TECHNIQUES FOR MONITORING RIVER RESTORATION SUCCESS FOLLOWING A DAM REMOVAL

A Thesis

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By

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ABSTRACT

A habitat suitability index (HSI) model for a target fish (greater redhorse) and macroinvertebrate (stonefly) species was developed along with a Remotely-Sensed Qualitative Habitat Evaluation Index (RS-QHEI) to determine the restoration success of the Saint John Dam removal for the Sandusky River, Ohio. Two separate habitat models were created for pre- and post-dam removal scenarios, one in Excel and the other in ArcGIS ® (ESRI). Each model produced similar results of habitat suitability polygon layers either manually (Excel) or programmatically (ArcGIS ®). The results of each model indicate a habitat improvement for both species following dam removal that was attributed to a drop in water level.

The RS-QHEI used a digital aerial photograph and a satellite image to quantitatively predict three of the six original metrics of the field based Qualitative Habitat Evaluation Index (QHEI). Output from the procedure was compared to nine field-based QHEI scores to determine the effectiveness of the procedure and applicability to riverine systems. No statistical differences in the field based QHEI scores and the RS-QHEI of this model were detected. The RS-QHEI scores were lower than the field based method and were not linearly correlated ($R^2 = 0.1425$). Both indices indicated improvement of the physical habitat one year after the dam removal. Therefore, the RS-QHEI can be viewed as a more quantitative tool for understanding larger scale attribute

changes in river systems. The RS-QHEI provides a fast and inexpensive procedure for monitoring restoration projects over many years to determine if restoration methods, such as dam removal, meet both short-term and long-term goals.

Dedicated to my late Grandmother. May the trampoline be fun in heaven!

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

Dams litter the world's rivers. They range from low-head dams (<5 m) to high-head dams (>5 m). There are more than 75,000 dams above 1.5 m high in the United States and 40,000 dams over 15 m high worldwide (Bednarek 2001). Nearly 80 % of the total discharge of large rivers in the northern third of the world is impacted by river regulation (Bednarek 2001). Dams are structures designed by humans to capture water and modify the magnitude and timing of discharge downstream (Poff and Hart 2002). Historically dams were designed to create reservoirs for aquaculture, mill operations, and power plants cooling. They have also been designed to reduce flood hazards by slowing the flow of a river, thus reducing the peaks of the hydrograph. Dams have also been designed to create electric power to the nations of the world (for example, the Hoover Dam).

Although these structures were designed to benefit human needs, the effect on the riverine ecosystems is detrimental. Sediments and debris that would normally remain suspended in the water column and continue to move downstream, instead settle out and collect within the reservoirs. Accumulation is often so substantial that some reservoirs shift from their original function of water storage to becoming sediment storage basins

(Stanley and Doyle 2003). This negates the purpose of the reservoir and ultimately causes stresses on the dam that increases likelihood of dam failure (Stanley and Doyle 2003).

Dams serve to change the river ecosystem from a lotic to a lentic environment. Upstream of the dam the river flows freely, driven by the slope of the riverbed. Once the water reaches the slow moving backwater created by the dam, the system shifts to a more lake environment. Settling of sediments can cause a shift in substrate from cobble/pebble to more of a finely sorted substrate of sand and silt. Fish and macroinvertebrates that thrive in a more lotic environment become less numerous behind the impoundment of a dam. The Edwards Dam in Maine contributed to a serious decline in numerous fish species within the Kennebec River by blocking migration and diminishing suitable habitat (Bednarek 2001).

Dams can severely affect river habitat and processes. Dams reduce connectivity of rivers, resulting in negative effects on stream biota above and below the impoundment (Teimann and Gillette 2004). Dam construction can fragment watersheds that can effect fish assemblages by reducing movement of migratory species upstream of a dam, causing reduced species richness (Gillette et al. 2005). Dams have also been shown to disrupt assemblages of unionid mussels (Sethi et al. 2004) and macroinvertebrates (Stanley et al. 2002, Mistak et al. 2003, Thomson et al. 2005).

Many of these structures were built at the turn of the century and are approaching their life expectancy. 30% of high-head dams are past their life expectancy (50 years) and by 2020, 80% of the dams will be outdated (River Alliance of Wisconsin and Trout Unlimited 2000). Due to the aging of dams, decisions need to be made on whether to

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repair the aging structures or remove them. Repair of these dams can be very expensive. The cost of repairing a small dam can be three times greater than the cost of removing it (Poff and Hart 2002). Therefore, it is extremely important to understand the effects of removing dams due to impact on river processes. Because of the negative effects of dams on river biota and processes, dam removal has become a popular river restoration option.

Dam removal has gained momentum within the past several decades due to its positive effects on river processes and biota. The removal of dams has been shown to increase river ecosystem diversity. Within a year after the removal of the Edwards Dam on the Kennebec River, large numbers of American eel (*Anguilla rostrata*), alewife (*Alosa pseudoharengus*), Atlantic and shortnose sturgeon (*Acipenser osyrhynchus* and *A. brevirostrum*), and striped bass (*Morone saxatilis*) were observed in upstream habitats that had been inaccessible to these species for more than 150 years (Hart et al. 2002). The removal of dams has been shown to increase smallmouth bass recruitment above a dam structure, mainly because of increased habitat quality and barrier elimination (Kanehl et al. 1997). Macroinvertebrate assemblages upstream of a former dam impoundment shifted to a more diverse feeding group, while downstream of the impoundment the assemblages remained similar to pre-dam removal status (Pollard and Reed 2004). Species of benthic algae and macroinvertebrates that were rare or absent within the impoundment of the Manatawny Creek increased in abundance within months after dam removal, transforming this zone from a lentic to a lotic environment (Hart et al. 2002).

Dam removal has been seen as a means to return natural flow regimes to previously altered river systems. Interactions of geomorphic and hydrologic processes shape river channels through both erosional and depositional processes that occur during floods that fill the active channel and extend across the river floodplains. Dams eliminate large floods resulting in channel incision and loss of flood plain interactions (Gregory et al. 2002). Although downstream sediment transport from a former impoundment has been shown to cause some deleterious effects on unionid mussel assemblages following a dam removal (Sethi et al. 2004), little is known about the long term effects of sediment release from dam removal.

Dam removal has acquired much notoriety in recent years. Over 540 dams have been removed in the U.S.A., 90% of these in the last two decades (Granata et al. 2006). Yet despite the large number of dam removals, few studies have investigated the before and after effects of dam removal. Many studies have focused on the after effects of a dam removal without understanding the initial condition of the system before the dam was taken out. Studies at The Ohio State University's Ecological Engineering group have focused on river functions before, during, and after dam removal. One such study conducted by Nechvatal and Granata (2006) focused on spatial and temporal trends in water quality data before and after the removal of the St. John Dam located on river mile 50.2 on the Sandusky River (Ohio) (Figure 2.2). The study focused on water quality parameters such as dissolved oxygen (DO), phosphate, nitrates, ammonia, pH, specific conductivity, turbidity, and oxidation-reduction potential (ORP). Before removal, the reservoir behind the dam exhibited thermal stratification. Yet, following dam removal the thermal stratification of the water had disappeared (Nechvatal and Granata 2006).

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Ammonia and phosphate levels were undetectable and no statistical differences in turbidity, pH, oxidation-reduction potential (ORP), or specific conductivity were evident comparing loads before and after dam removal (Nechvatal and Granata 2006).

Another study conducted by Cheng and Granata (2006a, b) focused on the before, during, and after effects of the St. John's Dam removal on sediment transport and channel adjustments. The study showed no difference in suspended sediment concentration and discharge during the breach of the dam when compared to an annual rainfall event. Complete removal of the dam showed an increase in suspended sediments and discharge downstream of the dam. Yet, these levels were small compared to the suspended sediments produced during an annual rainfall event. A separate study revealed net deposition occurring downstream of the dam and net erosion occurring in the reservoir (Cheng and Granata 2006a). This scouring and deposition led to an overall decrease in the bedslope by 30%.

Further studies on the Sandusky River (Ohio) downstream of the St. John Dam focused on the habitat suitability modeling of walleye. Studies conducted by Cheng et al. (2006) and Gillenwater et al. (2006) focused on how the walleye population in the Sandusky River (Ohio) would change following the removal of the Ballville Dam, a high-head dam located at RM 18.0. The results of their studies showed that the walleye population could utilize upstream habitat (Cheng et al. 2006), but that downstream habitat was not yet saturated with a walleye population. Therefore, the removal of the Ballville Dam would not have a direct effect on the amount of larval walleye produced in the

system (Gillenwater et al. 2006). However, there is much uncertainty as to the quality of the downstream habitat and thus, walleye may prefer the upstream habitat to the habitat below the dam.

The goal of this thesis is to complement the prior research in the Sandusky River by developing and testing new tools to assess river restoration, and specifically the extent of ecosystem recovery after the removal of a low-head dam. This thesis is divided into three remaining chapters. Chapter 2 describes two separate ways to define habitat suitability of a target fish and macroinvertebrate species for pre- and post-removal of the St. John Dam on the Sandusky River (Ohio) using modeling techniques created in Microsoft Excel and ArcGIS®. A version of this chapter is in review in the journal of *Ecological Engineering* (Tomsic et al. 2006). Chapter 3 defines a new technique for developing a Qualitative Habitat Evaluation Index using remotely sensed images. Finally, chapter 4 integrates the other two chapters summarizing the techniques and assesses their application to river restoration.

CHAPTER 2

HABITAT SUITABILITY MODELING OF A TARGET FISH
AND MACROINVERTEBRATE SPECIES TO DETERMINE
RESTORATION SUCCESS OF A DAM REMOVAL

2.1   Abstract

A habitat suitability index (HSI) model was developed for water quality sensitive

fish and macroinvertebrate species to determine the restoration success of the St. John

Dam removal for the Sandusky River (Ohio). Two separate models were created for pre-

and post-dam removal scenarios, one in Excel and the other in ArcGIS® (ESRI). Inputs

to the HSI models consist of substrate distributions from river surveys, and water level

and velocity from a hydrodynamic model. The Excel model focused on the habitat

suitability of the Greater Redhorse (*Moxostoma valenciennesi*) for 32 river cross sections.

The ArcGIS® model expanded on the Excel model by incorporating a higher precision of

habitat suitability, increased cross sectional output (45 cross sections), and an HSI for a

macroinvertebrate species (stonefly). Each model produced polygon layers either

manually (Excel) or programmatically (ArcGIS®) that could be displayed in an ArcGIS®

environment. The results of each model clearly show an increase of habitat suitability

from pre- to post-dam removal periods and in the former reservoir. The change in

suitability of each model is attributed mostly to the change in depth in the river following the dam removal. The results of the invertebrate model followed the same positive trend as species enumerations from the river basin.

2.2   Introduction

2.2.1   *Habitat Suitability Modeling*

Over the last few decades there has been increasing concern for the human impact on river ecosystems because very few rivers retain their natural state (Bockelmann et al. 2004). Natural and semi-natural habitats are exposed to increasing pressure from changing land-use by the intensification of agricultural activities, tourism, and other development (Weiers et al. 2004). Freshwater systems are extremely vulnerable to land-use change, which results in shifts in aquatic communities and degradation of stream biota (Snyder et al. 2005). Because of the manipulation of rivers and the surrounding landscape, vital habitats for aquatic organisms have either been severely altered or destroyed. Further, the distribution of organisms in a river can vary over large spatial and temporal scales, causing aggregations of animals (Brooks et al. 2005). For example, distributions of organisms within an aquatic ecosystem can vary between seasons because different types of habitat are necessary for summer and winter periods (Store and Jokimaki 2003).

Conversion of lands for agricultural and residential development typically cause increase in peak flows and temperature, lower summer flows, and increased sediments, nutrients, and contaminants (Baker et al. 1990), which cause detrimental effects on aquatic biota habitats. Velocity in rivers is particularly important because it determines

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rates of nutrient and oxygen replenishment and relates to the lift and drag force on aquatic species (McDonnell 1990). Benthic organisms are subject to constant change as the result of disturbance events such as physio-chemical fluctuations in flow, substrate, and temperature (Fowler and Death 2000). For example, no species of stoneflies or hellgrammites were found in sand or fine particulate organic matter in one Michigan stream (Holomuzki 1996). Fish populations and diversity can also be limited by habitat destruction caused by channelization, dredging, and flow alteration (An et al. 2002). For instance, flow fluctuations can potentially change the spawning habitat for subyearling fall Chinook salmon, both daily and hourly (Tiffan et al. 2002). The United States Environmental Protection Agency noted that 70% of freshwater mussels, 55% of crayfish, 42% of amphibians, and 40% of freshwater fishes are vulnerable, imperiled, or critically imperiled in the United States (USEPA 2002, cited in Snyder et al. 2005). Because of the widespread decline in stream biota health, monitoring techniques need to be implemented to map these ecosystem changes.

Habitat suitability index (HSI) models are one such way to monitor change within ecosystems. HSI modeling is a tool for developing information about organisms so environmental managers can make intelligent management decisions (Brown et al. 2000). The technique was first developed in the 1970's by the US Fish and Wildlife Service (USFWS) as part of the Habitat Evaluation Procedures (HEP) (USFWS 1980). The HEP system was used to determine the quality and quantity of habitat for a particular species to assess the human impacts on fish and wildlife populations (USFWS 1980). The main purpose of the HSI model is to determine habitat in an ecosystem that is best suited for a particular species life history, rather than for determining species abundance and diversity

as do population models. HSI models are based on assumptions that species will select and use areas that are best suited for a particular activity during a life stage, resulting in greater use of higher quality habitat (Kliskey et al. 1999).

HSI models are typically expressed as suitability curves (Jowett and Richardson 1990). These curves range from literature review/expert opinion curves (Type 1), utilization curves (Type 2), or preference curves (Type 3) (Cheng et al 2006; Gillenwater et al. 2006). Mathematical combinations, such as arithmetic or geometric means, combine the curves to acquire an overall suitability index ranging from 0 (unsuitable) to 1 (highly suitable). Geometric mean calculations are preferred over arithmetic means because they allow the HSI to tend to zero if any of the input suitability parameters are zero.

One of the first uses of HSI modeling in rivers was in the Instream Flow Incremental Methodology (IFIM) developed by the United States Geological Survey (USGS) (Bovee et al. 1998). The Physical Habitat Simulation System (PHABSIM) model, which is inherent in the IFIM, uses a modeling method that integrates measures of the physical characteristics of a river channel with suitability data of the physical habitat (i.e., velocity, depth, and substrate) for a target species (Jowett and Richardson 1990). PHABSIM uses hydraulic simulations to predict depth and velocity at unmeasured flows using basic physical and engineering principles (Waddle 2001).

Recent developments in HSI modeling have improved on the PHABSIM ideology. Lamouroux et al. (1998) predicted habitat suitability of lotic fishes by linking statistical hydraulic simulations with multivariate habitat use models. The advantage of this procedure is the simplicity of the inputs, mainly discharge and river reach

characteristics. The model predicts habitat suitability as a function of the frequency distribution of hydraulic variables within the fish habitat. Other researchers have used hydrodynamic models to develop HSI values. Pasternack et al. (2004) used a 2-D hydrodynamic model to predict HSI values based on different gravel bed configurations for Chinook salmon. The modeling effort was part of a restoration project aimed at increasing Chinook salmon spawning habitat. Several gravel bed configurations were modeled to predict the ideal spawning habitat. Their results helped ecosystem managers understand what types of habitat the fish preferred. Leclerc et al. (1996) developed a numerical method to simulate the rate of variation in spawning habitat conditions using a two-dimensional hydrodynamic model coupled with a fish model on habitat suitability indices (HSI). The study was used to determine the feasibility of a hydroelectric project and how varying flow regimes would affect juvenile habitats of landlocked salmon. The study resulted in the exclusion of peak flow regimes that could damage the salmon habitat.

Geographical Information System (GIS) software, such as ArcGIS®, is extremely efficient at manipulating spatial data from habitat suitability analyses. The software can be used to manually overlay multiple layers of data (i.e., velocity, depth, and substrate suitability) efficiently. GIS is very appealing to ecosystem managers because the software can be used to produce desired results in a matter of seconds and in a visual form that relates to management. GIS models can also be programmed making them very versatile in their functionality. All of these attributes make the GIS environment an ideal tool for HSI modeling. Many studies have used GIS as a way to analyze and present the results of a habitat suitability analyses (Kliskey et al. 1999; McDonnell 2000;

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Eastwood et al. 2001; Lauver et al. 2002; Store and Jokimaki 2003; Weiers et al. 2004). Yet, few studies have utilized the power of GIS platforms by way of coupling hydrodynamic models with GIS based HSI models (Tiffan et al. 2002; Gillenwater 2005).

2.2.2   Objective of Study

Few studies have documented changes in fish habitat or fish populations after dam removal. Kanehl and Lyons (1997) found an increase in castomids and darter abundance, as well as a decrease in tolerant omnivores (common carp) following a dam removal on the Milwaukee River. Therefore, it is important to understand the short-term effects of the removal of the St. John Dam on the Sandusky River (Ohio). The objectives of this work are to develop habitat suitability index models for the Greater Redhorse (*Moxostoma valenciennesi*) and stonefly species (*Plecoptera* spp.), and use these models to simulate pre- and post-restoration periods (i.e., pre- and post-dam removal) in the Sandusky River. We hypothesize that the abundance of habitat for the Greater Redhorse and stonefly species will increase after dam removal as water levels drop and riffle zones, their prime habitat, are exposed. Secondly, we hypothesize that an increase in the number of the target organisms is accompanied by an increase in modeled HSI scores.

2.3   Study Area and Species

2.3.1   Study Area and Model Domain

The study area was the Sandusky River (Ohio) from river mile (RM) 48.0 to 60.0. The location of the former St. John Dam was at RM 50.2, and it's reservoir extended approximately 7 miles upstream (Figure 2.1 and 2.2). The dam was removed on 18

November 2003 and the system was allowed to recover naturally. The watershed drainage area is 1251 mi^2 and the surrounding land is generally used for agricultural purposes. The river originates in Crawford County and flows north through several counties before draining into Lake Erie at the Sandusky Bay. This makes it an important resource of migratory aquatic organisms from the Lake. A section of the river from RM 53.0 to 20.3 was previously modeled by Cheng et al. (2006) using Mike-11, a 1-D hydraulic river model (Figure 2.2). For the ArcGIS® HSI model in this paper, the domain of the hydraulic model was extended upstream to RM 60.0 to capture the full effects of the restoration.

2.3.2   Target Fish (Greater Redhorse)

The Sandusky River is unique in that it has breeding populations of six different native species of redhorse in its waters (Yoder and Beaumier 1986). Since the 1950's, these fish declined in numbers in Ohio due to intolerance to siltation, turbidity, and chemical pollution (Yoder and Beaumier 1986).

Species of the castomids family include the Silver, Golden, Black, Shortnose, River, and Greater Redhorse. The Greater Redhorse is a long-lived migratory species that requires large, interconnected river systems to complete all of its life stages (Healy, 2002). Greater Redhorse spawn in spring or early summer over gravel and cobble riffles with medium velocities (Healy 2002). Spawning between a male and female typically happens over a coarse substrate free of silt and mud with large interstitial spaces for the

eggs to be deposited (Healy 2002). Once eggs are laid, the Greater Redhorse does not guard their nest like the River Redhorse. Rather they leave the nesting grounds and have been known to disperse up to 15 km downstream of the spawning area (Healy 2002).

The Greater Redhorse (*Moxostoma valenciennesi*) has been a very ellusive fish to researchers. Healy (2002) reports discrepancies in species identification during historical collections, which has prevented researchers from obtaining reliable distribution records for the Greater Redhorse. Even with reliable records, the yearly abundance of larval castomids has been found to vary greatly and was much lower in rivers regulated by dams, compared to a free-flowing river (Scheidegger and Bain 1995).

The *Moxostoma* species possess morphological adaptations that allow them to feed on invertebrates, such as stonefly larvae, in streambeds (Healy 2002). Sedimentation in impoundments is detrimental not only to the viability of Greater Redhorse eggs (Healy 2002), but also to their food supply. High siltation rates in regulated rivers and dammed impoundments in backwaters smother the substrates needed for feeding and spawning.

2.3.3   *Target Macroinvertebrate (Larval Plecoptera/Stonefly)*

Macroinvertebrates are important to streams and rivers because they convert allochthonous material, the river's major biogeochemical energy source, to biomass (i.e. body tissue) that can be utilized by higher trophic organisms (Orth and Maughan 1983). The species richness of macroinvertebrate communities within the ecosystem declines when rivers and streams are disturbed from human alterations. Zimmerman and Death (2002) noted that disturbances in aquatic systems reduced invertebrate species numbers

by washing away or smothering individuals or indirectly by reducing primary productivity. However, Death (2003) stated that streams with little to no substrate disturbances showed a higher diversity of invertebrate taxa, including stonefly larvae. Stonefly naiads (nymphs) usually live under stones in fast-moving, well-aerated water (Discover Life 2006), usually in rocky riffle zones. Stonefly larvae use the interstitial spaces in substrate for refuge from predators (McCuthen 2002). They do not have a strict diet that allows them to optimize feeding (Peckarsky 1994). They have a relatively short reproductive phase compared to their long larval stage (Taylor et al. 1998). Some species of adult stoneflies do not feed except during the larval stage (Hynes 1996; Ruprehct 1990, cited in Taylor et al. 1998), making the larval stage of development critical (Taylor et al. 1998). Stoneflies, as well as mayflies and caddisflies, are used in biomonitoring because they are generally intolerant of silt, warm water temperatures, and degraded water quality (Baker et al. 1990). Increases in stressors can cause decreased consumption (in the larval stage) of valuable nutrient building blocks. The reduced consumption can cause adult stages to suffer (Taylor et al. 1998).

2.4   Materials & Methods

2.4.1 Surveying

Cross-sections were acquired to extend the hydrodynamic model upstream where new geomorphic features developed following the dam removal. Surveying of river reaches from RM 46.0 to 60.0 involved acquiring ground control points (GCPs) using a Global Positioning System (GPS) receiver to provide accurate positions to locate channel cross-sections. A Trimble™ 5700 GPS receiver (accurate to $\pm$ 1cm horizontally and

vertically) was equipped with a Trimble™ Zephyr antenna and mounted to a stationary tripod to acquire GCPs. Generally, points were chosen in the floodplain of the river corridor. The exception was when it was possible to survey in the river channel (on islands or within the banks of the river not under the tree canopies), which allowed for multiple cross-sections to be developed for input to the hydrodynamic model using one ground control point, since the line of sight upstream and downstream along the river was optimal. The GPS collected data at a frequency of 1 Hz on September 6th, 8th, and 9th, 2005.

Originally, the GPS data were processed using the Trimble Geomatics Office™ software using a reference station in Tiffin (Ohio) operated by the Ohio Department of Transportation. However, the Tiffin station failed to acquire data on 9 September 2005, so a reference station in Kenton (Ohio) (~30 miles from the study site) had to be substituted. Differences in elevations were calculated for two of the surveys using the Tiffin and Kenton reference stations and both had minimal (1 cm) differences in elevations, thus it was concluded that the Kenton station was a reliable reference. Data points that did show unrealistic elevations (<10 % of the data) were subsequently discarded.

GPS points were converted into a shapefile (point file) in ArcGIS® using the UTM Zone 17N map projection (NAD 1983 datum). The shapefile was overlain on a 1 m pixel resolution digital image of the Sandusky River referenced to the same map reference system.

Total Station cross-section acquisition and processing:

A Sokkia™ SET 5E Total Station was used to survey 11 new river cross-sections for use in the hydrodynamic model. The total station was centered over the ground control points and elevations were measured. Cross-sections were measured perpendicular to the flow of the river at approximately 1 m resolution spacing (i.e., the resolution). The surveys were conducted on 10 September 2006 and 10 October 2006.

Each point in the cross-sections was post-processed in Microsoft Excel to correct for reflector pole height and total station height, giving the true elevation of the point with reference to the ground control point of the cross-section. Processed cross-sections were added to the hydrodynamic model for use in velocity and depth prediction scenarios.

2.4.2   Hydrodynamic Modeling

The one-dimensional hydrodynamic model used in this study was assembled by Cheng (2001) using the Mike-11 software (available from the Danish Hydraulic Institute, Denmark). The boundary conditions were defined by flows from four gauging stations established by the United States Geological Survey (USGS) in the Sandusky River Watershed. The lower boundary was given by a flow versus depth (Q~H) relationship at the Fremont gauge (gauge 04198000). The upstream boundary was a sum of the flow from the Upper Sandusky and Tymochtee stream gauges (gauges 04196500 and 04196800 respectively). Further, the summed flow was weighted by watershed between the gauges and RM 60.0 to account for the catchment area between the domain of the model and the gauging stations. The upstream boundary was located upstream of the

discontinued USGS gauging station at Mexico, Ohio (gauge 04197000), approximately 13 km upstream of the St. John Dam. Two major tributaries, Honey Creek and Wolf Creek, enter the Sandusky River downstream of the St. John Dam (Figure 2.3). Honey Creek enters the Sandusky River at RM 43.6 and Wolf Creeks joins Sandusky River at RM 22.3. Discharge at the upper boundary of Honey Creek was obtained from a real-time USGS gauging station, and discharge at the upper boundary of Wolf Creek was calculated from the discharge at Fremont weighted by the drainage area, as per Cheng and Granata (2006b)

The river network was modified by adding 11 new cross-sections that were acquired from the field survey to the cross-sections in the Cheng model. In some cases, new cross sections replaced existing ones. The total number of cross-sections in the hydrodynamic model was 100, although not all the cross-sections were used for habitat predictions.

The hydrodynamic model was calibrated against depth (and velocity derived from depth) data measured using a YSI Sonde deployed at RM 57.3. The YSI unit collected time series of pressure changes in the water column that were converted to depth after correcting for atmospheric pressure.

The YSI Sonde was mounted inside a PVC pipe (for protection), capped at both ends, and fixed to the streambed using chains with long metal stakes driven into the river substrate. The Sonde was placed in an area of the cross-section at RM 57.3 that displayed the average depth for the cross-section. This allowed measurements to be

compared to data calculated by the hydrodynamic model. The Sonde recorded data every 30 minutes from 23 December 2005 to 27 January 2006 and captured several high flow events.

Depth derived from the YSI Sonde was converted to velocity using the Mannings equation:

$$Q = A*(R^{2/3}*S^{0.5})/n$$

where: Q is the discharge (in m^3/s), A is the cross-sectional area (in m^2), S is the bed slope (m/m), n is the Manning roughness coefficient (unitless).

The Manning roughness factor was assumed to be 0.03 from previous studies on the Sandusky River (Cheng et al. 2006). By varying Mannings n in the model, the best fit of modeled velocities to the field values was determined. The slope of the river was calculated using the ratio of the difference in the upstream and downstream riverbed elevation to the thalweg length.

To validate the predicted velocity and depth output, measurements of velocity and depth were made at RM 57.3 using a Sontek® FlowTracker™ acoustic doppler velocimeter (ADV) and a depth stick. The ADV was mounted on a depth rod and mean velocity was estimated at 6/10 depth of flow for horizontal (perpendicular and parallel to flow) velocity components sampled at 1 Hz over 30 sec. Mean velocities and depth were recorded perpendicular to the flow, starting at the bank and progressing across the stream to the opposite bank at 1.5 m increments or at major changes in bed geometry. The cross-section at RM 57.3 was chosen because of its ease of access from a road and its relatively shallow depth. Velocities and depths were spatially averaged for the cross-

section and plotted in Microsoft Excel against the modeled velocity and depth at the station. The field measurements were repeated three times to collect a range of flows on 22 December 2005, 17 January 2006, and 27 January 2006.

The Mannings coefficient in the model was varied to give the best calibaration to the YSI field data. Once calibrated, the model was used to simulate summer seasons (since summer is when the Greater Redhorse spawns) and output daily averages of depth and velocity at all cross-sections. Velocities and depth were acquired for the 2003 to 2005 summer season coincident with the pre- to post-dam removal period.

2.4.3 Habitat Suitability Modeling

Separate models were developed to create HSI values for the Greater Redhorse and stonefly species. The first model was developed in Microsoft Excel and only simulated habitat suitability for the Greater Redhorse. The second program was developed in an ArcGIS® environment using Visual Basic® (V 6.3) programming of ArcObjects™ for both the Greater Redhorse and stonefly.

Substrate Data:

The Geological Survey of the Ohio Department of Natural Resources (GS-ODNR) mapped substrate distributions and morphological features of the river channel for selected river sections. For the HSIs, the physical mapping used the most recent data available. Aerial photography of the river was acquired through county and state

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agencies. The Ohio State Plane NAD 83 datum was overlain on the aerial photography. Hard copies of the aerial photography were used in the field to map collected Global Positioning System (GPS) line and point data to the correct field locations

Two sets of field maps of the river reaches in the study areas were printed and coated with a clear protective acrylic finish making the field maps water resistant. Field crews carried laminated sheets defining substrate and river morphology for reference throughout mapping. During mapping, the substrate contacts were drawn on one set of maps and the morphology was drawn on the second set of maps. Point and line data were collected with a GPS Pathfinder Pro XRS® to place baseline data on field maps and to map reaches with complicated substrate locations and morphology.

Two data collection methods were used depending on river conditions in 2003. Reconnaissance mapping was required when the river reach was too deep and/or swift to walk. Reconnaissance mapping was completed from a boat or canoe, using metal prods to probe the channel bed every 1.5 m to identify substrate contacts. Detailed substrate mapping methods were preferred and used when the river could be walked using a GPS to collect line and point data of most substrate and morphology contacts.

The data were in polygon forms useable in a GIS package. Each polygon represented a river area with differing substrates. Substrates ranged from mud, sand, and clay to bedrock and cobble/pebble areas. The substrate polygons were reclassified into 4 classes in ArcGIS 9.1® for Greater Redhorse spawning suitability according to Healy (2002). This 2003 polygon layer was used for both pre- and post-dam removal scenarios because data after 2003 were not available.

Greater Redhorse Suitability:

Habitat suitability of Greater Redhorse was first scrutinized by published velocity and depth suitability curves (Healy 2002). Four different life stages of the Greater Redhorse comprise each velocity and depth curve. The spawning life stage was studied due to the extensive wealth of knowledge available and because of the importance to establishing a breeding population. According to Healy, "Higher gradient sections of river with embedded, coarse substrates are used by spawning redhorse. Spawning occurs in riffles or runs in medium to large streams with moderate velocities (3.8-116.9 cm/s), shallow depths (10-100 cm), and gravel or cobble substrates" (Healy 2002). A substrate index (I_s) assumed gravel and cobble to be the ideal for spawning Greater Redhorse. The depth and velocity suitability curves were divided up into even HSI increments (0.2) for the ArcGIS model. However, the first two classes in the ArcGIS model were divided into a finer scale to discriminate between no to poor suitability.

Stonefly Suitability:

Stoneflies are probably the second most abundant aquatic insect in streams. Many stoneflies are known as clean-water insects, as they are often restricted to highly oxygenated water (Pennsylvania State University 2001). Stoneflies were used for the habitat analysis because they are susceptible to changes in substrate, water quality, and hydrodynamic parameters. Typically, stoneflies prefer pebble/cobble/boulder substrate with high velocities and relatively moderate depths (>60 cm). According to Jowett et al. (1990), stoneflies prefer a cobble substrate. Specifically the stonefly species, *Strophopteryx fasciata,* prefers a cobble substrate, velocities ranging from 10 to 100

cm/s, and depths ranging from 7 to 60 cm (Orth and Maughan 1983). According to

Larson (2001) substrate movement can be expected at 2.7 m/s for a 10 cm diameter

substrate. Because the preference curve of Orth and Maughan did not show an upper limit

for velocity suitability, a velocity of 2.7 m/s (i.e., bed movement) was assumed for the

upper limit of the stonefly velocity suitability. The upper limit of the depth preference

curve terminated at 50 cm, however, using the regression curve in Orth and Maughan

(1983) a value of 60 cm was used. Although these preference curves are species

specific, they were used because this species is known to inhabitat Ohio waters and were

the only stonefly species for which both velocity and depth suitability curves were

available.

