Computational Study of Fish Passage through Circular Culverts in Northeast Ohio

Prepared by:
Darshan Baral, Hans M. Tritico

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16. Abstract

An investigation has been carried out in Northeast Ohio to determine the percentage of culverts that act as barriers for fish passage and to identify the design parameters that can be associated with passage success through stream simulation in two computer programs – FishXing and HEC-RAS. The results from HEC-RAS shows that, out of 40 culverts analyzed, 55% are partial barriers and 45% are complete barriers. A comparable analysis in FishXing analysis suggest that out of the 54 culverts analyzed, 11% are partial barriers and 89% are complete barriers. Student's t-tests ($p \leq 0.05$) showed that the difference in the average perched height between partial barriers and complete barriers was significant for the output of both programs. Additional analysis was carried out in FishXing for greenside darter and largemouth bass by increasing diameter, decreasing length, decreasing slope, increasing Manning's roughness (n) of culvert material, and embedding the culverts with gravel substrate (n = 0.04) independently to examine the effect of those parameters on passage success. For greenside darter, embedding the culverts resulted in 36% of the culverts turning from complete barriers into partial barriers and had a greater impact on increasing passage success compared to varying other design parameters. Similar analysis for largemouth bass exhibited a less noticeable difference.

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Darshan Baral, Hans M. Tritico
Youngstown State University

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Prepared in cooperation with the Ohio Department of Transportation
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List of Abbreviations

BND	Blacknose dace
CS	Central stoneroller
DEM	Digital Elevation Model
FPS25	25% Low Flow
GAP	Gap analysis program
GS	Golden shiner
GSD	Greenside darter
LMB	Largemouth bass
LSF	Longear sunfish
n	Manning's roughness coefficient
NED	National Elevation Dataset
NP	Northern pike
ODNR	Ohio Department of Natural Resources
ODOT	Ohio Department of Transportation
PK2	Two year peak flow
PSF	Pumpkinseed sunfish
S	Seconds
SMB	Smallmouth bass
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WDFW	Washington Department of Fish and Wildlife
WS	White sucker
WYE	Walleye

Chapter 1: Introduction

1.1: Description

Installation of culverts can often lead to an unintended consequence of potentially creating barriers for fish passage and causing an ecological connectivity problem. Stream crossings, especially closed bottom structures such as culverts, have been known to thwart the movement of aquatic organisms traversing them. Previous research studies in British Columbia have shown that 60 to 90 percent of all closed bottom structures hinder fish movement (Mount *et al.*, 2011, Harper and Quigley, 2000).

Installation of culverts instead of bridges as stream crossings during road construction occur commonly because of the relatively low construction and maintenance cost (Larinier, 2002) and excellent conveyance properties of culverts. In the past, culverts used to be designed to ensure efficient passage of the design discharge through them (Vasconcelos *et al.*, 2011). In most cases, the design discharge was a high discharge corresponding to some probable flood event (Ohio Department of Transportation (ODOT), 2010). Understandably, successful passage of fish through culverts was not one of the primary requirements, and received only minimal attention.

The installed culverts have the potential to affect fish movement due to numerous factors (Mount *et al.*, 2011), and barriers can be created at the culvert inlet, outlet, and within the culvert itself (Nukurangi, 1999). The introduction of the barriers due to placement of culverts is a result of alteration in the stream properties (Larinier, 2002). Installation of a culvert can lead to constriction of the natural width of the river for a considerable distance including the immediate surrounding area in the upstream and the downstream of the culvert location. Consequently, there is substantial change in the depth, turbulence, and velocity of flow. These changes can often create a barrier for fish passage due to insufficient depth during low flows and/or increased velocity during high flows (Hotchkiss *et al.*, 2007). In addition, improperly installed culverts can lead to other problems like sediment deposition in the upstream of the culvert. Scouring in the downstream of the culvert can lead to excessive perched height or hang height. Even small perched heights can act as impassable barriers for fish with weak swimming and jumping abilities (MacPherson *et al.*, 2012). Also, the installation of culverts can cause a difference in substrate properties between the downstream and upstream of the culvert. Each of these alterations in the natural habitat of fish has the potential to create barriers for passage.

Culverts that have not been designed for fish passage can have an adverse impact on the ecosystem of the rivers. Fish in small streams are known to be mobile (Warren *et al.*, 1998). The reasons behind the need to move include the need to find food, escape predators, spawn, and adjust to variations of seasons. Culverts hinder the movement of fish and aquatic organisms, potentially causing passage barriers, community fragmentation, and an imbalance in the overall ecology of the system (Trombulak *et al.*, 2000). These passage barriers can lead to disruption of spawning and feeding habits of fish (Morrison, 2006). Hindrance to movement of fish can also have an impact on the movement and distribution of other species that depend on fish for locomotion within the river. For example, unionoids, a family of freshwater mussels, have the need to parasitize a fish host during the larval phase in their lifecycle. Restriction to fish movement affects the distribution of these freshwater mussels (Watters, 1995). The problem is particularly relevant in Ohio where there are 14 federally endangered mussel species and 27 species endangered in the state of Ohio (Watters, 1995). Thus, culverts have the potential of altering the ecosystem of a stream in multiple ways beyond fish passage and distribution.

As the environmental effects due to installation of culverts during road construction are becoming clearer, interest to reduce those effects is increasing. Efforts are being made to understand the problem of reduced ecological connectivity, and to look for solutions to alleviate the problem in the present, and completely avoid it in the future. In several places, studies have been carried out to measure the extent of the connectivity problem in the rivers, understand the reasons behind them, and discover ways to mitigate them. Such studies in North America have primarily been focused on anadromous salmonoid fish species (Bouska *et al.*, 2009). According to a Washington Department of Fish and Wildlife (WDFW) estimate, the total number of fish passage barriers in Washington State is 30,000 and culverts crossings are the most common type of barrier among them (WDFW, 2013). Similar studies have been carried out for important native fishes in Alaska, Montana, Ontario, etc. However, in Northeast Ohio, and the Midwest in general, such studies have not been carried out in large quantity. The presumed absence of important migratory fish species in the area, relatively mild terrain with slow moving streams, and less federal pressure due to the near absence of endangered fish species (U.S. Fish and Wildlife Service (USFWS), 2012) are some of the reasons for lack of sufficient study.

There are at least 176 different fish species (Ohio Department of Natural Resources Division of Wildlife (ODNR DOW), 2012) and 80 different mussel species (Watters, 2009) in the waters of Ohio. The number of culverts that ODOT maintains in the state of Ohio is estimated to be roughly 90,000. Given such large numbers of culverts, ODOT was interested in assessing the connectivity problem in Ohio. Specifically ODOT was interested in the study of the impact of culverts on the migrations of fishes in Ohio.

This study is an attempt to investigate the fish passage through circular culverts in Northeast Ohio. The outcome of this study is expected to provide a better understanding as to whether ecological connectivity is decreased by culverts in Northeast Ohio. As identification of the problem is the first step towards solving it, knowledge about potential fish migratory problems through culverts will assist in devising ways to remove these barriers. It is anticipated that the findings of this study will induce policy discussions among the concerned authorities about the choice of cross drainage structure, design parameters of culverts, and specific requirements about the desired level of fish passage through culverts.

There are several methods for assessing if a culvert acts as a barrier for fish passage or not. The field methods involve sampling fish upstream and downstream from the culverts. The process can involve comparing fish distribution between the downstream and the upstream of the culvert and correlating that to possible fish passage (Pearson *et al.*, 2006, Blank *et al.*, 2005), or capturing fish in the downstream of the culvert, tagging them, and identifying how many of those tagged fish make it to the upstream of the culvert (Blank *et al.*, 2005). Another method to assess passage is to simulate fish movement through culverts using computer software and record data on the success or failure of fish passage (Blank *et al.*, 2005). The flow properties and geometric characteristics of a barrier can be used to define the hydraulic conditions within the barrier, which can then be compared with known swimming abilities of fish to analyze passage success (Powers *et al.*, 1985). For example, when the flow velocity is higher than the swimming velocity of fish, the culvert can be assumed to be a barrier due to high flow velocity. Similarly, when the water depth is shallower than the body depth (the greatest depth between dorsal and ventral surface) of the fish, the culvert will pose an obstacle for upstream migration of fish due to insufficient flow depth. In other culverts, the fish can be exhausted before reaching the end, and will be unable to pass through the culvert due to the combination of water velocity and culvert length. When the difference in the water surface elevation between downstream end of the culvert and stream channel just downstream from the culvert is greater than the leaping ability of the fish, the culvert will be a barrier due to excessive outlet drop. Understandably, perched culverts (i.e., the culverts with their bottom above the streambed) will have greater outlet drop because of the additional perched height. It is to be noted that depending on the flow condition, it is possible for culverts to be a barrier due to more than one reason at once.

For this study, the culverts were analyzed for fish passage using FishXing 3 and HEC-RAS 4.1.0. A HEC-RAS add-on developed by Vasconcelos *et al.* (2011) was also used to carry out passage analysis so as to incorporate velocity variation across the culvert cross-section.

FishXing is freely available computer software developed and maintained by the USFWS that can be used to model the flow conditions through a culvert based on culvert parameters and geomorphic conditions of the stream. It then compares the modeled conditions with the swimming and leaping abilities of fish to simulate swimming performance of fish through the culvert. FishXing is a commonly employed simulation tool used to carry out fish passage analysis. The software is capable of performing one-dimensional hydraulic calculations to predict flow depth and velocity inside a culvert which are then compared to the swimming and leaping abilities of fish to identify if the culvert is a barrier for passage of that particular fish (Blank *et al.*, 2005). Output from FishXing has been found to replicate the results from field assessment in the range of 71-100 percent of time (Hotchkiss *et al.*, 2007). With proper field data collection, FishXing has been known to be a powerful tool to analyze culverts for fish passage. More information on FishXing has been provided in Section 3.5 of this report.

In addition to FishXing, passage analysis was also carried out using the software package HEC-RAS. HEC-RAS is the U.S. Army Corps of Engineers' River Analysis System developed by the Hydrologic Engineering Center that can be used to carry out one-dimensional hydraulic analysis in steady and unsteady conditions (Brunner *et al*., 2010). The program is capable of modeling inline culverts. This feature was used to predict flow depth and velocity, which were then compared with fish properties in Microsoft Excel spreadsheet to identify passage success rates of fish at fourteen different flow conditions. Additional information about HEC-RAS has been provided in Section 3.6 of this report.

An attempt has also been made in this study to use another utility, a post-processing tool for HEC-RAS, created by Vasconcelos *et al.* (2011). The tool utilizes the powerful computational abilities of HEC-RAS in association with an additional algorithm to calculate the velocity distribution along the culvert barrel cross-section (Vasconcelos *et al.*, 2011). This distribution is then compared with fish swimming abilities to determine if the culvert is a barrier or not. The fish are predicted to be able to pass through the culvert in instances when the reduced velocity zone near the walls of the culverts is large enough in area for the fish to fit through and the flow velocity against which the fish must swim upstream is less than the swimming capacity of the fish. Additional information about the HEC-RAS add-on has been provided in Section 3.7 of this report.

Fish dimensions and swimming data necessary for carrying out passage analysis are available for 11 species in watersheds of Ohio (Fish Xing, 2006a). They are blacknose dace (*Rhinichthys atratulus*), central stoneroller (*Campostoma anomalum*), golden shiner (*Notemigonus crysoleucas*), greenside darter (*Etheostoma blenniodes*), largemouth bass (*Micropterus salmoides*), longear sunfish (*Lepomis megalotis*), northern pike (*Esox lucius*), pumpkinseed sunfish (*Lepomis gibbosus*), smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), and white sucker (*Catostomus commersonii*).

Of these, largemouth bass, longear sunfish, northern pike, pumpkinseed sunfish, and walleye are designated as sport fish by the Ohio Department of Natural Resources (ODNR), while the remaining species have no special status. Due to commercial reasons, there is more interest in ensuring passage of the sport fish through culverts. However, given that the large sport fish are dependent on other small fish species for food, it is equally important that the movement of the non-sport fish is not hindered by the culverts.

1.2: Study Area

The study area is comprised of six counties in the ODOT District 4 which is located in Northeast Ohio. Those counties are Ashtabula, Mahoning, Portage, Stark, Summit, and Trumbull. The study area in general is characterized by a flat topography (Harstine, 1991) resulting in streams that are slow moving because of their relatively milder slope. The average slope of the culverts in the study area calculated from the inventory of culverts provided by the ODOT (discounting the culverts with slopes equal to zero) was 1.74%. It was unclear from the database used whether culverts whose slopes were reported to be zero were actually constructed at zero percent slopes or whether information did not exist for the slope of these culverts. Therefore culverts with a slope reported as zero were removed from analysis in this report.

Typically in Ohio, spring is the wet season while fall and winter are the dry seasons. Lake Erie is located adjacent to the study area on the northern side. In the UTM 17N zone, the northing of the north and the south extent of the project are respectively 4624196 m and 4514928 m while the easting of the west and the east extent are respectively 442976 m and 538893 m. The culverts that were analyzed in this project were the ones installed and maintained by ODOT. The majority of the culverts were located along major roadways such as Interstate 76, Interstate 77, Interstate 80, Interstate 271, State Route 7, State Route 11, State Route 14, State Route 21, State Route 30, State Route 46, State Route 62, State Route 224, U.S. Route 422, and State Route 534. Figure 1 depicts a county map of the state of Ohio with the study area in red.

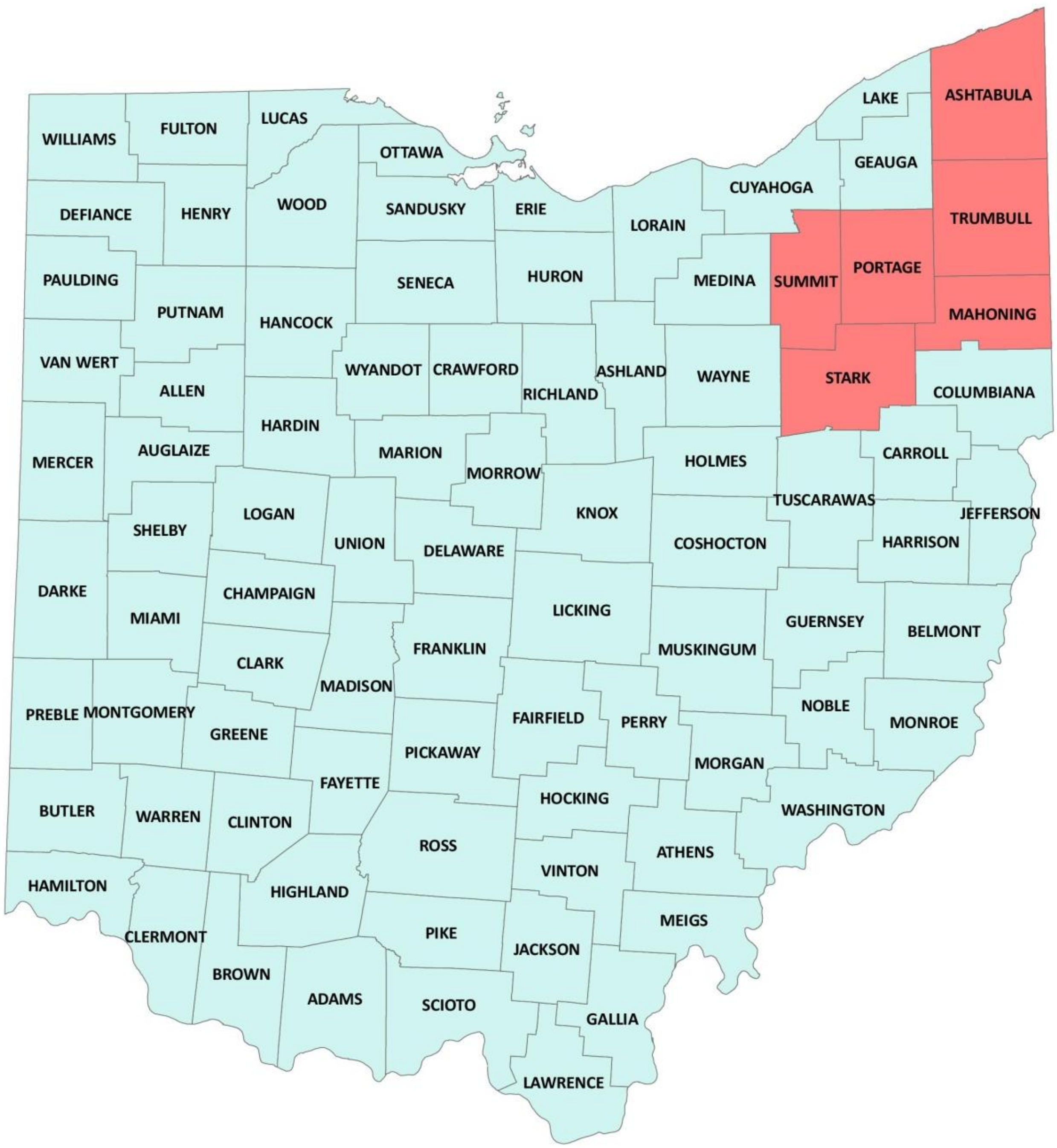

Figure 1: County map of Ohio and the study area in red

Chapter 2: Research Objectives

The primary goal of this study is to determine the percentage of circular culverts in Northeast Ohio that act as barriers for fish passage. Furthermore, the culverts will be classified into complete barriers, partial barriers, or non barriers based on the numbers of fish species that are able to successfully traverse the culvert and the frequency with which they do so.

Non barrier culverts are the ones that allow fish passage for all 11 fish species during all flow conditions. This condition is unlikely even in natural channels given that the criterion is that all fish species are able to move through the reach under flow conditions ranging from mild drought (25% flow) to mild flood (2 year flood event). On the other hand, complete barrier culverts are the ones that prohibit movement of all fish through them at all flow conditions. Partial barrier culverts are the ones that allow passage of at least one fish species for at least one flow condition.

The second goal of this study is to identify the culvert design parameters that affect fish passage success. A comparison of design parameters between culverts that allow fish passage and those that obstruct fish passage is expected to provide information about the correlation of passage success with culvert design parameters. For example, evaluation of results of passage analysis in relation to parameters like the diameter, the slope, and the length of the culvert is expected to reveal the impact of those parameters on fish passage success. This information can then be utilized to devise ways to ensure maximum fish passage when installing or replacing culverts in the future.

Chapter 3: General Description of Research

3.1: Data Sources and Data Collection

The data for this study were obtained from various sources including field collection and several online repositories. A database of 5,837 culverts containing information such as location (latitude and longitude), shape, size, material, slope, and length of culverts was made available by the ODOT (ODOT, 2009). Each culvert was assigned an arbitrary culvert number which was then used throughout the study to refer to it. The latitude and longitude of these culverts were used to import the culvert points into GIS so as to facilitate the extraction of the cross-section near culvert points and also to identify the presence of relevant fish species for each culvert. A field visit to each of the selected culvert (Section 3.3) was also carried out to collect more data and verify the data provided by ODOT. Additional information on selection of culverts and field visits is presented in Section 3.3.

The extraction of river cross-sections in GIS upstream and downstream from the culverts and channel bottom slope downstream from the culvert was done using raster data as the Digital Elevation Model (DEM). 1/9 arc second National Elevation Dataset (NED) with each raster pixel representing roughly 9.8 feet × 9.8 feet square on the ground was downloaded from the USGS seamless server to be used as the DEM. The boundary of the area to download the raster was defined by inputting the latitude and longitude of the extreme top, bottom, left and right of the study area so as to include all the culvert points. The downloaded NED 1/9 was in the form of multiple raster files and therefore had to be merged into one raster file. The basic raster file was then processed further to obtain contours and aspects to assist in the extraction of stream cross-sections. In addition to this, the Bing Hybrid base map and satellite imagery available as base map in the ArcGIS were also used as reference. The cross-section for each of the selected culvert was extracted by drawing a line across the stream channel in the DEM using the 'Interpolate Line' tool in the '3D Analyst' toolbar. The data were then exported into MS Excel. A screenshot of the extraction of cross-section in GIS is presented in Figure F.10 of Appendix F. The 'Interpolate Line' tool was also used to obtain a profile graph along the stream channel which was then used to compute channel bottom slope.

Ohio aquatic gap analysis program (GAP) was used as the information about the distribution of various fish species in Northeast Ohio and was downloaded from the online repository of USGS Ohio Water Science Center. The GAP compiled field collected data of fish, crayfish, and freshwater bivalves present in Ohio streams and used it to predict potential distributions of 130 fish, 17 crayfish, and 70 freshwater bivalves, respectively (Covert *et al.*, 2007). For this study, the GIS shapefile containing information on predicted distributions of the native fish species was used. According to the metadata of the shapefiles, these distributions are provided on a 14-digit hydrologic unit (HUC14) level. HUC14 watersheds are small watersheds with 14 digit codes and an average watershed area equal to 4.4 square miles (Energy and Environment Cabinet, 2010).

The data from Ohio Aquatic GAP was utilized to identify the presence of chosen fish species within the known culvert locations. More information on the selected fish species used for the analysis is presented in Section 3.4 of this report. The data for distribution of each fish species was a shapefile of polygons. First, the culvert points and the shapefiles containing fish distribution information were imported into GIS as separate 'Layers'. A 'Select By Location' was done to select data from the layer of culvert points that intersected with the layer of polygons (i.e., were contained within the polygons) to obtain the distribution of a particular fish. The highlighted culverts in the attribute table of the layer containing culvert points represented the culvert locations where that particular fish species were likely to be present. The unselected culverts were the ones where the presence of that particular fish was unlikely because, in those watersheds, the presence of that fish species was not predicted by the GAP.

In all operations in GIS, every layer was projected in NAD 1983 UTM Zone 17N before using the data for analysis and extraction.

The discharge data for streams were obtained using the online interactive map of USGS StreamStats (Office of Surface Water, 2010). The latitude and longitude of the selected culvert points were used to delineate the watershed for each point in the interactive map and the tool 'Estimate Flows using Regression Equations' was used to get the flow values. For each culvert watershed, the 12 average monthly flows, 2 year flow (PK2), and 25% low flow (FPS25) were acquired. The total number of flows extracted for each culvert was therefore 14. For each culvert, the passage analysis in FishXing was carried out for a continuous range of flows between the minimum and the maximum of the 14 extracted flows. In HEC-RAS, the 14 flows were used to construct a 14 day hydrograph. This hydrograph was used to carry out an unsteady flow analysis, the output of which was then used to carry out passage analysis. More information on the use of extracted flow data to carry out passage analysis in FishXing and HEC-RAS is provided in Section 3.5 and Section 3.6, respectively. The flow values obtained from StreamStats for each culvert are presented in Table B.3 of Appendix B.

The data on fish dimensions and swimming abilities were acquired from the Swim Table which was available from the help function of FishXing. More information on the selection of fish species and their properties is presented in Section 3.4.

3.2: Software Used

Several computer programs were used in this study to obtain data, carry out simulation, and analyze results. ArcGIS 10.0 was used to plot the culvert points, to obtain stream cross-section from DEM, and to identify fish distribution for each culvert. Fish passage analysis was carried out using FishXing 3, HEC-RAS 4.1.0, and a HEC-RAS add-on developed by Vasconcelos *et al.* (2011). Microsoft Excel and IBM SPSS Statistics were used to analyze the obtained data and create various plots.

3.3: Selection of Culverts for Analysis

From the database provided by the ODOT, the culverts were filtered using a number of preliminary requirements. The requirements imposed were that the culverts had to be single celled culverts with a span greater than 24 inches and the slope, length, and tributary information also needed to be provided in the database. If a culvert was reported to have a zero percent slope it was unclear whether the culvert had been constructed at a zero percent slope or whether no data were available on the slope. Therefore all culverts which were reported to have zero percent slopes were removed from this study. The goal was to select culverts which had a high likelihood of carrying a perennial stream as determined through the use of USGS topographic maps and which possessed all the data necessary to carry out the fish passage analysis. It was found that only 241 out of the 5,837 culverts met the aforementioned criteria. Out of the 241 culverts, 192 were circular culverts, 19 were box culverts, and 30 were elliptical culverts. Since the number of the culverts with shapes other that circular was limited, circular culverts were expected to be the only shape with a sufficient number of culverts to analyze for statistical significance. For this reason, the 192 circular culverts were kept for further consideration, no other analysis was performed on culverts of other shapes.

A closer inspection of the 192 circular culverts was carried out using GIS. The inspection in GIS involved extracting channel cross-section at least in the downstream of the culvert points and discarding culverts for which a stream channel could not be verified. The culverts that could be identified from GIS inspection to be placed for purposes other than conveying streams like draining a field or a pond were also discarded. Based on the GIS analysis, a total of 94 culverts were chosen for field visits. The purpose of the field visits was to verify the data provided by the ODOT and to ensure that the culverts were conveying a perennial stream.

The field visits to the 94 selected culverts were carried out over six days between June 15, 2012 and June 29, 2012. This was in the middle of a summer drought and there was essentially no rain during the visits. Therefore, if a culvert still had water moving in it, it was deemed to be perennial as it was assumed that the stream was hydraulically connected to the groundwater table. The field books made during the field visits are presented in Appendix G.

From the field visits, 23 circular culverts were judged to be placed in streams that were not perennial. Four additional culverts were believed to be draining water off the farmlands and one was observed to have a broken section. Also, eight culverts were found to be box culverts and three were found to be elliptical culverts. For the aforementioned reasons, 39 culverts in total were removed from consideration for further analysis. Ultimately, 55 circular culverts were deemed to be suitable for fish passage analysis as these were considered to have a strong likelihood of containing a perennial stream based on the observations made during the field visit. The map in Figure A.1 of Appendix A shows the 94 culverts visited in the field, the green dots representing the 55 culverts chosen for this study and the red dots representing the ones that were not considered for the reasons explained above. The list of the culverts chosen for the study along with their properties is presented in Table B.1 and B.2 of Appendix B. The photographs of the selected culverts are presented in Appendix C. Photographs are only available from either the culvert inlet or outlet due to safety considerations.

During the field visit, data on the culvert diameter, material, embedded depth, and perched height were recorded. Length and slope of the culverts was also measured using tape and spirit level respectively whenever it was deemed safe to work along the roadway shoulder. In some cases, GIS was also used to measure the length of the culverts. Out of the 55 culverts, length was measured for 23 culverts in the field and for 5 culverts using GIS. Slope was measured for

10 culverts in the field. In the absence of field collected data of length and slope, the values provided by the ODOT were used in the analysis. Whenever available, data collected in the field was preferred over the data in the inventory provided by the ODOT.

Out of the 55 culverts, 54 were analyzed using FishXing, as there was an ‘overflow error’ while performing analysis for one of the culverts (Culvert 279). An ‘overflow error’ indicates that at one of the flows FishXing calculated that the roadway was overtopped and therefore an accurate water velocity could not be calculated. Extraction of at least three cross sections both downstream and upstream from the culvert point using GIS was possible for only 40 out of the 55 culverts due to the fact that clear stream channels could not be discerned at six cross sections for 15 of the culverts. Therefore, only these 40 culverts were analyzed using HEC-RAS to assess fish passage success through them. The map in Figure A.2 of Appendix A shows the 55 culverts chosen for fish passage analysis, purple dots showing the culverts analyzed using both FishXing and HEC-RAS, green dots showing the culverts analyzed using only FishXing, and the red dot showing the culvert analyzed using only HEC-RAS.

3.4: Selection of Fish Species for Analysis

As mentioned before, there are 176 different species of fish that potentially could reside in the rivers and lakes in Ohio (ODNR DOW, 2012). However, data on swimming speeds is not available for most of them. FishXing provides the most complete swim speed table available for fishes of the U.S. It includes a collection of data on the swimming speed for 65 different fish species present in the U.S. (FishXing, 2006a). It was found that, of the 176 different fish species in Ohio, swimming speed data was available for only 11 fish species in the swim speed table. Hence, only these 11 fish species were chosen for analysis. The common names, swimming speeds, and dimensions of the fish species chosen for this study are presented in Table 1.

Table 1: Properties of the fish used in the study

Fish	Swimming Speed (feet/s)		Fish Length (feet)	Fish Body Depth (feet)
	Prolonged	Burst		
Blacknose dace	1.260	-	0.139	0.030
Central stoneroller	1.309	-	0.203	0.050
Golden shiner	2.433	-	0.458	0.140
Greenside darter	1.022	-	0.169	0.030
Largemouth bass	3.435	-	1.375	0.400
Longear sunfish	1.280	-	0.292	0.110
Northern pike	1.577	-	2.083	0.310
Pumpkinseed sunfish	1.220	-	0.417	0.190
Smallmouth bass	2.683	-	1.125	0.310
Walleye	1.710	7.200	1.198	0.190
White sucker	2.519	-	1.250	0.230

Ideally, in a non barrier culvert, the flow depth would always be more than the body depth of the deepest fish, the flow velocity would always be less than the swimming speed of the weakest swimming fish, and the outlet drop would always be less than the outlet drop requirements of the weakest fish. For a culvert to be a non barrier in the case of the 11 fish species chosen for this study, maximum flow velocity would always have to be less than 1.022 feet/s (greenside darter), minimum flow depth would always have to be more than 0.4 feet (largemouth bass), and maximum outlet drop would always have to be less than 0.139 feet (blacknose dace). It is worth remembering that this is a very strict requirement unlikely to exist even in natural streams.

The blacknose dace, also known as the eastern blacknose dace, usually dwells in pools and prefers areas with riffles and gravel substrate for spawning. It is relatively tolerant to turbidity in water (Rook, 1999). The benthic central stoneroller prefers to live in riffle areas with clear water (ODNR DOW, 2012). The white sucker, another bottom feeder, is an adaptable fish, as it is relatively tolerant to pollution and turbidity and has no specific preference for habitat. It swims up the tributaries during spring for spawning and is known to be one of the prey of bigger fishes like northern pike, largemouth bass, and smallmouth bass (Rook, 1999). Areas of the river with clean water and aquatic vegetation are the preferred habitat of the golden shiner and are commonly found in slow moving or stagnant water (ODNR DOW, 2012). The greenside darter also likes to live in slow moving water and pools but also prefers fast moving riffles for spawning (ODNR DOW, 2012). Although the largemouth bass is an adaptable fish, it prefers clear and relatively slow moving water with aquatic vegetation (ODNR DOW, 2012). On the contrary, the smallmouth bass likes streams with noticeable current and gravel or rock substrate (ODNR DOW, 2012). Slow moving water with clean gravel substrate is the preferred habitat of the longear sunfish (ODNR DOW, 2012). On the other hand, clear slow moving water with substrate of organic debris is preferred by the pumpkinseed sunfish (ODNR DOW, 2012). The northern pike is a voracious predator of suckers, shiners, and chubs and its preferred habitat is the areas of the river with clear water and dense aquatic vegetation (ODNR DOW, 2012). The walleye, one of the biggest sport fish of Ohio, prefers areas with relatively clear water and shallow depth with a firm substrate (ODNR DOW, 2012).

3.5: Passage Analysis using FishXing

To determine if fish can swim upstream through a culvert, passage analysis was carried out using FishXing. To run the one-dimensional flow simulation, FishXing requires several data to be input into the 'Crossing Input' window of the program. These data are fish properties (fish swimming speed, fish length, fish body depth, and maximum outlet drop), culvert data (diameter, slope, length, material, embeddedness, outlet bottom elevation, and culvert entrance type), and tailwater condition or the elevation of the water at the channel downstream of the culvert at varying flows. Ohio Passage Analysis Tool (OhPat), a step by step guide on how to carry out fish passage analysis through culverts in FishXing, is presented in Appendix F.

