGS Topographic Map, Google Earth Imagery, June 22, 2016.

Figure 47. Location of RESSED Reservoirs, 42.250930, -83.342847, eye elevation 96.91 miles. Accessed June 23, 2021. Google Earth Pro, Image Landstat/Copernicus, NOAA Image, Google Earth Imagery.

Gray JR and Simoes JM. 2008. Estimating Sediment Discharge. IN: Appendix D, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Great Lakes Commission. 2001. Waste to Resource: Beneficial Use of Great Lakes Dredged Material Waste to Resource: Beneficial Use of Great Lakes Dredged Material. Great Lakes Commission, Ann Arbor, MI. https://www.csu.edu/cerc/documents/WastetoResource.pdf.

Great Lakes Environmental Center, Inc. (GLEC). 2011. Photograph of the Vibracore Sampling Equipment Used to Collect Sediment 4-inch Sediment Cores for Radiometric Dating, WSU Sediment Yield and Dam Capacity in the Great Lakes Watershed. GLEC, Traverse City, Michigan. Photograph Date: June 9, 2011.

Great Lakes Environmental Research Laboratory (GLERL). 2020. Great Lakes Mean Basin Precipitation and Temperature, Lake Superior, Lake Michigan, Lake Huron, Lake St. Clair, and Lake Erie. GLERL, Ann Arbor, Michigan. https://www.glerl.noaa.gov/ahps/mnth-hydro.html

Heinemann HG. 1981. A New Sediment Trap Efficiency Curve for Small Reservoirs. Water Resources Bulletin, American Water Works Associate. Volume 17, Number 5. Date: October 1981.

Hicks DM, Hill J, and Shankar U. 1996. Variation of Suspended Sediment Yields Around New Zealand: the Relative Importance of Rainfall and Geology. International Association of Hydrological Sciences. Publication 236, pages 149-156.

Hunter TS, Clites AH, Gronewold AD, and Campbell KB. 2015. Development and application of a North American Great Lakes hydrometeorological database - Part I: Precipitation, evaporation, runoff, and air temperature. Journal of Great Lakes Research Volume 41(1), pages 65-77. http://www.glerl.noaa.gov/pubs/fulltext/2015/20150006.pdf

Interagency Advisory Committee on Water Data (IACWD). 1982. Guidelines for determining flood flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Virginia.

Inman DL and Jenkins SA. 1999. Climate change and the episodicity of sediment flux of small California rivers. Journal of Geology, Volume 107, pages 251–270.

Jweda J. and Baskaran M. 2011. Interconnected riverine-lacustrine systems as sedimentary repositories: Case study in southeast Michigan using excess ^{210}Pb and ^{137}Cs-based sediment accumulation and mixing models. Journal of Great Lakes Research Volume 37, pages 432-446.

Kapsimalis V, Pavlakis P, Poulos SE, Alexandri ST, Sioulas A, Filippas D, and Lykousis V. 2005. Internal structure and evolution of the late Quaternary sequence in a shallow embayment: the Amvrakikos Gulf, Northwest Greece. Marine Geology, Volume 222, pages 399–418.

Kumar A, Hage-Hassan J, Baskaran M, Miller CJ, Selegean JP, and Creech CT. 2016. Multiple sediment cores from reservoirs are needed to reconstruct recent watershed changes from stable isotopes (δ13C and δ15N) and C/N ratios: case studies from the mid-western United States. Journal of Paleolimnology, Volume 56, pages 15–31.

Leopold LB and Emmett WW. 1997. Bedload and River Hydraulics—Inferences from the East Fork River, Wyoming." U.S. Geological Survey, Reston, Virginia. Professional Paper 1583.

Ludwig W and Probst JL. 1998. River sediment discharge to the ocean: present-day controls and global budgets. American Journal of Science, Volume 298, pages 265–295.

Mabit L, Meusburger K, Fulajtar E, Alewell C. 2013. The usefulness of ^{137}Cs as a tracer for soil erosion assessment: A critical reply to Parsons and Foster (2011). Earth Science Reviews, Volume 127, pages 300-307.

