Determining Spawning Occurrence and Reproductive Potential of Shenango River Lake Walleye

by

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Abstract

The objective of this project was to achieve an assessment of walleye (*Sander vitreus*) spawning through the collection of eggs and physico-chemical data in the Shenango River, from the Shenango River Lake extending upstream approximately 24 river kilometers. It is generally thought that successful spawning of walleye in Pennsylvania is nearly non-existent, but the research to support this is limited. The data collected during sampling included river depth, flow velocity, water temperature, dissolved oxygen, pH, and river substrate content. This data will provide a baseline for future studies of the Shenango River and similar fisheries. This information was compared with that of other studies on walleye spawning habitat to establish a Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI). Walleye spawning attempts by Shenango River Lake walleye in the Shenango River was confirmed by this study. The WSQHEI appeared unsuitable for predicting walleye spawning in the Shenango River. Physico-chemical data displayed minimal gradients, which limited the development and effectiveness of the WSQHEI. This occurred because sampling was restricted to areas conducive to walleye spawning based upon literature of known environmental variables. Although walleye spawning activity was unrelated to environmental conditions among sites, migration distance was negatively correlated with walleye spawning activity. Sampling in 2008 and 2009 indicated that spawning occurrence decreased as distance from Shenango River Lake increased. The WSQHEI could be useful for baseline assessments when little or no data are available about the walleye spawning activities in a lotic system.

Chapter 1
Introduction

Shenango River Lake was constructed by the US Army Corps of Engineers in 1965 for flood control and recreation. The lake is located in Mercer County, Pennsylvania and has a drainage area of approximately 1525 km^2 (USACE 2001). It has supported a healthy fishery, including walleye and muskellunge, through substantial annual stockings. Shenango River Lake has received a total in excess of 250,000 walleye fingerlings (length $\geq$ 2 inches) and 104,410,000 walleye fry (length $\leq$ 1 inch) since 1992 (PAFBC 2007). Successful walleye spawning in the Shenango River may be possible, because favorable juvenile conditions likely exist or the stocking of walleye fingerlings would not be successful.

Protecting and improving spawning and nursery habitat throughout Shenango River Lake would increase in importance if even moderate densities of eggs were found to be present. However, if stocked fry survive well, but walleye do not successfully spawn, then river water quality, spawning substrate suitability, predation, fungal infestation, or sedimentation leading to smothering are all possible causes for reduced egg hatching success (Auer and Auer 1990).

The Pennsylvania Fish and Boat Commission have stocked large numbers of juvenile walleye throughout the state each year since 1975 (Lorantas et al. 2005). It is not known to what extent these fish are being recruited or if natural reproduction plays any role because research in this area is lacking (2007 personal communication from Anderson PAFBC; unreferenced, see “Notes”). It is possible that the stocked fish have a very low survival rate due to predation, lack of zooplankton prey when introduced, and/or other factors. Some fish harvested by anglers may result from natural reproduction rather than stocking efforts if spawning occurs in the Shenango River and the necessary habitat is present. If this is true, then it might be more advantageous to protect and enhance critical spawning habitat rather than to continue to intensively stock walleye. Previous studies have attempted to determine walleye spawning incidence for similar reasons in other watersheds, but differentiating between stocked and wild juvenile walleye negatively impacted results (Schramm et al. 2004, Dustin et al. 2003). The hatchery-raised juvenile walleye that are currently being stocked into Shenango River Lake could be used to further enhance fisheries elsewhere that must rely exclusively on stocking.

Spawning Requirements

Walleyes broadcast their eggs over gravel substrate at night in shallow riffle areas (Palmer et al. 2005) with substrate diameters of 2.5 to 15 cm being optimal for embryo survival (McMahon et al. 1984). Substrates of sand or detritus (organic matter) have been correlated with poor walleye egg survival (Auer and Auer 1990). Gravel and cobble substrates likely increase walleye egg survival because velocity is reduced at the substrate-water interface and more eggs are therefore retained in coarse substrates (Granata et al. 2001).

It is also reasonable to surmise that favorable larval conditions within Shenango River Lake, such as adequate plankton abundance and rapidly warming temperatures exist because of the apparent success of the large volume of walleye fry that have been annually stocked into Shenango River Lake. Over 80% of walleye fry survival in Pennsylvania can be attributed to spring zooplankton densities, so lakes with inadequate zooplankton densities are stocked with only fingerlings (Lorantas et al 2005). High river discharge volumes caused by storm events during the hatching period can increase suspended sediments which damage newly hatched larvae (Mion et al. 1998). Discharge velocities of 0.4 m/s to 0.9 m/s are considered optimal for walleye spawning (Lowie et al. 2001, McMahon et al. 1984).

Dissolved oxygen (DO) levels need to be at least 5 mg/l for embryo development or delayed hatching and reduced size at hatching may occur (McMahon et al. 1984). A high amount of organic debris among the substrate creates anoxic conditions via decomposition, which limits walleye reproductive success (Auer and Auer, 1990). Managing the amount of organic sediment entering the river may prove to be the best strategy for improving reproductive success, if low DO concentrations were found to be the limiting factor in the Shenango River. Additionally, the pH needs to be in the range of 6.0 - 9.0 for egg survival (McMahon et al. 1984).

Laboratory experiments have shown that extreme temperature fluctuations of ±19 °C are lethal to walleye embryos (Schneider et al. 2002). Walleye eggs incubating in natural spawning habitats are almost certainly not going to experience temperature changes great enough to impact hatching success since it is nearly impossible for spring water temperature fluctuations to exceed ±19 °C. Walleye spawn when water temperatures are 7 °C to 10 °C (Johnston 1997) and eggs take 14 to 21 days to hatch in temperatures of 8 to 15 °C (McMahon et al. 1984). Rach et al. (1997) successfully hatched walleye eggs in 10 days while maintaining the water temperature at 12±2 °C. Steadily rising water temperatures usually correspond to strong year-classes of walleyes (Schneider et al. 2002) with a steady increase of at least 0.28 °C/day being associated with the highest survival (McMahon et al. 1984). The warming rate on spawning reefs in Lake Erie ranged from 0.16 °C/day to 0.24 °C/day and egg survival was not significantly reduced during a five year period (Roseman et al. 2006). Walleye eggs that are spawned earliest in the season incubate longer because of the lower water temperatures at the beginning of the spawn and therefore become more susceptible to mortality (Johnston 1997).

Migratory distance to spawning sites has been shown to influence spawning occurrence in salmonids since more energy can be devoted to reproduction if suitable spawning habitat is a relatively short distance rather than expending large amounts of energy to reach spawning habitat (Crossin et al. 2004). Less energy is available for egg production when individuals expend greater amounts of energy to reach suitable spawning habitat (Rideout et al. 2005). Egg number and ovary mass decreases with increasing migration distance (Crossin et al. 2004). This means that the closest suitable spawning sites provide an advantage over farther sites.

Qualitative Habitat Evaluation Indices

Qualitative Habitat Evaluation Indices (QHEI) are used to predict the relevance and impact of various abiotic environmental attributes on particular species (D'Ambrosio et al. 2009, Moir et al. 2005). Although similar to Habitat Suitability Indices (HIS), QHEI's encompass a broader scope of variables and assign a single score to the habitat being assessed (Rankin 2006, Moir et al. 2005). Habitat Suitability Indices were used in a tributary of Chautauqua Lake, NY to assess walleye spawning parameters but varying degrees of suitability within each parameter was not distinguished (Lowie et al. 2001). The QHEI developed for use with this thesis (Appendix) was designed specifically for use with walleye spawning habitat in the Shenango River and similarly sized rivers, although, similar assessments have been developed for walleye in larger Lake Erie tributaries (Anderson et al. 2006, Granata et al. 2001) and for salmon populations globally (Moir et al. 2005, Gibbins et al. 2002). Developing the QHEI used for this thesis was necessary since the assessments used in Lake Erie tributaries were conducted primarily in larger watersheds and were concerned with only a few walleye spawning variables. The salmon spawning assessments were not suitable for use because salmon and walleye spawning conditions vary significantly.

Chapter 2

Materials & Methods

Egg Collection

Eggs were collected with egg mats similar to those used by Manny et al. (2007) in the Detroit River, which incorporated furnace filters and cement blocks placed on the river bottom (Figure 1). The egg mats were attached to shrimp buoys with 0.6 cm nylon rope and placed into the river at suitable locations through wading (Figure 2). The rough and porous surface of the furnace filters trapped the eggs as they floated downstream while still allowing water to circulate around the eggs.

Figure 1 (left) and 2 (right): Egg mats used to collect walleye eggs (left). Installation of egg mats (right) by Jonathan Kinney (on left) and Mike Hamilton (on right) in Lackawannock Creek where walleye spawning was believed to have occurred in previous years through angler observations.

Since wading was chosen as the preferred method of egg mat deployment, the depths of the egg mats were limited to the depth at which wading was possible. Once the water temperature reached approximately 8 °C and hatching of the earliest deposited eggs could have been occurring, surber samplers with 500 µm mesh were used to collect additional eggs and possibly drifting larvae at the sampling sites, since this would also indicate spawning occurrence (Mion et al. 1998, Lowie et al. 2001, Gillenwater et al. 2006).

The egg mats were retrieved by detaching a single egg mat from the buoy and quickly lifting the egg mat into a plastic container to collect any eggs that might fall off while carrying the egg mat back to shore. Some eggs were inevitably lost at the time of removal due to the disturbance created by lifting the egg mat through the water column against the river current. This would have hindered attempts to determine the frequency of spawning at the sampling sites. Once on shore, the egg mats were inspected for the presence of eggs (Figure 3 and 4), which if found were removed with forceps and placed into plastic bottles containing Shenango River water from the egg collection site.

Figure 3: Dr. Shane Smith (right) and fellow graduate student George Reedy (left) inspecting an egg mat and removing the eggs with forceps.

Figure 4: Mike Hamilton removing eggs from an egg mat with forceps.