First, the species for which the simulation was to be carried out was selected from the list provided in the program. Then, the fish dimensions including the length and body depth were entered into the program. An assumption was made that each fish can leap their body length and therefore, for outlet criteria, the maximum outlet drop was chosen to be equal to the body length for each fish. After that, the culvert parameters, namely the diameter, length, slope, pipe entrance type, Manning's roughness coefficient (n) of the culvert material and, whenever pertinent, the Manning's roughness coefficient (n) of the substrate in embedded culverts (i.e., the culverts with their bottom below the streambed) were input into the program. The Manning's n values for corrugated metal pipe, concrete pipe, HDPE pipe, and gravel substrate were chosen to be 0.024, 0.013, 0.010, and 0.040, respectively. These values for Manning's roughness (n) were chosen based on the recommended values within the FishXing program itself. The Manning's roughness for natural channel and clay substrate was chosen to be 0.027 and 0.018, respectively (Brunner *et al.*, 2010). The tailwater condition was defined by entering a cross-section and channel bottom slope immediately downstream from the culvert which was extracted using GIS. The passage analysis was carried out for a range between the minimum and maximum of the 14 flows (12 average monthly flows, 25% low flow, and 2 year peak flow) acquired from the StreamStats program and the passage results were noted. The process was repeated for all 11 fish species for each culvert. In total there were 538 different passage simulations run in FishXing.

If the flow depth at any discharge anywhere within the length of the culvert is predicted by FishXing to be less than the body depth of a fish species, then the culvert is classified as a barrier due to insufficient depth for that fish species for that particular discharge. If the flow depth is more than the body depth of the fish, it is assumed that at that particular discharge, the culvert is not a barrier due to insufficient depth for that fish.

Likewise, if the calculated difference in height between the water surface at the downstream end of the culvert and the water surface at the channel cross-section for each flow just downstream of the culvert is greater than the defined maximum outlet drop for a fish, the culvert is classified as a barrier due to excessive outlet drop for that fish. The following excerpt is from the help file of FishXing (FishXing, 2006b):

> "If the Outlet Drop (difference in elevation between the water surface at the culvert outlet and the tailwater) is greater than the Max Outlet Drop, as defined on the Crossing Input Window the culvert is a barrier at that flow due to the an excessive outlet DROP."

If the flow velocity is less than the prolonged swimming speed of the fish, it is assumed that the fish swims upstream at the prolonged swimming speed. If the burst swimming speed is available, the fish is assumed to swim at burst speed if the flow velocity is more than the prolonged swimming speed but less than the burst speed of the fish. When the predicted flow velocity anywhere inside the culvert is higher than the burst swimming speed of the fish (or prolonged swimming speed when burst swimming speed is unavailable), the culvert is classified as a velocity barrier. Also, if the time taken to reach the upstream end of the culvert exceeds the time range of exhaustion for the fish while swimming at either prolonged (less than 200 minutes) or burst speed (less than 20 seconds), the culvert is defined as a barrier due to high velocity (FishXing, 2006b).

Screenshots of longitudinal section of culverts from FishXing is presented in Figure D.1 and D.2 of Appendix D. A flow chart showing the major steps of fish passage analysis in FishXing is presented in Figure E.1 of Appendix E.

3.6: Passage Analysis using HEC-RAS

Fish passage analysis using HEC-RAS was carried out for 40 culverts. The passage analysis required creation of hydraulic models for each culvert which were created by entering the 'Geometric Data' and 'Unsteady Flow Data' which were obtained from the StreamStats website.

In HEC-RAS, a project was created for each culvert. For geometric data, the culvert dimension, at least three or more cross-sections on both the downstream and upstream of the culvert, and the distance between each cross-section at the right, left and center was used. The same values of Manning's n used in the case of FishXing models were used for HEC-RAS models. Based on the recommended values in the HEC-RAS 'Users Manual', the entrance loss coefficient of 0.5 was chosen for pipes with wingwalls or headwalls and 0.9 was chosen for projecting culverts. For unsteady flow data, a 'Flow Hydrograph' was used as the boundary condition in the most upstream cross-section and 'Normal Depth' was used as the boundary condition in the most downstream cross-section. A 14 day hydrograph was constructed using the 25% low flow, the two year peak flow, and the 12 average monthly flows in that respective order with a 'Data Time Interval' of eight hours and each flow persisting for 24 hours (i.e. three instances of eight hours at each discharge). A screenshot of the flow hydrograph constructed in HEC-RAS to carry out unsteady flow analysis is presented in Figure D.3 of Appendix D. The first discharge of the hydrograph was also used as the initial condition for the river section in the most upstream cross-section. After that, an 'Unsteady Flow Analysis' was run with the 'computation interval' one hour. When running the flow analysis, both 'Hydrograph Output Interval' and 'Detailed Output Interval' were chosen to be 4 hours and 'mixed flow regime' was selected. The programs that were selected to run in the 'Unsteady Flow Analysis' were 'Geometry Preprocessor', 'Unsteady Flow Simulation', and 'Post Processor'.

The flow depth and velocity in the upstream and downstream end of the culvert were noted from the 'Detailed Output Tables' in HEC-RAS and the values were compared to the body depth and the swimming speed of the fish respectively using Microsoft Excel spreadsheet to assess if the culvert would act as a barrier. The culvert was classified as a depth barrier for any particular fish if the flow depth at either the upstream or downstream end of the culvert was shallower than the body depth of that fish. Similarly, the culvert was classified as a velocity barrier if the flow velocity was higher than swimming speed of the fish at either end of the culvert. Unlike the analysis in FishXing, only the prolonged swimming speed was considered for each fish species to determine the effect of flow velocity. This distinction is only relevant to the walleye results. Also, unlike the analysis in FishXing, it was assumed that the fish can swim indefinitely at prolonged speed without getting exhausted. Therefore, time for exhaustion of the fishes was not taken into consideration in HEC-RAS analysis. Finally, if the difference between the water surface elevation at the downstream end of the culvert and the water surface elevation in the channel section just downstream of the culvert was found to be greater than the fish body length, the culvert was classified as an outlet drop barrier. A flow chart showing the major steps of fish passage analysis in HEC-RAS is presented in Figure E.2 of Appendix E.

3.7: Passage Analysis using HEC-RAS Add-on

It is known that zones of velocity lower than average exist closer to the culvert walls and that some small fish use these zones to travel through the culverts (Vasconcelos *et al.*, 2011). The results obtained from FishXing can have an inherent conservative bias when it comes to analyzing if a culvert is a barrier for small fish (Blank, 2005). The HEC-RAS analysis performed for this study has also not taken into account the velocity reduction near walls of the culvert. The post-processing tool was developed by Vasconcelos *et al.*, (2011) and can be used to assess the fish passage conditions in circular culverts while incorporating the effect of velocity reduction near culvert walls. For the 40 culverts which were analyzed using HEC-RAS, passage analysis was also carried out using the post-processing tool for HEC-RAS.

The add-on uses the same hydraulic models to carry out the passage simulation which were used to carry out the passage analysis in HEC-RAS. After the model was created in HEC-RAS, fish passage analysis was carried out in the HEC-RAS add-on. This add-on calculates the velocity distribution across the culvert in order to determine the velocity near the culvert walls. The velocity in these reduced velocity zones was then compared to the swimming speed of fish in the culvert. Culvert parameters like number of barrels, culvert diameter, Manning's coefficient, and culvert offset were entered into the add-on and the related HEC-RAS project file for the respective culvert was chosen. The fish species for which analysis was to be performed was selected from the list provided in the add-on itself. The passage simulation was run and the passage results were recorded.

It is to be noted that in the post processing HEC-RAS add-on, flow distribution is not known when flow depth is greater than half the culvert diameter or when the flow is super critical. As a result, the passage results for these conditions are unknown. When the flow depth is more than half the diameter of the culvert or when there is a fast shallow flow, the add-on is incapable of providing a useful result regarding whether or not a culvert is passable for the fish.

3.8: Identification of Design Parameters

In order to identify the parameters that affect passage success, further analysis was carried out in FishXing by changing major design parameters independently and recording the results. Greenside darter and largemouth bass were chosen from the list of 11 fish species for this analysis because of their shallowest body depth and fastest prolonged swimming speed respectively. The data on swimming speeds and fish dimensions are presented in Table 1 of Section 3.4. These two fish therefore represented two extremes of the passage analysis. The greenside darter has the shallowest body depth and therefore can traverse a culvert during the shallowest flow depths. The largemouth bass is the fastest swimmer and therefore will be able to traverse a culvert during the highest flow velocities. The greenside darter is therefore the most likely not to be restricted from passage due to insufficient depth or 'depth barriers' while the largemouth bass is the most likely not to be restricted from passage due to high flow velocity

‘velocity barriers’. Of the 54 culverts analyzed in FishXing, the greenside darter was present in 53 culverts and the largemouth bass was present in all 54 culverts. The design parameters that were altered independently were diameter, length, slope, material, and embeddedness of the culvert. The diameter was increased from the existing diameter to up to ten times the existing diameter of the culvert. The length of the culvert was changed from the existing length down to 25 feet while the slope of the culvert was changed from the existing slope down to 0% slope. Manning’s roughness was changed from the existing culvert material roughness to the roughness of the roughest commonly used culvert material, corrugated metal (n = 0.024). Based on the design methods mentioned in a Federal Highway Administration report, the culverts were embedded 6 inches for pipes with diameter less than 48 inches and 12 inches for pipes with diameter greater than 48 inches (Hotchkiss et al., 2007). This is also the embeddedness requirement employed by the state of Maine (Maine Department of Transportation, 2004). Gravel (n = 0.04) was chosen as the substrate for the embedded culverts.

Chapter 4: Results

4.1: Culverts used for Study

Out of the 55 culverts chosen for study, Ashtabula County and Portage County contained four each. Five culverts were located in Stark County and 13 were located in Summit County. Trumbull County, which contained 29 culverts, was the county where most culverts were located while none of the culverts chosen for the study were located in Mahoning County. The map in Figure A.3 of Appendix A shows the culverts and their position with respect to the counties of ODOT District 4.

The average length of the culverts chosen for analysis was 177 feet and the range of the length of the culverts was from 41 feet to 548 feet. The average diameter was 61 inches and the range was from 28 inches to 120 inches. Similarly, the average slope of the culverts was 1.00% and the range was from 0.06% to 3.70%. Out of the 55 culverts, 37 were made out of concrete, 17 were made out of corrugated metal, and only one was made out of HDPE pipe. Six out of the 55 culverts chosen were found to be embedded with natural substrate within the barrel of the culvert while the remaining 49 were not embedded. The average embedded depth among embedded culverts was 17 inches and the range was from six inches to 48 inches. There were 26 culverts that were found to be perched in the field, the average perched height (among perched culverts) being 17 inches and the range being from one inch to 66 inches (Culvert 287, Figure C.20 of Appendix C). The list of the culverts chosen for the study along with their properties is presented in Table B.1 and B.2 of Appendix B and the photographs of selected culverts are presented in Appendix C.

4.2: Fish Distribution in Culverts

As mentioned in Section 3.1, information from Ohio GAP was used to determine which of the 11 fish species chosen for passage analysis were present in each culvert. It was observed that the distribution of the fish species was not uniform across all culverts. Blacknose dace (BND), central stoneroller (CS), largemouth bass (LMB), pumpkinseed sunfish (PSF), and white sucker (WS) were predicted to be present in all 55 culverts. Golden shiner (GS), greenside darter (GSD), and smallmouth bass (SMB) were predicted to be present in 54 culverts, northern pike (NP) in 45 culverts, and walleye (WYE) in 43 culverts. Longear sunfish (LSF) was the rarest fish, predicted to be present in only 23 culverts out of the total 55. The fish distribution data for the 55 culverts is presented in Table B.4 of Appendix B. The bar chart in Figure 2 shows the distribution of all fish species by the number of culverts in which they are present.

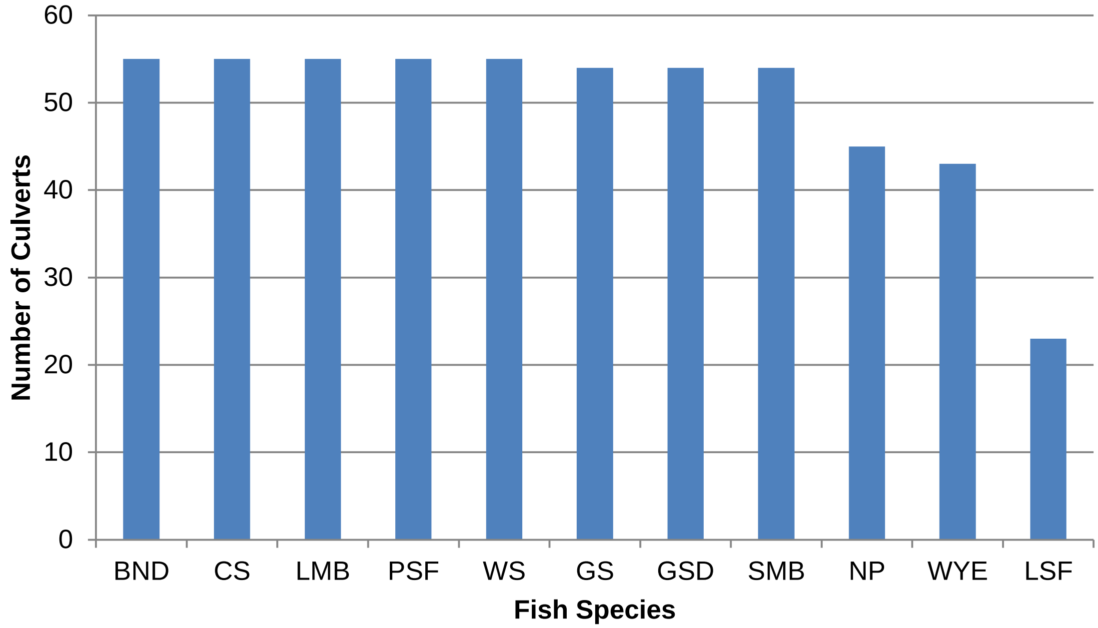

Figure 2: The number of culverts in which each fish species are present

There were only 23 culverts out of the total 55 in which all 11 fish species were likely to be present. The number of culverts with 10, nine, and eight fish species was 19, four, and eight respectively. There was one culvert that was predicted to have only 5 fish species in it. The pie chart in Figure 3 shows the grouping of culverts by the number of fish species present in them.

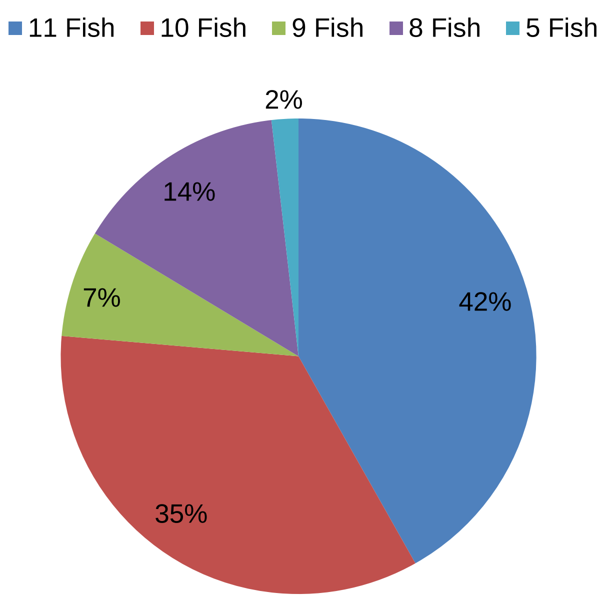

Figure 3: Percentage of culverts out of 55 grouped by number of fish species present

Out of the 54 culverts analyzed in FishXing, blacknose dace, central stoneroller, largemouth bass, pumpkinseed sunfish, and white sucker were predicted to be present in all 54 culverts whereas golden shiner, greenside darter, and smallmouth bass were predicted to be present in 53 culverts. Northern pike was predicted to be in 44 culverts, walleye in 42 culverts, and longear sunfish in 23 culverts. Of the 40 culverts analyzed in HEC-RAS, blacknose dace, central stoneroller, largemouth bass, pumpkinseed sunfish, and white sucker were predicted to be present in all 40 culverts. The number of culverts in which golden shiner, greenside darter, and smallmouth bass were predicted to be present was 39. Northern pike was predicted to be in 32 culverts, walleye in 29 culverts, and longear sunfish in 16 culverts. The distribution of the 11 fish species among the culverts analyzed in FishXing and HEC-RAS are presented in Table 2.

Table 2: Fish distribution among culverts analyzed in FishXing and HEC-RAS

Fish	Number of culverts with fish	
	out of the 54 culverts analyzed in FishXing	out of the 40 culverts analyzed in HEC-RAS
Blacknose dace	54	40
Central stoneroller	54	40
Largemouth bass	54	40
Pumpkinseed sunfish	54	40
White sucker	54	40
Golden shiner	53	39
Greenside darter	53	39
Smallmouth bass	53	39
Northern pike	44	32
Walleye	42	29
Longear sunfish	23	16

4.3: Analysis using FishXing

The output from FishXing was used to classify culverts into categories based on whether they allowed fish passage or not. The results according to passage analysis in FishXing are presented in Table B.5 of Appendix B. Out of the 54 culverts for which FishXing analysis was carried out, it was found that only six (11%) culverts were partial barriers. The remaining 48 (89%) culverts were found to be complete barriers and zero culverts were found to be non barriers. The map in Figure A.4 of Appendix A shows complete barriers (red dots) and partial barrier culverts (green dots) according to FishXing analysis.

Of the 11 fish species, only five species were predicted to be able to swim through at least one of the culverts for some range of flow conditions. They were blacknose dace (present in 54 culverts), golden shiner (present in 53 culverts), smallmouth bass (present in 53 culverts), walleye (present in 42 culverts), and white sucker (present in 54 culverts). Blacknose dace and golden shiner had the best predicted success rates at swimming upstream through culverts as both these species had a successful passage through three culverts each. Smallmouth bass, walleye, and white sucker had successful passage predicted through one culvert each. The remaining six species were not predicted to be able to swim upstream through any culverts at any flow conditions. The bar chart in Figure 4 shows the classification of culverts as non barriers, partial barriers, and complete barriers by fish species. The vertical axis in Figure 4 has been adjusted to begin at 90% so as to depict data more clearly.

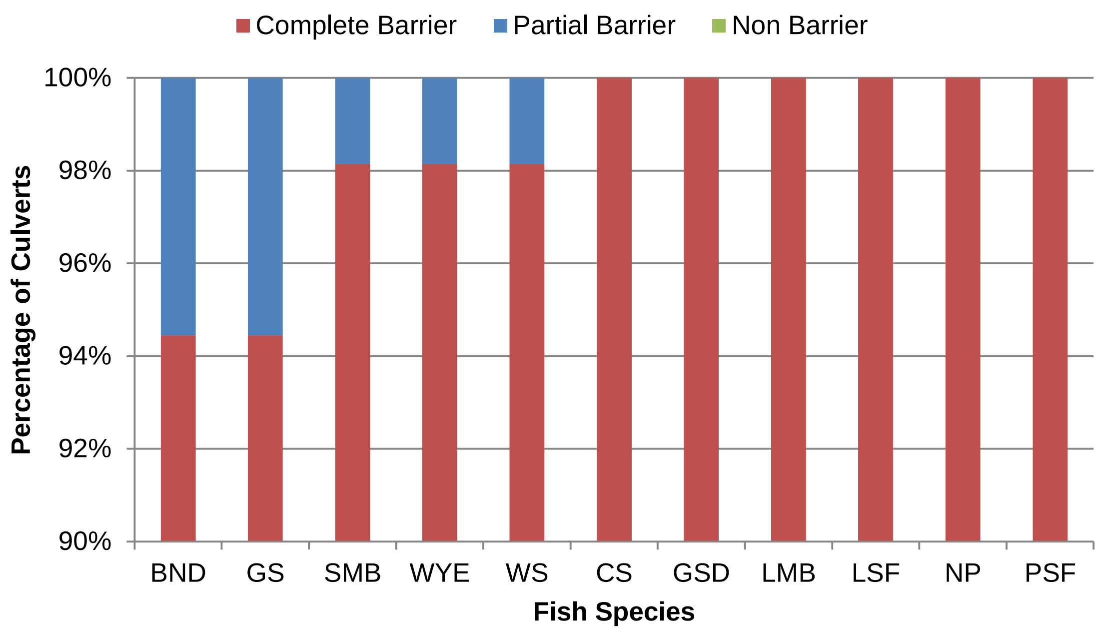

Figure 4: Percentage of culverts out of 54 that are non barriers, partial barriers, and complete barriers according to FishXing broken up by fish species.

Culvert 69 was the only culvert among the six partial barrier culverts that allowed passage of more than one fish species through it. Those fish species were golden shiner, smallmouth bass, walleye, and white sucker. Culvert 69 was a concrete culvert with length of 212 feet, diameter of 108 inches, and slope of 0.80% which was embedded 6 inches with gravel (n = 0.040) substrate. The remaining five partial barriers allowed passage of only one fish species through them. The results according to passage analysis in FishXing broken down by fish species are presented in Table B.6 of Appendix B.

4.4: Analysis using HEC-RAS

A group of 40 culverts was examined for fish passage by comparing swimming velocity, body depth, and body length of fish with flow velocity, flow depth, and drop at the culvert outlet obtained from output of the HEC-RAS model. The results according to passage analysis in HEC-RAS are presented in Table B.5 of Appendix B. Out of the 40 culverts for which HEC-RAS analysis was carried out, it was found that 22 (55%) culverts were partial barriers. The remaining 18 (45%) culverts were found to be complete barriers and zero culverts were found to be non barriers. The map in Figure A.5 of Appendix A shows complete barriers (red dots) and the partial barrier culverts (green dots) according to HEC-RAS analysis.

Except for the longear sunfish, the remaining 10 fish species were predicted to be able to swim up through at least one of the culverts for some range of flow conditions. The golden shiner (present in 39 culverts) was the most successful fish and was able to swim upstream through 15 culverts at certain flows followed by white sucker (present in 40 culverts) and smallmouth bass (present in 39 culverts) which were able to swim upstream through 11 and eight culverts, respectively, at some flows. Central stoneroller (present in 40 culverts) and largemouth bass (present in 40 culverts) had successful passage through five culverts each at some flow conditions, while blacknose dace (present in 40 culverts) passed through four culverts. The number of culverts that acted as partial barriers for northern pike (present in 32 culverts), greenside darter (present in 39 culverts), pumpkinseed sunfish (present in 40 culverts), and walleye (present in 29 culverts) was three. Longear sunfish (present in 16 culverts) was the least successful fish, unable to swim upstream through any culverts. The results according to passage analysis in HEC-RAS, broken down by fish species, are presented in Table B.7 of Appendix B. The bar chart in Figure 5 shows the classification of culverts as non barriers, partial barriers, and complete barriers for each fish species.

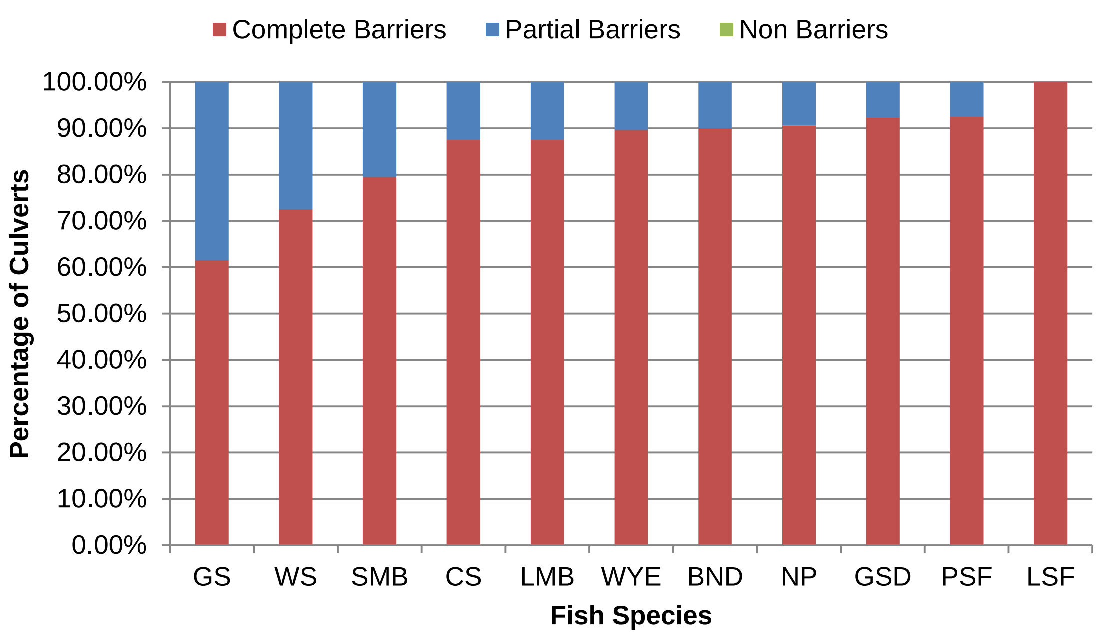

Figure 5: Percentage of culverts out of 40 that are non barriers, partial barriers, and complete barriers according to HEC-RAS broken up by fish species

Culvert 239 was the only culvert among the 22 partial barrier culverts that allowed passage of 10 fish species through it for some flow conditions. It was a corrugated metal culvert with length 124 feet, diameter 96 inches, and slope 0.30% which was embedded 9 inches with clay (n = 0.018) substrate. The number of culverts that allowed passage of six and five fish species was two and one respectively. There were two culverts that were partial barriers to four fish species. Similarly, the number of culverts that were partial barriers to two and three fish species was three. Finally, there were 10 culverts that facilitated passage of only one fish species through each of them.

4.5: Analysis using HEC-RAS Add-on

The passage simulation in HEC-RAS add-on showed that out of the 40 culverts for which the analysis was carried out, there was defined output for only 26 culverts. In the case of the remaining 14 culverts, either the flow depth was more than half the diameter of the culvert or the flow was supercritical (Froude number > 1), and therefore, the add-on could not provide a definite output because of the inherent limitations described in Section 3.7.

For the 26 culverts for which there was a defined output, it was seen that all of them were complete barriers as there was no successful passage of any fish species at any flow condition in any culvert. Out of the 26 culverts, 25 were barriers for all fish species due to insufficient depth. The remaining one culvert (Culvert 58) was a barrier due to both insufficient depth and excess velocity. In Culvert 58, excess velocity was the main reason behind unsuccessful passage for fish with shallow body depths like the greenside darter, blacknose dace, and central stoneroller and insufficient depth was a more prevalent problem for the remaining fish. Because this subset of culverts lacked sufficient water depth for passage, the calculation of reduced velocity zones was not important to the overall passage success of the fish.

Due to the limitations of flows for which the add-on was relevant, the output of the HEC-RAS add-on was not utilized for further analysis.

4.6: Identification of Design Parameters

In FishXing, further analysis was carried out by changing major design parameters (culvert diameter, culvert length, culvert slope, culvert material, and embeddedness) independently for greenside darter and largemouth bass. Before changing these design parameters, all the culverts were complete barrier for both greenside darter and largemouth bass. The changes in design parameters along with the reason for selecting greenside darter and largemouth bass are provided in Section 3.8.

The results for greenside darter showed that it could successfully pass through 21 out of 53 culverts at some flow conditions with some change in the design parameters. It was observed that embedding the culvert with gravel of Manning’s roughness of 0.04 alone could improve passage success making 19 out of 53 culverts partial barriers for greenside darter. Similarly, seven culverts improved to partial barriers due to increased diameter and decreased slope each. It was also seen that replacing existing culvert material with rougher corrugated metal pipe alone turned four culverts into partial barriers for greenside darter. Finally, the number of culverts that turned into partial barriers due to decrease in length alone was two. The bar chart in Figure 6 shows the percentage of culverts that turn from complete to partial barriers because of independent changes in each of the major culvert design parameters.

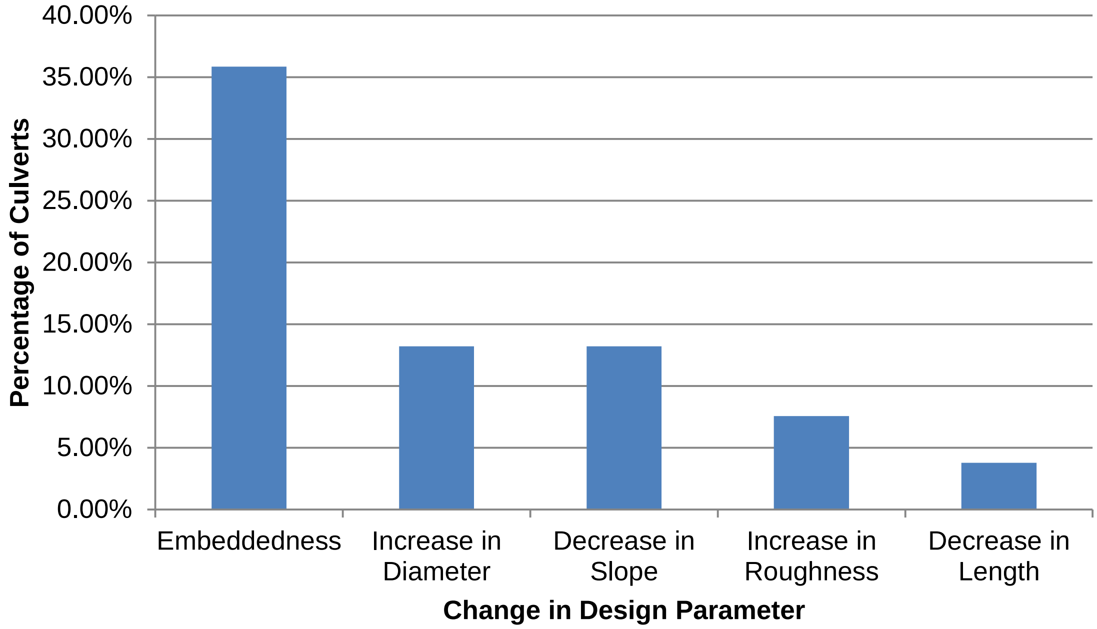

Figure 6: Percentage of culverts (out of 53) that turn from complete to partial barrier for greenside darter because of independent changes in design parameters according to FishXing analysis

For largemouth bass, the effect of changing each of the aforementioned design parameters was not as noteworthy as in the case of greenside darter. Changing the design parameters of diameter, length, slope, material, and embeddedness of the culvert independently changed nine complete barrier culverts in total into partial barriers. Increasing the culvert diameter or embedding the culvert with gravel could convert 5 out of 54 culverts into partial barriers for largemouth bass. Similarly, two complete barrier culverts turned into partial barriers due to decreased slope. It was also seen that replacing existing culvert material with rougher corrugated metal pipe alone turned one complete barrier culvert into a partial barrier. The bar chart in Figure 7 shows the percentage of culverts that turn from complete to partial barriers because of the independent changes in each of the major culvert design parameters.

