Introduction

In 2013, a Michigan Sea Grant award was presented to further the development of implementation of the two-stage channel. The focus of this award was to address the lack of technical basis in the drain code in Macomb County, provide options for transferring this process to other counties, and to provide a public outreach in order to ensure an understanding of these guidelines in the public, particularly to engineers in the area. This report describes the need for this project and the results of the project. The focus of the effort is the Clinton River Watershed, and Macomb County in particular.

Need for Two-Stage Channel Design

In the summer of 2014, Lake Erie experienced one of the worst summers for algal blooms. The algal blooms were so bad that the water intake for drinking water in Toledo, Ohio was determined to be too toxic for consumption, leaving 500,000 people without clean drinking water (source). This event was not new: the western basin of Lake Erie has been experiencing algal blooms for years during the summer. While algal blooms are not uncommon in bodies of water, the extent of Lake Erie's was particularly significant.

The reasons behind the algal blooms can be narrowed down to three basic premises: the summer months heat the water in the lake allowing a comfortable environment for algae to flourish, the western basin of Lake Erie is relatively shallow which allows light and heat to access a higher percent of the water column, and the loading of nutrients into the lake is high. While the first two situations are natural situations that cannot easily be changed, a solution for the third problem can be determined more easily.

Nutrient loading can be caused by a number of factors. Urban runoff, specifically from fertilized lawns, will ultimately end up in waterways. In addition, during large storm events sewer overflow is sometimes released in order to prevent flooding in urban areas. This release, which contains human waste, is high in phosphorous and nitrogen which both can accelerate algal growth. Ultimately though, the biggest issue is runoff from farming practices.

Drainage ditches are the most common conduit for transporting runoff from fields. A traditional drainage ditch is designed to transport water quickly from the fields during high storm events. However, due to its simplicity, it's doesn't act as a natural channel would and is faced with numerous problems:

- high bank erosion rates and channel bed sedimentation which requires frequent dredging and maintenance
- low flow during dry periods causing warmer water temperatures, increased turbidity, and lower oxygen levels
- little vegetation sustained in these channels which prevents natural absorption of pollutants

A solution to these issues is to redesign drains in order to mimic a natural channel which, on the whole, does not experience these issues. One way to do this is to use a multi-staged design approach.

A multi-staged design approach incorporates multiple levels into the stream. The lowest level, the low flow channel, allows, as the name suggests, low flow to continue through the channel to prevent standing water during drier periods. The next level incorporates benches and is also wider than a conventional trapezoidal channel. This allows water to be conveyed during large storm events but slows the velocity of the water. The slower velocity is the key to this. This prevents erosion and encourages plant life to proliferate, thereby increasing natural absorption of nutrients. Because of the lessened erosion, the need for maintenance also decreases. Beyond this, the channel can be designed with a floodplain, or can just be left as a two-stage channel drain.

In 2008, Macomb County, Michigan updated their drain code and incorporated two-stage ditch design guidelines for open channels. They also incorporated landscaping requirements. Prior to this, the two-stage design had been recommended. However, it was never actually formally written into code until this publication. In this publication, the two-stage design is accurately explained and discussed, however, it gives little technical basis for design and thus, there was little use of this very important and sustainable approach for channel design.

Project Objectives

The main objective of this project is to the development of tools/information to make it easier for people to further the use of the two-stage drains in Macomb County and elsewhere. In order to further this effort in Macomb County, where the two-stage drain guidelines already exist, we look at how we can improve these guidelines. Two approaches will be taken: looking at it from a technical angle and looking at it from a social angle. Outside of Macomb County, it's important to understand how these guidelines can be implemented. All of these are discussed further below.

In essence, the design criteria needing development is a regional curve for the Middle and North Branches of the Clinton River. A regional curve is a way of comparing the drainage area to the bankfull area, bankfull width, and the flow of runoff in a particular area. This allows one to determine the design dimensions for a two-stage channel.

Guidelines need to be implemented into the drain code that help engineers better design these drains. By recommending a regional curve, providing more information for two-stage design, and further clarifying the landscaping requirements for these drains, engineers will be better suited to design them.

In addition to providing technical criteria, outreach is important. In order to make sure that this can be implemented, the public needs to be involved, particularly those who will be designing these. Through a survey and public meeting, we gaged what those involved in designing two-stage channels want in order to help make the design process easier and the results from both of these will be analyzed and considered.

Last, the feasibility of implementing these procedures elsewhere will be examined. Eventually, the purpose is to make sure two-stage channels can be implemented on a large scale, since this will have the most benefit particularly related to ecological benefits in water bodies like Lake Erie. A number of different factors will help determine whether or not a region is a good place to implement two-stage channel guidelines. And most importantly, we'll end with a discussion of Macomb County and how they first implemented two-stage design into their guidelines in 2008.

The Clinton River Watershed

History of the Clinton River Watershed

The Clinton River watershed's hydrology, morphology, and gradient were all shaped by the Late Wisconsian glacier about 18,000 years ago. About 16,000 years ago, the glacier started to retreat and 10,000 years ago, the glacier had fully exposed Michigan. At this point, Native Americans settled here and at the time, primarily focused on hunting and minimal fathering for food. Eventually, as the climate warmed, they started growing crops. However, in the 17th century, the French arrived causing depopulation among the native population primarily due to disease and social turmoil.

In 1782, German Moravians were the first settlers on the Clinton River and in 1801, Christian Clemens established High Banks, a settlement that would eventually become Mount Clemens. In 1825, the name Clinton River was finally given to the river system, named after New York's governor DeWitt Clinton following the completion of the Erie Canal. It's presumed that around the 1840's is when land drainage for agriculture first was established in the area .

The population didn't substantially begin to increase until the beginning of the 20th century. Industries flooded the area in the beginning of World War II and population expanded drastically after the war. Between 1950 and 1970, Macomb County's population more than tripled, increasing from 185,000 to 625,000. From then, it steadily increased to the 2013 population of 854,769.

The land use has changed throughout the years since the first European settlers. At this time, the land was primarily forested but over time, the land moved toward agricultural use and, in more recent history, has been replaced with urban land use. Despite the urban sprawl within the county, north Macomb County still exists primarily as agricultural land.

Due to the rapid development after World War II, the impermeability of the land increased and flooding soon became an issue downstream. In Mount Clemens, a spillway had to be built between the city and Lake St. Clair.

The Clinton River

The Clinton River is made of seven subwatersheds: Clinton Main, Clinton River East, Lake St. Clair Drainage, North Branch, Red Run, Stony/Paint Creek, and Upper Clinton. Each subwatershed has many unique features; hydrologic features vary significantly within the subwatersheds. For example, the Upper Clinton and Clinton Main subwatersheds contain many lakes so flow tends to be slower and water tends to be warmer in temperature. The river mostly acts as a connector between the lakes. The Paint Creek/Stony Creek subwatersheds tend to have faster and steeper currents, which is what attracted mills to this area early on. Paint Creek and the North Branch are both cool-cold water streams. Finally, the Clinton River East Branch is mostly mild slope and dominated by run-off, having warm temperatures.

The water quality also varies among the watersheds. Pontiac, for example, was a very industrious town by the mid 1800's, which caused point source pollution issues. Because of this, downstream of Pontiac in the Clinton Main Watershed, fish populations have only relatively recently been better. In the 1970's, stations sampled in this area indicated low populations and very low pollution intolerant species populations. However, after the 1980's, pollution intolerant species were found more commonly in the area.

Most areas surveyed within the Clinton River Assessment were deemed acceptable or excellent. However, some were not: including the McClure Drain within the Stoney Creek watershed; Red Run Drain and Gibson Drain within the Red Run Watershed; and a number of downstream portions of the Clinton East. In fact, a number of the poorer quality areas are downstream portions within Macomb County. Apel Drain is an example of this, having been channelized and having numerous parts of the drains that are silted.

The stream flow of the river has ranged significantly over the years from an average of 230 cfs to a peak of 1,142 cfs. Precipitation has varied widely through the years, showing no significant pattern which indicates that infiltration rate changes are the perpetrators of this issue.

The population within the watershed has increased substantially: going from 98,000 in 1900 to 2 million in 2000. According to the Southeast Michigan Council of Governments (SEMCOG), impervious land was at 21.8% and open space is at 51.6% within Macomb County at this point in history.

While at first glance, open space may seem like a good thing, that is not always true. Ecologically speaking, open space accounts for land that is mowed, turfgrass, and of course, agricultural land. If we assume that tile drainage is prevalent in the county, it would mean that much of the agricultural land is a source of direct runoff. In 2008, a similar study by SEMCOG found that agricultural land was at 23% in Macomb County.

Macomb County and the Clinton River

The Clinton River drains 763 square miles of area in southeastern Michigan and along with its tributaries, flows through 60 communities with a population of 1.4 million. The watershed covers parts of 4 counties in Michigan, but the county it covers most of all is Macomb County, covering approximately 75% of it. It can't be understated how important the watershed is to the county. It provides recreation such as boating, paddling, and even public swimming. And in the past, as discussed earlier, it was a major reason why settlers chose the area.

In addition to the Clinton River, Lake St. Clair, which receives the Clinton Rivers flow, is also an important part of Macomb County. Lake St. Clair's total shoreline length in the US is over 89 miles (https://www.census.gov/compendia/statab/2012/tables/12s0360.pdf) and a large portion of this is Macomb County communities. The shoreline is home to beach access, marinas and residential and commercial lands whose land values are at a premium.

Despite its importance, human intervention has degraded the watershed quality thus far. Through land use alterations that have increased storm flow and runoff; channel morphology alterations and dam installations; factors that have degraded water quality such as CSOs, storm sewers, nonpoint sources, and NPDES discharges among numerous other influences, the watershed's quality has decreased substantially compared to years before development.

Despite the decrease in quality since development, the passage of the Clean Water Act in 1972 curbed a lot of the water quality issues. It implemented wastewater standards for industry, a major issue in the Clinton River, and made it unlawful to discharge a pollutant without a previously acquired permit. Since then, the quality of the Clinton River has increased substantially through the construction of wastewater treatment plants in the cities of Pontiac and Warren and the joining of other communities to Detroit's wastewater system.

The Clean Water Act improved the water quality but there is still more to be done. The Clinton River Assessment compiled a list of options that can be used to improve the water quality including protecting and restoring natural hydrologic features such as groundwater recharge, natural lake levels, and wetlands; avoiding excess sediment; protecting riparian zones, critical areas, and water quality; restoring habitat through unused dam removal and bridge reparation; surveying species in the river to determine critical habitat; and promoting citizen involvement in the protection and restoration of the watershed.

Multiple issues discussed in the assessment including decreasing sedimentation and promoting and supporting best management practices (BMPs) to reduce nutrient inflows into the river are related to the two-stage drain implementation. As discussed in future sections, the drains can improve water quality in streams. Considering that many of the downstream portions of streams within Macomb County are considered poor quality for fish habitat, it's vital to improve the water quality through two-stage drain construction.

Literature Review

Nutrient Loading

Arguably, one of the most significant impacts humans have had on the environment is the loading of nutrients into water bodies. Its effects are seen worldwide; from seasonal hypoxia at the mouth of the Mississippi River in the Gulf of Mexico to longer lasting hypoxia in the Chesapeake Bay. More recently, the effects of nutrient loading have been brought into the public eye in the western basin of Lake Erie. In the summer of 2014, Lake Erie experienced algal blooms so great that populations surrounding the western basin were instructed to not drink their water due to toxicity. While algal blooms are a reoccurring event in Lake Erie, the extent of the bloom in 2014 brought the issue to light with the public.

The Clinton River watershed empties into the western side of Lake St. Clair, loading the nutrients from the runoff within the watershed into the lake. As a result, algal blooms have developed at times on the western shore of the lake. Despite this, little research has been done on water quality and the effects of nutrient loading on the lake. In the Great Lakes region, the most impacted body of water is Lake Erie, which as discussed earlier, has been the subject of algal blooms among other problems caused by nutrient loading. Because of this, most of the research discussed further will pertain to Lake Erie. Ideally, it's hoped that this model for drainage design will eventually be used as a framework for other governments in the area, namely those within the Lake Erie watershed.

Causes

Nutrient loading happens in almost any body of water near humans, but it takes a special set of circumstances to cause detriment to the environment. While nutrient loading occurs in all the Great Lakes (Robertson and Saad, 2011), Lake Erie sees the most impact from this loading.

Some of the reasons why nutrient loading has such a high impact on the lake is summarized below:

- Lake Erie has the shallowest average depth causing warmer waters than any other lake. This also allows the hypoxic zone to expand from lower levels of the lake to shallower depths more easily.
- Zebra Mussels were introduced to the lake in 1988. They filter large quantities of water, making the water clearer and allowing sunlight to get through the water better to algae. While clean water is beneficial, it also causes algae blooms to grow at an extreme rate.
- Lake Erie's watershed includes a high proportion of the total population of the Great Lakes basin with 17 cities with populations over 50,000 residing in it and has the largest percentage of agricultural areas.

Due to these circumstances, Lake Erie is a prime target for eutrophication. In freshwater systems, it's generally concluded that phosphorus is the limiting nutrient. Because of this, most of the research relating to the Great Lakes and Lake Erie in particular focus on phosphorus reductions. However, nitrogen also plays a role; without nitrogen, phytoplankton would be unable to survive. In addition, during the summer nitrogen may play a greater role in nutrient loading due to the depletion of dissolved nutrients from the photic zone.

When Robertson and Saad (2011) modelled nutrient inputs into the Great Lakes using the Spatially Referenced Regressions on Watershed attributes (SPARROW) models, they found total nitrogen and total phosphorous levels were highest to Lake Erie than any other lake. Agricultural inputs were the largest source of nitrogen (56%) and fertilizer made up about 26% of the total nutrient input. Scavia et al. (2014) studied which phosphorous sources contributed most to the lake and therefore, which sources should be targeted for reduction. Ultimately, loads to the western basin of Lake Erie had most effects on the eutrophication of the central basin and non-point sources contributed most to the nutrient loading.

Furthermore, Scavia et al. considered the influence of climate change: more precipitation, lower lake levels, and warmer temperature which all are expected to exacerbate the hypoxia. The increase in precipitation which accounts for 60-75% of P inputs will increase nutrient loading, the lower lake levels will make it deplete dissolved oxygen, and the warmer temperatures will allow phytoplankton to thrive.

Effects

Scavia et al. (2014) reviewed all the effects of nutrient loading in Lake Erie. Nutrient loading causes an increase in algae production which eventually decompose. As the algae decompose, oxygen is consumed and dissolved oxygen rates plummet causing a hypoxic zone. For the most part, this hypoxic zone reduces the availability of quality habitat for fish harming their populations. Models indicated decline in habitat quality with increase in total phosphorous loads, with the most reductions occurring after phosphorous levels exceeded about 5000 MT/year.

Decrease in loads

Rucinski et al. (2013) modeled the hypoxia response to nutrient loads in Lake Erie. The model was developed with respect to eutrophication and hydrodynamic features and adjusted based on 19 years of observations. The results indicated total phosphorous loads to the western and central basin would need to be significantly decreased to 4300 MT/year to reduce the hypoxic area and dissolved reactive phosphorous must decrease 78% from 2005-2011 average loads. Depending on the focus (i.e. cyanobactria reduction, Mystoscis reduction, etc.), different areas would need different amount of decrease in load. However, the main takeaway is that the load needs to decrease substantially in order to decrease the hypoxia in the central basin.

Bosch et al. went a step further to analyze the effects of Best Management Practices (BMPs) and climate change on nutrient runoff entering Lake Erie. Models looked at a number of rivers and looked at the effects of no climate change, moderate climate change, and pronounced climate change as well as the effects of no BMPs, moderate BMPs, and high BMPs. The BMPs they modeled included no-till, cover crops, and filter strips. Ultimately, climate had a prominent effect on the loads into the lake. As the effects of climate change became more pronounced, the effectiveness of BMPs to reduce sediment, water, and nutrient export decreased. Despite this, expanded implementation of BMPs still play an important role in offsetting the anticipated impacts of climate change. Due to the results of these models, it's clear that decreased nutrient loads is necessary to achieve hypoxia reduction and to offset the impacts of climate change.