Habitat Suitability Index (HSI):

Individual substrate (I_S), velocity (I_V), and depth (I_D) suitability were defined for

each of the model domain cross-sections. Creation of the HSI was established using a

geometric mean. The geometric mean was used over an arithmetic mean since it gives a

more conservative estimate by allowing the HSI to go to zero if any of the HSI values

incorporated in the geometric mean were zero. The HSI was defined for each cross-

section and each time step in the summer season for the two models and is:

$$HSI = (I_V * I_D * I_S)^{1/3}$$

Excel Model:

Seasonal velocity and depth data at each cross-section were acquired from the 1-D hydrodynamic Mike-11™ model. The model was used to generate daily average velocity and depths for 32 cross-sections, from RM 55.0 to 47.0 in the Sandusky River, between the dates of 1 January 2003 to 24 July 2004. 32 cross-sections were used because the initial model domain only used these cross-sections. Spawning of Greater Redhorse is said to occur from the months of May through July (Healy 2002).

For each of the 32 cross-sections bed substrate, velocity, and depth were defined daily for the spawning season. Velocity and depth data were exported from the Mike-11™ model and imported into Excel as text files. Substrate data were visually interpreted from the ArcGIS® layers for each cross-section. The interpretation was then imported into Excel as being either suitable (1) or unsuitable (0) for each cross-section (only 2003 substrate data were available).

Based on a velocity suitability index (I_v), cells were coded to allow only velocities that were suitable (1) if they fell in the range between 3.8-116.9 cm/s. Velocities that fell below or above this range were labeled unsuitable (0) for spawning of Greater Redhorse.

A depth suitability index (I_d) was created much the same way as the velocity. The suitable depth (1) was defined between depths of 10-100 cm. Any value of depth that the Mike-11™ model predicted to be outside of this range was considered unsuitable (0) for Greater Redhorse spawning potential. Using the HSI equation above, velocity, depth, and substrate suitability layers were then overlain to acquire the final HSI. Each cross-

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section was defined by daily average HSI values. Finally, an average summer HSI was calculated for each of the 32 cross-sections calculated as the percent of time the HSI equals 1.

To define the river network, a polygon layer was developed for the HSI category in ArcGIS®. A 300 m swath, comprising 150 m upstream and downstream of the cross-section, defined each cross-section. Due to uneven spacing of the cross-sections in the river network, overlap of the HSI polygons existed. When this occurred, the area of overlap was divided up evenly between the two polygons. The layers were then manually labeled with the output from the Excel model. Finally, the HSI scores were reclassified into six distinct classes: no suitability (0-0.05), poor suitability (0.0501-0.2), fair suitability (0.201-0.3), moderate suitability (0.301-0.4), good suitability (0.401-0.5), and high suitability (0.501-0.65).

GIS Model:

The GIS model is very similar to the Excel model in that its inputs, such as velocity, depth, and substrate are similar. The major differences are how the model defines the suitability layers and how the model predicts the final habitat suitability of Greater Redhorse and stonefly. Also, because of the addition of new cross-sections the 2004 and 2005 model output created 45 distinct HSI values while the 2003 output still displayed the same number of HSI values previously. These cross-sections were chosen from the 100 cross-sections of the Mike-11 model to define the HSI model domain.

Velocity and depth inputs from the Mike-11 ™ model were imported into Excel and saved as a separate database 4 files (i.e. one velocity, depth, and substrate file). The

database files had to be saved in special ways. First, each database 4 file could only have one worksheet per file, since saving the file with multiple worksheets caused an error. All the cells of the worksheet were manually formatted (i.e., a number with as many decimal places as one desired) and the area of data coverage was selected (in order for the file to save the data in the correct format). The final product had a header column, a date column, and the velocity, depth, and substrate data. Database 4 files were used because it was the required format for the GIS model.

The GIS model was programmed in Visual Basic® (V 6.3) using ArcObjects™, an object-oriented programming tool for ArcGIS®. The program is divided into four separate graphical user interfaces (GUI). Each module allows the user to choose input database files from a file location to run the HSI calculations. The four separate modules are discussed below. The entire code for the program can be found in the Appendix A.

Velocity, Depth, Substrate Modules:

The velocity module requires the user to choose a database file for the input velocity. When a file has been selected, the program allows the user to select an output location and name for the velocity suitability layer. After naming the file, the program runs a routine that evaluates each cell value according to the programmed suitability parameters. Once the velocity layer has been created, the module informs the user that the code block is complete. The output velocity HSI values are based on a look-up table for the suitability curves established by Healy (2002). Suitability values are divided into six categories where the first two categories (no suitability 0-0.1 and low suitability 0.1-0.2) were the only two categories spanning a range of 0.1. All other categories were evenly spaced by an HSI value of 0.2.

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The depth and substrate modules are exactly the same as the velocity module aside from calculating the final depth and substrate HSI layers. The depth suitability values are derived from depth preference curves (Healy 2002). Again, the suitability was divided into six categories as above.

HSI Module:

The HSI module uses the newly created suitability layer for velocity, depth, and substrate to create a final HSI layer. The module has two buttons that the user can control. One button allows the user to clear the HSI module of all its inputs so the user may start a new calculation. The other button (Create New HSI layer) allows the user to proceed with the HSI calculations process. The module prompts the user to choose an output file location for the total HSI layer. The module then prompts the user to name the file so it is easily accessed. Once this process is initiated, the module executes the code that overlays all three suitability layers and creates a total HSI layer based on the geometric mean.

The user is then prompted to select a location for a new database 4 shapefile. This file is the final HSI layer that will be stored in the attribute table of an ArcGIS® polygon file. The user is prompted to name the database 4 shapefile. The module then executes the code by calculating the average value of all daily total HSI values.

The module prompts the user to select the folder where an input shapefile (.shp) is located. The model assumes that the user has previously created a polygon file (.shp) in ArcGIS® with the exact number of polygons as cells in the newly created database 4 shapefile. Selecting the shapefile initiates code to duplicate the input shapefile and add a "Percent_Suit" column to the new shapefiles attribute table to preserve the original

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shapefiles attributes. Once the duplicate shapefile is named, the program adds the database 4 shapefile to the attribute table of the duplicate polygon file. The module then runs code that takes the value in each cell of the attribute table and color-codes the value according to a predetermined scale of suitability. Six categories are created by the code. The suitability ranges are as follows: no suitability (0-0.1); low suitability (0.1-0.2); low/moderate suitability (0.2-0.4); moderate suitability (0.4-0.6); moderate/high suitability (0.6-0.8); and high suitability (0.8-1.0). Suitability ranges were chosen in this fashion to evenly divide the habitat suitability indices.

2.4.4   Statistical Analyses

Two separate statistical procedures were used to understand the relationship of data sets from year to year. Paired and unpaired two-tail t-tests were used to compare the differences in the average values of the data sets from 2003 to 2005 at a 95% confidence level. Resulting p-values determined the statistical difference in the data. P-values that were less than the tested alpha value (typically $\alpha = 0.5$) were considered statistically significant.

The second procedure was adopted from Zar (1984) that compares simple linear regression equations at a 95% confidence interval to compare upstream to downstream patterns in HSI. The procedure pools all data and results in a test statistic (t) that is compared to a critical t-value (t*) in a set of t-tables. If the absolute value of the test statistic is greater than the critical t-value then the null hypothesis can be rejected and it is determined that the regression equations are statistically different.

2.5 Results

2.5.1 Hydrodynamic Model Calibration

The calibration of the hydrodynamic model was done by regressing the field data at the Mexico cross-section (RM 57.3) to hydrodynamic data, where the best fit line resulted for a Mannings n = 0.03 (Figure 2.4). The model showed the same trend in both velocity and depth, matching the peaks and durations of the hydrograph during high to moderate depths (Figure 2.5) and velocities (Figure 2.6). However, the model underestimated smaller peaks during lower flows. Overall, it overestimated the depth on average of 0.143 m and underestimated the velocity on average of 0.0685 m/s. The depths to velocities measured in the field using the ADV were generally lower than those of the model output but tended to follow the same trend (Figure 2.7).

2.5.2 Excel Model Results

The spatial distribution of habitat suitability generated from the Excel model of the Greater Redhorse showed the region upstream of the dam had the greatest recovery from the pre-restoration (Figure 2.8) to the post-restoration (Figure 2.9) period. HSI values generally increased from 2003 to 2004 for both the reservoir backwater and the downstream reaches (Figure 2.10). The Excel model gave a positive spatial trend from upstream to downstream for the 2003 and 2004 data sets (Figure 2.11), however, the slopes of the regression lines from 2003 to 2004 HSIs were not statistically different at the 95% confidence interval (α (2)=0.05, DF=60, t=1.94, t*=2.00). Average, yearly HSI

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values of 0.147 in 2003 and 0.244 in 2004, were statistically different (p< 0.05 at a 95% confidence interval), illustrating the increase in habitat suitability from pre- to post-dam removal, and resulting most from increases in the backwater region.

2.5.3   GIS Model Results

Like the Excel output, the GIS distribution of Greater Redhorse HSIs showed the most improvement from pre-restoration (Figures 2.12) to post restoration (Figures 2.13 and 2.14) in the reaches upstream of the dam. Downstream of the dam structure, HSI values increased from 2003 to 2005 for areas in the backwater reservoir (Figure 2.15). HSIs had a positive trend from upstream to downstream in all years (Figure 2.16). Differences in slopes of spatial HSI data between the 2003 and 2004 HSIs and between the 2003 and 2005 HSIs were significant (α (2)=0.05, DF=69, $t_{03,04}$=3.353, $t_{03,05}$=4.21, t^*=1.994), however no differences were found between the 2004 and 2005 regressions. Average, yearly suitability ranged from 0.152 in 2003, to 0.246 in 2004, and 0.298 in 2005. There were statistically significant differences at the 95% level from 2003 to 2004 HSIs ($p<0.05$) and 2003 to 2005 HSIs ($p<0.05$). No statistical differences were found from 2004 to 2005 HSIs ($p = 0.253$).

Spatial distributions of stonefly habitat from the GIS model also showed regions of low HSI values upstream of the dam prior to restoration (Figure 2.17), which increased in subsequent years following the restoration (Figures 2.18 and 2.19). From 2003 to 2005, habitat recovery occurred in specific regions in both the backwater reservoir and downstream of the dam (Figure 2.20). Despite the apparent trend from upstream to downstream in HSI (Figure 2.21), no statistical differences were found between any slope

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comparisons (α (2)=0.05, DF=, $t_{03,04}$=1.02, $t_{03,05}$=1.71, $t_{04,05}$=0.81, t*=1.994). Still, stonefly suitability decreased slightly from 2003 to 2004, but increased gradually from 2004 to 2005. The average, annual suitability values were 0.191 in 2003; 0.183 in 2004; 0.211 in 2005. No statistical differences in annual means were detected at a 95% confidence interval between the 2003 and 2004 HSIs (p = 0.868), the 2003 and 2005 HSIs (p = 0.717), or the 2004 and 2005 HSIs (p = 0.556).

2.6   Discussion

2.6.1   Hydrodynamic model evaluation

The hydrodynamic model gave realistic values of both mean depth and velocity and provided valuable spatial data for calculating suitability indices. The overestimates of the model at low flows may have been the result of the placement of the YSI Sonde in the flow field. The Sonde was placed in a shallow portion of the cross-section, which was most affected at low flows. Placement of the Sonde is important in calibrating the hydrodynamic model because the model averages both the depth and the velocity in the cross-section. If the Sonde were shallower than the average depth of the cross-section, it would explain the discrepancies in the model calibration.

The ADV data also corresponded to the hydrodynamic model output, falling near the regression line. However, one of the measured velocities (on Jan. 17th) was calculated with only six data points near the banks because of high water levels. Generally, high water levels restricted measurements in the main channel, which could skew the field data to lower velocities. Although the three measured velocities do not lie

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directly on the regression line, they do tend to follow the same trend as the model output. Overall, the model gave a very good representation of low to moderate flows, which are most important for the two target species studied.

2.6.2   Greater Redhorse habitat model evaluation

Both the Excel model and the ArcGIS® model clearly indicate an improvement in the former backwater of the dam one year after removal of the dam. The depth suitability within the confines of the backwater reservoir for both models shows no suitability in 2003 as a result. Although velocity suitability indicated fairly good conditions for Greater Redhorse spawning in 2003, the final HSI was zero since it was calculated as a geometric mean of all the suitability metrics. After dam removal, depth suitability in the backwater increased substantially as water levels dropped, while velocity suitability changed very little. The increase in depth suitability caused an increase in the final HSI score in most sections. However, below the dam structure depth and velocity suitability from 2003 to 2004 stayed fairly constant because the dam had very little to no effect on velocity in the downstream cross sections. Some cross-sections showed a slight decrease in depth suitability, which could be the result of water levels rising slightly due to reconnection of the upper reaches of the river.

Between 2004 and 2005, the ArcGIS® model indicated a slight increase in depth and velocity suitability. The increase in suitability was the result of more optimal flow conditions during the spawning season. Because the model is driven by hydrograph data, any climactic change that causes more ideal flow regimes ultimately affects the habitat suitability of the Greater Redhorse.

The change in spawning area of the Greater Redhorse increased from zero during pre-removal (2003) conditions to approximately 13 acres for post-removal (2004) conditions using the Excel and GIS models. The GIS model in 2004 and 2005 gave a greater area for potential spawning of the Greater Redhorse. This would support increased spawning of Greater Redhorse, provided the adults were available to spawn (Gillenwater et al., 2006). Although substrate data in 2004 and 2005 are limited, it is believed that cobble (suitable) substrate in the upstream and downstream study area have not yet undergone much transport (Cheng and Granata, 2006a). As the river slowly recovers to a natural flow regime, the importance of substrate and its transport should increase. Within the backwater, the river should begin to transport sands from the reservoir leaving cobble/pebble substrate and resulting in a change in the amount and distribution of suitable habitat for the Greater Redhorse.

2.6.3 *Stonefly habitat model evaluation*

Results of the ArcGIS® stonefly habitat model indicate a slight increase in the final HSI score from 2003 to 2005. The increase in suitability was the result of small increases in depth suitability. Although the velocity suitability gradually decreased from 2003 to 2005, the change in depth suitability was great enough to increase the final HSI score.

Comparison of the model output to field samples, analyzed by Kenneth A. Krieger (The National Center for Water Quality Research, Heidelberg College, Ohio) shows some similarities in improvements of habitat for macroinvertebrate species when compared to HSI values (Table 2.1). Macroinvertebrates were collected in 2003 and

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2004 using Hester-Dendy samplers. Samples were sorted and keyed to species for Invertebrate Community Index (ICI) calculations. Two sites in particular coincided with cross sections that are part of the stonefly model (RM 50.2 and 52.2). In 2003 ICI data collected at these two sites indicated macroinvertebrate communities that did not meet warm water habitat standards. Comparing these numbers to the model output reveals some similarities with the HSI stonefly model. The model predicted no suitability of stoneflies at RM 52.2 that coincides with the ICI data output. However, at the dam site (RM 50.2) the model predicted relatively high suitability while the ICI calculation recorded low numbers of macroinvertebrates.

Post-removal ICI values increased at both stations. The model predicted improvements in the HSI scores one year after removal that coincided with the field data at RM 50.2. This increased the HSI from poor/moderate class to a moderate rating. However, at RM 52.2 the model predicted no suitability. The ICI score at this site increased a little, yet it still did not meet warm water habitat standards that indicated a poor habitat. The poor habitat rating coincided with the poor suitability rating that the model predicted.

The spatial trends in the ICI (Figure 2.22) generally agree with the stonefly HSI trends (Figure 2.21). The values for HSI and ICI upstream at Mexico stay fairly constant from 2003 to 2004. In the reservoir backwater both HSI and ICI increase from pre- to post-dam removal. Although the trend is less apparent in the ICI data (due to lack of data), there is still a clear increase in ICI scores.

One reason for the discrepancies in the ICI field data versus the model output deals with how the model operates. The stonefly model was based on very specific inputs (i.e., velocity, depth, and substrate). Substrate did not affect the model results from one year to the next since it remained constant. Thus, the model was solely based on changes in velocity and depth. If velocity or depth were out of the range of the preference curve, the HSI model predicted no suitability. However, the model fails to take into account changes in substrate and other morphological changes, such as woody debris and root wads. These additions to the system after dam removal would increase macroinvertebrate abundances because of high colonization potential. Therefore, the model is merely a prediction tool. It is not a tool to estimate the diversity of macroinvertebrates in the river system. Rather it is a tool to indicate areas of the river that have a high or low potential for colonization of stoneflies.

The preference curves derived from Orth and Maughan (1983) are defined up to a habitat suitability index of 1. However, both the preference curves show a tendency for higher values of velocity and depth to attain a HSI value of 1. If higher velocities and depths indicate a higher suitability, the final HSI score could indicate more suitable habitat for stonefly. Orth and Maughan (1983) note that their needs to be additional studies to refine the upper limit of the velocity preference curve of all the research species. They investigated several other resources that suggested that some species that they studied could possibly tolerate higher velocities. Increasing velocity thresholds for species, such as the stonefly, could more accurately represent the habitat suitability of these organisms.

2.6.4 *Excel and ArcGIS ® Model applicability to other systems*

Both the Excel and ArcGIS® model could be applied to other river systems and organisms rather simply. The major advantage of the Excel model is software availability. Because Microsoft Excel is part of almost every new computer system bought, it is both uncomplicated and cost effective to use. The Excel version of the HSI model is easily reprogrammed to accommodate new organisms and river networks. Therefore, the model is able to predict habitat suitability for many other species.

The disadvantage to Excel modeling is the massive amount of user input needed. All cells within the model have to be manually programmed for each new species or riverine system. Ultimately, the amount of time spent programming cells in the model depends on the amount of data to be processed.

On the other hand, GIS is a much more effective tool to conduct habitat suitability modeling because of its quick and easy results. The user only needs to be concerned with the inputs into the system, such as velocity, depth, or substrate, once the initial model programming has been established. The user could also choose to change the inputs (i.e., temperature, turbidity, and percent cover) to more accurately represent the species under study. However, choosing this route would require reprogramming of the modules within the program and creation of a new polygon layer river network because the polygon layer is very specific to the river network being modeled.

The main disadvantages to the GIS modeling technique are software availability, its specificity to a particular species, and creation of a polygon layer. The ArcGIS® software used for the modeling is widely available. The cost of the software to an individual, however, can be great enough to direct them towards another modeling

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technique, such as the Excel version. The models in this study were designed to calculate habitat suitability for Greater Redhorse and stonefly. While these two organisms have very distinct suitability ranges, many riffle-pool dwelling organisms have similar habitat requirements. Future development of the model could help to accommodate more disparate habitat types of organism within the Sandusky River domain and other river networks.

The polygon layers that graphically display the models output must be manually created with the exact number of polygons related to the number of cross-sections within a river network. Creating the polygon layer involves manual digitization of each individual polygon. The initial procedure takes time and patience. Although once developed, the polygon layer can be used for many different flow scenarios as long as the number of cross sections in the hydrodynamic model stays constant. Otherwise, multiple polygon layers would have to be created (much like this model) to accommodate different scenarios.

The Greater Redhorse and stonefly models created in this study compare to very few other studies. Gillenwater and Granata (2006) used a very similar procedure to this model. Programming of ArcGIS® by way of Visual Basic programming allowed linking of a 1-D hydrodynamic model to a walleye habitat model. However, output from the walleye model used interpolation procedures to produce a raster layer of suitability. Although the procedures used to create HSI layers are similar (i.e., Visual Basic programming), the output from the Greater Redhorse and stonefly models are different in that they give a reach scale suitability, while the Gillenwater model produces fine-scaled HSI maps.

Other studies have used hydrodynamic and ecological models in conjunction with a GIS (Tiffan et al. 2002; Store and Jokimaki 2003) or models that used public domain software, such as HEC-RAS (Bockelmann et al. 2004). However, these models only compare in the overall changes in aquatic systems. The use of GIS is limited to simple procedures of raster calculations and visual display. GIS programming of graphical user interfaces was not implemented. Therefore, these models can be seen as one of a few select procedures, which use a GIS to its full potential.

2.7   Conclusions

The habitat suitability models in this study clearly indicated an improvement in potential habitat availability for the two species studied as the natural hydraulic conditions returned in the former reservoir after dam removal. Generally, the result of the stonefly model mimicked field data on invertebrate abundances. The use of habitat suitability models to predict changes in river networks following disturbances or restoration efforts is a fast and effective way to predict improvements in river systems. The models allow researchers to deduce information about a river system that is sometimes infeasible and very time intensive to measure. With the development of GIS modeling techniques, species-specific data can be displayed spatially and temporally without the need to incorporate cumbersome population models. Advancements in coupling of GIS-based models with 2-D hydrodynamic models could improve on the prediction tools at the reach scale, by specifying transverse distribution of habitat. The higher spatial resolution models could more precisely locate pool and riffle areas where a suitable habitat for certain species exists.

2.8 TABLES AND FIGURES
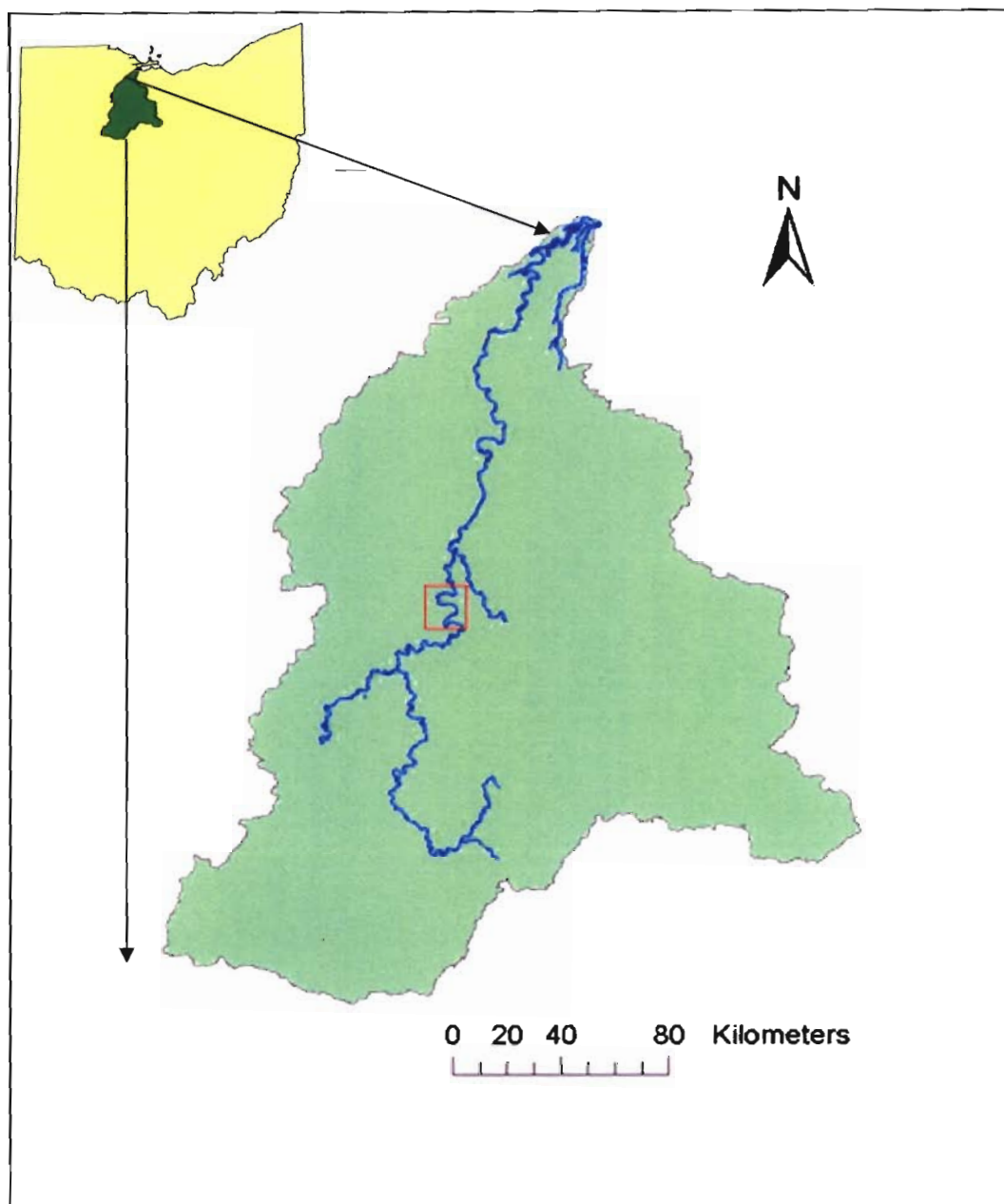
Figure 2.1. Map of the Sandusky River watershed located in the north central portion of Ohio. The boxed insert shows the location of the study area.
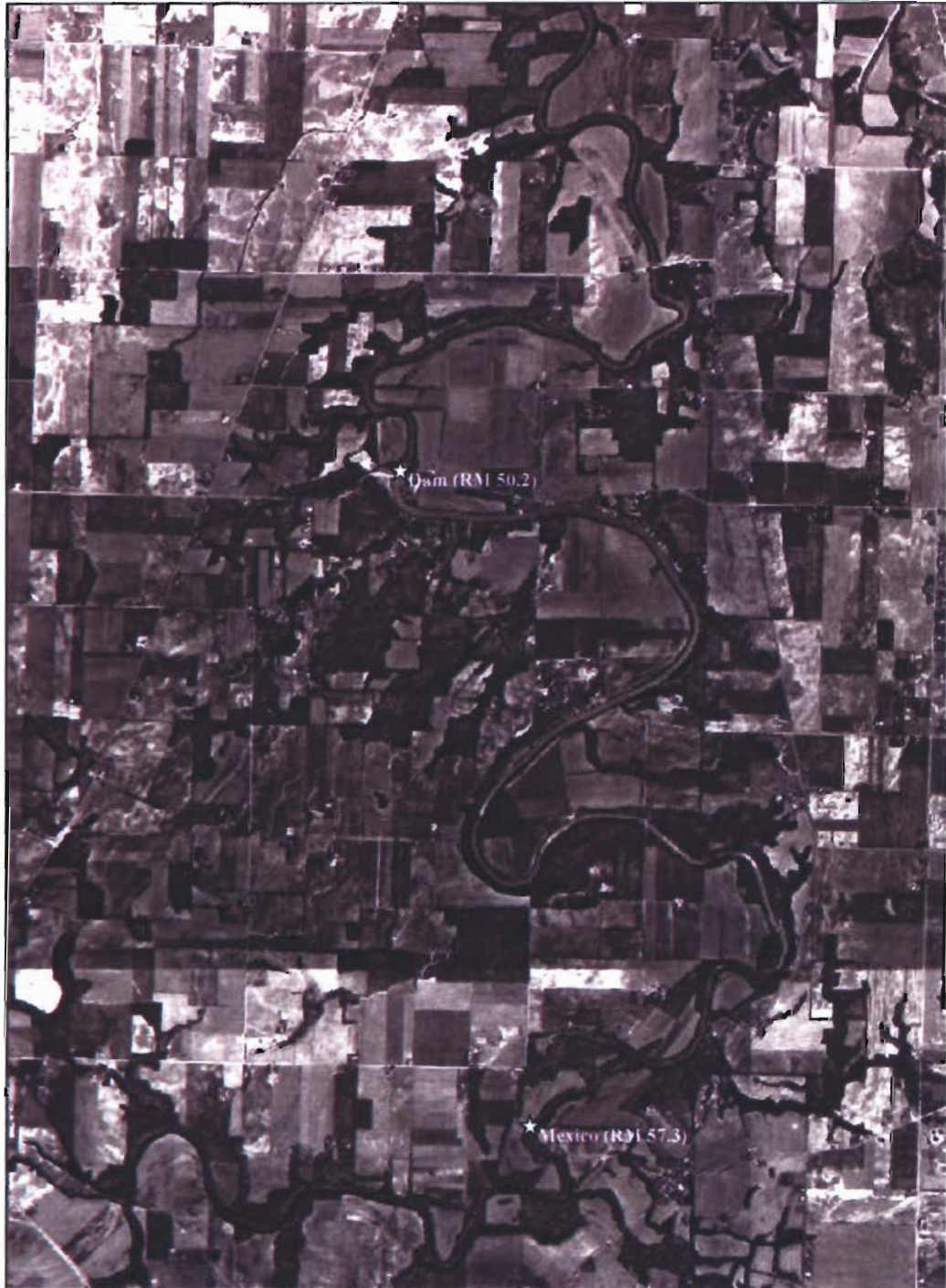
Figure 2.2. A digital aerial photograph of the study area (source: Franklin County
(Ohio) aerial photography data files). The location of the sampling
station used in the calibration of the model is designated by the star at river
mile RM 57.3 (lower right) and the dam is located at RM 50.2 (top center).