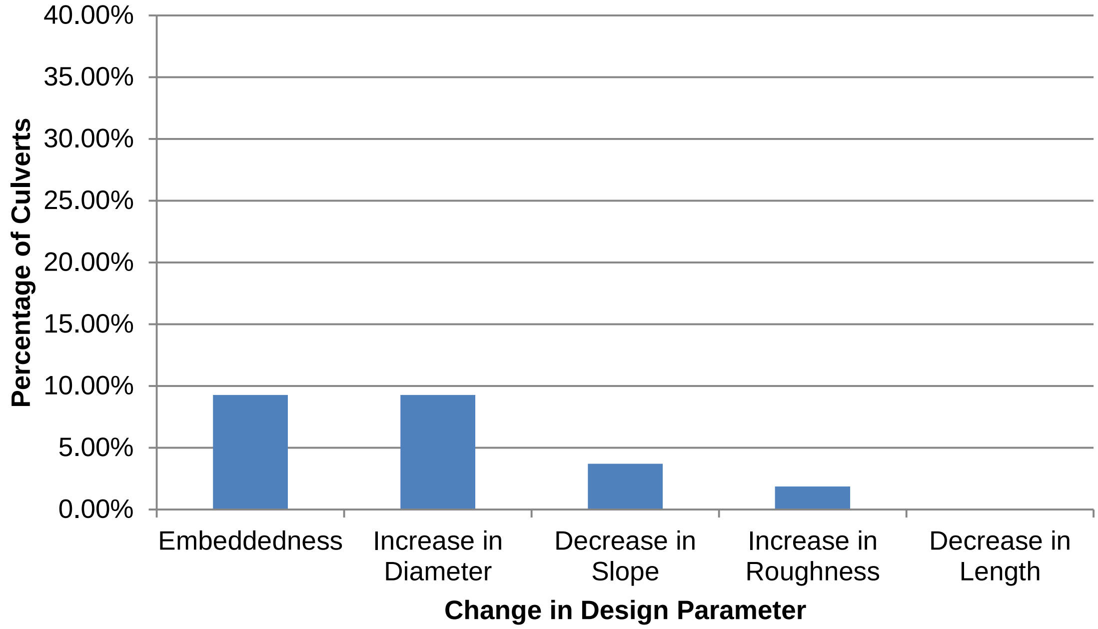

Figure 7: Percentage of culverts (out of 54) that turn from complete barrier into partial barrier for largemouth bass because of change in design parameters independently according to FishXing analysis

Chapter 5: Discussion

5.1: Analysis using FishXing

The results from the FishXing analysis show that most of the circular culverts (89%) in Northeast Ohio are complete barriers to fish passage. The range of discharge or flow conditions over which FishXing analysis was carried out goes from 25% low flow to two year peak flow. The bar chart in Figure 8 shows the average percentage of flows for each fish species at which the 54 culverts acted as a barrier due to insufficient flow depth, excessive outlet drop, and high flow velocity. In case of BND or blacknose dace for example, 100% of the time the water is too fast, 90% of the time there is too much outlet drop, and insufficient depth in the culvert is almost never a problem for upstream passage. A discussion of the culverts analyzed and not analyzed in FishXing and HEC-RAS is available in Section 3.3.

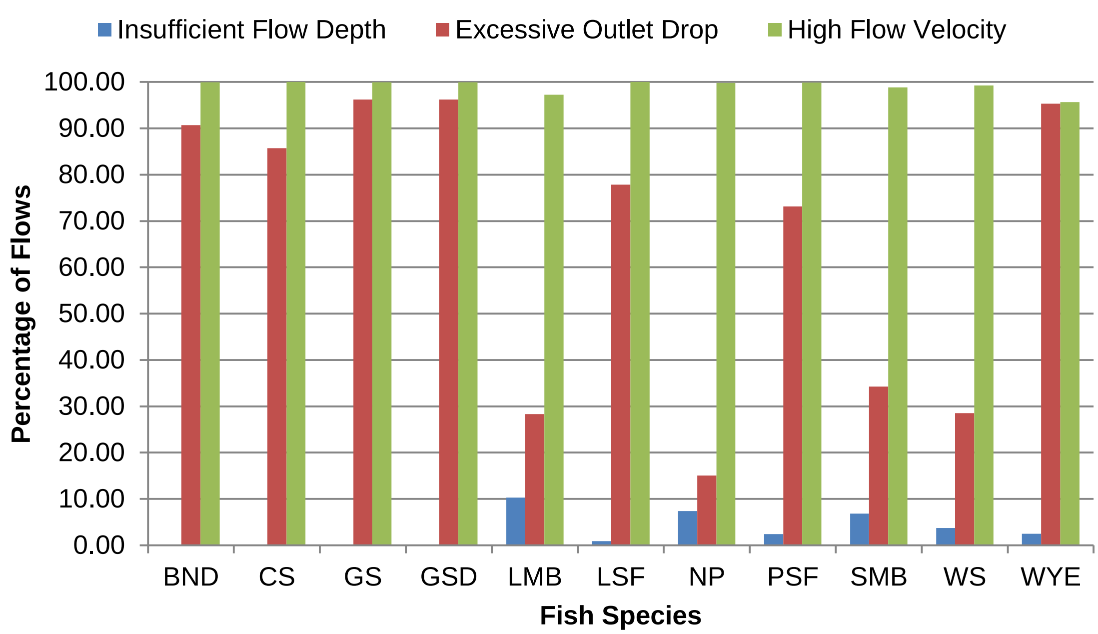

Figure 8: Barrier types for each fish species according to FishXing analysis

The percentage of flows for which the culvert acted as a particular type of barrier was obtained by dividing the range of flows at which the culvert is that type of barrier by the total range of flows for which the passage analysis was carried out. So, the less common high flows have been considered to be as frequent as the average monthly flows in FishXing.

For all 11 fish species under all flow conditions for which passage analysis was carried out in FishXing, it can be seen that high flow velocity is the most common reason for culverts to act as obstacles to upstream migration of fish in Northeast Ohio. Excessive outlet drop is the next most prevalent obstacle for the movement of fish through a culvert. In comparison, insufficient flow depth is a relatively small cause behind the obstruction of fish passage. This is as expected because the upper limit of the flow condition for which analysis was carried out goes up to the two year peak flood. The high flows, which are actually uncommon, have been over-sampled by treating them as equally likely to occur as the average monthly flows. Therefore, for a large percentage of the flow conditions, the flow velocity, flow depth, and outlet drop is understandably high.

While not statistically significant, the average length of the complete barriers (174 feet) was found to be slightly shorter than the average length of the partial barriers (196 feet). The average diameter of the partial barriers (69 inches) was slightly more than that of the complete barriers (61 inches) and the pipe slope of partial barriers (0.87%) was less than that of the complete barriers (0.97%). None of these differences were significant according to independent samples t-test (two tailed, $p \leq 0.05$). Among partial barriers, 50% of the culverts were embedded, none of the culverts were perched and the average embedded depth (as measured in the field at the culvert outlet) was five inches. Similarly, the percentage of culverts among complete barriers that were embedded was only 6% while the percentage of culverts that were perched was 54%. The average embedded depth was two inches and the average perched height of the culverts was nine inches.

The values of these culvert parameters categorized by complete barriers and partial barriers according to FishXing analysis are presented in Table 3 and Table 4. Based on independent samples t-tests (two tailed, $p \leq 0.05$), there was no significant difference in the average embedded depth of the culverts that acted as complete barriers and partial barriers. However, it was seen that the difference in average perched height was significant. The perched height of the culvert was an important culvert parameter affecting the passage success of fish species through culverts according to the independent samples t-test. Because of the small sample size, equal variance was not assumed when carrying out the test. The results from the independent samples t-test are presented in Table 5.

Table 3: Important culvert parameters according to FishXing analysis

Parameter	Barrier	N	Mean	Std. Deviation	Std. Error Mean
Length (feet)	Partial	6	196	98	40
	Complete	48	174	103	15
Diameter (inches)	Partial	6	69	26	11
	Complete	48	61	19	3
Slope	Partial	6	0.87%	0.76%	0.31%
	Complete	48	0.97%	0.65%	0.09%
Perched height (inches)	Partial	6	0	0	0
	Complete	48	9	14	2
Embedded depth (inches)	Partial	6	5	5	2
	Complete	48	2	7	1

Table 4: Embedded and perched culverts percentage according to FishXing analysis

Culvert Type	No.	% Culverts Embedded	% Culverts Perched
Partial Barrier	6	50.00%	0.00%
Complete Barrier	48	6.25%	54.17%

Table 5: Independent samples t-test on data from FishXing output

Parameter		t-test for Equality of Means		
		t	df	Sig. (2-tailed)
Length	Equal variances not assumed	.530	6.458	.614
Diameter	Equal variances not assumed	.747	5.643	.485
Slope	Equal variances not assumed	-.311	5.962	.766
Perched height	Equal variances not assumed	-4.496	47.000	.000
Embedded depth	Equal variances not assumed	1.249	7.660	.249

5.2: Analysis using HEC-RAS

The results from the HEC-RAS analysis indicate that 22 culverts out of 40 (55%) acted as partial barriers and the remaining 18 (45%) were complete barriers. For each culvert, the percentage of flows for which it acted as a barrier due to different reasons was noted for 11 fish species. The bar chart in Figure 9 shows the average percentage of flows for each fish species at which the 54 culverts acted as a barrier due to insufficient flow depth, excessive outlet drop, and high flow velocity.

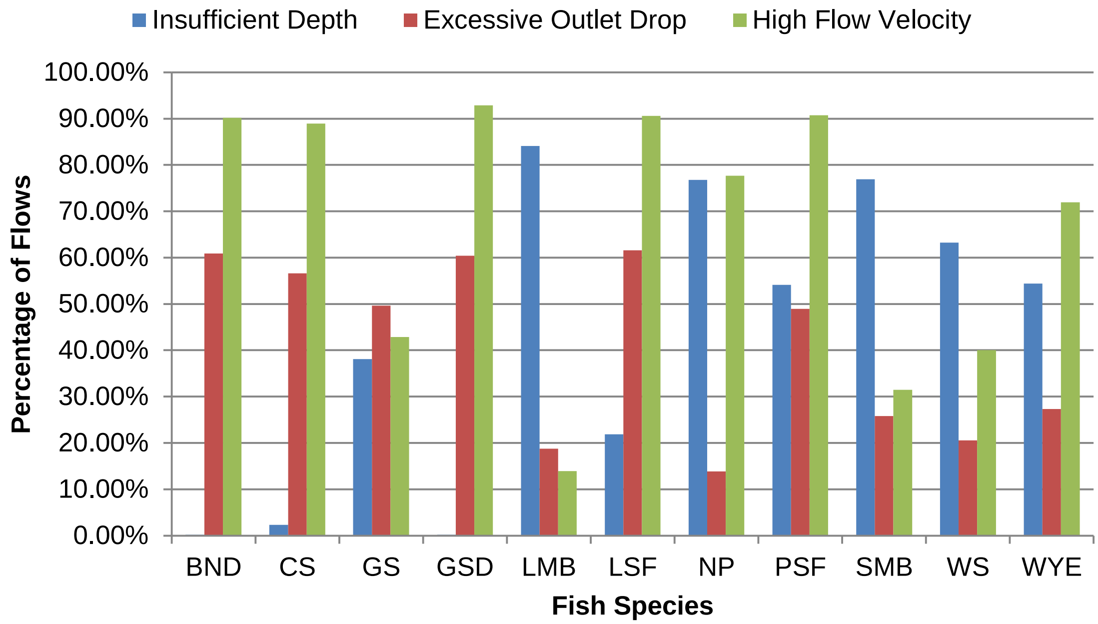

Figure 9: Barrier types for each fish species according to HEC-RAS analysis

The percentage was obtained by dividing the number of flows at which the culvert is a particular type of barrier by 14 which is the total number of flows for which the passage analysis was carried out. The 14 flows were sampled such that there was one 25% low flow, one 2 year flood, and 12 average monthly flows. Compared to the range over which passage analysis was carried out in FishXing, these flows are more representative of the flows experienced by the fish in the river.

Among the 11 fish species for which passage analysis was carried out in HEC-RAS, it can be seen that for fishes with slower swimming speed (e.g., blacknose dace, central stoneroller, greenside darter, longear sunfish, pumpkinseed sunfish), high flow velocity is a bigger reason behind the culverts acting as an obstacle in the upstream movement than it is for fast swimming fishes. Also, for the fishes with larger body depth (e.g., largemouth bass, northern pike, smallmouth bass, white sucker), insufficient depth is a major reason behind the culvert being an obstruction in the upstream passage. Similarly, it can be observed that for fish with short body length (e.g., blacknose dace, central stoneroller, golden shiner, greenside darter, longear sunfish, pumpkinseed sunfish), excessive outlet drop is a big problem for upstream passage.

While not statistically significant, the average length of the complete barriers (184 feet) was found to be longer than the length of the partial barriers (155 feet). The average diameter of the partial barriers (63 inches) was slightly more than that of the complete barriers (58 inches) and the pipe slope of partial barriers (0.89%) was less than that of the complete barriers (1.10%). None of these differences were significant according to independent samples t-test (two tailed, $p \leq 0.05$). Among partial barriers, 13.64% of the culverts were embedded and 27.3% of the culverts were perched. For partial barriers, the average embedded depth was one inches and the average perched height was two inches. Similarly, the percentage of culverts among complete barriers that were embedded was zero, while the percentage of culverts that were perched was 77.8% and the average perched height of the culverts was 17 inches.

The values of these culvert parameters categorized by complete barriers and partial barriers according to HEC-RAS analysis are presented in Table 6 and Table 7. Based on independent samples t-tests (two tailed, $p \leq 0.05$), there was no significant difference in the average embedded depth of the culverts that acted as complete barriers and partial barriers. However, it was seen that the difference in average perched height between complete and partial barriers was significant. It was observed from independent samples t-test that perched height of the culvert was an important parameter affecting the passage success of fish species through culverts. Because of the small sample size, equal variance was not assumed when carrying out the test. The results from the independent samples t-test are presented in Table 8.

Table 6: Important culvert parameters according to HEC-RAS analysis

Parameter	Barrier	N	Mean	Std. Deviation	Std. Error Mean
Length (feet)	Partial	22	155	80	17
	Complete	18	184	80	19
Diameter (inches)	Partial	22	63	21	4
	Complete	18	58	13	3
Slope	Partial	22	0.89%	0.74%	0.16%
	Complete	18	1.10%	0.72%	0.17%
Perched height (inches)	Partial	22	2	4	1
	Complete	18	17	18	4
Embedded depth (inches)	Partial	22	1	3	1
	Complete	18	0	0	0

Table 7: Embedded and perched culverts percentage according to HEC-RAS analysis

Culvert Type	No.	% Culverts Embedded	% Culverts Perched
Partial Barrier	22	13.64%	27.30%
Complete Barrier	18	0.00%	77.80%

Table 8: Independent samples t-test on data from HEC-RAS analysis output

Parameter		t-test for Equality of Means		
		t	df	Sig. (2-tailed)
Length	Equal variances not assumed	-1.115	36.388	.272
Diameter	Equal variances not assumed	.961	35.511	.343
Slope	Equal variances not assumed	-.886	36.724	.381
Perched height	Equal variances not assumed	-3.592	18.165	.002
Embedded depth	Equal variances not assumed	1.748	21.000	.095

5.3: Comparison between FishXing and HEC-RAS Results

The prediction of the percentage of complete barrier and partial barrier culverts between FishXing and HEC-RAS was different. According to FishXing analysis, 6 out of the 54 culverts analyzed (11%) were partial barriers while the remaining 48 (89%) culverts were complete barriers. According to HEC-RAS analysis, 22 out of the 40 (55%) culverts analyzed were partial barriers while the remaining 18 (45%) culverts were complete barriers. Based on the passage analysis carried out in FishXing and HEC-RAS, it was seen that the percentage of culverts that are complete barriers are 50-90% and that are partial barriers are 10-50%. The difference in categorizing culverts as partial versus complete barriers between HEC-RAS and FishXing also resulted in different average length, average diameter, average slope, average perched height, and average embedded depth of complete barrier and partial barrier culverts between the output from FishXing and HEC-RAS. The results of complete barrier and partial barrier culverts according to FishXing analysis and HEC-RAS analysis are presented in Table 9.

Table 9: Average culvert parameters according to FishXing analysis and HEC-RAS

Parameter	FishXing Analysis		HEC-RAS Analysis	
	Complete barrier	Partial barrier	Complete barrier	Partial barrier
Number	48	6	18	22
Average length (feet)	174	196	184	155
Average diameter (inches)	61	69	58	63
Average slope (%)	0.97	0.87	1.10%	0.89
Average perched height (inches)	9	0	17	2
Average embedded depth (inches)	2	5	0	1
Percent culverts embedded	6.25	50.00	0.00	13.64
Percent culverts perched	54.17	0.00	77.80	27.30

Except for the average length, remaining culvert design parameters among complete barriers and partial barriers for the output of both FishXing analysis and HEC-RAS analysis demonstrate a similar trend. For example, complete barriers have smaller average diameter, higher average slope, greater average perched height, and lower average embedded depth than partial barriers according to both FishXing and HEC-RAS analysis. It must be noted, however, that except for the difference in average perched height, none of the aforementioned differences were statistically significant according to independent samples t-test (two tailed, $p \leq 0.05$) for the output of both FishXing and HEC-RAS analysis.

We can see that the percentage of culverts that are perched is greater in complete barriers compared to partial barriers according to the analysis of both FishXing and HEC-RAS. We can also see that the percentage of culverts that are embedded is considerably greater in partial barriers compared to complete barriers according to the analysis of both FishXing and HEC-RAS. This suggests that, in NE Ohio, as has been seen in other parts of the U.S., it is important from a fish passage perspective that a culvert should be embedded and should not be perched to successfully allow passage of fish through it.

All six culverts that were predicted to be partial barriers by FishXing analysis were predicted to be partial barriers by HEC-RAS analysis also. Golden shiner, which was one of the fish predicted to be the most successful in upstream passage by FishXing analysis, was also the fish predicted to be most successful by HEC-RAS analysis. Culvert 69, which allowed passage of four fish species (golden shiner, smallmouth bass, walleye, and white sucker) according to FishXing analysis, allowed passage of two more fish species (largemouth bass and northern pike) according to HEC-RAS analysis. This suggests that the findings of the HEC-RAS analysis, while less conservative than the findings of FishXing analysis, are following a similar trend.

There were several differences in the way passage analysis was carried out in FishXing and HEC-RAS. The model used by FishXing for passage analysis requires only one cross-section downstream of the culvert while the model used by HEC-RAS uses at least three cross-sections both downstream and upstream from the culvert. The passage analysis in FishXing was carried out for all flows between the minimum and maximum of the 14 flows acquired from the StreamStats program. Twelve of these 14 flows were the monthly average discharges and the remaining two were 25% low flow and 2 year peak flow. Since it was not possible to run simulation over a range of flows in HEC-RAS, the passage analysis was carried out for the previously mentioned 14 individual flows using Microsoft Excel spreadsheet. The FishXing program considered flow velocity and depth at multiple points throughout the culvert length in carrying out the passage analysis but the HEC-RAS analysis was carried out by considering the flow velocity and depth only at the two ends of the culvert. The passage analysis in FishXing took into consideration the time for exhaustion for each fish species, whereas the analysis in HEC-RAS did not. Also, FishXing analysis took into consideration, when available, the burst swimming speed of fish, while HEC-RAS analysis did not. This distinction is only relevant to the walleye results. It is also worth noting that during unsteady flow analysis, HEC-RAS occasionally computes higher flow at the structure than the next upstream sections. This is due to the fact that a pre-computed family of rating curves is used for flow simulation at the structure during the unsteady flow calculations (Brunner *et al.*, 2010). Because of the aforementioned differences, there were differences in the prediction of the percentage of partial and complete barriers between FishXing and HEC-RAS. Between the two, the output of FishXing analysis is assumed to be more accurate because it is a well-tested standard program that is widely used to carry out fish passage analysis in the U.S.

5.4: Identification of Design Parameters

The analysis performed in FishXing by independently changing design parameters of the culverts suggested these changes can improve passage success. It was seen that the improvement in passage success due to changes in design parameters was more pronounced for greenside darter compared to largemouth bass. The changes in culvert design parameters involved decreasing pipe slope, increasing diameter, using material with higher value of Manning’s roughness, shortening length, and embedding the culverts with gravel substrate ($n = 0.04$). Embedding the culverts, in particular, drastically improved passage success of the greenside darter. The percentage of partial barrier culverts (out of 53) for greenside darter changed from zero to 36% and complete barrier culverts changed from 100% to 64% after embedding the culverts with gravel substrate.

The increased passage success with embeddedness can be explained by looking at the effect of the design parameter changes on the flow velocity and depth. Once the culverts are embedded with gravel substrate, the water flows through a substrate rougher than the original culvert material. Flow velocity in open channel flow is dependent on the roughness of the channel, hydraulic radius, and slope of the channel. Embedding the culvert with a gravel substrate assists the lowering of flow velocity because the roughness of the gravel is higher than that of the pipe material. This is a desired result from the fish passage point of view. Greenside darter, being the fish with shallowest body depth among the 11 fish species used in this study, is able to swim upstream through a culvert even at low flow depths which would otherwise impede the movement of other fish species. It shows that for fish species with shallow body depths, as long as the velocity is sufficiently low, flow depth is large enough even during low flow events for it to pass through the culvert.

We can also deduce that increasing the diameter of the circular pipe, reducing the pipe slope, or using a rougher material decreases the flow velocity of water through it. Therefore, it was observed that the passage success of greenside darter improved when the culvert diameter was increased, when the slope was decreased, or when the culvert material was replaced with rough corrugated metal. The improvement in passage success due to these changes was, however, less compared to the improvement due to embedding the culverts with gravel.

It was also seen that the effect of changing design parameters independently did not have equally noticeable effect on the passage success of largemouth bass according to FishXing analysis. While largemouth bass is the fastest swimming fish among the chosen 11 fish species, its body depth is also the highest. Therefore, while high flow velocity is not as big of a problem for it to move upstream of a culvert, insufficient flow depth is. In most cases, although the changes in the design parameters reduced the flow velocity, they did not increase the flow depth sufficiently to allow largemouth bass passage.

Chapter 6: Conclusion

6.1: Summary

The two goals of the study were to determine the percentage of circular culverts in Northeast Ohio that act as barriers for fish passage and to identify the design parameters that may affect the passage success to aid in future design. The study was carried out using data obtained from various sources, like the ODOT culvert inventory, USGS online data repositories, and the FishXing swim speed table, along with site visits and ArcGIS. The computer programs FishXing and HEC-RAS were used to carry out the passage analysis. A further study was also carried out in FishXing by changing the design parameters (culvert diameter, length, slope, material, and embeddedness) of culverts independently to investigate the effect of those parameters on passage success of greenside darter and largemouth bass. The greenside darter and largemouth bass were chosen for further analysis because of their lowest body depth and highest swimming velocity, respectively.

From the passage analysis in FishXing, it was observed that a large percentage of the 54 culverts for which the study was carried out were a complete barrier for the movement of fish. Specifically, 89% of the culverts were found to be complete barriers and only 11% were found to be partial barriers. The result from HEC-RAS suggested that out of the 40 culverts analyzed, 55% were partial barriers and 45% were complete barriers. The discrepancy in the output from FishXing and HEC-RAS is most likely due to the fact that the two programs compute flow velocity and depth inside culverts slightly differently. There were also some differences in the way passage analysis was carried out between FishXing and HEC-RAS. It is concluded that the percentage of culverts that are complete barriers are 50-90% and that are partial barriers are 10-50%. None of the culverts analyzed were classified as non barriers by either method.

Based on independent samples t-tests (two tailed $p \leq 0.05$) carried out for both FishXing and HEC-RAS output separately, it was concluded that the calculated perched height of the culverts was a significant factor affecting the passage success of the fish. The height of the culvert outlet above streambed at the downstream proved to be a significant predictor of whether a culvert was a barrier or not. Also, the difference in diameter, length, slope, and embedded depth between complete barriers and partial barriers was not found to be statistically significant for the output of either FishXing or HEC-RAS.

Further analysis carried out in FishXing by changing design parameters like culvert diameter, length, slope, material, and embeddedness independently suggests that having the culverts embedded with gravel greatly improves fish passage. While gravel may (aggregate greater than 2mm in diameter) may not be native to a stream it does indicate that embedding culverts with a rough substrate will significantly improve passage rates. The effect is more noticeable for fish with shallow body depth like green side darter compared to fish with large body depth like largemouth bass.

To improve fish passage success, efforts should be made to ensure the culverts do not become perched over time. It is also recommended that the culverts with diameter less than 48 inches should be embedded 6 inches and those with diameter greater than 48 inches should be embedded 12 inches to improve passage success for fish. Moreover, proper maintenance and monitoring should be performed to ensure that the culverts remain embedded during its lifetime.

6.2: Suggestions for Future Research

This study determined the percentage of circular culverts impeding fish movement in ODOT District 4 located in the Northeast Ohio and investigated the effect of various design parameters of culverts on passage success. Further studies should be carried out by considering a larger number of culverts over a broader geographic area so as to study the extent and spatial pattern of the fish passage problem in Ohio and the Midwest in general.

One of the limitations of FishXing is that it is a steady state one-dimensional code (Hotchkiss *et al.*, 2008) which calculates only the average speed of water through the culvert and does not allow for velocity distribution across the culvert cross-section. The same limitation also exists in HEC-RAS (Allen *et al.*, 2006). For further study, the effect of velocity reduction on fish passage could be studied. While the HEC-RAS add-on developed by Vasconcelos *et al.*, (2011) currently has some limitations, it was designed to overcome this shortfall and could be improved for future use so as to incorporate the effect of velocity distribution across culvert cross-section in passage analysis.

More research could be carried out so as to incorporate the collection of data on fish passage in the field using fish sampling. The field observations can help in identifying passage barrier culverts for the species for which data on swimming abilities is not available. Alternatively, it can also function to verify the results obtained from software simulation.

It could also be helpful to determine fish swimming and leaping data of even more species, including non-sport fishes, by carrying out controlled tests in a laboratory setup to use for passage analysis so that passage analysis can be carried out for a wide range of species. The movement pattern of every fish is unique and therefore carrying out passage analysis for more species would provide a more comprehensive results. Also, the information about the specific times of year during which different fish species move in the streams can be used to carry out more detailed fish passage analysis.

In this study, analysis was carried out for greenside darter and largemouth bass using FishXing by changing culvert design parameters independently to study the effect of those parameters on passage success. FishXing was chosen for the analysis because it is the widely used standard tool for carrying out passage analysis. However, similar analysis could be carried out in the future using both FishXing and HEC-RAS for all 11 fish species.

Bibliography

Allen G, Cook T, Olken N. 2006. Feasibility Study for Willowdale Dam Fish Passage Project. Commonwealth of Massachusetts Division of Marine Fisheries (DMF)

Blank M, Cahoon J, Burford D, McMahon T, Stein O. 2005. Studies of fish passage through culverts in Montana. Road Ecology Center, John Muir Institute of the Environment, UC Davis

Bouska WW, Paukert CP. 2009. Road Crossing Designs and Their Impact on Fish Assemblages of Great Plains Streams. Transactions of the American Fisheries Society 139:214–222, 2009.

Brunner GW, CEIWR-HEC. 2010. HEC-RAS River Analysis System User's Manual. Version 4.1. USACE Report Number CPD-68, January, 2010.

Covert SA, Kula SP, Simonson LA. 2007. Ohio Aquatic Gap Analysis: An Assessment of the Biodiversity and Conservation Status of Native Aquatic Animal Species. U.S. Geological Survey Open-File Report 2006-1385, 509 p.

Energy and Environment Cabinet. [Internet]. 2010. Cited 03/19/2013. Available from http://water.ky.gov/watershed/Documents/WatershedInfo.doc

FishXing. 2006a. "FX3_SwimTable.xls". *MS Excel* file. Available from the help in *FishXing* program.

FishXing. 2006b. Available from the 'Help' function in *FishXing* program.

Harper DJ, Quigley JT. 2000. No net loss of fish habitat: An audit of forest road crossings of fish-bearing streams in British Columbia, 1996–1999. Canadian Technical Report of Fisheries and Aquatic Sciences 2319.

Harstine LJ. [Internet]. 1991. Hydrologic Atlas for Ohio On-Line. Cited 01/27/2013. Available from: http://www.ohiodnr.com/water/pubs/hydatlas/tabid/4187/Default.aspx

Hotchkiss RH, Frei CM. 2007. Design for Fish Passage at Roadway-Stream Crossings: Synthesis Report. Publication No. FHWA-HIF-07-033. U.S. Department of Transportation, Federal Highway Administration.

Hotchkiss RH, Theile EA, Nelson EJ, and Thompson PL. 2008. Culvert Hydraulics: Comparison of Current Computer Models and Recommended Improvements.

Larinier M. 2002. Fish passage through culverts, rock weirs and estuarine obstructions. Bull. Fr. Pesche Piscic. (2002) suppl. 119-134.

MacPherson LM, Sullivan MG, Foote AL, Stevens CE. 2012. Effects of Culverts on Stream Fish Assemblages in the Alberta Foothills. North American Journal of Fisheries Management 32:480–490, 2012.

Maine Department of Transportation. 2004. Fish Passage Policy and Design Guide: 2nd Edition. Maine Department of Transportation.

Morrison RR. 2006. Turbulence Characteristics of Flow in a Full-Scale Spiral Corrugated Culvert Fitted With Sloped- And Slotted-Weir Baffles. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering, Washington State University.

Mount C, Norris S, Thompson R, Tesch D. 2011. GIS Modeling of Fish Habitat and Road Crossings for the Prioritization of Culvert Assessment and Remediation. Streamline, Watershed Management Bulletin Vol. 14/No. 2 Spring 2011

Nukurangi T. 1999. Fish Passage at Culverts: A review, with possible solutions for New Zealand indigenous species. Department of Conservation, Te Papa Atawhai.

Office of Surface Water. [Internet]. 2010. Cited 05/02/2013. Available from http://streamstats.usgs.gov/

Ohio Department of Natural Resources Division of Wildlife. [Internet]. 2012. Cited 02/02/2013. Available from: http://www.dnr.state.oh.us/Home/species_a_to_z/AZFish/tabid/17913/Default.aspx

Ohio Department of Transportation. 2009. “D04_Culvert_Inventory.xls”. *MS Excel* file. Emailed to Tritico HM.

Ohio Department of Transportation. 2010. Location and Design Manual. Volume 2 Drainage Design. Updated April 2010.

Pearson WH, Southard SL, May CW, Skalski JR, Townsend RL, Horner-Devine AR, Thurman DR, Hotchkiss RH, Morrison RR, Richmond MC, Deng D. 2006. Research on the Upstream Passage of Juvenile Salmon through Culverts: Retrofit Baffles. PNWD-3672

Powers PD, Orshorn JF. 1985. Analysis of Barriers to Upstream Fish Migration - An Investigation of the Physical and Biological Conditions Affecting Fish Passage Success at Culverts and Waterfalls. Bonneville Power Administration, Contract DE-A179-82BP36523, Project No. 82-14

Rook EJS. 1999. [Internet]. Cited 02/08/2013. Available from: http://rook.org/earl/bwca/nature/fish/

Trombulak SC, Frissell CA. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. Conservation Biology, 14(1), 18-30.

U.S. Fish and Wildlife Service. 2012. [Internet]. Cited 02/10/2013. Available from: http://www.fws.gov/midwest/endangered/lists/pdf/OhioSppList2012.pdf

Vasconcelos JG, Tritico HM, Hatcher TM. 2011. A Post-processing tool for HEC-RAS for the assessment of fish passage conditions in highway culverts, Proc: World Water and Environmental Resources Congress ASCE, Palm Springs, CA.

Warren ML, Pardew MG. 1998. Road Crossings as Barriers to Small-Stream Fish Movement. Transactions of the American Fisheries Society 127:637-644. American Fisheries Society 1998.

Washington Department of Fish & Wildlife. [Internet]. 2013. Cited 01/27/2013. Available from: http://wdfw.wa.gov/conservation/habitat/fish_passage/

Watters GT. 1995. Small Dams as Barriers to Freshwater Mussels (Bivalvia, Unionoida) and Their Hosts. Biological Conservation 75 (1996) 79-85.

Watters GT, Hoggarth MA, Stansbery DA. 2009. The Freshwater Mussels of Ohio. ISBN 978-0-8142-1105-2 (cloth : alk. paper). The Ohio State University.