While these models indicate the importance and impact that the decrease of nutrient loads can have, it's also necessary to realize that there are flaws in these models. Kim et al. (2014) evaluated and discussed the capacity of nutrient loading models for Lake Erie. Most datasets were found to have issues with parameterization, specifically being over-parameterized and having distinct differences in values. It's important to realize that the results of all these models are subject to significant scrutiny. The models are most helpful in comparing results of various land use scenarios on resulting loading.

Drainage

Prior to colonization in the United States, much of the Midwest was made up of wetlands. Due to the fertility of the soil, this land was ideal for cropland. However, in order to utilize this soil, the land was drained to keep it from being inundated and to prevent crop-loss from excess water. As technology furthered in the late 1800’s, open-ditch drainage networks and subsurface drainage systems were installed (Dahl and Allord, 1997).

In addition to preventing inundation and allowing natural wetland areas to be used for farming, drainage networks also allow more flexibility for farmers: a wider variety of crops can be planted, crops can be planted earlier, and crops are less susceptible to pests that thrive in marsh-like conditions, preventing the necessity for over-application of fungicides and pesticides (Blann et al. 2009). They also provide habitat for plants, invertebrates, fish, amphibians, birds, and mammals and function as ecosystems with respect to nutrient cycling, erosion control, water purification, and even providing pollination and pest control (Herzon and Helenius 2008).

Traditional drainage

Initial drainage systems focused on straightening and expanding existing streams and connecting agricultural fields to waterways done by dredging. These were designed to transport run-off from large storm events. Many drain codes reference a trapezoidal or V-ditch design to transport run-off, as these are simple to design.

Subsurface Drainage

Subsurface drainage has also been an option for shifting inundated land to agricultural land. Although it requires a greater initial investment, subsurface drainage has allowed quicker drainage and requires less space than drainage ditches. Subsurface drainage can also be used to control the water table better, allowing plants to root deeper and grow larger. Despite these seeming benefits, tile drainage used as a stand-alone drainage system reduces the residence time of the water and serves as a more direct route for nutrients to reach waterways, causing higher transport rates.

Issues with conventional drainage systems

As discussed earlier, drains have been constructed to move water from agriculture fields as quickly as possible. During large storms, it's easy for land to get flooded. By making drainage systems that transport these large volumes of water as quickly as possible, it can prevent a lot of the flooding issues. However, this traditional way of building ditches has caused issues within ditches and downstream of ditches (Madramootoo et al., 2007; Schottler et al, 2013; Short et al.).

Madramootoo et al. (2007) considered general issues associated with agricultural drainage. The main issues discussed are related to nutrient run-off. Most of the nutrient run-off in the Midwest has affected the western basin of Lake Erie, both which have seen hypoxic conditions. Traditionally, drainage practices focused on straightening and deepening the natural channels to increase their ability to transport water off the land. However, this practice separated the streams from the floodplain, lowering the ecological function of these waterways. Not only does it discourage species, but it also lowers the water quality. Drainage management seems to be the best way to combat these issues by encouraging systems that connect the channel and floodplain.

Needelman et al. (2007) provided a general overview of ditch management for improved water quality. The article highlights the issues with nutrients and sediment- the problems with nitrogen saturation in ditches and the transport of nitrogen and sediment. It also highlights the current in-ditch management, which require vegetation maintenance and dredging, both of which are an expense to the farmer.

Schottler et al. (2013) discussed the presence of excess sediment in rivers. The culprit of this issue is excess run-off caused by changes in land-use and climate, but Schottler considered each of these issues separately. To look at the effects of each: precipitation, crop conversions, and extent of drained depressional areas were compared. The research concludes that crop conversions- specifically forage crops displaced by soybean crops- have increased the amount of run-off and decreased the amount of evapotranspiration. In addition, the loss of residence time in the drainage systems has impacted the hydrological budget dramatically and by decreasing the amount of evapotranspiration, has increased the river flow.

In Shore et al.'s study (2014) on agriculture drainage channels, it was found that the drainage ditches most likely to have the greatest potential in mitigating particulate P were those that were low in slope as the sediment was less likely to be mobilized except for during large storms. In addition, channels that could retain sediments had the greatest potential in mitigating downstream P transfers. While it was mentioned that dredging can be helpful in allowing for more sediment retention, they also made it clear that dredging has downsides, including reducing the short-term soluble P adsorption capacity. Lastly, those streams with more surface area would do the best as there is more availability for P to adsorb. Ultimately, streams with the lowest velocities and largest areas for adsorption were the best options for mitigation.

Sharpley et al.'s (2007) analysis of drainage ditch management focused on phosphorus. In order to understand how and when phosphorus sorbs, an indoor fluvarium was used to model a stream. It was found that agricultural areas had a much higher equilibrium phosphorus content (over 10 times as much) compared to forested or mixed use land. In addition, as phosphorus sediment content in equilibrium increased, the potential for phosphorus release also increased. More interesting, the agricultural ditch sediments proved more effective than the other ditches.

In agricultural ditches, biotic processes play an important role in the uptake and release of phosphorus, much more than other ditches, indicating that the presence of biota leads to increases the uptake of phosphorus. Although other studies indicate that the presence of biota plays a much smaller role (Meyer 1979; Klotz 1988), it still does play a role, demonstrating that biota is important in nutrient removal.

The studies indicate that the methods (or lack of) of design for drainage systems have had disruptive impacts on the environments around these ditches. The biggest issues are the excess sediment and the nutrient loading. These issues are intertwined; the soil in the ditch can sorb nutrients and act as a sink for phosphorus. However, during large storms, the excess run-off causes the bank (which holds the nutrients as well) to erode, causing sediment to be released into downstream waterways. The solution to this issue was to decrease the shear- in essence, increase the residence time within the ditch. By designing a large ditch that can accompany large flows, the shear on the ditch will decrease, causing less sediment and less nutrient loading.

Furthermore, the more natural the design of the ditch, namely the connection to the floodplain, encourages vegetation to thrive within the ditch. This will allow phosphorus and nitrogen to be naturally removed from the run-off and prevent higher rates of nutrients downstream.

Two-Stage Ditches

As discussed earlier, ditches were originally constructed to drain former fertile wetlands as quickly as possible, particularly during large storms. Due to this, the design of the ditches focused almost exclusively on the transport function. Thus, designs featured primarily the straight, trapezoidal shaped ditches. While this provided a great method of transporting the water, it offered little ecological benefit due to the channels being separated from the floodplain and the steep slopes of the channel preventing plants to grow. In addition, the design of the channels yields high velocities and increased shear stresses on the channel, making it easier for sediment to transport and increasing the likelihood of failure of the channel walls. With the increase in sediment transport and the loss of plant life, the water quality also decreases.

Despite the issues with conventional drainage, there is an opportunity to alter the design of ditches in order to prevent some of these issues. Two-stage ditches offer a solution to many of these problems. Two-stage ditches may be able to increase water quality of run-off in agricultural areas (Roley, 2012; Roley, 2013) and prevent sediment issues in these ditches thereby increasing bank stability.

Stream quality

In Olli et al.'s study on phosphorus (P) transport and retention in drainage ditches, they studied the amount of phosphorus in different ditches, separating the phosphorus into dissolved phosphorus and bounded phosphorus. They found that downstream P concentrations tended to change with drainage reach depth and water flow conditions. Areas without tile-drained fields contained relatively low bounded phosphorus and areas with tile-drained flow contained much high amount of bounded phosphorus, about half of which was bioavailable. In the latter situation which is common in the Midwest, they predict bounded phosphorus would contribute more to eutrophication than dissolved phosphorus. Most notably, in one reach section with heavy vegetation, a majority of the bounded phosphorus was retained, indicating that more naturally vegetated channels may yield the highest amount of retained phosphorus.

Roley et al. (2012) looked at the effect that floodplain restoration (two-stage ditches) had on nitrogen in the water. Denitrification rates and residence times were the two factors analyzed in order to understand the efficacy of the nitrogen removal in the restoration. Higher residence times lead to higher denitrification rates because it allows water to have more interaction with the soil which then yields higher nitrogen removal. The most noticeable results were during storm flow when the floodplain is inundated with water; denitrification was more pronounced during this times. In addition, denitrification rates were most effective when nitrogen rates were lower. Therefore, when used in conjunction with another BMP, it seems likely to be able to remove nitrogen in higher quantities.

In a later study, Roley et al. (2013) studied the influence restoration had on the whole-stream metabolism, i.e. the ecosystems productivity. To analyze this, the gross primary production (GPP) and ecosystem restoration (ER) were measured and compared before and after restoration. Overall, these factors did not positively affect the ER, but they did have some effect on the GPP, which saw increased resilience. The GPP resistance is important since nutrient uptake tends to be higher in during storms.

Overall, both these studies indicate positive effects of floodplain restoration with respect to the quality of the stream. Notably, the improved water quality came during storm flow. This is important since agriculture streams tend to export the highest amount of nutrients during large storm events (Royer et al. 2006).

Royer et al. (2012) focuses solely on nitrogen, which is an important nutrient in salt-water systems. However, within the Great Lakes, phosphorus is the limiting nutrient. Phosphorus behaves different than nitrogen. Due to its ability to sorb easier to sediments, ditches can act as sources or sinks of phosphorus in addition to ditches being a conduit for contaminants from agricultural fields to waterways. Because of this, different aspects need to be considered when studying the ability of a ditch to manage these nutrients.

Krider et al. developed a guidance report regarding ditch designs. One important aspect of the report was a feasibility analysis of two-stage ditch designs. Since two-stage ditch designs require less ditch maintenance, this is the greatest economic benefit. In addition, as explained above, the two-stage ditch offers numerous ecological benefits.

Ditch Design

Arguably, the most important part of the two-stage drain implementation is the design aspect. Fortunately, Macomb County Drain Office provides design standards. However, the standards don’t provide much helpful guidance to the engineer or land owner. There are a number of things the county can do to improve their drain code in order to further help drain designers.

One thing they can consider adding is a regional curve. A regional curve relates the drainage area that runs off into a stream to the bankfull discharge, area, or width. In this section, the results of a number of stream surveys will be discussed and a regional curve will be assembled and further discussed.

Stream Surveys

In order to develop regional curves for Macomb County, numerous streams had to be surveyed. A total of five different streams were surveyed. Table 1 provides the primary characteristics of each survey site. Following the Table, an introduction to is provided to each survey site.

Table 1: Stream Surveys Completed for this Project

Site	Subwatershed	Watershed area (acres)	Slope	Bankfull Discharge (cfs)	Bankfull width (ft)	Average bankfull depth (ft)	Bankfull Area (sq ft)
Coon Creek	North Branch	7,638	0.09%	81.9	16.8	1.69	28.4
East Pond Creek	North Branch	16,427	0.33%	92.1	24.3	1.24	30.1
Middle Branch	Clinton River East	26,202	0.23%	661.6	40.7	3.29	133.9
North Branch	North Branch	32,423.6	0.13%	140.9	35	1.74	61
Price Brook	Clinton River East	4275.2	0.47%	63.5	11.5	1.41	16.2

Coon Creek

Site Description

This survey area located just east of Hayes Rd. and just south of 31 Mile Rd in Ray Township, MI. It is in a semi-rural area near farms and a golf course. The stream is in dense vegetation directly adjacent. This creek has a wide range of flow from low base flow to high peak flow. According to the Clinton River Assessment, which references a survey performed in 2001-2002, this area scored *acceptable* upstream of the site and *poor* downstream of the site according to the GLEAS Procedure 51. Figure 1 provides an aerial view of the surveyed area of Coon Creek.

Survey Area

The survey performed on this reach of the river stretched for 309 feet along the river (Figure 2). The cross-section survey (Figure 3) was taken at Station 135 where a riffle occurs.

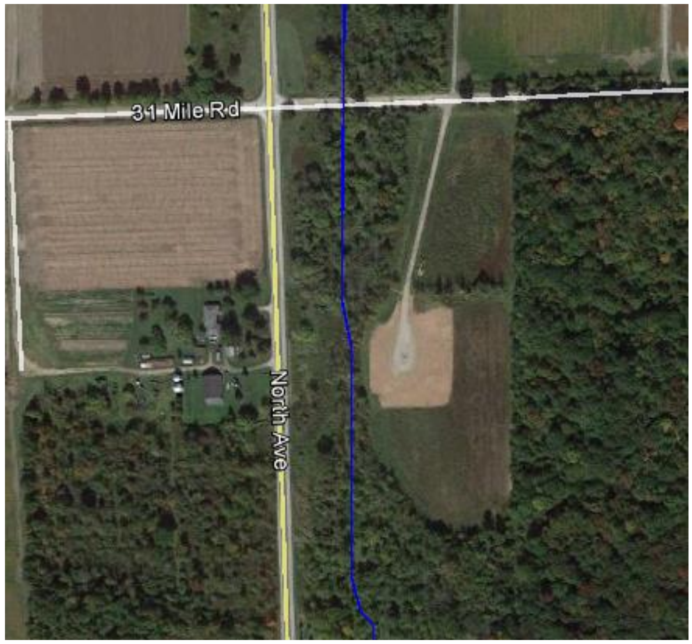

Figure 1: Aerial View of Coon Creek

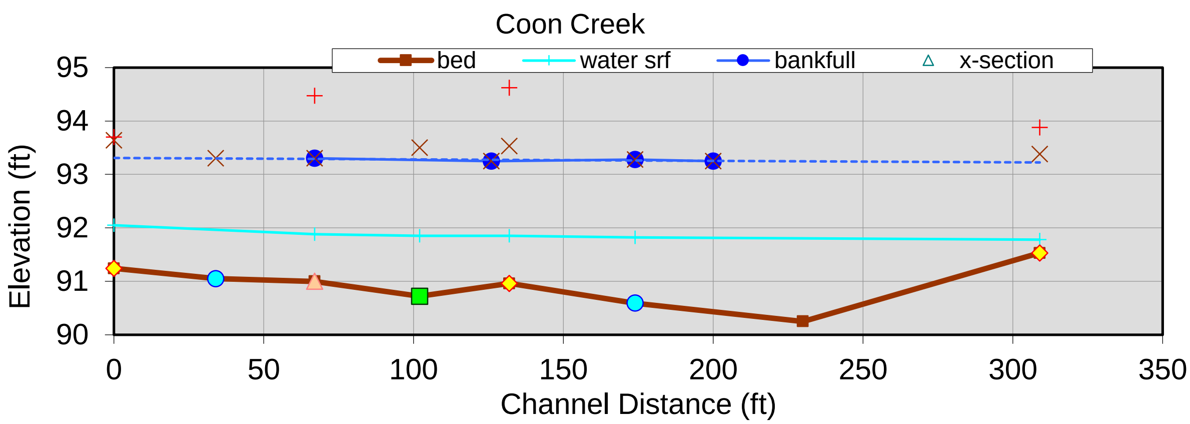

Figure 2: Longitudinal Profile

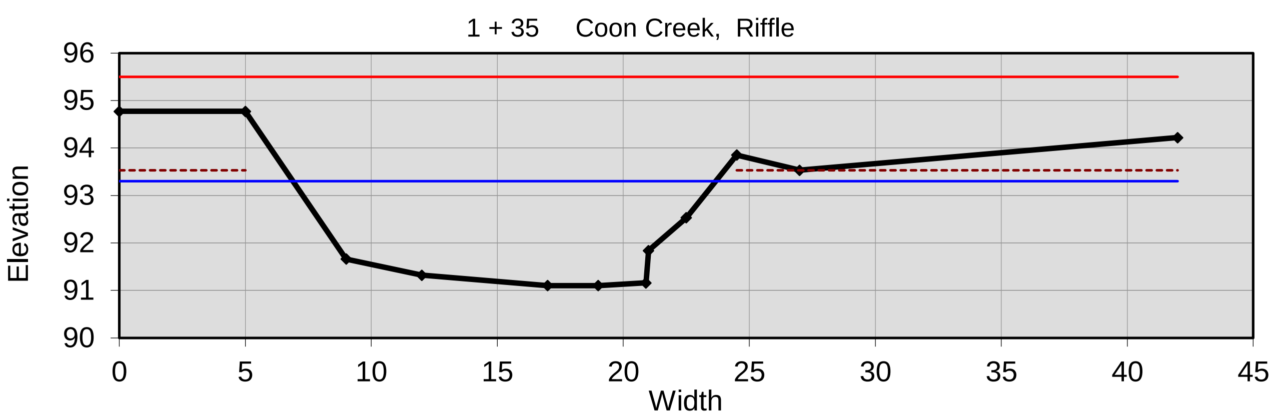

Figure 3: Cross sectional Profile of Station 135

Gage Information

The closest gage to this survey area is USGS 04164200 just north of 31 Mile Rd. at North Ave. It lies about ½ mile upstream of the survey area.

