In: Stream Restoration: Halting Disturbances,… ISBN: 978-1-60876-450-1
Editor: Gillian D. Hayes and Timothy S. Flores 

***Chapter 4***

# ADAPTIVE MANAGEMENT, RESTORATION, AND MONITORING FOR PERFORMANCE BASED RESULTS IN THE FISH CREEK WATERSHED IN NORTHEASTERN INDIANA AND NORTHWESTERN OHIO, USA

***Thomas P. Simon[1], Dave Altfater[2], Michael J. Tosick[1], James R. Smith[3], Wayne Faatz[4], Joseph Draper[5], Beth A. Warner[5], Carl Wodrich[6], Anne Remek[3], Jennifer Campbell-Allison[4], Daniel W. Sparks[1] and Forest Clark[1]***

[1] U.S. Fish and Wildlife Service, 620 South Walker Street, Bloomington, IN 47403, USA
[2] Ohio Environmental Protection Agency, Division of Surface Water, Ecological Assessment Section, 4675 Homer Ohio Lane, Groveport, OH 43125, USA
[3] Indiana Department of Environmental Management, NRD Program, OLC – OLQ, 100 N. Senate Ave. - N1307, Indianapolis, IN 46204-2251, USA
[4] Indiana Department of Natural Resources, Division of Fish and Wildlife, NRD Program, 402 W. Washington Street, Room W273, Indianapolis, IN 46204-2781
[5] The Nature Conservancy, Upper St. Joseph River, 1220 N. 200 W. Peachtree Plaza, Suite H, Angola, IN 46703, USA
[6] Indiana Department of Natural Resources, Division of Land Acquisition, 402 W. Washington Street, Room W261, Indianapolis, IN 46204-2788, USA

## ABSTRACT

The rupture of an oil pipeline on September 15, 1993, spilled over 30,000 gallons of #2 diesel fuel oil into a field that emptied into Fish Creek, Northeastern Indiana, USA and affected the lower seven miles of stream. This spill occurred upstream of the last remaining population of the White Cat's Paw Pearly mussel (*Epioblasma obiquata perobliqua*), a Federally Endangered mussel species. The action caused the federal and state governments to enter into a Natural Resource Damage Assessment (NRDA), which resulted in a $2.5 million settlement. The restoration of Fish Creek began in 1996 with the development of an adaptive management plan that was based on structured decision making. The framing of the restoration strategy enabled a variety of inputs from state, federal, and not-for-profit entities to be involved; however, the implementation of the strategy was done in 1996 by the Natural Resource Trustees. A variety of conventional best management practices were used to protect priority areas designated within the stream. Biological planning and hypothesis based assumptions were developed and monitored using a variety of biological indicators. Monitoring was conducted at 12 locations biannually and included prespill baseline surveys conducted in 1991 and 1992. Restoration of site specific changes were monitored using a watershed scale. Conservation management measures included tree plantings, purchase of conservation easements, creation of shallow water wetlands, and fencing of livestock from the stream. A time series assessment found that monitoring for recovery showed a decreasing biological integrity trend with additional protection and enhancement needed in upper Fish Creek. Mussel assemblage condition is declining in the middle Fish Creek; however, recovery to prespill conditions has been observed for the watershed scale especially in the lower river. Improvement is needed in the upper portions of the watershed and perhaps a two-stage ditch process, which includes a 3:1 bench for high flow relief, may improve habitat condition for aquatic organisms. The two-stage ditch is showing promise as a practice that reduces nutrients in the water column and controls 30% of nitrogen and phosphorus and controls sedimentation and erosion from adjacent bank sloughing.

## INTRODUCTION

Mussels are among the most endangered component of the aquatic fauna with nearly 213 of the 297 native freshwater species considered endangered, threatened, or special concern (Williams et al. 1993). Karr et al. (1985) found that 17 fish species disappeared and another 26 species were reduced in population numbers in the Maumee River basin since the middle of the last century. Fish Creek is among the most biologically diverse and pristine tributaries of the Maumee River drainage in the Lake Erie basin (Trautman 1981; Hoggarth 1990; USFWS 2006). The system supports three federally endangered mussel species including the White Cat's Paw Pearly mussel (*Epioblasma oliquata perobliqua*), the Northern Riffleshell mussel (*E. torulosa rangiana*), and the Clubshell mussel (*Pleurobema clava*). In addition, the Salamander mussel (*Simpsonaias ambigua*) and the Rayed-Bean mussel (*Villosa fabalis*), which are federal candidates for listing, are also found in Fish Creek. Hoggarth (1990) documents that the White Cat's Paw Pearly mussel has been extirpated from throughout its range with the last remaining population in the world occurring in Fish Creek. The highest mussel diversity in Fish Creek occurs in the lower 10-miles of the creek's 30-mile expanse (Watters 1988, 1996).

On September 15, 1993, a pipeline owned by NORCO, Inc. ruptured and subsequently discharged an estimated 30,000 gallons of #2 diesel fuel into a crop field in Dekalb County, IN (Fish Creek Council Trustees 1997). The diesel fuel seeped into a small drainage ditch that discharged into Fish Creek. The contaminant entered Fish Creek, spread downstream, and crossed into Williams County, OH. As a result, numerous natural resources were lost, including mammals, migratory birds, fish, reptiles and mussels, which were observed in the area of the spill plume.

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Federal Water Pollution Control Act authorize States and certain federal agencies to act as "trustees" on behalf of the public, to restore, rehabilitate, replace, and acquire natural resources equivalent to those harmed by the release of hazardous substances. Natural resource damages received, either through negotiated or adjudicated settlements, must be used to restore, rehabilitate, replace, and acquire the equivalent of those natural resources that have been injured.

In 1996, the United States of America, represented by the U.S. Fish and Wildlife Service, the State of Indiana (represented by Indiana Department of Environmental Management and the Department of Natural Resources), and the State of Ohio (represented by the Ohio Environmental Protection Agency and the Ohio Department of Natural Resources), settled claims for natural resource damages associated with the 1993 diesel spill. The trustees claim for natural resource damage by consent decree (United States of America et al. v. ARCO Pipe Line Company and NORCO Pipeline Inc., Civil Action No. 1:96 CV 0280 (N.D. Ind)) was settled under § 1006 of the Oil Pollution Act. The settlement established a $2,507,500 court registry account exclusively for the restoration, rehabilitation, replacement, or acquisition of equivalent resources harmed by the spill.

The current chapter documents the restoration alternatives taken in the Fish Creek watershed using adaptive management and structured decision making approaches (Gregory and Keeney 2002; USFWS 2008) for guiding restoration. Our study describes the restoration success based on objectives for conservation management including conventional measures (i.e., no-till agriculture), recognition of sedimentation and erosion potential, and Natural Resource Damage best management measures (i.e., tree plantings, purchase of conservation easements, creation of shallow water wetlands, and fencing of livestock from the watershed). We use monitoring information to assess the watershed for determining recovery and improve management decisions.

## METHODS

### Study Area

Fish Creek is a tributary of the St. Joseph River in northeastern Indiana and northwestern Ohio, USA (Figure 1). The creek drains 284.9 $km^2$ (110 $mi^2$) of agricultural land in three counties. The watershed begins in northeast Steuben and northwest Williams counties and stretches south to northeast Dekalb county and back into Williams county where it drains into the St. Joseph River. It encompasses approximately 48.3 km (30 mi) of primary stream channel and 144.8 km (90 mi) of tributaries and drainage ditches that flow in a southeasterly direction, ultimately draining to Lake Erie. Fish Creek is part of the Eastern Corn Belt Plain Ecoregion, but its zoogeography and drainage history is associated with the Huron Erie Lake Plain (Omernik and Gallant 1986). Land use in the watershed is dominated by agriculture (Figure 2A).

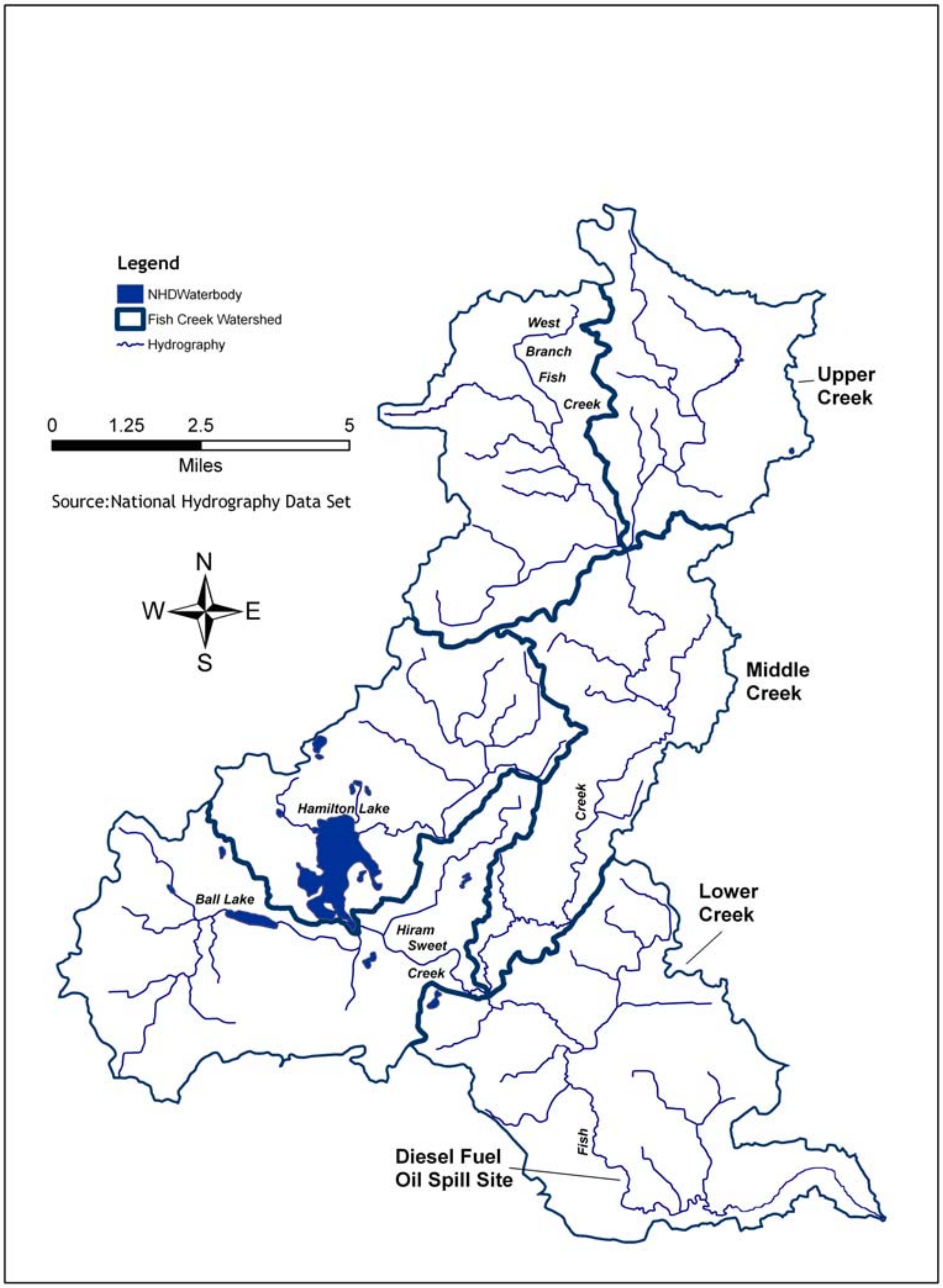
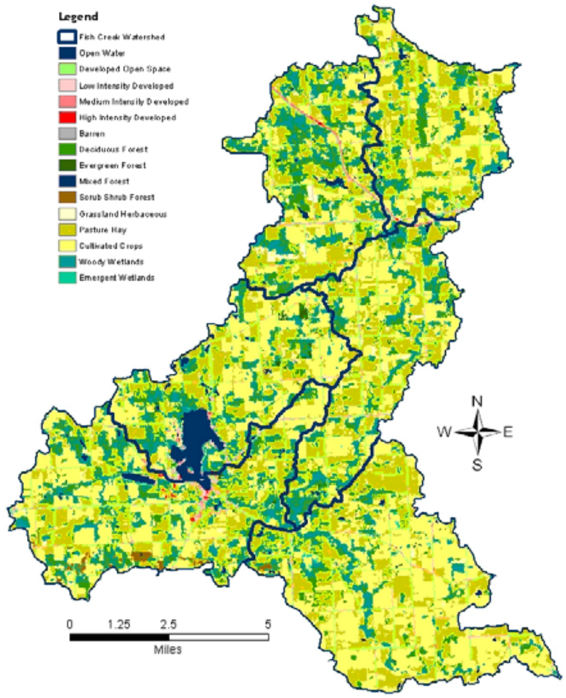
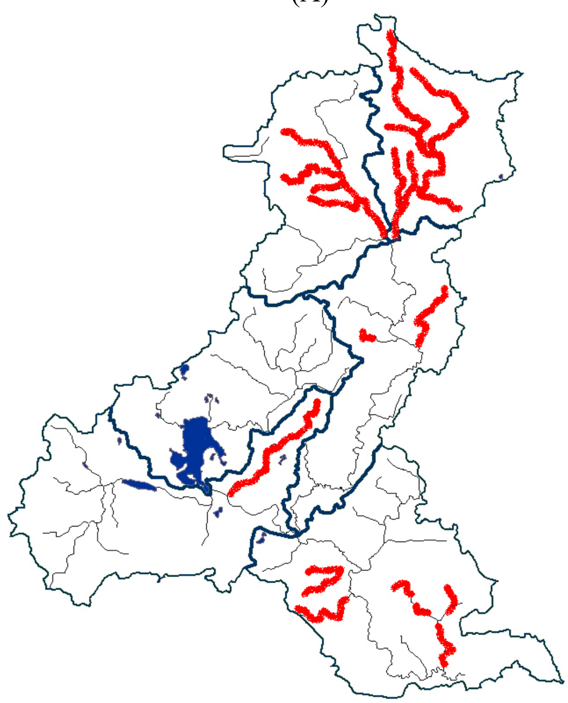



Figure 1. Fish Creek watershed in Northeast Indiana and Northwest Ohio showing point of entry for #2 diesel fuel oil spill on September 15, 1993.

