TEMPORAL ASSESSMENT OF MANAGEMENT PRACTICES AND WATER QUALITY IN THE DUCK CREEK WATERSHED, WISCONSIN

A report to the:

Environmental Health and Safety Division

Oneida Tribe of Indians of Wisconsin

By:

Daniel Cibulka
Paul Baumgart
Kevin Fermanich

University of Wisconsin Green Bay
Department of Natural and Applied Science and
Environmental Science and Policy Graduate Program
UW-Green Bay Project No: PRJ-14RP

For the Grant:

Duck Creek Watershed Data Analysis and Monitoring Project

June 2008 – July 2009

February 2010 (final draft)

TABLE OF CONTENTS

CHAPTER 1 – INTRODUCTION AND BACKGROUND 1

INTRODUCTION 1
GEOLOGY AND SOILS 2
HYDROLOGY AND WATER QUALITY 2
PROJECT OBJECTIVES 4

CHAPTER 2 - CHANGES IN THE DUCK CREEK WATERSHED 5

HISTORICAL CONTEXT 5
DUCK, APPLE AND ASHWAUBENON CREEKS PRIORITY WATERSHED PROJECT 6
DAAPWP RESULTS 6
AGRICULTURAL CROPLAND SURVEY 8
TRENDS IN DAIRY FARMS 10
AGRICULTURAL CROP TRENDS 10
ONEIDA LAND USE AND BMP IMPLEMENTATION 11
PERMITTED POINT SOURCE DISCHARGES 13
SUMMARY 14

CHAPTER 3 - DUCK CREEK WATER QUALITY ANALYSIS 15

INTRODUCTION 15
DUCK CREEK WATER QUALITY DATASET CHARACTERISTICS 15
METHODOLOGY – STATISTICAL ANALYSIS 17
MULTIPLE LINEAR REGRESSION RESULTS - TRENDS 18
Regression Analysis over the 20 year monitoring record 18
Period-Specific Regression Analysis 19
FURTHER INVESTIGATION 23
Period 1 vs Period 3 Comparison: non-parametric tests 23
Mid-Month and Mid-Week Sub-Sampled Statistical Comparison 25
TREND ANALYSIS SUMMARY 28
DISCUSSION 28

CHAPTER 4 - BIOLOGICAL INTEGRITY OF THE DUCK CREEK WATERSHED 30

INTRODUCTION 30
BIOLOGICAL INDICES 31
Biological Assessment of Fish Communities 31
Biological Assessment of Macroinvertebrate Communities 31
METHODS 33
Fish Methods 33
Macroinvertebrate Methods 35
FISH COMMUNITY TREND RESULTS 37
MACROINVERTEBRATE TREND RESULTS 38
SUMMARY 40
DISCUSSION 40

CHAPTER 5 - TROUT CREEK WATER QUALITY ANALYSIS 42

INTRODUCTION - ESTABLISHING A TROUT FISHERY 42
TROUT CREEK WATER QUALITY ANALYSIS - METHODS 43
Monitoring Locations and Nutrient and Sediment Monitoring 43
Physical Water Quality Monitoring 44
TROUT CREEK WATER QUALITY ANALYSIS - RESULTS 45

Flow and Physical Water Quality Parameters......45
Nutrient and Sediment Monitoring Results......48
DISCUSSION......50

CHAPTER 6 – PROJECT SUMMARY......52

OBJECTIVE 1 – LAND MANAGEMENT ANALYSIS......52
OBJECTIVE 2 – TREND ANALYSIS OF WATER QUALITY AND BIOTIC DATA......52
OBJECTIVE 3 – RELATIONSHIPS AMONG LAND-USE, WATER QUALITY, AND BIOTIC CONDITION......53
OBJECTIVE 4 – CHARACTERIZATION OF TROUT CREEK WATER QUALITY......54
OBJECTIVE 5 – MANAGEMENT IMPLICATIONS AND RECOMMENDATIONS......55

CHAPTER 7 - REFERENCES......56

LIST OF TABLES

Table 1.1. Preliminary water quality targets established by the Lower Fox River Basin TMDL Science Team and WDNR (Lower Fox River Basin TMDL Executive Summary, unpublished, 2009). Target values are for summer median concentrations. TSS targets for tributaries will be determined based upon the total percent reduction needed to meet the 20 mg/L concentration set for the Green Bay Area of Concern (AOC). 3

Table 2.1. BMPs installed from 1997-2008 within Brown County as a result of the DAAPWP. Results represent placements in the Duck, Apple, and Ashwaubenon watersheds. Data obtained from Jim Jolly of the BCLCD 6

Table 2.2. BMPs installed from 1997-2008 within Outagamie County as a result of the DAAPWP. Results represent placements in the Duck, Apple, and Ashwaubenon watersheds. Data obtained from Suzan McBurney of the OCLCD 7

Table 2.3. Estimated reductions achieved through DAAPWP projects from 1997-2008. Totals represent reductions in Duck, Apple, and Ashwaubenon Creeks combined. Reduction values were calculated using different methods for Brown and Outagamie Counties (WDNR, 1997; Jolly, 2009; McBurney unpublished March 2009). 8