Mabit L, Benmansour M, Abric JM, Walling DE, Meusburger K, Iurian R, Bernard C, Tarjan ST, Owens PN, Blake WH, Alewell C. 2014. Fallout ^{210}Pb as a soil and sediment tracer in catchment sediment budget investigations: A review. Earth Science Reviews, Volume 138, November 2014, Pages 335-351.

MacArthur RC, Neill CR, Hall BR, Galay VJ, and Shvidchenko AB. 2008. Overview of Sediment Engineering. IN: Chapter 1, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

McCuen RH. 2004. Hydrologic Analysis and Design, Third Edition. Prentice Hall, Upple Saddle River, New Jersey.

Mehta AJ and McAnally WH. 2008. Fine-grained Sediment Transport. IN: Chapter 4, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Meyer-Peter E and Müller R. 1948. Formula for bedload transport. Proceedings of the 2nd Meeting of the International Association for Hydraulic Research, Delft, Netherlands.

Michigan Department of Natural Resources (MDNR). 1978. Michigan Resource Information System (MIRIS) land use/land cover polygon CAD. MDNR, Lansing, Michigan.

Michigan Department of Environmental Quality. 1988. Michigan's 1988 Non-Point Source Pollution Assessment Report. Michigan Department of Environmental Quality, Surface Water Quality Division, Lansing, Michigan

Michigan Department of Environmental Quality. 1992. NPS BMP Manual, Other BMP Design References, and Pollutants Controlled. MDEQ, Lansing, Michigan. Dates: 1992 (original), September 1997, October 1998, and June 2017. https://www.michigan.gov/egle/0,9429,7-135-3313_71618_3682_3714-118554--,00.html

Michigan Department of Environmental Quality. 1998. Guidebook for Best Management Practices for Michigan Watersheds. MDEQ, Lansing, Michigan. Date: October 1998. https://www.a2gov.org/departments/systems-planning/planning-areas/water-resources/Documents/MI-BMP-Guidebook_1998.pdf

Michigan Department of Environmental Quality. 1999. Stormwater Management Guidebook, MDEQ, Land and Water Management Division, Lansing, Michigan. https://www.michigan.gov/documents/deq/wrd-stormwater-guidebook_560012_7.pdf

Michigan Department of Environmental Quality. 2008. Qualitative Biological and Habitat Survey Protocols for Wadeable Streams and Rivers. Surface Water Assessment Section, MDEQ, Lansing, Michigan. Document Number: WB-SWAS-051. Document date: December 2008.

Michigan Department of Environmental Quality. 2010. Calculating Runoff Curve Numbers with GIS. MDEQ, Land and Water Management Division, Lansing, Michigan. https://www.michigan.gov/documents/deq/wrd-scs_558239_7.pdf

Michigan Department of Environmental Quality. 2016. Calculating runoff curve numbers with GIS. Michigan Department of Environmental Quality (now EGLE), Land and Water Management Division, Lansing, Michigan. https://www.michigan.gov/deq/0,4561,7-135-3313_3684_3724-112833--,00.html

Michigan Department of Environmental Quality. 2017. Michigan Non-Point Source Best Practices Manual. MDEQ, Environmental Assistance Center, Lansing, Michigan. Date: June 27, 2017. https://www.michigan.gov/egle/0,9429,7-135-3313_71618_3682_3714-118554--,00.html

Michigan Department of Environment, Great Lakes, and Energy (EGLE). 2018. Sediment Testing for Dredging Projects, WRD-048. EGLE, Water Resources Division, Water Policy and Procedures, Lansing, Michigan. Effective Date: April 13, 2018.

Michigan Department of Environment, Great Lakes, and Energy (EGLE). 2019. Hydrologic Studies and Dam Safety Unit staff of provided mean annual river flows and recurrence interval flows for 60 rivers and contributing watershed areas for 45 watersheds. EGLE, Water Resource Division, Lansing, Michigan.

Michigan Department of Environment, Great Lakes, and Energy (EGLE). 2020. Michigan Dam Inventory. EGLE, Hydrologic Studies and Dam Safety Unit, Water Resources Division, Lansing, Michigan. Date: December 21, 2020.