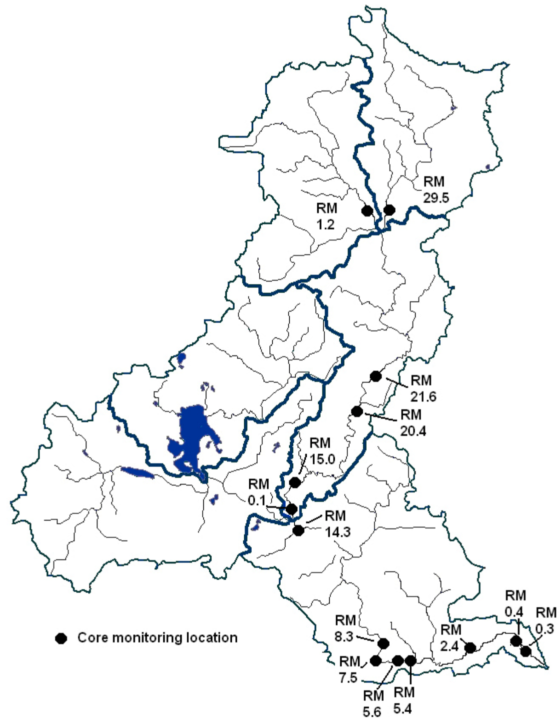



(A)

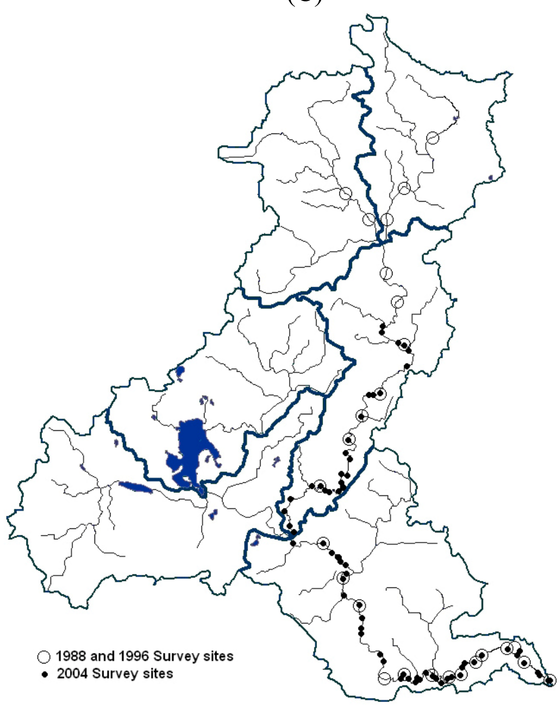


(B)

Figure 2. Fish Creek watershed maps. A) 1992 land use types and distribution (Forest Clark, unpublished data), B) sedimentation and erosion index showing areas with high priority erosion issues (P.M. Stewart, unpublished data), C) Biological indicator core monitoring sites, and D) Mussel survey locations from 1988, 1996, and 2004.




(C)




(D)

Figure 2. (Continued)

## Sediment Erosion Potential, Chemical Contaminants, and Habitat Indicators

Land use data from 1993 and generated by the US Fish and Wildlife Service Gap Analysis project for Indiana (Forest Clark, unpublished data) shows that the majority of Fish Creek is an agriculturally dominated landscape. Sedimentation and erosion potential from original 1992 data (Figure 2B) was provided by P.M. Stewart (unpublished data, Troy University). Habitat quality was determined annually using the Qualitative Habitat Evaluation Index (QHEI)(Rankin 1995). Surface water and sediment chemistry parameters were collected from grab samples from Fish Creek between River Mile (0.3 and 21.6). Two samples were collected during each monitoring event from each stream reach (Figure 2C) in August and September. Samples were analyzed for metals, acidity, biochemical oxygen demand, chloride, nitrogen compounds (i.e., Total nitrogen, total kjeldahl nitrogen, ammonia, nitrite+nitrate), phosphorus, alkalinity, sulfate, total suspended solids, total dissolved solids, and herbicides. Continuous datasonde water quality monitors were placed at each Fish Creek reach from August 5-7, 2002, with measurements of dissolved oxygen, conductivity, pH, total dissolved solids, nitrate, ammonia, and turbidity during September of each monitoring year. Additional turbidity sampling was done in 1999 and 2001 using the continuous datasonde monitors at four sites in Indiana that were distributed in the upper, middle, and lower Fish Creek. Sediment samples were analyzed for total metals, semivolatile organic compounds, polychlorinated biphenyls (PCBs), pesticides, total petroleum hydrocarbons (TPHs) and organic carbon. Samples were analyzed by the Ohio EPA chemical laboratory following standard water quality and sediment chemistry procedures (Ohio EPA 2002, 2008).

## Monitoring Biological Indicators

The restoration monitoring strategy goal for Fish Creek required the use of rapid response indicators to track short-term changes that were responsive to management activities. Despite the need to enhance imperiled mussel populations, it was apparent that mussel assemblages would not respond in a timeline that would facilitate the needed decision making process. The monitoring plan was based on a combination of surrogate indicators, including macroinvertebrates, fish, water and sediment quality, and habitat measures, which provided a quantitative standard for establishing priorities. Periodic monitoring of mussel populations using qualitative approaches was done during select periods in 1988, 1996, and 2004 to determine the overall benefit to mussel assemblages. The final project review step included quantitative surveys in 2005 to better estimate population parameters.

### *Surrogate Biological Indicators*

In order to accomplish conservation management objectives the trustees determined that responsive indicators able to determine the pulse of restoration projects had to be implemented to show rapid response to change. A suite of indicators including biological, chemical, and physical measures were based on standard operating procedures (Ohio EPA 1987, 1989; USEPA 1988). A series of fourteen core sites were selected from Indiana and

Ohio that bracketed the spill location that was representative of watershed conditions (Figure. 2C). Macroinvertebrate assemblages respond rapidly to water quality changes. In addition, they provide short-term, rapid assessment of site and watershed conditions. Since mussel assemblages are dependent on fish as primary hosts for early life stages, fish assemblage structure and function was monitored using an Index of Biotic Integrity (IBI) for the Eastern Corn Belt Plain based on calibrations for Indiana (Simon and Dufour 1998) and Ohio (Ohio EPA 2005).

***Mussel Assemblage***

Mussel collections included hand picking during conditions of low flow (Strayer and Smith 2003). During pre-spill surveys in 1988 and post-spill surveys in 1996, 30 sites were sampled, while final project surveys in 2004 included 64 sites including survey of 28 of the original 30 sites previously sampled (Figure 2D). All specimens were counted and identified. No live mussels were collected, but dead shells were vouchered at the Ohio State University Museum of Biological Diversity in 1988 and 1996. Effective conservation management and structured decision making required identifying mussel assemblages of significance within the Fish Creek watershed. A Mussel Classification Index (MCI) integrating several assemblage characteristics included species richness, intolerant species presence, total abundance, and evidence of reproduction by recruitment (Szafoni 2007). Scores are assigned for each factor and then summed to produce the final index score, which ranges from 4-20. Condition classification is based on five resource value classes including Unique ($\geq$16 points), Highly Valued (12-15), Moderate (8-11), Limited (5-7), and Restricted (<4). Unique and Highly Valued scores identify mussel communities of high conservation significance. None of the mussel assemblages were restricted.

## Statistics

General linear regression models showing habitat subcomponent features were generated using Statistica (Statsoft version 8.0, 2008). Temporal relationships were tested using Student t-test significance at $\alpha = 0.05$. All maps were generated using ArcMap version 9.2 (ESRI, Redwoods, CA). Landuse, restoration, and monitoring indicator data is available upon request from TPS.

# RESULTS AND DISCUSSION

## Adaptive Resource Management and Structured Decision Making

After the court settlement, restoration of Fish Creek began in 1996 with the development of an adaptive management plan (Fish Creek Council Trustees 1997). The plan was based on structured decision making management approach (Gregory and Keeney 2002). Structured decision making includes select actions that were expected to best achieve management objectives. These elements define the problem, clarify objectives, create alternatives, describe consequences, equate tradeoffs, identify and quantify uncertainty, account for risk tolerance, and advanced planning.

Adaptive management involves ongoing, real-time learning and knowledge creation, both in a substantive sense and in terms of the adaptive process itself (Williams et al. 2007). It is described in a series of nine steps, involving stakeholder involvement, management objectives, management alternatives, predictive models, monitoring plans, decision making, monitoring responses to management, assessment, and adjustment to management actions. An adaptive approach actively engages stakeholders in all phases of a project over its timeframe, facilitating mutual learning and reinforcing the commitment to learning-based management. The process is an iterative approach that is revisited for management actions selection (Figure 3).

The five agency trustees formed the Fish Creek Council, which held public meetings, then drafted and released a restoration plan for public review and comment. In response to public review and revision, the plan became final in 1997. Implementation of the restoration plan involved cooperative efforts between stakeholders including private and public landowners; city, county, state and federal agencies; not-for-profit organizations, public volunteers, contractors and consultants. As part of the adaptive management process, a list of project activities were identified with allocated funds. Watershed stakeholders were included during the restoration formation process; however, the Fish Creek Council trustees were the ultimate decision-makers. Projects were selected based on their potential to restore resources injured from the spill to pre-spill population and recovery potential. Restoration measures were focused on the recovery of native mussel populations. Restoration activities covered a broad range of natural resources associated with Fish Creek. Specific project selections have been based on many factors including technical feasibility, cost to benefit ratio, total cost, benefit to Fish Creek's resources, and cost effectiveness. The Fish Creek Council target objectives included 1) mussel recovery enhancement; (2) watershed water quality improvement, (3) riparian corridor protection, (4) community relations, (5) restoration implementation, and (6) restoration effectiveness monitoring. A management model was followed in principal that linked critical decision making processes to the recovery and enhancement of mussel populations (Figure 3).

The Fish Creek Council trustees had oversight of all recovery implementation and restoration activities. The restoration committee worked with stakeholders to assist the trustee council during the implementation of watershed water quality and riparian corridor protection. During the course of administering the funds and associated projects, priorities were changed if monitoring results were not accomplishing the original watershed objectives. During the course of the 16 year project, an annual review was done evaluating the monitoring data and any other information. Monthly conference calls between the trustees were conducted to discuss plans. The Fish Creek Council trustee committee reviewed and determined the efficacy of projects and provided critiques of project implementation. Unanimous agreement was required among the trustees for actions to be taken; however, a grievance procedure was designed in case of conflict. During the annual review, options such as redistribution of fund targets, review of new options and technologies, and assessment of project feasibility were done.

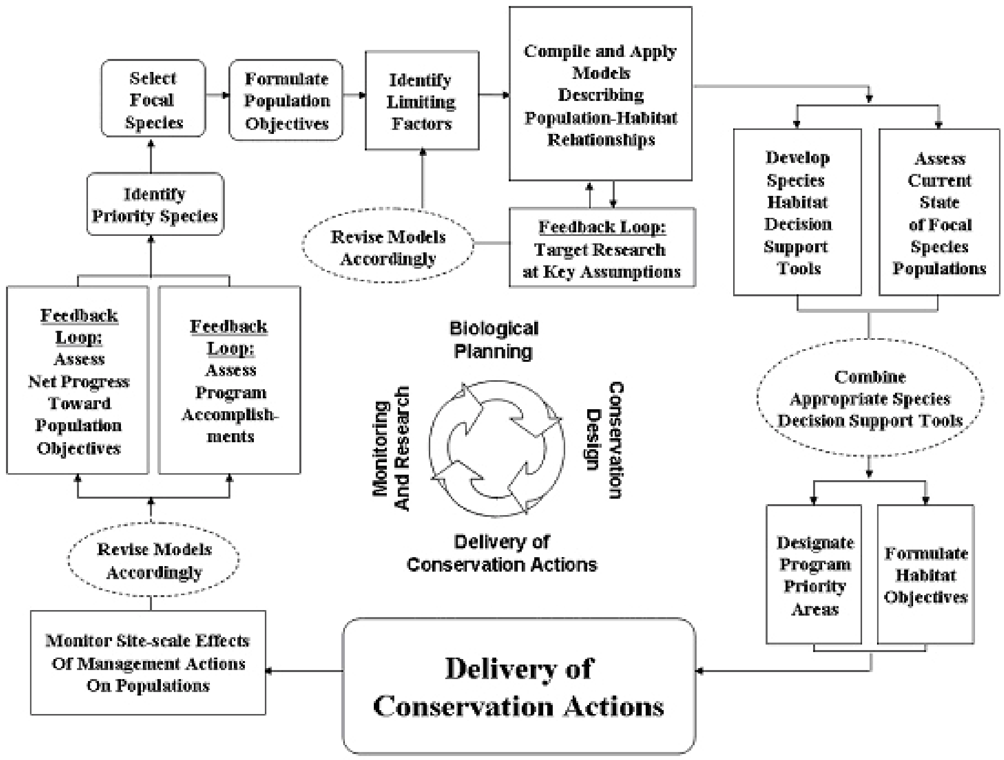



Figure 3. Management model schematic including many of the important elements in the iterative Strategic Habitat Conservation approach. Models link critical decision processes to the recovery and enhancement of mussel populations in the Fish Creek watershed (USFWS 2008).