Appendix A (Maps)

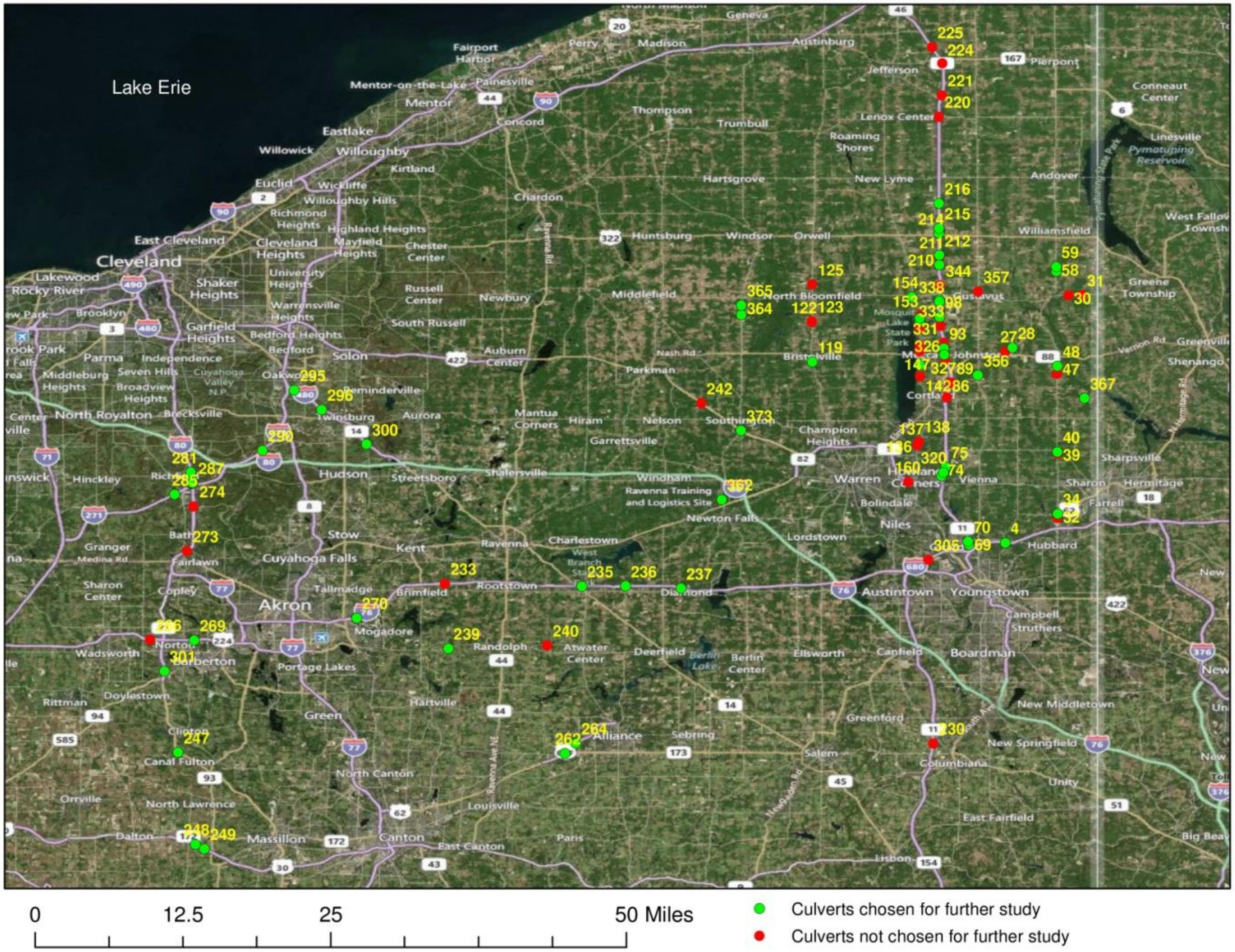

Figure A.1: Map showing the 94 culverts for which field visits were conducted

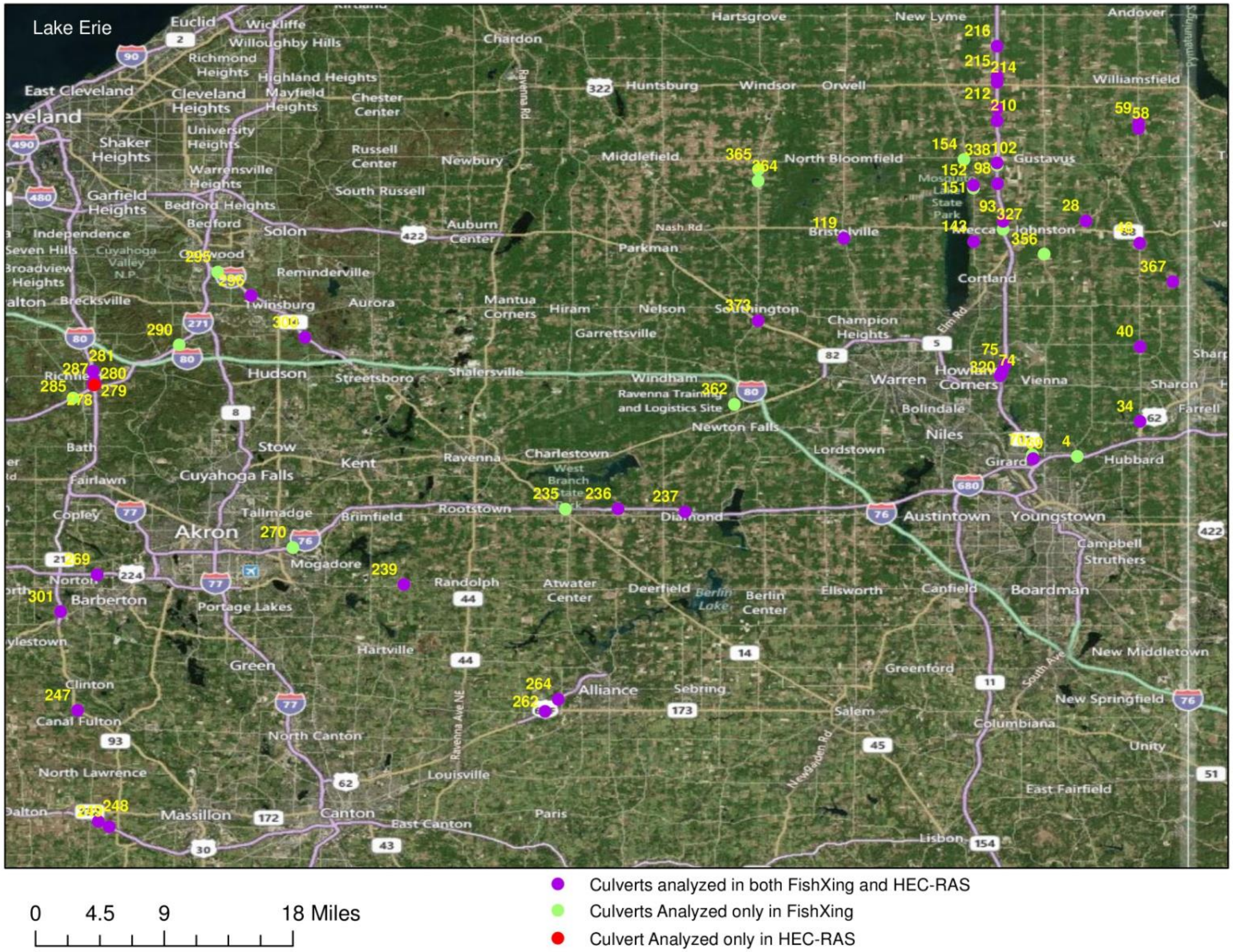

Figure A.2: Map showing the 55 culverts for which passage analysis was carried out

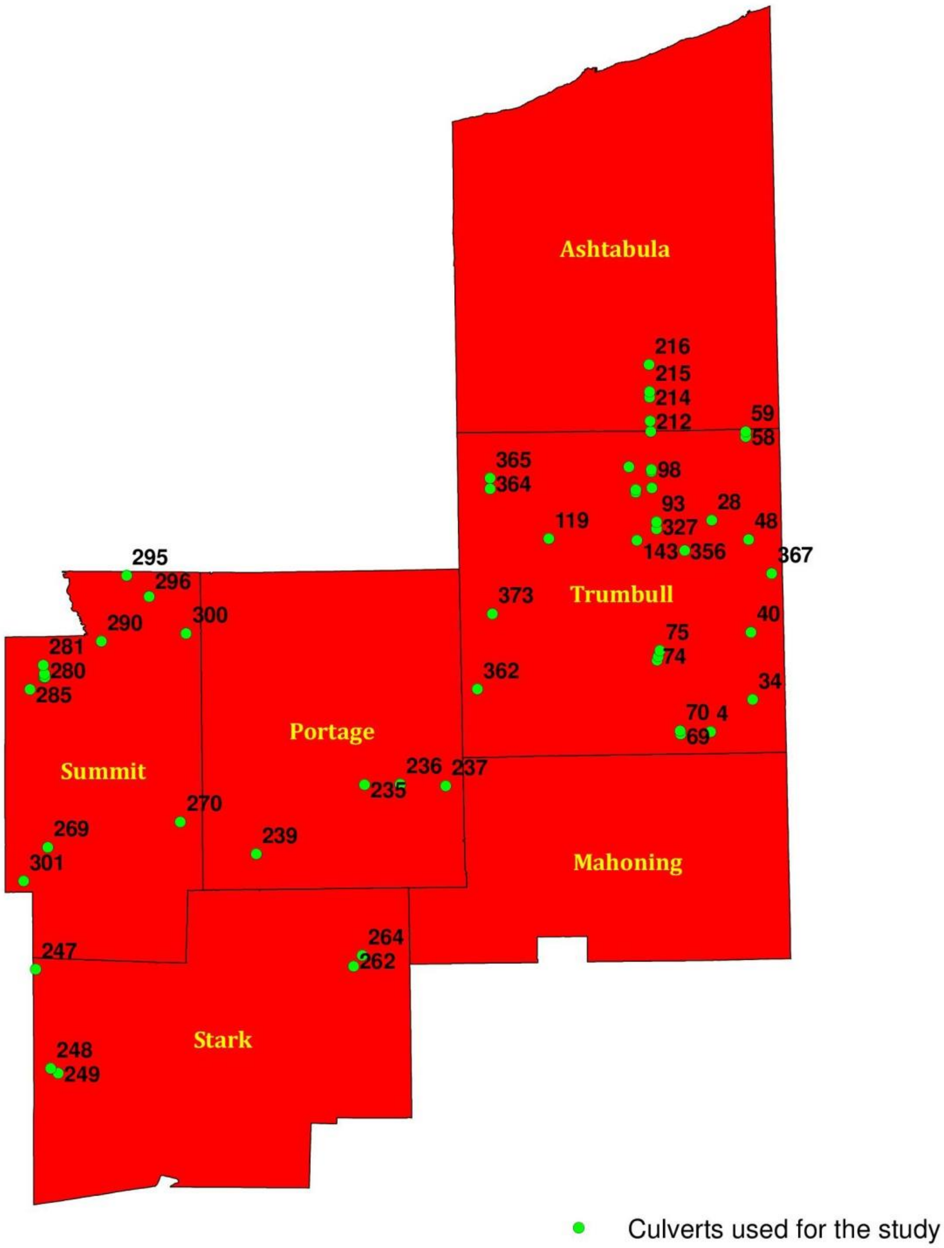

Figure A.3: Map showing culvert location in the county map

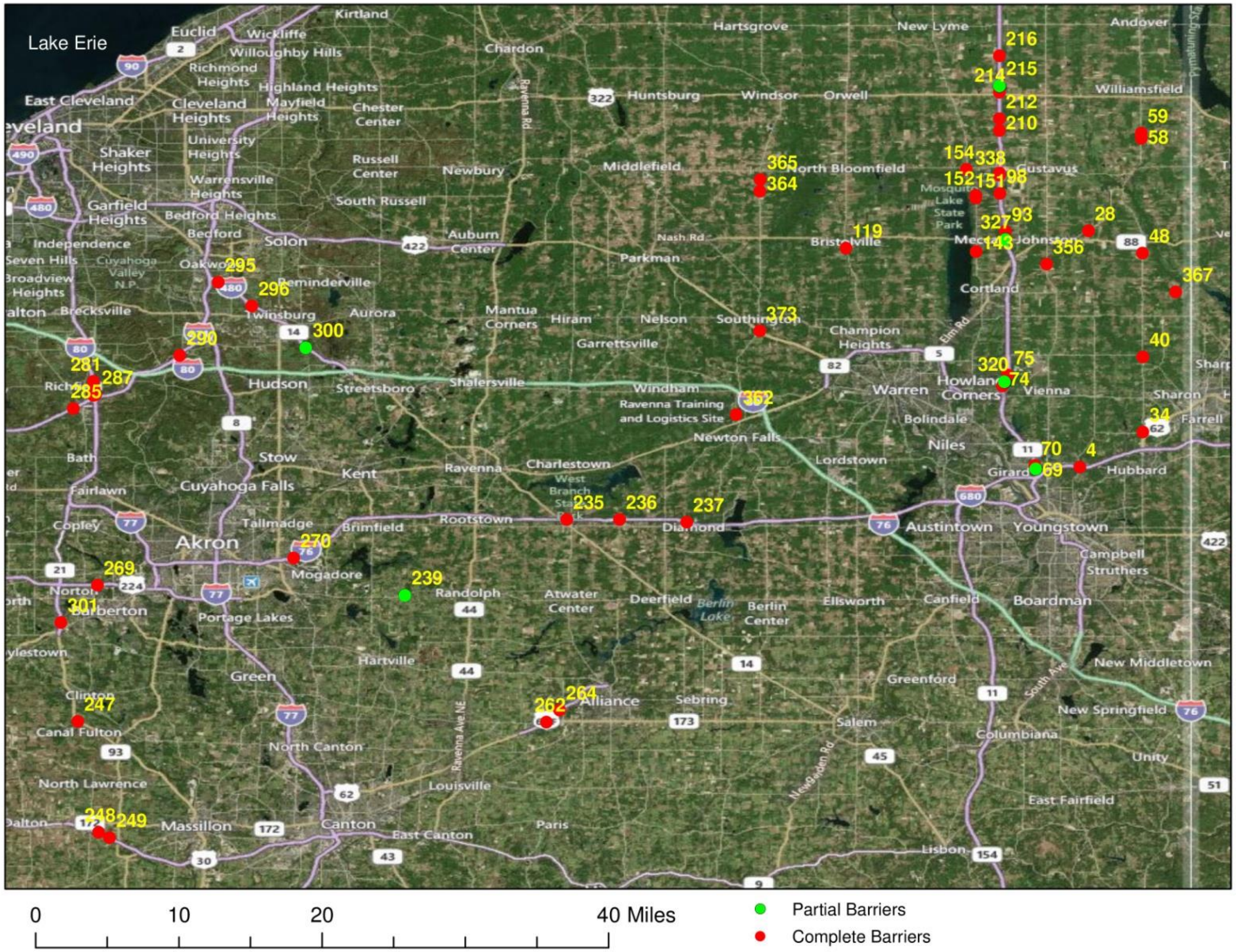

Figure A.4: Culvert map showing FishXing results

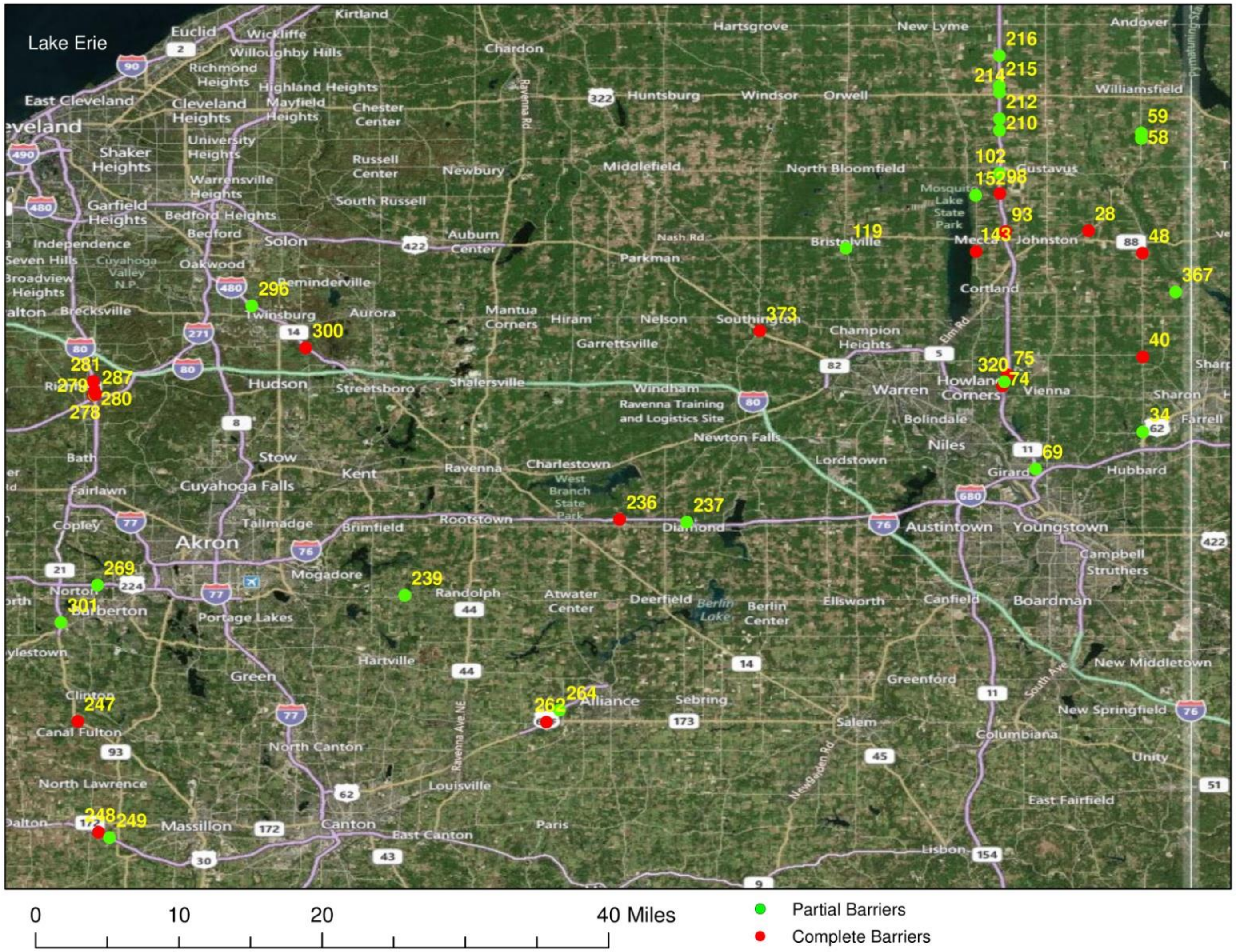

Figure A.5: Culvert map showing HEC-RAS results

Appendix B (Tables)

Table B.1: List of culverts used for the study (Part I)

Culvert	Longitude	Latitude	Diameter (inches)	Length (feet)	Pipe Slope (%)	Embedded depth (inches)	Substrate	Perched height (inches)
4	-80.632053	41.158901	66	243	0.30	0	-	3
28	-80.623362	41.397897	60	89	0.60	0	-	12
34	-80.568088	41.194369	54	49	1.07	0	-	3
40	-80.568249	41.270271	48	130	0.60	0	-	56
48	-80.568599	41.375295	48	72	0.70	0	-	18
58	-80.569876	41.491537	36	58	0.90	0	-	0
59	-80.569952	41.496962	42	68	1.12	0	-	1
69	-80.676721	41.156784	108	212	0.80	6	Gravel	0
70	-80.677594	41.160404	48	238	0.80	0	-	0
74	-80.709951	41.240880	42	202	1.00	0	-	0
75	-80.705045	41.251852	54	202	1.00	0	-	12
93	-80.707148	41.397258	48	218	1.00	0	-	0
98	-80.712597	41.435700	66	178	1.00	0	-	18
102	-80.712986	41.456470	42	99	1.10	0	-	0
119	-80.868290	41.380437	48	85	0.64	0	-	0
143	-80.736859	41.376833	84	56	0.87	0	-	14
151	-80.737113	41.431064	42	52	2.60	0	-	0
152	-80.736997	41.434046	48	42	0.86	0	-	0
154	-80.746731	41.460051	120	66	2.60	48	Clay	0
210	-80.713110	41.499441	90	202	0.40	0	-	6
212	-80.713135	41.511405	72	182	0.30	0	-	0

Culvert	Longitude	Latitude	Diameter (inches)	Length (feet)	Pipe Slope (%)	Embedded depth (inches)	Substrate	Perched height (inches)
214	-80.713204	41.538154	60	243	0.50	0	-	4
215	-80.713182	41.544496	54	208	0.50	0	-	0
216	-80.713147	41.575032	54	168	0.40	0	-	0
235	-81.150380	41.105694	48	246	1.50	0	-	7
236	-81.097086	41.105875	68	178	0.70	0	-	14
237	-81.029214	41.103081	48	159	0.80	0	-	0
239	-81.313782	41.029283	96	124	0.30	9	Clay	0
247	-81.644621	40.901788	60	221	1.00	0	-	37
248	-81.623420	40.789157	84	218	1.00	0	-	11
249	-81.612406	40.783738	96	234	0.50	0	-	14
262	-81.170951	40.900766	72	370	1.50	0	-	0
264	-81.157643	40.913050	60	180	0.80	0	-	0
269	-81.624696	41.039396	96	176	0.30	0	-	0
270	-81.426296	41.066716	58	190	1.30	7	Gravel	0
278	-81.628640	41.231424	42	96	0.80	0	-	20
279	-81.627417	41.231653	54	210	3.50	0	-	0
280	-81.627734	41.235583	60	272	3.70	0	-	12
281	-81.628779	41.245462	48	192	0.30	0	-	12
285	-81.648994	41.218176	96	360	1.00	0	-	12
287	-81.626675	41.232248	48	125	1.50	0	-	66
290	-81.541471	41.272008	84	548	1.20	0	-	24
295	-81.502532	41.345816	66	360	0.50	0	-	0

Culvert	Longitude	Latitude	Diameter (inches)	Length (feet)	Pipe Slope (%)	Embedded depth (inches)	Substrate	Perched height (inches)
296	-81.468665	41.321912	60	366	2.30	0	-	0
300	-81.413959	41.279641	60	286	1.00	0	-	0
301	-81.661500	41.001762	42	78	1.00	0	-	0
320	-80.707948	41.245054	54	190	0.30	12	Clay	0
327	-80.706881	41.389295	42	212	1.30	0	-	0
338	-80.712994	41.454316	66	218	0.60	0	-	38
356	-80.665576	41.364208	28	41	1.03	0	-	0
362	-80.979263	41.211834	80	52	0.10	0	-	0
364	-80.955182	41.438179	62	87	0.84	0	-	11
365	-80.954874	41.449976	48	88	0.06	17	Clay	0
367	-80.535185	41.336031	72	82	1.22	0	-	10
373	-80.955449	41.296523	48	200	1.50	0	-	12
		Average	61	177	1.00	2		8
		Minimum	28	41	0.06	0		0
		Maximum	120	548	3.70	48		66

Table B.2: List of culverts used for the study (Part II)

Culvert	Longitude	Latitude	Material	Entrance type	FishXing Analysis	HEC-RAS Analysis
4	-80.632053	41.158901	Concrete	Wingwall	Yes	No
28	-80.623362	41.397897	Concrete	Wingwall	Yes	Yes
34	-80.568088	41.194369	Concrete	Headwall	Yes	Yes
40	-80.568249	41.270271	Corrugated metal	Headwall	Yes	Yes
48	-80.568599	41.375295	Concrete	Headwall	Yes	Yes
58	-80.569876	41.491537	Concrete	Projected	Yes	Yes
59	-80.569952	41.496962	Concrete	Projected	Yes	Yes
69	-80.676721	41.156784	Concrete	Headwall	Yes	Yes
70	-80.677594	41.160404	Concrete	Headwall	Yes	No
74	-80.709951	41.240880	Concrete	Headwall	Yes	Yes
75	-80.705045	41.251852	Concrete	Headwall	Yes	Yes
93	-80.707148	41.397258	Concrete	Wingwall	Yes	Yes
98	-80.712597	41.435700	Concrete	Headwall	Yes	Yes
102	-80.712986	41.456470	Concrete	Headwall	Yes	Yes
119	-80.868290	41.380437	Corrugated metal	Headwall	Yes	Yes
143	-80.736859	41.376833	Concrete	Headwall	Yes	Yes
151	-80.737113	41.431064	Corrugated metal	Wingwall	Yes	No
152	-80.736997	41.434046	HDPE	Headwall	Yes	Yes
154	-80.746731	41.460051	Corrugated metal	Headwall	Yes	No
210	-80.713110	41.499441	Concrete	Headwall	Yes	Yes
212	-80.713135	41.511405	Concrete	Headwall	Yes	Yes
214	-80.713204	41.538154	Concrete	Wingwall	Yes	Yes

Culvert	Longitude	Latitude	Material	Entrance type	FishXing Analysis	HEC-RAS Analysis
215	-80.713182	41.544496	Concrete	Wingwall	Yes	Yes
216	-80.713147	41.575032	Concrete	Headwall	Yes	Yes
235	-81.150380	41.105694	Concrete	Wingwall	Yes	No
236	-81.097086	41.105875	Concrete	Wingwall	Yes	Yes
237	-81.029214	41.103081	Concrete	Headwall	Yes	Yes
239	-81.313782	41.029283	Corrugated metal	Headwall	Yes	Yes
247	-81.644621	40.901788	Corrugated metal	Wingwall	Yes	Yes
248	-81.623420	40.789157	Concrete	Headwall	Yes	Yes
249	-81.612406	40.783738	Concrete	Headwall	Yes	Yes
262	-81.170951	40.900766	Concrete	Headwall	Yes	Yes
264	-81.157643	40.913050	Concrete	Headwall	Yes	Yes
269	-81.624696	41.039396	Concrete	Headwall	Yes	Yes
270	-81.426296	41.066716	Concrete	Headwall	Yes	No
278	-81.628640	41.231424	Concrete	Wingwall	Yes	Yes
279	-81.627417	41.231653	Corrugated metal	Headwall	No	Yes
280	-81.627734	41.235583	Corrugated metal	Headwall	Yes	Yes
281	-81.628779	41.245462	Concrete	Headwall	Yes	Yes
285	-81.648994	41.218176	Corrugated metal	Headwall	Yes	No
287	-81.626675	41.232248	Concrete	Headwall	Yes	Yes
290	-81.541471	41.272008	Corrugated metal	Projected	Yes	No
295	-81.502532	41.345816	Corrugated metal	Wingwall	Yes	No
296	-81.468665	41.321912	Corrugated metal	Wingwall	Yes	Yes
300	-81.413959	41.279641	Concrete	Headwall	Yes	Yes
301	-81.661500	41.001762	Corrugated metal	Projected	Yes	Yes

Culvert	Longitude	Latitude	Material	Entrance type	FishXing Analysis	HEC-RAS Analysis
320	-80.707948	41.245054	Concrete	Projected	Yes	Yes
327	-80.706881	41.389295	Concrete	Projected	Yes	No
338	-80.712994	41.454316	Concrete	Headwall	Yes	No
356	-80.665576	41.364208	Concrete	Headwall	Yes	No
362	-80.979263	41.211834	Corrugated metal	Wingwall	Yes	No
364	-80.955182	41.438179	Corrugated metal	Headwall	Yes	No
365	-80.954874	41.449976	Corrugated metal	Projected	Yes	No
367	-80.535185	41.336031	Corrugated metal	Headwall	Yes	Yes
373	-80.955449	41.296523	Concrete	Wingwall	Yes	Yes

Table B.3: Flows from StreamStats used for passage analysis

Culvert	Flows (cfs)														
	FPS25	**PK2**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Min**	**Max**
4	0.08	75.50	0.76	1.03	1.15	1.08	0.63	0.39	0.25	0.14	0.09	0.10	0.25	0.58	0.08	75.50
28	0.23	50.70	1.54	2.01	2.15	1.84	1.13	0.54	0.27	0.24	0.16	0.39	0.78	1.42	0.16	50.70
34	0.04	30.60	0.27	0.36	0.39	0.38	0.20	0.12	0.07	0.05	0.03	0.03	0.08	0.20	0.03	30.60
40	0.08	41.70	0.64	0.94	1.00	0.87	0.54	0.25	0.13	0.11	0.07	0.17	0.35	0.65	0.07	41.70
48	0.03	46.00	0.38	0.69	0.72	0.63	0.37	0.18	0.12	0.08	0.05	0.12	0.25	0.47	0.03	46.00
58	0.05	24.30	0.38	0.56	0.58	0.51	0.29	0.14	0.07	0.07	0.04	0.10	0.20	0.38	0.04	24.30
59	0.14	41.20	1.01	1.34	1.40	1.23	0.69	0.35	0.18	0.17	0.10	0.25	0.51	0.91	0.10	41.20
69	0.54	143.00	3.61	3.99	4.58	4.16	2.53	1.58	0.85	0.57	0.40	0.44	1.04	2.35	0.40	143.00
70	0.12	63.10	0.82	1.03	1.15	1.08	0.65	0.40	0.23	0.14	0.09	0.11	0.25	0.58	0.09	63.10
74	0.09	30.40	0.51	0.75	0.81	0.70	0.46	0.21	0.11	0.08	0.06	0.15	0.28	0.53	0.06	30.40
75	0.03	19.40	0.18	0.31	0.32	0.28	0.18	0.08	0.05	0.03	0.02	0.06	0.11	0.21	0.02	19.40
93	0.02	31.60	0.26	0.45	0.46	0.41	0.24	0.12	0.07	0.05	0.03	0.08	0.16	0.30	0.02	31.60
98	0.08	69.30	0.97	1.55	1.64	1.42	0.85	0.41	0.25	0.18	0.11	0.29	0.60	1.07	0.08	69.30
102	0.01	20.00	0.13	0.24	0.24	0.22	0.12	0.06	0.04	0.03	0.02	0.04	0.09	0.15	0.01	20.00
119	0.08	25.80	0.47	0.66	0.69	0.61	0.36	0.15	0.07	0.06	0.04	0.10	0.24	0.45	0.04	25.80
143	0.13	78.70	1.24	1.90	2.04	1.74	1.10	0.51	0.29	0.21	0.15	0.37	0.73	1.35	0.13	78.70
151	0.04	55.00	0.57	0.96	1.01	0.88	0.52	0.25	0.15	0.11	0.07	0.17	0.36	0.66	0.04	55.00
152	0.03	40.20	0.37	0.63	0.66	0.58	0.34	0.16	0.10	0.07	0.04	0.11	0.23	0.43	0.03	40.20
154	0.08	69.20	1.00	1.52	1.60	1.39	0.80	0.39	0.23	0.17	0.11	0.27	0.59	1.04	0.08	69.20
210	0.19	101.00	2.40	3.34	3.55	3.04	1.75	0.85	0.47	0.40	0.25	0.61	1.35	2.33	0.19	101.00
212	0.17	47.60	1.44	1.85	1.96	1.69	0.97	0.44	0.21	0.20	0.14	0.30	0.69	1.29	0.14	47.60