Table 2.4. Tillage practices in the Duck Creek watershed, as determined by CTIC (1996, 1999/2000, 2002, 2007) and investigator (2009) transect surveys. The March, 2009 survey was prior to spring tillage and planting, so tillage estimates from this year likely understate the percentage of conventional tillage. The 2007 survey data only includes the Brown County portion of the watershed. 10

Table 2.5. Estimated cropland trends between 1992 and 2007 in the Duck Creek watershed upstream of CTH FF (280 km^2), and in Outagamie County. Both GIS-derived estimates (GIS) and USDA NASS statistics (Stats.) show a decrease in alfalfa/forage.. 11

Table 2.6. Acreage and soil phosphorus values (Bray P1 in ppm) for Oneida farms in the Duck Creek watershed. Data are based on field values from multiple years as reported in 2002 and 2007 nutrient management plans. 12

Table 2.7. Annual total phosphorus effluent concentrations from the Freedom Sanitary District #1 Wastewater Treatment Facility 1999 to 2008. 14

Table 3.1. Simple water quality statistics for samples collected at the USGS monitoring station (ID #04072150) on Duck Creek, 1988-2008. 17

Table 3.2. Regression model estimates, standard errors, and P-values of the coefficients in the Duck Creek log-transformed total phosphorus (LN_TP) and dissolved phosphorus (LN_DP) regression models for Period 1 (USGS water years 1989-1995). 20

Table 3.3. Non-parametric Wilcoxon Rank sum test (t-approximation) for several constituents under different flow and data censoring scenarios: Period 1 vs Period 3. Flow scenarios (in cfs) were created to account for differing sampling protocols and unusual weather events that occurred over the 20-year record. All flow scenarios omit water-year 1995, except the column labeled "All Years". NOTE: P1 indicates Period 1 (USGS water years 1989 to 1995), P3 indicates Period 3 (USGS water years 2004 to 2008). To reflect the different null hypotheses, statistical tests for TP and DP were one-sided, whereas tests for DP/TP and flow were two-sided. 25

Table 3.4. Non-parametric Wilcoxon Rank sum test (t-approximation) of TP, DP, DP/TP and flow data between Period 1 and Period 3. Data were sub-sampled under a once-per-month and once-per-week basis to increase independence between samples and to reduce serial correlation. USGS water-year 1995 was omitted from some of the analysis for comparison purposes. NOTE: P1 indicates Period 1 (USGS water years 1989 to 1995), P3 indicates Period 3 (USGS water years 2004 to 2008). Significant results are in bold. To reflect the different null hypotheses, statistical tests for TP and DP were one-sided, whereas tests for DP/TP and flow were two-sided. 27

Table 4.1. Evaluation of water quality based upon biotic indices associated with macroinvertebrate communities (Hilsenhoff 1987 and 1988). 32
Table 4.3. Metric categories for Lyons' 1992 and 2006 IBI classification system, and their tendencies under increasingly stressful situations. 37
Table 4.4. Fish metrics with significant change (P<0.05) between Periods 1 and 3, their locations in the watershed, the direction of change, and fish community implication in Duck Creek. The bottom portion of the table summarizes the number of positive and negative changes for each watershed location. 38
Table 5.1. Environmental tolerance and optimal habitat of brook trout species. Conditions may vary due to regional or genetic differences. 43
Table 5.2. Monthly physical water quality parameter statistics for Trout Creek at County Rd. FF (site TC1) and at Oak Ridge Road (site TC2). Data was continuously collected at 10 min. intervals using a multiparameter sonde. 47
Table 5.3. Published ranges of four parameters for brook trout, along with daily mean and 95% confidence intervals measured in Trout Creek at locations TC1 and TC2 in 2008. 47
Table 5.4. Summary statistics for water quality samples collected at two Trout Creek locations in 2008. All concentrations are in mg/L. 49
Table 5.5. Summary of bi-weekly low flow water quality samples collected at two locations on Trout Creek in 2008, and analyzed for TSS, total phosphorus and dissolved phosphorus. 49
Table 5.6. Simple statistics and p-values for a paired t-test performed on three water quality parameters monitored at two sites in Trout Creek (N=8). 50