Watershed description

The watershed that flows into this creek encompasses 7,638 acres of land. This watershed includes land area to the north of the creek. (Figures 4 and 5). Most of the land is cropland, forest, and pasture (Figure 6). No major population areas are located within the watershed.

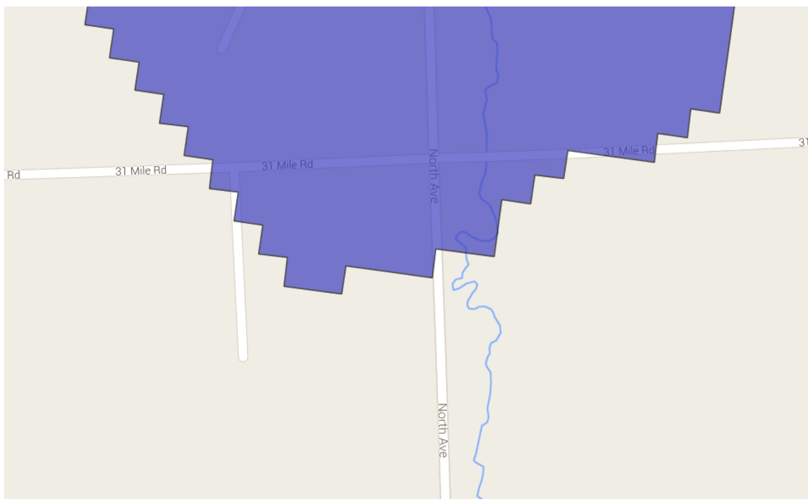

Figure 4: Watershed Delineation for Coon Creek (zoomed into East Pond Creek)

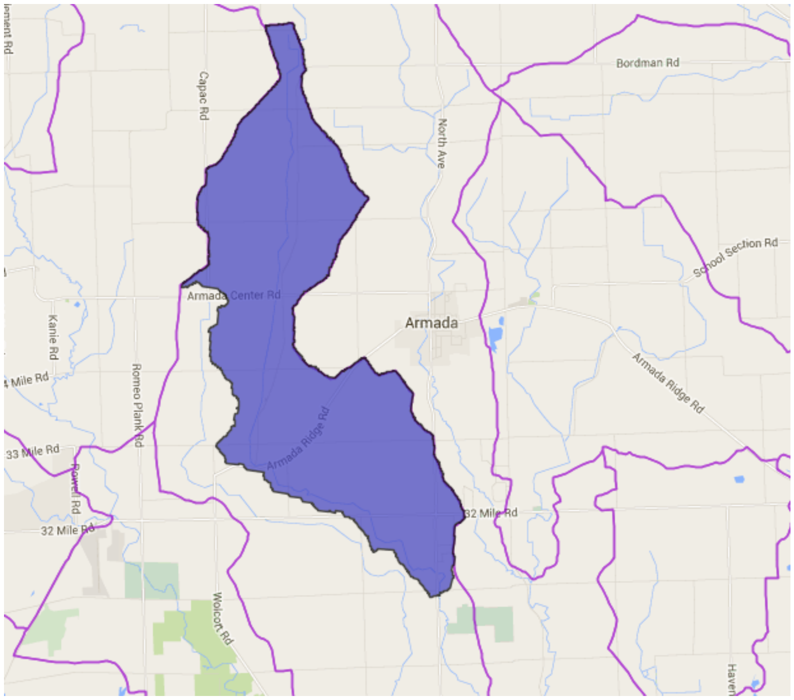

Figure 5: Watershed Delineation for Coon Creek (entire watershed)

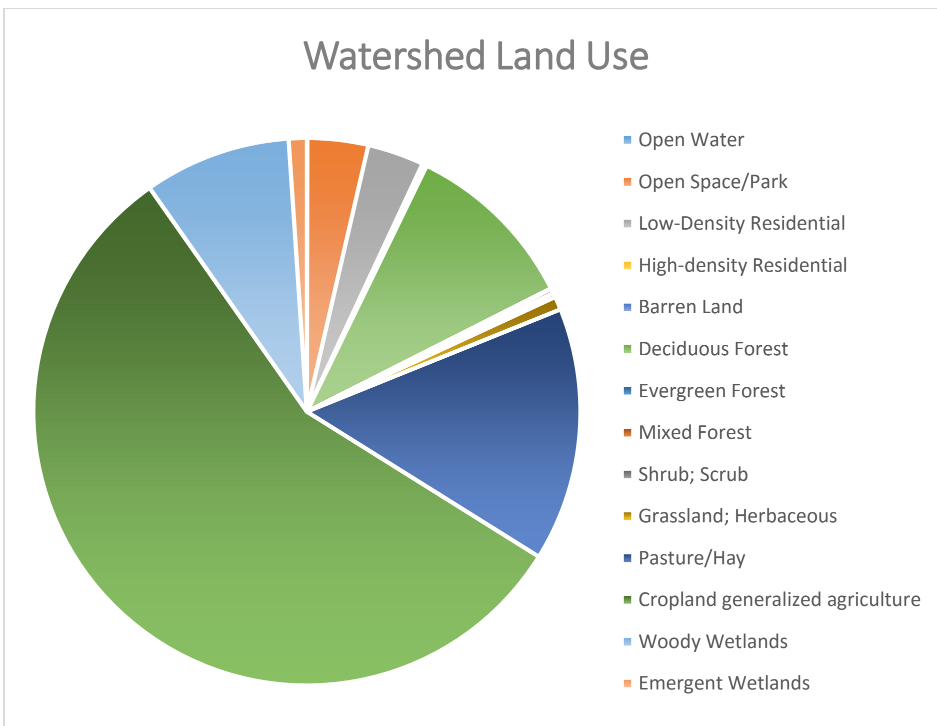

Figure 6: Summary of Coon Creek Survey Area Watershed

Analysis for Coon Creek

Using the STREAM module in addition to some manual calculations, the necessary results were determined for the stream. These results are shown in Table 2. Additional information about the STREAM module can be found in Appendix X. Additional results from the STREAM module can be found in Appendix X.

Table 2. Coon Creek Survey Analysis

Channel Slope	0.09%
Pebble Count	
d50	9.2
d84	17
Inset Dimensions (bankfull)	
Cross-sectional area (sq. ft.)	28.4
Width (ft.)	16.8
Mean depth (ft.)	1.69
Max depth (ft.)	2.2
Hydraulic radius	1.6
Discharge rate (cfs)	81.9

East Pond Creek

Site Description

This survey area which is part of East Pond Creek is located just northwest of the Powell and 32 Mile Rd. intersection in Romeo, MI. The area around the creek is developed and seems to be mowed on a regular basis. The terrain may have been altered near the creek as there are slightly unnatural hills around the creek and there is also an unusual dam in the creek that seems to have been placed there (see Figure 7).

Survey Area

The survey performed on this reach of the river stretched for 667 feet along the river (Figure 8). Two cross sections were surveyed: one at Station 21 (Figure 9) and one at Station 260 (Figure 10). At Station 185 and 260, there are riffle areas.

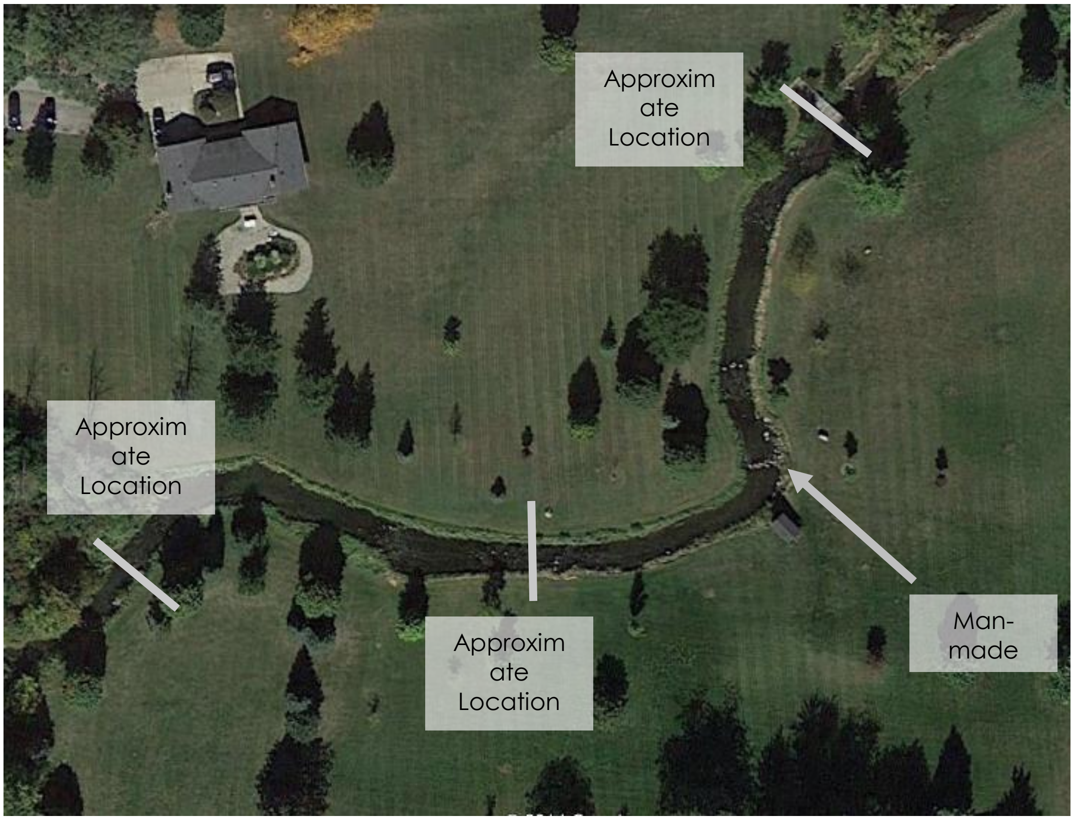

Figure 7: Aerial of East Pond Creek

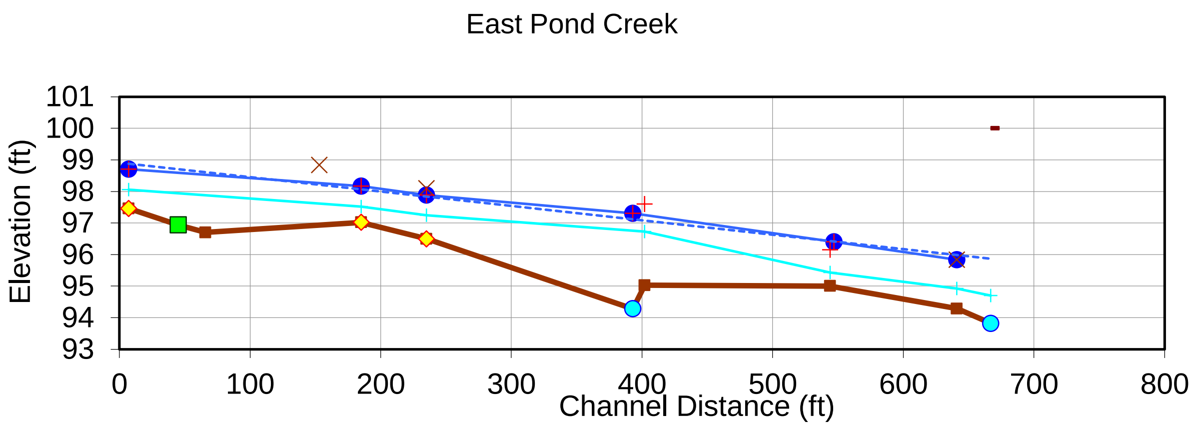

Figure 8: Longitudinal Profile of East Pond Creek

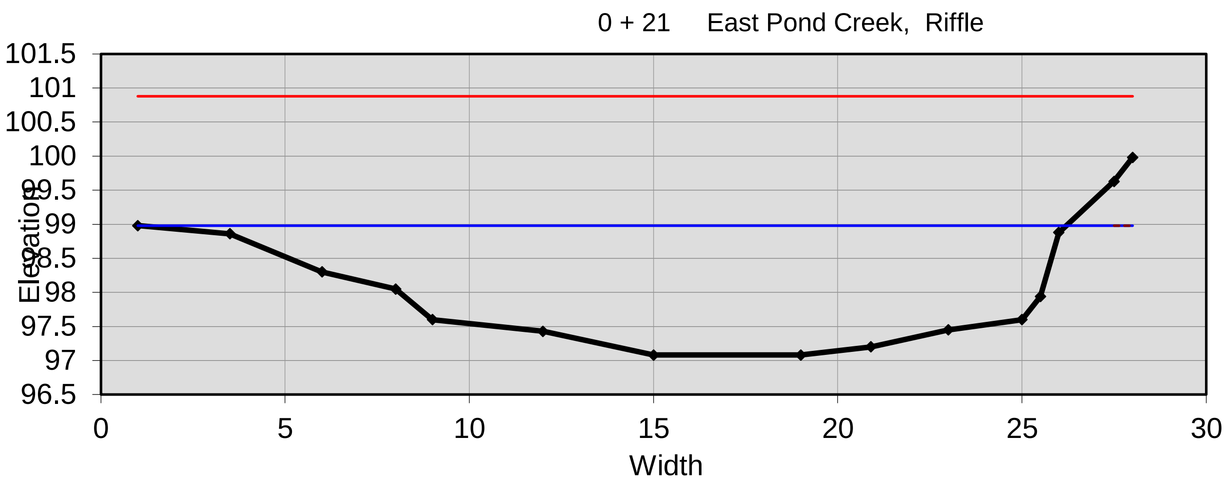

Figure 9: Cross sectional Profile of Station 21

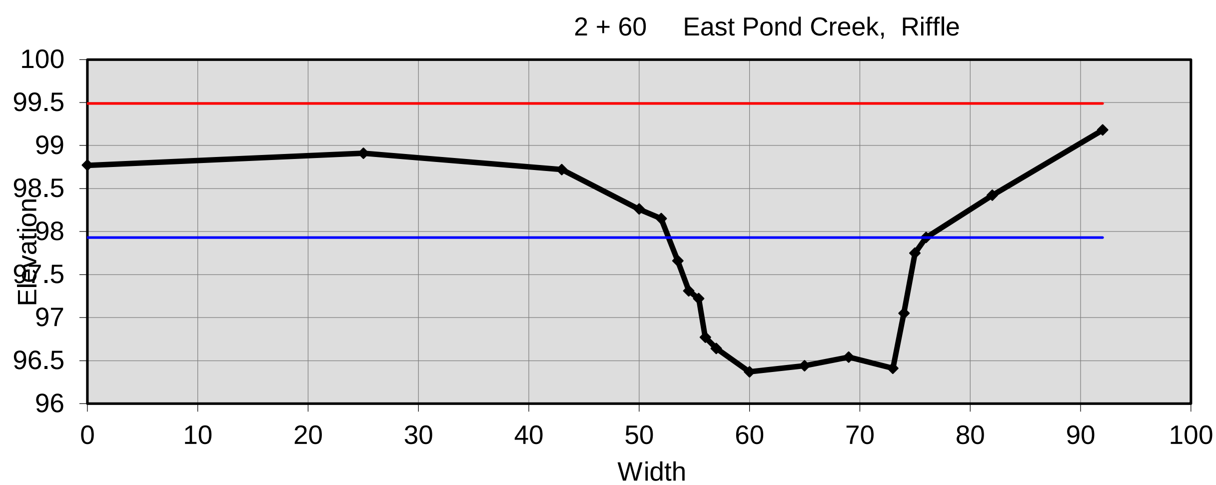

Figure 10: Cross sectional profile of Station 260

Gage Information

The closest gage to the survey area is USGS 04164100 at Romeo Plank Rd. between 25 and 26 Mile Rds. This gage is about a half mile downstream of the survey area.