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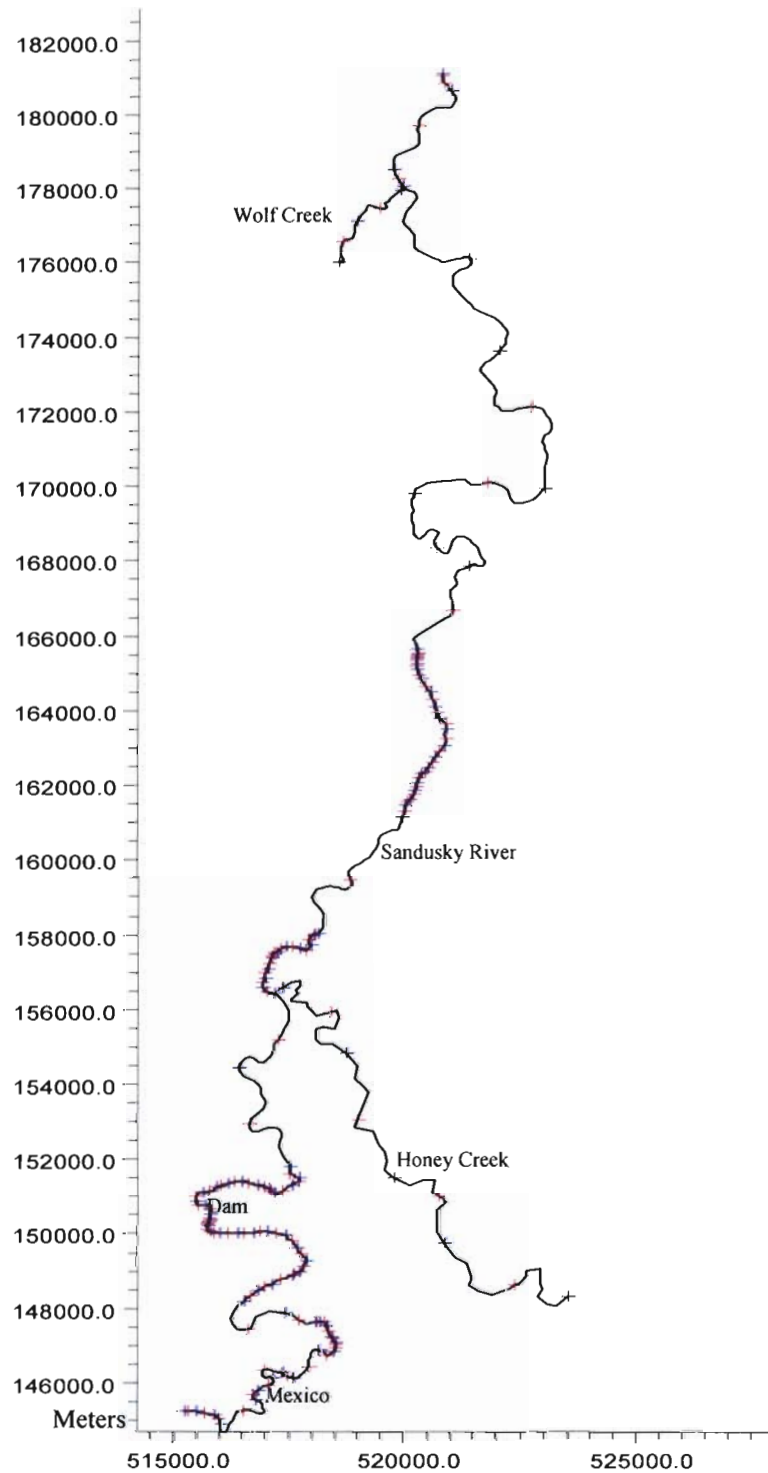
Figure 2.3. Mike-11 network. Blue dots represent cross-sections in the hydrodynamic model.
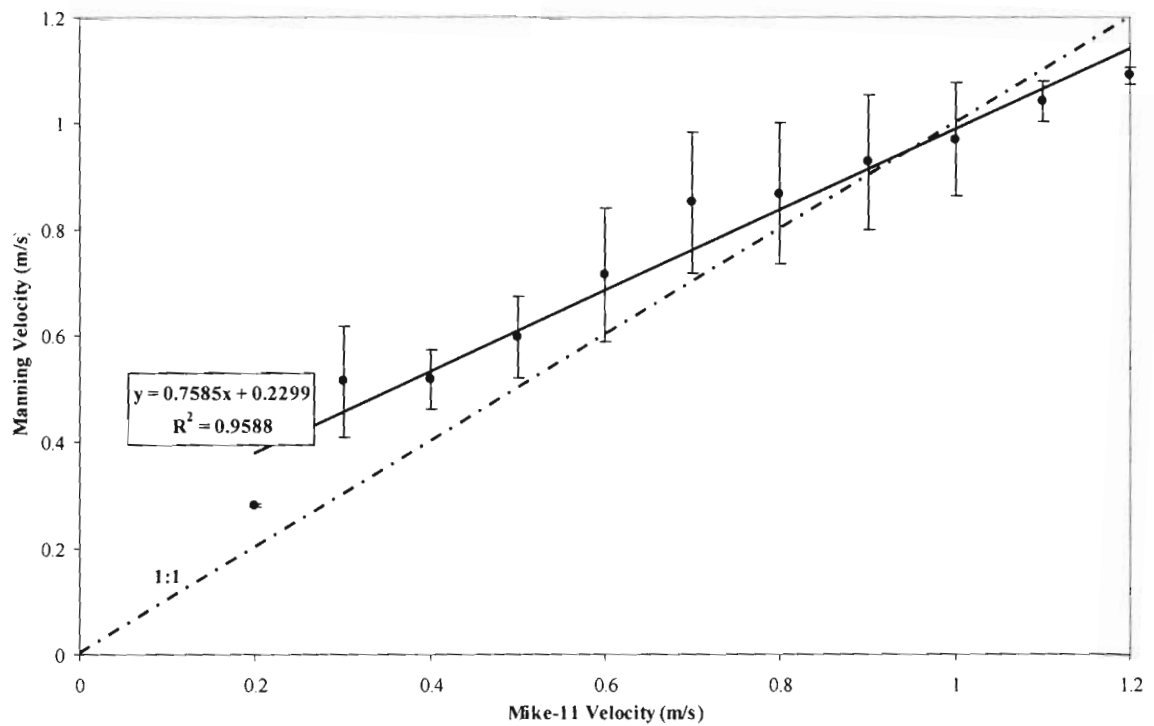
Figure 2.4. Manning velocity compared to Mike-11 velocity for velocity calibration. The trend line indicates a very close approximation to a one to one relationship (one standard deviation).
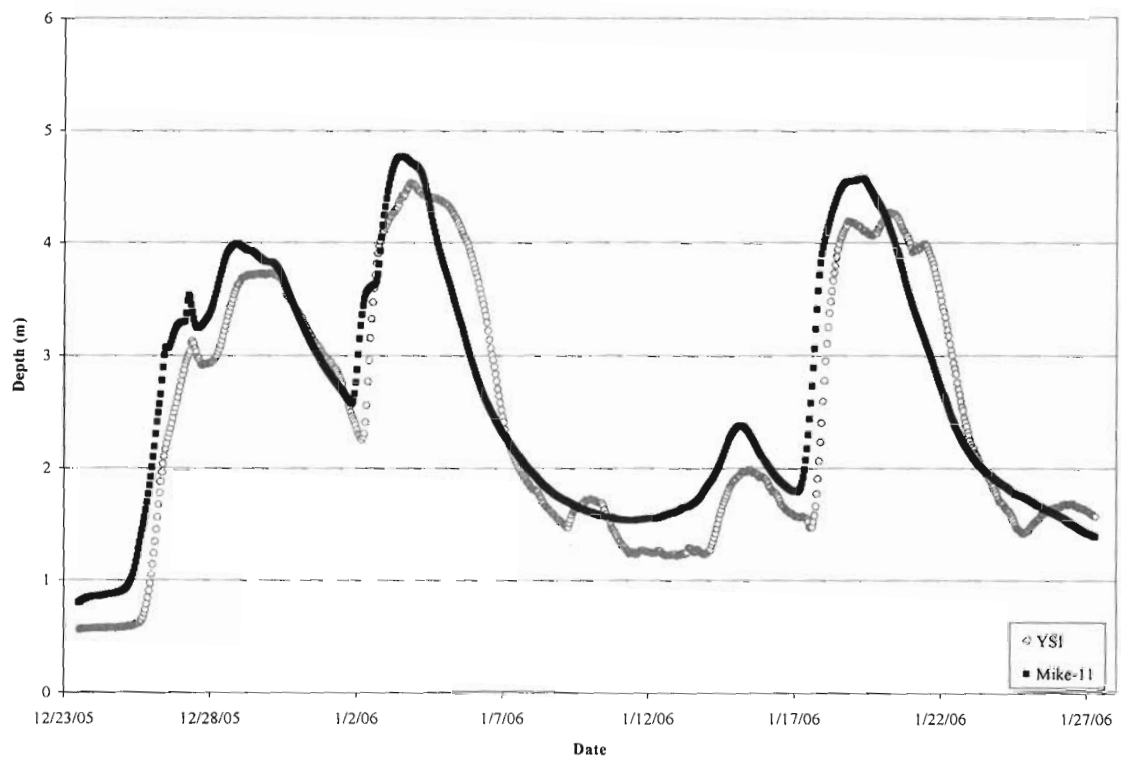
Figure 2.5. Graph of YSI Sonde depth measurements compared to Mike-11 model
output at RM 57.3 (Mexico cross-section).
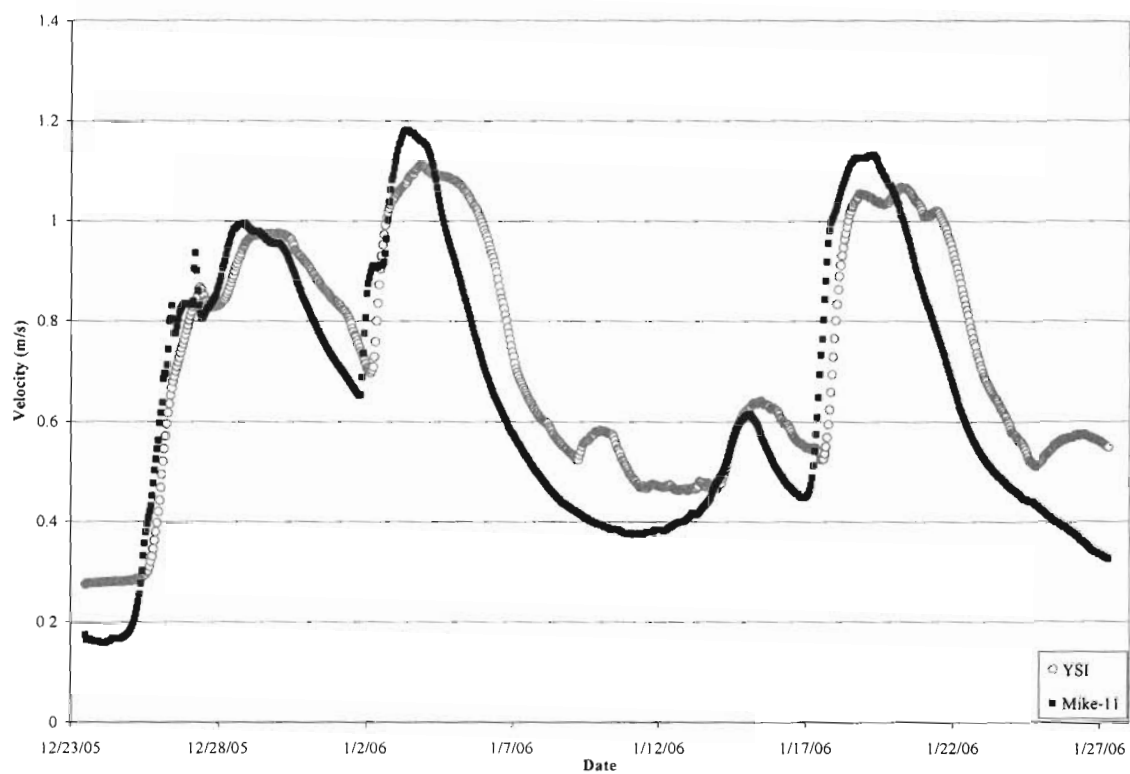
Figure 2.6. Graph of YSI Sonde calculated velocity measurements compared to Mike-11 model output at RM 57.3 (Mexico cross-section).
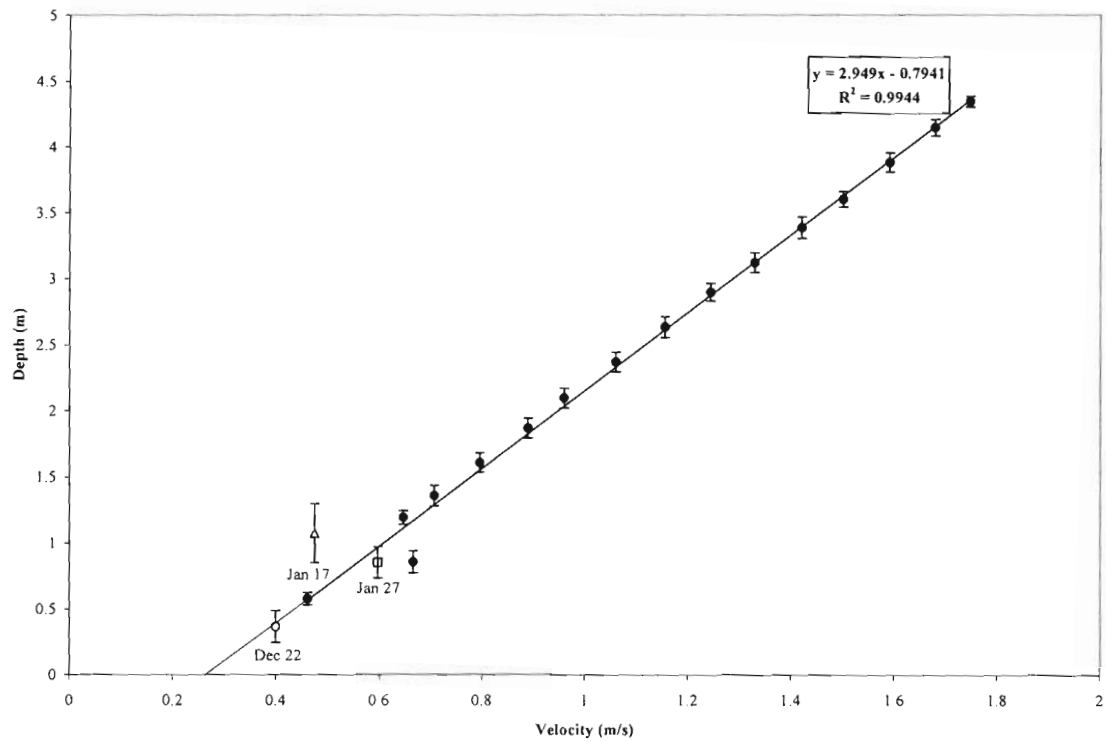
Figure 2.7. Acoustic Doppler Velocimeter (ADV) data plotted against Mike-11 model output for the Mexico cross-section (RM 57.3). The regression indicates a good fit of the velocity versus depth data. The ADV data collected indicates a good calibration of the hydrodynamic model (one standard deviation)
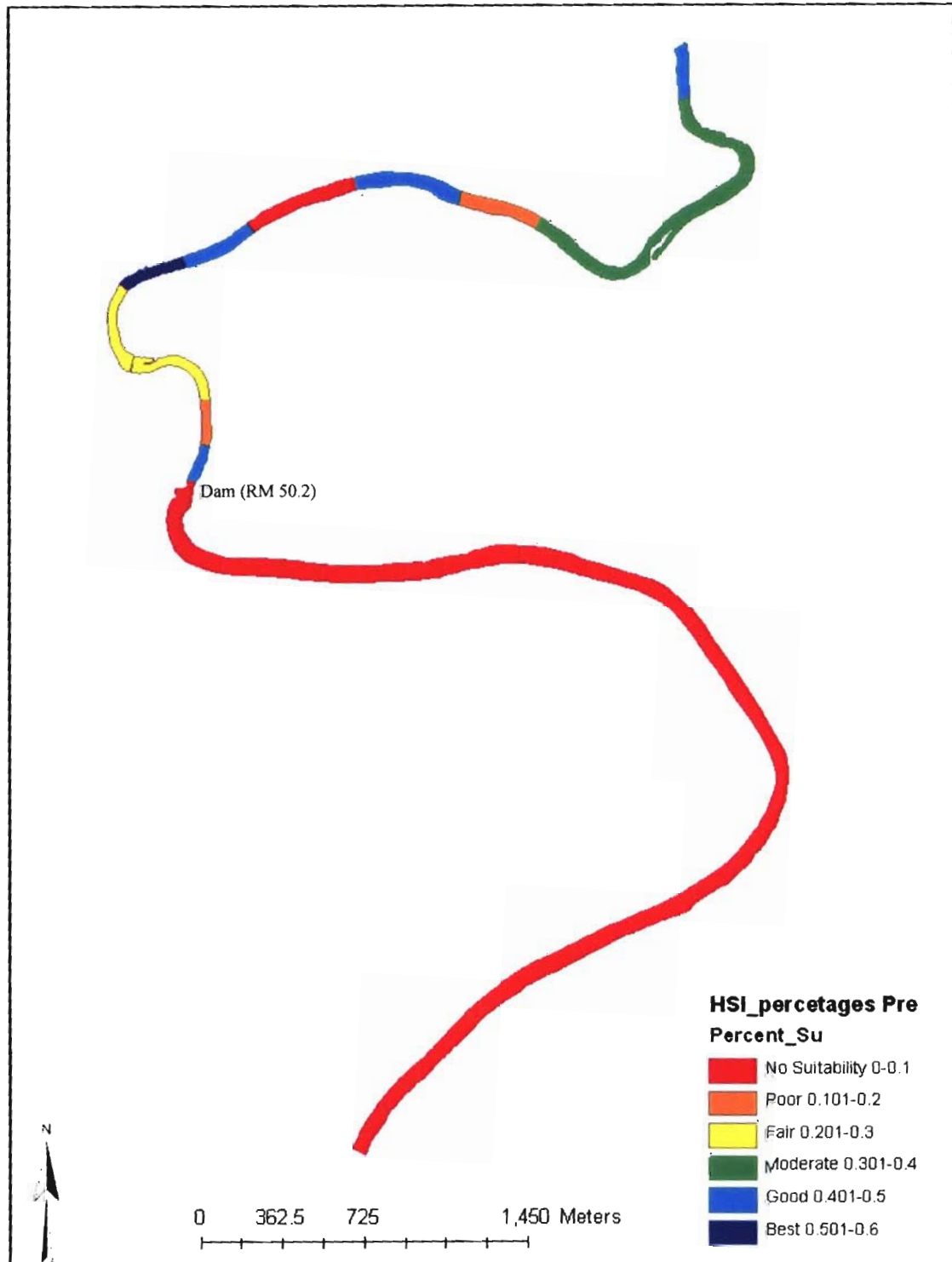
Figure 2.8. Pre-restoration HSIs from the Excel model output of the Greater Redhorse in 2003. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
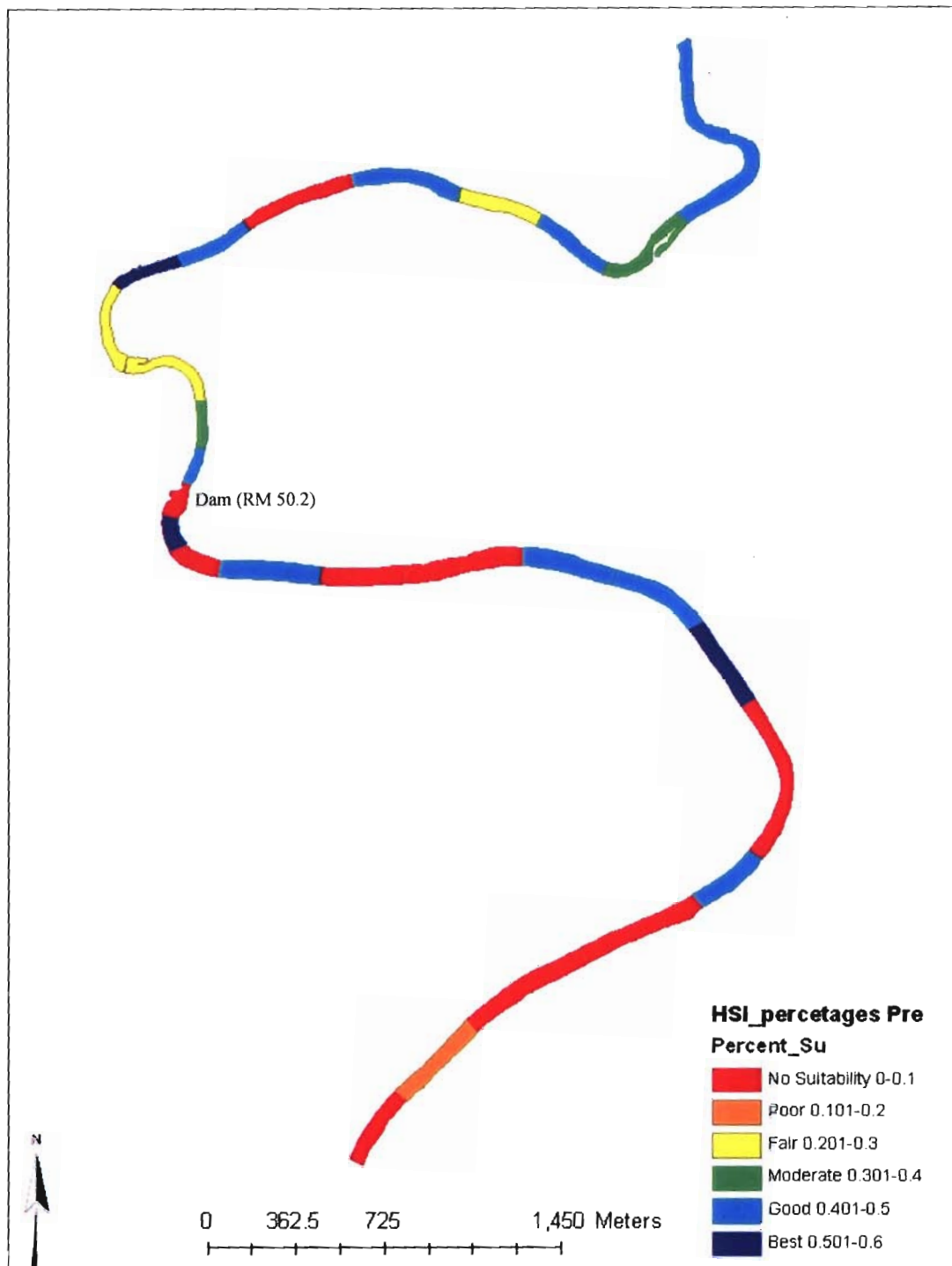
Figure 2.9. Post-restoration HSIs from the Excel model output of the Greater Redhorse in 2004. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
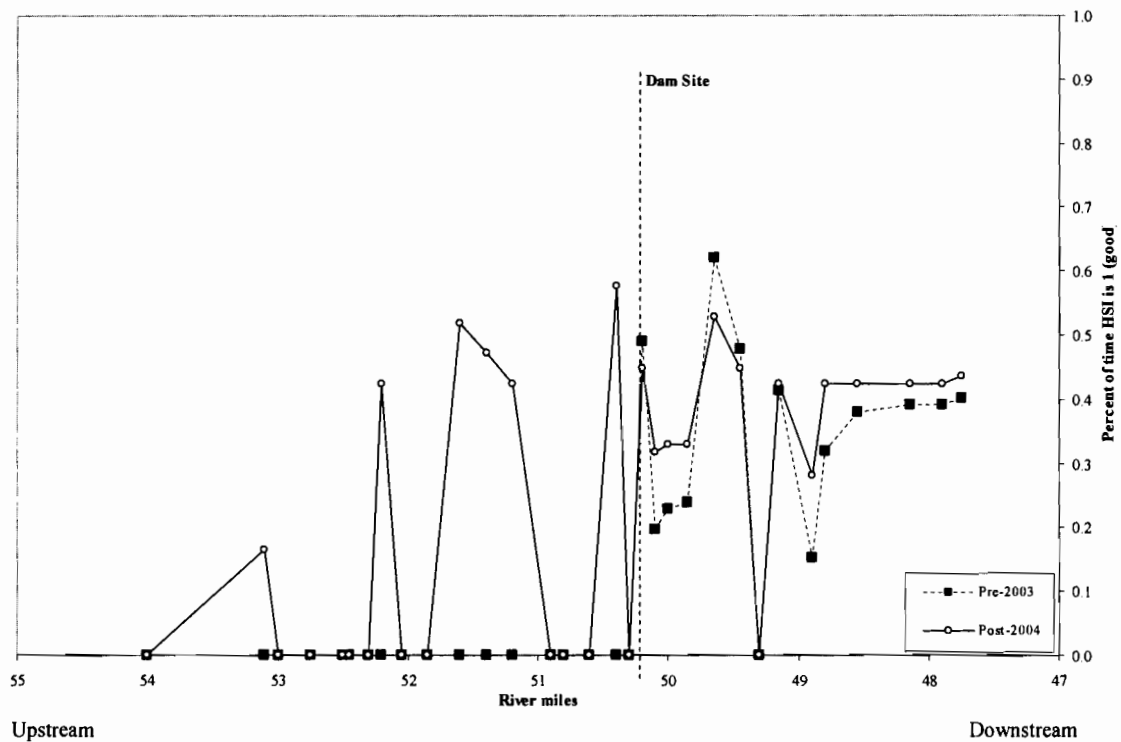
Figure 2.10. Excel model output of HSI plotted with line connecting data. Values in 2004 tended be higher in value for both the backwater reservoir and downstream of the dam.
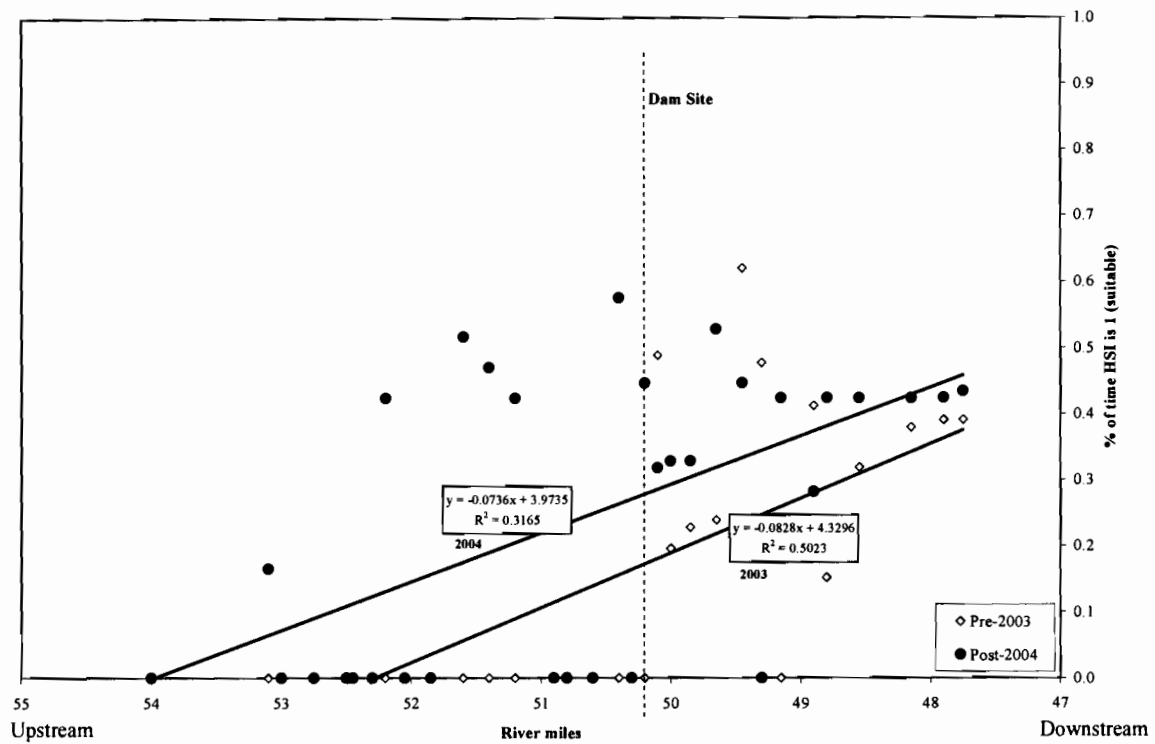
Figure 2.11. The trend in the longitudinal profile of HSI from the Excel model of the Greater Redhorse showing regression
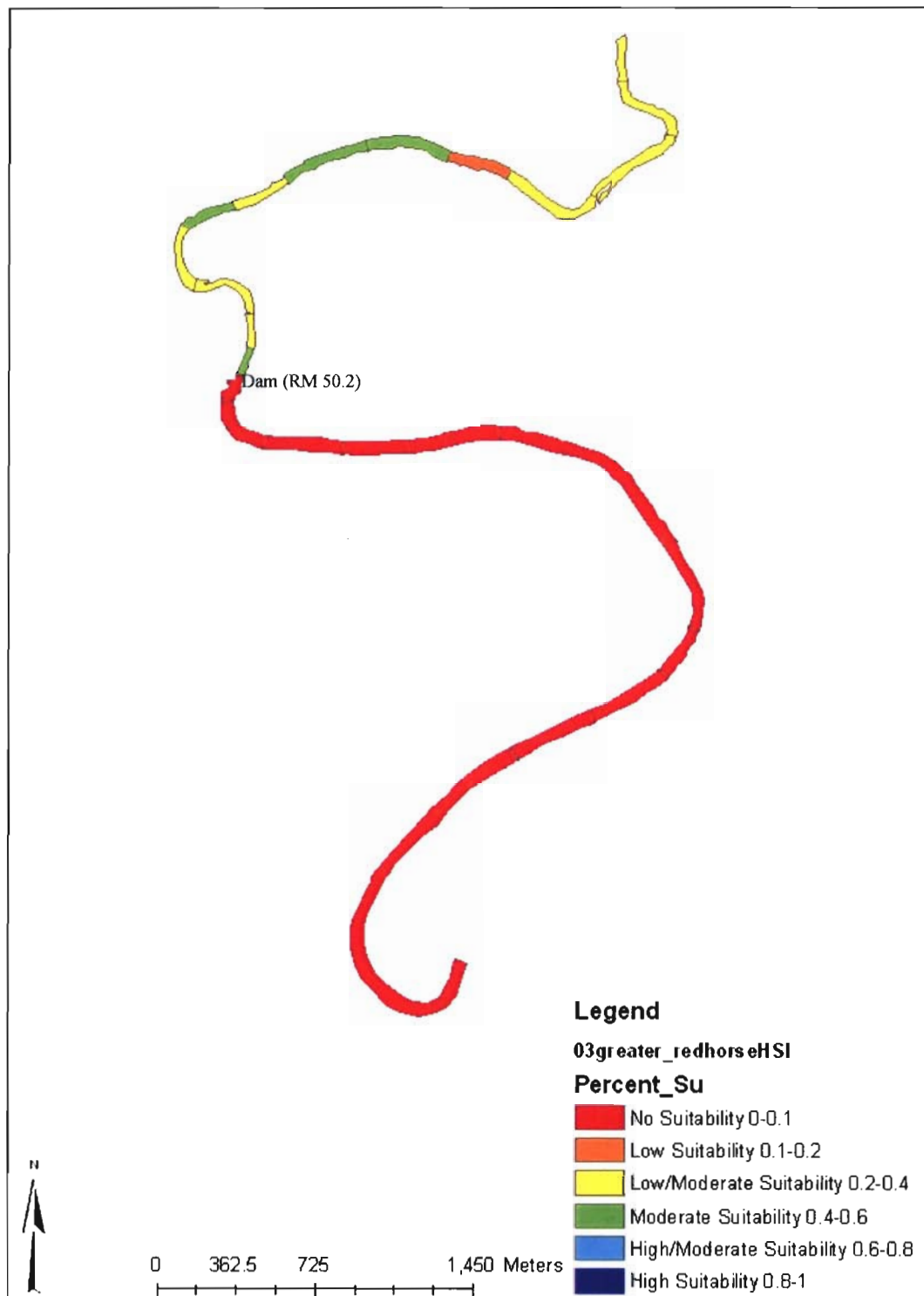
Figure 2.12. Pre-restoration HSIs from the ArcGIS model of Greater Redhorse in 2003. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).

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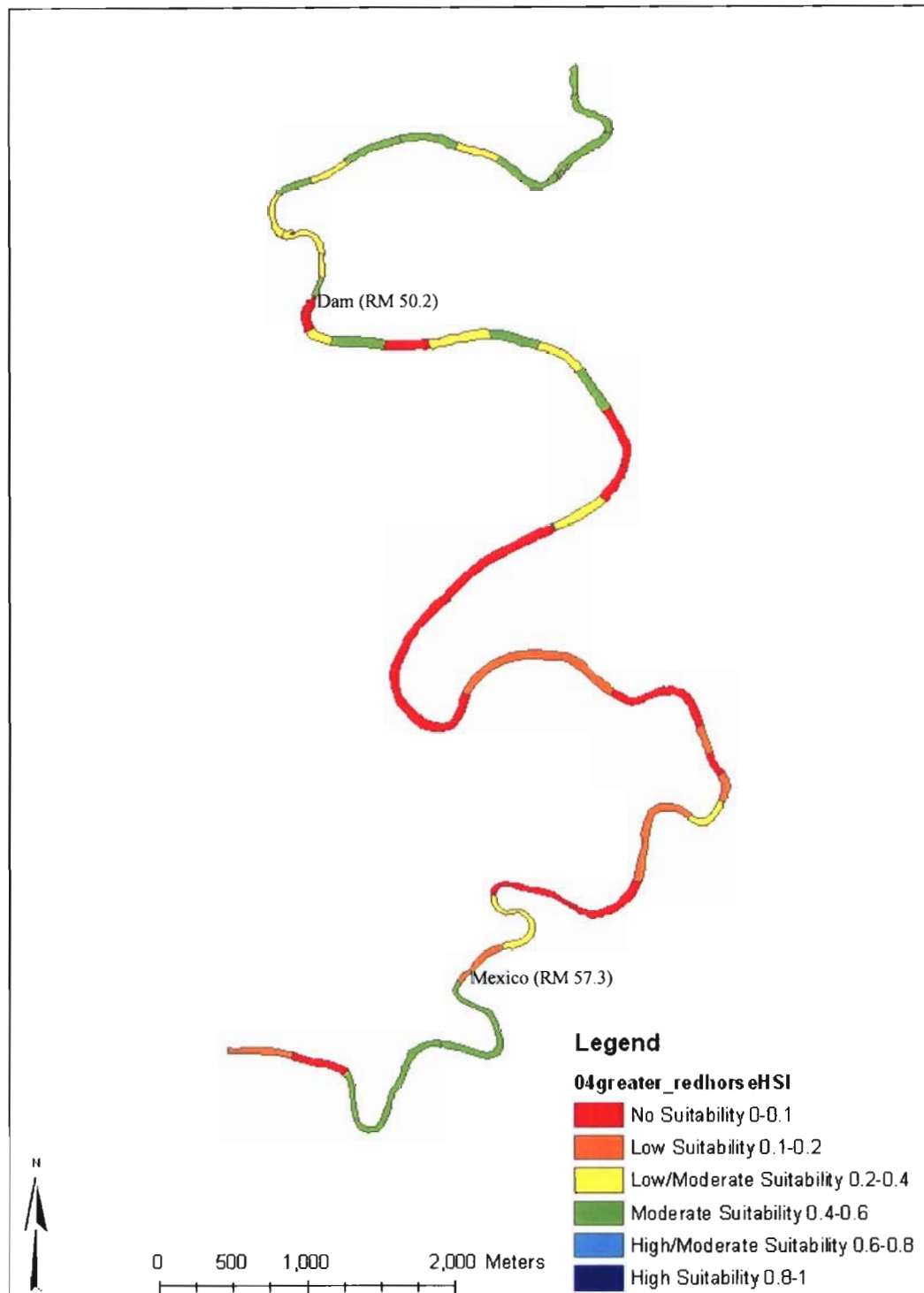
Figure 2.13. Post-restoration HSIs from the ArcGIS model of Greater Redhorse in 2004. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).