Sampling Site Locations

In a recent telemetry study conducted on Claytor Lake, Virginia and its primary influent, the New River, a majority of walleyes that reside in the lake throughout the year chose to spawn at the first riffle area above the lake (Palmer et al. 2005). For this reason, the first sampling site was to be located downstream of the Big Bend Access Area at the first riffle above Shenango River Lake. However, limited access to this area, as well as concerns about defining the first riffle, moved the first sampling site to the first tributary large enough for walleye passage. This was Lackawannock Creek approximately 2.3 kilometers (1.4 miles) from the lake (Figure 5). Egg mats were placed in the center of the creek approximately 20 meters downstream and 50 meters upstream of North Bend Road bridge.

The second sampling site was located about 30 meters downstream from the Hamburg Bridge, which is approximately 8.5 kilometers (5.3 miles) from the lake (Figure 5). Egg mats were placed in the center of the river on a gravel bar and in the channel along the east shore. Egg mats were not placed along the west shore because the water was too deep for wading. A small tributary, known as Lawango Run entered the river about 75 meters below the Hamburg Bridge on the east side of the Shenango River, so egg mats were placed in the center of a pool about a meter below the first riffle area upstream from the river in the tributary.

The third sampling site was located at the first riffle area downstream of Kidd's Mill Covered Bridge, which is approximately 17.2 kilometers (10.7 miles) upstream from Shenango River Lake (Figure 5). This portion of the river has ample access with the Shenango Trail on the northeast side and Rutledge Road on the southwest side. Egg mats were placed near the center of the river and in the channel along the west shore. None were placed along the east shore because the river depth was extremely shallow and prevented complete submersion of the egg mats.

The final sampling site was located at the confluence of the Little Shenango River and Crooked Creek, approximately 23.9 kilometers (14.9 miles) from the lake (Figure 5). Egg mats were placed approximately 5 meters from the west shore at a distance of about 20 meters downstream of the confluence. Additional egg mats were placed about 2 meters from the east shore in Crooked Creek. Swift current and depth created unsafe wading conditions and prevented egg mats from being placed downstream or near the middle of the river at this location.

All egg mat placement sites were evaluated prior to sampling to assess the likelihood of walleye spawning. The sites were selected based upon accessibility and the presence of previously stated critical spawning variables such as depth, temperature, DO, and substrate content.

Figure 5: Aerial photo indicating the approximate locations of Lackawannock Creek (A), Hamburg Bridge (B), Kidds Mill Covered Bridge (C), and Greenville (D) sampling sites.

Water Velocity

Velocity of surface current was obtained by measuring the rate of flow over a 3 meter distance at each site using a float (Figure 6). The average velocity of each site (excluding the tributaries) was used to achieve a single velocity for the river that was then used to determine the amount of time required for hatched larvae to reach the assumed nursery habitat in Shenango River Lake because prolonged river residence time has been associated with poor larval survival (Mion et al. 1998).

Figure 6: Jonathan Kinney (left) and Mike Hamilton (right) measuring the velocity of Lawango Run near the Hamburg Bridge site.

Substrate

The substrate was visually assessed prior to sampling and egg mat placement at all locations to ensure that it was suitable for spawning. The substrate assessment area was restricted because the substrate surrounding the egg mats was not ubiquitous throughout the river at each site. Figure 7 was collected as a grab sample adjacent to resting egg mats and only serves as an example of high quality gravel substrate.

Figure 7: A grab sample of high quality walleye spawning substrate at Kidds Mill Covered Bridge adjacent to where egg mats were resting.

Temperature

Walleyes spawn when the water temperature is between about 7 and 10 °C (Lorantas et al. 2005); so sampling was to begin as soon as the water temperature reached 7 °C and continued until it rose to about 11 °C. Temperatures remained in the specified ranges from late-March through late-April in 2008 and 2009, so egg collection and sampling was done once per week throughout this time period until the water temperature reached the maximum of 11 °C (Manny et al. 2007).

Depth

The depth at each site was measured with a meter stick immediately adjacent to where the egg mats were retrieved each week, rather than measuring the depth at the time of placement because the egg mats appeared to have drifted up to a meter in areas with greater current velocities. Depth measurements were acquired by wading into the river, therefore, maximum sampling depths were limited.

River Gradient

Gradient indices were established by incorporating definitions used by the Ohio EPA, which assign values to a stream's gradient, and vary according to drainage area (Rankin 2006). The portion of the Shenango River that was studied has a drainage area of approximately 337 mi² (USGS 2007 Water-Data Report).

The gradient for each site was determined with the use of remotely sensed orthoimage data with a resolution of 1 foot (0.33 m), and lake elevation being at 892 feet (291 m) at the time of photography (PADCNR 2006). ArcGIS 9.3 enabled accurate gradient estimates without field measurements. The elevation closest to one half mile upstream and one half mile downstream from the sampling site was used in most cases, since this provides the best representation of the area (Rankin 2006). Evaluations of stream gradient (Rankin 2006) used topographic maps with contour intervals of ten feet, which reduced the accuracy of the gradient estimates. A one foot contour interval was used in this study to increase accuracy of gradient estimates. Even with one foot contour intervals, the distance used for determining gradient upstream and downstream from the sampling site was occasionally greater than one half mile. This occurred at the Kidds Mill Covered Bridge and Hamburg Bridge sites. While restricting the area used to calculate the gradient to the nearest contour interval upstream and downstream of the sampling site would potentially provide a better gradient estimate, this was not logical in some instances and would result in an inaccurate gradient estimate.

Dissolved Oxygen & pH

Walleye eggs sink to the bottom and incubate within the substrate (Roseman et al. 2002), so DO concentrations were measured as close to the substrate-water interface as possible, since the eggs remain here until they hatch under natural conditions. The substrate-water interface is considered approximately 2 cm above the bottom because this is where the greatest amount of dissolved oxygen depletion occurs (Auer and Auer 1990). DO measurements were taken by attaching a YSI 80 dissolved oxygen/conductivity/temperature meter to a fiberglass pole and holding it just above the substrate until all measurements were recorded (Figure 8). The pH was measured using an Accumet pH meter. A pH meter was not available during the first two weeks of sampling in 2008, which prevented any pH measurements in Lackawannock Creek or Lawango Run.

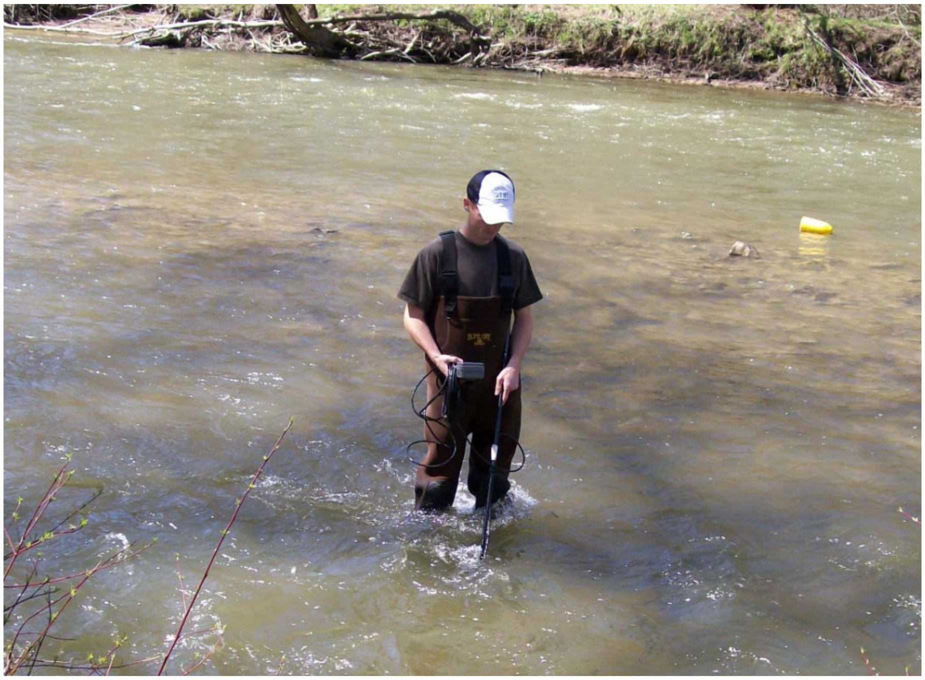

Figure 8: Taking measurements in the Shenango River at the Hamburg bridge site before collecting eggs from the egg mats in the background.

Egg Incubation & Larval Identification

Eggs were placed into containers with Shenango River water and transported in iced coolers back to Youngstown State University laboratories where they incubated for 2-3 weeks until hatching occurred and larvae were positively identified. Water from the collection sites was used to incubate the eggs (Figure 9) because this assures that Shenango River water quality is not limiting successful hatching (Auer and Auer 1990). Also, gamete viability may be compromised due to the accumulation of toxic chemicals in spawning adults (Auer and Auer 1990), so by using walleye eggs collected from the Shenango River Lake walleye population, successful hatching of eggs confirms gamete viability.

Figure 9: The incubation and aeration system that was used to incubate the eggs throughout the course of the study. The discoloration at the bottom of the jars is fungus surrounding the eggs.

Each jar was separated according to collection location; although eggs from each week were not separated. Forced aeration ensured a steady supply of oxygen and kept the water circulating. Fresh Shenango River water was equilibrated to the incubating temperature and then approximately fifty percent of the volume of the incubating jars was exchanged weekly to ensure water quality (Johnston 1997). The jars were checked twice a week for the presence of larvae and to remove dead eggs, which turned milky white and became encased in fungus (Dustin and Jacobson 2003, Roseman et al. 2002). Drawings (Figure 11 and 12) by Faber (2005) and a photo (Figure 10) by Moodie (1989) were used to identify hatched larvae.

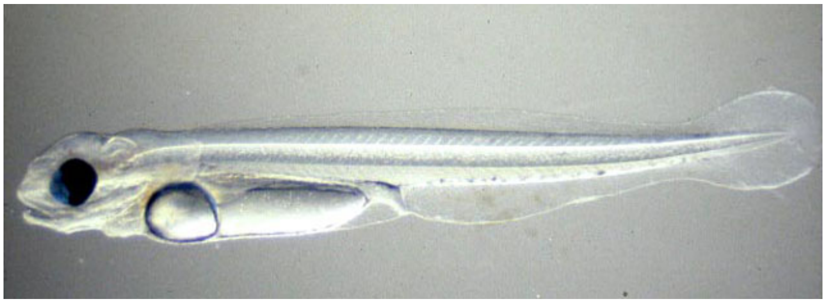

Figure 10: Photo of a Lake Manitoba walleye larva taken by Moodie (1989).