Culvert	Flows (cfs)														
	FPS25	PK2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Min	Max
214	0.01	18.40	0.19	0.29	0.29	0.27	0.14	0.07	0.04	0.03	0.02	0.04	0.11	0.18	0.01	18.40
215	0.06	53.80	1.01	1.46	1.51	1.33	0.71	0.34	0.19	0.17	0.10	0.23	0.57	0.97	0.06	53.80
216	0.13	37.30	1.35	1.61	1.68	1.46	0.79	0.35	0.16	0.17	0.11	0.23	0.60	1.10	0.11	37.30
235	0.07	25.70	0.33	0.40	0.44	0.42	0.25	0.16	0.09	0.05	0.04	0.04	0.09	0.22	0.04	25.70
236	0.12	57.10	0.75	0.89	0.99	0.93	0.57	0.36	0.20	0.12	0.08	0.10	0.22	0.50	0.08	57.10
237	0.11	51.50	0.80	0.94	1.05	0.98	0.61	0.37	0.19	0.12	0.07	0.09	0.23	0.53	0.07	51.50
239	0.44	163.00	2.85	3.39	3.84	3.54	2.17	1.53	0.93	0.56	0.35	0.44	0.93	1.95	0.35	163.00
247	0.14	67.00	0.89	1.19	1.32	1.24	0.75	0.51	0.33	0.20	0.12	0.14	0.30	0.66	0.12	67.00
248	0.25	62.60	1.07	1.34	1.48	1.40	0.85	0.62	0.38	0.25	0.15	0.18	0.35	0.74	0.15	62.60
249	0.35	89.20	1.74	2.17	2.42	2.26	1.38	1.00	0.63	0.40	0.25	0.29	0.58	1.22	0.25	89.20
262	0.20	61.30	1.03	1.20	1.33	1.25	0.75	0.48	0.26	0.18	0.12	0.13	0.29	0.67	0.12	61.30
264	0.05	45.70	0.38	0.52	0.57	0.54	0.32	0.20	0.13	0.08	0.05	0.05	0.12	0.28	0.05	45.70
269	0.85	195.00	6.05	7.11	8.10	7.37	4.34	2.98	1.81	1.26	0.84	0.89	1.94	4.16	0.84	195.00
270	0.16	77.80	0.99	1.24	1.37	1.29	0.75	0.51	0.31	0.20	0.13	0.14	0.31	0.69	0.13	77.80
278	0.03	29.10	0.22	0.39	0.40	0.36	0.21	0.10	0.06	0.05	0.03	0.07	0.13	0.26	0.03	29.10
279	0.04	32.60	0.25	0.44	0.45	0.40	0.23	0.12	0.07	0.06	0.04	0.08	0.15	0.29	0.04	32.60
280	0.12	91.10	1.00	1.71	1.81	1.56	0.94	0.47	0.31	0.24	0.16	0.36	0.64	1.19	0.12	91.10
281	0.03	23.00	0.16	0.28	0.29	0.26	0.15	0.08	0.05	0.04	0.02	0.05	0.10	0.19	0.02	23.00
285	0.20	79.00	1.33	2.01	2.13	1.83	1.11	0.55	0.32	0.28	0.19	0.42	0.76	1.40	0.19	79.00
287	0.04	34.20	0.27	0.46	0.48	0.42	0.25	0.12	0.08	0.06	0.04	0.09	0.16	0.31	0.04	34.20
290	0.28	133.00	1.98	3.13	3.33	2.85	1.66	0.87	0.55	0.49	0.34	0.69	1.20	2.20	0.28	133.00
295	0.12	36.90	0.52	0.83	0.85	0.75	0.41	0.23	0.15	0.15	0.09	0.19	0.30	0.55	0.09	36.90
296	0.24	63.20	1.16	1.74	1.82	1.57	0.89	0.47	0.28	0.29	0.20	0.38	0.63	1.20	0.20	63.20

Culvert	Flows (cfs)															
	FPS25	PK2	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Min	Max
300	0.11	69.50	0.86	1.38	1.42	1.25	0.70	0.38	0.24	0.21	0.13	0.29	0.53	0.92	0.11	69.50
301	0.02	12.20	0.11	0.15	0.16	0.16	0.09	0.06	0.04	0.02	0.01	0.02	0.03	0.08	0.01	12.20
320	0.01	6.60	0.03	0.06	0.06	0.06	0.04	0.02	0.01	0.01	0.00	0.01	0.02	0.04	0.00	6.60
327	0.03	28.70	0.27	0.42	0.42	0.38	0.22	0.12	0.07	0.05	0.03	0.08	0.16	0.27	0.03	28.70
338	0.16	84.20	1.70	2.41	2.55	2.20	1.29	0.64	0.36	0.29	0.18	0.46	0.97	1.67	0.16	84.20
356	0.04	16.20	0.24	0.35	0.36	0.32	0.19	0.09	0.05	0.04	0.02	0.06	0.13	0.23	0.02	16.20
362	1.55	186.00	7.62	9.66	10.90	8.94	6.37	3.23	1.69	1.24	0.89	2.58	4.20	7.35	0.89	186.00
364	0.01	17.40	0.12	0.20	0.19	0.18	0.09	0.05	0.03	0.02	0.01	0.03	0.07	0.12	0.01	17.40
365	0.10	58.90	1.10	1.58	1.64	1.43	0.79	0.37	0.20	0.19	0.12	0.26	0.59	1.07	0.10	58.90
367	0.09	87.00	0.89	1.50	1.58	1.37	0.81	0.43	0.29	0.21	0.13	0.33	0.58	1.03	0.09	87.00
373	0.04	27.90	0.23	0.39	0.41	0.36	0.22	0.12	0.08	0.06	0.03	0.09	0.14	0.26	0.03	27.90

Table B.4: Fish distribution across the culverts

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
4	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Present
28	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
34	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
40	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
48	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
58	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
59	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
69	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
70	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
74	Present	Present	Absent	Absent	Present	Absent	Absent	Present	Absent	Present	Absent
75	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
93	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
98	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
102	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
119	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
143	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
151	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
152	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
154	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
210	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
212	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
214	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
215	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
216	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
235	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
236	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
237	Present	Present	Present	Present	Present	Absent	Absent	Present	Present	Present	Absent
239	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
247	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
248	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
249	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
262	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
264	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
269	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Absent
270	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
278	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
279	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
280	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
281	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
285	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
287	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
290	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
295	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
296	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
300	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
301	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Absent

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
320	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
327	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
338	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
356	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
362	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
364	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
365	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Present
367	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present
373	Present	Present	Present	Present	Present	Absent	Present	Present	Present	Present	Absent

Table B.5: Result of fish passage analysis

Culvert	Longitude	Latitude	Result of analysis	
			According to FishXing	According to HEC-RAS
4	-80.632053	41.158901	Complete barrier	Not Analyzed
28	-80.623362	41.397897	Complete barrier	Complete barrier
34	-80.568088	41.194369	Complete barrier	Partial barrier
40	-80.568249	41.270271	Complete barrier	Complete barrier
48	-80.568599	41.375295	Complete barrier	Complete barrier
58	-80.569876	41.491537	Complete barrier	Partial barrier
59	-80.569952	41.496962	Complete barrier	Partial barrier
69	-80.676721	41.156784	Partial barrier	Partial barrier
70	-80.677594	41.160404	Complete barrier	Not Analyzed
74	-80.709951	41.240880	Complete barrier	Complete barrier
75	-80.705045	41.251852	Complete barrier	Complete barrier
93	-80.707148	41.397258	Complete barrier	Complete barrier
98	-80.712597	41.435700	Complete barrier	Complete barrier
102	-80.712986	41.456470	Complete barrier	Partial barrier
119	-80.868290	41.380437	Complete barrier	Partial barrier
143	-80.736859	41.376833	Complete barrier	Complete barrier
151	-80.737113	41.431064	Complete barrier	Not Analyzed
152	-80.736997	41.434046	Complete barrier	Partial barrier
154	-80.746731	41.460051	Complete barrier	Not Analyzed
210	-80.713110	41.499441	Complete barrier	Partial barrier
212	-80.713135	41.511405	Complete barrier	Partial barrier
214	-80.713204	41.538154	Complete barrier	Partial barrier
215	-80.713182	41.544496	Partial barrier	Partial barrier
216	-80.713147	41.575032	Complete barrier	Partial barrier
235	-81.150380	41.105694	Complete barrier	Not Analyzed
236	-81.097086	41.105875	Complete barrier	Complete barrier
237	-81.029214	41.103081	Complete barrier	Partial barrier
239	-81.313782	41.029283	Partial barrier	Partial barrier
247	-81.644621	40.901788	Complete barrier	Complete barrier
248	-81.623420	40.789157	Complete barrier	Complete barrier
249	-81.612406	40.783738	Complete barrier	Partial barrier

Culvert	Longitude	Latitude	Result of analysis	
			According to FishXing	According to HEC-RAS
262	-81.170951	40.900766	Complete barrier	Complete barrier
264	-81.157643	40.913050	Complete barrier	Partial barrier
269	-81.624696	41.039396	Complete barrier	Partial barrier
270	-81.426296	41.066716	Complete barrier	Not Analyzed
278	-81.628640	41.231424	Complete barrier	Complete barrier
279	-81.627417	41.231653	Not Analyzed	Partial barrier
280	-81.627734	41.235583	Complete barrier	Complete barrier
281	-81.628779	41.245462	Complete barrier	Complete barrier
285	-81.648994	41.218176	Complete barrier	Not Analyzed
287	-81.626675	41.232248	Complete barrier	Complete barrier
290	-81.541471	41.272008	Complete barrier	Not Analyzed
295	-81.502532	41.345816	Complete barrier	Not Analyzed
296	-81.468665	41.321912	Partial barrier	Partial barrier
300	-81.413959	41.279641	Complete barrier	Complete barrier
301	-81.661500	41.001762	Partial barrier	Partial barrier
320	-80.707948	41.245054	Partial barrier	Partial barrier
327	-80.706881	41.389295	Complete barrier	Not Analyzed
338	-80.712994	41.454316	Complete barrier	Not Analyzed
356	-80.665576	41.364208	Complete barrier	Not Analyzed
362	-80.979263	41.211834	Complete barrier	Not Analyzed
364	-80.955182	41.438179	Complete barrier	Not Analyzed
365	-80.954874	41.449976	Complete barrier	Not Analyzed
367	-80.535185	41.336031	Complete barrier	Partial barrier
373	-80.955449	41.296523	Complete barrier	Complete barrier

Table B.6: Percentage of flows at which fish can swim upstream successfully according to FishXing analysis

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
4	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	0.00
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
69	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	1.47	1.88	1.11
70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
74	0.00	0.00	No fish	No fish	0.00	No fish	No fish	0.00	No fish	0.00	No fish
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
102	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
143	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
151	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
152	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
154	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
212	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
214	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
215	0.00	0.00	0.09	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
216	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
235	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
236	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
237	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
239	0.24	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
247	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
248	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
249	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
262	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
264	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
269	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	No fish
270	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
278	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
280	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
285	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
287	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
290	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
295	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
296	0.00	0.00	0.02	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
301	0.25	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	No fish
320	0.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
327	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
338	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
356	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
362	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
364	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
365	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
367	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
373	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	No fish

Table B.7: Percentage of flows at which fish can swim upstream successfully according to HEC-RAS analysis

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	7.14	14.29	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.14	0.00	0.00
69	0.00	0.00	50.00	0.00	92.86	0.00	14.29	0.00	64.29	57.14	28.57
74	0.00	0.00	No fish	No fish	0.00	No fish	No fish	0.00	No fish	0.00	No fish
75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
102	0.00	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
119	42.86	42.86	42.86	35.71	0.00	No fish	0.00	35.71	0.00	14.29	0.00
143	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
152	0.00	7.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
210	0.00	0.00	0.00	0.00	21.43	No fish	No fish	0.00	14.29	14.29	No fish
212	0.00	0.00	28.57	0.00	0.00	No fish	No fish	0.00	0.00	7.14	No fish
214	0.00	0.00	14.29	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
215	0.00	0.00	21.43	0.00	0.00	No fish	No fish	0.00	0.00	7.14	No fish
216	0.00	0.00	57.14	0.00	0.00	No fish	No fish	0.00	7.14	21.43	No fish
236	0.00	0.00	0.00	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish
237	0.00	0.00	7.14	0.00	0.00	No fish	No fish	0.00	0.00	0.00	No fish

Culvert	BND	CS	GS	GSD	LMB	LSF	NP	PSF	SMB	WS	WYE
239	92.86	92.86	92.86	92.86	92.86	No fish	92.86	92.86	92.86	92.86	92.86
247	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
248	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
249	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	14.29	0.00
262	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
264	0.00	0.00	14.29	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
269	0.00	0.00	28.57	0.00	21.43	No fish	0.00	0.00	7.14	28.57	No fish
278	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
279	0.00	0.00	14.29	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
280	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
281	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
287	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
296	0.00	0.00	42.86	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
300	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	0.00
301	50.00	21.43	0.00	28.57	0.00	No fish	0.00	28.57	0.00	0.00	No fish
320	0.00	0.00	0.00	0.00	92.86	0.00	92.86	0.00	92.86	92.86	92.86
367	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.29	21.43	0.00
373	0.00	0.00	0.00	0.00	0.00	No fish	0.00	0.00	0.00	0.00	No fish

Appendix C (Photographs of Selected Culverts)

Figure C.1: Culvert No. 4

Figure C.2: Culvert No. 34

Figure C.3: Culvert No. 40

Figure C.4: Culvert No. 69

Figure C.5: Culvert No. 75

Figure C.6: Culvert No. 143

Figure C.7: Culvert No. 152

Figure C.8: Culvert No. 154

Figure C.9: Culvert No. 210

Figure C.10: Culvert No. 212

Figure C.11: Culvert No. 239

Figure C.12: Culvert No. 242

Figure C.13: Culvert No. 247

Figure C.14: Culvert No. 248

Figure C.15: Culvert No. 269

Figure C.16: Culvert No. 270

Figure C.17: Culvert No. 280

Figure C.18: Culvert No. 281

Figure C.19: Culvert No. 285

Figure C.20: Culvert No. 287

Figure C.21: Culvert No. 290

Figure C.22: Culvert No. 300

Figure C.23: Culvert No. 365

Figure C.24: Culvert No. 373

Appendix D (Screenshots)

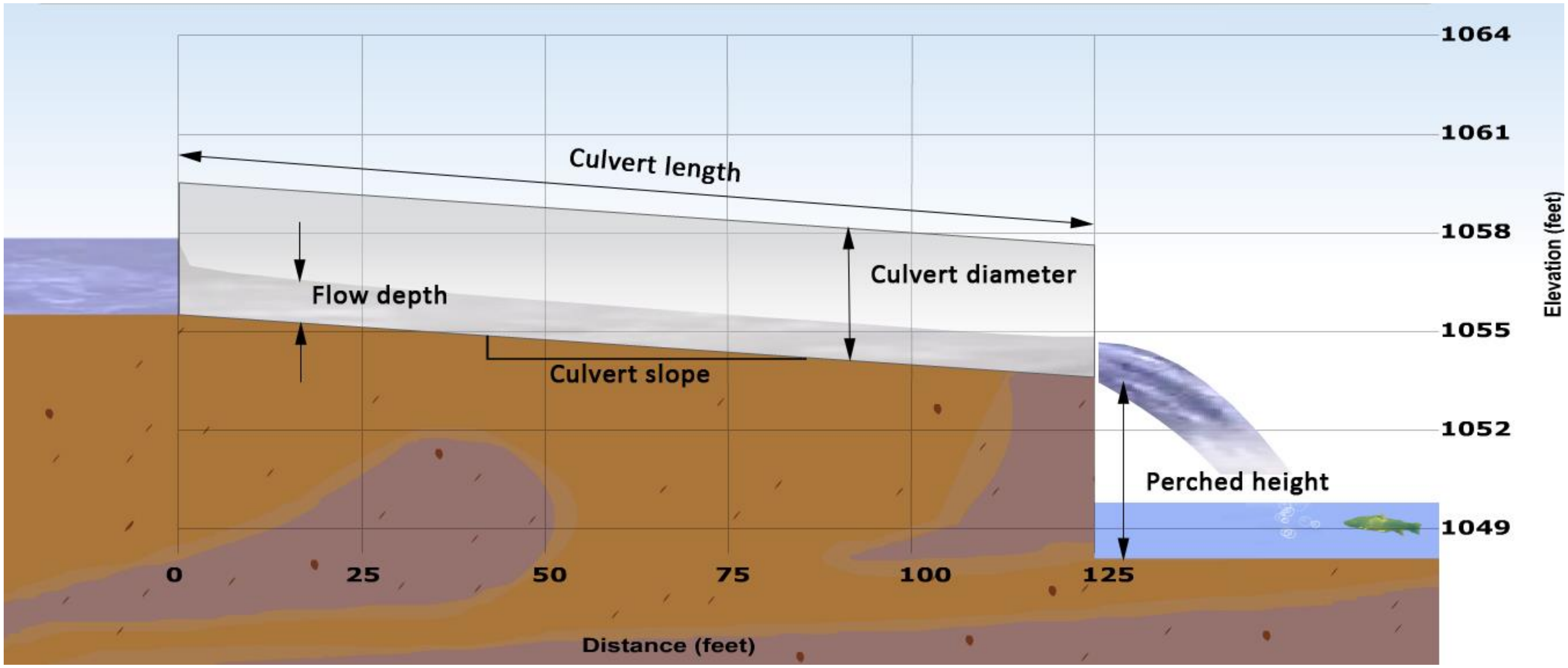

Figure D.1: Screenshot of longitudinal section of a perched culvert in FishXing

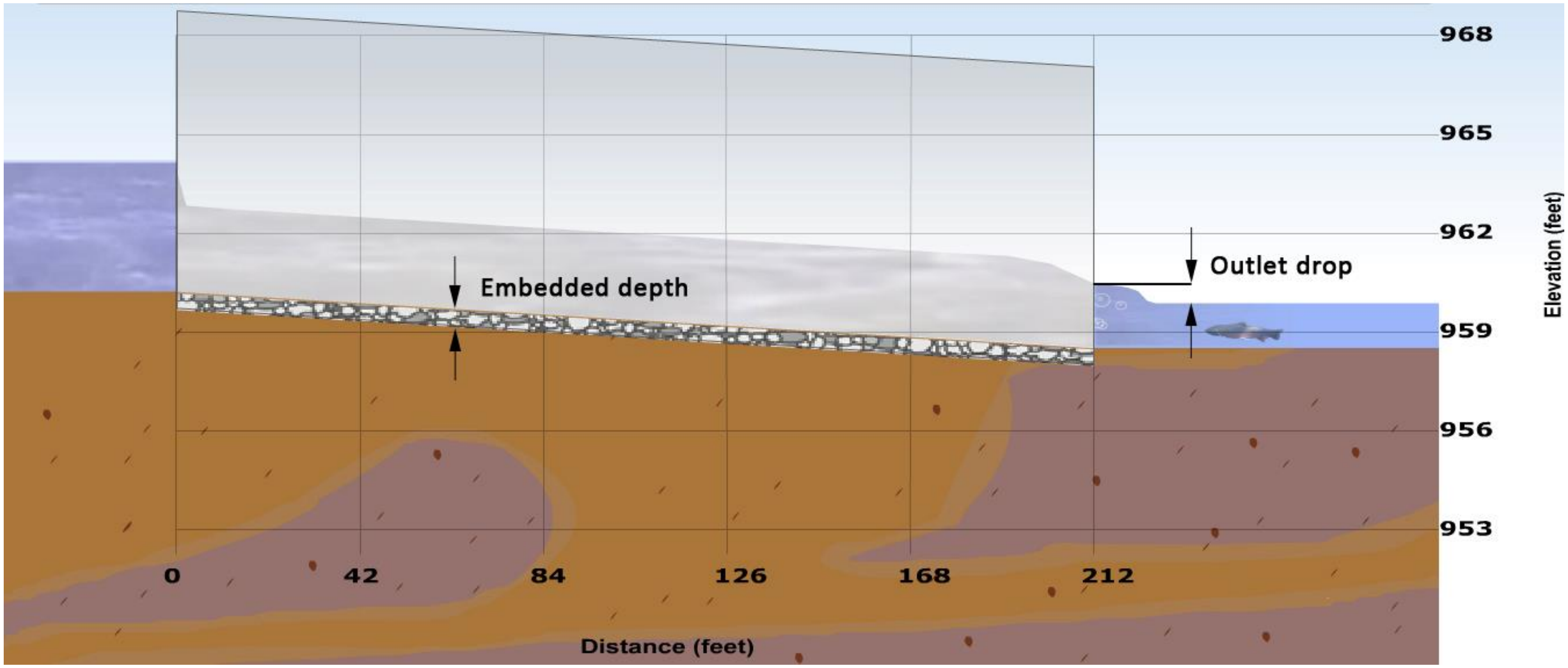

Figure D.2: Screenshot of longitudinal section of an embedded culvert in FishXing

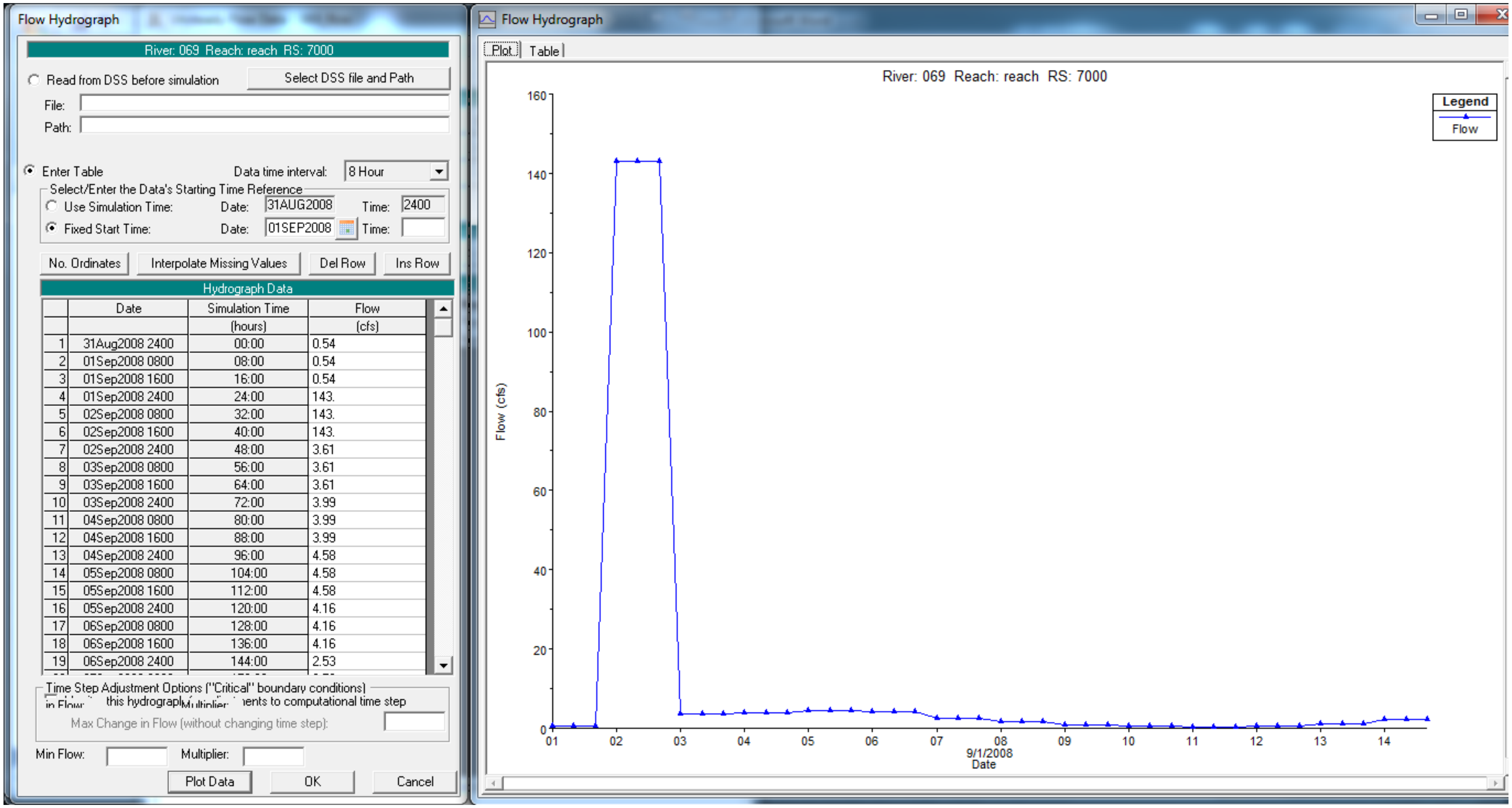

Figure D.3: Screenshot of a flow hydrograph used in HEC-RAS

Appendix E (Flow Charts)

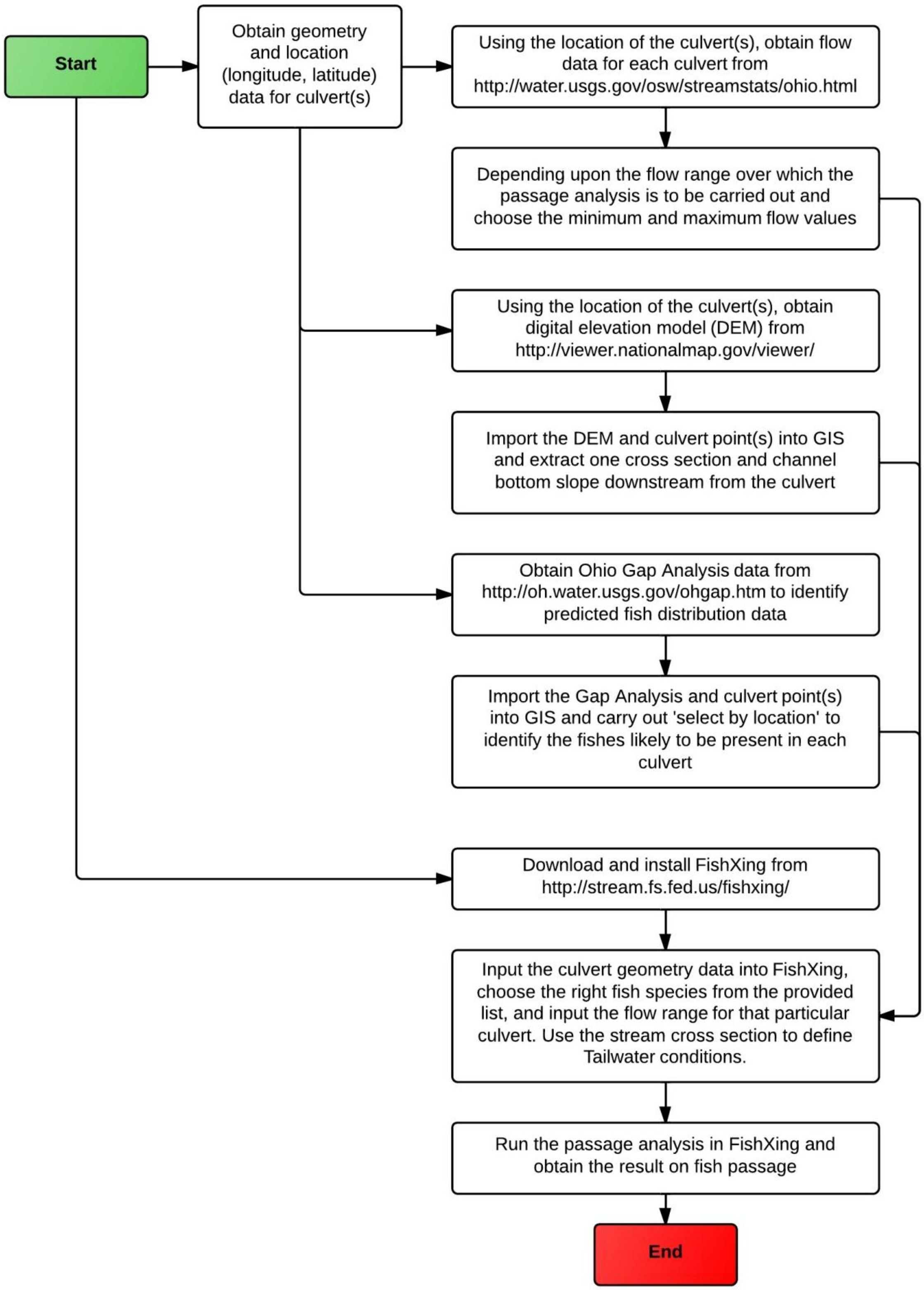

Figure E.1: Flow chart showing the process of passage analysis in FishXing

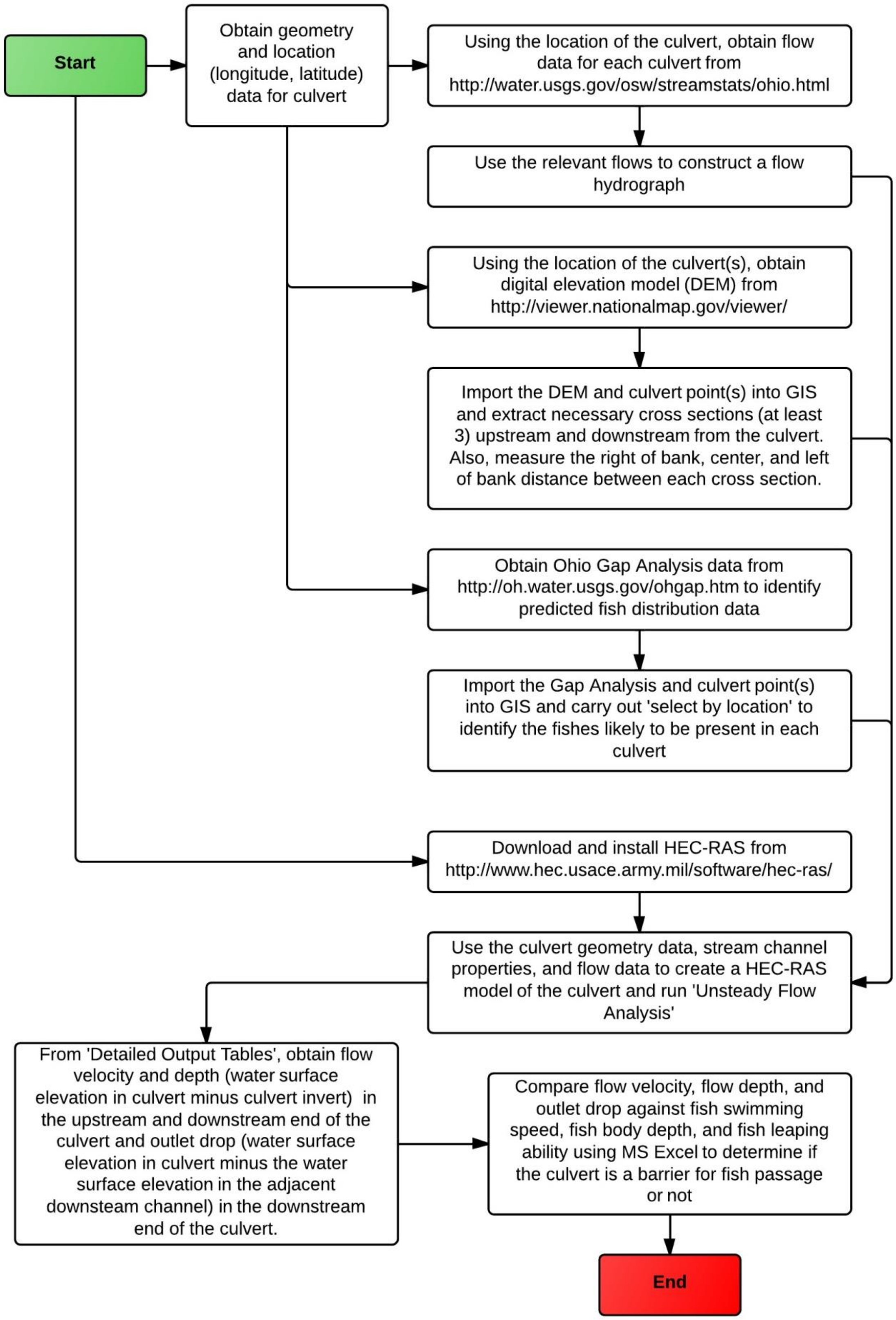

Figure E.2: Flow chart showing the process of passage analysis in HEC-RAS

Appendix F (OhPAT)

Ohio Passage Analysis Tool (OhPAT)

A flow diagram showing major steps of passage analysis in FishXing is presented in Figure E.1 of Appendix E. The things necessary to carry out fish passage analysis in FishXing are culvert properties, fish properties, discharge conditions, and stream properties.