Watershed description

The watershed that flows into this creek encompasses 16,427 acres of land. The encompassing watershed includes mostly land to the northwest of the creek (Figures 11 and 12). Most of the land is deciduous forest, open space/park, pasture/hay, woody wetlands, or cropland generalization (Figure 13). No major population areas are located within the watershed but at least part of the Ford Michigan Proving Grounds is located within the watershed.

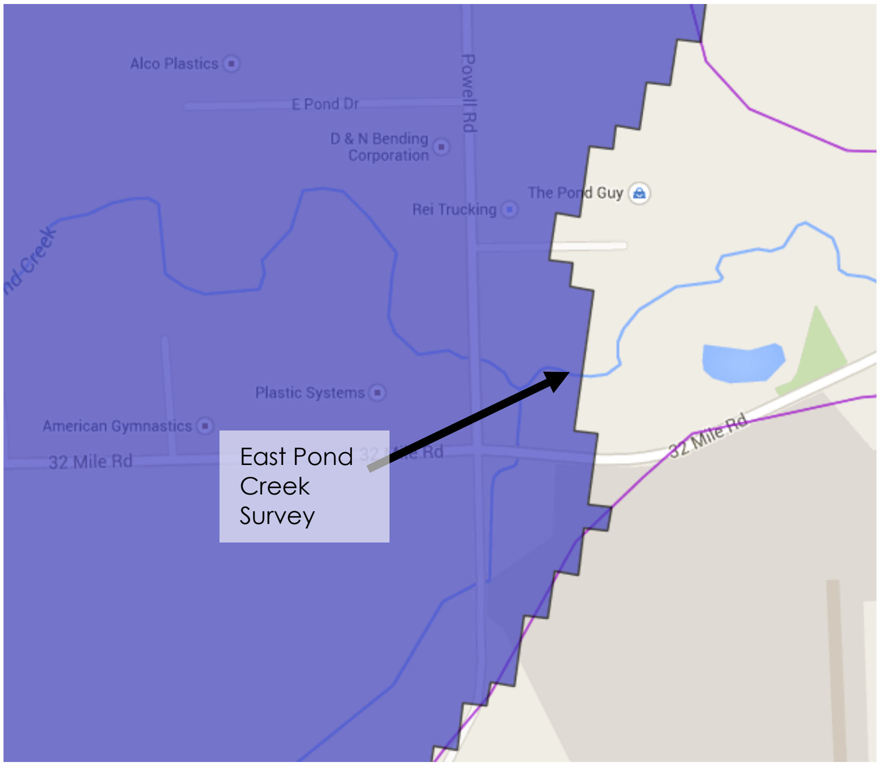

Figure 11: Watershed Delineation for East Pond Creek (zoomed in)

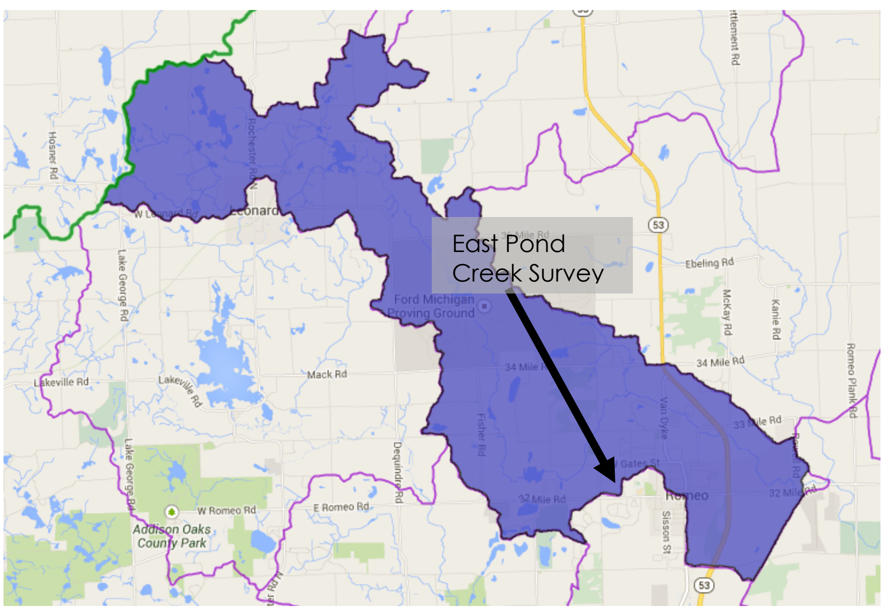

Figure 12: Watershed Delineation for East Pond Creek (entire watershed)

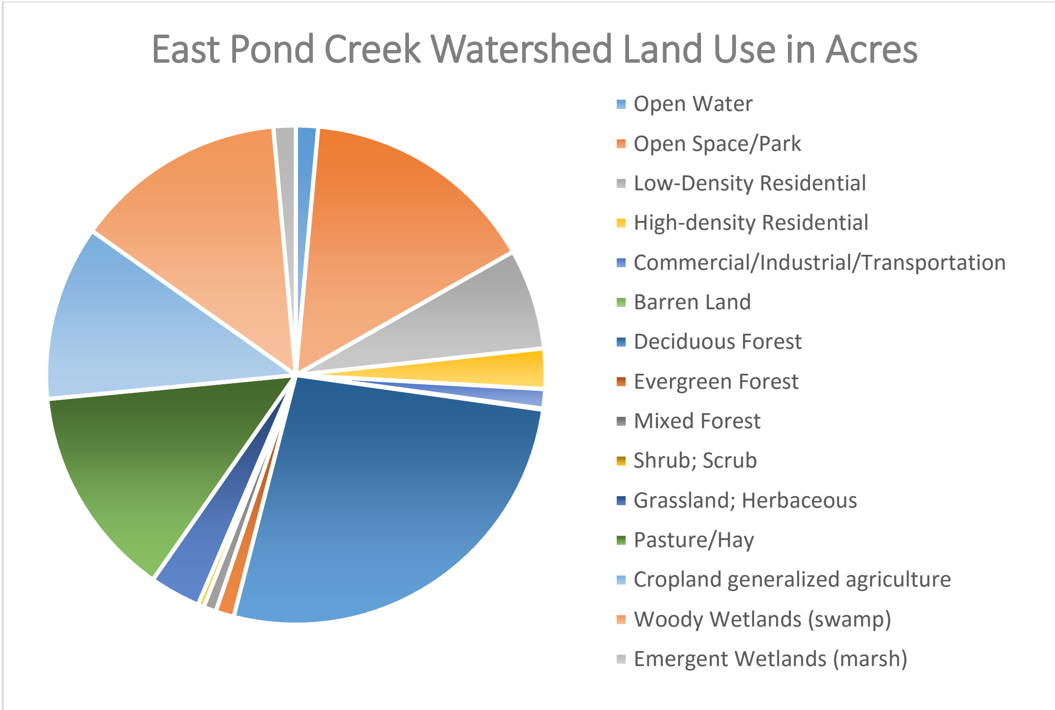

Figure 13: Summary of East Pond Creek Watershed

Analysis for East Pond Creek

Using the STREAM module in addition some manual calculations, the necessary results were determined for the stream. These results are shown in Table 3. Additional information about the STREAM module can be found in Appendix X. Additional results from the STREAM module can be found in Appendix X.

Table 3: East Pond Creek Survey Analysis

Channel Slope	0.33%
Pebble Count	
d50	18
d84	42
Inset Dimensions (bankfull)	
Cross-sectional area (sq. ft.)	30.1 (28.2-31.9)
Width (ft.)	24.3 (23.3-25.2)
Mean depth (ft.)	1.24 (1.2-1.3)
Max depth (ft.)	1.7 (1.6-1.9)
Hydraulic radius	1.2
Discharge rate (cfs)	92.1

Middle Branch

Site Description

This survey area is located northwest of Romeo Plank Rd and 25 Mile Rd (Figure 14). It is in a heavily wooded area just downstream of the Healy Drain. According to the Clinton River Assessment which referenced a survey performed in 2001-2002, the upper portion of the stream is well stocked with fish, a good indication of high water quality. In addition, downstream of the site had the most species present of any of the 38 sites they surveyed. Both surveys upstream and downstream were deemed *acceptable* according the GLEAS Procedure 51.

Survey Area

The survey on this reach stretches 665 feet (Figure 16). Two cross sections were surveyed: one at Station 490 (Figure 17) and one at Station 663 (Figure 18). Both stations are at riffle areas.

Figure 14: Aerial of Middle Branch Survey Area

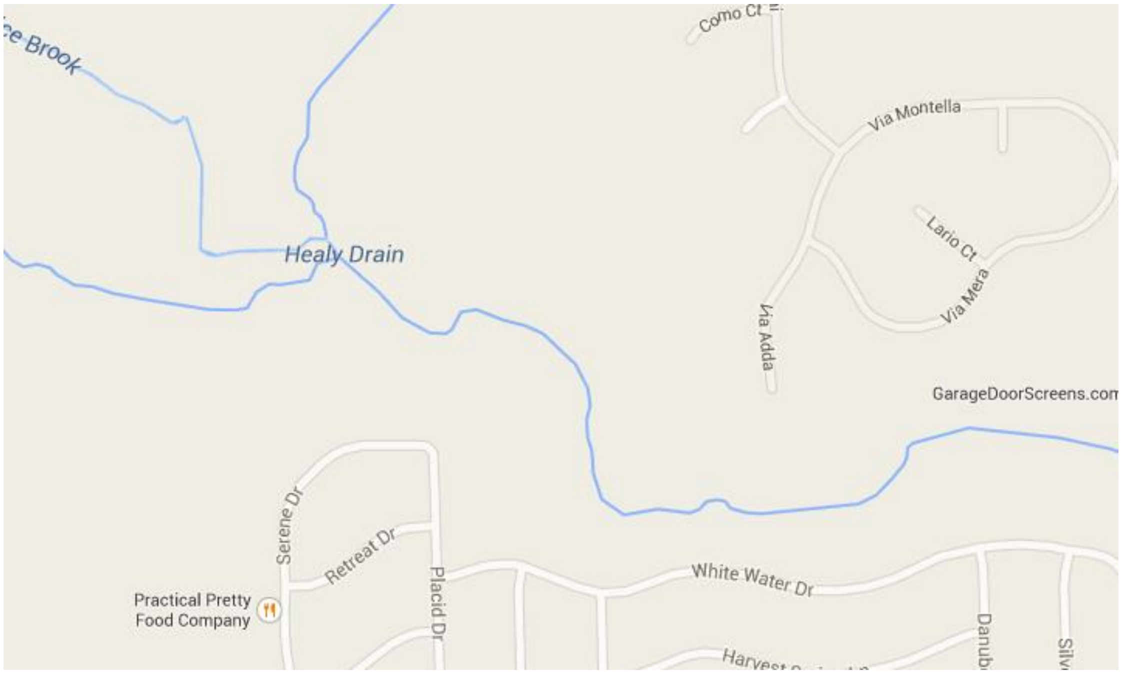

Figure 15: Map View of Middle Branch Survey Area

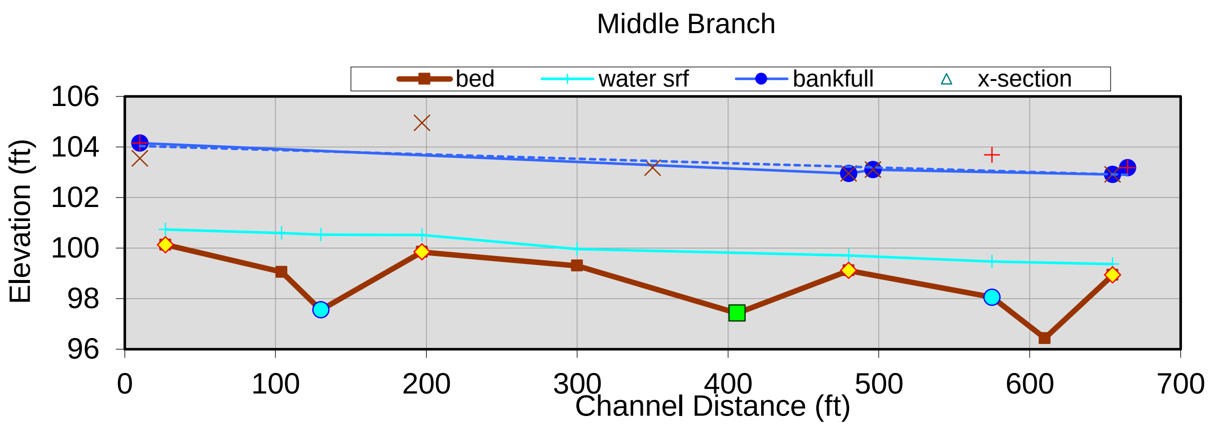

Figure 16: Longitudinal Profile of Middle Branch Survey Area

Figure 17: Cross sectional Profile of Station 490

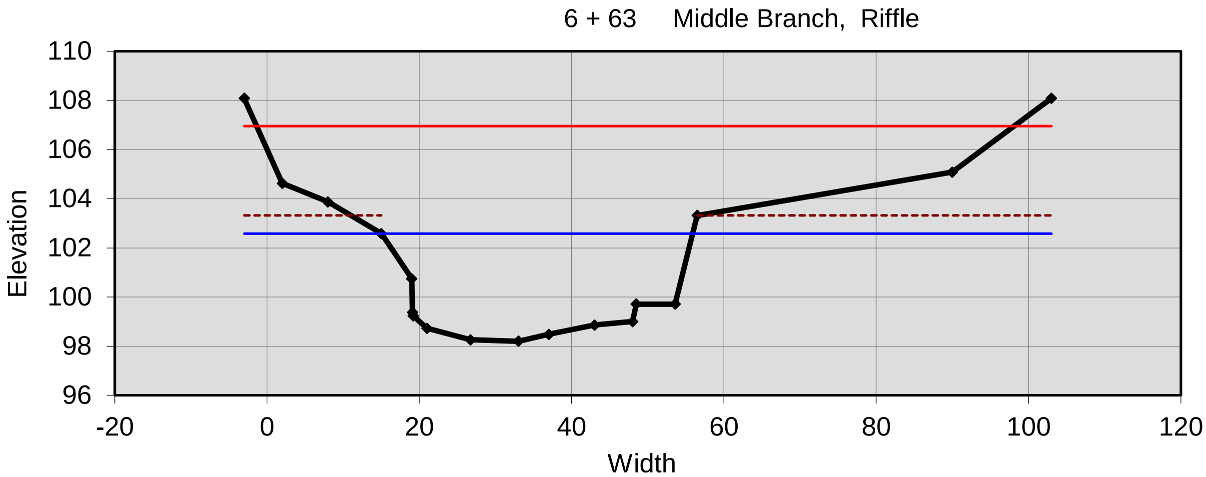

Figure 18: Cross sectional profile of Station 663

Gage Information

The closest gage to the survey area is USGS 04164800 at Van Dyke Rd just north of 33 Mile Rd. This gage is about 3.5 miles upstream of the survey area.