## Problem Statement: Environmental Impact of the Fish Creek Diesel Spill to Endangered Mussel Species

The type of fuel oil discharged into Fish Creek is the most toxic component of artificial refinery mixtures (Buikeima et al. 1981). The water soluble petroleum product fraction is the most soluble and becomes available for uptake, accumulation, and is acutely toxic (Keller et al. 1998). Petroleum hydrocarbons are sequestered into the sediments and slowly released back into the water column. Organisms feeding at the sediment surface, including filter-feeders, will have maximum exposure to sediment associated PAHs. Petroleum products bind to organic materials exposing filter feeders to contaminated detritus.

Mussels are disproportionately affected by diesel fuel oil because they are sessile organisms that cannot avoid pollution events. The sensitive early life and reproductive stages are especially vulnerable since mussels have external fertilization, exposing gametes to polluted water and sediment. The juvenile stage is the most critical life stage since mussels are buried in the substrate for multiple years, relying on fine sediment as a food source. These fine sediments are organic pollutant binders for toxic hydrocarbons.

**Table 1. Annual Restoration Projects Accomplished in the Fish Creek Watershed from 1993 to 2007. Projects Totals are Included for Natural Resource Damage Types Including Conservation Tillage, Conservation Easements, Property Purchase, Tree Plantings, and Wetland Creation and Restoration.**

| | | | | Restoration Best Management Practice | | | | | | | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Conservation Tillage | Cumulative Acres | Easements | Cumulative Acres | Property Purchases | Cumulative Acres | Tree Plantings | Cumulative Acres | Wetlands | Cumulative Acres | Total Acres |
| 1993 | 874 | 874 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 874 |
| 1994 | 1570 | 2444 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1570 |
| 1995 | 1081 | 3525 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3525 |
| 1996 | 0 | 3525 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1997 | 1801 | 5326 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1801 |
| 1998 | 65 | 5391 | 0 | 0 | 0 | 0 | 276.9 | 276.9 | 0 | 0 | 341.9 |
| 1999 | 1032 | 6423 | 0 | 0 | 155.5 | 155.5 | 0 | 276.9 | 8 | 8 | 1195.5 |
| 2000 | 697 | 7120 | 28.99 | 28.99 | 0 | 155.5 | 63.9 | 340.8 | 0 | 8 | 789.89 |
| 2001 | 1244 | 8364 | 151.43 | 180.42 | 19.23 | 174.73 | 25.8 | 366.6 | 7 | 15 | 1447.46 |
| 2002 | 622 | 8986 | 0 | 180.42 | 0 | 174.73 | 0 | 366.6 | 0 | 15 | 622 |
| 2003 | 423.4 | 9409.4 | 0 | 180.42 | 0 | 174.73 | 33.6 | 400.2 | 0 | 15 | 457 |
| 2004 | 802.8 | 10212.2 | 181.43 | 361.85 | 0 | 174.73 | 192.7 | 592.9 | 0 | 15 | 1176.93 |
| 2005 | 550 | 10762.2 | 50.66 | 412.51 | 44 | 218.73 | 27.8 | 620.7 | 0 | 15 | 672.46 |
| 2006 | 0 | 10762.2 | 156.09 | 568.6 | 0 | 218.73 | 81.4 | 702.1 | 0 | 15 | 237.49 |
| 2007 | 0 | 10762.2 | 53 | 621.6 | 0 | 218.73 | 64.5 | 766.6 | 0 | 15 | 117.5 |

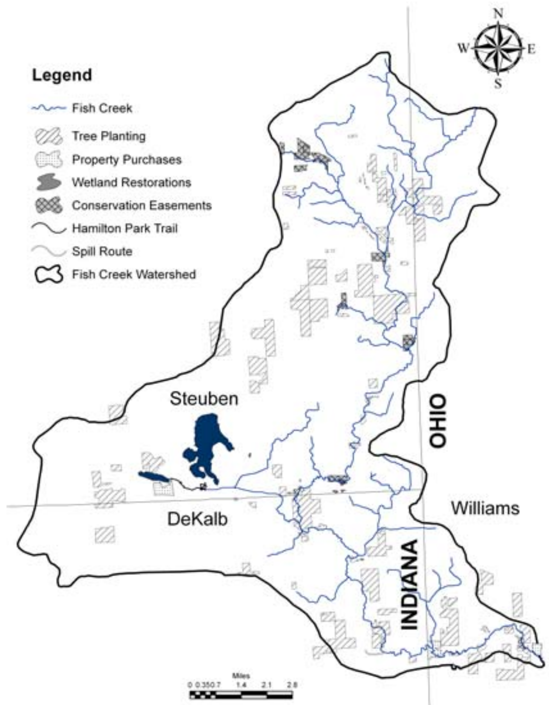



Figure 4. Location of conventional best management and restoration projects implemented in the Fish Creek watershed during 1993—2004.

## Clarification of Intended Conservation Measure Outcomes

The six conservation objectives for supporting the enhancement of mussel recovery in the Fish Creek watershed included a combination of scientific investigations, restoration activities, education and outreach, and monitoring assessments (Figure 4). A variety of conventional best management methods and restoration projects were implemented in the watershed (Table 1). Each objective described includes the intention and the accomplishments of the objective during the project period.

### Mussel Recovery Enhancement

In order to reintroduce mussels into former ranges, information on early life stages and surveys for additional populations and habitats were needed (Williams et al. 1993). Three mussel surveys were funded through the Fish Creek Council providing an accurate assessment of the current mussel populations (Watters 1996, 2000; Brady 2004, 2005). The first survey included a three-year freshwater mussel survey and study of natural history factors aimed at determining specific Fish Creek mussel life-cycle requirements, including habitat needs and fish hosts (Watters 1996; Watters 2000). Additional surveys were designed to characterize Fish Creek with an increased sample density. The 2004 survey involved walking the entire main channel of Fish Creek and performing timed mussel counts when mussel habitat was observed (Brady 2004). A 2005 survey involved searches in representative mussel beds from the 2004 survey (Brady 2005).

## Watershed Water Quality Improvement

Water quality is improved by promoting best management land use practices within the entire watershed. Based on pre-spill studies by Stewart et al. (1993) and Stewart and Swinford (1995) water quality improvement was dependent on limiting the amount of sediment entering the stream from tributary segments. Improvements were accomplished using a variety of conventional methods including conservation tillage, promotion of non-row crop restorations, fencing of livestock from the creek, stabilization of streambed erosion; and implementation of enhanced barriers such as silt fencing and straw bale filtering. Projects completed included wetland restorations that aided in increasing flood capacity and sediment control for the Fish Creek watershed, streambank stabilization projects that prevented bank loss and increased sediment loads, and reforestation along Fish Creek to reduce sediment loads and increase water storage capacity (Figure 4).

## Riparian Corridor Protection

Cooperative efforts with landowners through the use of perpetual conservation easements, leases, covenants, and land acquisition combined with restoration and enhancement activities was used to protect the riparian corridor along Fish Creek. Projects implemented during the study period included sixteen conservation easements and four property purchases (Figure 4).

## Community Relations

Public outreach to educational institutions, local organizations, and individual landowners were a priority during the project. Every restoration activity involved some type of outreach. Specific projects included the design and construction of a 2.57 km (1.6-mi) trail for the town of Hamilton (Fish Creek Trail), including the purchase of 8.94 ha (22.1-ac) tract that were used in trail development (Figure 4). The Fish Creek Council purchased environmental-education interpretive signs for the trail. Each sign focused on a different aspect of stream ecology. In addition, the Fish Creek Council contributed matching funds (US EPA) to the Lucas County (OH) Soil and Water Conservation District for the reprint of the "Mussel guide to the Maumee Drainage", a hard-bound document highlighting the Maumee River watershed.

## Restoration Implementation

The restoration activities involved multiple types including conventional conservation (i.e., CRP/No-till/filter strips), evaluation of sedimentation potential (i.e., grid and load analysis, Qualitative Habitat Evaluation Index, and chemical surveys), NRDA restoration phase (i.e., shallow wetland creation, tree plantings, easement and property purchases, and trail development), and The Nature Conservancy's two-stage ditch project (Figure 4).

## Restoration Effectiveness Monitoring

Monitoring of biological, chemical and physical parameters were done to evaluate the effects of the spill and direct subsequent restoration activity (Figures 2C and D). Stream surveys were performed by the Trustee agencies. The surveys were used as a measurement of creek recovery and for decision making (Table 2). The trustees also designed supplemental studies to estimate sediment bedload, water flow, quantitative habitat, and qualitative habitat measures.

## Surface Water and Sediment Chemical Quality

Overall water quality of the six reaches was considered good, with only Strontium exceeding State water quality criteria. All other water quality parameters were either within acceptable water quality criteria levels, were reported as not detected, or were below ecoregion reference conditions. Strontium exceeded state water quality criteria at all sites downstream of RM 14.3 (range: 841-1180 µg/L), but was below Ohio reference levels of 3600 µg/L. All other parameters were below water quality criteria. Herbicide analysis showed nearly all sites were below detection levels, with the exception of two locations that had atrazine values of 0.24 and 0.21 µg/L. These levels are below chronic aquatic life use criteria of 12 µg/L. Continuous water quality monitoring showed acceptable levels of all of the parameters.

Overall sediment quality during 2002 reflected non-contaminated conditions. None of the Fish Creek sediment samples exceeded the threshold effect concentration (TEC) or probable effect concentration (PEC) (MacDonald et al. 2000). Only a single detection of bis(2-ethyhexyl)phthalate at RM 8.3 was recorded. All other semivolatile organic compounds were reported as not detected, including all polycyclic aromatic hydrocarbon (PAH) compounds. No polychlorinated biphenyls (PCBs) were detected in any sediment sample and all organochlorinated pesticides were either not detected or were very low.

## Comparison of Conventional Best Management Practices and Biological Integrity

Since the late 1960's with the introduction of the no-till planter, the agricultural landscape has gradually changed as a result of no-till farming. A temporal comparison of historic aquatic assemblage changes was done using data from the Huron Erie Lake Plain (HELP) and Eastern Corn Belt Plain (ECBP). Sites from two time periods between 1979-1990 and 1991-2002 were sampled repetitively (n = 725) and evaluated for response patterns. A cumulative frequency distribution showed that the 1979-1990 and 1991-2000 IBI scores were influenced by nonpoint source (NPS) impairment (Figure 5). Sites influenced by NPS showed an increasing median change of two IBI points (change from 40 to 42 IBI score). Although this score change is within normal measurement error for the IBI and is not considered a biologically meaningful difference at individual sites, this change over the entire dataset and temporal period represents substantial changes within some watersheds.

Land use and conservation tillage data restoration was an ongoing effort by the Natur Conservancy, In addition, tillage data collected by The Nature Conservancy at the county and HUC-8 watershed scale was compared to aggregated county level biological measures for the two ecoregions (J. Draper, TNC, unpublished data). General land cover (percent agricultural or percent forest) was weakly correlated to IBI at the county scale, but was significantly different at the watershed scale. Habitat was strongly correlated to IBI at both the county and watershed scales. Land use characters were correlated to county land cover measures, which were weakly correlated to the IBI. Attainment of increased biological integrity (i.e., high IBI scores) in counties with high percent agriculture (at county scale) showed significant associations with QHEI and component metrics suggesting that habitat quality is a key factor in determining how agricultural land use affects biological assemblages.