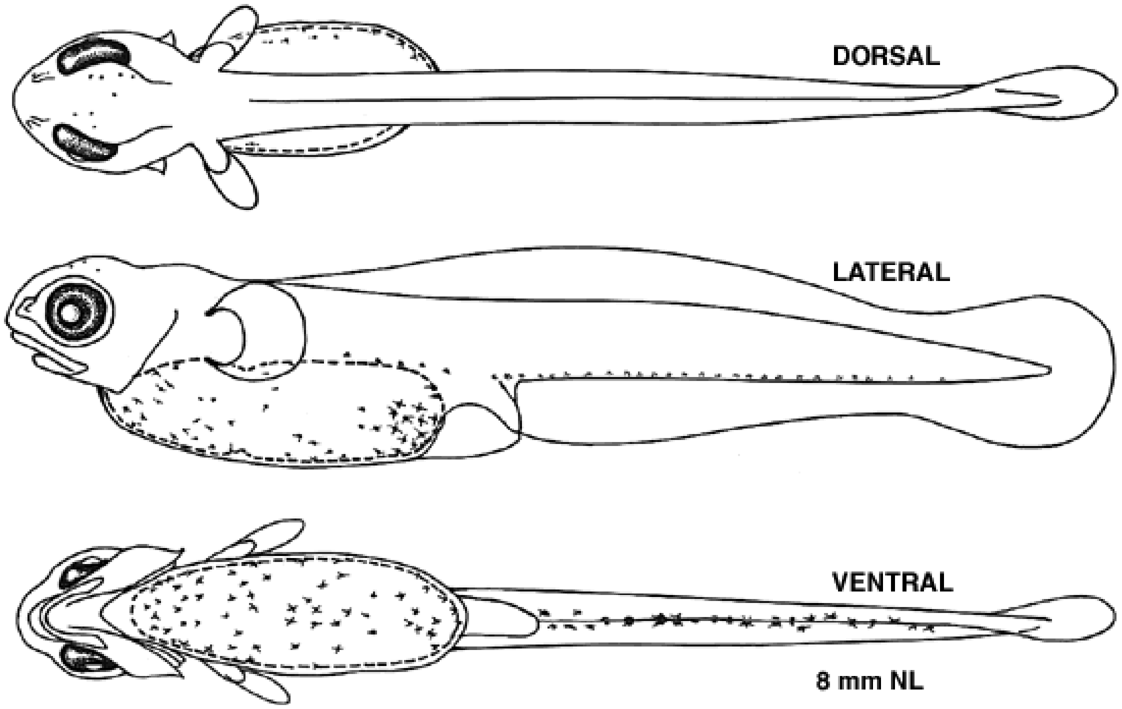

Figure 11: Drawing of walleye larvae by Faber (2005).

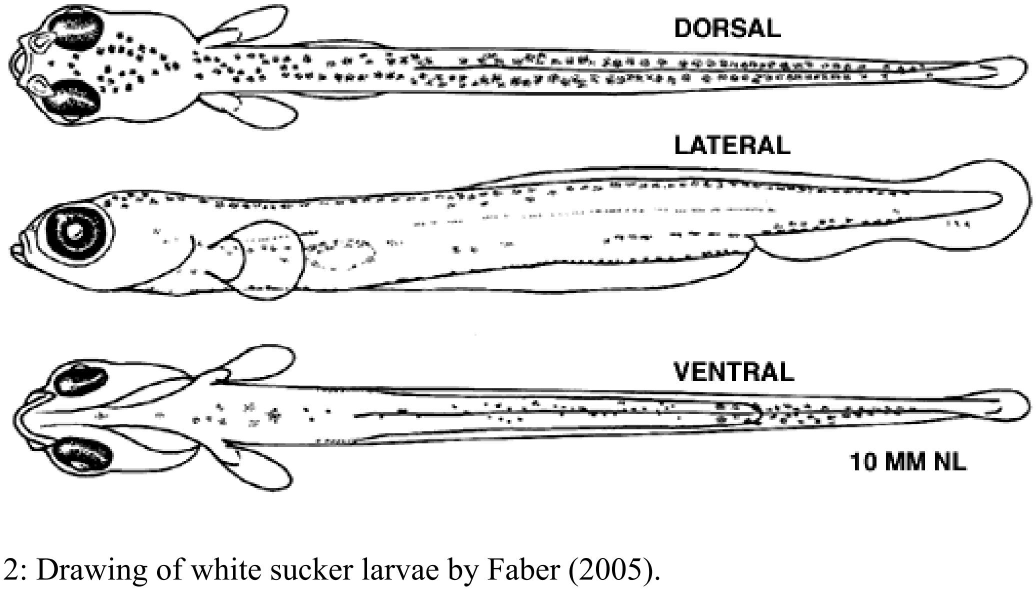

Figure 12: Drawing of white sucker larvae by Faber (2005).

WSQHEI Development

The Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI) (Table 1) adapted from the Ohio EPA QHEI for assessing habitat in flowing waters was used to show a correlation between varying degrees of habitat quality and walleye spawning habitat suitability based upon physical site characteristics at each sampling location. The importance of each characteristic was established through extensive literature review of walleye spawning requirements, as well as field observations in the Shenango River. Actual river measurements are recorded immediately to the right of the "*Range*" column, with each characteristics range being assigned a descriptive assessment in the "*Value*" column. The site evaluation is a reflection of the quality of walleye spawning habitat at that site. It is possible for a site to have high physical suitability but be eliminated as possible spawning habitat if the dissolved oxygen or pH is outside of the acceptable range specified on the WSQHEI. It is also highly unlikely that the site will support successful spawning if any of the variables received a "Poor" rating. The WSQHEI may reflect the presence of suitable walleye spawning habitat even if spawning activity is not documented. The following sections describe each environmental variable evaluated and the categorical rankings in excellent, good, fair, and poor.

Table 1: Proposed WSQHEI for use in the Shenango River to establish the likelihood of walleye spawning.

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site:			
Velocity	*Range*	**Observed**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s		Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*	**Observed**	*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< .06 mm		Poor
Warming Rate	*Range*	**Observed**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**Observed**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m		Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**Observed**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi		Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**Observed**	
Suitable or Unsuitable	≥ 5 mg/L		Required
pH	*Range*	**Observed**	
Suitable or Unsuitable	6.0-9.0		Required

Water Velocity

For the WSQHEI, water velocity measurements from each week were averaged to get one velocity measurement that roughly integrates the velocity experienced at each site throughout the sampling period. There is significant confidence in the average velocity measurements used for the WSQHEI since the recorded velocities from each week did not vary appreciably from week to week or between years. The maximum velocity associated with walleye spawning success is commonly reported as approximately 0.9 m/s (Lowie et al. 2001, McMahon et al. 1984). A velocity up to 1.0 m/s was used for the WSQHEI, since eggs were found at sites with this velocity, the method for measuring velocity was not extremely accurate, and walleye eggs were found in the Sandusky River at 0.95 m/s and the Detroit River at 1.0 m/s (Gillenwater et al. 2006, Manny et al. 2007). Velocity measurements in the range of 0.4 m/s to 1.0 m/s received an "Excellent" rating, 1.1 m/s to 1.2 m/s considered "Fair", and 1.3 m/s or greater were "Poor". Walleyes also spawn in lake environments where the velocity would likely be 0.0 m/s, but since this WSQHEI is being developed for flowing waters, velocities below 0.4 m/s were only rated as "Good" because the potential for sediment deposition increases as velocity decreases in fluvial habitats.

Substrate

Substrate WSQHEI ranges were established using definitions of substrate types based on particle size and a literature review of preferred substrates for spawning walleye (McMahon et al. 1984, Rankin 2006). Some variation in substrate quality was distinguishable between sites. Substrate comprised of primarily gravel or a gravel/cobble mixture of approximately equal parts received an "Excellent" rating. Sampling sites with

≥ 75% cobble received a “Good” rating, sand received a “Fair” rating, and boulders or silt substrates each received a “Poor” rating. The substrate value for each site was based on the area immediately surrounding the location of the egg mats and not the entire cross section of the river at the site. Eggs were successfully collected at sites with high quality substrate in the Shenango River, while sites with poor substrate quality did not yield eggs. This variable appears to be a very influential factor determining walleye spawning site selection, which correlates highly to the rate of hatching success in other studies of walleye and others river spawning species (Nykanen et al. 2002, Dustin et al. 2003). Substrate composition in lakes is also the greatest predictor of walleye spawning occurrence and success, with gravel bottoms associated with the highest success and detritus with poor success and low occurrence (Nate et al. 2003).

Warming Rate

The warming rate is calculated by subtracting the difference in water temperature from the first week to the last week of sampling, then dividing the temperature change by the elapsed time in days. Warming rates of at least 0.28 °C/day have been associated with the highest walleye hatching success and receive an “Excellent” rating. Locations with warming rates in the range of 0.16 °C/day to 0.24 °C/day are suitable and receive a “Good” rating, while any sampling locations below 0.16°C/day are unsuitable and receive a “Poor” rating.

Depth

The depths of the sampling locations recorded from each week were averaged to provide a single depth measurement for the sampling site that was then used for the WSQHEI. A depth range of 0.5-1.8 m was chosen as the optimum depth based on data from McMahon et al. (1984) and receive an “Excellent” rating, while the range of 1.8-8.0 m is suitable, but sub-optimal and receive a “Good” rating (Manny et al. 2007). All depths outside of these ranges were unsuitable for the purposes of the WSQHEI and receive a “Poor” rating. However, as Lowie et al. (2001) found when using and developing a Habitat Suitability Index (HIS) in a Chautauqua Lake, NY tributary, walleyes observed spawning did not have a preference for depth.