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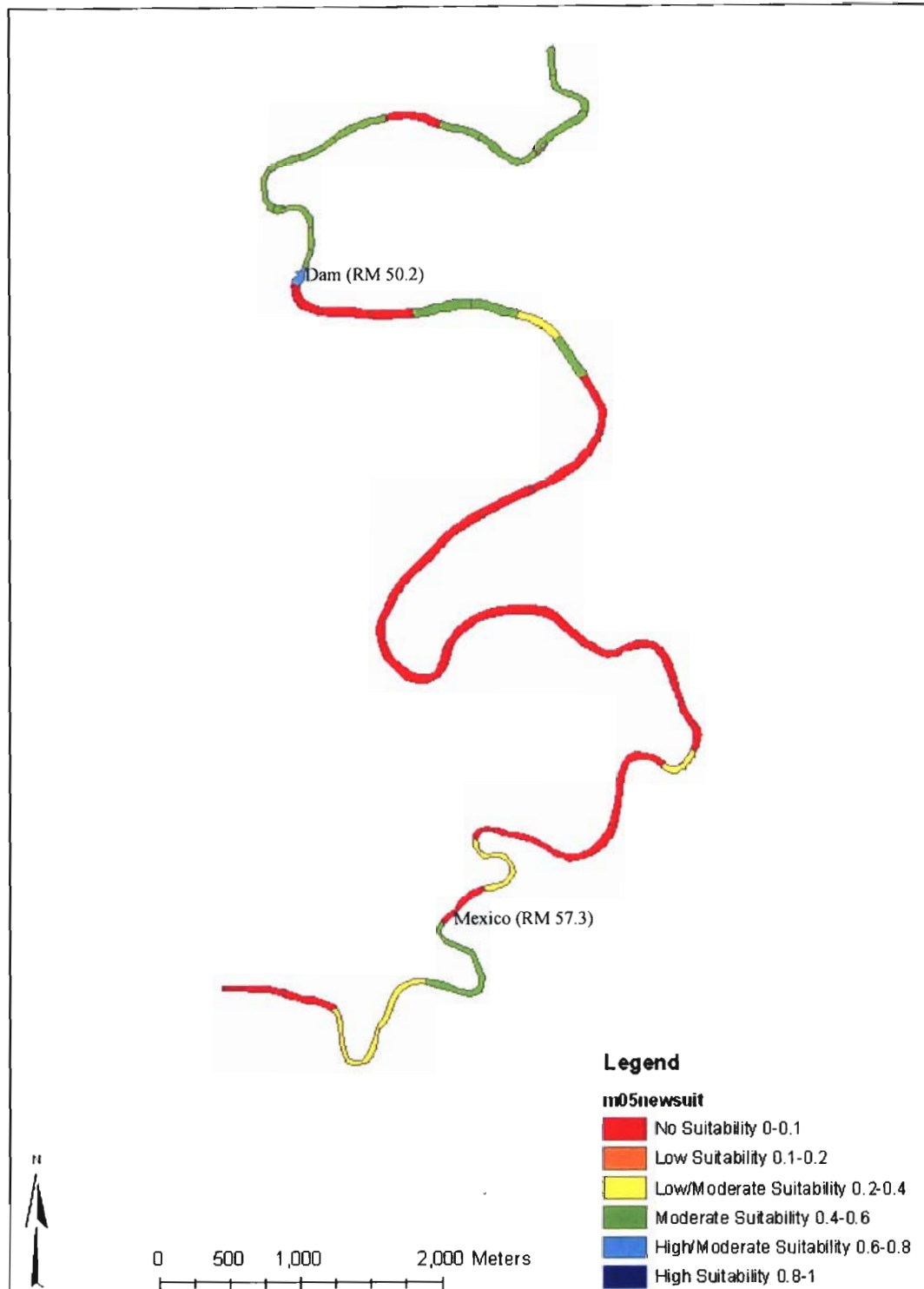
Figure 2.14. Post-restoration HSIs from the ArcGIS model of Greater Redhorse in 2005. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
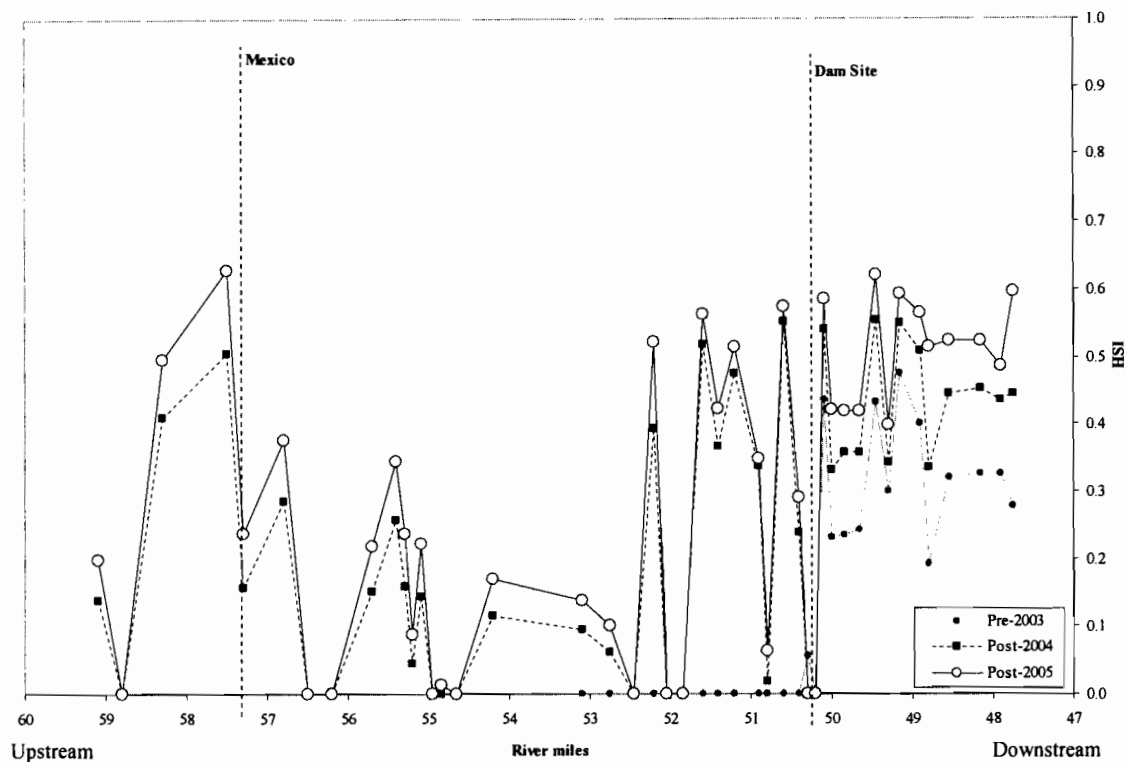
Figure 2.15. Longitudinal profile of HSI from the ArcGIS model of Greater
Redhorse for pre-restoration (2003) and post-restoration (2004-2005)
years.
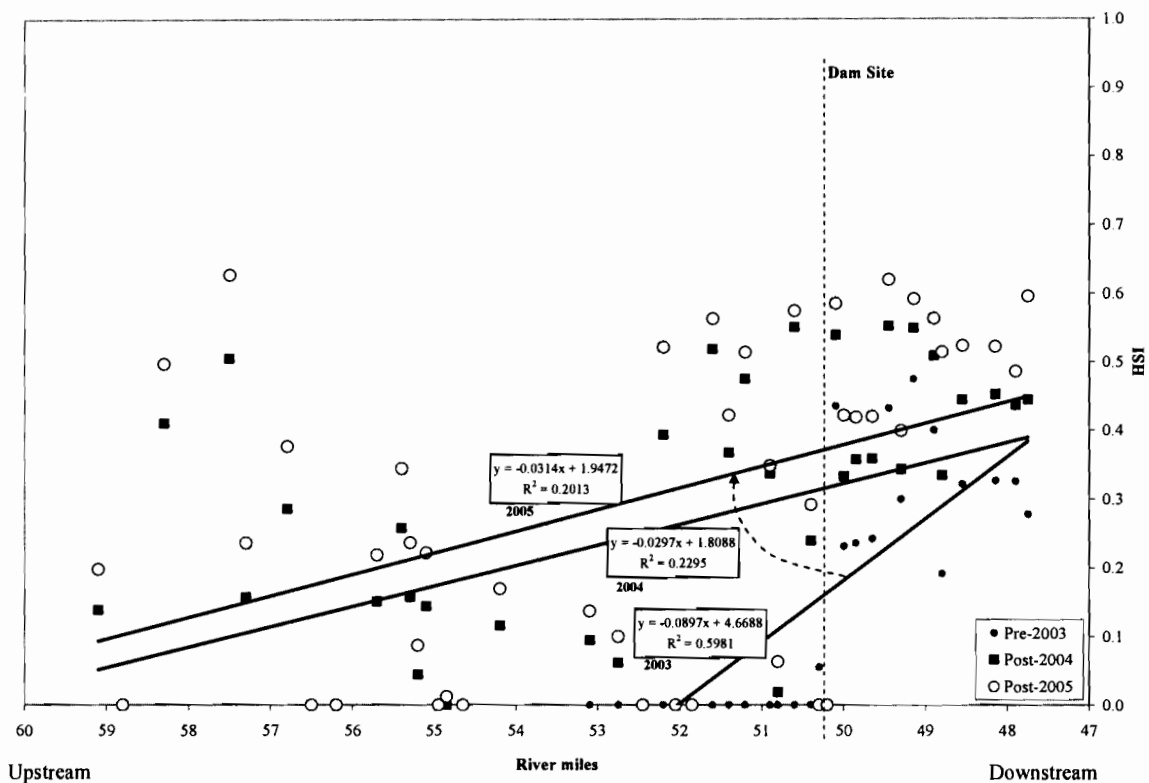
Figure 2.16. The trend in the longitudinal profile of HSI from the ArcGIS model of the Greater Redhorse showing regression line and root mean squares. Data are for pre-restoration (2003) and post-restoration (2004-2005) years and the arrow indicates the increase in values of HSI from 2003 to 2005.

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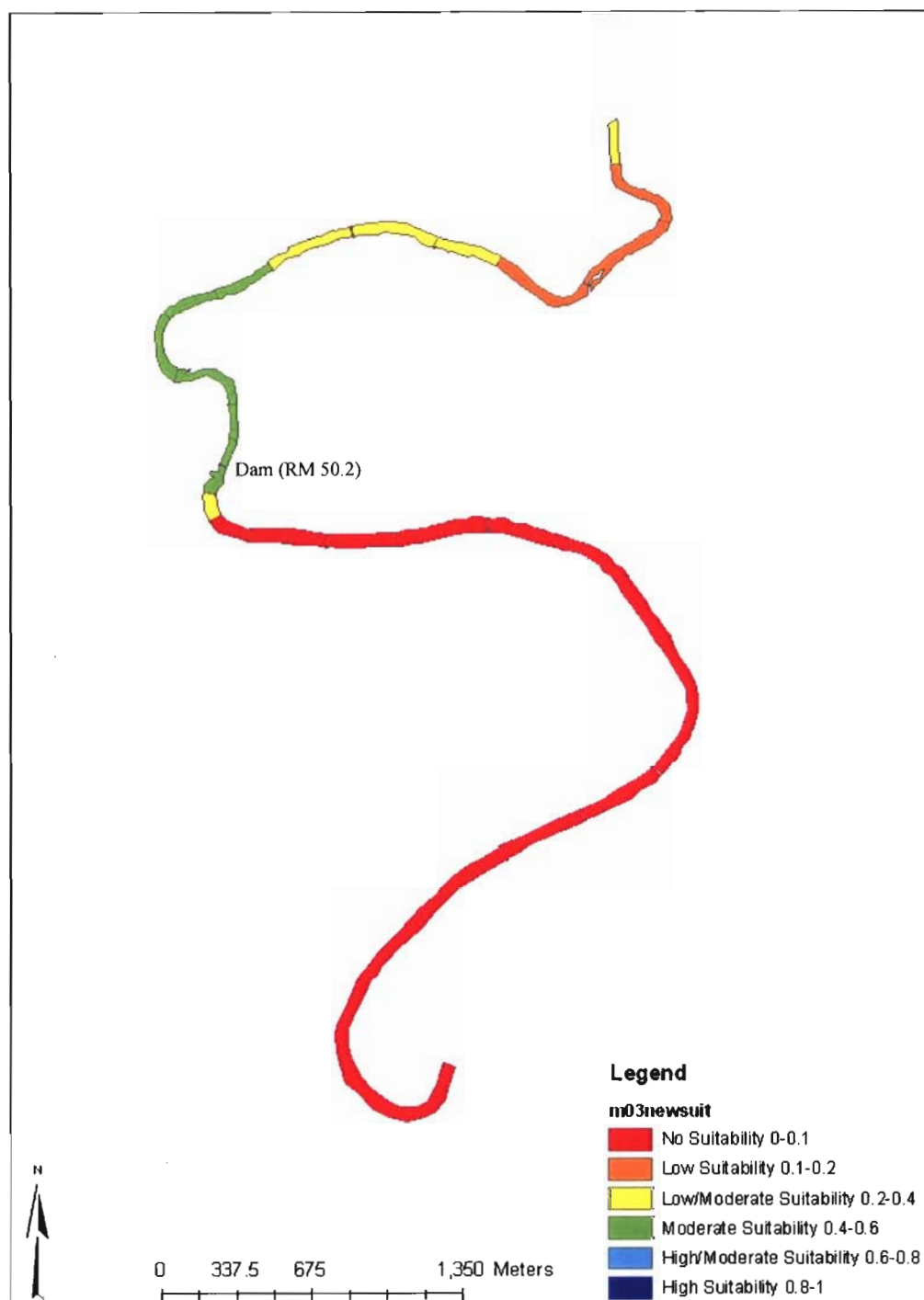
Figure 2.17. Pre-restoration HSIs from the ArcGIS model of stonefly for 2003. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
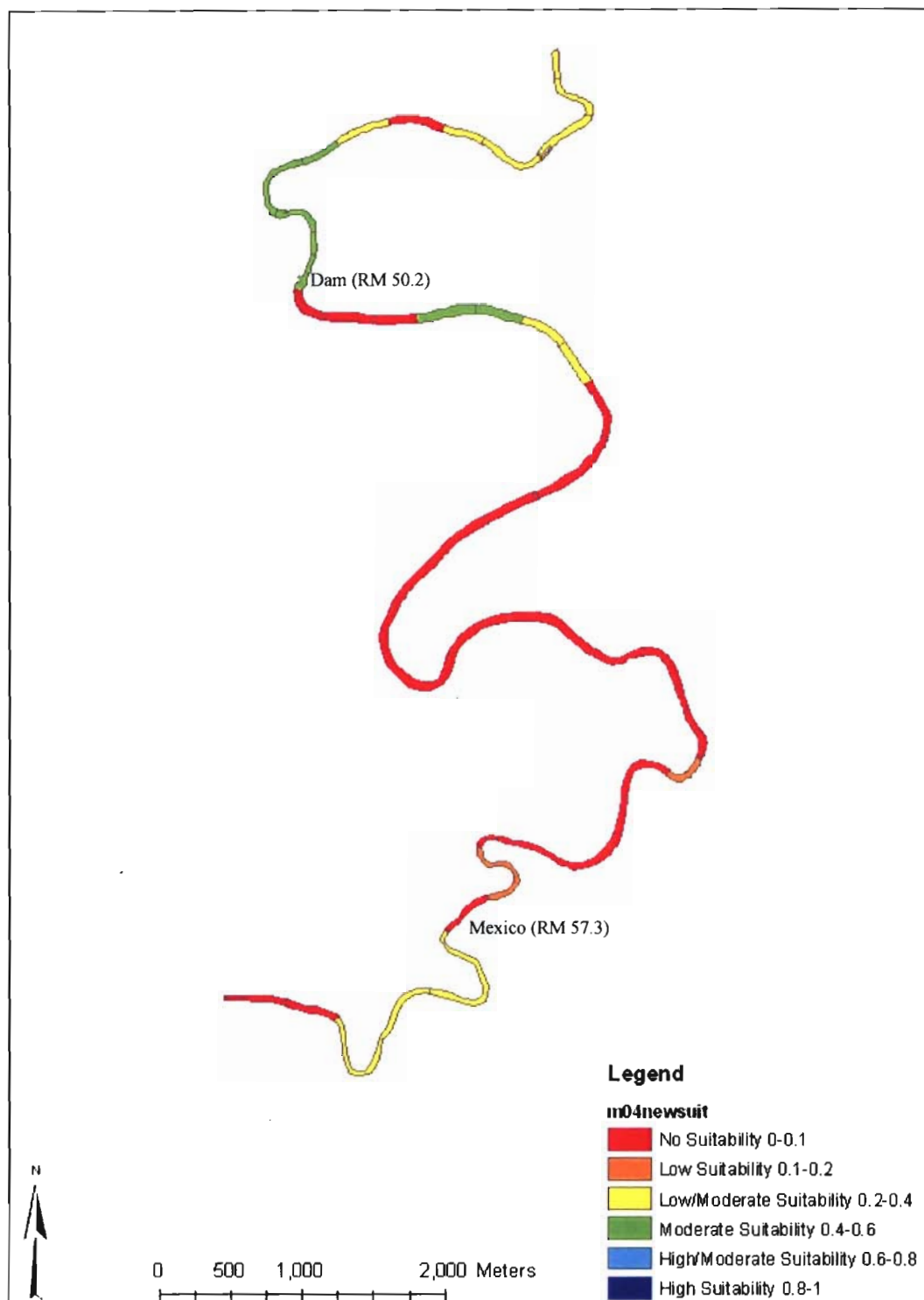
Figure 2.18. Post-restoration HSIs from the ArcGIS model of stonefly in 2004. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
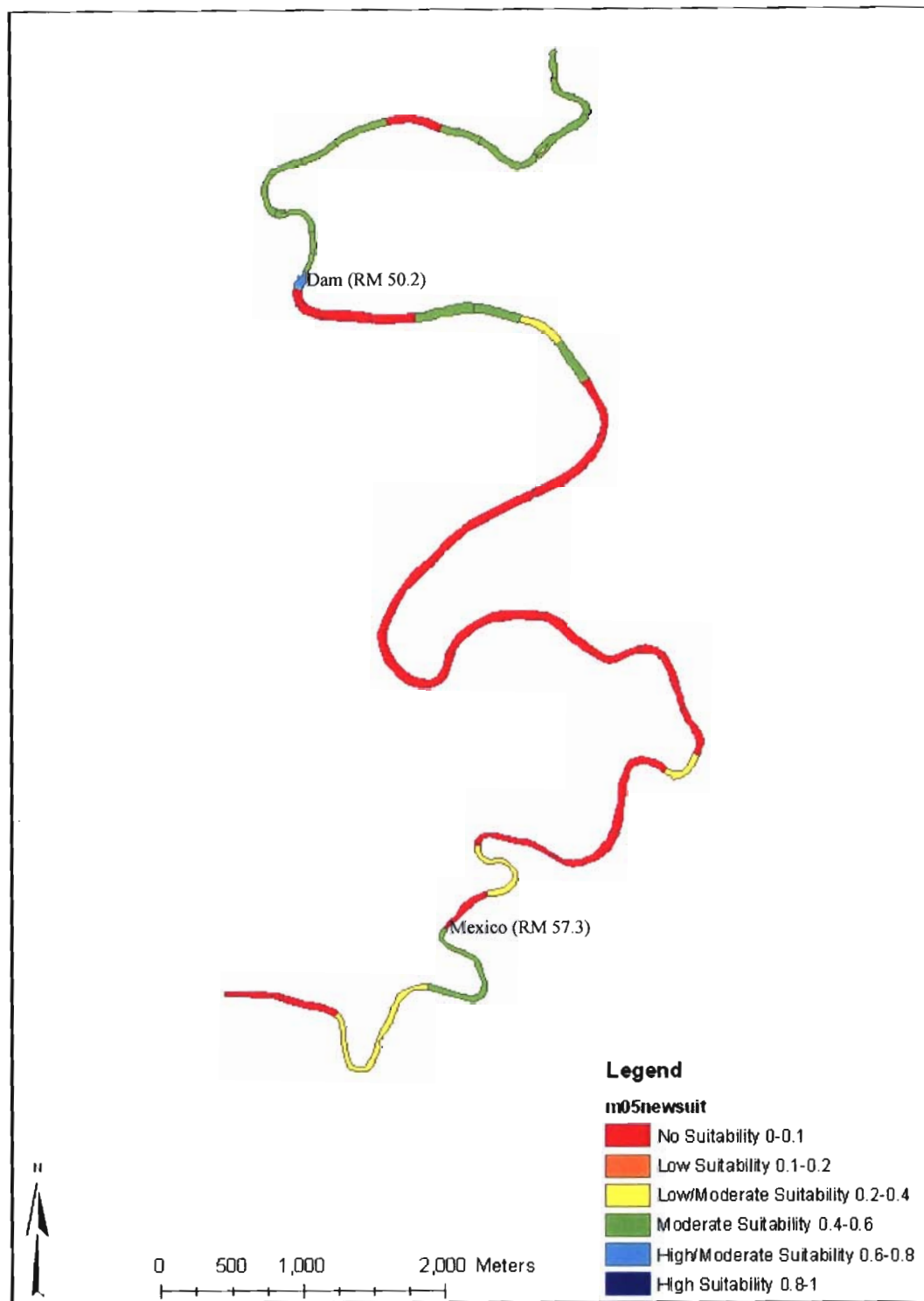
Figure 2.19. Post-restoration HSIs from the ArcGIS model of stonefly in 2005. The scale of percent suitable habitat is indicated in colors from no suitability (red) to high (blue).
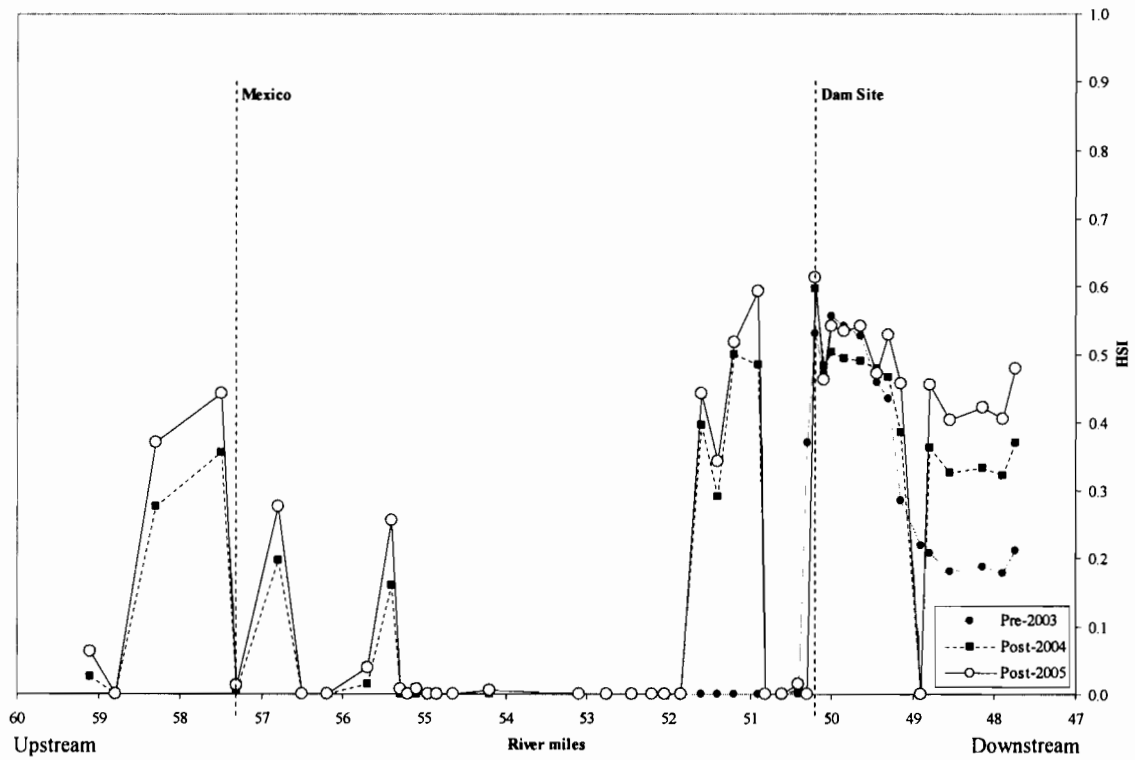
Figure 2.20. The longitudinal profile of HSI from the ArcGIS model of the stonefly for pre-restoration (2003) and post-restoration (2004-2005) years.
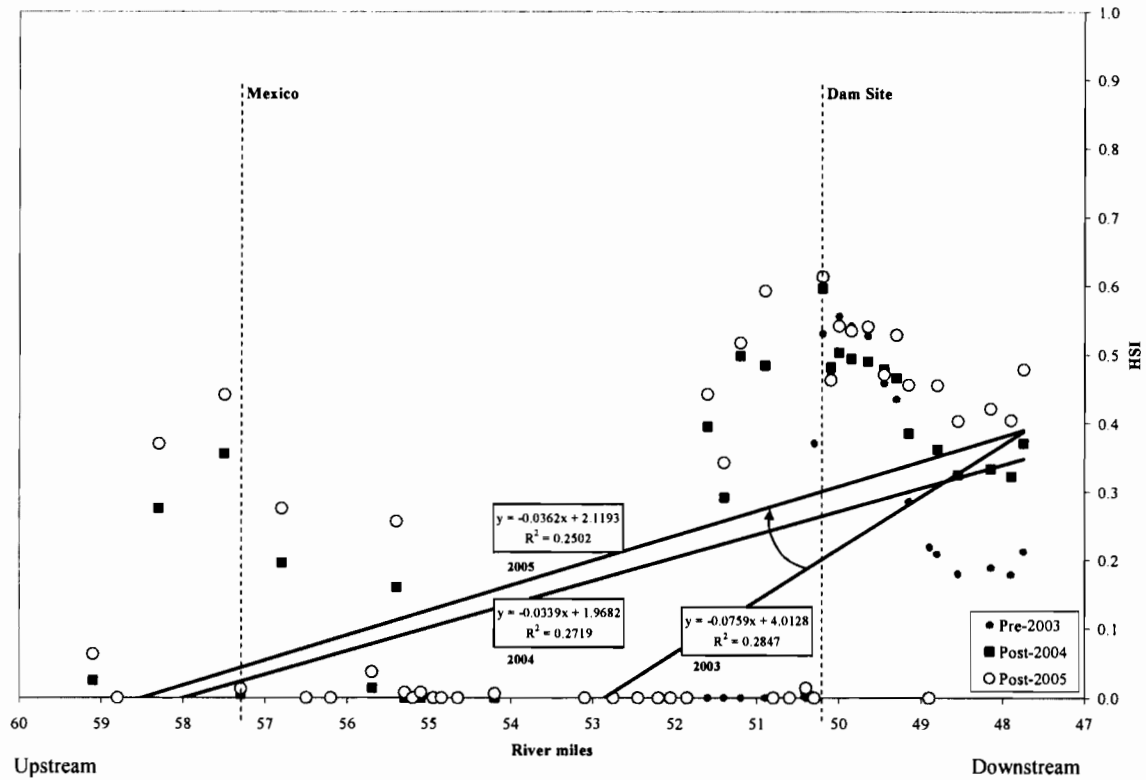
Figure 2.21. The trend in the longitudinal profile of HSI from the ArcGIS model of the stonefly showing regression line and root mean squares. Data are for pre-restoration (2003) and post-restoration (2004-2005) years and the arrow indicates the increase in values of HSI from 2003 to 2005.
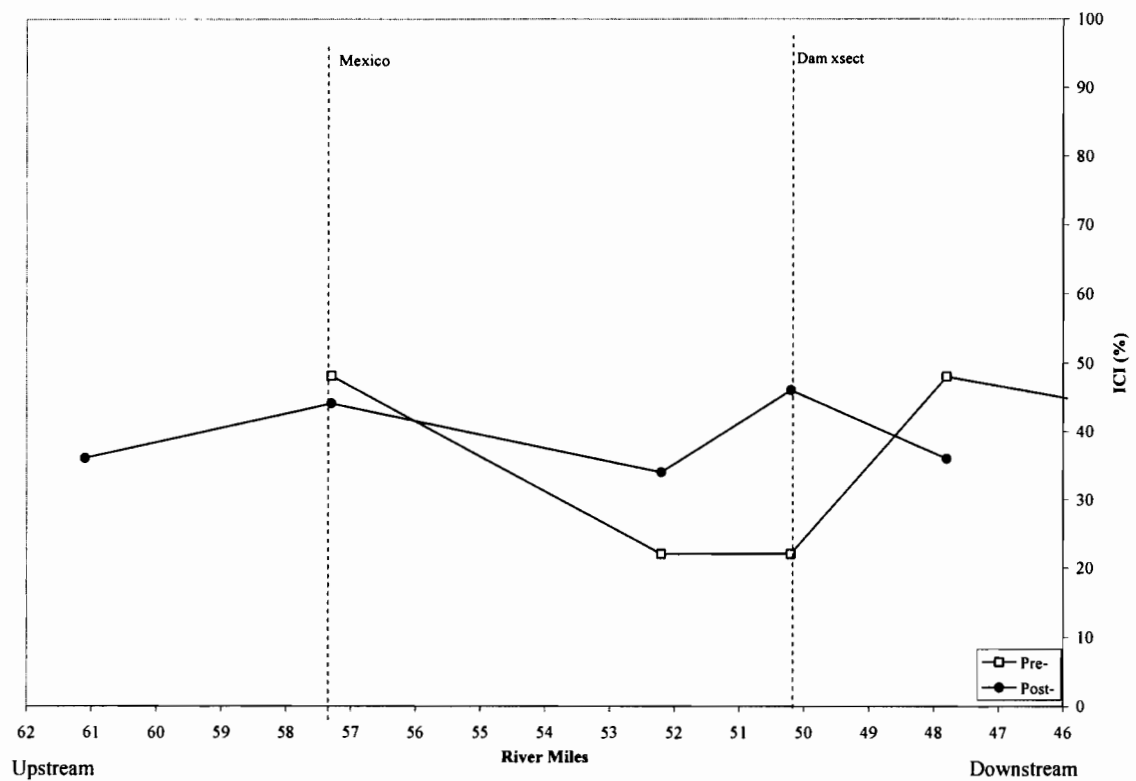
Figure 2.22. Invertebrate Community Index (ICI) plot against river mile from 2003 to 2004 (source: Kenneth Kreiger, Heidelberg College, Ohio). ICI scores increase in backwater reservoir post-dam removal.