The culvert properties include the following.

- Culvert diameter
- Entrance type
- Embeddedness information i.e. depth embedded and roughness of the substrate
- Perchedness information i.e. perched height
- Culvert material (for manning's roughness coefficient)
- Culvert length
- Outlet elevation, and
- Either culvert slope or inlet elevation.

The fish properties necessary to carry out passage analysis are

- Fish body length
- Fish swimming speed (preferably both prolonged swimming speed and burst swimming speed)
- Fish body depth
- Either 'Maximum Outlet Drop' or 'Maximum Leap Speed' to define Outlet Criteria

The range of flows over which analysis is to be carried out is required as the discharge condition.

For defining the tailwater condition, either 'Constant Tailwater', 'User Defined Rating Curve', or 'Channel Cross-Section' downstream from the culvert can be used. In this tool, the method to use the 'Channel Cross-Section' has been described. The channel cross-section downstream from the culvert, Maning's roughness of the channel, outlet pool bottom elevation, and channel bottom slope are the required stream properties.

We will use culvert 239 as an example of how use the OhPAT to identify design parameters that are associated with passage success. The information for Culvert 239 was obtained from the inventory provided by the ODOT and field visit. Its properties (from Table B.1 and B.2 of Appendix B) are presented below.

- Culvert diameter = 96 inches
- Culvert entrance type = Headwall
- Embedded depth = 9 inches
- Embedded material = Clay (n = 0.018)
- Culvert material = Corrugated metal (0.024)

- Culvert length = 124 feet
- Pipe Slope = 0.30%
- Perched height = 0 inch
- Culvert location (Longitude, Latitude) = (-81.313782, 41.029283)

Step 1: Obtaining flow range

The flow values for each culvert location can be obtained from the Ohio StreamStats website at http://water.usgs.gov/osw/streamstats/ohio.html. Following the link for 'Interactive Map' in the website, one can go to the page with maps and several tools. In the dropdown menu for "Zoom to:" there is an option called 'Lat/Long' that allows one to zoom to the required point by entering the coordinates of the point (Figure F.1). This optionopens a box where the coordinates of the culvert point can be entered (Figure F.2). Once the coordinates of the point are entered, the point is marked on the map with a cross sign (Figure F.3). Then, the tool 'Watershed delineation from a point' can be used to fix the watershed for the culvert point by choosing an appropriate point close to the cross previously marked on the map (Figure F.4). Finally, 'Estimate Flows using Regression Equations' can be used to obtain the required flows (Figure F.5). The minimum and maximum of these flows should be identified for carrying out the passage analysis in FishXing.

Step 2: Obtaining Stream Channel Cross-Section and Channel Bottom Slope

To extract the cross-section of the channel downstream from the culvert, a Digital Elevation Model (DEM) is required. It can be obtained from the website of USGS National Map Viewer at http://viewer.nationalmap.gov/viewer/. The first step is to go to the 'Download Data' on top right of the map viewer and choose 'Click here to download by coordinate output' in the box that pops up (Figure F.6). A new box pops up which requires input of coordinates of the limits of the desired area (Figure F.7). The coordinates should be entered such that the culvert point is located within the selected box. After the coordinates are input, the list of available USGS data for the selected area is shown in a new box. Select the 'Elevation' and click 'Next' (Figure F.8). In the box that shows up next, check the 'National Elevation Dataset (1/9 arc second)' and click 'Next'. On the left side of the map viewer, in the 'Cart', click on the 'Checkout' button and follow the instructions to have the data emailed to the chosen address. Next, the DEM can be downloaded by following the instructions in the email. The downloaded DEM should be imported into GIS (ArcMap) along with the culvert point (Figure F.9). It is best to have all the layers in the same projection. Contours can be constructed from the DEM and/or base map available in the GIS can be used to assist in examining the culvert closely. The 'Interpolate Line' tool along with 'Create Profile Graph' tool in the 3D Analyst Toolbar can be used to extract channel cross-section downstream from the culvert and export it as an MS Excel file (Figure F.10). Similarly, channel bottom slope can be obtained by extracting a section from a profile graph along the channel and then dividing the difference of elevation by the distance between the two ends of the profile graph.

Care should be taken to note the units of the exported cross-section. For convenience when working with more than one culvert points, it may be necessary to merge the downloaded raster files to create a larger raster containing all the culvert points. The pieces of raster files can be merged by using the ‘Mosaic to New Raster tool’ under ‘Raster Dataset’ under ‘Raster’ of ‘Data Management Tools’ in the ‘Arc Toolbox’.

Step 3: Identifying the fish species for which analysis can be carried out

There are 176 different species of fish that reside in the rivers and lakes in Ohio (ODNR DOW, 2012). However, data on swimming speeds is not available for most of them. FishXing provides the most complete swim speed table available for fishes of the U.S., and includes a collection of data on the swimming speed for 65 different fish species present in the U.S. (FishXing, 2006). It was found that out of the 176 different fish species in Ohio, swimming speed data was available for only 11 fish species in the swim speed table. Hence, only these 11 fish species were chosen for analysis. The common and scientific names, swimming speeds, and dimensions of the fish species chosen for this study are presented in Table 1.

Step 4: Identifying the fish species that are present in the culvert

Ohio GAP analysis can be used to find information about the distribution of various fish species in Northeast Ohio. The GIS file of Ohio Gap analysis is available for download from the online repository of USGS Ohio Water Science Center i.e. http://pubs.usgs.gov/of/2006/1385/. The GIS shapefile containing information on potential predicted distributions of the native fish species should be used. The data for distribution of each fish species is a shapefile containing polygons. First, the culvert points and the shapefiles containing fish distribution information must be imported into GIS as separate layers. A ‘Select By Location’ must be done to select data from the layer of culvert points (Target Layer) that intersects with the layer of polygons or the contained within the polygons for the distribution of a particular fish (Figure F.11). The highlighted culverts in the ‘attribute table’ of the layer containing culvert points represents the culvert locations where that particular fish species were likely to be present. For example in Figure F.12, the culvert 239 is highlighted suggesting that golden shiner is present in culvert 239. The unselected culverts were the ones where the presence of that particular fish was unlikely because in those watersheds, the presence of that fish species was not predicted by the GAP analysis. For example in Figure F.13, the culvert 239 is not highlighted denoting that longear sunfish is absent in culvert 239.

Step 5: Passage Analysis in FishXing

The next step is to carry out the passage analysis in FishXing. FishXing is freely available computer software developed and maintained by the U.S. Fish and Wildlife Service (USFWS) that can be used to model the flow conditions through a culvert based on culvert parameters and geomorphic conditions of the stream. It then compares the modeled conditions with the swimming and leaping abilities of fish to simulate swimming performance of fish through the culvert. It can be downloaded from http://stream.fs.fed.us/fishxing/.

First, create a ‘New Crossing’ in the FishXing and after filling the ‘Site Information’ click ‘Continue’ (Figure F.14). The site information is only useful in facilitating the organization of many crossings and is not used for passage analysis. The next window is the ‘Crossing Input’ window. Fill all the ‘Fish Information’, ‘Culvert Information’, and ‘Fish Passage Flows’ (Figure F.15). Care must be taken with units to enter all data correctly. Then click on ‘Tailwater’ on the bottom left of the ‘Crossing Input’ window, choose ‘Channel Cross-Section’, and click ‘Enter Data’. In the window that appears next, copy and paste enter cross-section data and channel bottom slope that was extracted in Step 2 (Figure F.16). If the pool bottom elevation has not been measured in the field, identify the shallowest point of the channel and copy the elevation of that point into the ‘Outlet Pool Bottom Elevation’ box. Once all the data is filled, click ‘Continue’. In the ‘Crossing Input’ window, input the ‘Outlet Bottom Elevation’ so as to account for the parchedness of the culvert. If the perched height is zero, the outlet bottom elevation would be the same as the elevation of shallowest point of the cross-section downstream from the culvert. If the culvert is perched, the perched height must be added to the elevation of the shallowest point of the cross-section downstream of the culvert to obtain outlet bottom elevation. Once all the data has been entered, click on ‘Calculate’, which will give the output of the passage analysis for the range of flows entered (Figure F.17)

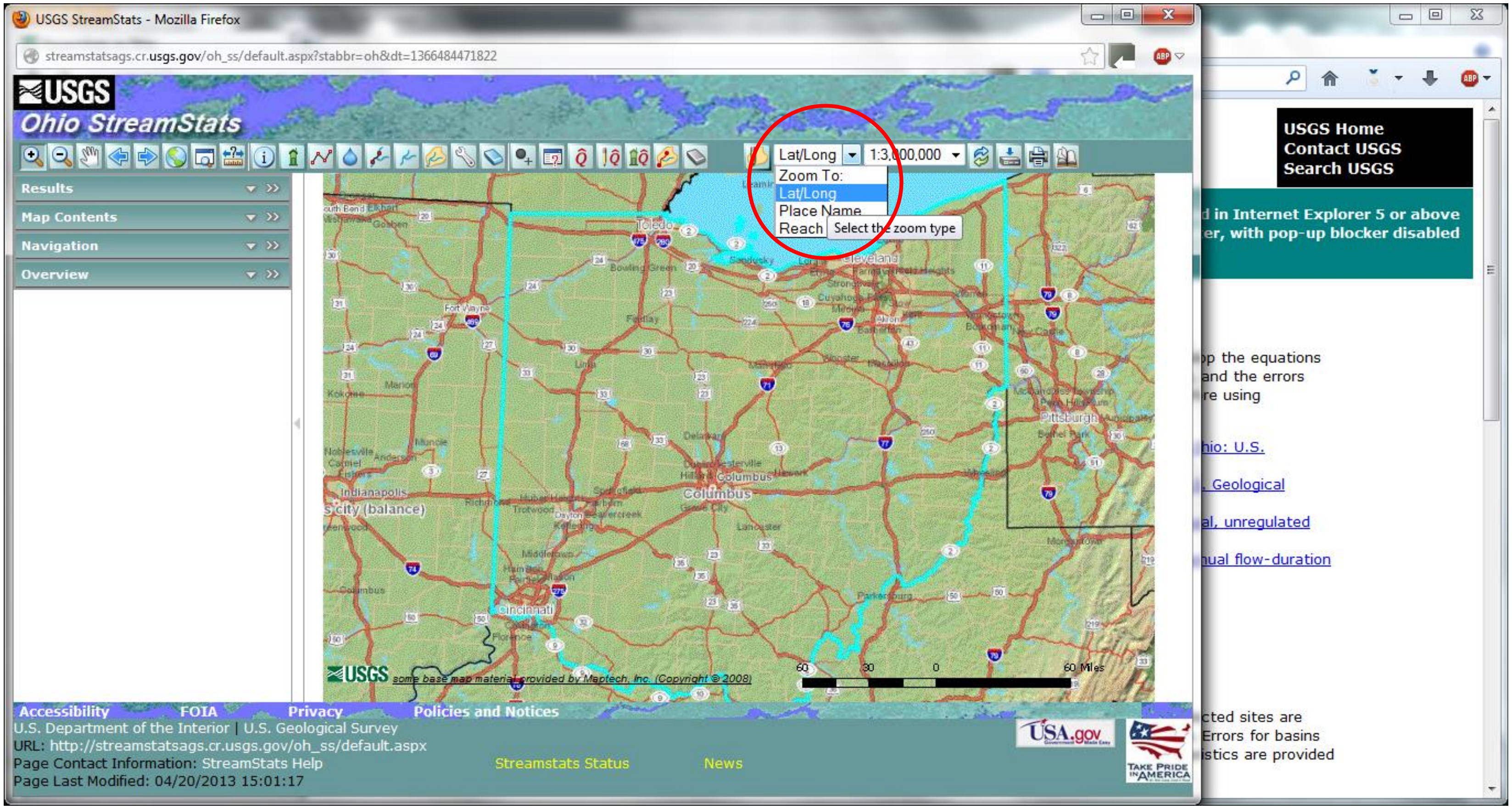

Fig. F.1: Screenshot of Ohio StreamStats showing the option to enter coordinates of the culvert point

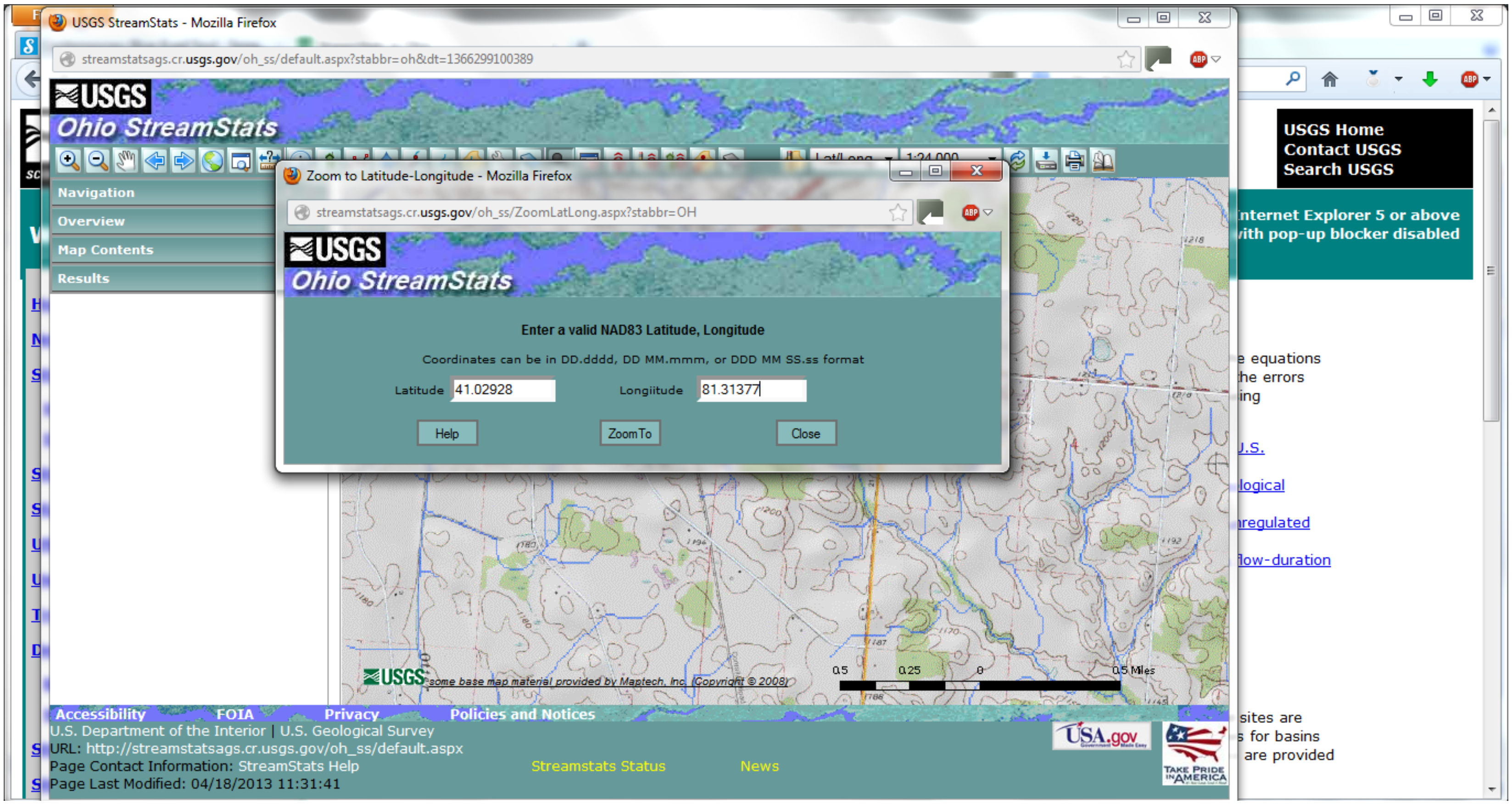

Fig. F.2: Screenshot of Ohio StreamStats asking user to input coordinates of the culvert point

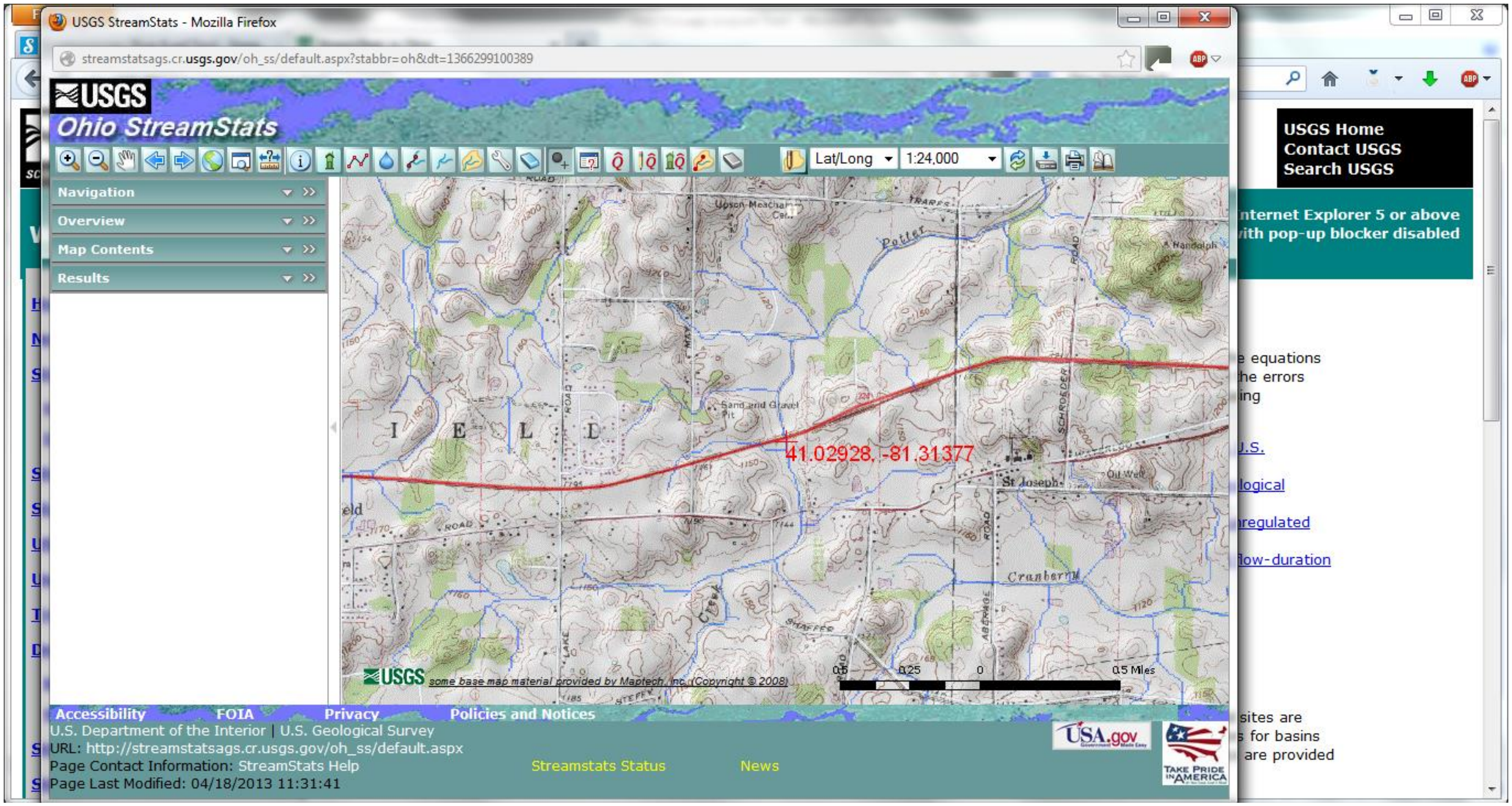

Fig. F.3: Screenshot of Ohio StreamStats depicting the culvert point with a cross

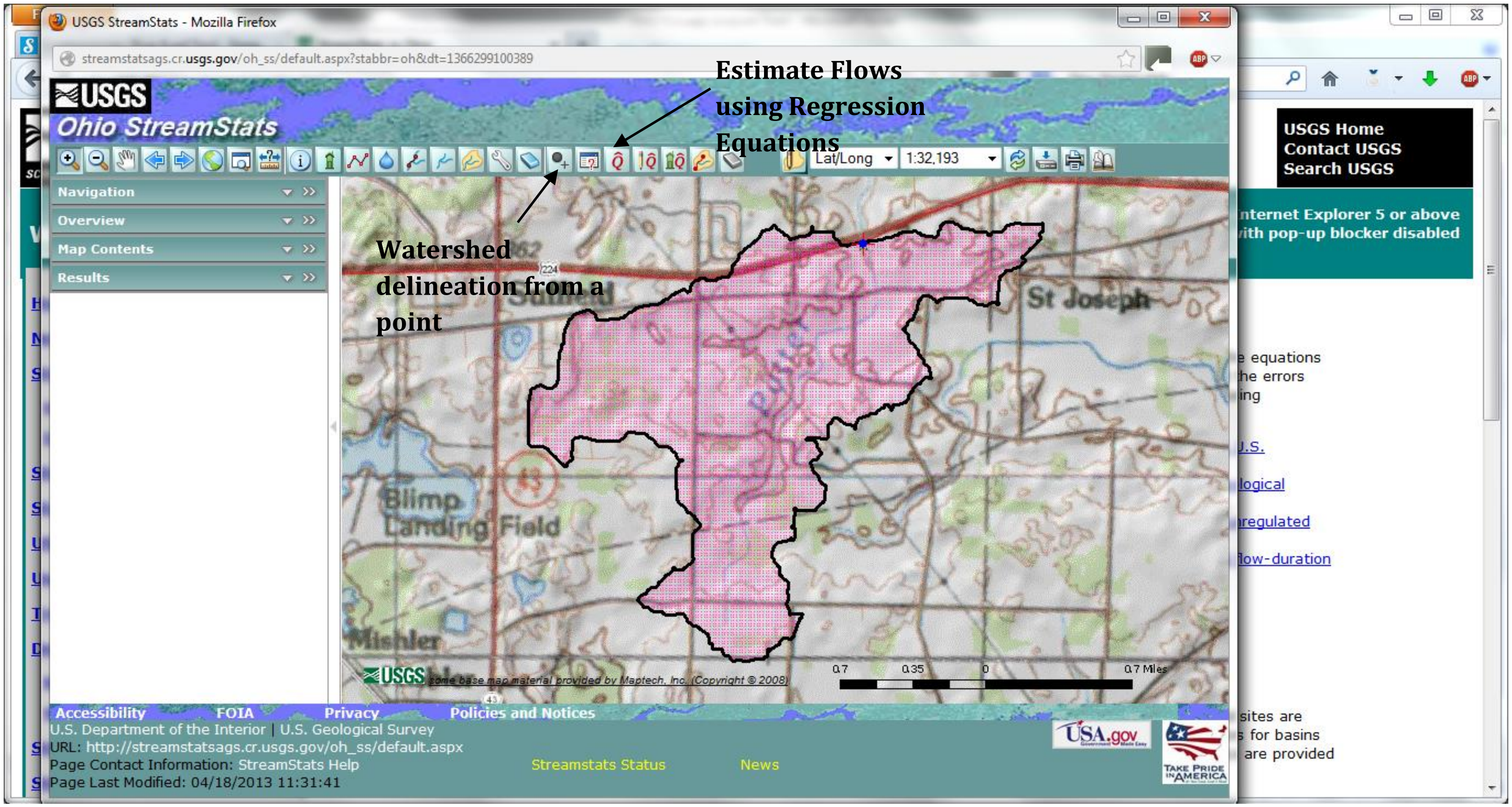

Fig. F.4: Screenshot of Ohio StreamStats showing delineated watershed

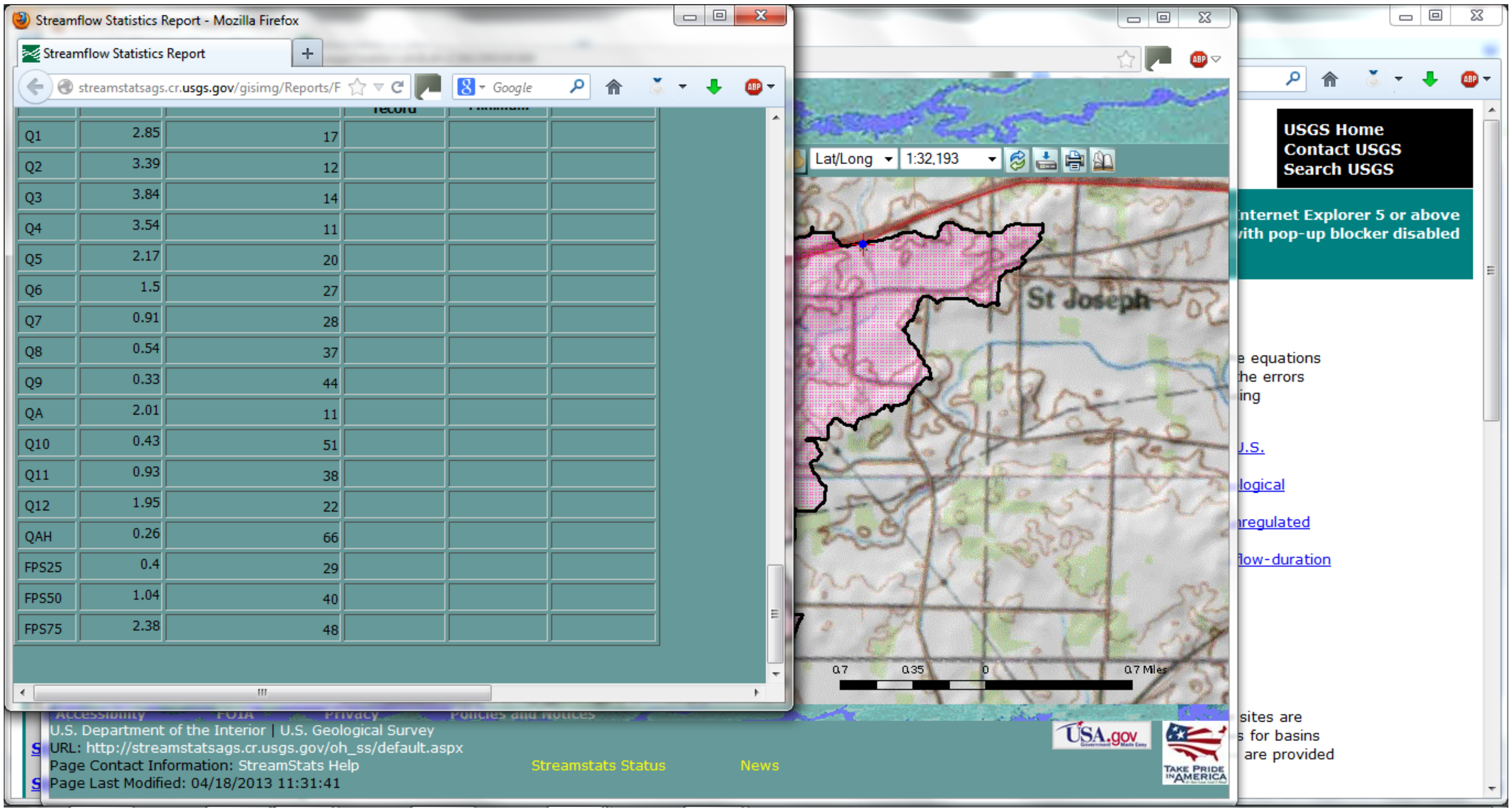

Fig. F.5: Screenshot of Ohio StreamStats giving output of flow values

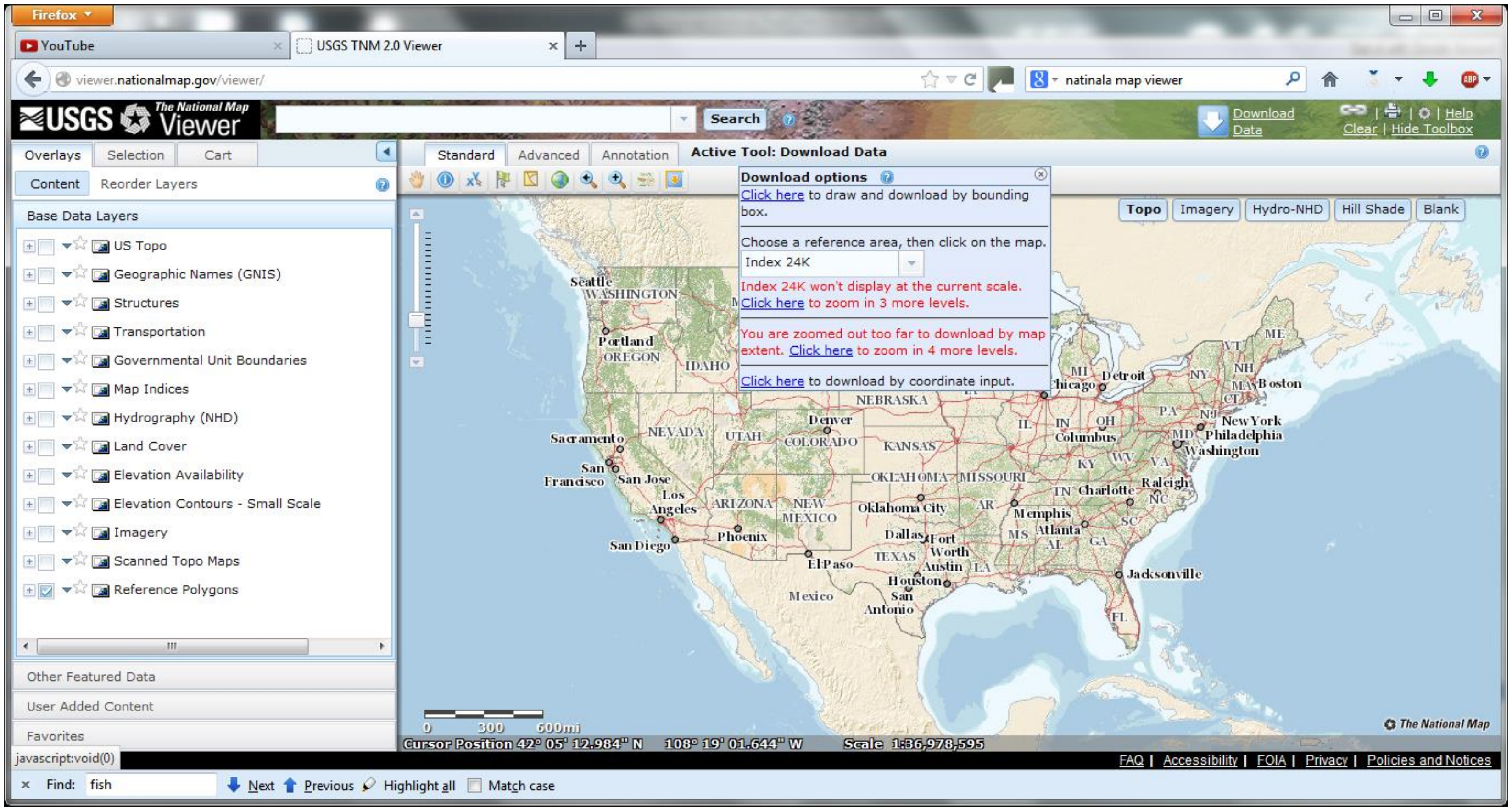

Fig. F.6: Screenshot of USGS TNM viewer showing the download options

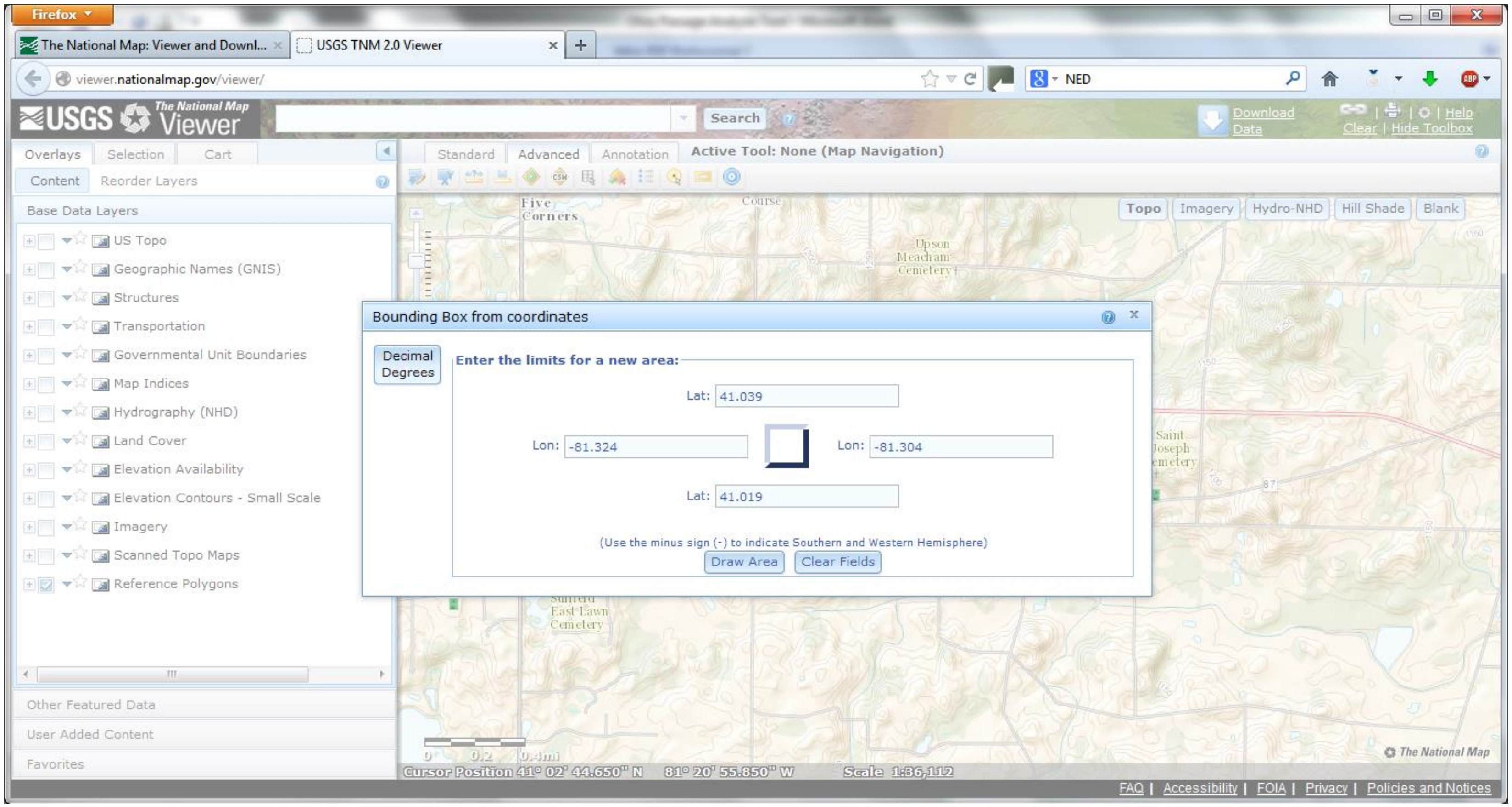

Fig. F.7: Screenshot of USGS TNM viewer asking user to input the coordinates of the limits of area of interest