**Table 2. Monitoring Indicators and Attainment Status for Exceptional Warmwater Habitat (EWH) in Ohio and General Use Habitat in Indiana. Information was Used for Annual Review of Restoration Progress from the Fish Creek Watershed (See Figure 4C) for Pre-Spill (1991-1992), Post-Spill Prior to Restoration Implementation (1993-1995), and During Restoration Activities (1997-2005).**

| | Habitat | Macroinvertebrate Indicators | | | Fish Indicators | | | | Attainment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream/ River Mile** | **QHEI** | **Total Taxa** | **EPT index** | **Abun dance** | **ICI** | **Condition** | **Total Species** | **Abun-dance** | **Miwb** | **IBI** | **Condition** | **Support Status (OH/IN)** |
| *Fish Creek – 2005* | | | | | | | | | | | | |
| 21.7 | 73 | | | | 28 | Fair | | | | 34 | Poor | NON/ PARTIAL |
| 14.1 | 71.5 | | | | 46 | Very Good | | | | 38 | Fair | PARTIAL/FULL |
| 8.3 | 66.5 | | | | 42 | Good | | | | 42 | Fair | NON/FULL |
| 5.6 | 74.5 | | | | 48 | Exceptional | | | | 40 | Marginally Good | PARTIAL/FULL |
| 0.3 | 65 | | | | 42 | Good | | | | 28 | Poor | NON/PARTIAL |
| *Fish Creek – 2003* | | | | | | | | | | | | |
| 21.7 | 78 | | | | 50 | Exceptional | | | | 28 | Poor | PARTIAL/PARTIAL |
| 14.1 | 78.5 | | | | 38 | Good | | | | 36 | Fair | NON/FULL |
| 8.3 | 74 | | | | 34 | Fair/Good | | | | 34 | Poor | NON/NON |
| 5.6 | 72 | | | | 40 | Good | | | | 36 | Fair | NON/FULL |
| 0.3 | 64 | | | | 20 | Fair | | | | 32 | Poor | NON/NON |
| *Fish Creek – 2002* | | | | | | | | | | | | |
| 29.5 | 47.5 | NA | NA | NA | NA | NA | 13 | 188 | NA | 28 | Poor | NON/NON |
| 27.7 | 60 | NA | NA | NA | NA | NA | 12 | 109 | NA | 22 | Very Poor | NON/NON |
| 21.6 | 72 | 58 | 13 | 565 | 48 | Exceptional | 26 | 757 | 8.9 | 46 | Very Good | PARTIAL/FULL |
| 20.4 | 68.5 | NA | NA | NA | NA | NA | 15 | 209 | NA | 34 | Poor | NON/NON |
| 15 | 76 | NA | NA | NA | NA | NA | 18 | 165 | NA | 38 | Fair | NON/PARTIAL |
| 14.3 | 75 | 54 | 15 | 471 | 52 | Exceptional | 34 | 871 | 9.2 | 41 | Good/Very Good | PARTIAL/FULL |
| 14.3 | 71.5 | NA | NA | NA | NA | NA | 24 | 233 | NA | 42 | Fair | NON/PARTIAL |
| 8.3 | 70.5 | 66 | 13 | 463 | 44 | Very Good | 32 | 941 | 9.2 | 44 | Good/Very Good | NON/FULL |
| 7.5 | 77.5 | 76 | 12 | 697 | 44 | Very Good | 32 | 790 | 8.8 | 41 | Good | NON/FULL |
| 5.4 | 75.5 | 66 | 16 | 810 | 50 | Exceptional | 32 | 837 | 9.2 | 43 | Good/Very Good | PARTIAL/FULL |
| 0.3 | 69.5 | 56 | 11 | 594 | 50 | Exceptional | 27 | 467 | 8 | 39 | Marginally Good | PARTIAL/FULL |
| 5.4 | | 72 | 12 | 688 | 50 | | 26 | 727 | 8.7 | 43 | Good | PARTIAL/FULL |
| 0.3 | | NA | NA | NA | NA | | 23 | 308 | 7 | 41 | Fair/Good | PARTIAL/PARTIAL |

## Table 2. (continued)

| | Habitat | Macroinvertebrate Indicators | | | Fish Indicators | | | | Attainment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Stream/ River Mile** | **QHEI** | **Total Taxa** | **EPT index** | **Abun dance** | **ICI** | **Condition** | **Total Species** | **Abun-dance** | **Miwb** | **IBI** | **Condition** | **Support Status (OH/IN)** |
| *West Branch Fish Creek* | | | | | | | | | | | | |
| 1.2 | | NA | NA | NA | NA | NA | 11 | 216 | NA | 30 | Poor | PARTIAL/NON |
| *Hiram Sweet Creek* | | | | | | | | | | | | |
| 0.1 | | NA | NA | NA | NA | NA | 16 | 184 | NA | 32 | Poor | PARTIAL/NON |
| 29.5 | | NA | NA | NA | NA | | 9 | 100 | NA | 32 | Poor | NON/NON |
| 27.7 | | NA | NA | NA | NA | | 15 | 49 | NA | 28 | Poor | NON/NON |
| 20.4 | | NA | NA | NA | NA | | 14 | 100 | NA | 36 | Fair | PARTIAL/FULL |
| 15 | | NA | NA | NA | NA | | 15 | 113 | NA | 36 | Fair | PARTIAL/FULL |
| 14.3 | | NA | NA | NA | NA | | 18 | 158 | NA | 42 | Fair | NON/FULL |
| 8.3 | | NA | NA | NA | NA | | 19 | 211 | NA | 48 | Good | NON/FULL |
| 5.6 | | NA | NA | NA | NA | | 15 | 82 | NA | 46 | Good/Fair | NON/FULL |
| 5.5 | | NA | NA | NA | NA | | 30 | 612 | 9.5 | 46 | Very Good/Exceptional | NON/FULL |
| 2.4 | | NA | NA | NA | NA | | 25 | 665 | 8.1 | 36 | Marginally Good | NON/FULL |
| 0.4 | | NA | NA | NA | NA | | 18 | 320 | 7.6 | 30 | Fair | NON/NON |
| 1.2 | | NA | NA | NA | NA | | 7 | 181 | NA | 32 | Poor | PARTIAL/NON |
| 0.1 | | NA | NA | NA | NA | | 10 | 65 | NA | 28 | Poor | PARTIAL/NON |
| 21.7 | | 69 | 15 | 273 | 54 | | 23 | 527 | 8.5 | 36 | Good/Marginally Good | PARTIAL/FULL |
| 14.3 | | 62 | 14 | 157 | 52 | | 31 | 271 | 8.1 | 39 | Marginally Good | PARTIAL/FULL |
| 8.3 | | 55 | 13 | 194 | 46 | | 23 | 275 | 8.2 | 43 | Good/Marginally Good | PARTIAL/FULL |
| 7.5 | | 50 | 11 | 484 | 50 | | 22 | 230 | 8.3 | 39 | Good/Marginally Good | PARTIAL/FULL |
| 5.4 | | 47 | 13 | 325 | 40 | | 31 | 437 | 8.7 | 42 | Good | NON/FULL |
| 0.3 | | 54 | 14 | 402 | 50 | | 24 | 182 | 7 | 30 | Fair | PARTIAL/PARTIAL |
| 21.7 | | 74 | 20 | 451 | 54 | | 25 | 651 | 8.3 | 45 | Good | PARTIAL/FULL |
| 14.3 | | 62 | 16 | 758 | 54 | | 34 | 360 | 7.9 | 48 | Marginally Good/Very Good | PARTIAL/FULL |
| 8.3 | | 59 | 15 | 716 | 48 | | 29 | 694 | 8.5 | 46 | Good/Very Good | PARTIAL/FULL |
| 7.5 | | 82 | 14 | 860 | 56 | | 28 | 410 | 8.1 | 39 | Marginally Good | PARTIAL/FULL |

**Table 2. (continued)**

| | Habitat | Macroinvertebrate Indicators | | | Fish Indicators | | | | Attainment | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stream/ River Mile | QHEI | Total Taxa | EPT index | Abun dance | ICI | Condition | Total Species | Abun-dance | Miwb | IBI | Condition | Support Status (OH/IN) |
| 5.4 | | 72 | 12 | 688 | 50 | | 26 | 727 | 8.7 | 43 | Good | PARTIAL/FULL |
| 0.3 | | NA | NA | NA | NA | | 23 | 308 | 7 | 41 | Fair/Good | PARTIAL/PARTIAL |
| 21.7 | | 58 | 7 | 568 | Good | | 26 | 819 | 8.1 | 40 | Marginally Good | NON/FULL |
| 14.3 | | 48 | 8 | 801 | Exceptional | | 34 | 411 | 7.5 | 42 | Fair/Good | PARTIAL/FULL |
| 8.3 | | 48 | 7 | 1260 | Exceptional | | 28 | 429 | 9.3 | 47 | Very Good | PARTIAL/FULL |
| 6.5 | | 65 | 9 | 1701 | Exceptional | | 27 | 903 | 8.9 | 43 | Very Good/Good | PARTIAL/FULL |
| 5.4 | | 73 | 6 | 774 | Good | | 26 | 617 | 8.5 | 41 | Good | NON/FULL |
| 0.3 | | 72 | 12 | 842 | Exceptional | | 24 | 457 | 7.6 | 41 | Fair/Good | PARTIAL/FULL |
| 21.7 | | 87 | 20 | 658 | Exceptional | | | | | | | PARTIAL/PARTIAL |
| 17.1 | | 65 | 14 | 290 | Exceptional | | | | | | | PARTIAL/PARTIAL |
| 13.8 | | 69 | 11 | 4167 | Very Good | | | | | | | NON/PARTIAL |
| 9.9 | | 70 | 14 | 761 | Exceptional | | | | | | | PARTIAL/PARTIAL |
| 5.4 | | 45 | 7 | 155 | Fair | | | | | | | NON/NON |
| 0.3 | | 60 | 8 | 118 | Good | | | | | | | NON/PARTIAL |
| 30.5 | | NA | NA | NA | NA | | 17 | 4777 | NA | 44 | Good | NON/FULL |
| 5.4 | | 54 | 13 | 698 | Exceptional | | 30 | 587 | 9.3 | 44 | Very Good/Good | PARTIAL/FULL |
| 0.2 | | NA | NA | NA | NA | | 26 | 695 | 7.5 | 43 | Fair/Good | NON/FULL |
| 5.4 | | NA | NA | NA | NA | | 27 | 572 | NA | 52 | Exceptional | FULL/FULL |

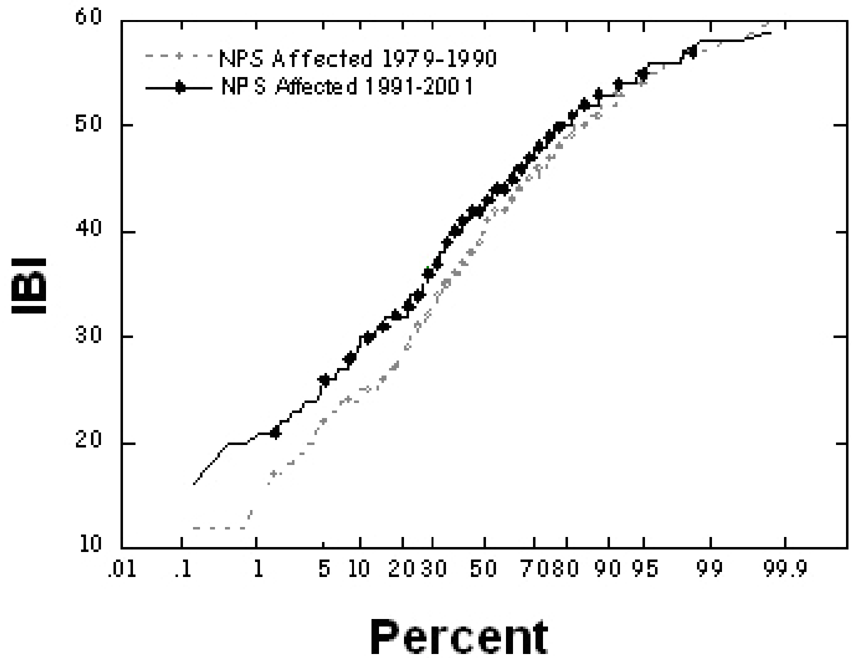
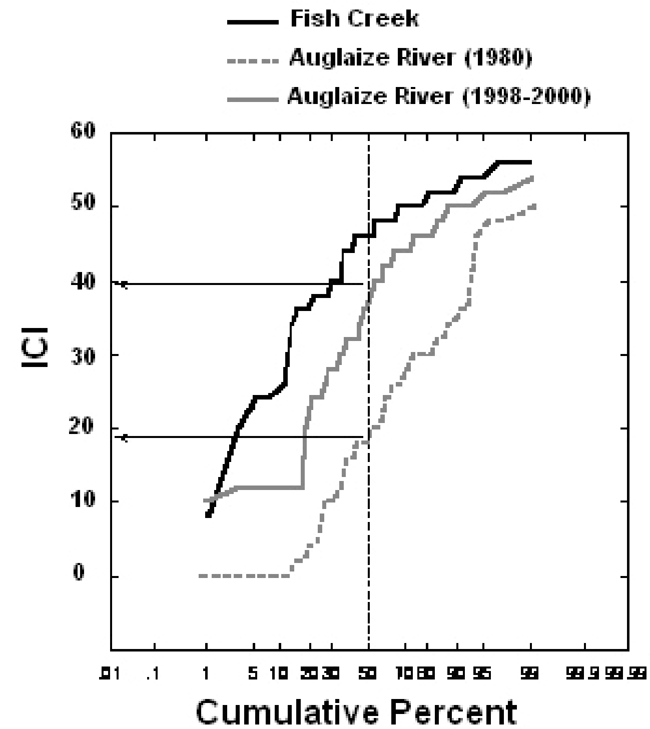


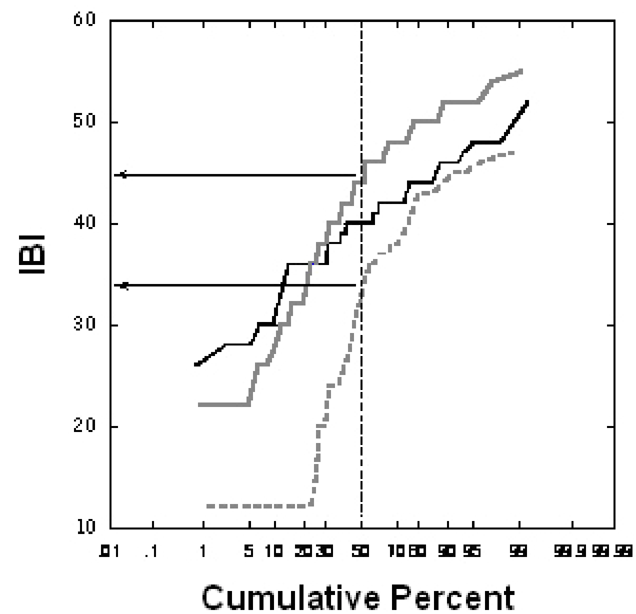

Figure 5. A cumulative frequency distribution showing 1979-1990 and 1991-2000 IBI scores were influenced by nonpoint source (NPS) impairment .