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River Mile	ICI 2003	ICI 2004	HSI 2003	HSI 2004
52.2	22	44	0	0
50.2	22	46	0.53	0.6

Table 2.1. ICI data collected in 2003-2004 and HSI stonefly model output for
corresponding river miles.

CHAPTER 3

DEVELOPMENT OF A REMOTELY SENSED QUALITATIVE
HABITAT EVALUATION INDEX (RS-QHEI) USING
AERIAL PHOTOGRAPY AS A TOOL FOR RIVER RESTORATION

3.1   Abstract

A Remotely Sensed Qualitative Habitat Evaluation Index (RS-QHEI) is

developed and used to assess a restoration project on the Sandusky River (Ohio). The

RS-QHEI used digital aerial photographs to quantitatively define three of the six original

metrics of the field based Qualitative Habitat Evaluation Index (QHEI). Values of

channel morphology, riparian zone width/type, and gradient/ pool-riffle width were

qualitatively and quantitatively evaluated from the digital images. Metrics were scored,

summed, and compared to field based QHEI's calculated by the Ohio Department of

Transportation (ODOT) as part of a restoration monitoring program. The field based

QHEI's were taken at nine stations in over ten river miles for a three year period to assess

river conditions prior to and after the removal of a low-head dam. There were no

significant differences in the final QHEI scores calculated by ODOT and the RS-QHEI

method. The QHEI scores were lower than RS-QHEIs and were not linearly correlated

(R^2 = 0.1425). The RS-QHEI can be viewed as complementary to the field based QHEI.

Both methods showed a clear recovery of the physical habitat in the Sandusky River one

year after the dam removal. We suggest that the RS-QHEI is a more quantitative tool for evaluating larger scale attributes in rivers and could be used prior to the QHEI to better plan the field surveys. The RS-QHEI provides a fast and cheap procedure for monitoring restoration projects over many years to determine if restoration, such as dam removal, meets both short-term and long-term goals.

3.2 Introduction

The occurrence and number of aquatic organisms within a stream ecosystem depends heavily on the physical and chemical characteristics of a stream (Dyer et al. 1998). Natural habitats are important because they can provide shelter for special status invertebrates, vascular plants, and migratory birds (Hunter et al. 1999) and assimilate nutrients and pollutants (Narumalani et al. 1996). Changes to habitat can cause shifts in the stream biota numbers and types (Rankin 1989). Evaluation of the changes to stream biota can be measured directly using the Index of Biological Integrity (IBI) (Karr 1981) and the Invertebrate Community Index (ICI) (DeShon 1995). Each index uses type and number of organisms to calculate a ranking of stream biota. However, these metrics fail to account for the surrounding physical habitat that can directly affect in-stream conditions. Also, these biotic indices require extensive field and laboratory time that involves collecting and identifying organisms. Rapid assessment methods need to be developed that can be used to provide information on the general status of ecosystems (Tiner 2004).

The Qualitative Habitat Evaluation Index (QHEI) was designed to correspond to physical ecosystem factors affecting not only fish assemblages, but also other aquatic life (Rankin 1989). The QHEI was created in response to the 1972 Federal Water Pollution Control Act where there was a desire to develop a procedure relating habitat quality to in-stream performance (Rankin 1989). The Ohio EPA is currently using the QHEI as a water quality indicator.

The QHEI was developed as a rapid field assessment tool for ranking attributes of the physical habitat in a stream or river reach. The QHEI is composed of six physical habitat attributes (Table 3.1). Each metric is further subdivided into categories with a range of scores. Values for each metric are scored and then summed to create the overall score of physical habitat. The maximum score that can be attained through this ranking is 100, designated as an ecosystem that is in excellent attainment. Degradation of the physical habitat by channelization or hydro-modifications, such as impoundments, reduces the score.

Rivers and streams have been readily assessed using the QHEI and compared with other variables. Researchers have used the index to relate diatom assemblage structure to stream habitat quality (Kutka and Richards 1996). Others have used the index in conjunction with the IBI to understand how physical habitat affects fish community assemblages in agricultural landscapes (Sullivan et al. 2004). Yet, there is little concrete evidence on how physical habitat changes following restoration projects. The lack of monitoring of restoration activities is linked to the long time scales needed for these activities to recover, the large spatial scales of the restoration activity, and the cost and

difficulty of the monitoring program. Monitoring of restoration activities can be achieved by assessment of pre- and post-restoration of ecosystems using a method that is fast, cheap, and meaningful over long time scales and large spatial scales.

Remote sensing techniques can be used to determine long-term physical changes in habitat over a range of temporal and spatial scales. Remote sensing can be used as a more cost effective way to gather high-resolution habitat data that would be infeasible using traditional field methods (Jones and Stoner 1997). Remotely-sensed indices of natural habitat integrity require large-scale environmental assessment, but can be readily updated making them effective monitoring tools for natural resource agencies (Tiner 2004). Remotely-sensed indices would not replace more traditional field based approaches such as the Index of Biological Integrity, but would give a more landscape scale understanding of the natural habitats (Tiner 2004).

The use of remotely sensed images could provide a rapid and more quantitative method for understanding how natural habitats change. Remote sensing of the landscape has been widely used for many environmental applications. Landsat Thematic Mapper data coupled with a GIS has been used to map the extent of southern Australian mangrove forests (Long and Skewes 1995). Studies have also focused on using remotely sensed images to map riparian buffers (Narumalani et al. 1996; Muller 1997; Hunter et al. 1999; Goetz et al. 2003). Understanding the effects of land-use change using satellite imagery has also been conducted (Matheussen et al. 2000; Fohrer et al. 2002). Others have used satellite data to estimate river discharge (Bjerklie et al. 2003; Xu et al. 2004). Understanding discharge in rivers is crucial for determining areas of suitable habitat for many fish and macroinvertebrate species.

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The objective of this work is to determine a fast and cost effective method for habitat analysis in river systems using remotely sensed data. Specifically, metrics of the Qualitative Habitat Evaluative Index (QHEI) (Rankin 1989) will be coupled with a 1 m resolution aerial photograph and a 2 m resolution aerial image to create a Remotely-Sensed QHEI (RS-QHEI). The RS-QHEI will then be used to assess habitat response to a dam removal by comparing pre- and post-dam removal scores. Traditionally, the QHEI has been used as a field based tool to quantitatively assess parameters in a river or stream reach (Rankin 1989). Emphasis of the RS-QHEI, however, will be based on interpretation of several of the QHEI metrics from aerial photographs. These metrics will be more quantitative and can cover a larger spatial scale. RS-QHEI results are compared to field-based QHEI scores.

3.3   Methods

3.3.1   Study area

The Remotely Sensed QHEI (RS-QHEI) analysis was conducted on the Sandusky River (Ohio) between river miles (RM) 46.0 to 60.0 (Figure 3.1). The 1251 mi^2 (3573 km^2) drainage area of the Sandusky River basin is comprised of agriculture, forest, residential, and industrial uses. The river originates in Crawford County (Ohio) and flows through eight other counties before ultimately draining into Lake Erie. The upper watershed is relatively unimpaired and is designated a State Scenic River. Because of the Lake connection, the river is an important conduit for spawning migratory fishes. A low-head dam at RM 50.2 impacted the section of the river from river miles 46.0 to 60.0. The dam, which impounded backwater upstream to RM 57.3 (Mexico, Ohio), was removed

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on 18 November 2003. Prior to and since the removal, the ecosystem has been monitored for recovery of biota, water quality, and habitat. QHEI data have been gathered by the Ohio Department of Transportation (ODOT). The National Water Quality Laboratory and the Ohio Department of Natural Resources (ODNR) have collected data for biological indices.

3.3.2   Remotely Sensed Data and GIS Tools

For the RS-QHEI analysis, a digital aerial photograph of the river taken in the year 2000 was used to represent the pre-restoration condition (Figure 3.2) and a false-color composite aerial image acquired in 2005 (Figure 3.3) was used to assess post-restoration conditions. The black and white aerial image obtained from the Department of Civil and Environmental Engineering and Geodetic Sciences Great Lakes Forecasting group at The Ohio State University (Franklin County, Ohio data files) had a 1 m pixel resolution. The image was georeferenced in a UTM Zone 17N projection (NAD 1983 datum). The false-color image was obtained from the Ohio Geographically Referenced Information Program (OGRIP) website (http://metadataexplorer.gis.state.oh.us) and was georeferenced in the UTM Zone 17N projection (NAD 1983 datum) with a 2 m pixel resolution.

ArcGIS 9.1® was used to analyze the two images (i.e., the digital aerial photograph and the false-color composite image). Both images were imported into the software package and projected in a UTM Zone 17N projection (NAD 1983 datum).

Units of measurement were set to metric units to compare with QHEI metrics. Measurement tools inherent in the software were used for quantitative assessment of QHEI metrics.

3.3.3 Methodology

The RS-QHEI assessment was conducted on nine sites between river miles 46.0 to 60.0 (Figure 3.2). The sites were selected to coincide with QHEI locations established by the Ohio Department of Transportation (ODOT). The QHEI's were used to monitor the ecosystem recovery for the post-dam removal period and were sampled on July 27 and 28, 2004. Since ODOT performed only one QHEI before the dam removal, 1999 QHEI's were obtained from surveys done by the Ohio Environmental Protection Agency (OEPA) and served as a baseline for pre-removal condition.

Point shapefiles were created in ArcGIS 9.1® to locate the QHEI locations on the digital aerial photographs (white asterisks Figure 3.2 & 3.3). Once sites were located, measurements of 150 meters upstream and downstream of the QHEI point were conducted down the thalweg of the river channel using the ArcGIS measurement tool. These boundaries were defined based on 300 m ODOT transects taken at river miles where QHEI's were conducted.

The RS-QHEI consists of three of the original QHEI metrics: 1) channel morphology; 2) riparian zone; 3) gradient/drainage area and pool width to riffle width that is detailed in Table 3.2. These metrics above were chosen for the RS-QHEI because

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many of the aspects of these metrics could be calculated from the remotely sensed images. Only the portions of these three metrics that could be visually detected in the images (both aerials) were analyzed.

Channel morphology was broken down into three separate categories: sinuosity, channelization, and impairments. Sinuosity (S) was calculated by the ratio of the stream channel length (SCL) to basin length (BL) from the upper to lower RS-QHEI point and was defined as:

$$S = SCL/BL$$

The values of sinuosity were then converted to four categories from highly sinuous (>1.5) to no sinuosity (1) based on the Rosgen level 2 measurements and interpretation criteria (Table 3.3). Amendments were made to the Rosgen sinuosity criteria to adhere to the sinuosity class of the RS-QHEI because the original QHEI sinuosity category consisted of four possible scores (Table 3.1) and the Rosgen classification of sinuosity was broken down into five classes (Table 3.3).

Channelization was defined as the extent of anthropogenic modifications in the river and the number of modifications (Rankin 2004). Channelization referred to any type of human alteration made to the river, such as impoundments, bank shaping, and riparian corridor loss. Parts of the river with no anthropogenic modifications (i.e., below the dam and above the backwater of the reservoir) typically showed high values (scores of 6). For each modification, one point was deduced from the total metric score.

The original QHEI metric of channel morphology consisted of a stability class and a development class, but it was concluded that no information on stability or development could be recognized given the low resolution of the images, i.e., 1 or 2 m. The maximum score that could be attained for the RS-QHEI channel morphology metric was 10 (Table 3.2).

The riparian zone metric consisted of two categories, one for riparian zone width and one for riparian zone type (extended beyond the 100 m riparian zone). Riparian zone width was calculated on the left and right bank of each RS-QHEI point. Measurement tools inherent to ArcGIS® were used to measure the distance of riparian zone width at the upper, middle, and lower RS-QHEI points. The average width was calculated and an overall average, for both banks, was used to define the riparian zone width. Riparian zone type beyond a 100 m distance was determined visually. Bank erosion could not be seen in the images (an original QHEI category), so it was not categorized. The maximum score that could be attained in the RS-QHEI riparian zone metric was 7 (Table 3.2).

The final metric used for the RS-QHEI was the gradient/drainage area. Incorporated into this metric was a calculation of pool width to riffle width. The gradient for the riverbed was calculated from USGS topographic maps using the bank slope as a proxy for bed-slope. The gradient of the stream was calculated by determining the elevation of the most upstream and most downstream RS-QHEI points. Thalweg length was then calculated using the ArcGIS measurement tool. The gradient of the stream was calculated by dividing the elevation change from the upper to lower RS-QHEI point by the thalweg length. Values calculated from the topographic maps were cross-referenced with gradients calculated by the ODOT survey. Drainage area of the Sandusky River

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basin was acquired from the USGS website for real-time water data. Scores for this category were calculated from a predetermined table established by the original QHEI (Table 3.4).

Pool width to riffle width was calculated from visual inspection of the image. Riffles showed up as distinct white water areas. The assumption was made that below each riffle zone there was a pool. If the pool was wider than the riffle this was scored high (2). Riffles that were absent or visually wider than the pools were scored 0. Riffles and pools that showed equal widths were scored 1. The maximum score for the gradient/drainage area and pool/riffle width metric of the RS-QHEI was 12 (Table 3.2). Gradient and drainage area were assumed not to change from site to site and therefore the score calculated for this category stayed the same for each RS-QHEI location.

After scoring all three classes, the total RS-QHEI was determined. The final score for the analysis was calculated out of 29 total points. RS-QHEI, ranked by percentile, was based on OEPA's QHEI criteria for aquatic life use, which are as follows: > 60 good overall RS-QHEI (full attainment); 60<RS-QHEI<45 moderate (partial attainment); <45 poor (not attaining). Finally, values of the RS-QHEI were compared to the field QHEI scores assessed by ODOT to determine the methods accuracy.

3.3.4   Statistical Analyses

Paired two-tail t-tests were used to compare the differences in the average values of the data sets for the ODOT QHEI and the RS-QHEI at a 95% confidence level. Resulting p-values determined statistical differences in the data. P-values that were less than the tested alpha value (typically $\alpha = 0.5$) were considered statistically significant.

3.4   Results

RS-QHEI scores for the nine sites, along with the three pre-dam removal QHEI's

calculated by OEPA, showed a decreasing trend from upstream to downstream for pre-

dam removal condition (Table 3.5, Figure 3.4). RS-QHEI values for the pre-removal

ranged from 44.83 at site 3 to 77.59 at sites 8 and 9. RS-QHEI values for post-removal

ranged from 58.62 at site 3 to 77.59 at site 8 and 9 and had a negative trend from

upstream to downstream (Figure 3.4). Increases in RS-QHEI from pre- to post-dam

removal range from 0 to 13.90 and were mainly confined to the reservoir backwater

(Figure 3.5). ODOT values ranged from 59.50 at site 3 to 81.50 at site 1 and showed a

positive trend from upstream to downstream (Figure 3.4). Differences in ODOT and RS-

QHEI for post-dam removal values ranged from 0.88 at site 3 to 14.83 at site 1.

The ODOT QHEI scores were not linearly related to the RS-QHEI metric ($R^2 =$

0.1425) and were generally the same or lower (Figure 3.6). However, a paired t-test of

average ODOT-QHEI and post RS-QHEI values showed no significant difference ($p =$

0.148) at the 95% confidence level, indicating the results of the two methods were

similar. Both QHEIs and RS-QHEIs showed an increase in scores after the dam removal

(Figure 3.4). After the removal, changes in RS-QHEI were most apparent within the

confines of the backwater.

As a sensitivity analysis, category values scored by ODOT that matched the RS-

QHEI categories were substituted into the RS-QHEI to predict how the RS-QHEI would

change if field measurements were used. Scores ranged from 70.69 to 93.10, indicating

an overestimation of the QHEIs (Table 3.5).

3.5   Discussions

Post-restoration RS-QHEI values increased from pre-restoration values in six of the nine sites reaching full attainment for warm water habitat. Sites downstream of the dam (Site 1 River mile 47.7) and upstream of Site 7 (RM 57.3 to 59.0) showed no changes in RS-QHEI values. The result was expected, since the dam did not affect the downstream site and the site at Mexico was upstream of the backwater created by the dam, hence out of its influence for all but high flows. The largest and most consistent changes in RS-QHEI values occurred upstream of the dam in the former impoundment (i.e. backwater). Pre-removal QHEI and RS-QHEI values equate to aquatic life use designations that range from full attainment status to non-attainment. The low QHEI and RS-QHEI scores in the reservoir backwater are the result of a reduction in the impoundment and loss of riffle/pool sequences. All full attainment area occurred outside the effects of the impoundment. The post removal QHEI and RS-QHEI scores increased due to the removal of the impoundment and the creation of riffle/pool sequences. As a result, the aquatic life designations increased. All sites except for site 3 (RM 52.2) increased to full attainment status. Thus, the removal of the dam can be viewed as a successful restoration effort. Specifically, the main metrics that accounted for these increased scores were change in the modification category and riffle-pool quality. A maximum increase of 4 points in the final RS-QHEI score produced significant changes in the final RS-QHEIs.

RS-QHEI trends were not similar to ODOT's QHEIs. Major differences in the techniques are mainly the product of the number of metrics used in the score and how they were calculated. ODOT used the traditional QHEI method, which involves six metrics divided up into multiple categories. Categories within metrics that reveal less than ideal scores have less of an impact on the total score and thus can reflect smaller changes in the final score. Because the QHEI is calculated out of 100, a reduction of 1 point in any metric would reduce the final QHEI by 1%. In contrast, the RS-QHEI was made up of three metrics and thus slight changes in any of the categories of the metrics contributed a larger change in the total score. For example, a reduction of 1 point from any of the three metrics would reduce the final RS-QHEI by 2.9%.

Differences could also be the result of errors in category scores. Field investigation limits the score to the field of view of the investigator's eye. Because the RS-QHEI was conducted on a landscape scale, values for metrics, such as riparian zone width, type beyond 100 m, and sinuosity, could be assessed more accurately than in the field method. Since the QHEI and RS-QHEI values were not significantly different, they both express the same level of aquatic life use attainment. One of the largest differences in the scores was in the channelization category of the channel morphology metric, which could have been interpreted in different ways. The category is defined as any anthropogenic channel modification (Rankin 2004). We emphasized modifications were any departure from the natural environment, such as impoundments (dams), bank shaping, and bank armoring. Therefore, the dam's backwater was considered an anthropogenic channel modification and was scored as a recovering zone pre-removal

(score of 3). Below the dam (RM 50.2) and above Mexico Bridge (RM 57.3), the dam did not place any unnatural stress on the river and was considered unchannelized (score of 6).

Creation of accurate land-use maps involves high-resolution data sources, manual interpretation, and fieldwork (Russell et al. 1997). The use of remotely sensed images in determining a RS-QHEI for a river or stream can complement a field-based QHEI. Whether it can substitute for a QHEI will require more trials than the nine data points in this study. Typically, land-use/land-cover or watershed studies using satellite imagery (Iverson et al. 2001; Gupta et al. 2002; Miranda and Porter 2003) to acquire data, which are coarser in resolution and in most cases free. The key to developing a more accurate RS-QHEI depends on high-resolution data, the time of year, and the data type (e.g., color). The higher the resolution, the more accurate the results will be since higher resolution data would reveal more geomorphic river features. For example, riffle and pool sequences can be detected and quantified. For very high-resolution data (resolution < 0.5 meter), new metrics can potentially be added for root wads, woody debris, and overhanging vegetation that would more closely resemble the field-based QHEI attributes.

The main issues with higher resolution data are cost and availability. There are very few satellites, such as the Quickbird-2 satellite, which can produce sub-meter (0.61 m) pixel resolution (Xu et al. 2004). Currently, public access to images is generally limited to 1 m pixel resolution. A 1 m pixel resolution means that each cell in the image represents a 1 m by 1 m area. Therefore, if the scale of interest is less than the 1 m^2 pixel

resolution no information can be deduced, since it cannot be resolved. Root wads and woody debris are very difficult to detect at the resolutions of the 2000 and 2005 images in this study, but could be detected at a 0.6 m^2 pixel resolution.

The time of year images are acquired is also a very important aspect for an accurate RS-QHEI analysis. The 2005 image used for the study was taken in the summer and during a high flow event. Ideally, images should be taken during times of low flow to see normal channel boundaries and during the non-growing season (October through December for Ohio) to avoid leaf cover. The advantages of using these types of data are ease of understanding of geomorphologic features in the channel/floodplain and less shadow effect from trees and bushes. During high flows, geomorphologic features can be inundated obscuring the delineation of the floodplain from the channel. Additionally, low flows will display the true bedform of the river through riffle and pool sequences, which are drown during high flows. The reduction in the shadow effect from vegetation clarifies the extent of the riparian corridor, riverbanks, and instream structures (woody debris and root wads). Images acquired before or after the growing season can also reveal agricultural practices, such as no till or conservation tilling, which can increase the overall RS-QHEI score.

The data type also affects the accuracy of the RS-QHEI metrics. False-color composites derived from satellite imagery enhance the understanding of the landscape by distinctly differentiating between landscape features by the use of color. Black and white

images can cause misinterpretation of features because the shades of gray cannot always be discriminated, causing problems with determining where features start. Although, there are good black and white photo interpreters which can aid in the interpretation.

The quality of data, such as cloud free images, greatly increases chances of deducing accurate and precise analyses. Many satellite and aerial based images are useless when extensive cloud cover obscures surface features. Data must be acquired on relatively cloud free days to determine most land cover metrics. Radar data, such as Synthetic Aperture Radar data, can be obtained in any weather condition (Xu et al. 2004). Yet, this data type is very coarse in resolution (~25 m pixel resolution). Data of this type could help to alleviate the problems with clouds and thus could serve to increase data availability to consumers.

The RS-QHEI analysis is designed as a tool to use before field based procedures are conducted. Our results indicate a close relationship with more standard QHEI scores, but the RS-QHEI can help field technicians create a more accurate and reliable QHEI for a stretch of stream or river, because metrics such as sinuosity and riparian zone width and type (past the 100 meters riparian zone) can be calculated more accurately than ground-based observations. If images with a spatial resolution of < 1 m are used, metrics such as woody debris and root wads could be added to the RS-QHEI analysis, improving its accuracy. The amount of woody debris and root wads can be assessed to a more exact number, rather than just estimating the percent of these categories in the field. Therefore, future emphasis needs to be placed on refining the RS-QHEI by increasing the spatial resolution, time of year, and data quality and type of images to provide an accurate assessment of habitat quality in aquatic systems.

3.6   Conclusion

RS-QHEI surveys give similar results to QHEI data, but add accuracy by incorporating quantitative data. The use of satellite and aerial based imagery in the RS-QHEI is useful for monitoring river restoration because it reveals habitat changes on landscape scales > 100 m, but with a resolution of 1 m. Further, these changes in river corridors and geomorphology can easily be detected from images, while field based approaches may only accurately assess small spatial scales, < 100 m ,e.g., the reach scale. When initiated prior to QHEI surveys, the RS-QHEI analysis will complement the field-based approach and provide it with quantitative data to augment the survey.

3.7 TABLES AND FIGURES
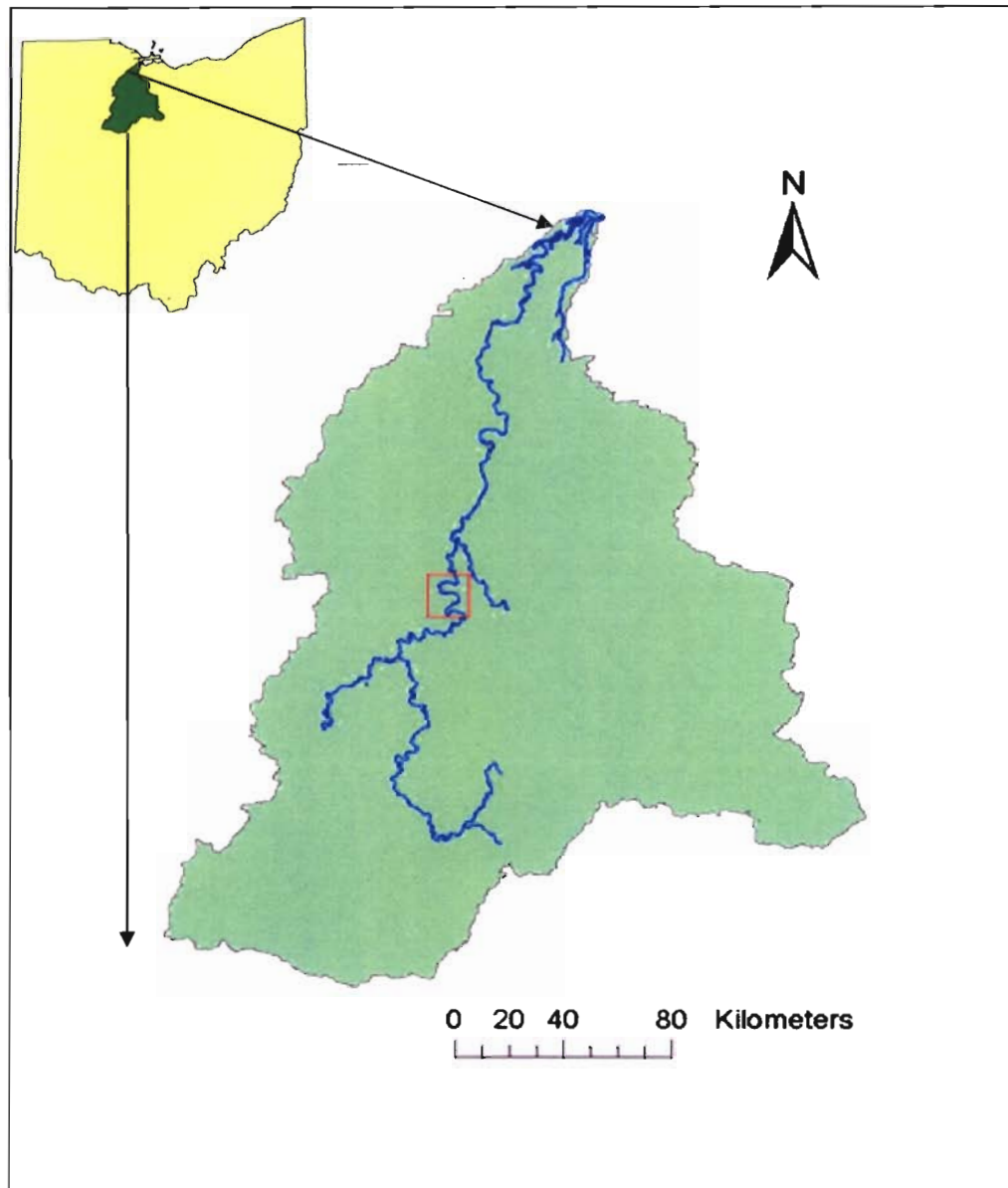
Figure 3.1. Map of the Sandusky River watershed located in the north central portion of Ohio. The boxed area shows the location of the study area.

Figure 3.2. 2000 digital aerial photograph showing nine RS-QHEI sites. Each site contained three RS-QHEI points that were averaged for the reach of river.

Figure3.3. 2005 false-color composite of Sandusky River, Ohio study area.
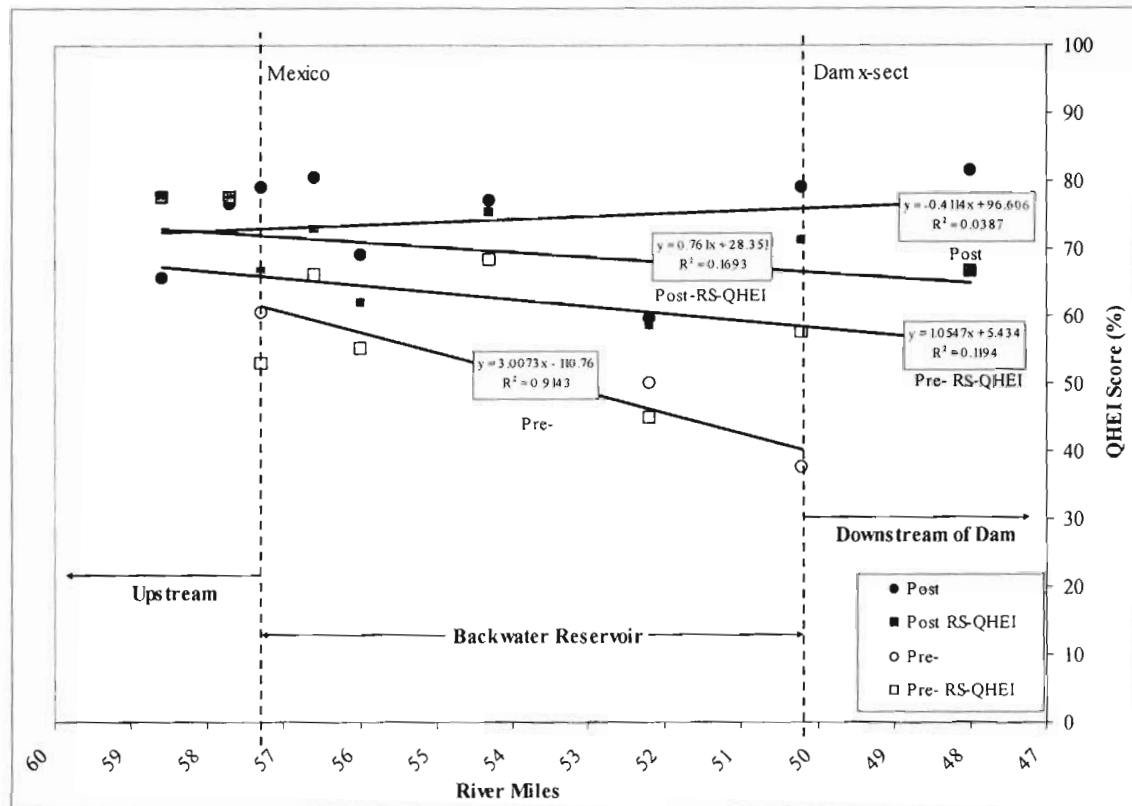
Figure 3.4. Pre- and Post QHEI and RS-QHEI plotted from upstream to downstream. Trend lines indicate tendency of data to both negative (Pre- and Post RS-QHEI and Pre-) and positive (Post).
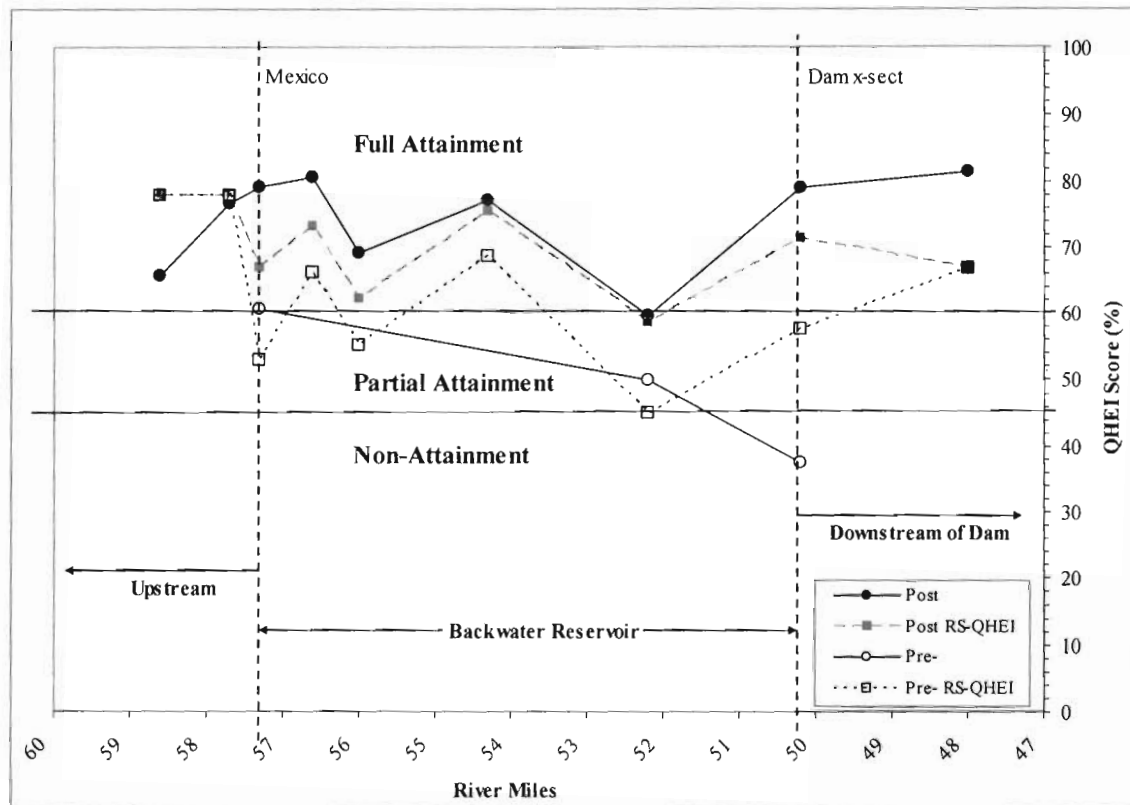
Figure 3.5. Plot of longitudinal QHEI values from upstream to downstream along the river. Pre- are represented by open symbols, closed represent post, QHEI scores are represented by circles & RS-QHEI by squares.
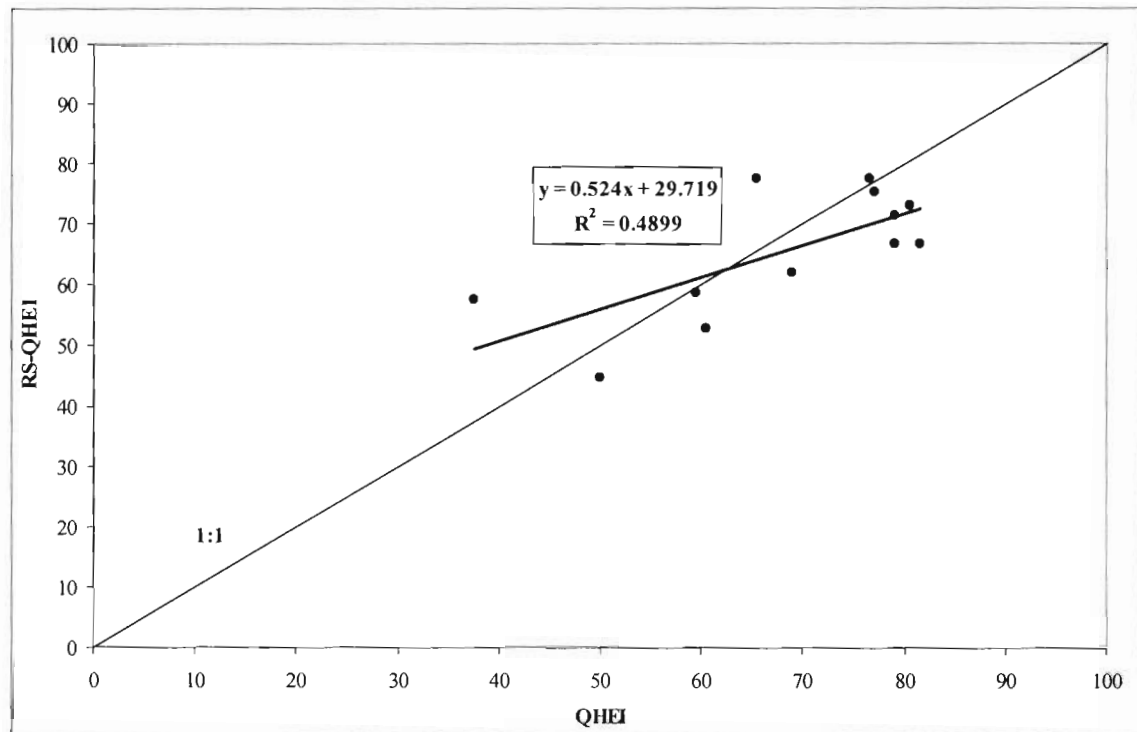
Figure 3.6. Plot of ODOT QHEI versus post RS-QHEI with regression line
calculated.