Michigan Department of Environment, Great Lakes, and Energy (EGLE). 2021. Michigan's Major Watersheds. EGLE, Water Resource Division, Lansing, Michigan. Date accessed. May 31, 2021. https://www.michigan.gov/documents/deq/wrd-mi-watersheds_559937_7.pdf

Michigan Department of Natural Resources. 1978. Michigan Resource Information System (MIRIS), Landuse/Cover Polygon. MDNR, Lansing, Michigan. http://www.dnr.state.mi.us/spatialdatalibrary/metadata/lu1978_PolygonCAD.htm

Michigan Department of Transportation (MDOT). 2018. MDOT Guidelines for Evaluation of Scour and Scour Analysis Work Sheets. MDOT, Lansing, Michigan. Document date: December 2018.

Milliman JD. 1980. Transfer of river-borne particulate material to the oceans. In Martin J, Burton JD, and Eisma D, eds. River inputs to ocean systems. UNESCO Review and Workshop. Rome, Food and Agriculture Organization of the United Nations, pages 5-12.

Milliman JD and Meade RH. 1983. Worldwide delivery of river sediment to the oceans. Journal of Geology, Volume 91, pages: 1–21

Milliman JD and Syvitski JPM. 1992. Geomorphic tectonic control of sediment discharge to the ocean: the importance of small mountainous rivers. Journal of Geology, Volume 100, pages: 525–544.

Milliman JD and Farnsworth KL. 2011. River discharge to the coastal ocean, a global synthesis. Cambridge University Press, Cabridge, United Kingdom.

Minear JT and Kondolf MG. 2009. Estimating reservoir sedimentation rates at large spatial and temporal scales: A case study of California. Water Resources Resarch, Volume 45, W12502, doi:10.1029/2007WR006703, 2009.

Montgomery DR. 2012. Dirt, The Erosion of Civilizations. University of California Press, Oakland, California. ISBN #9780520272903.

Morisawa M. 1968. Streams: their dynamics and morphology. McGraw Hill Book Company, New York.

Morris GL, Annanadale G, and Hotchkiss. 2008. Reservoir Sedimentation IN Sedimentation Engineering, Processes, Measurements, Modeling, and Practice. American Society of Civil Engineers (ASCE), ASCE Manuals and Reports on Engineering Practice No. 110.

Mulder T and Syvitski JPM. 1996. Climatic and Morphologic Relationships of Rivers: Implications of Sea Level Fluctuations on River Loads. Journal of Geology, Volume 104, pages 509-523.

Mulu A and Dwarakish GS. 2015. Different Approach for Using Trap Efficiency for Estimation of Reservoir Sedimentation. An Overview. International Conference On Water Resources, Coastal and Ocean Engineering (ICWRCOE 2015). Aquatic Procedia 4, pages: 847 – 852.

National Land Cover Databases (NLCD). 2011. National Land Cover Databases Multi-Resolution Land Characteristics Consortium (MRLC). Updated by the Michigan Department of Environmental Quality, 2005. http://www.mcgi.state.mi.us/mgdl/?rel=thext&action=thmname&cid=5&cat=Land+Cover+2005

NRCS. 1986. Urban Hydrology for Small Watersheds, Technical Release 55. Natural Resources Conservation Service, U.S. Department of Agriculuture, Washington D. C. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044171.pdf

NRCS. 2020. Web Soil Survey. Natural Resources Conservation Service, U.S. Department of Agriculture, Washington D. C. https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Ouyang D and Bartholic J. 1997. Predicting Sediment Delivery Ratio in Saginaw Bay Watershed. Institute of Water Research, Michigan State University, Lansing, Michigan. Proceedings of the 22nd National Association of Environmental Professionals, May 19-23, 1997, Orlando, FL, pages: 659 – 671. http://www.iwr.msu.edu/rusle/sdr/sdr.htm

Parker G. 2008. Transport of Gravel and Sediment Mixtures. IN: Chapter 3, Sedimentation Engineering, Processes Measurement, Modeling, and Practice, edited by Marcelo H. Garcia, Ph.D. American Society of Civil Engineers, Practice No. 110. ASCE, Reston, Virginia.