## Paired Watershed Conventional Best Management Practices Case Study

A paired watershed approach, comparing the Auglaize River, Fish Creek, and the upper St. Joseph River watersheds shows that impact trends are related to NPS impairments (Figure 6). Based on Ohio EPA biological, chemical, and physical data from the Auglaize River watershed improving trends in communities were associated with changes in tillage practices. Myers et al. (2000) documented decreases in suspended sediments (11.2%) that corresponded with increases in conservation tillage in the Maumee and Auglaize River watersheds. Biological data across this approximate time period, excluding point source affected reaches, show a small, but significant improvement. The Auglaize River had some point source and spill-related effects in the 1980s, but most watershed impairment was attributed to NPS. Changes in biological condition from 1979-1989 compared to 1990-2000 were substantial based on CFD plots (Figure. 6). Association trends between QHEI and IBI for 1979-1990 and 1990-2000 show two different regression line slopes (Figure 7). The limitation imposed by habitat is evident by the ceiling threshold along these curves. Greater improvement is evident along the upper part of the curve, while the lower part of the curve was constrained by poor habitat conditions. Biological integrity improvement can occur under situations where habitat is improved or stabilized.




(A)




(B)

Figure 6. Cumulative Frequency Plots of ICI scores (A) and IBI scores (B) in the Auglaize River watershed during the 1980s (red dashed lines), the Auglaize River watershed during the 1998-2000 (light blue solid line), and Fish Creek (dark blue solid line). Arrows show median values for the Auglaize River for temporal time scales.

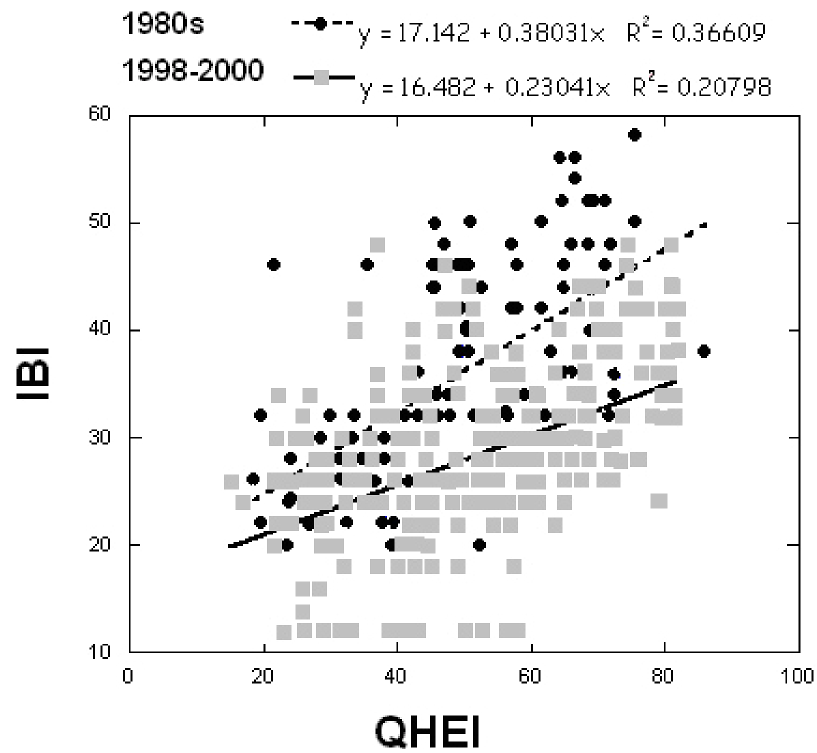



Figure 7. Plots of QHEI associations with IBI for data from the Auglaize River watershed from the 1980s-early 1990s (black circles, dotted trend line) and the late 1998s/2000 (gray squares /dashed trend line).

Fish Creek Exceptional Warmwater Habitat (EWH) improvements occurred in the early 1990s, but neither fish nor macroinvertebrates had previously achieved significant attainment at sites with EWH ranges in the 1980s. By 2000, approximately 20% of fish and macroinvertebrate stations met or exceeded EWH biocriteria (46 for ICI, 50 for IBI). This data shows that upland erosion protection and treatment can positively effect aquatic assemblages; however, spatial analyses suggest that habitat conditions place an upper threshold ceiling on what is biologically attainable in streams and rivers. Most streams in the HELP ecoregion are habitat limited due to extensive channelization and entrenchment for agricultural drainage and flood control. We predict that, even with increases in watershed conservation tillage, most of these streams, especially the smaller ones, will be limited in terms of aquatic condition.

In Fish Creek, land use changes in tillage practices reduced erosion potential, which had beneficial effects on loadings of sediment and nutrients to streams and rivers. A strong association between habitat and aquatic communities exist, especially with effects of loss of cover, channel diversity, and riparian structure. Despite efforts to enhance the riparian areas of Fish Creek, substrate condition shows that upstream conditions may limit further improvement. Temporal recovery is concerning since upstream data in Fish Creek is lacking making it difficult to determine whether conventional watershed BMPs had sufficient time to reduce fine sediments or eliminate them from the system. Silt covering in Fish Creek has worsened during the last 16 years.

## Quantification of Restoration Potential, Sedimentation, and Habitat Relationships

Monitoring previous to the fuel oil spill showed that Fish Creek was experiencing increasing sedimentation impairments (Stewart et al. 1993; Stewart and Swinford 1995). Subsequent biological, physical, and chemical assessment of Fish Creek (Ohio EPA 1993b, 1995, 1996, 2003, 2005) and the St. Joseph River watersheds (Ohio EPA 1993a) confirmed that in addition to the 1993 diesel fuel spill that significant system stress was attributed to habitat degradation and nonpoint sources runoff of silt and nutrients. Tributary turbidity showed increased levels immediately downstream of select tributaries and further investigation showed that water quality was being degraded by nutrients. Stewart and Swinford (1995) found pre-spill watershed turbidity mean was 38.2 NTU, but that tributary and main channel turbidity was significantly different among stations. Both upper and lower creek sites had extreme turbidity measures. Stewart and Swinford (1995) found that the highest total residues (suspended solids) measurement in the study area was over 1 g/L. A threshold of 0.1 g/L suspended silt reduced the water pumping rate efficiency of bivalves and affected shell movement of adults (Loosanoff 1961).

Stewart (unpublished data) provided an assessment of the Fish Creek watershed and identified areas of high sedimentation contribution potential (Figure. 2B). These areas were identified and bracketed for evaluating sediment impairments. Chemical contaminants in sediment cause impairment to mussel assemblages (Marking and Bills 1980; Havlik and Marking 1987). Surface water quality stability and improvements are integral to sediment restoration and conservation efforts. In addition, the trustees initiated several monitoring strategies to understand sediment and sedimentation issues. First, sediment contaminants were sampled from each of the core sites established for watershed monitoring (Figure. 2C). Second, a gauging station was established to monitor flow and bedload in the system, while additional site specific turbidity and physio-chemical parameters were measured (J. Smith, unpublished data). Turbidity of Fish Creek was associated with substrate disturbance and was directly associated with increasing flow. During low flow conditions, walking in the stream channel caused a significant increase in turbidity. Visual observation of biologists that sampled Fish Creek over this time period was that the silt layer observed in the stream was more prominent compared to previous time periods. Ohio EPA datasonde data from this time period did not identify gross impairments, however, higher pH data at the upstream site could reflect high algal biomass and uptake of $CO_2$ that often results in higher pH values.

Grab samples of Fish Creek water chemistry found that total phosphorus (TP) values exceeded those from EWH sites attaining uses in the ECBP (Ohio EPA 2005). Elevated TP was observed in mid September during high flows and in August during low flow from the lower reaches of Fish Creek. We speculate that TP originates from adjacent agricultural land in the watershed and would be worse if the riparian corridor buffer along Fish Creek was not as intact. In addition, *E. coli* bacteria also exceeded limits during high flow events. Thus, runoff during storm events may be delivering excessive nutrients, sediment, and bacteria to Fish Creek.

The effect of habitat is exerted at multiple spatial scales (Angermeier and Winston 1998, Rankin 1995). Table 3 summarizes $r^2$ values for associations between selected habitat parameters and the IBI. In addition, several important metrics from data within the Fish Creek

**Table 3. $R^2$ Values for Correlations Between Habitat Parameters Derived from the QHEI and Fish Community Biological Response Metrics. Data is from Wadeable Streams in the Fish Creek and St. Joseph River watershed. QHEI = Qualitative Habitat Evaluation Index score; SUBS – QHEI Substrate Metric, EMB – QHEI Embeddedness Measure, COV – QHEI Cover Metric, CHAN – QHEI Channel Metric, RIP – QHEI Riparian Metric, POOL – QHEI Pool Metric, and RIFF – QHEI Riffle Metric.**

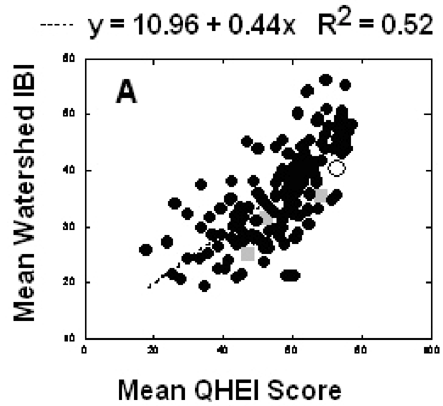
| Metric | QHEI | SUBS | EMB | COV | CHAN | RIP | POOL | RIFF |
|---|---|---|---|---|---|---|---|---|
| IBI | 0.32 | 0.19 | 0.05 | 0.04 | 0.28 | 0.13 | 0.03 | 0.26 |
| Sensitive species | 0.33 | 0.06 | 0.06 | 0.11 | 0.26 | 0.08 | 0.32 | 0.13 |
| Intolerant species | 0.25 | 0.05 | 0.02 | 0.08 | 0.2 | 0.05 | 0.28 | 0.11 |
| Omnivore species | 0.23 | 0.24 | 0.02 | 0.05 | 0.17 | 0.11 | 0 | 0.11 |
| Insectivore species | 0.2 | 0.11 | 0.13 | 0.05 | 0.15 | 0.1 | 0.07 | 0.06 |

and St. Joseph River watersheds show relatively weak relationships for embeddedness (EMB). This result is due to the uniformly embedded conditions in most of Fish Creek. Embeddedness was present at all reaches and most substrates were moderately to heavily embedded. Variation in embeddedness response gradient for Fish Creek was not sufficient to resolve this relationship. When sufficient range of conditions existed (i.e., QHEI, CHAN) correlations were found between sensitive and intolerant species occurrence and QHEI metrics.

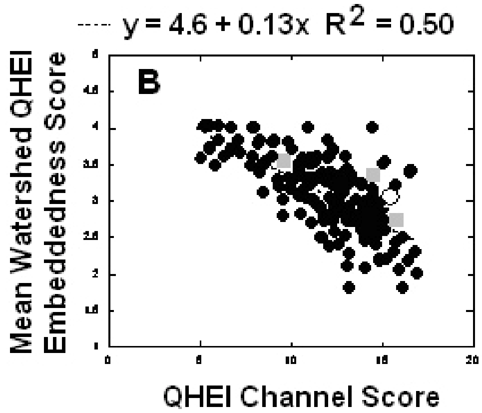
Habitat quality, as measured by average qualitative habitat evaluation index (QHEI) scores, has a strong association with IBI (Figureure 8a) and a weak association to macroinvertebrates (Simple linear regression, $R^2$ = 0.33) at the subwatershed scale. The widespread extirpation and number reduction of many fish species in the Maumee River drainage is due to widespread channelization and drainage (Karr et al. 1985). The extent of habitat loss infers a linear relationship between mean subwatershed QHEI scores and average biological IBI condition (Figure 8a).

### *Stream Gradient*

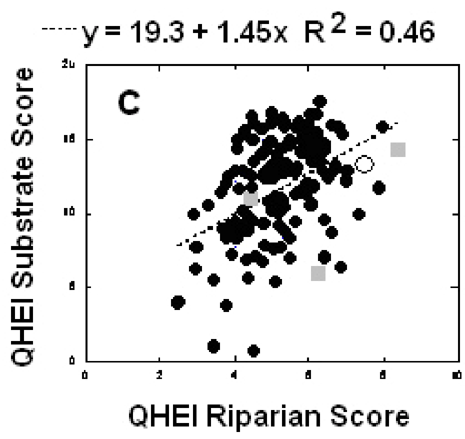
Increasing substrate size is associated with increasing stream gradient, while parent material affects actual substrates found in streams (Morisawa 1968). The expected substrate type and relationship between stream gradient and substrate size in reaches is an important factor determining substrate condition. In the ECBP and HELP, low stream gradient was not associated with low QHEI substrate score (Simple linear regression, r2 = 0.243). For low gradient streams there is a non-significant trend of increasing median substrate scores with increasing stream gradient; however, few high gradient streams have low substrate scores. The IBI scores increase positively with stream gradient, which is elevated along the upper portion of the regression threshold between IBI score and stream gradient. Thus, low gradient by itself is not a strong predictor of either low substrate score or low IBI value. High gradient streams may be more able to flush away sand, silt and other fines from habitats limiting to many sensitive aquatic life. Many sensitive taxa rely on coarse substrates for cover, spawning, or feeding or require clean interstitial spaces.