Watershed description

The watershed that flows into this creek encompasses 26,202 acres of land. This includes mostly land west and northwest of the survey area. Most of the land is open space/park, low-density residential, deciduous forest, cropland, and pasture/hay (Figure 19). The watershed includes land within Shelby Charter Township, Washington, and Romeo.

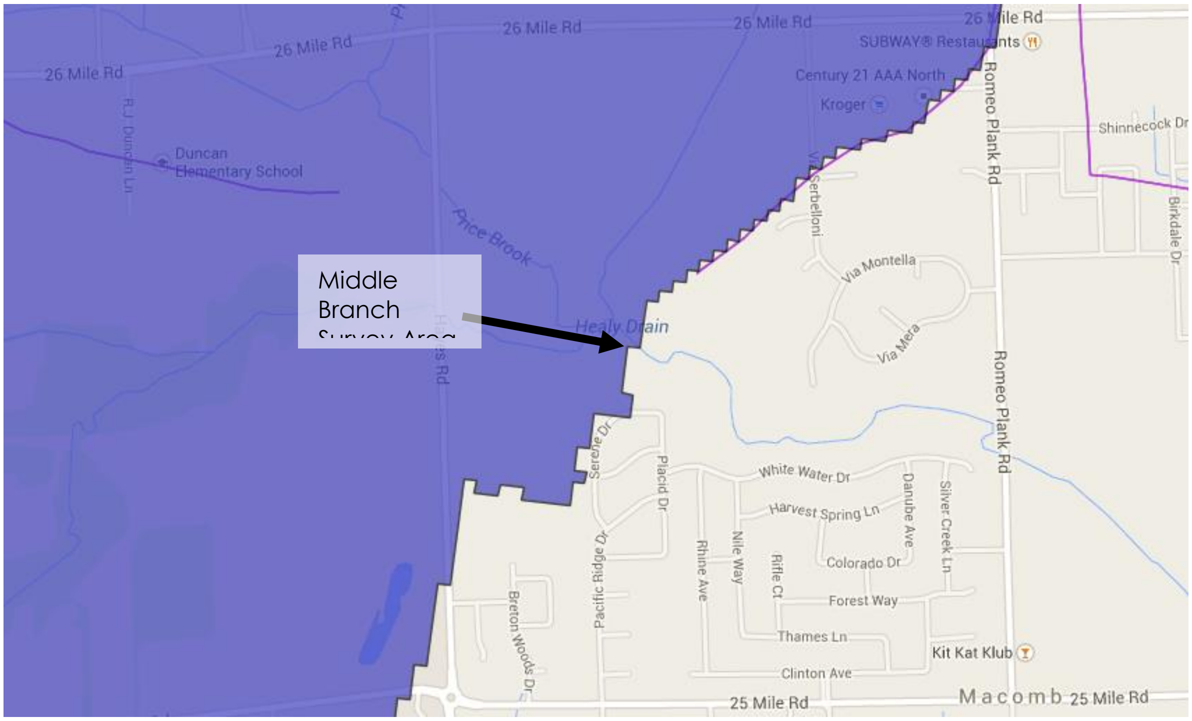

Figure 19: Watershed Delineation for Middle Branch (zoomed into Middle Branch)

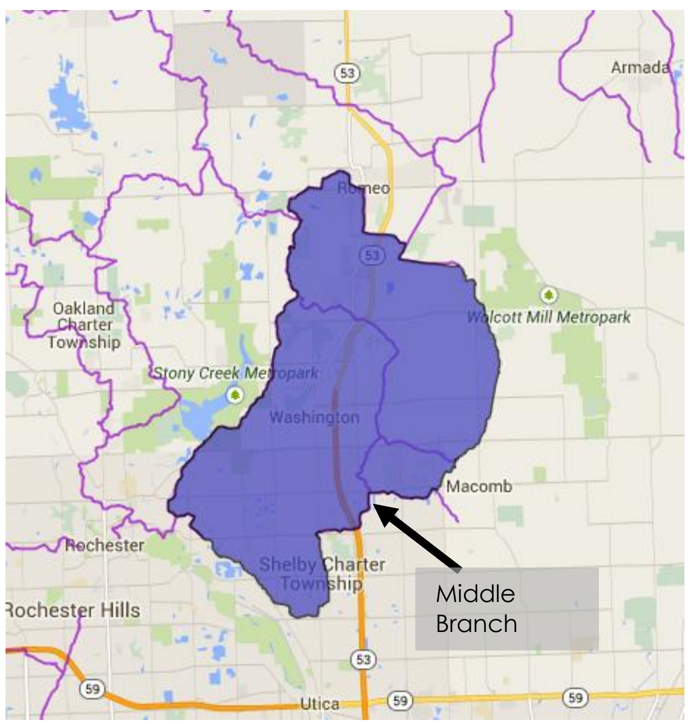

Figure 20: Watershed Delineation for Middle Branch Survey Area (entire watershed)

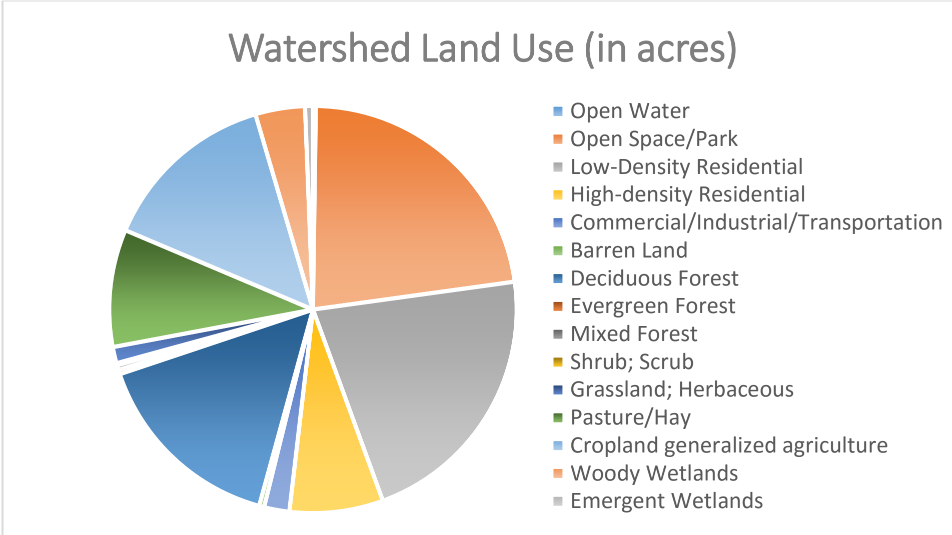

Figure 21: Summary of Middle Branch Watershed

Analysis for Middle Branch

Using the STREAM module in addition to manual calculations, the necessary results were determined for the stream. These results are shown in Table 4. Additional information about the STREAM module can be found in Appendix A. Additional results from the STREAM module can be found in Appendix B.

Table 4: Middle Branch Survey Analysis

Channel Slope	0.23%
Pebble Count	
d50	18
d84	38
Inset Dimensions (bankfull)	
Cross-sectional area (sq. ft.)	133.9 (128.1-139.6)
Width (ft.)	40.7 (40.4-40.9)
Mean depth (ft.)	3.29 (3.2-3.4)
Max depth (ft.)	4.3 (4.1-4.4)
Hydraulic radius	3.1
Discharge rate (cfs)	661.6 (659.1-664.1)

North Branch

Site Description

This survey area is located east of the East Pond Creek survey area in Romeo, MI. It is in a less developed area: the land directly next to the creek is not mowed and seems undisturbed for the most part (see Figure 22). Conversely, east of the survey area, there is an area that is mowed (about 60-70 feet away from the creek). Within 50 feet downstream of the survey area, the creek joins with another creek that is downstream from East Pond Creek. However, this reach of the creek is not **directly** downstream of East Pond Creek.

According to the Clinton River Assessment which references a survey performed in 2001-2002, the stream is considered a cool water stream. Out of the 38 streams surveyed, an area downstream of the site had the second highest level of species richness and the greatest number of pollution intolerant species. Overall, the area had a very high quality of water.

Survey Area

The survey performed on this reach of the river stretched for 487 feet along the river (Figure 23). One cross section was surveyed: Station 300 (Figure 24). A ripple area is at Station 300, which will be used to determine the properties of the stream needed for design. The creek's depth varies more along the longitudinal cross-section and resembles a natural stream more than East Pond Creek.

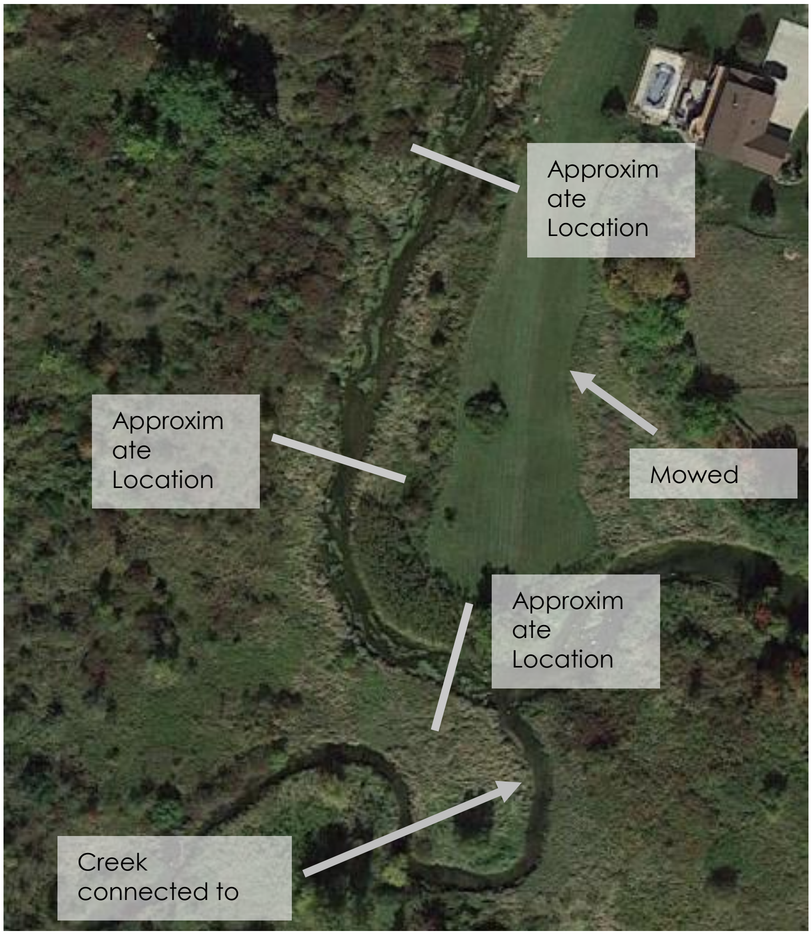

Figure 22: Aerial of North Branch Survey Area

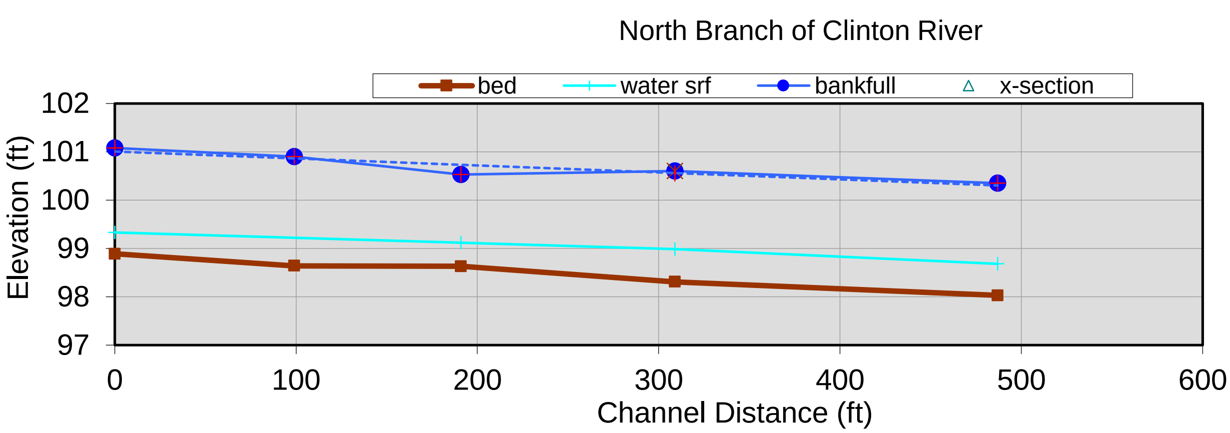

Figure 23: Longitudinal Profile of North Branch

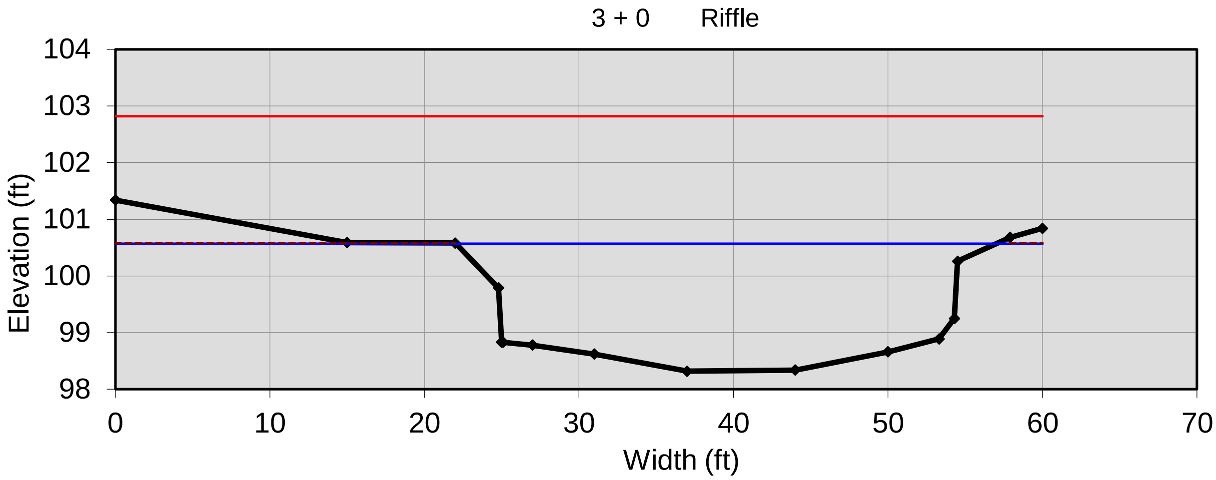

Figure 24: Cross sectional profile of Station 300

Gage Information

The closest USGS gage to this survey area is USGS 04164050 at 33 Mile Rd. in Romeo, MI. It lies about a mile upstream of the survey area.

Watershed description

The watershed that flows into this creek incorporates 32,423.6 acres of land. The watershed includes land north of the creek. The major land uses in this area include cropland generalized agriculture, pasture/hay, deciduous forest, and woody wetlands. This watershed is completely separate than the watershed from East Pond Creek and is more developed than East Pond Creek's watershed. More so, it encompasses more area and due to the agriculture in the area, it will more likely have areas with higher runoff coefficients. Due to the larger area and high runoff coefficients, it will convey more water than East Pond Creek.