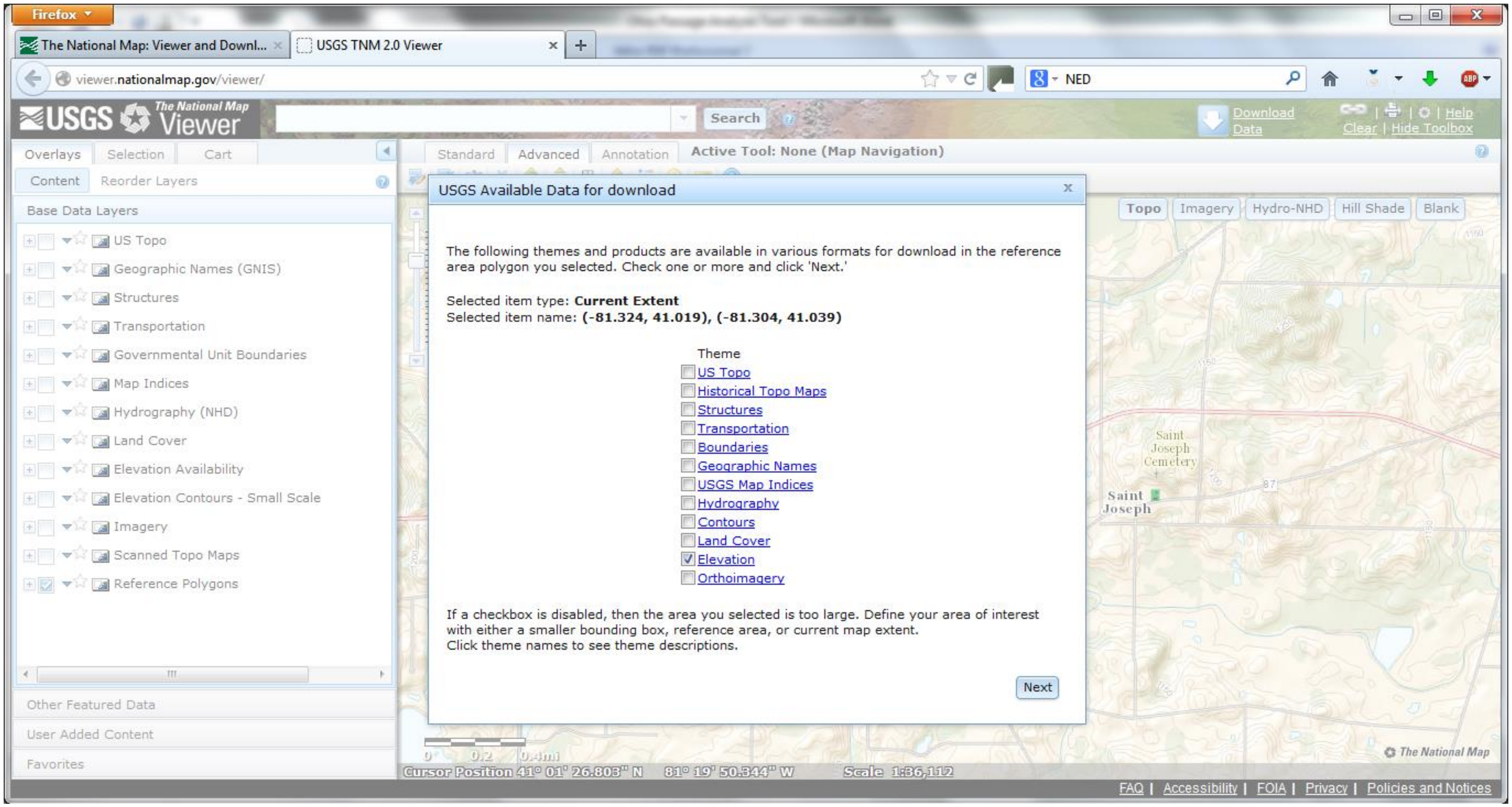

Fig. F.8: Screenshot of USGS TNM viewer showing data available for download

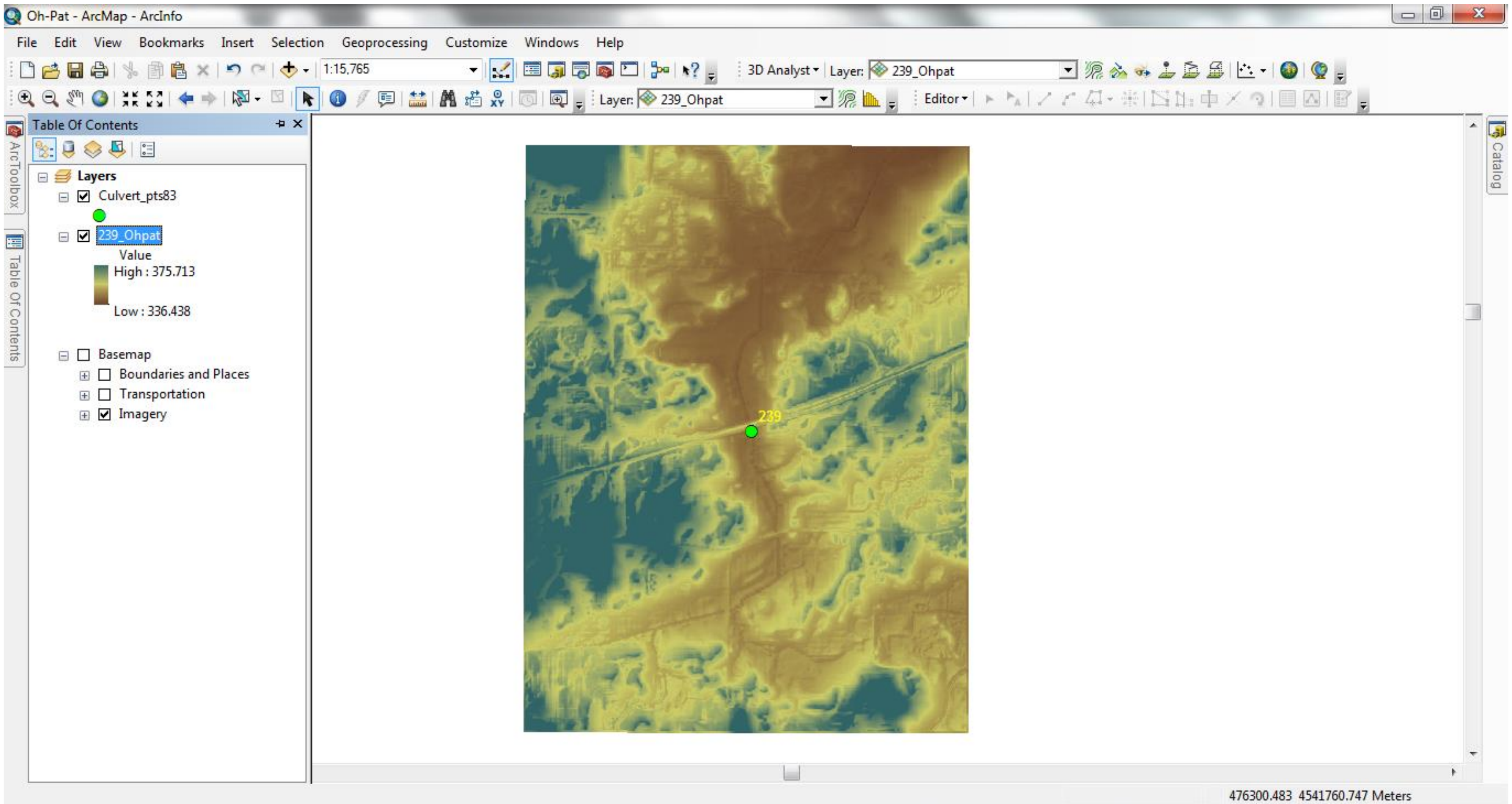

Fig. F.9: Screenshot of ArcMap showing the downloaded DEM under the culvert point

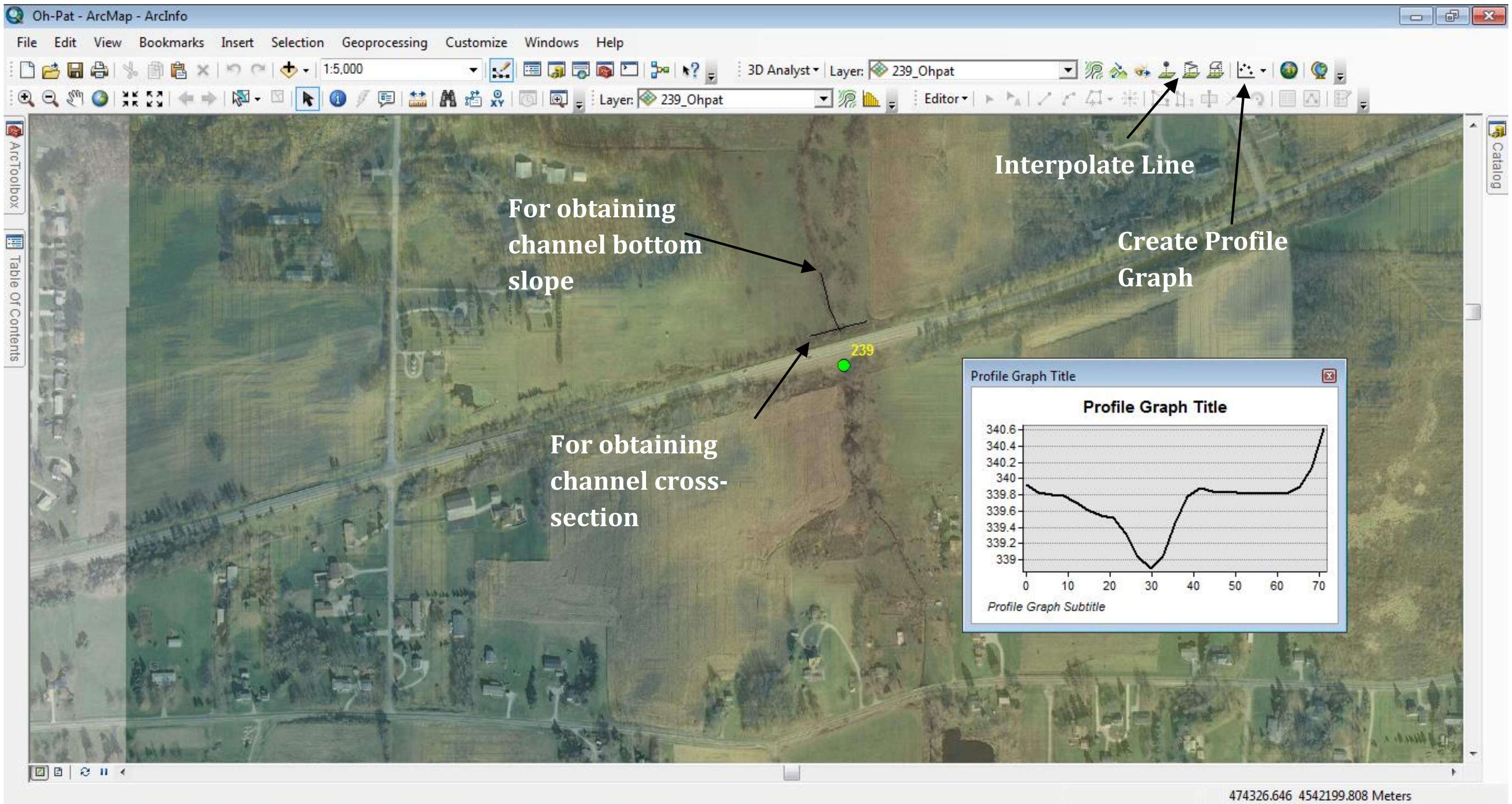

Fig. F.10: Screenshot of ArcMap showing the interpolate lines to download cross section and channel bottom slope

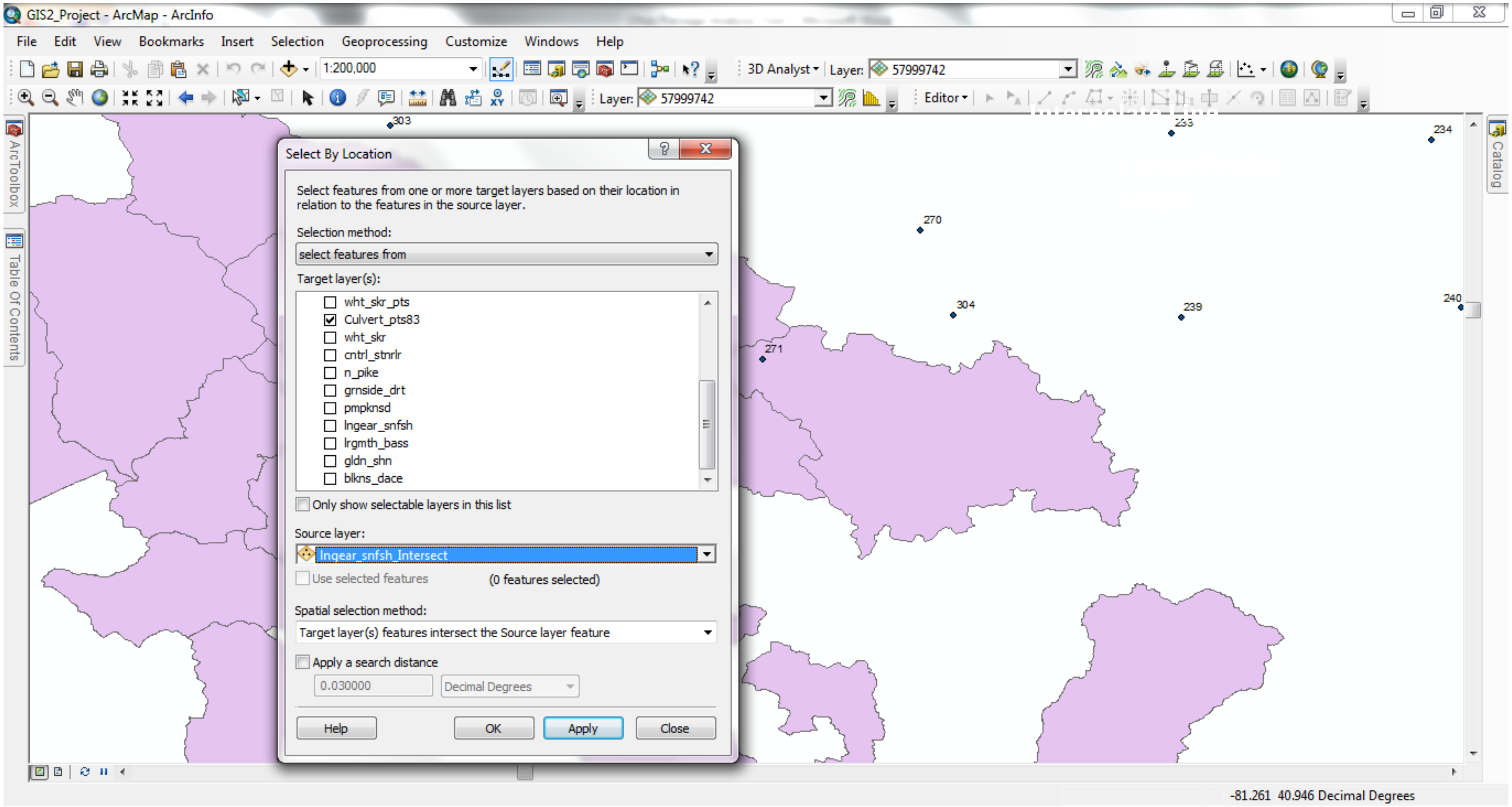

Fig. F.11: Screenshot of ArcMap showing a 'Select By Location'

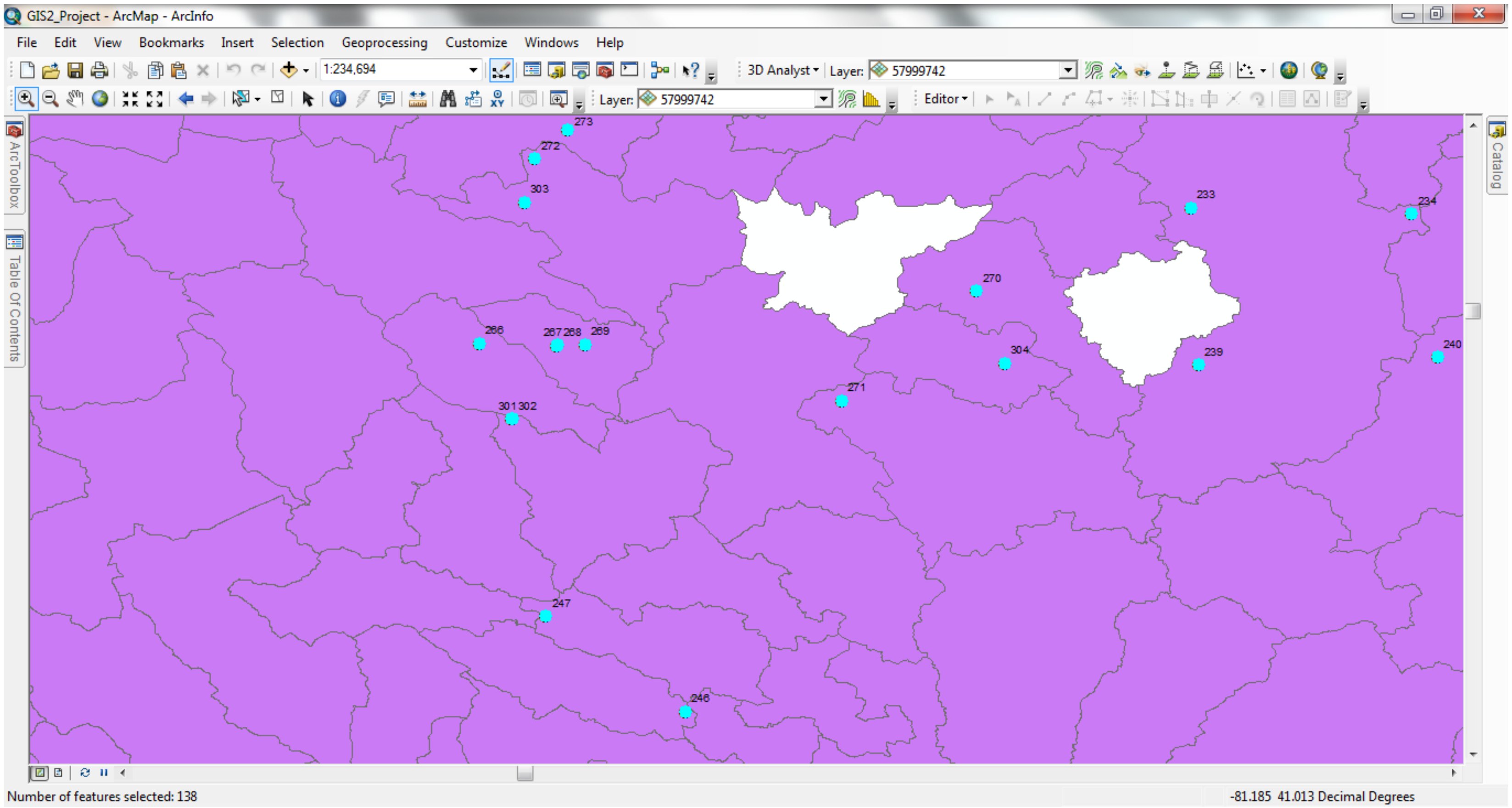

Fig. F.12: Screenshot of ArcMap showing polygon layer for golden shiner under culvert points

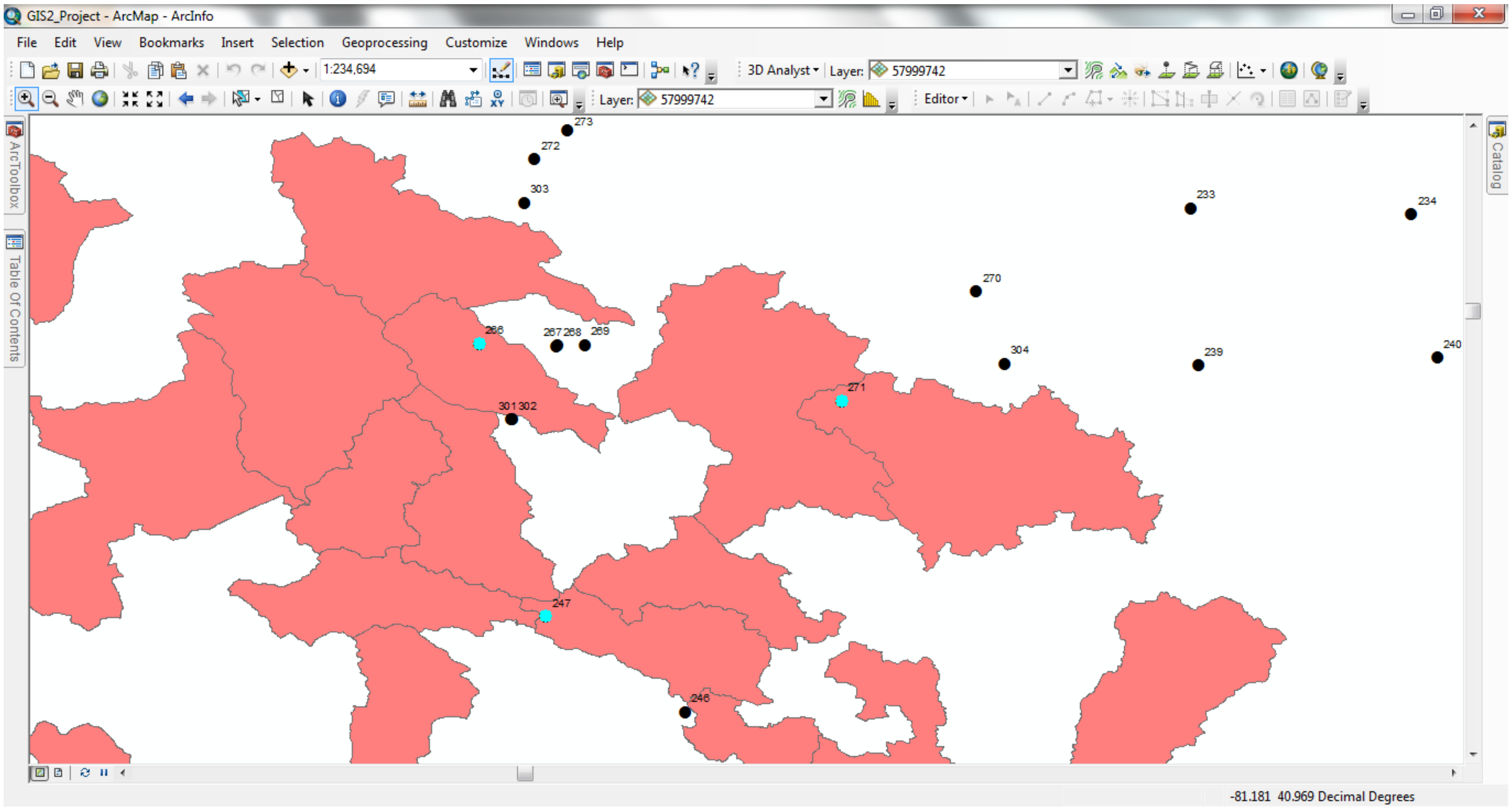

Fig. F.13: Screenshot of ArcMap showing polygon layer for longear sunfish under culvert points