Gradient

Based on the drainage area of the Shenango River, the gradient of the river and each sampling location can be used to determine a high or low value, as indicated by the WSQHEI that was developed. If the stream gradient fell within the range of 2.1 to 10.0 ft/mi, the site received a “Good” rating. However, if the site was outside of this range, it received a “Poor” rating.

The gradient metric is potentially important for spawning walleye because streams with gradients below 2.1 ft/mi are likely to have low velocities and greater rates of sediment deposition, which could potentially smother incubating eggs (Auer and Auer 1990). Gradients above 10 ft/mi likely have velocities that are beyond the suitable range for walleye larvae to survive, since velocities increase with increasing stream gradient (Lowie et al. 2001, McMahon et al. 1984). Since this metric is static, meaning that it remains constant for many years, it is of less importance to the WSQHEI for spawning walleye because it cannot account for small scale or short term variances, which often determine the success or failure of spawning walleye.

Dissolved Oxygen & pH

The pH at all sampling sites in the Shenango River were within the suitable range of 6.0-9.0 (McMahon et al. 1984). A pH within this range is a requirement for egg survival and anything outside of this range is considered detrimental to walleye egg survival. Therefore, a pH outside of the range would be unsuitable for walleye spawning regardless of the assessments of the other variables at the site. Dissolved oxygen (DO) was assessed similar to pH because a DO measurement below 5 mg/l would also result in the site being unsuitable for walleye spawning regardless of the other variables at the site (McMahon et al. 1984).

Chapter 3
Results & Discussion

Greenville

As indicated by the WSQHEI (Appendix), the velocity of the Greenville west site was nearly 0.4 m/s slower than the velocity of the Greenville east site. However, the velocity at both sites was within the optimum velocity values associated with spawning site selection, larval survival, and the highest walleye spawning success (Lowie et al. 2001, McMahon et al. 1984).

The substrate at the Greenville east site was comprised of cobble as opposed to the gravel/cobble mixture that was present at the Greenville west site. This difference resulted in a lower WSQHEI value at the east site, since a primarily cobble substrate creates the possibility for eggs to become trapped in the interspatial voids between the rocks where oxygen often becomes depleted because water circulation is restricted (McMahon et al. 1984).

With the confluence of the Little Shenango River and Crooked Creek it was possible to estimate the gradient for both the east and west sampling sites in Greenville separately (Figure 13). The gradient of the Shenango River at the Greenville site was best represented by using the Little Shenango River and the main Shenango River, rather than Crooked Creek since the site characteristics of velocity, temperature, and substrate were most similar to the Little Shenango River. This yielded a gradient of 6.36 ft/mi at the Greenville west site, which was used for the WSQHEI of this site. The gradient above the sampling site in the Little Shenango River is 7.14 ft/mi, still within the acceptable range for walleye spawning of 2.1 to 10.0 ft/mi.

The Greenville east site had a gradient of 8.23 ft/mi, but a gradient of 11.63 ft/mi upstream of the sampling site in Crooked Creek. The 8.23 ft/mi gradient was used for the WSQHEI because it incorporated the gradient of the main Shenango River downstream of the site, although it should be noted that the WSQHEI value would be reduced at locations upstream from the sampling site because the 11.63 ft/mi gradient is outside of the acceptable range for this metric.

This site yielded no eggs in 2009, but did yield a few walleye eggs in 2008. The large abundance of eggs collected at the Greenville east site in 2008 was most likely white suckers rather than walleye because of the high temperatures experienced at this site during sampling. The Greenville west site had temperatures exceeding those associated with walleye spawning activity on April 10th, 2008, possibly due to the influence of Crooked Creek. A below optimum warming rate of 0.22 °C/day at the Greenville west sampling site likely reflected the temperature regime of Crooked Creek rather than the Shenango River and resulted in a lower WSQHEI ranking. However, some of the eggs were spawned by walleye because walleye larvae hatched from this site even with the increased river temperature. This can be explained by the fluctuating temperatures at this site in 2008 and the fact that the egg mats are left in the river for one week before eggs are collected and measurements are taken, providing the opportunity for water temperatures to drop below 10 °C and then rise above 10 °C at the time of sampling.

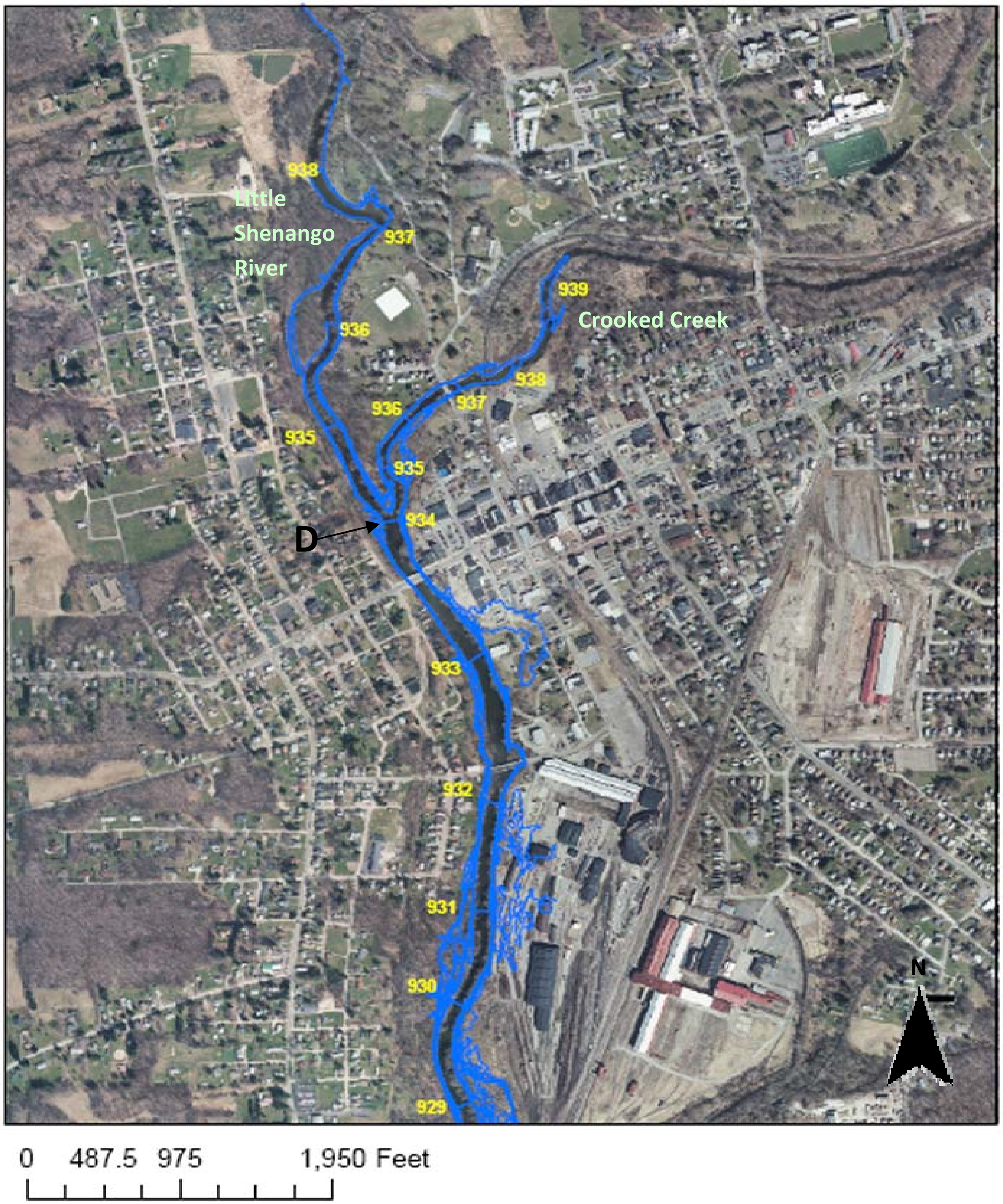

Figure 13: Aerial photo of Greenville with the sampling sites (D) indicated. The blue contour lines are at a 1-foot interval with the each elevation in the river marked in yellow.

Kidds Mill Covered Bridge

The substrate at the Kidds Mill Covered Bridge site was comprised of primarily gravel across the entire width of the Shenango River, yielding the highest possible WSQHEI value for the east and west sites. Since this metric is of primary importance to egg survival and spawning site selection by walleye, this location seemed highly likely to support walleye spawning activity.

The Kidds Mill Covered Bridge site had a gradient of 3.38 ft/mi (Figure 14), which was used for the east and west WSQHEI because the egg collection sites were at a uniform distance upstream from the lake. As indicated by the elevations in Figure 14, the gradient is higher immediately upstream from the site; and lower immediately downstream from the site. For this reason, the gradient was calculated using the 910 foot contour interval, which was over one mile downstream of the sampling site.

The velocities at the Kidds Mill Covered Bridge sites varied less than 0.1 m/s from each other and were both within the optimum walleye spawning velocity values. However, despite the high WSQHEI values at this site (Appendix), limited walleye spawning activity occurred in 2008, and no activity was discovered in 2009.