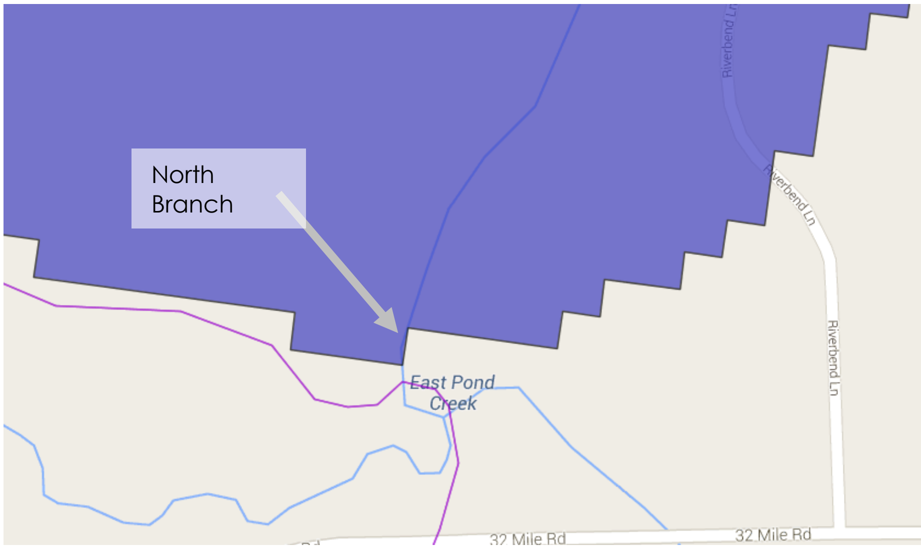

Figure 25: Watershed Delineation for North Branch of Clinton River (zoomed in)

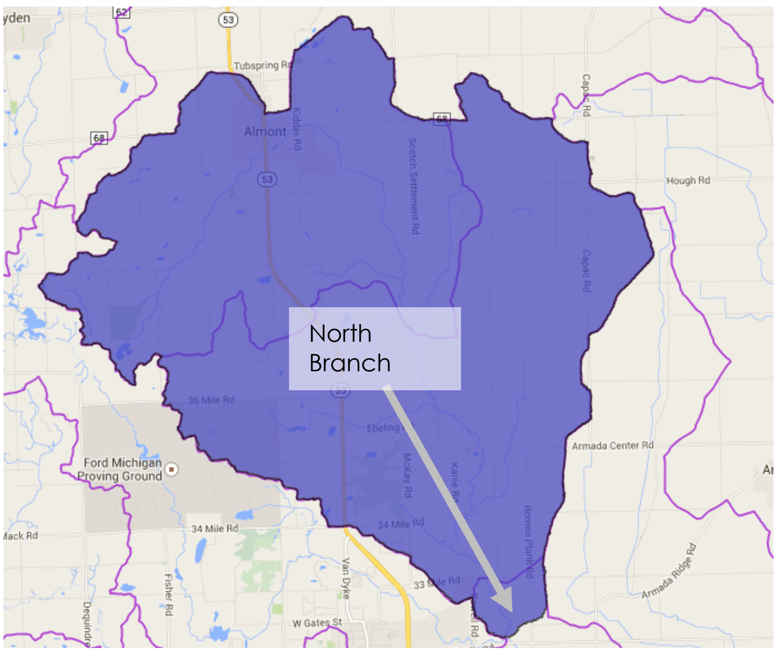

Figure 26: Watershed Delineation for North Branch of Clinton River (entire watershed)

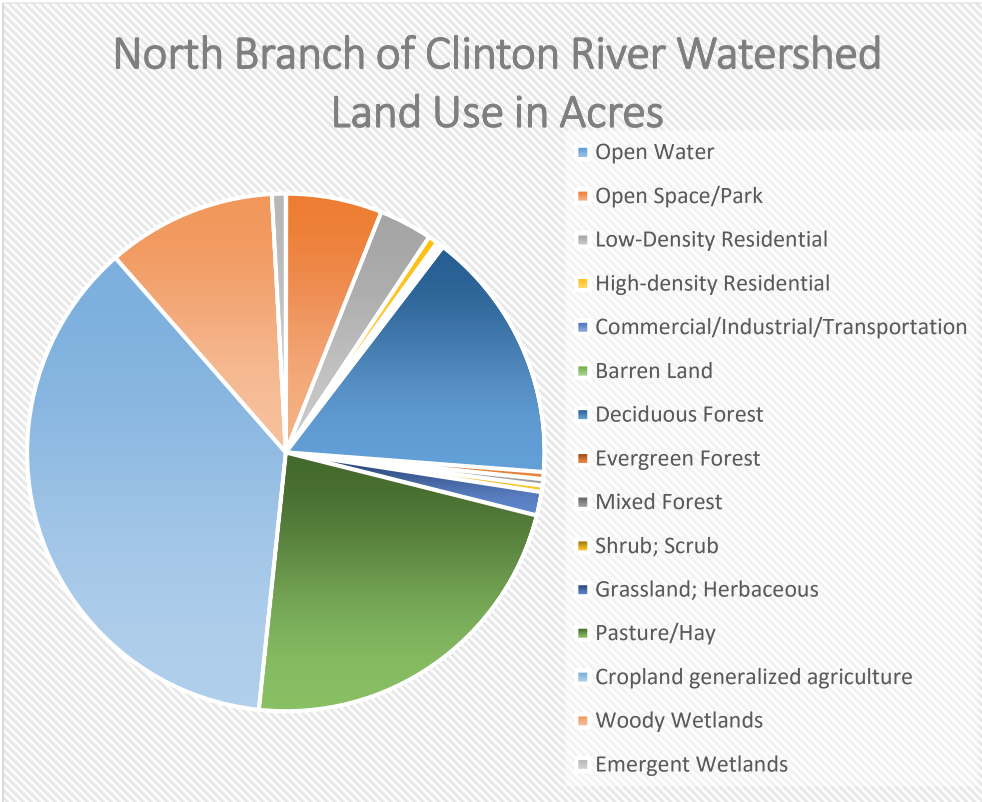

Figure 27: Summary of Land Use for North Branch of Clinton River Watershed

Analysis for North Branch

Using the STREAM module in addition some manual calculations, the necessary results were determined for the stream. These results are shown in Table 5. Additional information about the STREAM module can be found in Appendix A. Additional results from the STREAM module can be found in Appendix B.

Table 5: North Branch Survey Analysis

Channel Slope	0.13%
Pebble Count	
d50	41
d84	73
Inset Dimensions (bankfull)	
Cross-sectional area (sq. ft.)	61
Width (ft.)	35
Mean depth (ft.)	1.74

Max depth (ft.)	2.2
Hydraulic radius	1.7
Discharge rate (cfs)	140.9

Price Brook

Site Description

This survey area is located off of Hayes Road south of 26 Mile Rd in Macomb, MI. It is in a less developed area near a few houses. Directly adjacent to the stream it is unmowed, but about 10 feet out, it looks to be regularly mowed. This site is about 2,300 feet upstream of the Middle Branch survey site and about 2,000 feet upstream of where the Price Brook drain joins with Healy Drain. Downstream of the survey area, an area included in the Clinton River Assessment stream survey had the most species present of all the 38 streams they surveyed within the Clinton River watershed and the site was scored *acceptable* according to GLEAS Procedure 51.

Survey Area

The survey performed on this reach stretched for 256 feet along the stream (Figures 28 and 29). Two stretches were surveyed: Station 24.5 and Station 128 (Figures 30 and 31). There are three riffle areas along the stretch: approximately at stations 18, 74, and 124. At the downstream end of the survey area, there is also a concrete weir.

Figure 28: Aerial of Price Brook

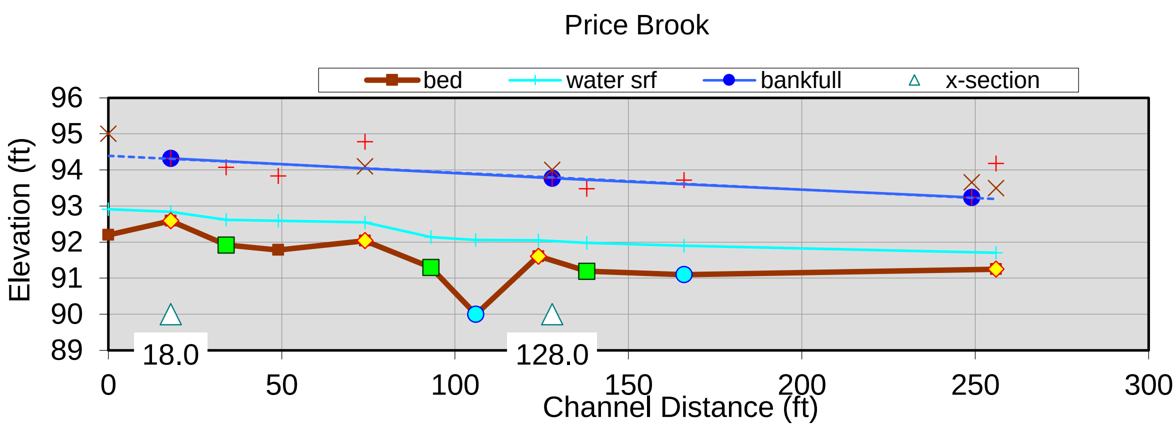

Figure 29: Longitudinal Profile of Price Brook

*Elevation is arbitrary, not tied to USGS benchmark

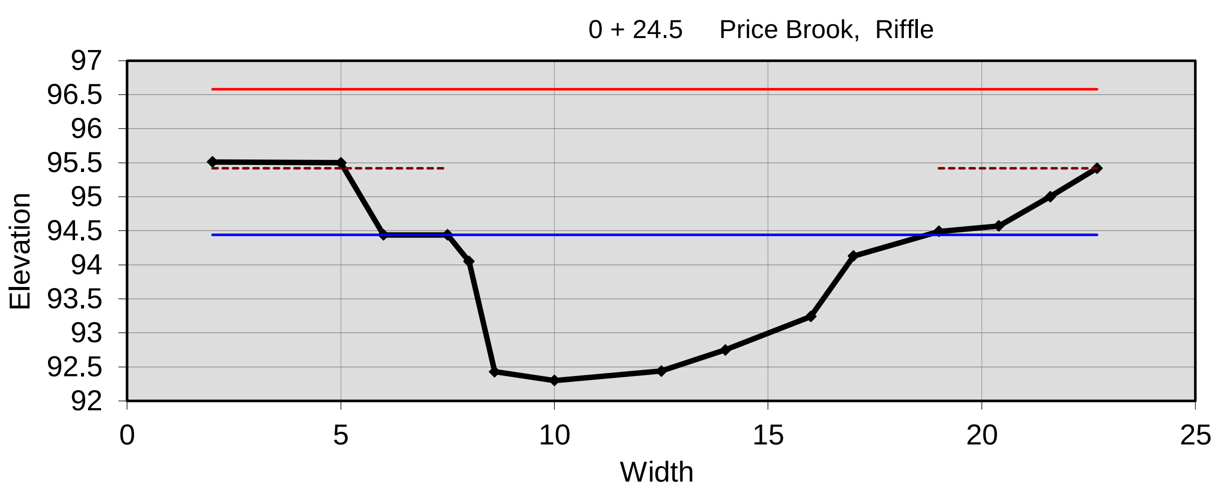

Figure 30: Cross sectional profile of Station 24.5

*Elevation is arbitrary

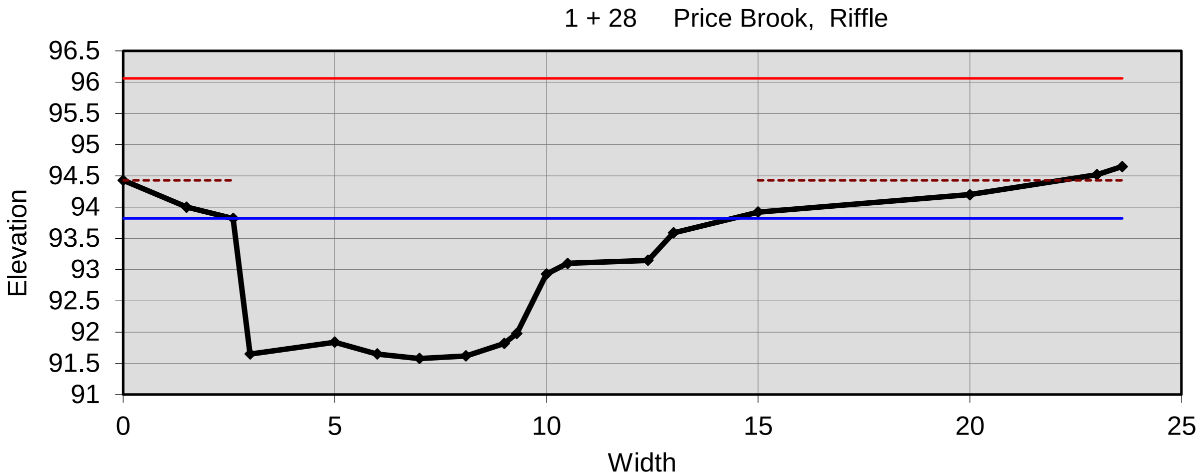

Figure 31: Cross sectional profile of Station 128

*Elevation is arbitrary

Gage Information

The closest USGS gage to this survey area is USGS 04164800 at Romeo Plank Rd. north of 25 Mile Rd.in Macomb, MI. It lies about a mile downstream of the survey area.

Watershed description

The watershed that flows into this creek incorporates about 4,406.8 acres of land (Figures 32-34). The watershed includes land north of the creek. The main land uses in the watershed include cropland generalized agriculture, deciduous forest, pasture/hay, and open space/park. The major land uses in this area include cropland generalized agriculture, pasture/hay, deciduous forest, and woody wetlands. Due to the higher percent of developed land, it will likely have higher runoff coefficients.

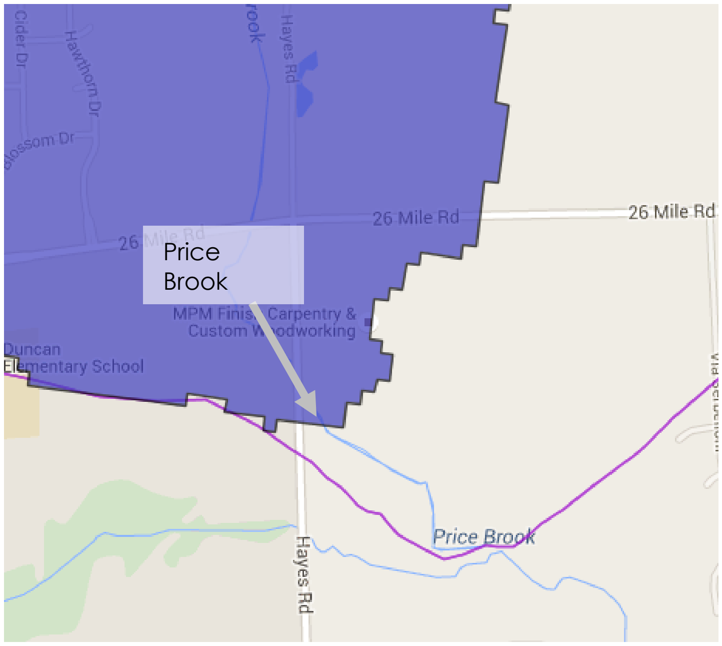

Figure 32: Watershed Delineation for Price Brook (zoomed in)

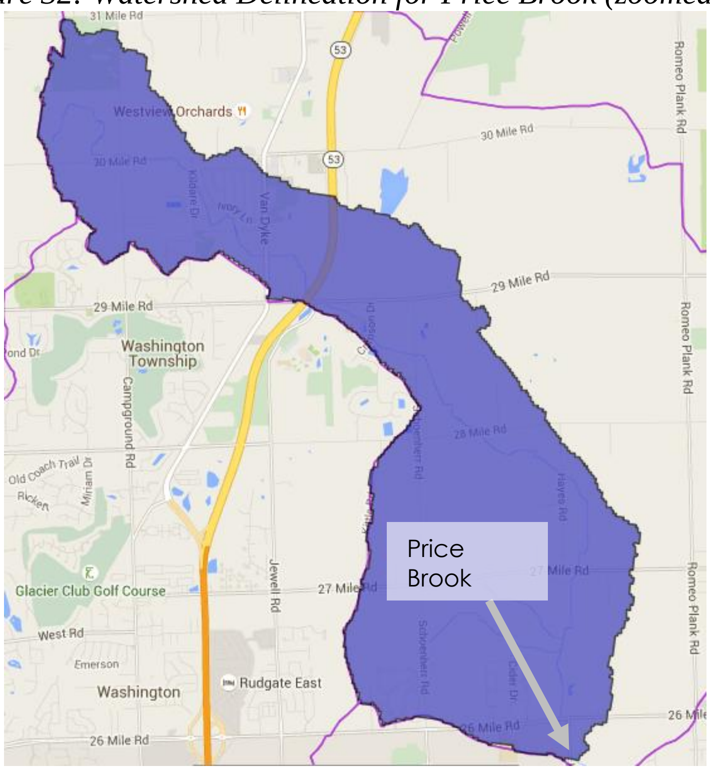

Figure 33: Watershed Delineation for Price Brook (entire watershed)