(A)

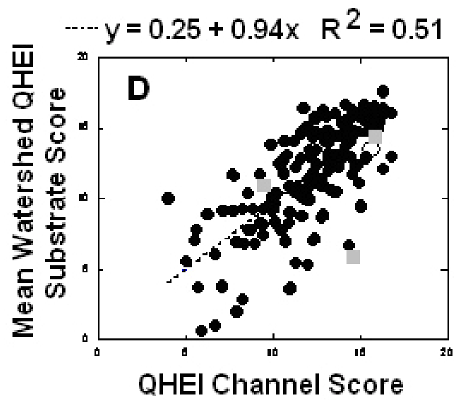



(B)

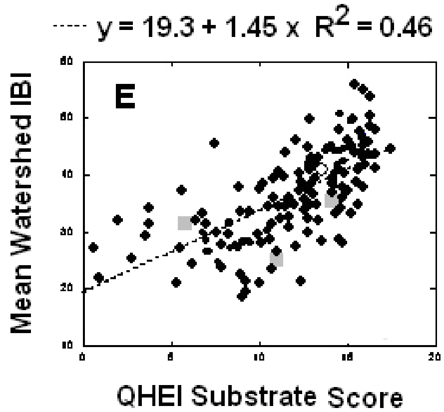



(C)

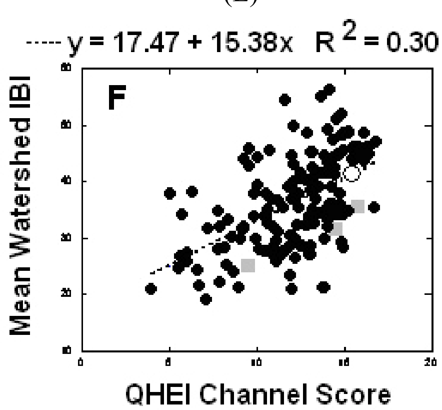
Figure 8. Plots of mean HUC11 watershed QHEI vs. mean IBI (a, top left), mean HUC11 watershed channel score vs. mean QHEI embeddedness score (b, top right), mean HUC11 watershed riparian score vs. mean HUC11 watershed substrate score (c, middle left), mean HUC11 watershed channel score and mean QHEI embeddedness score (d, middle right), mean HUC11 watershed substrate score and mean IBI (e, bottom left) and mean HUC11 channel score and mean IBI (f, bottom right) in the HELP and ECBP ecoregions of Ohio from 1994-2001.




(D)




(E)




(F)

Figure 8. (Continued)

**Table 4. Comparison of EWH IBI, ICI, and QHEI Metrics Scores with those of Fish Creek and Streams of the St. Joseph River Watershed. "EWH" Data are Averaged Metrics Scores for wadeable sites in the ECBP Ecoregion with IBI Values Above 50 (and Associated QHEI Scores) and for ICI values of 50 or Above, at Sites Between 20 and 120 sq mi Drainage. Data from Fish Creek was any Acceptable Data Between 1989-1997 (2002 Data are Provided in Parentheses). Comparisons are Summarized as Arrows indicating better than (), approximate to (ı), or worse than () EWH sites Based on Magnitude of Deviation.**

| IBI Metric | Sites w IBI Scores >= 50 | Fish Creek Sites (2002 Data) | Comparison | St. Joseph R. Watershed Sites | Comparison |
|---|---|---|---|---|---|
| Fish Community Data | | | | | |
| IBI | 51.7 | 40.7 (42.3) | ↓↓↓ | 33.5 | ↓↓↓ |
| Percent Tolerant Individuals | 17.18 | 35.27 (45.0) | ↓↓ | 52.07 | ↓↓↓ |
| Percent Omnivores | 10.87 | 18.58 | ↓↓ | 27.96 | ↓↓↓ |
| Number of Sensitive Species | 10.86 | 5.92 (7.67) | ↓↓↓ | 3.40 | ↓↓↓ |
| Number of Intolerant Species | 3.19 | 2.38 | ↓ | 1.20 | ↓↓ |
| Number of Declining Species | 1.71 | 0.91 | ↓↓ | 0.54 | ↓↓↓ |
| Percent Top Carnivores | 5.50 | 7.73 (2.03) | ↑ | 2.68 | ↓ |
| DELT Anomalies | 0.30 | 0.47 (0.35) | ↓ | 1.86[a] | ↑ |
| Percent Insectivores | 62.60 | 58.57 | ↔ | 43.25 | ↓ |
| Percent Simple Lithophil Spawners | 45.30 | 35.40 | ↓ | 20.77 | ↓↓ |
| Number of Simple Lithophil Species | 10.46 | 7.93 | ↓ | 5.83 | ↓↓ |
| Macroinvertebrate Data | | | | | |
| ICI | 52.0 | 45.7 | ↓ | 42.2 | ↓↓ |
| Qual EPT Taxa | 14.90 | 12.38 | ↓ | 9.35 | ↓↓ |
| Number of Taxa | 43.77 | 34.75 | ↓ | 32.7 | ↓ |
| Number of Mayfly Taxa | 9.11 | 7.15 | ↓ | 6.66 | ↓ |
| Number of Caddisfly Taxa | 4.74 | 4.96 | ↔ | 4.49 | ↔ |
| Percent Mayflies | 30.67 | 30.93 | ↔ | 33.00 | ↔ |
| Percent Caddisflies | 13.26 | 19.15 | ↑ | 19.89 | ↑ |
| Percent Tolerant | 3.51 | 6.57 | ↓ | 4.32 | ↓ |
| Habitat (QHEI) Data | | | | | |
| QHEI | 75.1 | 72.69 | ↔ | 57.90 | ↓↓ |
| QHEI Substrate Metric | 15.27 | 13.81 | ↓↓ | 11.19 | ↓↓↓ |
| QHEI Embeddedness Score | 2.61 | 2.96 | ↓ | 2.98 | ↓ |
| QHEI Cover Metric | 15.46 | 15.50 | ↔ | 12.78 | .↓ |
| QHEI Channel Metric | 15.88 | 15.82 | ↔ | 13.02 | .↓ |
| QHEI Riparian Metric | 6.04 | 7.37 | ↑ | 6.00 | ↔ |
| QHEI Pool Metric | 9.80 | 9.10 | ↔ | 7.72 | ↓ |
| QHEI Riffle Metric | 4.17 | 4.15 | ↔ | 2.02 | ↓↓ |
| QHEI Gradient Score | 8.51 | 6.94 | NA | 5.19 | NA |
| Gradient (ft/mi) | 10.69 | 3.78 | NA | 3.21 | NA |

[a] 1980s data – 3.30%; 1990s data – 0.65%.

Stewart and Swinford (1995) found that fine particles and clays (< 0.031 mm diameter) comprised a small proportion of the bed material in Fish Creek. Medium sized substrate particles (< 8.0 mm diameter) comprised a large part of the bed material in the creek upstream of the Hamilton Lake tributary confluence. The lower creek had the greatest amount of bed material greater than 8 mm diameter (Stewart and Swinford 1995).

Since gradient affects substrate size, a comparison among all sites of 20-200 sq mi in the ECBP ecoregion that attain an IBI of 50 or more showed that gradients of 8.5 ft/mi was slightly higher than the average 5.6 ft/mi median gradient value. Streams with low gradients (0-1.5 ft/mi) were not represented by stations with IBI values above 50. Fish Creek has stream gradients generally ranging from the 3-4 ft/mi, which is at the lower range of gradient values for EWH streams, but still within the range where EWH IBI values were observed in other ECBP streams of similar size.

### *Channel Quality*

A much stronger predictor of substrate score is the QHEI channel metric, which shows a significant watershed trend for the HELP and ECBP (Figures 8b, d, f). Higher channel condition values were directly related to low embeddedness (Figure 8b), high substrate scores (Figure. 8d), and high IBI scores (Figure 8f). The QHEI channel metric integrates channelization effects, channel stability and the development of natural pool and riffle systems. Streams with extensive channelization, usually result in the entrenchment of the channel and loss of connections with floodplains, benches, and other natural channel features (Rosgen 1994). Channelization reduces export and deposition of fine sediment onto these floodplain features and remains within the wetted stream channel. Thus, fine substrates embed riffles, runs and pools rather than being deposited in natural deposition areas. The direct association between increasing QHEI channel metric and the IBI (Figure. 8f) suggests that habitat management, enhancement, and restoration is necessary to maintain high quality aquatic life.

### *Riparian Corridors*

Riparian zones reduce sediment and nutrient delivery to streams and are important mitigating factors in erosion control. Mean subwatershed QHEI riparian/bank erosion metric is positively correlated with mean IBI, but the relationship is perhaps a covariate with the overall QHEI score or other QHEI metrics such as substrate, cover, or channel condition (Figure 8). High or low riparian/bank erosion scores are associated with high or low IBI scores, respectively; however, the middle ranges show metric variability. The Fish Creek watershed was surveyed along the main channel, thus the riparian score was not strongly associated with QHEI substrate score. This validates the trustees plan to focus restoration activities in Fish Creek on those stressors (i.e., channel quality, substrate conditions) originating in headwaters.

We also examined deviation in habitat conditions between Fish Creek, the St. Joseph River streams and habitat data from streams that scored IBIs of 50 or more. Overall QHEI scores were very similar in Fish Creek compared to high IBI streams (Table 4). The primary metric that varied was the substrate measure and a subcomponent of this, an embeddedness score. This matched field observations reported by Ohio EPA (2002, 2005). These are complex relationships and not necessarily directly causal; however, streams with very good habitat and large, clean, unembedded substrates are likely intact stream systems that are assimilating nutrients and storing fine sediments outside of the wetted portion of the streams. This results in substrates in the flowing part of the channel that provide for the intricate life history components (i.e., spawning, feeding, cover) for the sensitive fish and invertebrate species that are the focus of protection efforts.

## Relationships between Restoration and Watershed Indicator Condition

Prior to the 1993 spill, Fish Creek was considered an Exceptional Warmwater Habitat (EWH) attainment stream in Ohio and was fully meeting General Aquatic Life Uses in Indiana (Ohio EPA 1993, 2005) (Table 2). During pre-spill conditions, 57% (n = 4) of the macroinvertebrate samples and 25% of the fish indicators were meeting EWH and 100% of the sites met Indiana use attainment status (Table 1). During post-spill years (1993-1997) while the restoration strategy was being developed and restoration had not been implemented, monitoring information showed that 82.4% (n = 14) of the macroinverebrate indicators and none of the fish attained EWH.

## Comparison of Percent Restored Land within the Watershed to Determine Temporal Response Thresholds

The acquisition, implementation, and indicator response of restoration projects were assessed from 1994 and continued until 2007. A total of 12,384.13 acres in the Fish Creek watershed has been restored by NRD court settlement funds including conservation tillage (86.9%), conservation easements (5.02%), property purchase (1.77%), tree plantings (6.19%), or wetland creation and restoration (0.12%)(Table 1). During 1993 to 1996 very little restoration activity was initiated in the Fish Creek watershed. Most of the Fish Creek Council trustee’s effort was spent developing the restoration plan and constructing the court case.

Restoration activities increased from 1996-2007. During 1993-1996 all of the conservation measures involved conservation tillage implementation, which amounted to 3525 acres (Table 1). Most (49.5%) of the conservation tillage was accomplished during 1993-1997. Conservation easements were implemented during 2000-2007 with equal effort distributed along this time period. Focus was shifted from lower Fish Creek watershed to the upper and middle Fish Creek watershed as a result of the 2002 and 2003 monitoring results. Nineteen properties were included as conservation easements with 16 in upper and middle Fish Creek watershed riparian areas. These easements include a 30 year lease agreement and for state easements leases were “in perpetuity” that prohibits mowing, tree cutting, or other anthropogenic disturbance. Property purchase was targeted in Ohio with four of the five purchases in Williams County. This area included the last known remaining population of White Cat’s Paw Pearly mussel and also included the tributary branch recognized as contributing towards the greatest sedimentation potential in the lower Fish Creek watershed (Figure. 2B). Tree planting began in 1998 and has continued since. Over 431,970 hardwood trees have been planted on 37 properties since 1998. Tree plantings were targeted in upper and middle Fish Creek as a result of the monitoring data collected in 1999. It is likely that with increased growth and maturation of trees, these areas will continue to increase shading, nutrient removal, and buffer riparian erosion and sedimentation. Shallow wetlands were created during 1999-2001 and included five properties. These areas have benefited migratory birds and provided habitat for copperbelly water snake (*Nerodia erythrogaster neglecta*), a Federally Threatened species.

Pre-spill monitoring in the Fish Creek watershed included three sites located at RM 0.2, RM 5.4, and RM 21.7. Repeat sampling at these sites from 1994-2005 has shown that all sites trend towards declining biological integrity post-spill based on monitoring biological indicators. A time series comparison of IBI scores with an area buffer around each site over time shows that RM 0.2 and 21.7 both declined post-spill and RM 21.7 declined into non attainment of EWH conditions (Figure. 9). The lowest integrity conditions were observed during 1997-1999. As restoration activity increased with increases in easements, property purchases, and tree plantings, biological integrity conditions stabilized to warmwater habitat (WWH) use attainment. None of the three long-term sites have attained pre-spill conditions during the 16 years of monitoring and assessment (Figure. 9). Significant watershed declines in ICI condition ($t = -2.2167$, $p = 0.042516$) has been observed, while no significant change has been observed in IBI condition ($t = 0.6863$, $p = 0.502985$).