OhioEPA Qualitative Habitat Evaluation Index Field Sheet   QHEI Score. ☐

River Code: _____ RM:_____ Stream:_____
Date:_____ Location:_____
Scorers Full Name: _____ Affiliation:_____

1) SUBSTRATE (Check ONLY Two SubstrateTYPE BOXES. Estimate % present

TYPE POOL RIFFLE	POOL RIFFLE	SUBSTRATE ORIGIN Check ONE (OR 2 & AVERAGE)	SUBSTRATE QUALITY Check ONE (OR 2 & AVERAGE)
☐☐-BLDR /SLBS[10] ___ ___	☐☐-GRAVEL [7] ___	Check ONE (OR 2 & AVERAGE)	Check ONE (OR 2 & AVERAGE)
☐☐-BOULDER [9] ___ ___	☐☐-SAND [6] ___ ___	☐ -LIMESTONE [1] SILT:	☐- SILT HEAVY [-2]
☐☐-COBBLE [8] ___ ___	☐☐-BEDROCK[5] ___	☐ -TILLS [1]	☐ -SILT MODERATE [-1]
☐☐-HARDPAN [4] ___ ___	☐☐-DETRITUS[3] ___	☐ -WETLANDS[0]	☐ -SILT NORMAL [0]
☐☐-MUCK [2] ___ ___	☐☐-ARTIFICIAL[0] ___	☐ -HARDPAN [0]	☐ -SILT FREE [1]
☐☐-SILT [2] ___	NOTE: Ignore Sludge Originating From Point Sources	☐ -SANDSTONE [0] EMBEDDED	☐-EXTENSIVE [-2]

Substrate ☐ Max 20

NUMBER OF SUBSTRATE TYPES: ☐-4 or More [2]   ☐ -RIP/RAP [0]   NESS   ☐ -EXTENSIVE [-2]
(High Quality Only, Score 5 or >)   ☐-3 or Less [0]   ☐ -LACUSTRINE [0]   ☐ -MODERATE [-1]
    ☐ -SHALE [-1]   ☐ -NORMAL [0]
COMMENTS _____   ☐ COAL FINES [-2]   ☐ -NONE [1]

2) INSTREAM COVER (Give each cover type a score of 0 to 3, see back for instructions)   AMOUNT: (Check ONLY One or check 2 and AVERAGE)   Cover ☐ Max 20

(Structure)   TYPE: Score All That Occur

___UNDERCUT BANKS [1]   ___POOLS> 70 cm [2]   ___OXBOWS, BACKWATERS [1]   ☐ - EXTENSIVE > 75% [11]
___OVERHANGING VEGETATION [1]   ___ROOTWADS [1]   ___AQUATIC MACROPHYTES [1]   ☐ - MODERATE 25-75% [7]
___SHALLOWS (IN SLOW WATER) [1]   ___BOULDERS [1]   ___LOGS OR WOODY DEBRIS [1]   ☐ - SPARSE 5-25% [3]
___ROOTMATS [1]   COMMENTS:____   ☐ - NEARLY ABSENT < 5%[1]

3) CHANNEL MORPHOLOGY (Check ONLY One PER Category OR check 2 and AVERAGE)   Channel ☐ Max 20

SINUOSITY	DEVELOPMENT	CHANNELIZATION	STABILITY	MODIFICATIONS/OTHER	
☐ - HIGH [4]	☐ - EXCELLENT [7]	☐ - NONE [6]	☐ - HIGH [3]	☐ - SNAGGING	☐ - IMPOUND.
☐ - MODERATE [3]	☐ - GOOD [5]	☐ - RECOVERED [4]	☐ - MODERATE [2]	☐ - RELOCATION	☐ - ISLANDS
☐ - LOW [2]	☐ - FAIR [3]	☐ - RECOVERING [3]	☐ - LOW [1]	☐ - CANOPY REMOVAL	☐ - LEVEED
☐ - NONE [1]	☐ - POOR [1]	☐ - RECENT OR NO RECOVERY [1]		☐ - DREDGING	☐ - BANK SHAPING
				☐ - ONE SIDE CHANNEL MODIFICATIONS	

COMMENTS:____

4) RIPARIAN ZONE AND BANK EROSION check ONE box per bank or check 2 and AVERAGE per bank) // River Right Looking Downstream   Riparian ☐ Max 10

RIPARIAN WIDTH L R (Per Bank)	FLOOD PLAIN QUALITY (PAST 100 Meter RIPARIAN) L R (Most Predominant Per Bank) L R		BANK EROSION L R (Per Bank)
☐☐ - WIDE - 50m [4]	☐ ☐-FOREST, SWAMP [3]	☐ ☐-CONSERVATION TILLAGE [1]	☐ ☐-NONE/LITTLE [3]
☐☐ - MODERATE 10-50m [3]	☐ ☐-SHRUB OR OLD FIELD [2]	☐ ☐-URBAN OR INDUSTRIAL [0]	☐ ☐-MODERATE [2]
☐☐ - NARROW 5-10 m [2]	☐ ☐-RESIDENTIAL,PARK,NEW FIELD [1]	☐ ☐-OPEN PASTURE,ROWCROP [0]	☐ ☐-HEAVY/SEVERE[1]
☐☐ - VERY NARROW -5 m[1]	☐ ☐-FENCED PASTURE [1]	☐ ☐-MINING/CONSTRUCTION [0]	
☐☐ - NONE [0]			

COMMENTS:____

5) POOL/GLIDE AND RIFFLE/RUN QUALITY   Pool/ Current ☐ Max 12

MAX. DEPTH (Check 1 ONLY!)	MORPHOLOGY (Check 1 or 2 & AVERAGE)	CURRENT VELOCITY [POOLS & RIFFLES'] (Check All That Apply)	
☐ - >1m [6]	☐ -POOL WIDTH > RIFFLE WIDTH [2]	☐ -EDDIES[1]	☐ -TORRENTIAL[-1]
☐ - 0.7-1m [4]	☐ -POOL WIDTH = RIFFLE WIDTH [1]	☐ -FAST[1]	☐ -INTERSTITIAL[-1]
☐ - 0.4-0.7m [2]	☐ -POOL WIDTH < RIFFLE W. [0]	☐ -MODERATE [1]	☐ -INTERMITTENT[-2]
☐ - 0.2-0.4m [1]		☐ -SLOW [1]	☐ -VERY FAST[1]
☐ - 0.2m [POOL -0]	COMMENTS:____		

Riffle/Run ☐ Max 8

CHECK ONE OR CHECK 2 AND AVERAGE

| RIFFLE DEPTH	RUN DEPTH	RIFFLE/RUN SUBSTRATE	RIFFLE/RUN EMBEDDEDNESS
☐ - Best Areas >10 cm [2]	☐ - MAX > 50 [2]	☐-STABLE (e.g.,Cobble, Boulder) [2]	☐ - NONE [2]
☐ - Best Areas 5-10 cm[1]	☐ - MAX < 50[1]	☐-MOD. STABLE (e.g.,Large Gravel) [1]	☐ - LOW [1]
☐ - Best Areas < 5 cm [RIFFLE-0]		☐-UNSTABLE (Fine Gravel,Sand) [0]	☐ - MODERATE [0]
			☐ - EXTENSIVE [-1]

Max 8
Gradient ☐ Max 10

COMMENTS:____   ☐ - NO RIFFLE [Metric-0]

6) GRADIENT (ft/mi) _____ DRAINAGE AREA (sq.mi.) : _____   %POOL: ☐   %GLIDE: ☐
    %RIFFLE: ☐   %RUN: ☐

" Best areas must be large enough to support a population of riffle-obligate species

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Table 3.1. QHEI field sheet. Each metric and category is scored in the field for an approximately 300 meter swath of river or stream.

Site

1.) Channel Morph

Sinuosity =	Channelization	Modifications (-1)	Max = 10
High (4)	None (6)	Snagging	Impounded
Moderate (3)	Recovered (4)	Relocation	Islands
Low (2)	Recovering (3)	Canopy removed	Leveed
None (1)	Recent or no recovery (1)	Dredging	Bank shaping

Total =

2.) Riparian Zone

Riparian Width

	L	R		Most pred Typ of Veg		Max = 7
D	Avg: Wide > 50 m (4)			L	R	Forest/Swamp (3)
M	Moderate 10-50 m (3)		D			Shrub or Old Field (2)
U	Narrow 5-10 m (2)		M			Res,Park,New Field (1)
	Very Narrow <5 (1)		U			Fenced Pasture (1)
	None (0)				Avg	Consevation Tillage (1)
						Urban or Industrial (0)
						Open Pasture, Rowcrop (0)
						Mining/Construction (0)

Total =   Total =

3.) Pool/Glide & Riffle Run Quality (max 2)

Gradient (max 10)

	Drainage area = 1251 mi²	
Pool Width > Riffle Width (2)		
Pool Width = Riffle Width (1)	Slope =	Score =
Pool Width < Riffle Width (0)		

Total =

QHEI SCORE(max = 29) =

Table 3.2. RS-QHEI sheet used for scoring the nine sites in the study area.

Rosgen Value	Rosgen Interpretation	RS-QHEI Value	RS-QHEI Interpretation	RS-QHEI Score
<1.2	Low	1	No	1
>1.2	Moderate	<1.2	Low	2
>1.4	High	>1.2	Moderate	3
>1.5	Very High	>1.5	High	4

Table 3.3 Rosgen and RS-QHEI sinuosity values along with interpretation of the value. Scores calculated for the RS-QHEI were based off the original QHEI

Stream Width	Drainage Area (sq mi)	Gradient (feet/mile)						
		Very low	Low	Low-Moderate	Moderate	Moderate-High	High	Very High[1]
≤ 4.7	< 9.2	0 - 1.0 (2)	1.1- 5.0 (4)	5.1 - 10.0 (6)	10.1 -15.0 (8)	15.1 - 20 (10)	20.1 - 30 (10)	30.1 - 40 (8)
4.8 -9.2	9.2 - 41.6	0 - 1.0 (2)	1.1- 3.0 (4)	3.1 - 6.0 (6)	6.1 - 12.0 (10)	12.1 - 18 (10)	18.1 - 30 (8)	30.1 - 40 (6)
9.3 - 13.8	41.7 - 103.7	0 - 1.0 (2)	1.1- 2.5 (4)	2.6 - 5.0 (6)	5.1 - 7.5 (8)	7.6 - 12 (10)	12.1 - 20 (8)	20.1 - 30 (6)
13.9 - 30.6	103.8 - 622.9	0 - 1.0 (4)	1.1- 2.0 (4)	2.1 - 4.0 (8)	4.1 - 6.0 (10)	6.1 - 10 (10)	10.1 - 15 (8)	15.1 - 25 (6)
> 30.6	> 622.9		0 - 0.5 (4)	0.6 - 1.0 (8)	1.1 - 2.5 (10)	2.6 - 4.0 (10)	4.1 - 9 (10)	> 9 (8)

[1]Any site with a gradient greater than the upper bound of the "very high" gradient classification is assigned a score of 4.

Table 3.4. Classification of stream gradient for Ohio by stream size, Modified from Trautman (1981). Scores were derived from plots of IBI versus stream gradient for each stream size category (Rankin, 2004)

Site	Pre	Post	RS-QHEI sub	pre- RS-QHEI	post- RS-QHEI	Δ RS-QHEI	Δ QHEI to RS-QHEI
1		81.50	81.03	66.67	66.67	0.00	14.83
2	37.5*	79.00	72.41	57.48	71.26	13.78	7.74
3	50**	59.50	70.69	44.83	58.62	13.79	0.88
4		77.00	93.10	68.38	75.28	6.90	1.72
5		69.00	82.76	55.17	62.07	6.90	6.93
6		80.50	81.03	66.10	73.00	6.90	7.50
7	60.5**	79.00	79.31	52.86	66.67	13.81	12.33
8		76.50	82.76	77.59	77.59	0.00	-1.09
9		65.50	77.59	77.59	77.59	0.00	-12.09

* 2003 ODOT data   ** 2001 OEPA data

Table 3.5. Values of pre- QHEI, post-QHEI, pre- and post RS-QHEI, and differences
in pre- and post- scores.

CHAPTER 4

CONCLUSIONS

The removal of the Saint John Dam on the Sandusky River (Ohio) caused drastic, but positive changes in the aquatic ecosystem. The conversion of the backwater region from a lentic to a lotic environment and the reduction of flow depth and velocity have been shown to increase habitat suitability for Greater Redhorse and stoneflies. These changes were evident in the two habitat monitoring techniques developed as part of this thesis and described in Chapter 2. Two models were developed, one in Excel and the other in ArcGIS®. Results of both models illustrated that the reduction in water level following the dam removal was the key hydraulic parameter for establishing habitat of the sensitive target species. The models were developed to compare the compatibility of different software for determining suitability parameters. The Excel model showed improvements in habitat suitability for only one target species, the Greater Redhorse, following the dam removal. Greater Redhorse spawning potential was highest during relatively low flows in riffle areas. The potential spawning area (i.e., the distribution of habitat) for these intolerant fish increased following dam removal. The widely available and relatively inexpensive cost of the Excel software makes it an appealing habitat

modeling tool. However, the programming of the cells in the modeling procedure is cumbersome and time consuming, making it appealing only when small amounts of data are processed.

The ArcGIS® model also showed improvements in the Greater Redhorse and stonefly species that were investigated. Improvements in habitat suitability of both Greater Redhorse spawning and stonefly habitat were detected following dam removal, however it also indicated that the target fish habitat recovered faster than the invertebrate target species. The use of ArcGIS® expanded on the method used in the Excel model, by allowing users to interact with the modeling software. Inputs into the system were easily accessed through the use of graphical user interfaces (GUI). This allowed for modeling of different hydraulic conditions to determine habitat suitability on a yearly basis or scenario basis. The program allowed for faster results to be developed by the user. However, the model was programmed in a software package that is extremely costly, which limits its availability to the public. It also demands that the user have a good understanding of programming in computer languages, such as Visual Basic, which can be trying for novices. While the programs were very specific for habitat of the two target species, simple changes in the model would allow for inclusion of many different species and river reaches.

The Remotely Sensed Qualitative Habitat Evaluation Index (RS-QHEI), described in Chapter 3, was another method developed to independently assess the restoration of aquatic habitat. The RS-QHEI index used remotely sensed images to evaluate three metrics from the field based QHEI. The field based QHEI showed improved scores within the confines of the backwater reservoir of the Saint John Dam following its

removal. When compared to RS-QHEI results, the field based QHEI gave statistically lower scores. Developments of riffle pool sequences along with the impoundment removal reduce the QHEI scores drastically in some areas. The technique allows for quick and easy determination of QHEIs before field-based surveys are conducted. This gives environmental managers a way to understand and plan restoration efforts and to visualize the effects on aquatic systems before intensive field-based procedures are conducted. However, the RS-QHEI is not proposed as a replacement to the field-based QHEI because particular attributes in the field based method cannot be measured from remotely-sensed images.

The advantage of the RS-QHEI is that the method provides quantitative values over larger spatial scales than the QHEI. However, it is limited by image resolution, availability of images, and time of image capture. All three parameter are important for developing an accurate RS-QHEI. However, as sensor technology improves and images become much finer scaled and more widely available, the accuracy of the RS-QHEI should also improve. Using higher resolution images and new metrics such as woody debris and root wads, can be incorporated into the RS-QHEI, making it more comparable to the field-based method.

The two monitoring techniques developed in this thesis give similar results and indicate that the backwater region of the dammed reservoir has developed a higher quality habitat after the removal of the St. John Dam. Although the trends in the data from the two techniques are not similar, they both indicate that the river restoration was a success. The discrepancies in trends are likely the result of lack of data in the RS-QHEI technique. Both techniques provide new and better tools for understanding how

restoration efforts affect a river ecosystem. They provide swift and effective ways to assess how these systems react to environmental stressors, such as dams and other hydromodifications. The procedures also allow for long term monitoring of environmental conditions that sometimes are feasibly impossible to acquire using traditional field methods. The procedures make them ideal for environmental managers to monitor the success of restoration projects. Finally, the methods could be extended to restoration design and planning, allowing different plans and scenarios to be evaluated in a cost-effective manner.

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APPENDIX A

MODEL CODE

Macroinvertebrates

Option Explicit

```vb
Public m_sStartBrowseLoc As String 'start location for the file browser
Public Path As String
Public HSIVelOut As String 'path of HSI Velocity table
Public HSISubOut As String 'path of HSI Substrate table
Public HSIDepthOut As String 'path of HSI Depth table
Public VelocityPath As String 'Velocity input path
Public DepthPath As String 'Depth input path
Public SubstratePath As String 'Substrate input path
Public pHSIVelTable As ITable 'output hsi velocity table
Public pHSIDepTable As ITable 'output hsi depth table
Public pHSISubTable As ITable 'output hsi substrate table
Public pDepthTable As ITable 'input depth database file
Public pVelocityTable As ITable 'input velocity database file
Public pSubstrateTable As ITable 'input substrate database file
Public NumOfVelCol As Long 'number of columns in velocity table
Public NumOfSubCol As Long 'number of columns in substrate table
Public NumOfDepCol As Long 'number of columns in depth table

Private Sub Velocity_Input_Click()
  Dim pInStTable As IStandaloneTable
  Dim pMxDoc As IMxDocument
  Set pMxDoc = ThisDocument
  Dim pMap As IMap
  Set pMap = pMxDoc.FocusMap
  Dim pGxDialog As IGxDialog
  Set pGxDialog = New GxDialog
  pGxDialog.AllowMultiSelect = True

  'set title of the selection box
  pGxDialog.Title = "Velocity Module: Please Select the Input Velocity Database File
  (ext .dbf)"

  'Set the type of object filter for the search
  Dim pGxFilter As IGxObjectFilter
  Set pGxFilter = New GxFilterdBASEFiles
  Set pGxDialog.ObjectFilter = pGxFilter

  Dim pGxObjects As IEnumGxObject
  pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects
```

```
If (pGxObjects Is Nothing) Then Exit Sub
 pGxObjects.Reset

 Dim pGxDataset As IGxDataset
 Set pGxDataset = pGxObjects.Next
 'create an object that can return the path of the selected table
 Dim pGxObject As IGxObject

 'Set the selected item to a new table variable
 'This code is written as a loop so that more than one selected item
 'may be added.
 Do Until (pGxDataset Is Nothing)
 Set pVelocityTable = pGxDataset.Dataset

  'set the path of the table to VelocityPath
  Set pGxObject = pGxDataset
  VelocityPath = pGxObject.FullName

  'create standalone table to store table data
  Set pInStTable = New StandaloneTable
  Set pInStTable.Table = pVelocityTable
  'add table to the map
  Dim pStTabColl As IStandaloneTableCollection
  Set pStTabColl = pMap
  pStTabColl.AddStandaloneTable pInStTable
  Set pGxDataset = pGxObjects.Next

  HSI_Calculator.lblVelocityIn.Caption = pGxObject.FullName

 Loop

 'update contents
 pMxDoc.UpdateContents

 'Calling Subroutine for user to choose output location for HSI Velocity table
 VelHSI_Output
 End Sub

'Allows the user to select the output location for the Velocity HSI file

Private Sub VelHSI_Output()
   Dim pBrowser As IGxDialog
   Set pBrowser = New GxDialog
   Dim pEnumGX As IEnumGxObject
```

```vba
'Set the type of objects the object filter will recognize (folders)
Dim pObjectFilter As IGxObjectFilter
Set pObjectFilter = New GxFilterBasicTypes

' +++ Open browser
Dim blnFlag As Boolean
pBrowser.Title = "Velocity Module: Select Location of Output Velocity HSI File
(ext .dbf)"
pBrowser.ButtonCaption = "Select"
pBrowser.AllowMultiSelect = False
pBrowser.RememberLocation = True
Set pBrowser.ObjectFilter = pObjectFilter

' +++ Set browser to open at last location
pBrowser.StartingLocation = m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub

pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   HSIVelOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If
'Calling the Subroutine to create the HSI Velocity table

CreateHSIVelTable

End Sub
Private Sub CreateHSIVelTable()
'Defining the number of columns in the velocity table
Dim pClass As IClass
Dim pFields As IFields
```

```
Set pClass = ThisDocument.pVelocityTable
Set pFields = pClass.Fields
NumOfVelCol = pFields.FieldCount - 2

Set pClass = Nothing
Set pFields = Nothing

Dim VfilePath As String
VfilePath = ThisDocument.HSIVelOut 'path of the hsi velocity table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(VfilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace

Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field
Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
 .Length = 30
 .Name = "Date"
 .Type = esriFieldTypeDate
End With

pFieldsEdit.AddField pField
Set pField = Nothing

'Create HSI velocity fields
 Dim j
For j = 1 To NumOfVelCol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
```

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```vb
    .Length = 30
    .Name = "Sandusky" & j
    .Type = esriFieldTypeSingle
   End With

   pFieldsEdit.AddField pField
   Set pField = Nothing
   Next

  'Allows user to name the output velocity table
  velocityrename:
  Dim VelTableName As String
  VelTableName = InputBox("Please Name Your Output Velocity Table.", "Velocity
  Table Name", "", 8000, 6000)

  Dim pSameName As String
  pSameName = VfilePath & "\" & VelTableName & "*.dbf"

  If VelTableName = "" Then
    MsgBox "Please give your file a name", vbOKOnly
    GoTo velocityrename
    ElseIf VelTableName & ".dbf" = Dir$(pSameName) Then
    MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
    GoTo velocityrename
  End If

  Set ThisDocument.pHSIVelTable = pFeatureWorkspace.CreateTable(VelTableName,
  pFields, Nothing, Nothing, "")

  HSI_Calculator.VelHSIOutput.Caption = VfilePath 'labels the userform with the path
  were the table is stored

  ADD_NUMBERS_TO_HSI_VELOCITY_TABLE

End Sub



Private Sub ADD_NUMBERS_TO_HSI_VELOCITY_TABLE()
"""'THIS CODE BLOCK CREATES THE VELOCITY SUITABILITY LAYER"""
'Adding the velocity table to the document
  Dim pVTable As ITable 'creating variable to get velocity table
  Set pVTable = ThisDocument.pVelocityTable
```

```
Dim pVelCursor As ICursor 'creating a cursor to hold the velocity table entries
Set pVelCursor = pVTable.Search(Nothing, True) 'adding all entries to the cursor

Dim pVelRow As IRow
Set pVelRow = pVelCursor.NextRow


'Adding the HSI velocity table to the document

Dim pHSIVTable As ITable 'creating variable to get velocity table
Set pHSIVTable = ThisDocument.pHSIVelTable

Dim pHSIVCursor As ICursor 'creating a cursor to hold the HSI velocity table entries
Set pHSIVCursor = pHSIVTable.Search(Nothing, True) 'adding all entries to the cursor

Dim i

Do Until pVelRow Is Nothing

  Dim pHSIVRow As IRow
  Set pHSIVRow = pHSIVelTable.CreateRow

  For i = 1 To ThisDocument.NumOfVelCol + 1
   If pVelRow.Value(i) = Empty Then
    Exit For
    ElseIf pVelRow.Value(i) = 0 Then
     Exit For
    ElseIf pVelRow.Value(i) < 0.09 And pVelRow.Value(i) > 2.7432 Then
    pHSIVRow.Value(i) = 0
    ElseIf pVelRow.Value(i) >= 0.09 And pVelRow.Value(i) <= 0.145 Then
     pHSIVRow.Value(i) = 0.1
    ElseIf pVelRow.Value(i) > 0.145 And pVelRow.Value(i) <= 0.2 Then
     pHSIVRow.Value(i) = 0.2
    ElseIf pVelRow.Value(i) > 0.2 And pVelRow.Value(i) <= 0.3 Then
     pHSIVRow.Value(i) = 0.4
    ElseIf pVelRow.Value(i) > 0.3 And pVelRow.Value(i) <= 0.57 Then
     pHSIVRow.Value(i) = 0.6
    ElseIf pVelRow.Value(i) > 0.57 And pVelRow.Value(i) <= 0.65 Then
     pHSIVRow.Value(i) = 0.8
    ElseIf pVelRow.Value(i) > 0.65 And pVelRow.Value(i) <= 2.7432 Then
     pHSIVRow.Value(i) = 1
   End If
  Next
  pHSIVRow.Store
```

```vb
 Set pHSIVRow = pHSIVCursor.NextRow
  Set pVelRow = pVelCursor.NextRow
  Loop
  MsgBox "Velocity Table Complete", vbOKOnly, "Velocity Module"
 End Sub




Private Sub Depth_Input_Click()
  Dim pInStTable As IStandaloneTable
  Dim pMxDoc As IMxDocument
  Set pMxDoc = ThisDocument
  Dim pMap As IMap
  Set pMap = pMxDoc.FocusMap
  Dim pGxDialog As IGxDialog
  Set pGxDialog = New GxDialog
  pGxDialog.AllowMultiSelect = True

  'set title of the selection box
  pGxDialog.Title = "Depth Module:  Please Select the Input Depth Database File
  (ext .dbf)"

  'Set the type of object filter for the search
  Dim pGxFilter As IGxObjectFilter
  Set pGxFilter = New GxFilterdBASEFiles

  Set pGxDialog.ObjectFilter = pGxFilter

  Dim pGxObjects As IEnumGxObject
  pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects

  If (pGxObjects Is Nothing) Then Exit Sub
  pGxObjects.Reset

  Dim pGxDataset As IGxDataset
  Set pGxDataset = pGxObjects.Next
  'create an object that can return the path of the selected table
  Dim pGxObject As IGxObject

  'Set the selected item to a new table variable
  'This code is written as a loop so that more than one selected item
  'may be added.
  Do Until (pGxDataset Is Nothing)
    Set pDepthTable = pGxDataset.Dataset
```

```
'set the path of the table to TablePath
Set pGxObject = pGxDataset
DepthPath = pGxObject.FullName

'create standalone table to store table data
Set pInStTable = New StandaloneTable
Set pInStTable.Table = pDepthTable

'add table to the map
Dim pStTabColl As IStandaloneTableCollection
Set pStTabColl = pMap
pStTabColl.AddStandaloneTable pInStTable
Set pGxDataset = pGxObjects.Next

HSI_Calculator.lblDepthIn.Caption = pGxObject.FullName
Loop

'update contents
pMxDoc.UpdateContents

'Calling the subroutine for user to choose depth HSI output file location

DepthHSI_Output

End Sub

'Allows the user to select the output location for the Depth HSI file
 Private Sub DepthHSI_Output()
    Dim pBrowser As IGxDialog
    Set pBrowser = New GxDialog
    Dim pEnumGX As IEnumGxObject

    'Set the type of objects the object filter will recognize (folders)
    Dim pObjectFilter As IGxObjectFilter
    Set pObjectFilter = New GxFilterBasicTypes

    ' +++ Open browser
    Dim blnFlag As Boolean
    pBrowser.Title = "Depth Module: Select Location of Output Depth HSI File (ext .dbf)"
    pBrowser.ButtonCaption = "Select"
    pBrowser.AllowMultiSelect = False
    pBrowser.RememberLocation = True
    Set pBrowser.ObjectFilter = pObjectFilter
```

```
' +++ Set browser to open at last location
pBrowser.StartingLocation = m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub


pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   HSIDepthOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

Set pBrowser = Nothing

'Calling subroutine to create Depth HSI table

CreateHSIDepthTable

End Sub
Private Sub CreateHSIDepthTable()

'Defining the number of columns in the Depth table

Dim pClass As IClass
Dim pFields As IFields
Set pClass = ThisDocument.pDepthTable
Set pFields = pClass.Fields
NumOfDepCol = pFields.FieldCount - 2

Set pClass = Nothing
Set pFields = Nothing
```

```
Dim DepthfilePath As String
DepthfilePath = ThisDocument.HSIDepthOut 'path of the hsi Depth table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(DepthfilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace

Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
.Length = 30
.Name = "Date"
.Type = esriFieldTypeDate
End With

pFieldsEdit.AddField pField
Set pField = Nothing

'Create HSI velocity fields

Dim j
For j = 1 To NumOfDepCol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
  .Length = 30
  .Name = "Sandusky" & j
  .Type = esriFieldTypeSingle
 End With
```

```
      pFieldsEdit.AddField pField
      Set pField = Nothing

   Next

   'Allows user to name the output depth table

depthrename:

   Dim DepthTableName As String
   DepthTableName = InputBox("Please Name Your Output Depth Table.", "Depth Table
Name", "", 8000, 6000)

   Dim pSameName As String
   pSameName = DepthfilePath & "\" & DepthTableName & "*.dbf"
   If DepthTableName = "" Then
    MsgBox "Please give your file a name", vbOKOnly
    GoTo depthrename
     ElseIf DepthTableName & ".dbf" = Dir$(pSameName) Then
      MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
      GoTo depthrename
   End If

   'Creates the output velocity table

   Set ThisDocument.pHSIDepTable = pFeatureWorkspace.CreateTable(DepthTableName,
pFields, Nothing, Nothing, "")

   HSI_Calculator.DepHSIOutput.Caption = DepthfilePath 'labels the userform with the
path were the table is stored

   ADD_NUMBERS_TO_HSI_DEPTH_TABLE

End Sub

Private Sub ADD_NUMBERS_TO_HSI_DEPTH_TABLE()
"""""THIS CODE BLOCK CREATES THE VELOCITY SUITABILITY LAYER"""""
'Adding the DEPTH table to the document
 Dim pDTable As ITable 'creating variable to get DEPTH table
 Set pDTable = ThisDocument.pDepthTable

 Dim pDEPTHCursor As ICursor 'creating a cursor to hold the DEPTH table entries
 Set pDEPTHCursor = pDTable.Search(Nothing, True) 'adding all entries to the cursor
```

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```
Dim pDEPTHRow As IRow
 Set pDEPTHRow = pDEPTHCursor.NextRow

'Adding the HSI DEPTH table to the document

Dim pHSIDTable As ITable 'creating variable to get DEPTH table
Set pHSIDTable = ThisDocument.pHSIDepTable

Dim pHSIDCursor As ICursor 'creating a cursor to hold the HSI DEPTH table entries
Set pHSIDCursor = pHSIDTable.Search(Nothing, True) 'adding all entries to the cursor

Dim i

Do Until pDEPTHRow Is Nothing

 Dim pHSIDRow As IRow
 Set pHSIDRow = pHSIDepTable.CreateRow

 For i = 2 To ThisDocument.NumOfDepCol + 1
  If pDEPTHRow.Value(i) = Empty Then
    Exit For
  ElseIf pDEPTHRow.Value(i) = 0 Then
    Exit For
  ElseIf pDEPTHRow.Value(i) < 0.09 And pDEPTHRow.Value(i) > 0.6 Then
    pHSIDRow.Value(i) = 0
  ElseIf pDEPTHRow.Value(i) >= 0.125 And pDEPTHRow.Value(i) <= 0.2125 Then
    pHSIDRow.Value(i) = 0.1
  ElseIf pDEPTHRow.Value(i) > 0.2125 And pDEPTHRow.Value(i) <= 0.3 Then
    pHSIDRow.Value(i) = 0.2
  ElseIf pDEPTHRow.Value(i) > 0.09 And pDEPTHRow.Value(i) <= 0.125 Then
    pHSIDRow.Value(i) = 0.4
  ElseIf pDEPTHRow.Value(i) > 0.3 And pDEPTHRow.Value(i) <= 0.37 Then
    pHSIDRow.Value(i) = 0.4
  ElseIf pDEPTHRow.Value(i) > 0.37 And pDEPTHRow.Value(i) <= 0.42 Then
    pHSIDRow.Value(i) = 0.6
  ElseIf pDEPTHRow.Value(i) > 0.42 And pDEPTHRow.Value(i) <= 0.46 Then
    pHSIDRow.Value(i) = 0.8
  ElseIf pDEPTHRow.Value(i) > 0.46 And pDEPTHRow.Value(i) <= 0.6 Then
    pHSIDRow.Value(i) = 1
End If
Next

pHSIDRow.Store

Set pHSIDRow = pHSIDCursor.NextRow
```

```
   Set pDEPTHRow = pDEPTHCursor.NextRow
   Loop

   MsgBox "Depth Table Complete", vbOKOnly, "Depth Module"
   End Sub

Private Sub Substrate_Input_Click()
   Dim pInStTable As IStandaloneTable
   Dim pMxDoc As IMxDocument
   Set pMxDoc = ThisDocument
   Dim pMap As IMap
   Set pMap = pMxDoc.FocusMap
   Dim pGxDialog As IGxDialog
   Set pGxDialog = New GxDialog
   pGxDialog.AllowMultiSelect = True

   'set title of the selection box
   pGxDialog.Title = "Substrate Module: Please Select the Input Substrate Database File
(ext .dbf)"

   'Set the type of object filter for the search
   Dim pGxFilter As IGxObjectFilter
   Set pGxFilter = New GxFilterdBASEFiles

   Set pGxDialog.ObjectFilter = pGxFilter

   Dim pGxObjects As IEnumGxObject
   pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects

   If (pGxObjects Is Nothing) Then Exit Sub
   pGxObjects.Reset

   Dim pGxDataset As IGxDataset
   Set pGxDataset = pGxObjects.Next
   'create an object that can return the path of the selected table
   Dim pGxObject As IGxObject

   'Set the selected item to a new table variable
   'This code is written as a loop so that more than one selected item
   'may be added.
   Do Until (pGxDataset Is Nothing)
     Set pSubstrateTable = pGxDataset.Dataset
```

```
'set the path of the table to TablePath
    Set pGxObject = pGxDataset
    SubstratePath = pGxObject.FullName

    'create standalone table to store table data
    Set pInStTable = New StandaloneTable
    Set pInStTable.Table = pSubstrateTable

    'add table to the map
    Dim pStTabColl As IStandaloneTableCollection
    Set pStTabColl = pMap
    pStTabColl.AddStandaloneTable pInStTable
    Set pGxDataset = pGxObjects.Next

  Loop

  HSI_Calculator.lblSubstrateIn.Caption = pGxObject.FullName


'update contents
  pMxDoc.UpdateContents

  'Calling subroutine for user to choose output location for Substrate HSI table

  SubHSI_Output
End Sub
'Allows the user to select the output location for the Velocity HSI file

Private Sub SubHSI_Output()
    Dim pBrowser As IGxDialog
    Set pBrowser = New GxDialog
    Dim pEnumGX As IEnumGxObject

    'Set the type of objects the object filter will recognize (folders)
    Dim pObjectFilter As IGxObjectFilter
    Set pObjectFilter = New GxFilterBasicTypes

    ' +++ Open browser
    Dim blnFlag As Boolean
    pBrowser.Title = "Substrate Module: Select Location of Output Substrate HSI file
    (ext .dbf)"
    pBrowser.ButtonCaption = "Select"
    pBrowser.AllowMultiSelect = False
    pBrowser.RememberLocation = True
    Set pBrowser.ObjectFilter = pObjectFilter
```

```vba
' +++ Set browser to open at last location
pBrowser.StartingLocation = m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub


pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   HSISubOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

Set pBrowser = Nothing


'Calling subroutine to create Substrate HSI table
CreateHSISubTable

End Sub

Private Sub CreateHSISubTable()
 'Defining the number of columns in the depth table
 Dim pFields As IFields
 Dim pClass As IClass
 Set pClass = ThisDocument.pSubstrateTable
 Set pFields = pClass.Fields
 NumOfSubCol = pFields.FieldCount - 2

Set pClass = Nothing
Set pFields = Nothing
```

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```
Dim SubstratefilePath As String
SubstratefilePath = ThisDocument.HSISubOut 'path of the hsi Substrate table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(SubstratefilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace

Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
 .Length = 30
 .Name = "Date"
 .Type = esriFieldTypeDate
End With

pFieldsEdit.AddField pField
Set pField = Nothing

'Create HSI velocity fields

Dim j
For j = 1 To NumOfSubCol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
  .Length = 30
  .Name = "Sandusky" & j
  .Type = esriFieldTypeSingle
 End With
```

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```vb
        pFieldsEdit.AddField pField
        Set pField = Nothing

    Next

    'Allows user to name the output Substrate table

    substraterename:

    Dim SubTableName As String
    SubTableName = InputBox("Please Name Your Output Substrate Table.", "Substrate
    Table Name", "", 8000, 6000)

    Dim pSameName As String
    pSameName = SubstratefilePath & "\" & SubTableName & "*.dbf"

    If SubTableName = "" Then
     MsgBox "Please give your file a name", vbOKOnly
     GoTo substraterename
       ElseIf SubTableName & ".dbf" = Dir$(pSameName) Then
        MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
        GoTo substraterename
    End If

    Set ThisDocument.pHSISubTable = pFeatureWorkspace.CreateTable(SubTableName,
    pFields, Nothing, Nothing, "")

    HSI_Calculator.SubHSIOutput.Caption = SubstratefilePath

    ADD_NUMBERS_TO_HSI_SUBSTRATE_TABLE

End Sub
Private Sub ADD_NUMBERS_TO_HSI_SUBSTRATE_TABLE()
"""""THIS CODE BLOCK CREATES THE SUBSTRATE SUITABILITY LAYER"""""
'Adding the SUBSTRATE table to the document
 Dim pSTable As ITable 'creating variable to get SUBSTRATE table
 Set pSTable = ThisDocument.pSubstrateTable

 Dim pSUBTRATECursor As ICursor 'creating a cursor to hold the SUBSTRATE table
 entries
 Set pSUBTRATECursor = pSTable.Search(Nothing, True) 'adding all entries to the
 cursor

 Dim pSUBSTRATERow As IRow
 Set pSUBSTRATERow = pSUBTRATECursor.NextRow
```

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```
'Adding the HSI SUBSTRATE table to the document

Dim pHSISTable As ITable 'creating variable to get SUBSTRATE table
Set pHSISTable = ThisDocument.pHSISubTable

Dim pHSISubstrateCursor As ICursor 'creating a cursor to hold the HSI SUBSTRATE
table entries
Set pHSISubstrateCursor = pHSISTable.Search(Nothing, True) 'adding all entries to the
cursor

Dim i

Do Until pSUBSTRATERow Is Nothing

  Dim pHSISubRow As IRow
  Set pHSISubRow = pHSISubTable.CreateRow

  For i = 2 To ThisDocument.NumOfSubCol + 1
    If pSUBSTRATERow.Value(i) = "" Then
      Exit For
    ElseIf pSUBSTRATERow.Value(i) = 0 Then
      pHSISubRow.Value(i) = 0
    ElseIf pSUBSTRATERow.Value(i) = 0.5 Then
      pHSISubRow.Value(i) = 0.5
    ElseIf pSUBSTRATERow.Value(i) = 0.75 Then
      pHSISubRow.Value(i) = 0.75
    ElseIf pSUBSTRATERow.Value(i) = 1 Then
      pHSISubRow.Value(i) = 1
  End If
  Next

  pHSISubRow.Store
  Set pHSISubRow = pHSISubstrateCursor.NextRow
  Set pSUBSTRATERow = pSUBTRATECursor.NextRow
Loop
MsgBox "Substrate Table Complete", vbOKOnly, "Substrate Module"
End Sub

Private Sub HSICalculator_Click()
  HSI_Calculator.Show
End Sub
```

Greater Redhorse

Option Explicit

Public m_sStartBrowseLoc As String 'start location for the file browser
Public Path As String
Public HSIVelOut As String 'path of HSI Velocity table
Public HSISubOut As String 'path of HSI Substrate table
Public HSIDepthOut As String 'path of HSI Depth table
Public VelocityPath As String 'Velocity input path
Public DepthPath As String 'Depth input path
Public SubstratePath As String 'Substrate input path
Public pHSIVelTable As ITable 'output hsi velocity table
Public pHSIDepTable As ITable 'output hsi depth table
Public pHSISubTable As ITable 'output hsi substrate table
Public pDepthTable As ITable 'input depth database file
Public pVelocityTable As ITable 'input velocity database file
Public pSubstrateTable As ITable 'input substrate database file
Public NumOfVelCol As Long 'number of columns in velocity table
Public NumOfSubCol As Long 'number of columns in substrate table
Public NumOfDepCol As Long 'number of columns in depth table

```
Private Sub Velocity_Input_Click()
  Dim pInStTable As IStandaloneTable
  Dim pMxDoc As IMxDocument
  Set pMxDoc = ThisDocument
  Dim pMap As IMap
  Set pMap = pMxDoc.FocusMap
  Dim pGxDialog As IGxDialog
  Set pGxDialog = New GxDialog
  pGxDialog.AllowMultiSelect = True

  'set title of the selection box
  pGxDialog.Title = "Velocity Module: Please Select the Input Velocity Database File
  (ext .dbf)"

  'Set the type of object filter for the search
  Dim pGxFilter As IGxObjectFilter
  Set pGxFilter = New GxFilterdBASEFiles

  Set pGxDialog.ObjectFilter = pGxFilter

  Dim pGxObjects As IEnumGxObject
  pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects
```

```
If (pGxObjects Is Nothing) Then Exit Sub
pGxObjects.Reset

Dim pGxDataset As IGxDataset
Set pGxDataset = pGxObjects.Next
'create an object that can return the path of the selected table
Dim pGxObject As IGxObject

'Set the selected item to a new table variable
'This code is written as a loop so that more than one selected item
'may be added.
Do Until (pGxDataset Is Nothing)
  Set pVelocityTable = pGxDataset.Dataset

  'set the path of the table to VelocityPath
  Set pGxObject = pGxDataset
  VelocityPath = pGxObject.FullName

  'create standalone table to store table data
  Set pInStTable = New StandaloneTable
  Set pInStTable.Table = pVelocityTable
  'add table to the map
  Dim pStTabColl As IStandaloneTableCollection
  Set pStTabColl = pMap
  pStTabColl.AddStandaloneTable pInStTable
  Set pGxDataset = pGxObjects.Next

  HSI_Calculator.lblVelocityIn.Caption = pGxObject.FullName

Loop

'update contents
pMxDoc.UpdateContents

'Calling Subroutine for user to choose output location for HSI Velocity table

VelHSI_Output

End Sub

'Allows the user to select the output location for the Velocity HSI file

Private Sub VelHSI_Output()
  Dim pBrowser As IGxDialog
  Set pBrowser = New GxDialog
```

```
Dim pEnumGX As IEnumGxObject
'Set the type of objects the object filter will recognize (folders)
Dim pObjectFilter As IGxObjectFilter
Set pObjectFilter = New GxFilterBasicTypes

' +++ Open browser
Dim blnFlag As Boolean
pBrowser.Title = "Velocity Module: Select Location of Output Velocity HSI File
(ext .dbf)"
pBrowser.ButtonCaption = "Select"
pBrowser.AllowMultiSelect = False
pBrowser.RememberLocation = True
Set pBrowser.ObjectFilter = pObjectFilter

' +++ Set browser to open at last location
pBrowser.StartingLocation = m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub

pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   HSIVelOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

'Calling the Subroutine to create the HSI Velocity table

CreateHSIVelTable
End Sub
```

```
Private Sub CreateHSIVelTable()
'Defining the number of columns in the velocity table
 Dim pClass As IClass
 Dim pFields As IFields
 Set pClass = ThisDocument.pVelocityTable
 Set pFields = pClass.Fields
 NumOfVelCol = pFields.FieldCount - 2

 Set pClass = Nothing
 Set pFields = Nothing

 Dim VfilePath As String
 VfilePath = ThisDocument.HSIVelOut 'path of the hsi velocity table

 Dim pWorkspace As IWorkspace
 Dim pWorkspaceFactory As IWorkspaceFactory

 Set pWorkspaceFactory = New ShapefileWorkspaceFactory
 Set pWorkspace = pWorkspaceFactory.OpenFromFile(VfilePath, 0)

 Dim pFeatureWorkspace As IFeatureWorkspace
 Set pFeatureWorkspace = pWorkspace

 Dim pField As IField
 Dim pFieldEdit As IFieldEdit
 Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
 Set pFields = New Fields
 Set pFieldsEdit = pFields

'Create date field

 Set pField = New Field
 Set pFieldEdit = pField
 With pFieldEdit
  .Length = 30
  .Name = "Date"
  .Type = esriFieldTypeDate
 End With

 pFieldsEdit.AddField pField
 Set pField = Nothing
```

```vbnet
'Create HSI velocity fields
 Dim j
For j = 1 To NumOfVelCol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
   .Length = 30
   .Name = "Sandusky" & j
   .Type = esriFieldTypeSingle
 End With

 pFieldsEdit.AddField pField
 Set pField = Nothing

Next

'Allows user to name the output velocity table

velocityrename:

 Dim VelTableName As String
 VelTableName = InputBox("Please Name Your Output Velocity Table.", "Velocity
Table Name", "", 8000, 6000)

Dim pSameName As String
pSameName = VfilePath & "\" & VelTableName & "*.dbf"

If VelTableName = "" Then
  MsgBox "Please give your file a name", vbOKOnly
  GoTo velocityrename
  ElseIf VelTableName & ".dbf" = Dir$(pSameName) Then
   MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
   GoTo velocityrename
End If

 Set ThisDocument.pHSIVelTable = pFeatureWorkspace.CreateTable(VelTableName,
pFields, Nothing, Nothing, "")

 HSI_Calculator.VelHSIOutput.Caption = VfilePath 'labels the userform with the path
were the table is stored

 ADD_NUMBERS_TO_HSI_VELOCITY_TABLE

End Sub
```

```
Private Sub ADD_NUMBERS_TO_HSI_VELOCITY_TABLE()
""""THIS CODE BLOCK CREATES THE VELOCITY SUITABILITY LAYER""""
'Adding the velocity table to the document
 Dim pVTable As ITable 'creating variable to get velocity table
 Set pVTable = ThisDocument.pVelocityTable

 Dim pVelCursor As ICursor 'creating a cursor to hold the velocity table entries
 Set pVelCursor = pVTable.Search(Nothing, True) 'adding all entries to the cursor

 Dim pVelRow As IRow
 Set pVelRow = pVelCursor.NextRow

 'Adding the HSI velocity table to the document

 Dim pHSIVTable As ITable 'creating variable to get velocity table
 Set pHSIVTable = ThisDocument.pHSIVelTable

 Dim pHSIVCursor As ICursor 'creating a cursor to hold the HSI velocity table entries
 Set pHSIVCursor = pHSIVTable.Search(Nothing, True) 'adding all entries to the cursor

 Dim i

 Do Until pVelRow Is Nothing

  Dim pHSIVRow As IRow
  Set pHSIVRow = pHSIVelTable.CreateRow

  For i = 1 To ThisDocument.NumOfVelCol + 1
   If pVelRow.Value(i) = Empty Then
    Exit For
   ElseIf pVelRow.Value(i) = 0 Then
    Exit For
   ElseIf pVelRow.Value(i) < 0.0379 Then
    pHSIVRow.Value(i) = 0
   ElseIf pVelRow.Value(i) > 1.1689 Then
    pHSIVRow.Value(i) = 0
   ElseIf pVelRow.Value(i) >= 0.0379 And pVelRow.Value(i) <= 0.22035 Then
    pHSIVRow.Value(i) = 0.1
   ElseIf pVelRow.Value(i) >= 0.79665 And pVelRow.Value(i) <= 1.1689 Then
    pHSIVRow.Value(i) = 0.1
   ElseIf pVelRow.Value(i) > 0.22035 And pVelRow.Value(i) <= 0.28815 Then
    pHSIVRow.Value(i) = 0.2
   ElseIf pVelRow.Value(i) >= 0.76275 And pVelRow.Value(i) < 0.79665 Then
    pHSIVRow.Value(i) = 0.2
   ElseIf pVelRow.Value(i) > 0.28815 And pVelRow.Value(i) <= 0.347475 Then
```

```
  pHSIVRow.Value(i) = 0.4
 ElseIf pVelRow.Value(i) >= 0.7119 And pVelRow.Value(i) < 0.76275 Then
  pHSIVRow.Value(i) = 0.4
 ElseIf pVelRow.Value(i) > 0.347475 And pVelRow.Value(i) <= 0.4068 Then
  pHSIVRow.Value(i) = 0.6
 ElseIf pVelRow.Value(i) >= 0.6449 And pVelRow.Value(i) < 0.7119 Then
  pHSIVRow.Value(i) = 0.6
 ElseIf pVelRow.Value(i) > 0.4068 And pVelRow.Value(i) <= 0.45765 Then
  pHSIVRow.Value(i) = 0.8
 ElseIf pVelRow.Value(i) >= 0.62715 And pVelRow.Value(i) < 0.6449 Then
  pHSIVRow.Value(i) = 0.8
  ElseIf pVelRow.Value(i) > 0.45765 And pVelRow.Value(i) < 62715 Then
  pHSIVRow.Value(i) = 1
 End If
 Next

 pHSIVRow.Store
 Set pHSIVRow = pHSIVCursor.NextRow
 Set pVelRow = pVelCursor.NextRow
 Loop
 MsgBox "Velocity Table Complete", vbOKOnly, "Velocity Module"
End Sub

Private Sub Depth_Input_Click()
 Dim pInStTable As IStandaloneTable
 Dim pMxDoc As IMxDocument
 Set pMxDoc = ThisDocument
 Dim pMap As IMap
 Set pMap = pMxDoc.FocusMap
 Dim pGxDialog As IGxDialog
 Set pGxDialog = New GxDialog
 pGxDialog.AllowMultiSelect = True

 'set title of the selection box
 pGxDialog.Title = "Depth Module:  Please Select the Input Depth Database File
 (ext .dbf)"

 'Set the type of object filter for the search
 Dim pGxFilter As IGxObjectFilter
 Set pGxFilter = New GxFilterdBASEFiles

 Set pGxDialog.ObjectFilter = pGxFilter

 Dim pGxObjects As IEnumGxObject
 pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects
```

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```
If (pGxObjects Is Nothing) Then Exit Sub
pGxObjects.Reset

Dim pGxDataset As IGxDataset
Set pGxDataset = pGxObjects.Next
'create an object that can return the path of the selected table
Dim pGxObject As IGxObject

'Set the selected item to a new table variable
'This code is written as a loop so that more than one selected item
'may be added.
Do Until (pGxDataset Is Nothing)
  Set pDepthTable = pGxDataset.Dataset

  'set the path of the table to TablePath
  Set pGxObject = pGxDataset
  DepthPath = pGxObject.FullName

  'create standalone table to store table data
  Set pInStTable = New StandaloneTable
  Set pInStTable.Table = pDepthTable

  'add table to the map
  Dim pStTabColl As IStandaloneTableCollection
  Set pStTabColl = pMap
  pStTabColl.AddStandaloneTable pInStTable
  Set pGxDataset = pGxObjects.Next

  HSI_Calculator.lblDepthIn.Caption = pGxObject.FullName
Loop

'update contents
pMxDoc.UpdateContents

'Calling the subroutine for user to choose depth HSI output file location

DepthHSI_Output

End Sub

'Allows the user to select the output location for the Depth HSI file
Private Sub DepthHSI_Output()
  Dim pBrowser As IGxDialog
  Set pBrowser = New GxDialog
```

```
Dim pEnumGX As IEnumGxObject
'Set the type of objects the object filter will recognize (folders)
Dim pObjectFilter As IGxObjectFilter
Set pObjectFilter = New GxFilterBasicTypes

' +++ Open browser
Dim blnFlag As Boolean
pBrowser.Title = "Depth Module: Select Location of Output Depth HSI File (ext .dbf)"
pBrowser.ButtonCaption = "Select"
pBrowser.AllowMultiSelect = False
pBrowser.RememberLocation = True
Set pBrowser.ObjectFilter = pObjectFilter

' +++ Set browser to open at last location
pBrowser.StartingLocation = m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub


pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   HSIDepthOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

Set pBrowser = Nothing

'Calling subroutine to create Depth HSI table

CreateHSIDepthTable

End Sub
```

```vba
Private Sub CreateHSIDepthTable()
  'Defining the number of columns in the Depth table
  Dim pClass As IClass
 Dim pFields As IFields
 Set pClass = ThisDocument.pDepthTable
 Set pFields = pClass.Fields
 NumOfDepCol = pFields.FieldCount - 2

 Set pClass = Nothing
 Set pFields = Nothing

 Dim DepthfilePath As String
 DepthfilePath = ThisDocument.HSIDepthOut 'path of the hsi Depth table

 Dim pWorkspace As IWorkspace
 Dim pWorkspaceFactory As IWorkspaceFactory

 Set pWorkspaceFactory = New ShapefileWorkspaceFactory
 Set pWorkspace = pWorkspaceFactory.OpenFromFile(DepthfilePath, 0)

 Dim pFeatureWorkspace As IFeatureWorkspace
 Set pFeatureWorkspace = pWorkspace

 Dim pField As IField
 Dim pFieldEdit As IFieldEdit
 Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
 Set pFields = New Fields
 Set pFieldsEdit = pFields

'Create date field

 Set pField = New Field
 Set pFieldEdit = pField
 With pFieldEdit
 .Length = 30
 .Name = "Date"
 .Type = esriFieldTypeDate
 End With

 pFieldsEdit.AddField pField
 Set pField = Nothing

'Create HSI velocity fields
```

```vba
 Dim j
For j = 1 To NumOfDepCol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
  .Length = 30
  .Name = "Sandusky" & j
  .Type = esriFieldTypeSingle
 End With

 pFieldsEdit.AddField pField
 Set pField = Nothing

Next

'Allows user to name the output depth table

depthrename:

 Dim DepthTableName As String
 DepthTableName = InputBox("Please Name Your Output Depth Table.", "Depth Table
Name", "", 8000, 6000)

 Dim pSameName As String
 pSameName = DepthfilePath & "\" & DepthTableName & "*.dbf"
 If DepthTableName = "" Then
  MsgBox "Please give your file a name", vbOKOnly
  GoTo depthrename
  ElseIf DepthTableName & ".dbf" = Dir$(pSameName) Then
   MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
   GoTo depthrename
 End If

'Creates the output velocity table

 Set ThisDocument.pHSIDepTable = pFeatureWorkspace.CreateTable(DepthTableName,
pFields, Nothing, Nothing, "")

 HSI_Calculator.DepHSIOutput.Caption = DepthfilePath 'labels the userform with the
path were the table is stored

 ADD_NUMBERS_TO_HSI_DEPTH_TABLE
End Sub
```

```
Private Sub ADD_NUMBERS_TO_HSI_DEPTH_TABLE()
"""""THIS CODE BLOCK CREATES THE VELOCITY SUITABILITY LAYER"""""
'Adding the DEPTH table to the document
Dim pDTable As ITable 'creating variable to get DEPTH table
Set pDTable = ThisDocument.pDepthTable

Dim pDEPTHCursor As ICursor 'creating a cursor to hold the DEPTH table entries
Set pDEPTHCursor = pDTable.Search(Nothing, True) 'adding all entries to the cursor

Dim pDEPTHRow As IRow
Set pDEPTHRow = pDEPTHCursor.NextRow

'Adding the HSI DEPTH table to the document

Dim pHSIDTable As ITable 'creating variable to get DEPTH table
Set pHSIDTable = ThisDocument.pHSIDepTable

Dim pHSIDCursor As ICursor 'creating a cursor to hold the HSI DEPTH table entries
Set pHSIDCursor = pHSIDTable.Search(Nothing, True) 'adding all entries to the cursor

Dim i

Do Until pDEPTHRow Is Nothing

  Dim pHSIDRow As IRow
  Set pHSIDRow = pHSIDepTable.CreateRow

  For i = 2 To ThisDocument.NumOfDepCol + 1
   If pDEPTHRow.Value(i) = Empty Then
     Exit For
   ElseIf pDEPTHRow.Value(i) = 0 Then
     Exit For
   ElseIf pDEPTHRow.Value(i) < 0.07 Then
     pHSIDRow.Value(i) = 0
   ElseIf pDEPTHRow.Value(i) > 1 Then
     pHSIDRow.Value(i) = 0
   ElseIf pDEPTHRow.Value(i) >= 0.07 And pDEPTHRow.Value(i) <= 0.1 Then
     pHSIDRow.Value(i) = 0.1
   ElseIf pDEPTHRow.Value(i) >= 0.7854 And pDEPTHRow.Value(i) <= 1 Then
     pHSIDRow.Value(i) = 0.1
   ElseIf pDEPTHRow.Value(i) > 0.1 And pDEPTHRow.Value(i) <= 0.151725 Then
     pHSIDRow.Value(i) = 0.2
   ElseIf pDEPTHRow.Value(i) >= 0.66402 And pDEPTHRow.Value(i) < 0.7854 Then
     pHSIDRow.Value(i) = 0.2
   ElseIf pDEPTHRow.Value(i) > 0.151725 And pDEPTHRow.Value(i) <= 0.18564 Then
```

```
  pHSIDRow.Value(i) = 0.4
 ElseIf pDEPTHRow.Value(i) >= 0.5712 And pDEPTHRow.Value(i) < 0.66402 Then
  pHSIDRow.Value(i) = 0.4
 ElseIf pDEPTHRow.Value(i) > 0.18564 And pDEPTHRow.Value(i) <= 0.22848 Then
  pHSIDRow.Value(i) = 0.6
 ElseIf pDEPTHRow.Value(i) >= 0.4998 And pDEPTHRow.Value(i) < 0.5712 Then
  pHSIDRow.Value(i) = 0.6
 ElseIf pDEPTHRow.Value(i) > 0.22848 And pDEPTHRow.Value(i) < 0.2499 Then
  pHSIDRow.Value(i) = 0.8
 ElseIf pDEPTHRow.Value(i) >= 0.45696 And pDEPTHRow.Value(i) < 0.4998 Then
  pHSIDRow.Value(i) = 0.8
 ElseIf pDEPTHRow.Value(i) > 0.2499 And pDEPTHRow.Value(i) < 0.45696 Then
  pHSIDRow.Value(i) = 1
 End If
 Next

 pHSIDRow.Store
 Set pHSIDRow = pHSIDCursor.NextRow
 Set pDEPTHRow = pDEPTHCursor.NextRow
 Loop
 MsgBox "Depth Table Complete", vbOKOnly, "Depth Module"
End Sub


Private Sub Substrate_Input_Click()
 Dim pInStTable As IStandaloneTable
 Dim pMxDoc As IMxDocument
 Set pMxDoc = ThisDocument
 Dim pMap As IMap
 Set pMap = pMxDoc.FocusMap
 Dim pGxDialog As IGxDialog
 Set pGxDialog = New GxDialog
 pGxDialog.AllowMultiSelect = True

 'set title of the selection box
 pGxDialog.Title = "Substrate Module: Please Select the Input Substrate Database File
(ext .dbf)"

 'Set the type of object filter for the search
 Dim pGxFilter As IGxObjectFilter
 Set pGxFilter = New GxFilterdBASEFiles

 Set pGxDialog.ObjectFilter = pGxFilter

 Dim pGxObjects As IEnumGxObject
 pGxDialog.DoModalOpen ThisDocument.Parent.hWnd, pGxObjects
```

```
    If (pGxObjects Is Nothing) Then Exit Sub
pGxObjects.Reset

Dim pGxDataset As IGxDataset
Set pGxDataset = pGxObjects.Next
'create an object that can return the path of the selected table
Dim pGxObject As IGxObject

'Set the selected item to a new table variable
'This code is written as a loop so that more than one selected item
'may be added.
Do Until (pGxDataset Is Nothing)
  Set pSubstrateTable = pGxDataset.Dataset

  'set the path of the table to TablePath
  Set pGxObject = pGxDataset
  SubstratePath = pGxObject.FullName

  'create standalone table to store table data
  Set pInStTable = New StandaloneTable
  Set pInStTable.Table = pSubstrateTable

  'add table to the map
  Dim pStTabColl As IStandaloneTableCollection
  Set pStTabColl = pMap
  pStTabColl.AddStandaloneTable pInStTable
  Set pGxDataset = pGxObjects.Next

Loop

HSI_Calculator.lblSubstrateIn.Caption = pGxObject.FullName

'update contents
pMxDoc.UpdateContents

'Calling subroutine for user to choose output location for Substrate HSI table

SubHSI_Output

End Sub
'Allows the user to select the output location for the Velocity HSI file
 Private Sub SubHSI_Output()
   Dim pBrowser As IGxDialog
   Set pBrowser = New GxDialog
   Dim pEnumGX As IEnumGxObject
```