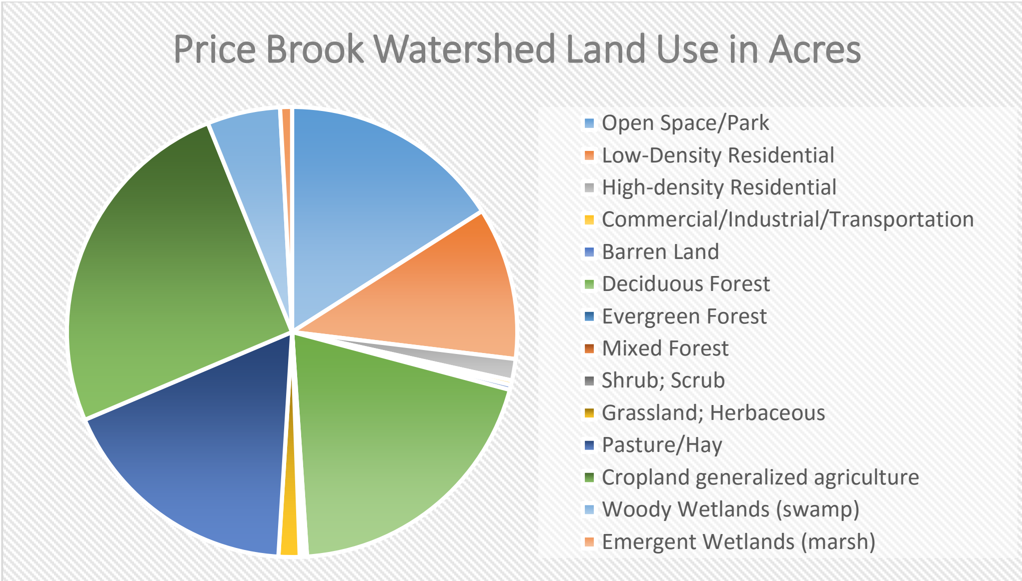

Figure 34: Summary of Land Use for Price Brook

Analysis for Price Brook

Using the STREAM module in addition some manual calculations, the necessary results were determined for the stream. These results are shown in Table 6. Additional information about the STREAM module can be found in Appendix A. Additional results from the STREAM module can be found in Appendix B.

Table 6: Price Brook Survey Analysis

Channel Slope	0.47%
Pebble Count	
d50	18
d84	44
Inset Dimensions (bankfull)	
Cross-sectional area (sq. ft.)	16.2
Width (ft.)	11.5
Mean depth (ft.)	1.41
Max depth (ft.)	2.2
Hydraulic radius	1.2
Discharge rate (cfs)	63.5

Channel Flow and the Regional Curve

In order to design a channel, you first have to be able to size it. Most typically, the expected discharge will determine the channel dimensions. There are multiple factors that go into determining the design flow for a channel including, but not limited to, drainage area, precipitation, soil types of the channel and drainage area, and infiltration rate in the drainage area to name a few. One way to avoid looking into every aspect listed above is to use pre-existing information from other known stream crossings in a similar area.

The designer must be able to understand how the flow changes and how it affects these channels, especially during low flow and during high flow. The flows during drier weather is important because you'd like to avoid stagnant water and you want to size the channel appropriately. The flow during large storms will help determine the width and depth of the channel. During large storms, the flow will be at its highest: it will have a large velocity and it will cover the most surface area of the channel meaning it will have the greatest probability of eroding the largest amount of soil.

In a natural channel, during normal flow the water is carried in the main channel and during high flow, the channel floods the active floodplain. Without an active floodplain, the channel will flood the surrounding areas or, if the channel is oversized, it will put strain on the walls of the channel causing erosion. The active floodplain allows the kinetic energy (velocity head) in the water to be dissipated so that less soil is eroded, which allows for plant life to be better sustained.

The portion of the flow occupying the main part of the channel is termed the bankfull discharge. According to Ward et al., the bankfull discharge is similar to the flow of the stream associated with floodplain development.

The bankfull discharge is important to understand because the bankfull discharge and the corresponding bankfull geometry (width and depth) can all be related to the drainage area of that particular reach. This relationship can be plotted on what is called a regional curve. The regional curve is extremely helpful in the design, or assignment, of channel dimensions. Armed with the regional curve for an area, the designer can properly size the channel using regional curve details. Note: it must be emphasized that the regional curve does not substitute for appropriate engineering analysis and calculations to design a channel. It should only be used as a check point and does not guarantee appropriately sized channels.

Developing a regional curve

In order to develop a regional curve, one must have survey data from sites in the area. The channel reaches chosen should be natural channels with well-developed banks and floodplain. Most importantly, the bankfull elevation needs to be determined and at this point, a cross-sectional survey can be performed. The location of the bankfull elevation can be found by looking for certain signs: according to Harrelson et al., indicators of bankfull elevations are the top of point bars; changes in vegetation, slope, or bank materials; bank undercuts; or stain lines.

Once the survey is completed, the bankfull discharge can be determined. As discussed in the previous section, one way of analyzing the survey data is to use the STREAM Modules developed by Mecklenburg and Ward.

Use of the regional curve requires knowledge of the size of the contributing drainage area that flows into a particular reach. In the previous section, the drainage areas for each of the reaches was determined by using L-THIA, a program designed out of Purdue University that calculates the drainage area for a reach as well as the soil type and land usage within the drainage area.

Once the drainage area and the bankfull dimensions are determined, the regional curve can be plotted.

Regional Curve for Clinton River Watershed

The surveys from the previous section are good choices for developing a regional curve. The streams chosen are a good representation of the majority of streams in Clinton River and Macomb County, not the minority of streams in the area. For example, using a stream that is steep would not be a good representation of the streams of Macomb County because Macomb County is relatively flat. In addition, it’s necessary to have a variety of streams. Streams that are all similar will not represent the variety of classifications of streams that exist. D.L. Rosgen developed a system that classifies streams based on stream types, slope ranges, and dominant channel material particle sizes. This can be used as a way to classify particular streams and ensure that you have a varied representation of streams.

Once streams are selected, a site (or reach of channel) for cross-sectional analysis must be selected on that stream. According to Ward et al., the survey should be performed over a length equal to 20 times the width of the channel. Overall, the site should be relatively natural with as little impact from human development (roads, bridges, buildings, tire tracks, etc.) as possible. Lastly, a stream that is gaged is ideal so that there is historic flow data available for the stream. USGS gages are located on many streams and some have data that extends back decades.

The Regional Curve that was developed using the data from this project can be found in Figure 35.

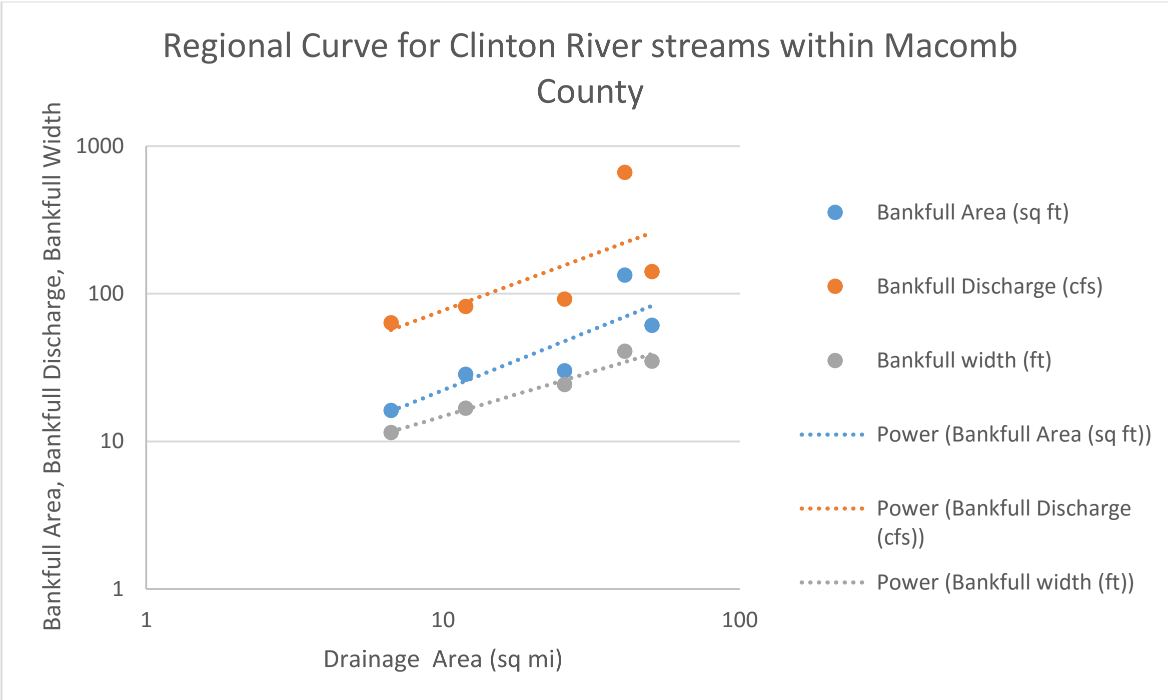

Figure 35: Regional Curve for Clinton River streams within Macomb County

The regional equations for the curve are as follows:

$$\text{Bankfull Discharge}=13.686*DA^{0.7496},\ R^2=0.4654$$

$$\text{Bankfull Area}=3.4207*DA^{0.8122},\ R^2=0.7197$$

$$\text{Bankfull Width}=3.723*DA^{0.5991},\ R^2=0.9579$$

There are a number of takeaways from the curves and equations. First, the bankfull discharge and bankfull area equations are not very precise, indicating that the equation developed from the data isn't a fully representative equation that captures all features of the relationship given the limited number of channel cross sections. Notably, the East Pond Creek and North Branch sites stand out more than the others. The bankfull discharge and area are both significantly less than what would be expected for their drainage areas. In fact, when those sites are taken out of the calculation, the precision increases dramatically (see Figure 36).

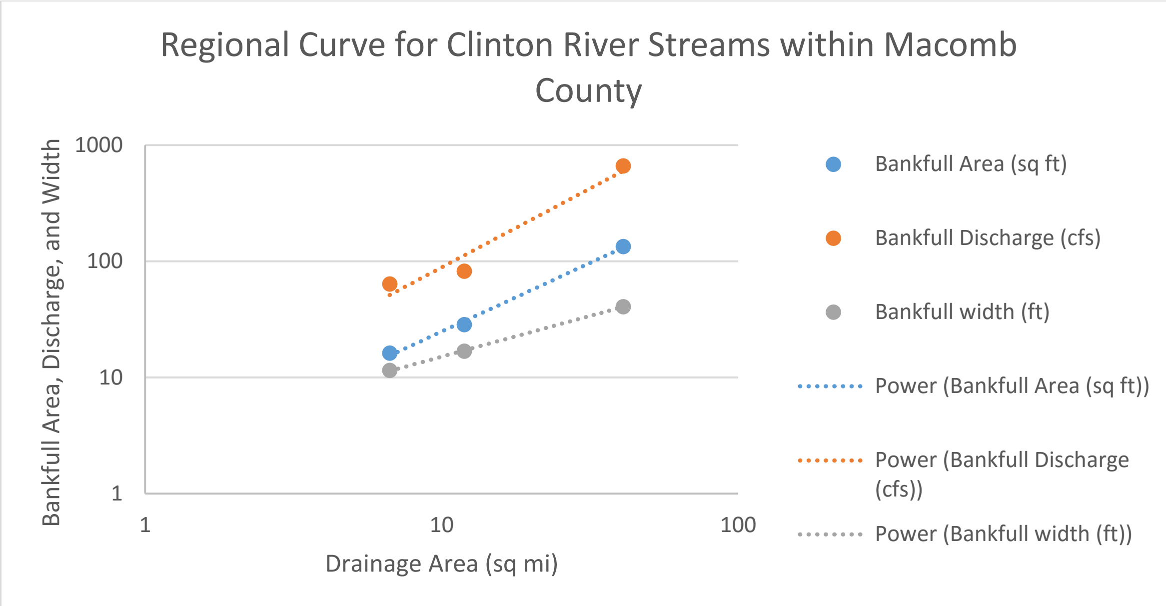

Figure 36. Regression for Regional Curve using Three Cross Sections

$$\text{Bankfull Discharge}=3.9013*DA^{1.3555},\ R^2=0.9525$$

$$\text{Bankfull Area}=1.6408*DA^{1.1795},\ R^2=0.9965$$

$$\text{Bankfull Width}=3.0078*DA^{0.7004},\ R^2=0.9995$$

Both these sites may have had common errors associated with the flow measurement. First, these two sites are located close to one another and their streams join just downstream of the North Branch site. Therefore, the sites are draining water from areas near one another. If this upstream source area is impacted, it will impact both these downstream cross sections. An example of this could be a lake control structure; these are found widely throughout the Clinton River watershed. In fact, upstream of East Pond Creek are two lakes, which could be the reason for the lessened flows. In addition, the East Pond Creek site has a number of features that were not natural. In the middle of the site, there was a man-made riffle with a number of larger rocks that was obstructing flows. In addition, the stream was straighter than a natural stream would typically be and the area around the stream was mowed, showing that this stream underwent some alterations.

Due to the limited number of sites, these equations should not be taken as a representation of drains in Macomb County. At least a dozen sites are needed to get an accurate regional curve. However, these can be used as a comparison to the already developed curves for Southeast Michigan.

The current regional equations for Southern Michigan were developed in 2009 by Rachol and Boley-Morse. Twenty-eight stream sites were surveyed in Southern Michigan, each with a corresponding USGS streamgage and regional curves and equations were developed from the data. The discharge equation is as follows:

$$\text{Discharge} = 4.05 \times DA^{0.95}\,;\ R^2 = 0.60$$

Since then, a new equation has been developed and is currently in review with the Michigan Department of Environmental Quality (MDEQ). Sites from the previous study were re-evaluated; nine were removed and five sites were added. The new bankfull discharge equation is as follows:

$$\text{Discharge}=17.63*\text{DA}^{0.70};\ R^2=0.94$$

When the two regional curves are plotted with the remaining three sites, it’s clear that the sites align more with the adjusted curve (particularly the Price Brook and Coon Creek sites). See Figure 36. These two sites are particularly important because they’re in two different areas; Price Brook is on the Clinton River East branch and Coon Creek is on the North Branch, indicating that these equations don’t align with one branch over another.