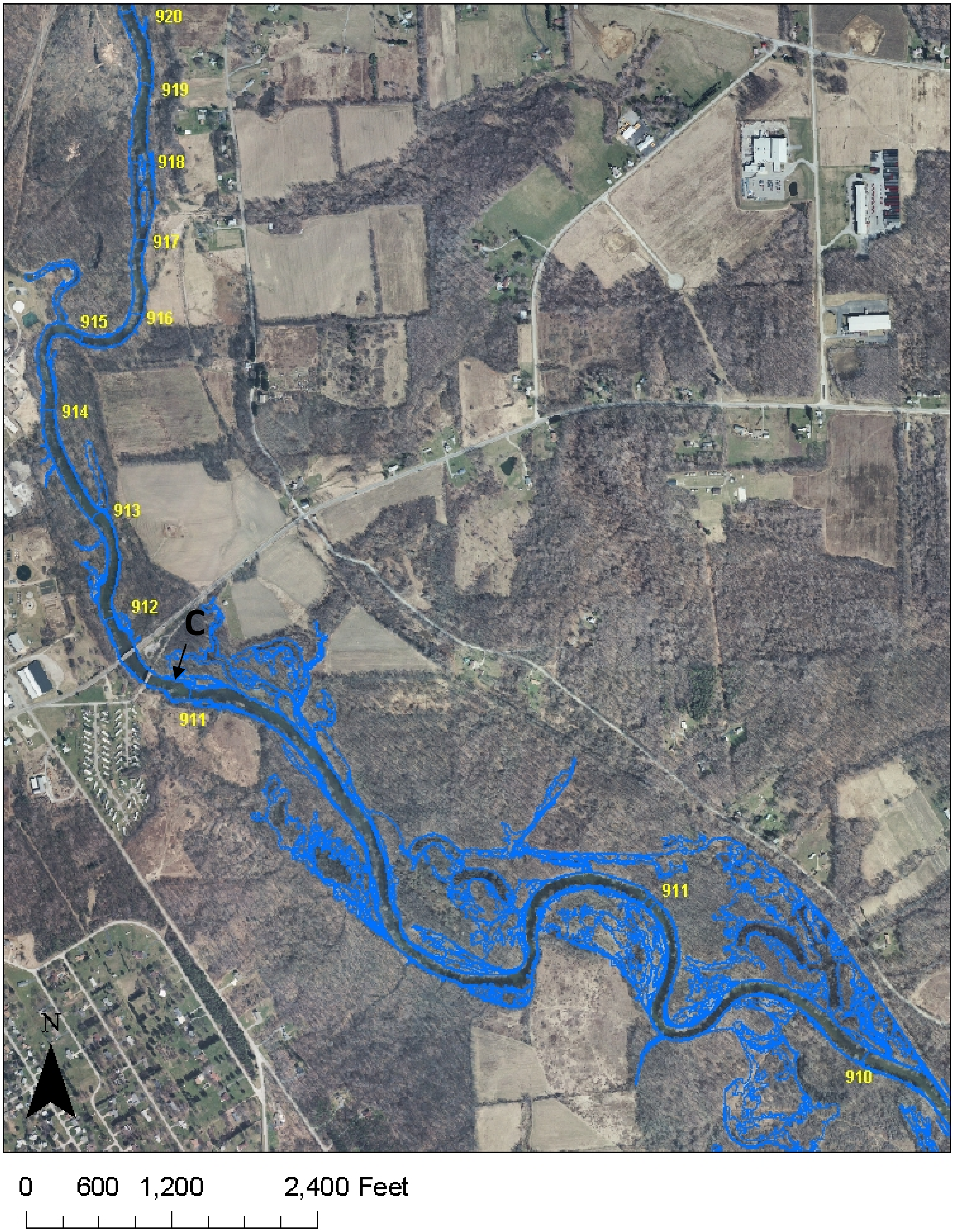

Figure 14: Aerial photo of Kidds Mill Covered Bridge with the sampling site (C) indicated. The blue contour lines are at a 1-foot interval with the each elevation in the river marked in yellow.

Hamburg Bridge

This sampling site was located below Hamburg Bridge in part because it had optimum substrate comprised of a gravel/cobble mixture across the entire width of the river. The Hamburg Bridge egg mat placement locations had slightly different velocities, with the center site velocity being optimum for walleye spawning, but the near-bank site being slightly too fast at 1.18 m/s, which has been shown to damage newly hatched larvae by driving them against the substrate and other debris (Lowie et al. 2001, McMahon et al. 1984). It should be noted that the accuracy of the velocity measurements may have impacted the reported value and that the velocity may be within the acceptable range if measured by another means. A below optimum warming rate of 0.25 °C/day at the Hamburg bridge bank location may be attributed to the inflow of the Lawango Run only about 25 meters upstream of the sampling location. This is the only sampling site that yielded walleye eggs during sampling in both 2008 and 2009, which corresponds to its high WSQHEI ratings (Appendix).

The gradient at the Hamburg Bridge site was 1.74 ft/mi (Figure 15) for the center and bank side sites. This site required the 904 foot contour interval to be used because an elevation change did not occur within one-half mile upstream from the site, resulting in the gradient being estimated below the acceptable spawning range. However, field visits indicated that the site gradient was more consistent with that of the river downstream of the sampling site, which was 6.45 ft/mi so this value was used in the WSQHEI. The sampling site and the area downstream consisted of riffles, while the area upstream was a pool.

A small tributary named Lawango Run, just upstream from the Hamburg Bridge sampling sites, had good substrate comprised of primarily gravel, which is why this site also received egg mats at the beginning of the sampling period in 2008. A gradient for Lawango Run could not be established with the available data, resulting in this variable not being assessed. The velocity in Lawango Run was less than 0.1 m/s and contributed to the poor walleye spawning habitat at this location (Appendix). Also, the egg mats were placed at the deepest part of Lawango Run enabling a value in the optimum range for the depth category. However, the depth of Lawango Run upstream from the sampling location was well below the minimum depth of 0.5 m and appeared impassible to adult walleye under normal flow conditions. This would have resulted in a "Poor" value for the depth category and deemed the entire site as unsuitable for walleye spawning. Due to the extremely slow velocity and rapid algal growth that covered the egg mats, this site did not indicate any potential for walleye spawning and the egg mats were removed during the second week of sampling in 2008 and no sampling was conducted in Lawango Run in 2009 which prevented an estimation of warming rate.

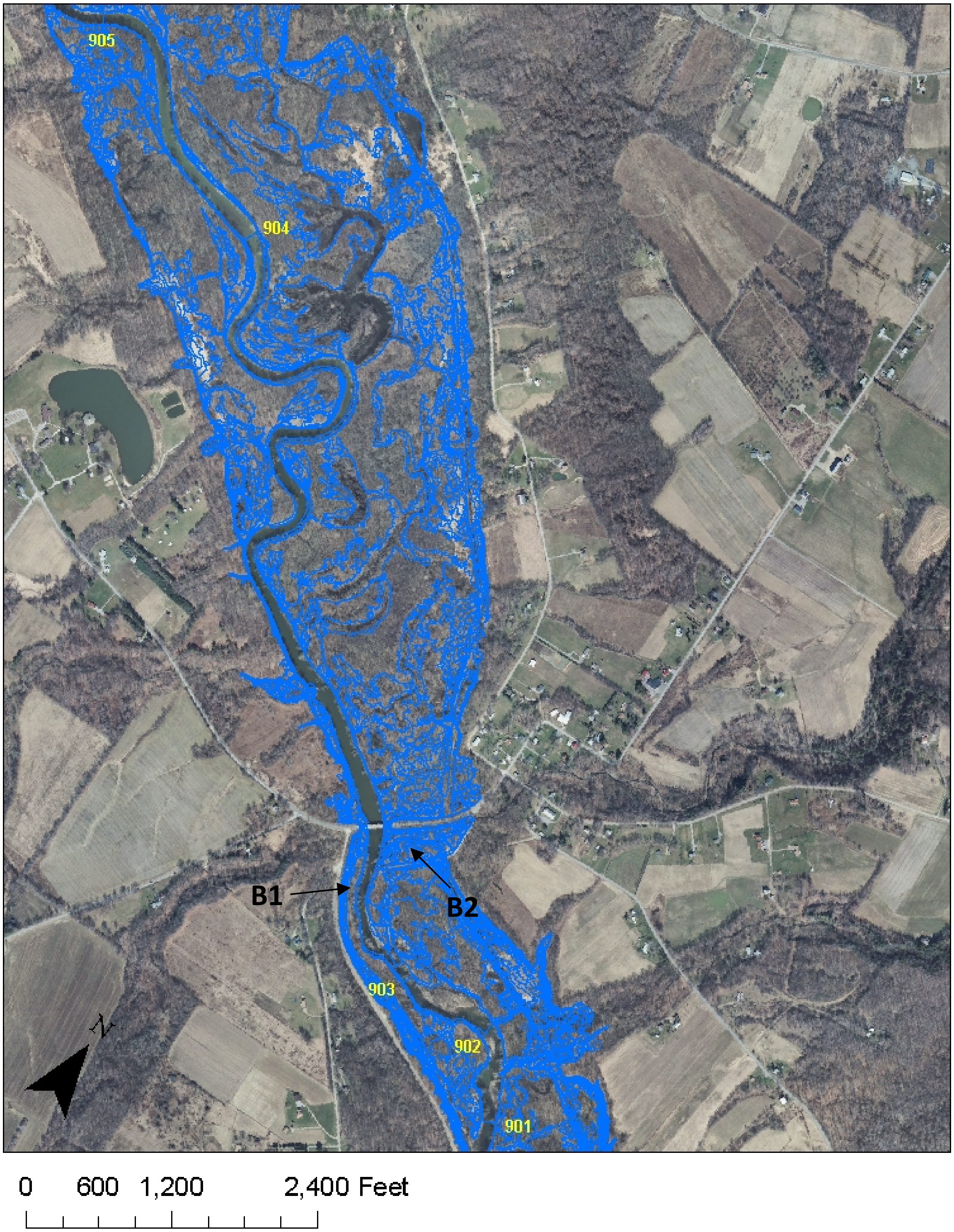

Figure 15: Aerial photo of the Hamburg Bridge with the river sampling sites (B1) and Lawango Run (B2) indicated. The blue contour lines are at a 1-foot interval with the each elevation in the river marked in yellow.

Lackawannock Creek

Lackawannock Creek has a gradient of 16.7 ft/mi (Figure 16), which is within the acceptable range of 6.1 to 18.0 ft/mi for a small stream (Rankin 2006). The temperature of Lackawannock Creek was already 13 °C on April 10th, 2008, which indicated that any walleye spawning activity would have ceased at this location. Since Lackawannock Creek was no longer sampled after the second week of 2008 and not sampled in 2009, only one temperature measurement was recorded and warming rates could not be established. Lackawannock Creek had extremely poor substrate comprised of primarily detritus material and silt. The velocity at the site below the bridge over Lackawannock Creek was within the optimum range at 0.44 m/s, although the velocity at the site about fifty meters upstream was below the optimum range at 0.31 m/s (Figure 16). The lower velocities within Lackawannock Creek compared with the velocities in the Shenango River likely contributed to the poor substrate quality by allowing greater sediment deposition to occur (Auer and Auer 1990). It is unlikely that spawning is occurring in this tributary since this type of substrate has been associated with poor egg survival (Auer and Auer 1990). While anglers have indicated that walleye or other fish species have been observed in this tributary during March and April when spawning is likely to be occurring, results did not confirm that any spawning activity occurs at this location. Due to poor substrate composition, increased water temperature, algal growth, and lack of eggs at this site, the egg mats were removed after the second week of sampling in 2008 and no sampling was conducted in 2009.