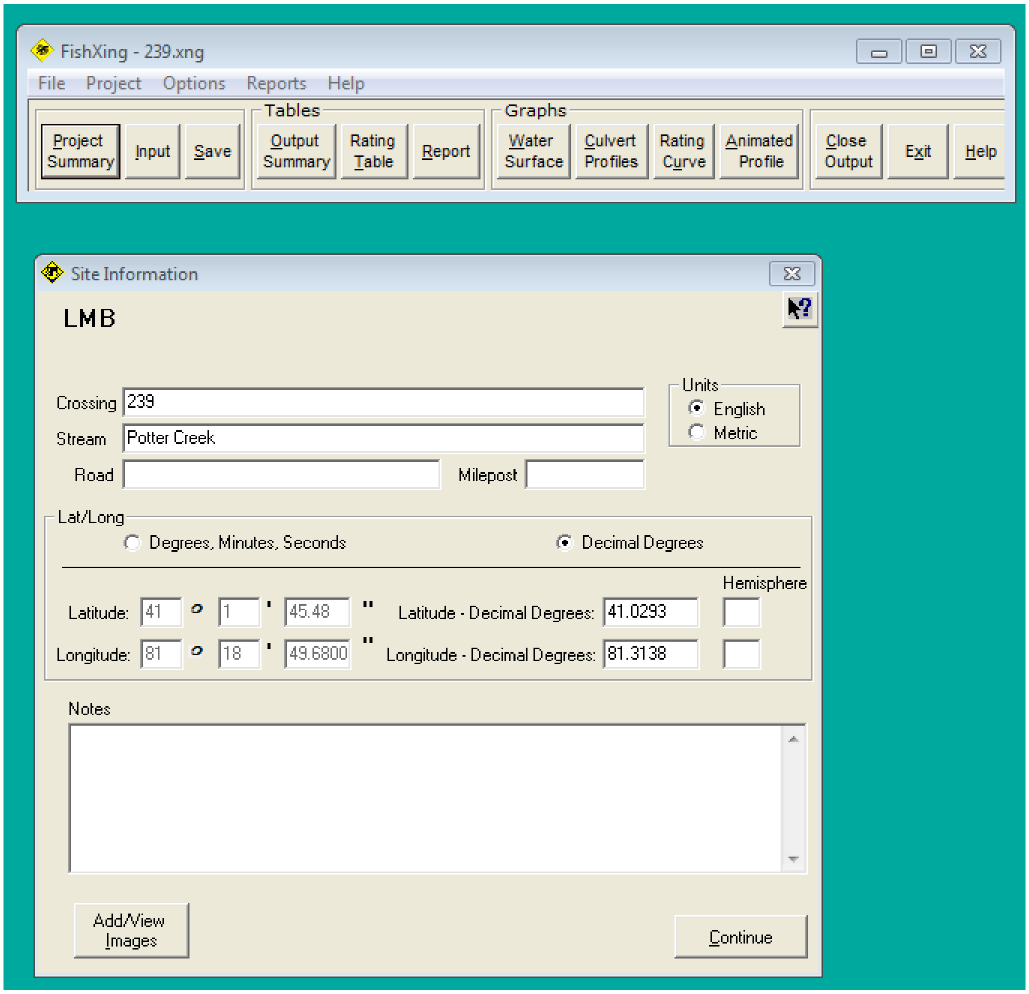

Fig. F.14: Screenshot of FishXing 'Site Information' window

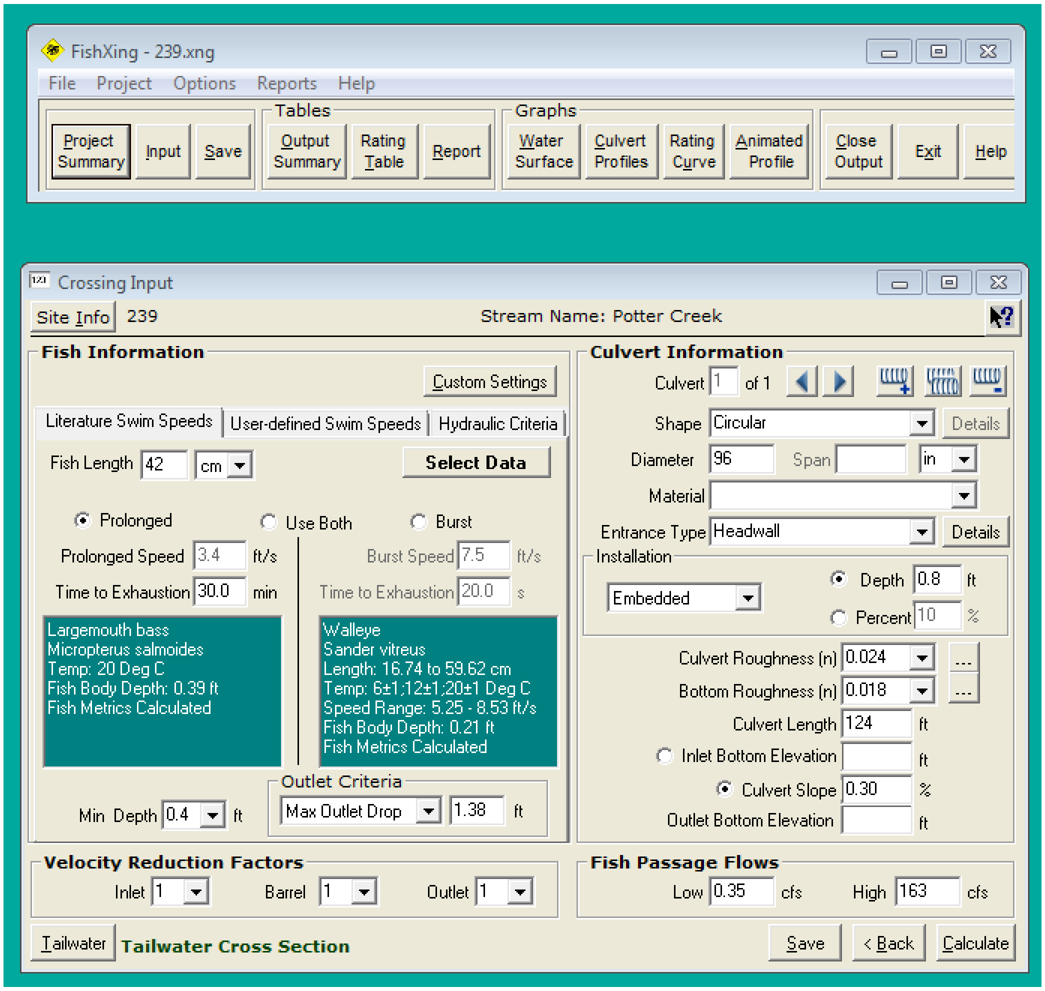

Fig. F.15: Screenshot of FishXing 'Crossing Input' window

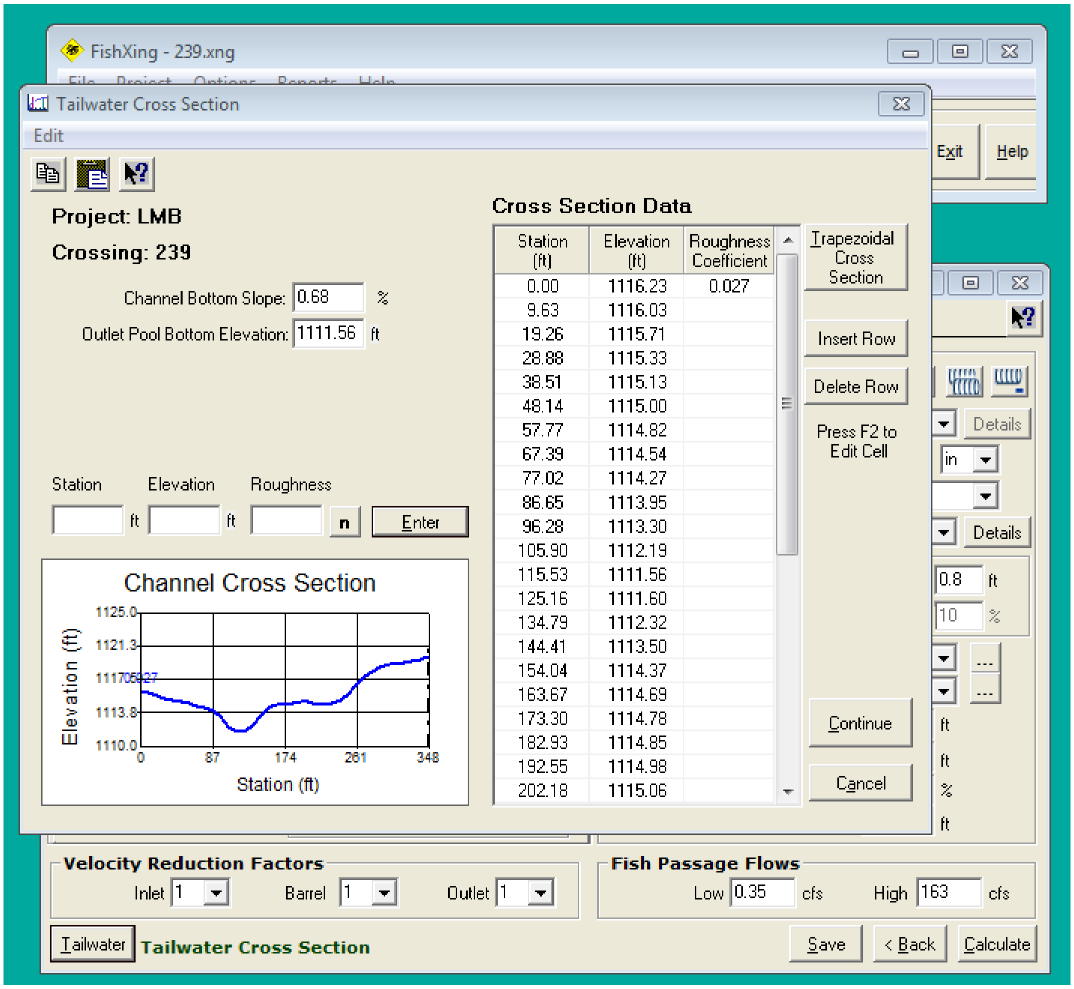

Fig. F.16: Screenshot of FishXing 'Tailwater Cross-Section' window

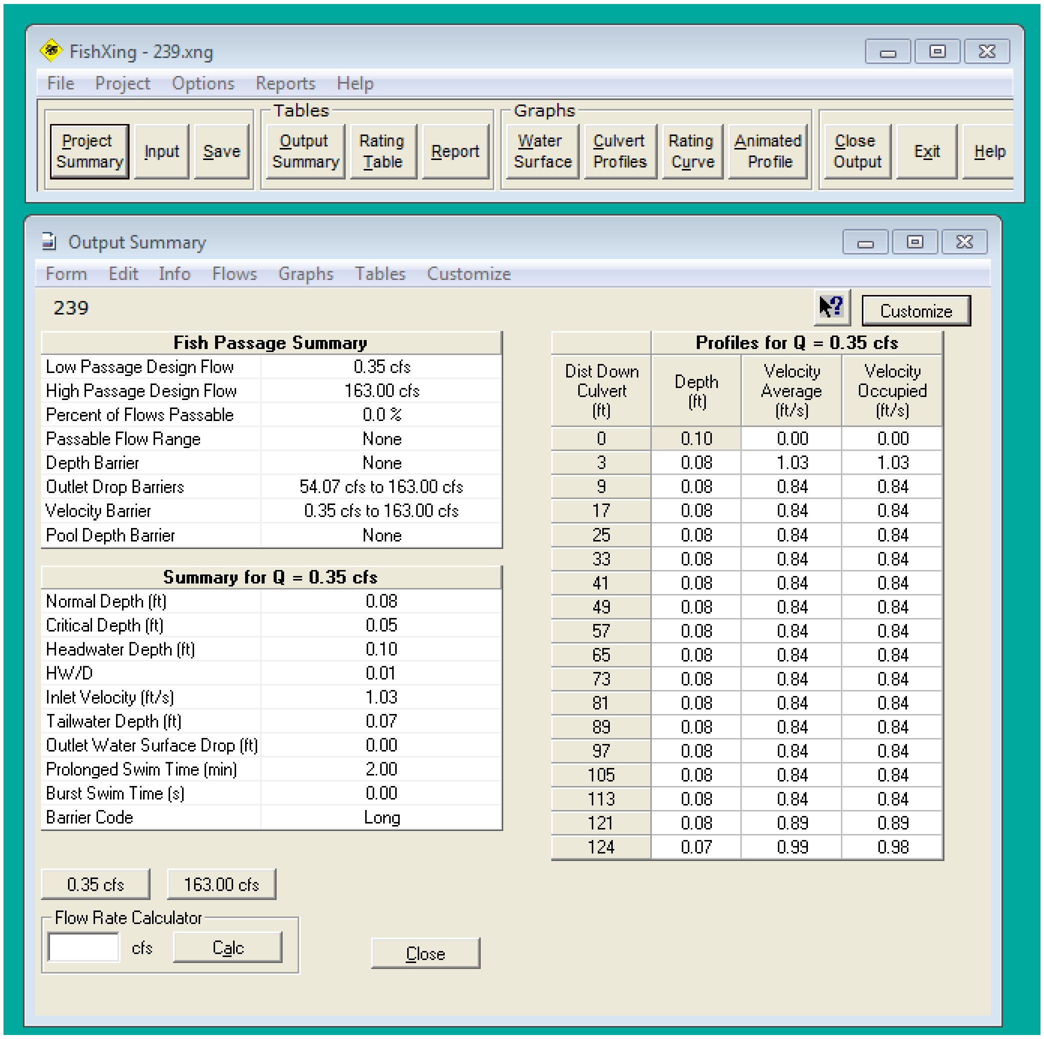

Fig. F.17: Screenshot of FishXing output

Appendix G (Field Books)

BRING FLASHLIGHT NEXT TIME
AND CAMERA

Date: 06/15/2012

SN 74		GPS SN A04
Latitude / Longitude		
Shape	CIRCULAR	
Diameter (in)	41 / 42	
Length (ft)		
Slope (ΔH)	Spirit level	7cm/4ft |
	Laser level	|
Material	CONCRETE	
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: | Outlet:	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

SN 331 / Not Stream		GPS SN
Latitude / Longitude		
Shape	CIRCULAR	
Diameter (in)	36	
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material	CONCRETE	
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: | Outlet:	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

Date: 06/15/2012

SN SKIPPED #93		GPS SN
Latitude / Longitude		
Shape		
Diameter (in)		
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material		
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*
Embedded Depth	Inlet:	Outlet:
Embedded Material	Inlet:	Outlet:
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

SN 333/Not Stream		GPS SN
Latitude / Longitude		
Shape		
Diameter (in)		
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material		
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*
Embedded Depth	Inlet:	Outlet:
Embedded Material	Inlet:	Outlet:
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

Date: 06/15/2012

SN 338		GPS SN C04		
Latitude / Longitude				
Shape	~~ELLIPTICAL~~ CIRCULAR			
Diameter (in)	~~66 long / 42 deep~~ 66"			
Length (ft)	8'1" x27			
Slope (ΔH)	Spirit level	-ve/1.5	0	
	Laser level			
Material	Concrete			
Pool Depth (in)				
Outlet Drop from bed (in)	38" / 10" from ~~pool to~~ water			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*		
Embedded Depth	Inlet:	Outlet:		
Embedded Material	Inlet:	Outlet:		
Perched height (in)				
Entrance Type	Projected	Headwall	Wingwall	Mitered

SN 210		GPS SN D04		
Latitude / Longitude				
Shape	CIRCULAR			
Diameter (in)	90"			
Length (ft)	8'1" x25			
Slope (ΔH)	Spirit level	0.5cm	-ve 0.5cm	
	Laser level			
Material	CONCRETE			
Pool Depth (in)				
Outlet Drop from bed (in)	6" bed / 1 inch water			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*		
Embedded Depth	Inlet:	Outlet:		
Embedded Material	Inlet:	Outlet:		
Perched height (in)				
Entrance Type	Projected	Headwall	Wingwall	Mitered

Date: 06/15/2012

SN 154		GPS SN	004/005
Latitude / Longitude			
Shape	CIRCULAR		
Diameter (in)	120		
Length (ft)	66		
Slope (ΔH)	Spirit level	-ve 1.25cm | +0.5cm	
	Laser level	|	
Material	CORRUGATED METAL		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet: 40%	
Embedded Material	Inlet:	Outlet: Clay	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 149 (No Stream)		GPS SN	
Latitude / Longitude			
Shape	BOX		
Diameter (in)			
Length (ft)			
Slope (ΔH)	Spirit level	|	
	Laser level	|	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: ~~*Yes*~~ / *No*	Outlet: ~~*Yes*~~ / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date: 06/15/2012

SN	147	GPS SN 006
Latitude / Longitude		
Shape	BOX	
Diameter (in)	8 ft wide / 38 in from substrate	
Length (ft)	38' 4"	
Slope (ΔH)	Spirit level	|
	Laser level	|
Material	CONCRETE	
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: Clay | Outlet: Clay	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

SN	137 / No water	GPS SN
Latitude / Longitude		
Shape		
Diameter (in)		
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material		
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: | Outlet:	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

Date:

SN	138 / No stream	GPS SN
Latitude / Longitude		
Shape		
Diameter (in)		
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material		
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: | Outlet:	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

SN	160 / No stream	GPS SN
Latitude / Longitude		
Shape		
Diameter (in)		
Length (ft)		
Slope (ΔH)	Spirit level	|
	Laser level	|
Material	corrugated metal	
Pool Depth (in)		
Outlet Drop from bed (in)		
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*	
Embedded Depth	Inlet: | Outlet:	
Embedded Material	Inlet: | Outlet:	
Perched height (in)		
Entrance Type	Projected | Headwall | Wingwall | Mitered	

1 ft ~~tall~~ deep by 5 ft wide Date: 06/20/12

SN 70 / has a weird weir		GPS SN:	Photos: 3
Stream	Yes / No		
Shape	Circular		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	74	GPS SN:	Photos: 2
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	42	Height	
Length (ft)	Approx ~~50~~ 25' x 8'		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

DRY / w fish Date:

SN	75	GPS SN:	Photos: 1
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	54	Height	
Length (ft)	25 x 8'		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)	1 ft D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	86	GPS SN:	Photos: 1
Stream	Yes / No		
Shape	Elliptical		
Diameter / Width (in)	104	Height	68
Length (ft)	31 x 6'1"		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	5 in water depth D/S		
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)	4 in D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

1st 6ft section broken

Date:

SN 89		GPS SN:	Photos: 0
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	30	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 326		GPS SN:	Photos: 2
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 327		**GPS SN:**	**Photos:** 2
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	42	**Height**	
Length (ft)			
Slope (ΔH)	**U/S**	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	**Inlet:** *Yes* / *No*	**Outlet:** *Yes* / *No*	
Embedded Depth	**Inlet:**	**Outlet:**	
Embedded Material	**Inlet:**	**Outlet:**	
Perched height (in)			
Entrance Type	**Projected** | **Headwall** | **Wingwall** | **Mitered**		

SN	23	**GPS SN:**	**Photos:** 2
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	48	**Height**	
Length (ft)			
Slope (ΔH)	**U/S**	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	**Inlet:** *Yes* / *No*	**Outlet:** *Yes* / *No*	
Embedded Depth	**Inlet:**	**Outlet:**	
Embedded Material	**Inlet:**	**Outlet:**	
Perched height (in)			
Entrance Type	**Projected** | **Headwall** | **Wingwall** | **Mitered**		

looking D/S pipe is on right.

11" drain drains in middle Date:

SN	98	**GPS SN:**	**Photos:** 2
Stream	***Yes*** / ***No***		
Shape	CIRCULAR		
Diameter / Width (in)	66	**Height**	
Length (ft)	22 x 8'		
Slope (ΔH)	**U/S**		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	9in water to bed D/S		
Embedded	**Inlet:** ***Yes*** / ***No***	**Outlet:** ***Yes*** / ***No***	
Embedded Depth	**Inlet:**	**Outlet:**	
Embedded Material	**Inlet:**	**Outlet:**	
Perched height (in)	9in D/S		
Entrance Type	**Projected | Headwall | Wingwall | Mitered**		

Drains woods 4 farm / no fish seen / lots of shrub

SN	102	**GPS SN:**	**Photos:**
Stream	***Yes*** / ***No***		
Shape	CIRCULAR		
Diameter / Width (in)	42	**Height**	
Length (ft)			
Slope (ΔH)	**U/S**		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	**Inlet:** ***Yes*** / ***No***	**Outlet:** ***Yes*** / ***No***	
Embedded Depth	**Inlet:**	**Outlet:**	
Embedded Material	**Inlet:**	**Outlet:**	
Perched height (in)			
Entrance Type	**Projected | Headwall | Wingwall | Mitered**		

Draining a field

Date:

SN 211	211	GPS SN:	Photos: 0
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	54	Height	
Length (ft)			
Slope (ΔH)	U/S		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	212	GPS SN:	Photos: 3
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	72	Height	
Length (ft)	22x8'1"		
Slope (ΔH)	U/S		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet: 2"		
Embedded Material	Inlet: | Outlet: Clay		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Bluegills & minnows D/S Date:

SN	214	GPS SN:	Photos: 2
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	60	Height	
Length (ft)	30 x 8'1"		
Slope (ΔH)	U/S		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	4" bed to water D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	0		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Blockage.

SN	215	GPS SN:	Photos: 2
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S		
	D/S		
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN	216	GPS SN:	Photos: 2
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	54	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)	0		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	220	GPS SN:	Photos:
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	60	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Draining a field

Date:

SN	221	GPS SN:	Photos: 3
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	42	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

NEW CONSTRUCTION

SN	224	GPS SN:	Photos: 3
Stream	*Yes* / *No*		
Shape	CIRCULAR		
Diameter / Width (in)	72	Height	
Length (ft)	28 maybe X 8'1"		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet: Clay		
Embedded Material	Inlet: | Outlet: 10%.		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN	225	GPS SN:	Photos: 2
Stream	*Yes* / *No*		
Shape	Elliptical		
Diameter / Width (in)	82	Height	54
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

D/S & U/S

SN	153	GPS SN:	Photos: 2
Stream	*Yes* / *No*		
Shape	BOX		
Diameter / Width (in)	~~36~~ 48	Height	~~48~~ 36
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN	152	GPS SN:	Photos: 2
Stream	*Yes* / *No*		
Shape			
Diameter / Width (in)	48	Height	
Length (ft)	41.5		
Slope (ΔH)	U/S	5.26 |	
	D/S	5.62 |	
Material	HDPE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet: 1"		
Embedded Material	Inlet: | Outlet: Clay		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	150	GPS SN:	Photos: 2
Stream	*Yes* / *No*		
Shape	BOX		
Diameter / Width (in)	48	Height	38
Length (ft)	30.5		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*		
Embedded Depth	Inlet: | Outlet: 1"		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

→ There's Pond U/S

Date:

SN	151	GPS SN:	Photos: 1
Stream	Yes / No NO movement.		
Shape	CIRCULAR		
Diameter / Width (in)	42	Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	Corru. Metal		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	148	GPS SN:	Photos:
Stream	Yes / No		
Shape	Box		
Diameter / Width (in)	120	Height	44 / Embedded
Length (ft)	42.5		
Slope (ΔH)	U/S	|	
	D/S	|	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

DID IN FISHXING 7/2/12'

Date:

SN	143	GPS SN:	Photos: 2
Stream	Yes / No		
Shape	CIRCULAR		
Diameter / Width (in)	84	Height	
Length (ft)	56		
Slope (ΔH)	U/S	3.88 |	
	D/S	4.365 |	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	8" D/S		
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)	6" D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	142	GPS SN:	Photos: 1
Stream	Yes / No		
Shape	BOX		
Diameter / Width (in)	48	Height	36
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	Concrete		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No | Outlet: Yes / No		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: clay | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN	136	GPS SN:	Photos:
Stream	*Yes / No*		
Shape	ellipse		
Diameter / Width (in)	42	Height	26
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material	Concrete		
Pool Depth (in)			
Outlet Drop from bed (in)	4" bed		
Embedded	Inlet: *Yes / No* | Outlet: *Yes / No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)	18" |		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN		GPS SN:	Photos:
Stream	*Yes / No*		
Shape			
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S	|	
	D/S	|	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes / No* | Outlet: *Yes / No*		
Embedded Depth	Inlet: | Outlet:		
Embedded Material	Inlet: | Outlet:		
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date: 06/25/12

SN 4	Photos 3/First 2 U/S & D/S
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	66 | Height
Length (ft)	30 x 8' 1"
Slope (ΔH)	U/S D/S
Material	
Pool Depth (in)	1" in D/S
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	2" in D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 32	Photos 3
Remarks	corrugated Metal/Rusted on bottom/ Dry with scour pool/No fish seen.
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	26 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	corrug. metal
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 34	Photos 4
Remarks	
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	54 | **Height**
Length (ft)	6x 8'2"
Slope (ΔH)	U/S 7·46'+21" D/S 7·9'+22"
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	2" in D/S
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	1" in D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 39	Photos 3
Remarks	
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	42 | **Height**
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 40	Photos 7 8
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	48 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	18" D/S
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	38" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 367	Photos 4
Remarks	Large concrete PAD in D/S perched 7" D/S | should not pass fish because of perchedness
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	70 | Height
Length (ft)	81'9"
Slope (ΔH)	U/S 4.14 D/S 5.14
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	1" D/S
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	9" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 47	Photos 2		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	36	Height	
Length (ft)	61'		
Slope (ΔH)	U/S 8.01'	D/S 9.1'	
Material	HDPE CORRUGATED		
Pool Depth (in)			
Outlet Drop from bed (in)	8" D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	26" D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 48	Photos		
Remarks Measure length in GIS.	Inlet collects water 3 ways → MAYBE NO.		
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	4" D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	14" D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 30	Photos 3
Remarks	
Stream	Yes / No
Shape	BOX
Diameter / Width (in)	10' | Height 8'
Length (ft)	3 x 8' 1"
Slope (ΔH)	U/S 3.82' D/S 4.77'
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	4" D/S
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	1' D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 31	Photos 1
Remarks	
Stream	Yes / No
Shape	BOX
Diameter / Width (in)	9.5' | Height 2'
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 58	Photos 2 in D/S
Remarks	GIANT LAKE D/S
Stream	Yes / No
Shape	CIRCULAR
Diameter / Width (in)	36 | Height
Length (ft)	57.5'
Slope (ΔH)	U/S 4.84' D/S 5.36'
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	0" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 59	Photos 2
Remarks	GIANT LAKE D/S
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	42' | Height
Length (ft)	69.7'
Slope (ΔH)	U/S 6.19' D/S 6.97'
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	1" D/S
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	0" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 28	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	60 | Height
Length (ft)	11 X 8'
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	5" D/S
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	7" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 27	Photos 1
Remarks	Pond ~~?~~ D/S Backed up into culvert, so stream starts?
Stream	*Yes* / *No*
Shape	BOX
Diameter / Width (in)	5' | Height 50"
Length (ft)	
Slope (ΔH)	U/S D/S
Material	
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 356	Photos 2		
Remarks	whitish water		
Stream	Yes / No		
Shape	circle		
Diameter / Width (in)	28	Height	
Length (ft)	40		
Slope (ΔH)	U/S 8.25'	D/S 7.84'	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	0		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 320	Photos 1		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	54	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet: 12"	
Embedded Material	Inlet:	Outlet: Clay	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Maybe

Date:

SN 69	Photos 2		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	9x12	Height	
Length (ft)			
Slope (ΔH)	U/S		D/S
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet: Gravel	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 205	Photos ~~8~~ 2		
Remarks	Deep Bowl		
Stream	Yes / No		
Shape			
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S		D/S
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date: 6/27/12

SN 70	Photos
Remarks	Already visited before. Has a weir like str. Should not pass fish.
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 344	Photos 2
Remarks	Drains field
Stream	*Yes* / *No*
Shape	
Diameter / Width (in)	54 Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 357	Photos 3
Remarks	
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	36 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	VITRIFIED CLAY
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 125	Photos 1
Remarks	
Stream	*Yes* / *No*
Shape	
Diameter / Width (in)	52 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR HDPE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 122	Photos 2
Remarks	
Stream	Yes / No
Shape	D/S U/S
Diameter / Width (in)	26/22 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	Metal Not Corrugated D/S
Pool Depth (in)	Corr HDPE in U/S
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 123	Photos 3
Remarks	
Stream	Yes / No
Shape	
Diameter / Width (in)	24 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 19	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	48 | Height
Length (ft)	21.5' + 41.8' + 21.0'
Slope (ΔH)	U/S 10.42' D/S 10.96'
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 364	Photos 3
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	62" | Height
Length (ft)	86.7'
Slope (ΔH)	U/S 5.93' D/S 6.66'
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	11" D/S
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet: 2"
Embedded Material	Inlet: | Outlet: Clay
Perched height (in)	0"
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 365	Photos 3		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)	88'		
Slope (ΔH)	U/S 9.06'	D/S 9.11'	
Material	CORR. METAL		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet: 17"	Outlet: 17"	
Embedded Material	Inlet: Clay	Outlet: Clay	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 373	Photos 3		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)	0" D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	1' D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 242	Photos 2
Remarks	DRY / Looks like must be a river
Stream	*Yes / No*
Shape	
Diameter / Width (in)	Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes / No* | Outlet: *Yes / No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 362	Photos 3
Remarks	
Stream	*Yes / No*
Shape	CIRCLE
Diameter / Width (in)	80" Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	12" D/S
Embedded	Inlet: *Yes / No* | Outlet: *Yes / No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	0
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 237	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	48 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR.
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 236	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	68 | Height
Length (ft)	22x8' 1"
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	4" D/S
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	10" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

Maybe Not

Date:

SN 235	Photos 2		
Remarks			
Stream	*Yes* / *No*		
Shape	CIRC		
Diameter / Width (in)	18	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR.		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 235	Photos 2		
Remarks	Some creek chub seen.		
Stream	*Yes* / *No*		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR		
Pool Depth (in)			
Outlet Drop from bed (in)	7" D/S		
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	0		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 233	Photos 2
Remarks	
Stream	*Yes* / *No*
Shape	CIRCLE
Diameter / Width (in)	36" | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	50% roughly
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 239	Photos 3
Remarks	
Stream	*Yes* / *No*
Shape	CIRC
Diameter / Width (in)	96 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR MET
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: 7" | Outlet: 9"
Embedded Material	Inlet: clay | Outlet: Clay
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 240	Photos 1		
Remarks			
Stream	*Yes* / *No*		
Shape	CIRC		
Diameter / Width (in)	60	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR.		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet: 3"	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	Photos		
Remarks			
Stream	*Yes* / *No*		
Shape			
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date: 6/28/12

SN 270	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	58 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCRETE
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: 7" | Outlet:
Embedded Material	Inlet: Gravel | Outlet:
Perched height (in)	0"
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 300	Photos 3
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	60 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	0"
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 296	Photos 3
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	60 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	~~CONCR~~ CORR. METAL
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 295	Photos 3
Remarks	Dam is present in U/S forming a lake. 26" high stopping structure.
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	66 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR MET
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 290	Photos 3		
Remarks	very Deep.		
Stream	Yes / No		
Shape	CIRC		
Diameter / Width (in)	~~90~~ 84	Height	
Length (ft)	47X2'		
Slope (ΔH)	U/S	D/S	
Material	CORR METAL		
Pool Depth (in)			
Outlet Drop from bed (in)	8" D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet: 1"	Outlet:	
Embedded Material	Inlet: Gravel	Outlet:	
Perched height (in)	16" D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 287	Photos 4		
Remarks	should not pass fish		
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	66" D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 279	Photos 2		
Remarks			
Stream	Yes / No		
Shape	CIRC		
Diameter / Width (in)	54	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CORR METAL		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 280	Photos 1		
Remarks	Fish Seen		
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	60	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CORRMETAL		
Pool Depth (in)			
Outlet Drop from bed (in)	12" D/S		
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 281	Photos
Remarks	
Stream	Yes / No
Shape	CIRC
Diameter / Width (in)	46 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	10" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

279

SN 278	Photos 2 + 1 of D/S in intersection
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	42 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	14" D/S
Embedded	Inlet: *Yes* / *No* | Outlet: *Yes* / *No*
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	6" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 285	Photos 3		
Remarks			
Stream	Yes / No		
Shape	CIRC		
Diameter / Width (in)	96	Height	
Length (ft)	36 x 10'		
Slope (ΔH)	U/S	D/S	
Material	CORR METAL		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet: 3"	Outlet: 3"	
Embedded Material	Inlet: Concrete	Outlet: Concrete	
Perched height (in)	1' D/S		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 274	Photos		
Remarks			
Stream	Yes / No		
Shape	CIRCLE		
Diameter / Width (in)	42	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: Yes / No	Outlet: Yes / No	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 273	Photos 1
Remarks	
Stream	Yes / No
Shape	CIRC
Diameter / Width (in)	48 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	either D/S
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: 20" | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 266	Photos 2
Remarks	
Stream	Yes / No
Shape	CIRC
Diameter / Width (in)	48 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CONCR
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 269	Photos 3		
Remarks			
Stream	Yes / No		
Shape	CRC		
Diameter / Width (in)	92	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	0		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	Photos		
Remarks			
Stream	*Yes* / *No*		
Shape			
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date: 6/29/12

SN 301	Photos 1
Remarks	There's another in line seperator This ends and another begins
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	42 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	
Entrance Type	Projected | Headwall | Wingwall | Mitered

SN 247	Photos
Remarks	
Stream	Yes / No
Shape	CIRCLE
Diameter / Width (in)	60 | Height
Length (ft)	
Slope (ΔH)	U/S D/S
Material	CORR METAL
Pool Depth (in)	
Outlet Drop from bed (in)	
Embedded	Inlet: Yes / No | Outlet: Yes / No
Embedded Depth	Inlet: | Outlet:
Embedded Material	Inlet: | Outlet:
Perched height (in)	37" D/S
Entrance Type	Projected | Headwall | Wingwall | Mitered

Date:

SN 249	Photos 3				
Remarks					
Stream	Yes / No				
Shape	CIRCLE				
Diameter / Width (in)	96	Height			
Length (ft)	29 X 8'				
Slope (ΔH)	U/S		D/S		
Material	CONCRETE				
Pool Depth (in)					
Outlet Drop from bed (in)					
Embedded	Inlet: Yes / No		Outlet: Yes / No		
Embedded Depth	Inlet:		Outlet:		
Embedded Material	Inlet:		Outlet:		
Perched height (in)	14" D/S				
Entrance Type	Projected	Headwall	Wingwall	Mitered	

SN 248	Photos 2				
Remarks					
Stream	Yes / No				
Shape	CIRCLE				
Diameter / Width (in)	84	Height			
Length (ft)					
Slope (ΔH)	U/S		D/S		
Material	CONCR				
Outlet Drop from bed (in)	~~#~~ 11" D/S				
Pool Depth (in)					
Embedded	Inlet: Yes / No		Outlet: Yes / No		
Embedded Depth	Inlet:		Outlet:		
Embedded Material	Inlet:		Outlet:		
Perched height (in)	0"				
Entrance Type	Projected	Headwall	Wingwall	Mitered	

Date:

SN 262	Photos 2		
Remarks			
Stream	*Yes* / *No*		
Shape	CIRCLE		
Diameter / Width (in)	72	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet: 11"	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN 264	Photos 2		
Remarks			
Stream	*Yes* / *No*		
Shape	CIRC		
Diameter / Width (in)	60	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCR		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)	0"		
Entrance Type	Projected | Headwall | Wingwall | Mitered		

Date:

SN 230	Photos 2		
Remarks			
Stream	*Yes* / *No*		
Shape	CIRCLE		
Diameter / Width (in)	48	Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material	CONCRETE		
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		

SN	Photos		
Remarks			
Stream	*Yes* / *No*		
Shape			
Diameter / Width (in)		Height	
Length (ft)			
Slope (ΔH)	U/S	D/S	
Material			
Pool Depth (in)			
Outlet Drop from bed (in)			
Embedded	Inlet: *Yes* / *No*	Outlet: *Yes* / *No*	
Embedded Depth	Inlet:	Outlet:	
Embedded Material	Inlet:	Outlet:	
Perched height (in)			
Entrance Type	Projected | Headwall | Wingwall | Mitered		