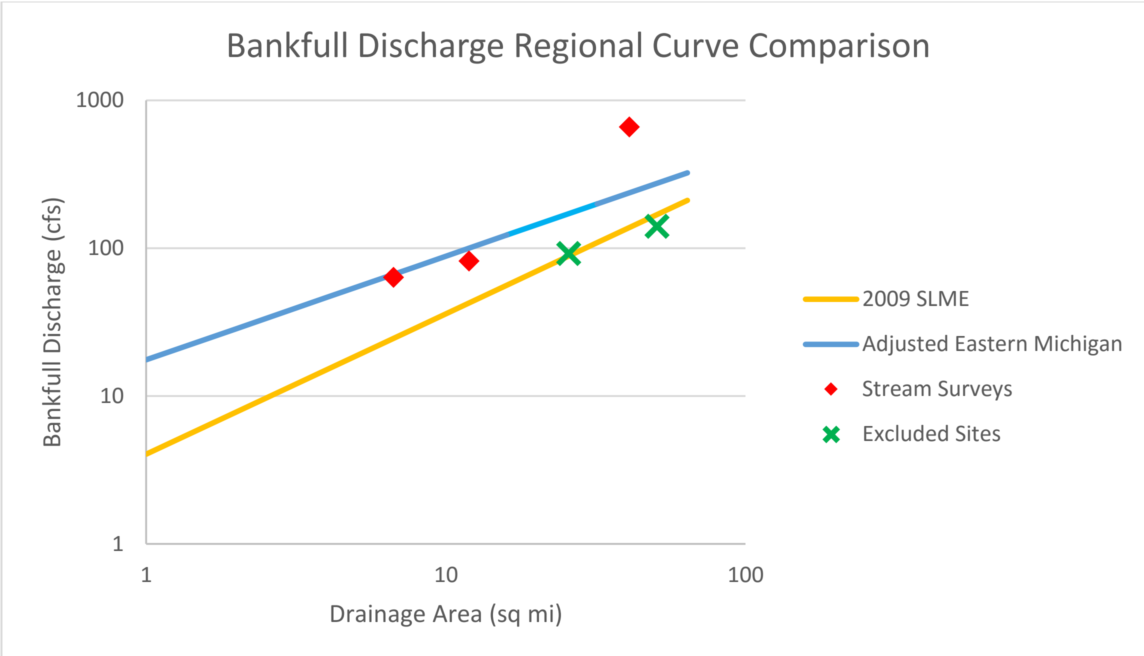

Figure 37: Bankfull Discharge Regional Curve Comparison with Survey Sites

In addition, the East Pond Creek and North Branch sites are both below the adjusted curve and are about that of the previous SLME curve.

The biggest takeaway from this is not the regional equations, although they do provide an approximation for checking drain sizes, but instead highlights the need for many sites to be surveyed. Despite the sites chosen being seemingly representative of the drains in Macomb County, a couple of them were not good choices for the regional curve. Even more importantly, it highlights that while the regional curve is a good indication on sizing in terms of magnitude, it should definitely not be used for designing the channel.

Guidelines (By Jamie Steis)

In 2008, Macomb County implemented Procedures and Design Standards for Stormwater Management in response to the Phase II National Pollutant Discharge Elimination System (NPDES) Stormwater Regulations. These standards are broken into many parts:

- Procedures for Subdivision Plat approval
- Procedure for Approval of Engineering Plans for Unplatted Developments
- Requirements for Drains under MCPWO Jurisdiction
- Design Criteria for County Drains
- Managing Stormwater Runoff
- Landscape and Maintenance Standards

The areas that related to this work are the Design Criteria for County Drains and Landscaping and Maintenance Standards (and to some degree, Managing Stormwater Runoff).

Currently, the part discussing design criteria is basically split into two sections: criteria for closed county drains and criteria for open county drains. The criteria for enclosed county drains discusses a number of relevant items such as pipe requirements, the trench width, bedding and cradles, guidelines for laying pipe, backfilling pipe, and structures (manholes, catch basins, etc.) to name a few. In addition, it mentions calculating culvert sizes.

The open county drain criteria section is a bit more general. The channel design approach is discussed, going into the different stages of a two-stage channel and discussing the requirements of designing the open county drains. It discusses the method for determining design discharge, and then the construction requirements are set forth. While this section discusses most aspects related to the two-stage drains, it does little to help the designer actually design the channel. There are no examples of design and no recommendations for determining the bankfull channel. In addition, it doesn't give a recommendation for designers to check their bankfull dimensions; namely, a regional curve. While Macomb County does have a good basis for helping engineers in two-stage channel design, it offers little additional help in ensuring designers are on the right track.

The point of the standards is not to do the design work for the engineers or provide too many guidelines so that the designers are constrained in what they can do. However, providing recommendations and guidance can go a long way. For example, a regional curve can serve as a check for engineers to make sure that there designs are not completely out of line. In addition, recommending a software such as STREAM or even doing an example of a calculation determining bankfull would also be helpful. A sample calculation of the MDEQ method for computing flood discharges in watersheds in provided in an appendix; a similar calculation for determining bankfull might be a good addition.

The second aspect of the standards related to two-stage design is landscaping. Within the landscaping section is requirements for plantings within open county drains, swales, and upland areas; and maintenance and inspection requirements. The landscaping requirements for open county drains discusses the zones of a two-stage drain (i.e. floodplain, banks, sloped walls, etc.) and what plant requirements are necessary for each. In addition, it discusses maintenance of open county drains.

The biggest issue within the landscaping requirements, which will be discussed further in the *Feasibility in other regions* section, are that they aren't specific enough. For example, it mentions that a woody vegetation canopy shall be established and maintained for 50-70% bankfull channel canopy, but it doesn't give details about how far this should go (along how much of the drain) and when this canopy should be established by (how many years after the drain is established). Improvements to this section would include clarifying some of these requirements and providing examples of how to establish the canopy.

As discussed, the standards provide a great start to helping engineers with a design basis for a two-stage drain. This is the first drain code that has included a requirement for two-stage design and it does a great job for paving the way for future guidelines in other counties. However, it doesn't seem to be specific enough to really help engineers. Keeping in mind that these are standards and do not serve as a how-to guide for designing two-stage drains, it is still definitely possible to add more helpful parts to these standards. Providing a regional curve or equation to check calculations, providing an example of bankfull calculation or at least a recommendation for a method or software (such as STREAM) to help determine bankfull, and updating the landscaping requirements to clarify some obscure requirements could be helpful in the long run.

Outreach (By Jamie Steis)

As part of the Michigan Sea Grant award, an outreach component was required. While it was important to further implement this design into the Macomb County standards, it was even more important to be able to educate and gain support from the public. Without support, the standards would only go so far in their implementation. In addition to support, feedback was an important part of the outreach. We wanted people to understand these standards and also wanted to improve the standards in order to make it easier for people to utilize the standards.

There were two components to the outreach. A survey was sent out to engineers in the area which asked about their experience with two-stage ditches, their familiarity with Macomb County's design standards for stormwater management, and what enhancements would assist their design of two-stage ditches. Second, a public meeting was held to present information regarding two-stage ditches and to get in person feedback regarding standards. The public meeting was in the form of a lunch and learn where Macomb County provided food and we presented our topic of discussion.

Lunch and Learn

On June 5 2015, the Lunch and Learn was held at the Macomb County Public Works office regarding Macomb County's engineering standards. Topics in this Lunch and Learn included an overview of the Sea Grant Project, a summary of current standards, and a discussion on proposed improvements to the current standards. Approximately XX people came to the discussion, representing companies and municipalities in the area.

Four people spoke at the presentation: Lynne Seymour, an Environmental Engineer with Macomb County Public Works; Carol Miller, a Civil Engineer professor at Wayne State who is also the lead of the Michigan Sea Grant project; Jamie Burton, an associate for Hubbell, Roth, and Clark; and myself. The agenda was as follows:

- Lynne Seymour offered an introduction into why we were there and gave a quick overview of the
- Carol Miller presented a summary of the Michigan Sea Grant project
- I presented a summary of the current standards and then went over possible changes that could be made to those standards to allow engineers to more easily use the standards to design and construct two-stage drainage ditches.
- Jamie Burton ended by opening the presentation up for discussion with the attendees. Topics discussed included:
    - Challenges of constructing two-stage drainage ditches
        - Data collection
        - Urbanization and developer interactions
        - Determining base flows
        - Explaining the value of two-stage design to developers
    - Tips for design
        - Standardization between consultants
        - Making an earlier, more straightforward approval process
    - Future meetings

In addition to the discussion, we also received some informal feedback regarding the presentation. In summary, the informal feedback was that the presentation was a good format, there was useful information in the presentation, and that they were interested in attending more in the future.

Going into the discussion, I expected attendees to focus on troubles with design and how we could improve the standards to address these. However, it seemed that most of the troubles with utilizing the two-stage design had less to do with the actual design and construction process and more to do with getting buy-in from the developer. As explained earlier, while the upfront costs of a two-stage design are higher than a trapezoidal design, the long-term costs tend to even out between the designs. When a developer looks at a design like this, it’s hard to justify why this should be done since developers usually only pay for upfront costs (i.e. construction and design costs) and do not usually pay for the costs over time.

One of the solutions discussed was the importance of being able to get developers to understand. More importantly though is ensuring that public officials are also informed about these issues. If public officials don’t understand why these standards are in place and can’t properly defend them, it’s hard to gather support from the public, particularly developers.

As discussed earlier, the main purpose of the lunch and learn was to educate those who utilize the design standards and gain feedback on what improvements can be made. By promoting the use of two-stage design through the public forum, we gained support for our efforts and provided a means of giving feedback. This meeting was a great introduction to further meetings that will hopefully address issues related to two-stage ditch design and the Macomb County design standards.

Survey

The other component of outreach was a survey sent out to engineers in the area. The purpose of the survey was to get a sense of people’s understanding of two-stage ditch design. It also was used as a way to get people’s feedback on methods to improve the current design standards for Macomb County.

The survey was sent out to approximately 30 regional engineers. Initially, only four responded. However, at the lunch and learn, attendees were encouraged to fill out the survey and were resent the link to the survey after the lunch and learn. After this follow-up, there were a total of 13 responses.

The makeup of the responders are as follows:

Role in using Macomb County Storm Water Standards	Number of respondents (percentage of respondents)
Site Design Engineer	7 (53%)
Site Plan Review Engineer	4 (31%)
Community Engineering Consultant	4 (31%)
City/Village/Township Employee	3 (23%)
County Employee	1 (8%)

*Note: Percentages/number do not add up to total number of respondents because some respondents have multiple roles in using Macomb County Storm Water Standards

Out of the 13 responders, eight had used Macomb County's Procedures and Design Standards for Storm Water Management to design site plans and drain improvements and only four had designed a two-stage open channel cross-section.

The most helpful part of the survey was a section inquiring about enhancements that could be made the standards in order to assist one in their design/evaluation of two-stage channels and rating their usefulness. The options that were most useful were a plan review checklist/spreadsheet, more guidance on landscaping and maintenance standards, and more USGS gage locations. Surprisingly, more information on implementing storm water credits was the least useful action that could be made to the standards.

Another helpful portion of the survey was question 6, which asked about what was challenging in implementing the standards. The most frequent sentiment was regarding inconsistency and example calculations. Numerous comments focused on the inconsistencies between how designers interpret them and also how Macomb County Public Works interprets them. One responder even commenting that there were inconsistencies between sections of the standards. Evidently, it’s not completely clear how to design using these standards. A solution to this, which numerous responders brought up, was including example calculations. Calculations would offer people a better understanding on how certain aspects of the design were determined i.e. bankfull dimensions.

The full results of the survey can be found in an attachment to this report.

Feasibility in other regions

Having the ability to regulate the design of two-stage ditches as well as provide helpful tools to those designing these are both important aspects of county-wide application of these designs. With a significant portion of Macomb County (primarily northern Macomb County) being rural farmland, it's particularly important to be able to implement and encourage this type of design. As discussed earlier, Lake St. Clair is experiencing these algae blooms and since the Clinton River is a primary drain into the lake, the Clinton River is a primary conduit for nutrient transport into the lake. In addition, Lake St. Clair is upstream of Lake Erie (with the Detroit River), one of the most significant bodies of water affected by algae blooms. However, despite the nutrient inputs into these bodies of water, ultimately this design standard will only be significant if it can be implemented elsewhere.

Arguably, one of the most important factors that determines the feasibility of implementing this regulation in other counties is a regional aspect. It's important to consider whether or not this will be supported by the region (i.e. state government) and whether or not designers and developers in the area have heard or worked with these designs before. In addition, it's important that there's a significant need for this. Macomb County, which is located in southeast Michigan, is close to other counties that have watersheds that ultimately end up in Lake Erie. Washtenaw County and Oakland County all contain parts of the Clinton River or River Rouge watersheds that both eventually drain to Lake Erie. Even more so, Monroe County is directly affected by the nutrient loading, since it lies on the western side of Lake Erie. All of these counties also have a significant portion of farmland, which means they have a lot of nutrient runoff that can be curbed.

As discussed earlier, despite the importance of getting these guidelines implemented, a lot of what will determine the success of a guideline is how much support you have from the community. A community that would support this guideline is one that has been affected by nutrient loading into a lake and one that sees and is impacted by the nutrient loading firsthand. Monroe County is a perfect example of this.

The algal blooms have a detrimental effects ecologically speaking, but also socioeconomically. Tourism is of course affected by them. The algal blooms wash onto the shores which decreases the amount of interest in water recreation. Even more so, the algal blooms raise public health issues. Swimming in the water can cause health concerns and the algal blooms can also affect drinking water as they produce a toxin called microcystis. As seen in the summer of 2014, Toledo's drinking water, which also serves parts of Monroe County, was severely affected by the toxin the algal blooms produce and were forced to shut off drinking water for 3 days (source). This isn't a minor issue that will go away in a few years. It's a vigorous issue that will continue to come back as long as the current conditions persist.

Multi-Stage Drain in Macomb County

In addition to understanding whether a guideline implementation will be successful in one region, it's important to understand whether this can be implemented elsewhere and what steps need to be taken in order to implement it elsewhere. In order to further understand this, we can look at Macomb County and the steps they took in order to incorporate these standards into their drain code.

As discussed earlier, the requirement for the two-stage drain formally was implemented in Macomb County in the Procedures and Design Standards for Stormwater Management in response to the NPDES Stormwater Regulations. According the Lynne Seymour, an environmental engineer with Macomb County, prior to this, it had been decades since the written standards had been updated, specifically, since the 1967 Rules and Regulations for Internal and External Drainage for Subdivisions was implemented. The standards had informally been changing through the years, but there had never been anything that was actually written as a requirement. The two-stage design was one part that was informally used by the county, however there was little basis for the design. While they recommended the channel slopes and benches, they couldn't provide designers with tangible guidelines.

In addition to the design aspects, the two-stage channel requires landscape changes in order to prevent soil erosion. While the two-stage design alone lessens the amount of soil erosion in itself, the most benefit comes when the channel and landscape are both considered. The addition of the two-stage design garnered little resistance but the addition of the landscaping changes did. Since design was already informally required, it wasn't as big of a surprise that it was being written into the guidelines. However, landscaping requirements weren't as strongly enforced and with the new guidelines, landscape requirements were much more specific. In order to develop the guidelines further, they plan to improve the next guidelines to incorporate more clarifications for landscape requirements.

Overall, a lot of Macomb County's work was focused on getting support for the community. Macomb County didn't incorporate the two-stage design standards on a whim- they incorporated it after years of using these standards informally. By the time these standards were actually written into their drain code, most of the community understood that this was a norm. On the other hand, the landscaping requirements were not widely known or incorporated when they were put into the standards. When they were put into the standards, people were a bit surprised.

Ultimately, what can be learn from Macomb County's experience is that those involved with these standards should be aware that these standards will be put into place and ultimately have some say in what they would like to see from these guidelines. This isn't to imply that the public should be able to say that they don't want these standards (for financial reasons or other), but have some input in what things they might want to see in the guidelines that may help them meet these standards. With this understanding, there would probably be less resistance.

In summary, most of what will determine if these guidelines can be implemented and will be successful is dependent on regional and social understanding of drainage ditches with respect to the items that drainage ditches effect i.e. nutrient loading into lakes, soil erosion, etc. Counties near lakes that are directly affected by the effects of nutrient loading i.e. Lake St. Clair, Lake Erie, and that have significant farming communities are prime targets for implementation of these guidelines. They are the communities directly affected by nutrient loading and it will be much easier to justify the excess costs or excess upfront work to build and design to those who understand the negative impacts of nutrient runoff. In addition, educating those who work on drain designs and requesting input on the guidelines instead of just "surprising" this design should gain more support for these designs and ensure their implementation move forward.