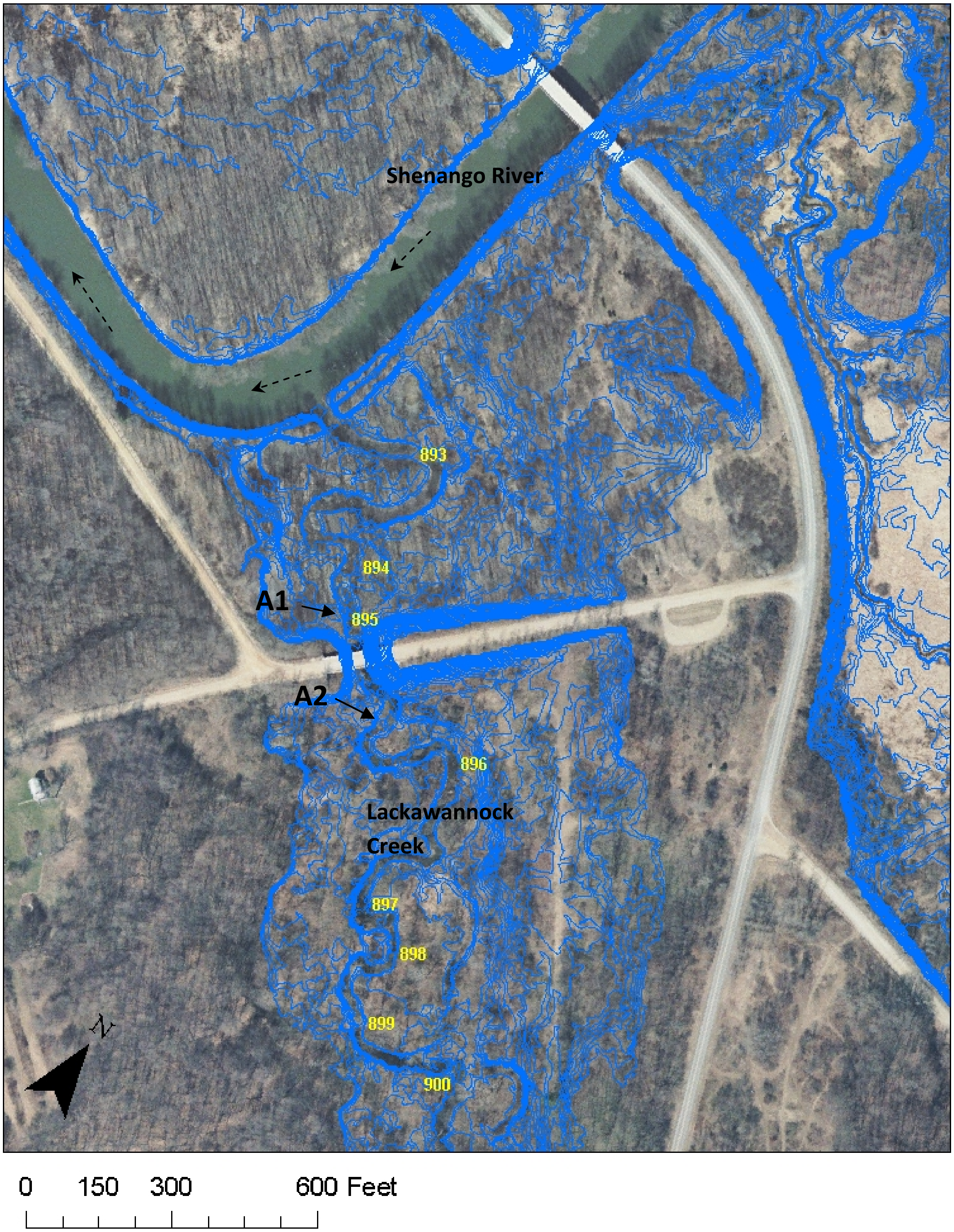

Figure 16: Aerial photo of Lackawannock Creek near the Big Bend access area of the Shenango River with the downstream (A1) and upstream (A2) sampling sites indicated. The blue contour lines are at a 1-foot interval with the each elevation in the river marked in yellow.

Egg Collection

Surber sampling was attempted in 2008, but was impractical at Shenango River sites because the strong current would not allow the surber sampler to rest on the bottom with its own weight. It was necessary to stand on the front corner of the surber opening to keep it from washing downstream. This not only diverted water away from the surber's opening and potentially prevented eggs and larvae from entering the surber, but also negated attempts at determining the volume of water passing through the surber. High amounts of leaf litter, small stones, and other debris were collected at each site and placed into one gallon Zip-loc bags until the material could be sorted through and examined under laboratory conditions with a dissecting scope for the presence of larvae or eggs. No site yielded eggs through this method and only one white sucker (*Catostomus commersonii*) larva was found at the Hamburg Bridge site through this method. The surber sampler was only used once during 2008 and discontinued afterwards because of the difficulties experienced while using it and the poor results. Based on the materials recovered and the difficulties sampling, this method would not be advisable for future studies on the Shenango River.

White suckers are present in the Shenango River and were spawning in the river during the latter sampling dates. They typically spawn when water temperatures are about 10°C and select similar habitat as do walleye (Freeman 2007, Steiner 2002, Dustin and Jacobson 2003). Walleye and white sucker eggs are similar in size, averaging 2.0 mm in diameter (Figure 17), and do not have significant variations in color or other characteristics that could have been used for egg identification (Roseman et al. 2006); therefore the number of walleye eggs collected at each sample site could not be determined. In 2009, collected eggs were counted, but could not be verified as walleye until identification of hatched larvae.

Figure 17: A typical egg collected during sampling in the Shenango River demonstrating the size and color of the eggs.

Larval Rearing & Identification

Under hatchery conditions, eggs are treated with a fungicide before incubation to prevent fungal growth (Johnston 1997), but since Shenango River water was used during incubation, a fungicide treatment was not performed on the collected walleye eggs (Manny et al. 2007). This prevented the determination of hatching success rates from the collected eggs because many of the eggs perished from the high amount of fungus that developed while incubating in the lab.

The incubator temperature in the YSU lab was to be held at approximately 12±2 °C, since Rach et al. (1997) successfully hatched walleye eggs in approximately 10 days with this same water temperature. However, malfunctioning of the external temperature control on the incubator in 2008 caused the temperature to reach nearly 16.5 °C and fall to a low of around 9.0 °C during the first week of incubation. Maintaining a steady temperature in the incubator was a difficult task throughout incubation during both years of egg collection. The higher temperature in 2008 likely caused increased fungal growth and consequently increased egg mortality (Schneider et al. 2002), but the extent to which this influenced the hatching success is unknown. The temperature fluctuation may have added additional stress to the eggs, but was unlikely to cause direct mortality of the eggs (Schneider et al. 2002). The temperature was maintained within the suitable incubation range during 2009, but a substantial number (greater than 75%) of eggs were still lost to fungus.

A total of eight larvae were hatched from the collected eggs in 2008. The exact hatching dates of the larvae were unknown, since they were not monitored daily. Two eggs hatched from the Hamburg Bridge site in 2008, but the larvae were not developed enough to positively identify (Figure 19). While they could not be identified as walleye with certainty, they did resemble the other walleye larvae. Three larvae hatched from the Greenville site in 2008, although two of them were too decomposed and encased with fungus to identify. The other larva from the Greenville site was positively identified as a walleye. Figure 18 of the hatched walleye larvae was taken with a digital microscope (NOSII 2005), and compared with drawings (Figure 10 and 11) by Faber (2005) and a photo (Figure 12) by Moodie (1989). Larval characteristics (Figure 18) of hatched larvae clearly exhibited the characteristics of the walleye (Figure 10) compared to the characteristics of the white sucker larvae (Figure 11) that also spawns at similar times and conditions (Faber 2005, Moodie 1989). Larvae lengths were also used to identify the larvae as walleye, since the larvae hatched from the collected eggs were approximately 7.5 mm in length and white sucker larvae are 10 mm in length (Anderson et al. 2006, Faber 2005). This single walleye larva confirmed that successful walleye spawning was possible in the Shenango River and that walleye were attempting to spawn in the river.

Three additional larvae hatched and were identified as walleye from the Kidds Mill Covered Bridge site in 2008.

In 2009, only the Hamburg Bridge site yielded any eggs. This was the only site that yielded eggs each week in both 2008 and 2009. Seventeen larvae hatched from the eggs at this site and were all identified as walleye.

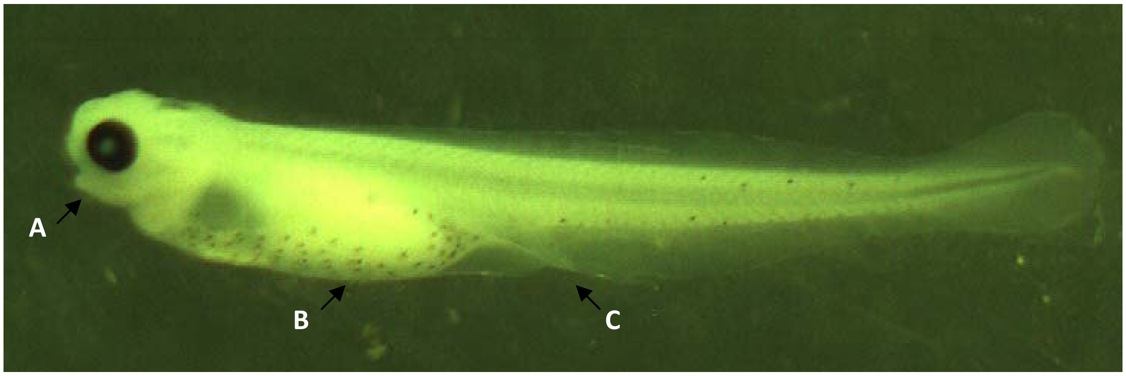

Figure 18: Picture of Shenango River walleye larvae in 2008. Note the jaw structure (A), the yolk sac and spots (B), and the location of the anus (C).