Pinet P and Souriau M. 1988. Continental erosion and large-scale relief. Journal Tectonics, Volume 7, pages 563–582.

Probst JL and Suchet S. 1992. Fluvial suspended sediment transport and mechanical sediment transport in Mahgreb. Hydrological Sciences Journal, Volume 37, Issue 6, pages: 621-637.

Riedel M, Selegean J, and Dahl T. 2010. Sediment Budget Development for the Great Lakes Region. 2nd Joint Federal Interagency Conference, Las Vegas, Nevada. Conference dates: June 27th to July 1st, 2010.

Ries III KG. 2007. The national streamflow statistics program: A computer program for estimating streamflow statistics for 545ngagged sites: U.S. Geological Survey Techniques and Methods 4-A6. U.S. Geological Survey Reston, Virginia.

Ritter J. 2015. Soil Erosion Causes and Effects. Ontario Ministry of Agriculture, Food, and Rural Affairs (OMAFRA), Ministry of Agriculture, Food and Rural Affairs, Guelph, Ontario. Publication Number: 12-053.

Sanchez-Cabeza JA and Ruiz-Fernandez JC. 2012. 210Pb sediment radiochronology: An integrated formulation and classification of dating models. Geochimica et Cosmochimica Acta, Volume 82, pages 183-200.

Schumm SA and Hadley RF. 1961. Progress in the application of landform analysis in studies of semiarid erosion. USGS, Washington D.C., USGS Circular 437.

Smith SDP et al. 2015. Rating Impacts in a Multi-Stressor World: a Quantitative Assessment of 50 Stressors Affecting the Great Lakes. Ecological Applications by the Ecological Society of America. Volume 25(3). Pages 717-728.

Sommerlot AR, Nejadhashemi, AP, Woznicki SA, Giri, S, and Prohaska, MD. 2013. Evaluating the Capabilities of Watershed-scale Models in Estimating Sediment Yield at Field-Scale. Journal of Environmental Management, Volume 127, September 2013, pages 228-336.

Stantec. 2014. Michigan Lake Plain Regional Reference Curves Project, Revised Bankfull Discharge for Selected Michigan Rivers and Regional Hydraulic Geometry Curves for Estimating Bankfull Characteristics in Southern Michigan Rivers Study. Prepared for the Michigan Department of Environmental Quality and the Bay County Drain Commissioner. Stantec, Ann Arbor, Michigan. Report Number: 2011-0100.

State of Michigan. 2020. Geographic Information System Open Data Portal. State of Michigan, Center for Shared Solutions, Lansing, Michigan. https://www.mcgi.state.mi.us/AGOOpenData/contact.html

Striffler DW. 1963. Suspended Sediment Concentrations in a Michigan Trout Stream as Related to Watershed Characteristics. Federal Interagency Sediment Conference, Symposium on Sedimentation, Jackson, MS. Publication 970, Paper 22.

Syvitski JPM. 2002. Supply and flux of sediment along hydrological pathways: research for the 21st century. Environmental Computation and Imaging Group, Institute of Arctic and Alpine Research, University of Colorado. Elsevier, Global and Planetary Change. Volume 39, pages 1-11.

Syvitski JP and Milliman JD. 2007. Geology, Geography, and Humans Battle for Dominance over the Delivery of Fluvial Sediments to the Coastal Ocean. Journal of Geology, The University of Chicago. Volume 115, pages 1-19.

Syvitski JPM and Kettner AJ. 2008. Scaling sediment flux across landscapes. Sediment dynamics in changing environments, proceedings of a symoposium held by Christchurch, New Zealand, December 2008. IAHS Publication 325, date 2008.

Syvitski JPM. 2019. Personal communication regarding application of the BQART equation to Michigan watersheds.

Thomas DM and Beson MA. 1975. Generalization of streamflow characteristics from drainage-basin characteristics: USGS, Lansing, Michigan. Water-Supply paper, pages 1-55.