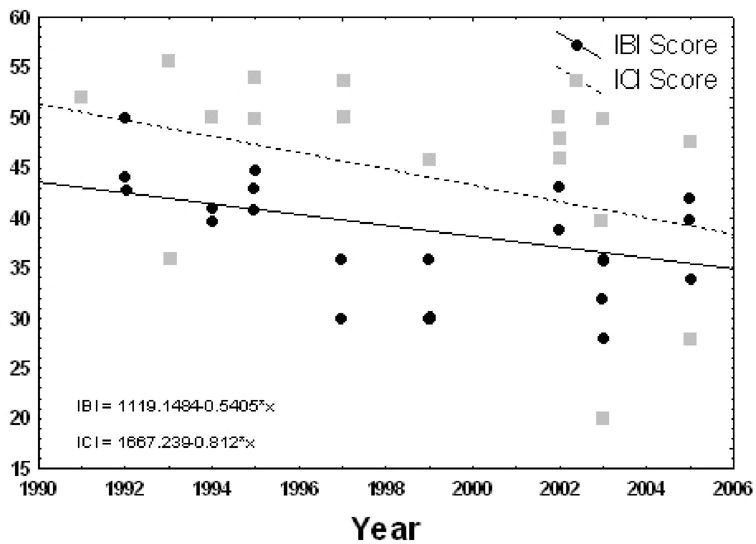



Figure 9. Annual changes in IBI and ICI score from pre-spill (1991) to post-spill recovery (2005) in lower (RM 0.3 and RM 5.4) and middle Fish Creek (RM 21.7) watershed.

Habitat degradation and sedimentation are identified as limiting factors in the Fish Creek and St. Joseph River watersheds (Stewart et al. 1991; Stewart and Swinford 1995). The habitat constituents in Fish Creek are intact and have been protected by easements and riparian restoration. These BMPs reflect "good-excellent" QHEI scores in the sampled portion of the stream (Table 4). Silt and fine sediment has aggregated and is being delivered from upstream headwaters providing higher than desirable nutrients (as reflected in TP and TKN). Nitrogen assimilation and processing has shown that headwater streams can transform greater than 50% of nutrient load in these watersheds (Peterson et al. 2001). Habitat is likely a mitigating factor providing a critical link in these mechanisms. Much nutrient processing occurs on sediments and biofilms (i.e., bacteria, fungi, periphyton) covering the substrates and structures (e.g., woody debris) in these streams. We hypothesize that channelized streams lose functional surface area when fine substrates are embedded and coarse substrates and natural substrates are covered. Loss of reproductive and feeding habitats in large wadeable stream embeddedness and loss of habitat heterogeneity in headwater streams may initiate large shifts in trophic dynamics caused by inefficient removal or transformation of nutrients. In ecosystems of the heavily agricultural Midwest, already nutrient overloaded headwaters streams will cause effects that cascade downstream to larger waters.

Table 4 compares average IBI, ICI and QHEI metrics from Fish Creek and the St. Joseph River watershed with other similar sized stations in the ECBP that have IBI or ICI scores ≥ 50 (general EWH base value). We assigned arrows to the comparisons between the sites with high IBIs or ICIs with Fish Creek and the St. Joseph River values based on whether we considered the Fish Creek differences biologically significantly worse (↓), similar to (--), or better (↑) than the "reference" values. The goal of this analysis is to discriminate among the components of IBI and ICI that may explain the deviation from EWH attainment and to assign potential causative or at least associative factors that may explain these deviations.

For the IBI, the strongest deviation in the Fish Creek fish data compared to sites that attained an IBI of 50 came from the number of sensitive and declining fish species and from two proportionate metrics, percent individuals as tolerant species and percent individuals as omnivore species (Table 4). The percent insectivore metric show little change; however, some of the insectivores are more facultative and tolerant (e.g., green sunfish) and the lower numbers of sensitive and declining fish species indicate that a lack of more sensitive species was compensated by insectivorous, but less sensitive species. A similar, but even stronger pattern of deviation is found in the St. Joseph River fish data. All of these fish metrics are associated with degraded habitats, although the omnivore and especially the tolerant metric can respond strongly to organic and nutrient enrichment and low dissolved oxygen.

Macroinvertebrates showed less deviation from stations in the ECBP with ICI values ≥ 50 although there were fewer Qualitative EPT taxa and fewer total and mayfly taxa from the Hester Dendy samplers (Table 4). These sites had similar numbers of caddisfly taxa to high ICI sites and actually a greater percent of caddisflies in the samples (Table 4). Most macroinvertebrate metrics scored were much lower in the St. Joseph River watershed; although number of caddisfly taxa was similar to high ICI at Fish Creek sites and the St. Joseph station had an even higher average proportion of caddisflies in samples.

## Two-stage Ditch Design Implementation in Upper Creek Headwaters

Natural stream restoration techniques have been advancing rapidly over the past decade (Rosgen 1994) and the creation of what is termed a "two-stage" channel in a lowered floodplain in headwaters streams may be an opportunity to maintain drainage and flood control while enhancing ecological conditions. Perhaps, the best management strategy for upper Fish Creek is the implementation of a two-stage ditch process to stabilze bank erosion and eliminate downstream sediment loads. This practice would apply if bank slumping, high nutrient levels are being exported via the water to downstream source, high levels of sedimentation is occurring in the ditch, and a high frequency of "bottom scouring" is occurring.

A two-staged ditch consists of a natural base flow channel with floodplain “benches” which are adjacent to the base flow channel within a drainage ditch. This practice can be applied as a management system, including provision of a larger water holding capacity at high flows which can reduce downstream flooding while providing drainage; allow for sediment sorting and depositing on the bench areas in high flows, which will improve habitat for aquatic communities and trap and store sediment; maximize nutrient removal via the vegetated bench areas; reduce in-stream sedimentation due to unstable banks and bank failure that occurs in standard trapezoidal ditch channels; increase the surface area where denitrification can occur; and can decrease the need for frequent ditch maintenance activities.

Design features of the benches include the minimum of two times the width of the inset channel (current wetted water width) or one-sided bench construction uses the same two times channel width criteria; side slopes will vary and depend on the current slope and soil type; design side slopes to be stable, for most designs a 2:1 slope will be appropriate; and bench height will depend on the ditch’s drainage area and flashiness, and will be determined by using a regional runoff curve that is calculated for the area. Each tile outlet will be repaired and will outlet onto the newly formed benches. These areas will have a rip rapped, concrete, or similar pad that the tile water will drop onto as a preventative measure for any erosion that could potentially take place on the benches. Additional consideration should be paid to the depth and width of the existing ditch channel during the site selection process to minimize the amount of soil that must be moved to create the floodplain “benches”. Adjacent areas of the field should be identified so that spoil removed from the “bench” areas can be conveniently spread over the adjacent field areas, rather than hauled off-site. Special attention should also be paid to ensure that there is no impact to adjacent wetlands within the areas to be excavated. Permits may need to be secured by state water agencies or the Army Corps of Engineers. Post-construction site conditions need to be monitored so that appropriate native seeding mixes can be obtained to meet the site conditions (i.e., a wet mix should be used on the bench areas and dry seed mixes can be used on the adjacent uplands and side slope areas as appropriate). Existing site vegetation in the buffer zone of the ditch should also be considered when selecting a site, as it is not as advantageous to remove a higher quality forested buffer to create a 2-stage ditch.

## Restoration Effects on Mussel Assemblage Diversity

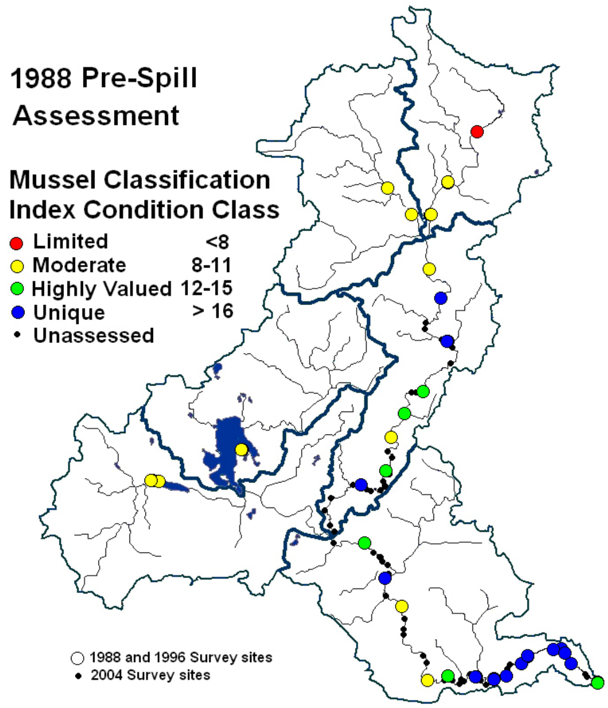
During the pre-spill 1988 survey, 28 mussel species were found in the Fish Creek watershed, including five listed species (Watters 1988). A decline to 25 species was observed during the post-spill 1996 monitoring (Watters 1996). Watters (1996) found in 1996 that precipitous declines in the relative abundance of live individuals occurred at virtually every site. No White Cat’s Paw Pearly mussel was found during the 1996 surveys, and only two individuals had been collected during the previous decade. Hope that the species may still be present in Fish Creek post-spill is contingent on whether its numbers have fallen below the level of detection.

Qualitative mussel surveys in Fish Creek post-restoration were conducted to locate mussel beds and determine population densities. Initial emphasis was placed on locating the federally endangered Clubshell mussel and Cat’s Paw Pearly mussel. A total, of 38.9 km (24.2 mi) of Fish Creek were surveyed at 64 mussel beds including 49 sites in Indiana and 15 sites in Ohio. Site searching totaled 27.9 man-h and 1669 live mussels were found comprising 22 species. A portion of Hiram Sweet Creek, the main tributary feeding Fish Creek below Hamilton Lake, had excellent habitat, but no live mussels including no obvious signs of other aquatic life, including fish and insects were found. Additional sites in the Ball Lake tail-waters found 70 live mussels. No White Cat's Paw Pearly mussel was found (including no shells or shell remnants) and three Clubshell mussels were found. A single Clubshell mussel was found in Ohio and another two were found in Indiana. The State-listed Rabbitsfoot mussel (*Quadrula cylindrical*) was found at two sites in Ohio. Also, the State of Indiana's listed Kidneyshell Mussel (*Ptychobranchus fasciolaris*) was located at 44 sites (280 total animals); and Indiana's state-listed Wavy-rayed Lampmussel (*Lampsilis fasciola*) was located at a single site in Ohio. These species are both mussels of special concern in their respective states.

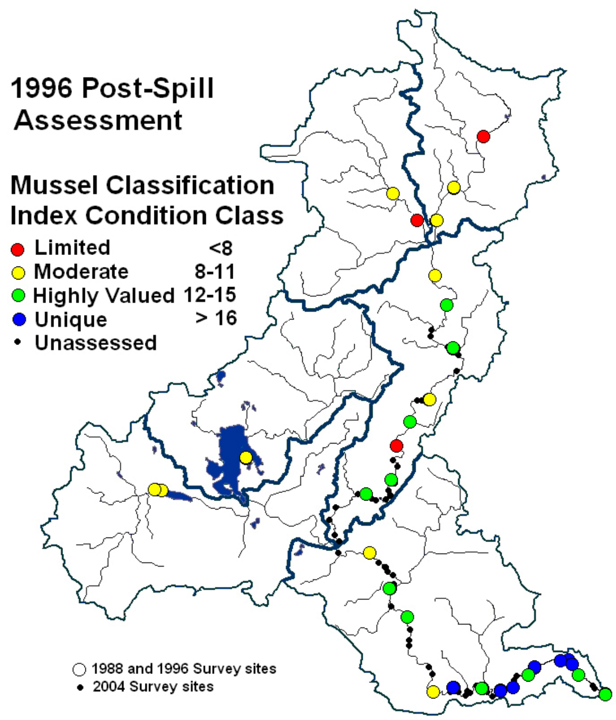
A quantitative mussel survey in 2005 was conducted to locate juvenile mussels and determine mussel distributions of species that occur deeper in the substrates. The eleven sites surveyed ranged in mussel classification from limited (1), moderate (2), highly valued (6), to unique (2) and included seven Indiana and four Ohio sites. The emphasis of the study was to determine recruitment within species. In total, 340 mussels were found representing eighteen different species. Juvenile mussels were located from eleven species, including Clubshell and Kidneyshell mussels. Of the eleven sites, six had juvenile mussels and each of these six sites had juveniles from multiple species represented. Only a single site failed to produce any mussels, while another site in the upper creek produced two adult mussels. These two sites ranked as *restricted* and *limited*, respectively, according to the 2004 survey. Findings show recruitment of mussels in Fish Creek by several species, including Clubshell and Kidneyshell mussels. Locating productive mussel beds is the first step in preserving adequate habitat for continued survival and restoration.