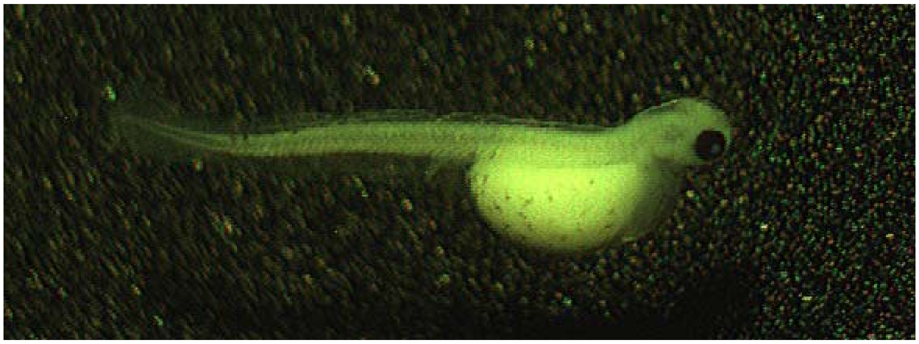

Figure 19: Photo of a hatched larva in 2008 from the Hamburg Bridge, which has characteristics similar to those of the other walleye larvae.

River Residence Time

The Greenville site was the greatest distance from Shenango River Lake at 23.9 kilometers (14.9 miles), but hatched larvae from this site have an estimated drift time of slightly greater than 7 hours with an average velocity of 0.91 m/s for the Shenango River. Walleye larvae can survive 3-5 days before their yolk sac is absorbed and starvation occurs (Anderson et al. 2006, McMahon et al. 1984). This suggests that river residence time is likely not a limiting factor for larval survival at any of the sampling locations because walleye larvae are not starving before reaching the assumed nursery habitat in Shenango River Lake.

Migration Distance & Spawning Occurrence

Figure 20 illustrates that there is a preference for the closest suitable spawning site sampled to Shenango River Lake, which was the Hamburg Bridge location. The frequency and number of eggs was greatest at the Hamburg Bridge location in 2008 while the other locations sampled in the Shenango River contained less frequent eggs in 2008. The higher spawning occurrence at this site was even more evident in 2009, since no other site yielded eggs and the number of eggs was consistent with that of the previous year. The results of Shenango River walleye egg collection were analyzed through Statistical Package for the Social Sciences (SPSS) with regression analysis based on P values. This observation is consistent with that of walleyes in Claytor Lake, Virginia that primarily spawn at the first riffle area upstream from the lake (Palmer et al. 2005).

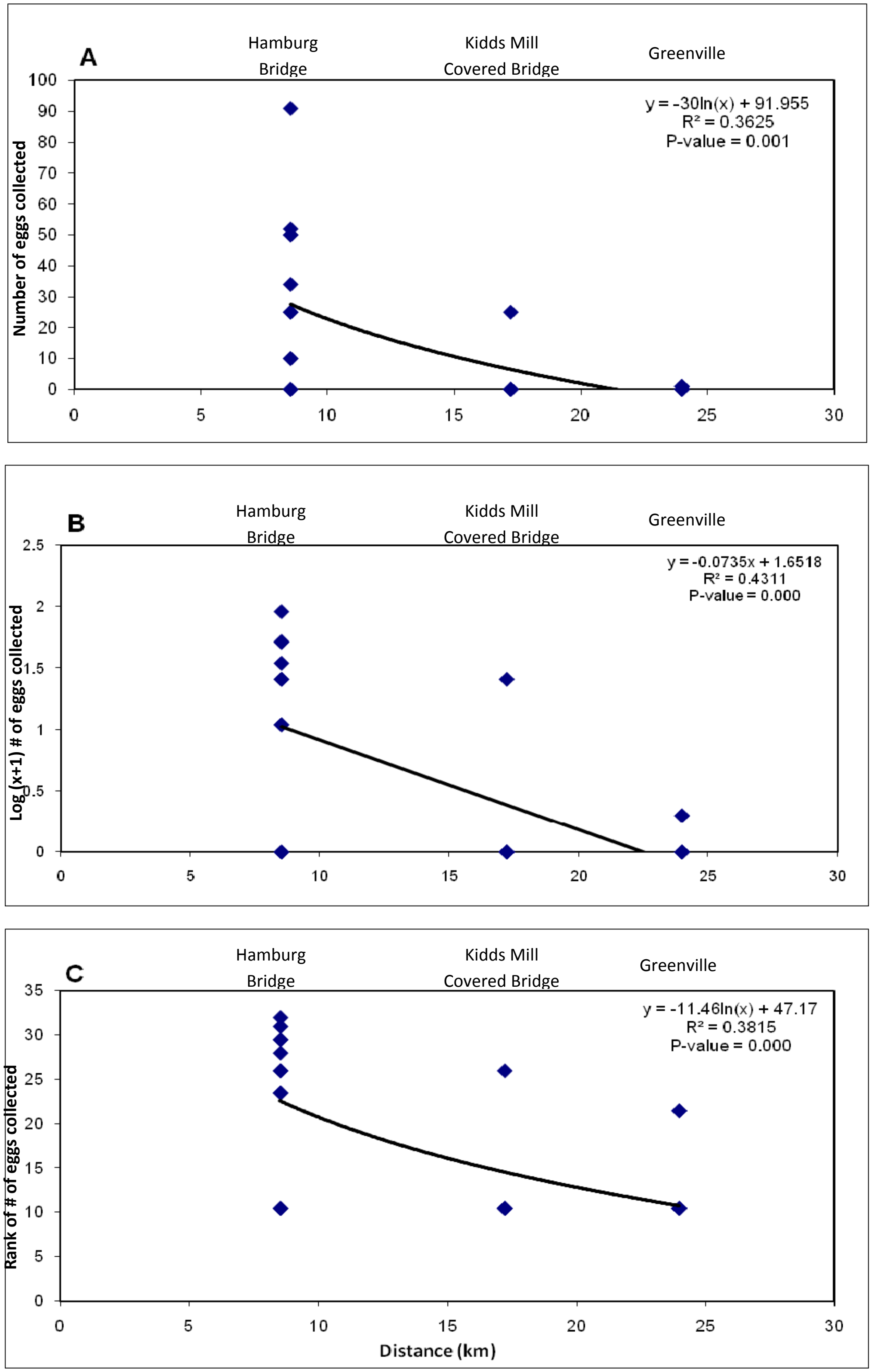

Figure 20: Analysis of sampling site distance from Shenango River Lake. A (number of eggs collected) and C (rank of number of eggs collected) are logarithmic models, while B (Log (x+1) number of eggs collected) is a linear model.

Chapter 4
Conclusions

The presence of walleye eggs confirms spawning by Shenango River Lake walleyes is occurring in the Shenango River. However, the presence of eggs in the collection area does not necessarily preclude spawning elsewhere in Shenango River Lake. Regardless, the importance of protecting the integrity of the Shenango River and its watershed is even more crucial now that walleyes are known to spawn in the river.

Additionally, the prediction of spawning habitat suitability through the WSQHEI and even the presence of eggs or larvae does not confirm recruitment of walleye into the Shenango River Lake population (Moir et al. 2005). Drawing conclusions based on correlations between variables or the WSQHEI is susceptible to error because walleye eggs and fry are most influenced by interacting abiotic variables. Ranking systems and statistical analysis do not account for such interactions, which limits their applicability (Rose 2000). A numerical scoring system could not be established with the data available because the ranking of environmental variables is necessary. This is not possible since the importance of one variable versus another is unclear, so a descriptive value was used as a substitute. With this in mind, the WSQHEI suggests that the Shenango River appears to have adequate walleye spawning habitat, supported by the collection of walleye eggs at several locations in the Shenango River. Walleye spawning in the Shenango River tributaries of Lackawannock Creek and Lawango Run was not documented, and was not predicted based upon the WSQHEI. The usefulness of the WSQHEI may increase with the inclusion of several additional years of data and by including a wider range of physico-chemical conditions, enabling the prediction of walleye spawning occurrence at other locations within the Shenango River or similar rivers.

The only variable statistically related to walleye spawning was the migratory distance upstream from Shenango River Lake because the environmental variables described in this study were specifically chosen for their spawning habitat suitability. Sites that appeared conducive to walleye spawning were sampled whereas those that did not appear conducive were not sampled. To establish a gradient among environmental variables, sites would need to be randomly selected and sampled. Also, I suspect that additional spawning sites downstream from the Hamburg Bridge site might indicate higher spawning frequency, and should be sampled in the future. It is possible that another egg collection method, such as the one used by Roseman et al. (2002) in the Maumee Bay and Maumee River, which incorporated a benthic pump to suck eggs from the substrate could be effectively used in the Shenango River to better determine spawning frequency. The addition of migratory distance may be a beneficial addition to a future WSQHEI.

The development of an egg identification system would enable accurate egg deposition estimates and usable spawning frequency comparisons between sampled sites. Slight variations in egg color, from translucent to yellow, were observed in the Shenango River and may be an indicator of the species; although, it might be attributed to fertilized versus unfertilized walleye eggs. Careful collection, observation, sorting, and incubation of different colored eggs in the Shenango River should be performed to determine the feasibility of egg identification.

It would be useful to perform a follow-up study on the suitability of walleye larval habitat in the eastern portion of Shenango River Lake where the Shenango River enters the lake, to determine whether their survival is occurring or even possible. Determining how many walleye larvae exist in the lower portions of the Shenango River as well as their physical condition would be beneficial to establishing an estimate of recruitment in Shenango River Lake. Spawning may also occur on shallow gravel reefs within the lake. Additional studies would need to be done to evaluate the situation within the lake itself.