Thomas WA, Copeland RR, and McComas DN. 2002. SAM –Hydraulic Design Package for Channels. U.S. Army Corps of Engineers Engineer Research and Development Center, Coastal and Hydraulics, Laboratory, Vicksburg MS.

Trimble SW and Lund SW. 1982. Soil Conservation and the Reduction of Erosion and Sedimentation in the Coon Creek Basin, Wisconsin. U.S. Geological Survey, Alexandria, Virgina. USGS Professional Paper 1234.

UNESCO. 2013. Soil Erosion and Sediment Production on Watershed Landscapes: Processes and Control. Peter F. Ffolliott, Daniel G. Neary, Kenneth N. Brooks, Roberto Pizarro Tapia, Pablo García Chevesich. The International Hydrological Programme (IHP) of the Regional Office for Science for Latin America and the Caribbean of the United Nations Educational, Scientific and Cultural Organizations (UNESCO).

U.S. Army Corps of Engineers. 1993. Figure 2-1 from HEC-6, Scour and Deposition in Rivers and Reservoirs, User’s Manual. USACE, Hydrologic Engineering Center, Davis, California. Date: August, 1993.

U.S. Army Corps of Engineers. 1995. Sedimentation Investigations of Rivers and Reservoirs. Department of the Army, Washington DC. Manual No. 1110-2-4000. Revision date: October 31, 1995.

U.S. Army Corps of Engineers. 1999. Saginaw River Basin Sediment Transport Modeling. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit Michigan. Report date: September 15, 1999.

U.S. Army Corps of Engineers. 2000. Sediment Transport Modeling: Saginaw Bay and Saginaw River Basin. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: October 2000.

U.S. Army Corps of Engineers. 2001. Sediment Trap Assessment, Saginaw River, Michigan. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: December 2001.

U.S. Army Corps of Engineers. 2005. Clinton River Sediment Transport Modeling Study. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: May 16, 2005.

U.S. Army Corps of Engineers. 2007a. St. Joseph River Sediment Transport Modeling Study. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: May 16, 2007.

U.S. Army Corps of Engineers. 2007b. Grand River Sediment Transport Modeling Study. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: May 23, 2007.

U.S. Army Corps of Engineers. 2007c. Sebewaing River Sediment Transport Modeling Study. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: December 2007.

U.S. Army Corps of Engineers. 2008. Fluvial Sediment Budget Development for the Great Lakes Region, Great Lakes Tributary Modeling Program (516(e)), Draft Document. USACE, Engineer Research and Development Center, USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: July 2008.

U.S. Army Corps of Engineers. 2010a. Ontonagon River Watershed 516(e) Sediment Study. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: August 2010.

U.S. Army Corps of Engineers. 2010b. Navigable Waters of the United States Within the U.S. Army Corps of Engineers, Detroit District. USACE, Detroit, Michigan. Date: January 10, 2010.

U.S. Army Corps of Engineers. 2012. Sediment Trap Assessment, Saginaw River, Michigan. USACE-Detroit District, Great Lakes Hydraulics and Hydrology Office, Detroit, Michigan. Report Date: February 13, 2012.

U.S. Army Corps of Engineers. 2014. Dredging backlog growth under constrained funding, 2013—2018. USACE Sediment Dredging Backlog Slide, Detroit District. May 2014. USACE, Detroit-District, Detroit, Michigan. http://www.lre.usace.army.mil/Portals/69/docs/Navigation/FY2015/backlogslidesMay2014.pdf

U.S. Army Corps of Engineers. 2015. Dredging and Dredged Material Management, Engineer Manual. U.S. Army Corps of Engineers, Washington D.C. EM1110-2-5025. Date: July 31, 2015.

U.S. Army Corps of Engineers. 2018. National Inventory of Dams Database. US Army Corps of Engineers, Washington, DC . https://nid.sec.usace.army.mil/

U.S. Army Corps of Engineers. 2019a. Condition Assessment Sheet VH103, St. Joseph Harbor and Navigation Channel. USACE Detroit District, Operations Office, Technical Services Branch, Detroit, Michigan. Date: April 2019.