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```
      'Set the type of objects the object filter will recognize (folders)
      Dim pObjectFilter As IGxObjectFilter
      Set pObjectFilter = New GxFilterBasicTypes

      ' +++ Open browser
      Dim blnFlag As Boolean
      pBrowser.Title = "Substrate Module: Select Location of Output Substrate HSI file
      (ext .dbf)"
      pBrowser.ButtonCaption = "Select"
      pBrowser.AllowMultiSelect = False
      pBrowser.RememberLocation = True
      Set pBrowser.ObjectFilter = pObjectFilter

      ' +++ Set browser to open at last location
      pBrowser.StartingLocation = m_sStartBrowseLoc

      ' +++ Open browser
      blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

      ' +++ Save the current location
      m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

      If blnFlag = False Then Exit Sub


      pEnumGX.Reset
      Dim pGxObject As IGxObject

      'Determine if the selected item is indeed a folder
      'If it is, set the path variable to the folder's path

      Set pGxObject = pEnumGX.Next
      If pGxObject.Category = "Folder" Then
         HSISubOut = pGxObject.FullName
         Else
            MsgBox "Wrong target data type"
      End If

      Set pBrowser = Nothing


      'Calling subroutine to create Substrate HSI table
      CreateHSISubTable

End Sub
```

```
Private Sub CreateHSISubTable()
 'Defining the number of columns in the depth table
  Dim pFields As IFields
 Dim pClass As IClass
 Set pClass = ThisDocument.pSubstrateTable
 Set pFields = pClass.Fields
 NumOfSubCol = pFields.FieldCount - 2

Set pClass = Nothing
Set pFields = Nothing

Dim SubstratefilePath As String
SubstratefilePath = ThisDocument.HSISubOut 'path of the hsi Substrate table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(SubstratefilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace

Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
  .Length = 30
  .Name = "Date"
  .Type = esriFieldTypeDate
 End With

pFieldsEdit.AddField pField
Set pField = Nothing
```

```vb
'Create HSI velocity fields
Dim j
For j = 1 To NumOfSubCol
Set pField = New Field
Set pFieldEdit = pField
  With pFieldEdit
    .Length = 30
    .Name = "Sandusky" & j
    .Type = esriFieldTypeSingle
  End With

  pFieldsEdit.AddField pField
  Set pField = Nothing
Next

'Allows user to name the output Substrate table

substraterename:

Dim SubTableName As String
SubTableName = InputBox("Please Name Your Output Substrate Table.", "Substrate
Table Name", "", 8000, 6000)

 Dim pSameName As String
 pSameName = SubstratefilePath & "\" & SubTableName & "*.dbf"

 If SubTableName = "" Then
  MsgBox "Please give your file a name", vbOKOnly
  GoTo substraterename
   ElseIf SubTableName & ".dbf" = Dir$(pSameName) Then
   MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
   GoTo substraterename
 End If

Set ThisDocument.pHSISubTable = pFeatureWorkspace.CreateTable(SubTableName,
pFields, Nothing, Nothing, "")

HSI_Calculator.SubHSIOutput.Caption = SubstratefilePath

ADD_NUMBERS_TO_HSI_SUBSTRATE_TABLE

End Sub
```

```
Private Sub ADD_NUMBERS_TO_HSI_SUBSTRATE_TABLE()
""""THIS CODE BLOCK CREATES THE SUBSTRATE SUITABILITY LAYER""""
'Adding the SUBSTRATE table to the document
 Dim pSTable As ITable 'creating variable to get SUBSTRATE table
 Set pSTable = ThisDocument.pSubstrateTable

Dim pSUBTRATECursor As ICursor 'creating a cursor to hold the SUBSTRATE table
entries
Set pSUBTRATECursor = pSTable.Search(Nothing, True) 'adding all entries to the
cursor

Dim pSUBSTRATERow As IRow
Set pSUBSTRATERow = pSUBTRATECursor.NextRow

'Adding the HSI SUBSTRATE table to the document

Dim pHSISTable As ITable 'creating variable to get SUBSTRATE table
Set pHSISTable = ThisDocument.pHSISubTable

Dim pHSISubstrateCursor As ICursor 'creating a cursor to hold the HSI SUBSTRATE
table entries
Set pHSISubstrateCursor = pHSISTable.Search(Nothing, True) 'adding all entries to the
cursor

Dim i
Do Until pSUBSTRATERow Is Nothing

  Dim pHSISubRow As IRow
  Set pHSISubRow = pHSISubTable.CreateRow

  For i = 2 To ThisDocument.NumOfSubCol + 1
   If pSUBSTRATERow.Value(i) = "" Then
    Exit For
    ElseIf pSUBSTRATERow.Value(i) = 0 Then
    pHSISubRow.Value(i) = 0
    ElseIf pSUBSTRATERow.Value(i) = 0.5 Then
    pHSISubRow.Value(i) = 0.5
    ElseIf pSUBSTRATERow.Value(i) = 0.75 Then
    pHSISubRow.Value(i) = 0.75
    ElseIf pSUBSTRATERow.Value(i) = 1 Then
    pHSISubRow.Value(i) = 1
End If
Next
```

```
pHSISubRow.Store
Set pHSISubRow = pHSISubstrateCursor.NextRow
Set pSUBSTRATERow = pSUBTRATECursor.NextRow
Loop
MsgBox "Substrate Table Complete", vbOKOnly, "Substrate Module"
End Sub

Private Sub HSICalculator_Click()
 HSI_Calculator.Show
End Sub
```

HSI Calcualtor

```
Public pHSIShapefileTable As ITable
Public pTotalHSITable As ITable
Public pShapeFileLocation As String 'path of shapefile
Public pShapeFolderLocation As String 'path of shapefile folder location

Private Sub cmdCancel_Click()
 HSI_Calculator.Hide
 HSI_Calculator.lblDepthIn.Caption = ""
 HSI_Calculator.lblVelocityIn.Caption = ""
 HSI_Calculator.lblSubstrateIn.Caption = ""
 HSI_Calculator.VelHSIOutput.Caption = ""
 HSI_Calculator.DepHSIOutput.Caption = ""
 HSI_Calculator.SubHSIOutput.Caption = ""
 HSI_Calculator.TotalHSIOutput.Caption = ""
 HSI_Calculator.ShapeTableOutput.Caption = ""
 HSI_Calculator.FinalShapefile.Caption = ""
End Sub

Private Sub create_HSI_layer_Click()
    'Table that will be created to store total hsi values
    Dim pTotalHSIOut As String 'Path of the Total HSI table
    Dim pBrowser As IGxDialog
    Set pBrowser = New GxDialog
    Dim pEnumGX As IEnumGxObject

    'Set the type of objects the object filter will recognize (folders)
    Dim pObjectFilter As IGxObjectFilter
    Set pObjectFilter = New GxFilterBasicTypes

    ' +++ Open browser
    Dim blnFlag As Boolean
    pBrowser.Title = "Total HSI Module: Select Location of Output Total HSI File
    (ext .dbf)"
    pBrowser.ButtonCaption = "Select"
    pBrowser.AllowMultiSelect = False
    pBrowser.RememberLocation = True
    Set pBrowser.ObjectFilter = pObjectFilter

    ' +++ Set browser to open at last location
    pBrowser.StartingLocation = ThisDocument.m_sStartBrowseLoc

    ' +++ Open browser
    blnFlag = pBrowser.DoModalOpen(0, pEnumGX)
```

```
' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub

pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   pTotalHSIOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

Set pBrowser = Nothing

"""Creating a table that will store the Total HSI values""
'Defining the number of columns in the HSI table

Dim pClass As IClass
Dim pFields As IFields
Dim NumOfHSICol As Long
Set pClass = ThisDocument.pHSIDepTable
Set pFields = pClass.Fields
NumOfHSICol = pFields.FieldCount - 2 '30 fields created to hold hsi values

Set pClass = Nothing
Set pFields = Nothing

Dim pHSIfilePath As String
pHSIfilePath = pTotalHSIOut 'path of the hsi Depth table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(pHSIfilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace
```

```
Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
 .Length = 30
 .Name = "Date"
 .Type = esriFieldTypeDate
End With

pFieldsEdit.AddField pField
Set pField = Nothing

'Create Total HSI  fields

Dim j
For j = 1 To NumOfHSICol
Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
   .Length = 30
   .Name = "Sandusky" & j
   .Type = esriFieldTypeSingle
 End With

 pFieldsEdit.AddField pField
 Set pField = Nothing

Next

'Allows user to name the output Total HSI table

TotalHSIrename:

Dim TotalHSITableName As String
TotalHSITableName = InputBox("Please name your Output Total HSI .dbf Table.",
"Total HSI Table Name", "", 8000, 6000)
```

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```
Dim pSameName As String
pSameName = pHSIfilePath & "\" & TotalHSITableName & "*.dbf"

If TotalHSITableName = "" Then 'if nothing in inputbox then promp to name file
something
 MsgBox "Please give your file a name", vbOKOnly
 GoTo TotalHSIrename
 ElseIf TotalHSITableName & ".dbf" = Dir$(pSameName) Then
 MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
 GoTo TotalHSIrename
End If

'Creates the output Total HSI table

 Set pTotalHSITable = pFeatureWorkspace.CreateTable(TotalHSITableName, pFields,
Nothing, Nothing, "")

 HSI_Calculator.TotalHSIOutput.Caption = pHSIfilePath  'labels the userform with the
path were the table is stored

'Adding the HSI velocity table to the document

Dim pfHSIVTable As ITable 'creating variable to get the HSI velocity table
Set pfHSIVTable = ThisDocument.pHSIVelTable

Dim pfHSIVCursor As ICursor 'creating a cursor to hold the HSI velocity table entries
Set pfHSIVCursor = pfHSIVTable.Search(Nothing, True) 'adding all entries to the
cursor

Dim pfHSIVRow As IRow
Set pfHSIVRow = pfHSIVCursor.NextRow

'Adding the HSI DEPTH table to the document

Dim pfHSIDTable As ITable 'creating variable to get DEPTH table
Set pfHSIDTable = ThisDocument.pHSIDepTable

Dim pfHSIDCursor As ICursor 'creating a cursor to hold the HSI DEPTH table entries
Set pfHSIDCursor = pfHSIDTable.Search(Nothing, True) 'adding all entries to the
cursor

Dim pfHSIDRow As IRow
Set pfHSIDRow = pfHSIDCursor.NextRow
```

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```
'Adding the HSI SUBSTRATE table to the document

Dim pfHSISTable As ITable 'creating variable to get SUBSTRATE table
Set pfHSISTable = ThisDocument.pHSISubTable

Dim pfHSISubstrateCursor As ICursor 'creating a cursor to hold the HSI SUBSTRATE
table entries
Set pfHSISubstrateCursor = pfHSISTable.Search(Nothing, True) 'adding all entries to
the cursor

Dim pfHSISRow As IRow
Set pfHSISRow = pfHSISubstrateCursor.NextRow

'Adding the Total HSI table to the document

'Use this to create variable to get Total HSI table
Dim pHSITotalTable As ITable
Set pHSITotalTable = pTotalHSITable

Dim pfHSITotalCursor As ICursor 'creating a cursor to hold the HSI Total table entries
Set pfHSITotalCursor = pHSITotalTable.Search(Nothing, True) 'adding all entries to the
cursor


'Below will take all the values of the above table and evaluate the total hsi according to
velocity
'depth, and substrate

Dim i

Do Until pfHSIVRow Is Nothing

  Dim pfHSITotalRow As IRow
  Set pfHSITotalRow = pTotalHSITable.CreateRow

  For i = 2 To NumOfHSICol + 1
    If pfHSIVRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIDRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSISRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIVRow.Value(i) > 0 And pfHSISRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIVRow.Value(i) > 0 And pfHSIDRow.Value(i) <= 0 Then
```

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```
        pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIVRow.Value(i) > 0 And pfHSIDRow.Value(i) > 0 And
      pfHSISRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIVRow.Value(i) > 0 And pfHSISRow.Value(i) > 0 And
      pfHSIDRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIDRow.Value(i) > 0 And pfHSIVRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIDRow.Value(i) > 0 And pfHSISRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIDRow.Value(i) > 0 And pfHSISRow.Value(i) > 0 And
      pfHSIVRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSISRow.Value(i) > 0 And pfHSIDRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSISRow.Value(i) > 0 And pfHSIVRow.Value(i) <= 0 Then
      pfHSITotalRow.Value(i) = 0
    ElseIf pfHSIVRow.Value(i) > 0 And pfHSIDRow.Value(i) > 0 And
      pfHSISRow.Value(i) > 0 Then
      pfHSITotalRow.Value(i) = (pfHSIVRow.Value(i) * pfHSIDRow.Value(i) *
      pfHSISRow.Value(i)) ^ (1 / 3)
  End If
Next

pfHSITotalRow.Store 'storing the values in the newly created total hsi table

Set pfHSITotalRow = pfHSITotalCursor.NextRow ' skipping to next row in the table
Set pfHSIVRow = pfHSIVCursor.NextRow ' skipping to next row in the table
Set pfHSIDRow = pfHSIDCursor.NextRow ' skipping to next row in the table
Set pfHSISRow = pfHSISubstrateCursor.NextRow ' skipping to next row in the table
Loop

MsgBox "Done Creating Total HSI Table", vbOKOnly, "HSI Table Complete"

Read_Write_Values
End Sub

'This sub reads the values in the new HSI table, adds each column, divides by the number
of rowsstores them in a new field to write into the shapefile already created

Private Sub Read_Write_Values()
'''Defining the output location of the new shapefile table
  Dim pShapfileOut As String 'Path of the Shapefile table
  Dim pBrowser As IGxDialog
```

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```
Set pBrowser = New GxDialog
Dim pEnumGX As IEnumGxObject

'Set the type of objects the object filter will recognize (folders)
Dim pObjectFilter As IGxObjectFilter
Set pObjectFilter = New GxFilterBasicTypes

' +++ Open browser
Dim blnFlag As Boolean
pBrowser.Title = "Shapefile: Select Location of Output Shapefile Database File
(ext .dbf)"
pBrowser.ButtonCaption = "Select"
pBrowser.AllowMultiSelect = False
pBrowser.RememberLocation = True
Set pBrowser.ObjectFilter = pObjectFilter

' +++ Set browser to open at last location
pBrowser.StartingLocation = ThisDocument.m_sStartBrowseLoc

' +++ Open browser
blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

' +++ Save the current location
m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

If blnFlag = False Then Exit Sub

pEnumGX.Reset
Dim pGxObject As IGxObject

'Determine if the selected item is indeed a folder
'If it is, set the path variable to the folder's path

Set pGxObject = pEnumGX.Next
If pGxObject.Category = "Folder" Then
   pShapfileOut = pGxObject.FullName
   Else
      MsgBox "Wrong target data type"
End If

Set pBrowser = Nothing
```

'''Creating table to store the values calculated below'''

```
Dim NumOfColShapefile As Integer
NumOfColShapefile = 2 'two fields in the table.

Dim pHSIShapefilePath As String
pHSIShapefilePath = pShapfileOut 'path of the Shapefile table

Dim pWorkspace As IWorkspace
Dim pWorkspaceFactory As IWorkspaceFactory

Set pWorkspaceFactory = New ShapefileWorkspaceFactory
Set pWorkspace = pWorkspaceFactory.OpenFromFile(pHSIShapefilePath, 0)

Dim pFeatureWorkspace As IFeatureWorkspace
Set pFeatureWorkspace = pWorkspace

Dim pField As IField
Dim pFieldEdit As IFieldEdit
Dim pFieldsEdit As IFieldsEdit

'Creates new fields collection
Set pFields = New Fields
Set pFieldsEdit = pFields

'Create date field

Set pField = New Field
Set pFieldEdit = pField
With pFieldEdit
.Length = 30
.Name = "Date"
.Type = esriFieldTypeDate
End With

pFieldsEdit.AddField pField
Set pField = Nothing

'Create Shapefile HSI  fields

Set pField = New Field
Set pFieldEdit = pField
 With pFieldEdit
   .Length = 60
   .Name = "HSI__Sandusky"
   .Type = esriFieldTypeSingle
 End With
```

```
    pFieldsEdit.AddField pField
    Set pField = Nothing

    'Allows user to name the output Total HSI table

HSIShapefilerename:

    Dim HSIShapefileTableName As String
    HSIShapefileTableName = InputBox("Please name your output .dbf Shapefile Table.",
    "Shapefile Table Name", "", 8000, 6000)

    Dim pSameName As String
    pSameName = pHSIShapefilePath & "\" & HSIShapefileTableName & "*.dbf"

    If HSIShapefileTableName = "" Then 'if nothing in inputbox then prompt to name file
    something
     MsgBox "Please give your file a name", vbOKOnly
     GoTo HSIShapefilerename
       ElseIf HSIShapefileTableName & ".dbf" = Dir$(pSameName) Then
       MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
       GoTo HSIShapefilerename
    End If

    'Creates the output Total HSI table

    Set pHSIShapefileTable = pFeatureWorkspace.CreateTable(HSIShapefileTableName,
    pFields, Nothing, Nothing, "")

    HSI_Calculator.ShapeTableOutput.Caption = pHSIShapefilePath 'labels the userform
    with the path were the table is stored

    'Code Will add the pertinent tables and create means for each field in the total his table
    then add those value to the new shapefile table

    Dim ppFields As IFields
    Dim pClass As IClass
    Dim pNumOfHSICol As Long
    Set pClass = ThisDocument.pHSIDepTable
    Set ppFields = pClass.Fields
    pNumOfHSICol = ppFields.FieldCount - 2

    'Adding the Total HSI table to the document

    Dim pTotal As ITable 'creating variable to get Total HSI table
    Set pTotal = pTotalHSITable
```

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```
Dim pHSICursor As ICursor 'creating a cursor to hold the HSI Total table entries
Set pHSICursor = pTotal.Search(Nothing, True) 'adding all entries to the cursor

Dim pHSISRow As IRow
Set pHSISRow = pHSICursor.NextRow

'Adding the Shapefile table to the document

Dim pfShapefileTable As ITable 'creating variable to get Total HSI table
Set pfShapefileTable = pHSIShapefileTable

Dim pShapefileCursor As ICursor 'creating a cursor to hold the HSI Total table entries
Set pShapefileCursor = pHSIShapefileTable.Search(Nothing, True) 'adding all entries to
the cursor

'Setting up Statistical procedure for table evaluation

Dim pStatsResults As IStatisticsResults
Dim pDataStatistics As IDataStatistics
Set pDataStatistics = New DataStatistics
Dim Mean As Double

'Loop will look at each field in the new HSI table and calculate the mean value for each
field

For i = 1 To pNumOfHSICol
 Set pHSICursor = pTotal.Search(Nothing, True) 'adding all entries of the final hsi table
 to the cursor
 Set pDataStatistics = New DataStatistics
 Set pDataStatistics.Cursor = pHSICursor
 pDataStatistics.Field = "Sandusky" & i
 Set pStatsResults = pDataStatistics.Statistics
 Mean = pStatsResults.Mean

 Set pShapefileCursor = pHSIShapefileTable.Search(Nothing, True)
 Dim pShapeRow As IRow
 Set pShapeRow = pHSIShapefileTable.CreateRow
 pShapeRow.Value(2) = Mean
 pShapeRow.Store 'Storing the Mean value in the Shapefile table
 Set pShapeRow = pShapefileCursor.NextRow 'Skipping to next row

Next
 MsgBox "Done creating .dbf Shapefile Table", vbOKOnly, "Shapefile Table Created"
```

```
LOOK_FOR_SHAPEFILE_FOLDER
End Sub

Private Sub LOOK_FOR_SHAPEFILE_FOLDER()

    Dim pBrowser As IGxDialog
    Set pBrowser = New GxDialog
    Dim pEnumGX As IEnumGxObject

    'Set the type of objects the object filter will recognize (folders)
    Dim pObjectFilter As IGxObjectFilter
    Set pObjectFilter = New GxFilterBasicTypes

    ' +++ Open browser
    Dim blnFlag As Boolean
    pBrowser.Title = "Shapefile Folder:  Please Select the FOLDER Location of the input
    Shapefile"
    pBrowser.ButtonCaption = "Select"
    pBrowser.AllowMultiSelect = False
    pBrowser.RememberLocation = True
    Set pBrowser.ObjectFilter = pObjectFilter

    ' +++ Set browser to open at last location
    pBrowser.StartingLocation = ThisDocument.m_sStartBrowseLoc

    ' +++ Open browser
    blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

    ' +++ Save the current location
    m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

    If blnFlag = False Then Exit Sub


    pEnumGX.Reset
    Dim pGxObject As IGxObject

    'Determine if the selected item is indeed a folder
    'If it is, set the path variable to the folder's path

    Set pGxObject = pEnumGX.Next
    If pGxObject.Category = "Folder" Then
        pShapeFolderLocation = pGxObject.FullName
        Else
            MsgBox "Wrong target data type"
```

```
        End If
        Set pBrowser = Nothing
        LOOK_FOR_SHAPEFILE
End Sub
Private Sub LOOK_FOR_SHAPEFILE()
        Dim pBrowser As IGxDialog
        Set pBrowser = New GxDialog
        Dim pEnumGX As IEnumGxObject

        'Set the type of objects the object filter will recognize (Shapefiles)
        Dim pObjectFilter As IGxObjectFilter
        Set pObjectFilter = New GxFilterShapefiles

        ' +++ Open browser
        Dim blnFlag As Boolean
        pBrowser.Title = "Shapefile Module:  Please Select Location of Input Shapefile
        (ext .shp)"
        pBrowser.ButtonCaption = "Select"
        pBrowser.AllowMultiSelect = False
        pBrowser.RememberLocation = True
        Set pBrowser.ObjectFilter = pObjectFilter

        ' +++ Set browser to open at last location
        pBrowser.StartingLocation = ThisDocument.m_sStartBrowseLoc

        ' +++ Open browser
        blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

        ' +++ Save the current location
        m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

        If blnFlag = False Then Exit Sub


        pEnumGX.Reset
        Dim pGxObject As IGxObject

        'Determine if the selected item is indeed a folder
        'If it is, set the path variable to the folder's path

        Set pGxObject = pEnumGX.Next
        If pGxObject.Category = "Shapefile" Then
            pShapeFileLocation = pGxObject.Name

        Else
```

```vba
        MsgBox "Wrong target data type"
    End If

    Set pBrowser = Nothing
    ADD_SHAPEFILE_TO_DOCUMENT
End Sub

Private Sub ADD_SHAPEFILE_TO_DOCUMENT()
  Dim pWorkspaceFactory As IWorkspaceFactory
  Dim pFeatureWorkspace As IFeatureWorkspace
  Dim pFeatureLayer As IFeatureLayer
  Dim pMxDocument As IMxDocument
  Dim pMap As IMap

  Set pWorkspaceFactory = New ShapefileWorkspaceFactory
  Set pFeatureWorkspace = pWorkspaceFactory.OpenFromFile(pShapeFolderLocation,
0)

  Dim pDataSet As IDataset
  Set pDataSet = pFeatureWorkspace.OpenFeatureClass(pShapeFileLocation)

  Dim pOutWorkspace As IWorkspace
  Set pOutWorkspace = pWorkspaceFactory.OpenFromFile(pShapeFolderLocation, 0)

askagain:

  Dim buck As String
  buck = InputBox("Please name your Shapefile (extension .shp) .", "Shapefile Name", "",
8000, 6000)

  Dim pSameName As String
  pSameName = pShapeFolderLocation & "\" & buck & ".shp"

  If buck = "" Then
   MsgBox "Please give your shapefile a name", vbOKOnly
   GoTo askagain
   ElseIf buck & ".shp" = Dir$(pSameName) Then
    MsgBox "FILE ALREADY EXISTS! Please choose another name.", vbOKOnly
    GoTo askagain
  End If

'Below copies the above shapefile

  If pDataSet.CanCopy Then
  Dim pDatasetCopy As IDataset
```

```
  On Error Resume Next
 Set pDatasetCopy = pDataSet.Copy(buck & pDataSet.Name, pOutWorkspace)
  If Err.Number <> 0 Then
   Debug.Print "Error Copying, Maybe it already Exists"
  ElseIf pDatasetCopy Is Nothing Then
   Debug.Print "Not Copied"
  Else
   Debug.Print pDatasetCopy.Name & "The new File was created"
  End If
 End If


">Starting a new search to choose the new shapefile created above

   Dim pBrowser As IGxDialog
   Set pBrowser = New GxDialog
   Dim pEnumGX As IEnumGxObject

   'Set the type of objects the object filter will recognize (Shapefiles)
   Dim pObjectFilter As IGxObjectFilter
   Set pObjectFilter = New GxFilterShapefiles

   ' +++ Open browser
   Dim blnFlag As Boolean
   pBrowser.Title = "Shapefile Finder:  Please Select the Location of the Newly Named
   Shapefile"
   pBrowser.ButtonCaption = "Select"
   pBrowser.AllowMultiSelect = False
   pBrowser.RememberLocation = True
   Set pBrowser.ObjectFilter = pObjectFilter

   ' +++ Set browser to open at last location
   pBrowser.StartingLocation = ThisDocument.m_sStartBrowseLoc

   ' +++ Open browser
   blnFlag = pBrowser.DoModalOpen(0, pEnumGX)

   ' +++ Save the current location
   m_sStartBrowseLoc = pBrowser.FinalLocation.FullName

   If blnFlag = False Then Exit Sub


   pEnumGX.Reset
   Dim pGxObject As IGxObject
```

```
        'Determine if the selected item is indeed a folder
        'If it is, set the path variable to the folder's path

        Set pGxObject = pEnumGX.Next
        If pGxObject.Category = "Shapefile" Then
           pNewShapeFileLocale = pGxObject.Name

        Else
             MsgBox "Wrong target data type"
        End If

        Set pBrowser = Nothing

    'Below will add the new shapefile to arc

        Set pFeatureLayer = New FeatureLayer
        Set pFeatureLayer.FeatureClass =
        pFeatureWorkspace.OpenFeatureClass(pNewShapeFileLocale)
        pFeatureLayer.Name = buck

        Set pMxDocument = Application.Document
        Set pMap = pMxDocument.FocusMap
        pMap.AddLayer pFeatureLayer

        pMxDocument.ActiveView.Refresh
        pMxDocument.UpdateContents

        HSI_Calculator.FinalShapefile.Caption = pNewShapeFileLocale  'labels the userform
        with the path were the table is stored

        ADD_NEW_FIELD_TO_SHAPEFILE
    End Sub

    Private Sub ADD_NEW_FIELD_TO_SHAPEFILE()
     Dim pMxDocument As IMxDocument
     Set pMxDocument = ThisDocument

     Dim pMap As IMap
     Set pMap = pMxDocument.FocusMap 'grabs the map document and looks at the layer in
     the map

     Dim pFeatureLayer As IFeatureLayer
     Set pFeatureLayer = pMap.Layer(0) 'sets the layer equal to the first layer in the toc

     Dim pFClass As IFeatureClass
```

```
Set pFClass = pFeatureLayer.FeatureClass

Dim pFields As IFields
Set pFields = pFClass.Fields

Dim HSIColumn As Integer
HSIColumn = pFields.FindField("Percent_Su")

'If statement is here so if Percent_Su does not exist it will be created.

If HSIColumn = -1 Then
  Dim pFieldEdit As IFieldEdit
  Set pFieldEdit = New Field

  pFieldEdit.Name = "Percent_Su"
  pFieldEdit.Type = esriFieldTypeSingle

  pFClass.AddField pFieldEdit

End If

Dim pfcursor As IFeatureCursor
Set pfcursor = pFClass.Update(Nothing, True)

Dim pFeature As IFeature
Set pFeature = pfcursor.NextFeature 'setting cursor to first feature in table

Dim HSITable As ITable
Set HSITable = pHSIShapefileTable

Dim pHSICursor As ICursor
Set pHSICursor = HSITable.Search(Nothing, True) 'adding all entries of table to cursor

Dim pHSIRow As IRow
Set pHSIRow = pHSICursor.NextRow 'sets cursor to read first line in hsi table

Do Until pFeature Is Nothing

pFeature.Value(HSIColumn) = pHSIRow.Value(2) 'sets the feature cell equal to the hsi
cell
pfcursor.UpdateFeature pFeature 'updates value in the feature layer
Set pFeature = pfcursor.NextFeature 'skips to next row in feature
Set pHSIRow = pHSICursor.NextRow 'skipping to next row in hsi table

Loop
```

'>Starting renderer to add color and legend values to the new added map

```
Dim pCBR As IClassBreaksRenderer
Set pCBR = New ClassBreaksRenderer

pCBR.Field = "Percent_Su" 'Setting the renderer to look at the Percent suitability layer

pCBR.BreakCount = 6 'dividing suitability in six classes

 'Defining the break classes
With pCBR
 .Break(0) = 0.1
 .Break(1) = 0.2
 .Break(2) = 0.4
 .Break(3) = 0.6
 .Break(4) = 0.8
 .Break(5) = 1
End With

'Defining the break labels
With pCBR
 .Label(0) = "No Suitability 0-0.1"
 .Label(1) = "Low Suitability 0.1-0.2"
 .Label(2) = "Low/Moderate Suitability 0.2-0.4"
 .Label(3) = "Moderate Suitability 0.4-0.6"
 .Label(4) = "High/Moderate Suitability 0.6-0.8"
 .Label(5) = "High Suitability 0.8-1"
End With

'Defining variables for color classifications
Dim pUnsuit As IRgbColor
Dim pLowsuit As IRgbColor
Dim pLowModSuit As IRgbColor
Dim pModeratesuit As IRgbColor
Dim pHighModsuit As IRgbColor
Dim pHighsuit As IRgbColor

Set pUnsuit = New RgbColor
Set pLowsuit = New RgbColor
Set pLowModSuit = New RgbColor
Set pModeratesuit = New RgbColor
Set pHighModsuit = New RgbColor
Set pHighsuit = New RgbColor
```

```vb
'Defining the color of each class
pUnsuit.RGB = RGB(255, 0, 0) 'Red
pLowsuit.RGB = RGB(255, 170, 0) 'Orange
pLowModSuit.RGB = RGB(255, 255, 41) 'Yellow
pModeratesuit.RGB = RGB(170, 255, 0) 'Light Green
pHighModsuit.RGB = RGB(115, 223, 255) 'Apetite Blue
pHighsuit.RGB = RGB(0, 0, 255) 'Blue

'Defining a fill symbol to fill the appropriate symbol with the correct color

Dim pFill As ISimpleFillSymbol
Set pFill = New SimpleFillSymbol

'Assigning color values to each class
pFill.Color = pUnsuit
pCBR.Symbol(0) = pFill

pFill.Color = pLowsuit
pCBR.Symbol(1) = pFill

pFill.Color = pLowModSuit
pCBR.Symbol(2) = pFill

pFill.Color = pModeratesuit
pCBR.Symbol(3) = pFill

pFill.Color = pHighModsuit
pCBR.Symbol(4) = pFill

pFill.Color = pHighsuit
pCBR.Symbol(5) = pFill

Dim pGeoFeaturelayer As IGeoFeatureLayer
Set pGeoFeaturelayer = pFeatureLayer

Set pGeoFeaturelayer.Renderer = pCBR

pMxDocument.ActiveView.Refresh
pMxDocument.UpdateContents
End Sub
```