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Notes

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Appendix 1

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Lackawannock Creek Downstream of Bridge			
Velocity	*Range*	**0.44 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	●	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm	●	Poor
Warming Rate	*Range*	**N/A**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**0.4 m**	*Value*
Unsuitable	< 0.5 m	●	Poor
Preferable	0.5 - 1.8 m		Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**16.7 ft/mi**	*Value*
Unsuitable	≤ 6.0 ft/mi		Poor
Suitable	6.1 - 18 ft/mi	●	Good
Unsuitable	≥ 18.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**11.8 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**N/A**	
Suitable or Unsuitable	6.0-9.0		Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Lackawannock Creek Upstream of Bridge			
Velocity	*Range*	**0.31 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s		Excellent
Slow	< 0.4 m/s	●	Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm	●	Poor
Warming Rate	*Range*	**N/A**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**0.5 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**16.7 ft/mi**	*Value*
Unsuitable	≤ 6.0 ft/mi		Poor
Suitable	6.1 - 18 ft/mi	●	Good
Unsuitable	≥ 18.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**11.9 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**N/A**	
Suitable or Unsuitable	6.0-9.0		Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Lawango Run			
Velocity	*Range*	**0.09 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s		Excellent
Slow	< 0.4 m/s	●	Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm	●	Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**N/A**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**0.7 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**N/A**	*Value*
Unsuitable	≤ 15.0 ft/mi		Poor
Suitable	15.1 - 30 ft/mi		Good
Unsuitable	≥ 30.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**13.2 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**N/A**	
Suitable or Unsuitable	6.0-9.0		Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)

Site: Hamburg Bridge Center

Velocity	*Range*	**0.91 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	●	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm	●	Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.29 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr	●	Excellent
Depth	*Range*	**0.5 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**6.45 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	●	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**10.5 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**7.6**	
Suitable or Unsuitable	6.0-9.0	●	Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Hamburg Bridge East			
Velocity	*Range*	**1.18 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s	•	Fair
Moderate	0.4 - 1.0 m/s		Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm	•	Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.25 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr	•	Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**0.6 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	•	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**6.45 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	•	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**10.6 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	•	Required
pH	*Range*	**7.6**	
Suitable or Unsuitable	6.0-9.0	•	Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Kidds Mill Covered Bridge West			
Velocity	*Range*	**0.94 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	●	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm	●	Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.29 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr	●	Excellent
Depth	*Range*	**0.7 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**3.38 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	●	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**11.2 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**7.7**	
Suitable or Unsuitable	6.0-9.0	●	Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)

Site: Kidds Mill Covered Bridge East

Velocity	*Range*	**0.88 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	●	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm	●	Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.28 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr	●	Excellent
Depth	*Range*	**0.7 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**3.38 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	●	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**10.6 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**7.4**	
Suitable or Unsuitable	6.0-9.0	●	Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Greenville West			
Velocity	*Range*	**0.6 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	●	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm	●	Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm		Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.22 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr	●	Good
Preferable	≥ 0.28°C/24 hr		Excellent
Depth	*Range*	**0.6 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	●	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**6.36 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	●	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**10.1 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	●	Required
pH	*Range*	**7.8**	
Suitable or Unsuitable	6.0-9.0	●	Required

Walleye Spawning Qualitative Habitat Evaluation Index (WSQHEI)			
Site: Greenville East			
Velocity	*Range*	**0.97 m/s**	*Value*
Very Fast	≥ 1.3 m/s		Poor
Fast	1.1 - 1.2 m/s		Fair
Moderate	0.4 - 1.0 m/s	•	Excellent
Slow	< 0.4 m/s		Good
Substrate	*Range*		*Value*
Gravel/Cobble Mix	2 - 256 mm		Excellent
≥ 75% Gravel	2 - 64 mm		Excellent
≥ 75% Cobble	65 - 256 mm	•	Good
Sand	0.06 - 2 mm		Fair
Boulder	> 256 mm		Poor
Detritus/Silt	< 0.06 mm		Poor
Warming Rate	*Range*	**0.31 °C/day**	*Value*
Unsuitable	≤ 0.15°C/24 hr		Poor
Suitable	0.16°C - 0.27°C/24 hr		Good
Preferable	≥ 0.28°C/24 hr	•	Excellent
Depth	*Range*	**0.5 m**	*Value*
Unsuitable	< 0.5 m		Poor
Preferable	0.5 - 1.8 m	•	Excellent
Suitable	1.8 - 8.0 m		Good
Unsuitable	> 8.0 m		Poor
Gradient	*Range*	**8.23 ft/mi**	*Value*
Unsuitable	≤ 2.0 ft/mi		Poor
Suitable	2.1 - 10 ft/mi	•	Good
Unsuitable	≥ 10.1 ft/mi		Poor
Oxygen (mg/L)	*Range*	**10.6 mg/L**	
Suitable or Unsuitable	≥ 5 mg/L	•	Required
pH	*Range*	**6.5**	
Suitable or Unsuitable	6.0-9.0	•	Required

Table A1: Data table of 2008 sampling with approximate egg counts.

2008 Observations										
Location	Date	Velocity (m/s)	Distance (km)	Substrate	Temperature (°C)	Depth (cm)	Gradient (ft/mi)	Oxygen (mg/L)	pH	Eggs
Greenville East	4/10/2008	0.91	23.98	2	11.6	55	8.23	11.5		0
Greenville East	4/17/2008	0.99	23.98	2	10.9	50	8.23	11	6.3	100
Greenville East	4/24/2008	1.01	23.98	2	14	36	8.23	9.3	6.7	0
Greenville West	4/10/2008	0.83	23.98	3	7.9	50	6.36	10.3		1
Greenville West	4/17/2008	0.63	23.98	3	9.5	70	6.36	10.7	7.8	0
Greenville West	4/24/2008	0.35	23.98	3	12.2	44	6.36	9.3	7.8	0
Kidds Mill Bridge East	4/10/2008	1.04	17.22	3	8.8	75	3.38	11.4		25
Kidds Mill Bridge East	4/17/2008	0.93	17.22	3	9.8	82	3.38	11	7.4	0
Kidds Mill Bridge East	4/24/2008	0.67	17.22	3	12.7	50	3.38	9.4	7.4	0
Kidds Mill Bridge West	4/10/2008	1.01	17.22	3	9	67	3.38	11.3		0
Kidds Mill Bridge West	4/17/2008	0.87	17.22	3	10.1	63	3.38	11.1	7.7	0
Hamburg Bridge Center	4/10/2008	0.98	8.53	3	9	60	6.45	11.3		10
Hamburg Bridge Center	4/17/2008	0.86	8.53	3	10	54	6.45	10.9	7.5	25
Hamburg Bridge Center	4/24/2008	0.88	8.53	3	13	29	6.45	9.2	7.6	25
Hamburg Bridge Bankside	4/10/2008	1.46	8.53	3	9.4	63	6.45	11.6		50
Hamburg Bridge Bankside	4/17/2008	0.94	8.53	3	10	63	6.45	10.9	7.5	50
Hamburg Bridge Bankside	4/24/2008	1.14	8.53	3	12.9	45	6.45	9.3	7.7	10
Lawango Run	4/10/2008	0.09	8.53	3	12.4	70		13.2		0
Lackawannock DwnStr	4/10/2008	0.44	2.25	0	13	35	16.7	11.8		0
Lackawannock UpStr	4/10/2008	0.31	2.25	0	13	51	16.7	11.9		0

*Excluded from statistical analysis because of high water temperature.

Table A2: Data table of 2009 sampling with actual egg counts.

2009 Observations										
Location	Date	Velocity (m/s)	Distance (km)	Substrate	Temperature (°C)	Depth (cm)	Gradient (ft/mi)	Oxygen (mg/L)	pH	Eggs
Greenville East	3/23/2009	1.69	23.98	2	5	72	8.23	12.5	6.7	0
Greenville East	3/30/2009	0.67	23.98	2	7.6	66	8.23	10.6	7.7	0
Greenville East	4/5/2009	0.96	23.98	2	9.4	51	8.23	10.3	7.1	0
Greenville East	4/17/2009	0.86	23.98	2	9.6	76	8.23	11.6	7	0
Greenville West	3/23/2009	0.72	23.98	3	5.4	63	6.36	12.1	6.2	0
Greenville West	3/30/2009	0.84	23.98	3	5.6	56	6.36	11.1	7.5	0
Kidds Mill Bridge East	3/23/2009	1.02	17.22	3	5.3	88	3.38	11.9	6.7	0
Kidds Mill Bridge East	3/30/2009	0.85	17.22	3	6.6	84	3.38	10.9	6.9	0
Kidds Mill Bridge East	4/5/2009	1.05	17.22	3	8.9	58	3.38	10.2	7.4	0
Kidds Mill Bridge East	4/17/2009	0.89	17.22	3	9.1	75	3.38	11.1	7.2	0
Kidds Mill Bridge West	3/23/2009	0.98	17.22	3	5.4	84	3.38	12.2	7.2	0
Kidds Mill Bridge West	3/30/2009	0.66	17.22	3	6.5	79	3.38	10.6	6.9	0
Kidds Mill Bridge West	4/5/2009	1.21	17.22	3	8.7	71	3.38	10.4	7.7	0
Kidds Mill Bridge West	4/17/2009	0.86	17.22	3	9	49	3.38	11.6	7.4	0
Hamburg Bridge Center	3/23/2009	0.77	8.53	3	5.5	61	6.45	11.9	7.3	0
Hamburg Bridge Center	3/30/2009	0.61	8.53	3	6.1	74	6.45	11.3	7.1	34
Hamburg Bridge Center	4/5/2009	1.04	8.53	3	8.8	60	6.45	10.1	8	52
Hamburg Bridge Center	4/17/2009	0.82	8.53	3	9.5	64	6.45	10.5	7.5	91
Hamburg Bridge Bankside	3/23/2009	0.82	8.53	3	5.5	53	6.45	11.9	7.3	0
Hamburg Bridge Bankside	3/30/2009	0.7	8.53	3	6.8	84	6.45	11.8	7.1	0
Hamburg Bridge Bankside	4/5/2009	0.82	8.53	3	8.7	39	6.45	10.4	8	0
Hamburg Bridge Bankside	4/17/2009	0.82	8.53	3	9.6	44	6.45	11	7.5	0