## Mussel Classification Index

Using the Mussel Classification Index (Szafoni 2007) as a management decision tool, Fish Creek showed a large amount of unique mussel habitat in the lower and middle creek pre-spill (Figure 10A). Changes observed post-spill were principally found downstream of the fuel oil spill, but that middle creek sites also showed declines in condition (Figure 10B). Mussel Classification Index (MCI) scores from the post-restoration 2004 survey showed that of the 64 surveyed sites, five ranked as unique, 31 as highly valued, 20 as moderate, and 8 as limited. There was a distinct watershed pattern that separated quality and sub-standard mussel beds. The upper and middle creek segments had 2 sites that ranked as *highly valued* and seven sites that rank as *limited*. The remaining seventeen are considered as *moderate* in this segment. Sites in the lower creek segment included a single site ranked as *limited* and only three sites ranked as *moderate*. The remaining sites ranked as *highly valued* (29) and *unique* (5).

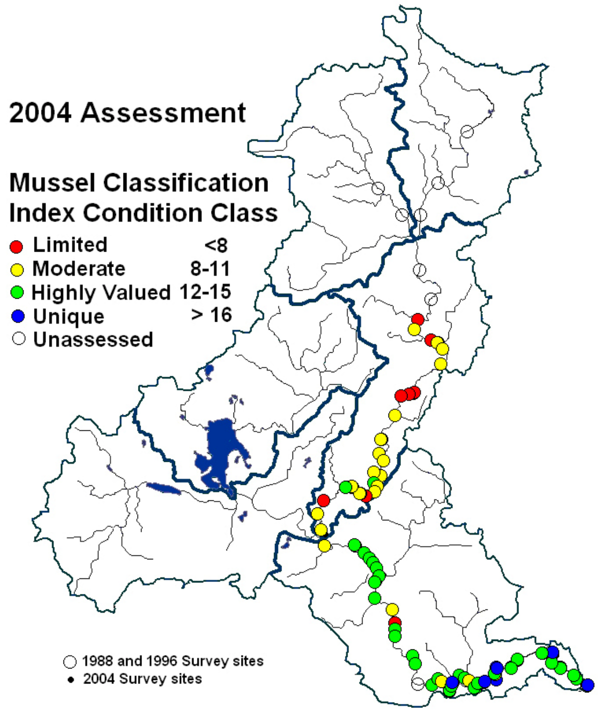



(A)




(B)

Figure 10. Mussel Classification Index assessment for the Fish Creek Watershed. A) Pre-spill assessment 1988, B) Post-spill assessment 1996, and C) 2004 Post-restoration assessment.




(C)

Figure 10. (Continued)

Post-restoration monitoring found the greatest changes in mussel classification (Figure 10C). The upper creek sites have improved, while the middle creek sites showed the greatest drop in quality. Lower creek sites have recovered to pre-spill conditions. Mussel Classification Index (MCI) scores increased with increasing drainage area. Upper Fish Creek had excessive sedimentation from livestock access. Natural riparian corridor buffers exist along both sides of Fish Creek; however, some areas have restrictive buffers that are too narrow to adequately protect Fish Creek from sedimentation and agricultural run-off.

## CONCLUSION

Based on monitoring data, the biological performance of fish and to a lesser degree macroinvertebrates in Fish Creek fall short compared to other high scoring streams in the ECBP. Chemical stressors were slightly above EWH ranges in Fish Creek for TP, TKN, and conductivity; and elevated bacteria suggest that biological performance was less than expected for EWH. Degradation of the substrate condition was reflected in the QHEI with upstream sources likely contributing to this condition. EWH streams are more sensitive to a large number of stressor types than WWH or Modified Warmwater Habitat (MWH) streams. These relationships are not necessarily causal, but correlated with land disturbance. It is likely that there are multiple factors that interact to affect aquatic communities in Fish Creek. The Auglaize River example and the background relationships between habitat and aquatic life indicate for region and watershed scales show that habitat conservation is the primary factor for restoration of aquatic life. Sediment and nutrient runoff control will enhance habitat structural component improvements. When habitat is poor, no amount of upland BMPs are likely to protect or restore ecological function into the high biological integrity. Similarly, even the best habitat cover could be limited by water quality, such as the delivery of nutrients and sediment that exceed the assimilative capacity of these habitats. Focus on headwater restoration in Fish Creek requires more intensive conservation actions so that downstream protection of important mussel diversity can be maintained.

## ACKNOWLEDGEMENTS

Numerous individuals assisted the Natural Resource Trustees in maintaining biological diversity in Fish Creek. The Fish Creek Council thanks Alger Van Hoey, District 3 Wildlife, and Larry Clemens, TNC, for their tireless efforts in securing restoration projects in the Fish Creek watershed. The opinions in the paper do not necessarily reflect those of the U.S. Fish and Wildlife Service, Indiana Department of Environmental Management, Ohio Environmental Protection Agency, or the Indiana or Ohio Departments of Natural Resouces.

## REFERENCES

Angermeier, P. L. & Winston M. R. (1998). *Local vs. regional influences on local diversity in stream fish communities of Virginia. Ecology 79:* 911-927.

Brady, T. (2004). *Qualitative Survey of the Freshwater Mussels of Fish Creek in Ohio and Indiana.* U.S. Department of the Interior, Fish and Wildlife Service, Genoa National Fish Hatchery, Genoa, WI.

Brady, T. (2005). *Quantitative Survey of the Freshwater Mussels of Fish Creek in Ohio and Indiana.* U.S. Department of the Interior, Fish and Wildlife Service, Genoa National Fish Hatchery, Genoa, WI; 2005.

Buikeima, A. L., Niederlehner, B. R., & Cairos, J. (1981). The effects of a simulated refinery effluent and its components on the estuarine crustacean, *Mysidopsis bahia. Archives Environmental Contamination and Toxicoloy 10:* 231-240.

Fish Creek Council Trustees. (1997). Joint environmental assessment and restoration plan for the Fish Creek #2 diesel fuel spill. Bloomington: U.S. Department of the Interior, Fish and Wildlife Service.

Gregory, R. S., & Keeney, R. L. (2002). Making smarter environmental management decisions. *Journal of the American Water Resources Association 38:* 1601-1612.

Havlik, M. E. & Marking, L. L. (1987). Effects of contaminants on naiad mollusks (Unionidae) a review. *U.S. Department of the Interior, Fish and Wildlife Service, Resource Publication 164.*

Hoggarth, M. (1990). Recovery Plan for the White Cat's Paw Pearly Mussel. *Reynoldsburg: U.S. Fish and Wildlife Service.*

Karr, J. R., Toth, L. A., & Dudley, D. R. (1985). Fish communities of Midwestern rivers: a history of degradation. *BioScience 35*: 90-95.

Keller, A. E., Ruessler, D. S., & Chaffee, C. M. (1998). Testing the toxicity of sediments contaminated with diesel fuel using glochidia and juvenile mussels (Bivalvia, Unionidae). *Aquatic Ecosystem Health and Management 1:* 37-47.

Loosanoff, V. L. (1961). Effects of turbidity on some larval and adult bivalves. *Gulf Caribbean Fisheries Institute, University of Miami Proceedings 14:* 80-95.

MacDonald, D., Ingersoll, C. & Berger, T. (2000). Development and evaluation of consensus-based sediment quality guidelines for freshwater ecosystems. *Archives Environmental Contamination Toxicology 39:* 20-31.

Marking, L. L. & Bills, T. D. (1980). *Acute effects of silt and sand sedimentation on freshwater mussels.* In. Rasmussen JL (ed). Proceedings of the symposium on upper Mississippi River bivalve mollusks. Upper Mississippi River Conservation Committee, Rock Island, IL.

Morisawa, M.(1968). Streams: Their Dynamics And Morphology. *McGraw-Hill, New York, NY.*

Myers, D.N., Metzker, K. D.., & Davis, S. (2000). Status and trends in suspended sediment discharges, soil erosion, and conservation tillage in the Maumee River Basin—Ohio, Michigan, and Indiana: U.S. *Geological Survey Water-Resources Investigations Report 00–4091:* 1-38.

Ohio Environmental Protection Agency (OEPA). (1987). Biological criteria for the protection of aquatic life: *Volume 1. The role of biological data in water quality assessment. Columbus: Division of Water Quality Planning and Assessment, Ecological Assessment Section.*

Ohio Environmental Protection Agency (OEPA). (1989). *Biological criteria for the protection of aquatic life: Volume III.* Standardized biological field sampling and laboratory methods for assessing fish and macroinvertebrate communities. Columbus: Division of Water Quality Planning and Assessment, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency (OEPA).(1993a). *Biological and water quality study of the St. Joseph River and selected tributaries.* OEPA Technical Report EAS/1993-12-7. Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency (OEPA). (1993b). *Macroinvertebrate community assessment of Fish Creek: 1993-1998.* Steuben and Dekalb Counties (Indiana) and Williams County (Ohio). Project Summary – Sampling Year 1993. Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency (OEPA). 1995. Fish and macroinvertebrate study of Fish Creek. (1994). *Steuben and Dekalb Counties (Indiana) and Williams County (Ohio).* Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency (OEPA). (1996). *Addendum to Fish and macroinvertebrate study of Fish Creek: 1994.* Steuben and Dekalb Counties (Indiana) and Williams County (Ohio). Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency. (2002). *Manual of laboratory operating procedures. Volumes I,II,III and IV.* Columbus: Division of Environmental Services, OH.

Ohio Environmental Protection Agency (OEPA). 2003. Fish and macroinvertebrate study of Fish Creek. (1997). *Steuben and Dekalb Counties (Indiana) and Williams County (Ohio).* Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency (OEPA). (2005).*Fish and macroinvertebrate study of Fish Creek 2002: Steuben and Dekalb Counties (Indiana) Williams County (Ohio).* OEPA Technical Report MAS/2005-2-2. Columbus: Division of Surface Water, Ecological Assessment Section, OH.

Ohio Environmental Protection Agency. (2008). *Ohio EPA manual of surveillance methods and quality assurance practices, updated edition*. Columbus: Division of Environmental Services, Ohio.

Omernik, J. M., & Gallant, A. L. (1988). Ecoregions *of the Upper* Midwest *States: EPA/600/3- 88/037. Corvallis:* US Environmental Protection Agency, Corvallis, OR.

Rankin ET. (1995). The use of habitat assessments in water resource management programs, Pp. 181-208.In Davis WS & Simon TP (eds.). Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Boca Raton: Lewis Publishers, FL.

Rosgen, D. 1994. *A classification of natural rivers. Catena 22:* 169-199.

Simon, T. P. & Dufour, R. L. (1998). *Development of Index of Biotic Integrity Expectations for the Ecoregions of Indiana. V*. Eastern Corn Belt Plain. EPA 905/R-96/003. Chicago: U.S. Environmental Protection Agency, IL.

Statsoft. (2008). *Statistica, version 8.0.* Tulsa, OK.

Stewart, P. M., Duffey, R., & Swinford, T. O. (1993). Water quality of Fish Creek in reference to the endangered White Cat's Paw Pearly Mussel. *Indiana Water Resources Research Center Technical Report 193:* 17-46.

Stewart, P. M. & Swinford, T. O. (1995). *Identification of sediment and nutrient sources impacting a critically endangered mussel species' habitat in a small agricultural stream. Pp. 45-64. In Pratt JR, Bowers N, & Stauffer, JR, Jr (eds).* Making Environment Science: A Festschrift in honor of John Cairns, Jr. Portland: OR.

Strayer, D. L. & Smith, D. R. (2003). *A guide to sampling freshwater mussel populations*. American Fisheries Society Monograph 8. Bethesda: MD.

Szafoni, R. E. (2007). *Making mussel metrics: identifying significant mussel communities*. Abstract 68th Midwest Fish and Wildlife Conference. http://wiatri.net/projects/mfwcsearch/viewAbstract.cfm?AbstractID=131

Trautman, M. B. (1981). *Fishes of Ohio*. Columbus: Ohio State University Press.

United States Environmental Protection Agency (USEPA). 1988. Standard Operating Procedures for assessing the biological integrity of fish communities. Chicago: US EPA, Central Regional Laboratory, IL.

United States Fish and Wildlife Service (USFWS). (2006). *Fish Creek Mussels. Bloomington, IN:* U.S. Department of the Interior, Fish and Wildlife Service.

United States Fish and Wildlife Service (USFWS). (2008). *Strategic Habitat Conservation Handbook:* A guide to implementing the technical elements of Strategic Habitat Conservation (Version 1.0). Washington DC: National Technical Assistance Team.

Watters, G. T. (1988). *A survey of the freshwater mussels of the St. Joseph River system, with emphasis on the federally endangered white cat's paw pearly mussel*. Indianapolis: Indiana Department of Natural Resources.

Watters, G. T. (1996). *1996 Survey of the mussels of the Fish Creek drainage*. Indianapolis: The Nature Conservancy Indiana Chapter.

Watters, G. T. (2000). *Three Year Freshwater Mussel Life Requirement Investigation. Columbus:* Ohio Biological Survey, Columbus.

Williams, B. K., Szaro, R. C., & Shapiro, C. D. (2007). *Adaptive Management: The U.S. Department of the Interior Technical Guide.* Adaptive Management Working Group, Washington, D.C.: U.S. Department of the Interior.

Williams, J. D., Warren, N. L., Jr, Cummins, K. S., Harris, J. L., & Neves, R. J. (1993). *Conservation status of freshwater mussels of the United States and Canada. Fisheries 18*: 6-22.