U.S. Army Corps of Engineers. 2019b. Condition Assessment Sheet VH101, Holland Harbor and Navigation Channel. USACE Detroit District, Operations Office, Technical Services Branch, Detroit, Michigan. Date: July 2019.

U.S. Army Corps of Engineers. 2019c. Personnel communication with Josh Hachey, Chief, Technical Services Branch, Operations Office, USACE-Detroit District. Date: July 18th, 2019.

U.S. Army Corps of Engineers. 2020a. Great Lakes Harbors Fact Sheets. USACE Detroit District, Operations Office, Technical Services Branch, Detroit, Michigan. https://www.lre.usace.army.mil/Missions/Operations.aspx

U.S. Army Corps of Engineers. 2020b. Summary of Dredging Backlogs, Michigan Harbors. USACE-Detroit District, Technical Services Branch, Operations Office, USACE-Detroit District. Date: October 6, 2020.

U.S. Army Corps of Engineers. 2021a. FY21 Final Allocation, USACE-Detroit District, January 2021. https://www.lre.usace.army.mil/Portals/69/docs/Navigation/NavFundingSummaries/FY21%20GL%20Budget%20Workplan%20Final.pdf?ver=76t_iak12vhS8cB-18_nzw%3d%3d.

U.S. Army Corps of Engineers. 2021b. Ordinary High-Water Mark and Low Water Datum. USACE-Detroit District, Detroit, Michigan. https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Links/Ordinary-High-Water-Mark-and-Low-Water-Datum/

U.S. Army Corps of Engineers. 2021c. Maintenance Dredging Summary, Michigan Harbors, 2018 and 2019. USACE-Detroit District, Technical Services Branch, Operations Office, USACE-Detroit District. Date: January 13, 2021.

U.S. Army Corps of Engineers. 2021d. Great Lakes Water Level Data, 1918-2021, Long-term Mean, Max, and Min. USACE-Detroit District, Great Lakes Hydraulics and Hydrology, Detroit, Michigan. Date accessed: May 31, 2021. https://www.lre.usace.army.mil/Missions/Great-Lakes-Information/Great-Lakes-Information-2/Water-Level-Data/

U.S. Climate Data. 2019. https://www.usclimatedata.com/

U.S. Department of Agriculture. 1972. Natural Resources Conservation Service, NRCS National Engineering Handbook, Chapter 14, Stage-Discharge Relationships. USDA, Washington, D.C.

U.S. Department of Agriculture. 1983. National Engineering Handbook, Second Edition. Section 3, Sedimentation. Chapter 8, Sediment storage design criteria. USDA, Soil Conservation Service, Washington DC.

U.S. Department of Agriculture. 2007. National Engineering Handbook, Part 654, Stream Restoration Design. STREAMTools Sediment Transport Module 4.0. USDA, Natural Resources Conservation Services, Washington D.C. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/water/manage/restoration/?cid=stelprdb1043243

U.S. Department of Agriculture. 2011. National Land Cover Database. USDA, Washington D.C. https://data.nal.usda.gov/dataset/national-land-cover-database-2011-nlcd-2011.

U.S. Department of Agriculture. 2019. USDA Geospatial Data Gateway. https://datagateway.nrcs.usda.gov/

U.S. Department of Agriculture. 2019. Conservation Reserve Program Fact Sheet. USDA, Farm Service Agency, Washington D.C. Date: December 2019. https://www.fsa.usda.gov/Assets/USDA-FSA-Public/usdafiles/FactSheets/2019/conservation-reserve_program-fact_sheet.pdf

U.S. Department of Agriculture. 2021. Conservation Reserve Program, Acres Under Contract Each Fiscal Year, 1986-2019. USDA, Farm Service Agency, Washington D.C. https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index

U.S. Environmental Protection Agency and U.S. Army Corps of Engineers. 2007. Identifying, Planning, and Financing Beneficial Use Projects Using Dredged Material Beneficial Use Planning Manual. U.S. Environmental Protection Agency and U.S. Army Corps of Engineers, Washington D.C. Document Number: EPA842-B-07-001. Date: October 2007. https://www.epa.gov/sites/production/files/2015-08/documents/identifying_planning_and_financing_beneficial_use_projects.pdf

U.S. Environmental Protection Agency. 2021. Watershed Assessment, Tracking & Environmental Results System (WATERS) GeoViewer. USEPA, Washington D.C. https://www.epa.gov/waterdata/waters-geoviewer

U.S. Geological Survey. 1984a. National Water Summary – Hydrologic Events and Issues, USGS, Washington DC. Water Supply Paper: 2250.

U.S. Geological Survey. 1984b. Statistical Models for Estimating Flow Characteristics of Michigan Streams. USGS, Lansing, Michigan. Water-Resources Investigations Report 84-4207. http://pubs.usgs.gov/wri/1984/4207/report.pdf.

U.S. Geological Survey. 1984c. Sediment characteristics of Tennessee Streams and Reservoirs. USGS, Nashville, Tennessee. Open File Report 84-749.

U.S. Geological Survey. 1994. Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites. U.S. Geological Survey, Reston, VA. Water-Resources Investigations Report 94-4002.

U.S. Geological Survey. 1998. Indirect Groundwater Discharge to the Great Lakes. U.S. Geological Survey, U.S. Department of Interior, Denver, Colorado. Open-File Report 98-579.

U.S. Geological Survey. 2005. Base Flow in the Great Lakes Basin. U.S. Geological Survey, U.S. Department of Interior, Denver, Colorado. Scientific Investigations Report 2005-5217.

U.S. Geological Survey. 2009. Estimated Bankfull Discharge for Selected Michigan Rivers and Regional Hydraulic Geometry Curves for Estimating Bankfull Characteristics in Southern Michigan Rivers. U.S. Department of the Interior, USGS, Washington DC. Scientific Investigations Report 2009–5133.

U.S. Geological Survey. 2011. Sediment Load from Major Rivers into Puget Sound and its Adjacent Waters. U.S. Department of the Interior, USGS, Washington DC. https://pubs.usgs.gov/fs/2011/3083/pdf/fs20113083.pdf

U.S. Geological Survey. 2014. Reservoir Sedimentation (RESSED) Database, U.S. Department of the Interior, USGS, Washington DC. https://water.usgs.gov/osw/ressed/

U.S. Geological Survey. 2016. Diagram of Channel Cross-Section IN: How Stream Flow is Measured. USGS, Water Science School, Washington D.C. Figure Credit: Credit: S.A. Olson and J.M. Norris, USGS. https://www.usgs.gov/special-topic/water-science-school/science/how-streamflow-measured?qt-science_center_objects=0#qt-science_center_objects

U.S. Geological Survey. 2019a. National Map Viewer. USGS, National Geospatial Program (NGP), U.S. Department of the Interior, Washington D.C. https://www.usgs.gov/core-science-systems/ngp/tnm-delivery

U.S. Geological Survey. 2019b. Guidelines for Determining Flood Flow Frequency Bulletin 17C, Chapter 5 of Section B Surface Water, Book 4, Hydrologic Analysis and Interpretation, Techniques and Methods 4-B5, Version 1.1. U.S. Department of the Interior, Washington D.C Date: May 2019. tm4b5.pdf - Guidelines for Determining Flood Flow Frequency—Bulletin 17C (usgs.gov)

U.S. Geological Survey. 2020. National Hydrography Dataset (NHD). USGS, National Geospatial Program (NGP), U.S. Department of the Interior, Washington D.C. https://www.usgs.gov/core-science-systems/ngp/national-hydrography

U.S. Geological Survey. 2021. Regionalization of Surface-Water Statistics Using Multiple Linear Regression, Chapter 12 of Section A, Statistical Analysis, of Book 4, Hydrologic Analysis and Interpretation. USGS, U.S. Department of the Interior, Washington D.C. Techniques and Methods 4A12 Version 1.1, February 2021. https://doi.org/10.3133/tm4A12

Verstraeten G and Poesen J. 2000. Estimating trap efficiency of small reservoirs and ponds: methods and implications for the assessment of sediment yield. Progress in Physical Geograph. Volume 24, Pages 219-251.

Vorosmarty C, Meybeck M, Fekete B, Sharma K, Green P, and Syvitski JPM. 2003. Anthropogenic sediment retention: major global-scale impact from the population of registered impoundments. Global and Planetary Change. Volume 39, pages 169-190.

Wayne State University. 2017. Sediment Yield and Dam Capacity in the Great Lakes Watershed. Report prepared in behalf of the USACE-Detroit District. Wayne State University, Detroit, Michigan. Report date: May 2017.

Wilson L. 1973. Variations in mean annual sediment yield as a function of mean annual precipitation. American Journal of Science, Volume 273, pages 335–349.

Yalin MS. 1963. An expression for bed-load transportation. Journal of Hydraulics Division, Volume 89 (3): 221–250.

Yang CT. 2006. Reclamation, Managing Water in the West, Erosion and Sedimentation Manual. U.S. Department of the Interior, Bureau of Reclamation. U.S. Government Printing Office, ISBN-10, 0-16-077628-7.

ABSTRACT

ESTIMATING BEDLOAD SEDIMENT DELIVERY TO THE GREAT LAKES FROM SIXTY MICHIGAN RIVERS

by

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Major: Civil and Environmental Engineering

Degree: Doctor of Philosophy

This research involved development of an empirical equation using regression analysis to predict bedload sediment delivery to the river outlet of 60 Michigan rivers and five sub-watersheds. Watershed sediment delivery is the total amount of sediment generated within a watershed and delivered to the river outlet over a particular timeframe. Estimation of watershed sediment delivery involves an understanding of the complex processes of soil erosion, sediment transport, and sediment deposition. The total sediment load transported by a river to the river outlet consists of dissolved load, wash load (silts and clays), and bed material load. Bed material load consists of suspended load and bed load. Suspended load is the portion of the bed material load that is lifted by turbulence to travel within the water column above the river bed at elevations greater than a few sediment grain diameters. Prediction of bed load sediment delivery at the river outlet was the focus of this research and is the portion of the bed material load that travels within a few grain diameters of the river bed and moves by rolling, sliding, and saltating

along the bed of the river. With respect to the regression analysis, the dependent variable was the measured watershed sediment delivery estimates based on (1) analysis of U.S. Army Corps of Engineers dredging data at federally maintained Harbors and navigation channels at the outlets of 12 Michigan rivers, and (2) watershed sediment delivery estimates based on the results of ^{137}Cs and ^{210}Pb radiometric dating of sediment cores collected from five Michigan reservoirs. Eighteen characteristics of the fluvial system and watershed were evaluated using step-wise regression analysis. Based on log normal transformation of the dependent and independent variables, a regression equation was developed to predict bedload sediment delivery to the river outlet using three predictor variables: the 1.5-year recurrence interval flow of the river, the percent of the watershed covered in upland and aquatic wetlands, and the percent of the watershed covered in manmade reservoirs.

AUTOBIOGRAPHICAL STATEMENT

At an early age, I developed a strong interest in earth processes and fluvial systems, especially the movement and interaction of soil, groundwater, surface water and sediment. I received my Bachelors of Science in Geology from Michigan State University during 1983 and a Master of Science in Hazardous Waste Management from the Department of Engineering at Wayne State University during 1991.

Since 1984, I have worked as a consultant for a variety of industrial, municipal and government clients and have extensive experience in site investigation and remediation at federal RCRA Corrective Action sites, Superfund sites, at a wide range of industrial, commercial, and military sites encompassing the following industries:

Military Munitions Manufacturing	Metal Plating Operations
Automotive Parts Manufacturing	Foundry Operations
Petroleum Refining and Storage	Coal Fired Power Plants
RCRA Hazardous Waste Landfills	Municipal Landfills

The research associated with my Doctorate in Civil Engineering at Wayne State University involved extensive study with respect to sediment transport and sediment delivery in rivers, impoundments, and coastal areas. My graduate work included coursework and research in open channel hydraulics, hydrologic analysis and design, surface water quality modelling, river assessment and restoration, and sediment transport.