LIST OF FIGURES

Figure 1.1. Land Cover and Landuse in the Duck Creek Watershed. 1
Figure 2.1. Agricultural practice survey sites, permitted point source discharges, and County Road FF USGS monitoring station in the Duck Creek watershed. Agricultural practice survey took place on March 16, 2009. 9
Figure 2.2. Point source phosphorus loads to Duck Creek for the Freedom Sanitary District #1 and Provimi Foods 1993 to 2008 (source WDNR). 13
Figure 3.1. Distribution of total phosphorus concentrations (mg/L) in samples collected throughout the 20-year monitoring period (1988-2008). In years 1996-2002, sampling was primarily performed monthly, resulting in fewer samples and no samples of higher concentrations (>0.5 mg/L). 16
Figure 3.2. Flow and seasonally-adjusted residuals of log-transformed TP during the 20-year USGS monitoring record (USGS water years 1989-2008). 19
Figure 3.3. Decreasing trend of flow and seasonally-adjusted residuals of log-transformed total phosphorus during Period 1 (USGS water years 1989-1995). 21
Figure 3.4. Flow and seasonally-adjusted residuals of log-transformed dissolved phosphorus during Period 1 (USGS water years 1989-1995). 21
Figure 3.5. Observed and predicted log-transformed total phosphorus (LN_TP) concentrations during Period 1 with the selected best fit regression model (adjusted R^2 = 0.38). Pattern indicates regression model reasonably predicts TP concentration in Period 1. 22
Figure 3.6. Histogram of stream flow during phosphorus sampling between periods one (1989-1995) and three (2004-2008). Proportionally fewer samples were taken at higher flows (>675 cfs) during Period 1, while fewer samples were collected at low flow (<75 cfs) during Period 3. 24
Figure 3.7. Measured stream flow (cfs) during phosphorus sampling from 1988-2008 at the Duck Creek USGS monitoring station. Three distinguishable periods are apparent, which coincide with different sampling protocols. 24
Figure 4.2. Location of macroinvertebrate survey sites included in this study. All locations are located on the main stem of Duck Creek. 36
Figure 4.3. Calculated metrics for Duck Creek macroinvertebrate surveys. Metrics include FBI (A), Number of Species (B), EPT% (C), and HBI (D) for Seminary Rd., County Rd. FF and all other watershed locations with respect to time. 39
Figure 5.1. Location of the Trout Creek watershed and two water quality monitoring locations. Nutrient and physical water quality parameters were measured at TC1 (downstream) and TC2 (upstream) during 2008. 44
Figure 5.2. Gage height and water temperature for Trout Creek during May-November of 2008. Data was recorded at County Road FF using a datalogger, pressure transducer and thermocouple. 46

LIST OF ACRONYMS

Area of Concern (AOC)
Best Management Practice (BMP)
Brown County Land Conservation Department (BCLCD)
Clean Water Act (CWA)
Conservation Technology Information Center (CTIC)
Department of Agriculture and Trade and Consumer Protection (DATCP)
Dissolved Oxygen (DO)
Dissolved Phosphorus (DP)
Duck, Apple and Ashwaubenon Priority Watershed Project (DAAPWP)
Environmental Protection Agency (EPA)
Ephemeroptera, Plecoptera, Trichoptera Index (EPT)
Five-day Biological Oxygen Demand (BOD5)
Freedom Sanitary District #1 (FSD#1)
Lower Fox River Watershed Monitoring Program (LFRWMP)
Global Positioning Unit (GPS)
Green Bay Metropolitan Sewerage District (GBMSD)
Hilsenhoff Biotic Index (HBI)
Index of Biological Integrity (IBI)
Lower Fox River Watershed Monitoring Project (LFRWMP)
National Pollutant Discharge Elimination System (NPDES)
National Weather Service (NWS)
Natural Resources Conservation Service (NRCS)
Outagamie County Land Conservation Department (OCLCD)
Oneida Tribe of Indians (OTI)
Program on Agricultural Technology Studies (PATS)
Suspended Solids Concentration (SSC)
Total Maximum Daily Load (TMDL)
Total Phosphorus (TP)
Total Suspended Solids (TSS)
Water and Sediment Control Basin (WASCOB)
Wisconsin Department of Natural Resources (WDNR)
United States Census Bureau (USCB)
United States Geological Survey (USGS)
United States Fish and Wildlife Service (UWFWS)

Chapter 1 – INTRODUCTION AND BACKGROUND

Introduction

The Duck Creek watershed drains approximately 393 km^2 of Brown (33%) and Outagamie (67%) counties in northeastern Wisconsin. Duck Creek is classified as a fifth-order, intermittent, warmwater stream. The headwaters of Duck Creek originate approximately 4 km south of Seymour, Wisconsin in an area just north of Burma Swamp. From here, the stream flows 74.3 km until it spills into the Bay of Green Bay. Seven sub-watersheds comprise the Duck Creek watershed: Beaver Dam, Fish Creek, Lancaster Brook, Silver Creek, Oneida Creek, Trout Creek and one unnamed system. The tributary watersheds of Duck Creek total roughly 184 km^2, and several of these tributaries are classified as cold-water perennial streams. Many of the tributaries and a large portion of mainstem Duck Creek meanders through the Oneida Indian Reservation, which straddles the boundary of Brown and Outagamie counties. The watershed makes up a portion of the larger Lower Fox River Basin. The Lower Fox River drains a 1,654 km^2 basin and is the Bay of Green Bay's largest tributary. According to 2001 land use data provided by the Lower Fox River Watershed Monitoring Program (LFRWMP), the Duck Creek watershed is predominately agricultural (55.3%) with urban land (18.8%), forested land (13%) and wetlands (8.5%) comprising significant parts of the watershed as well (Figure 1.1).

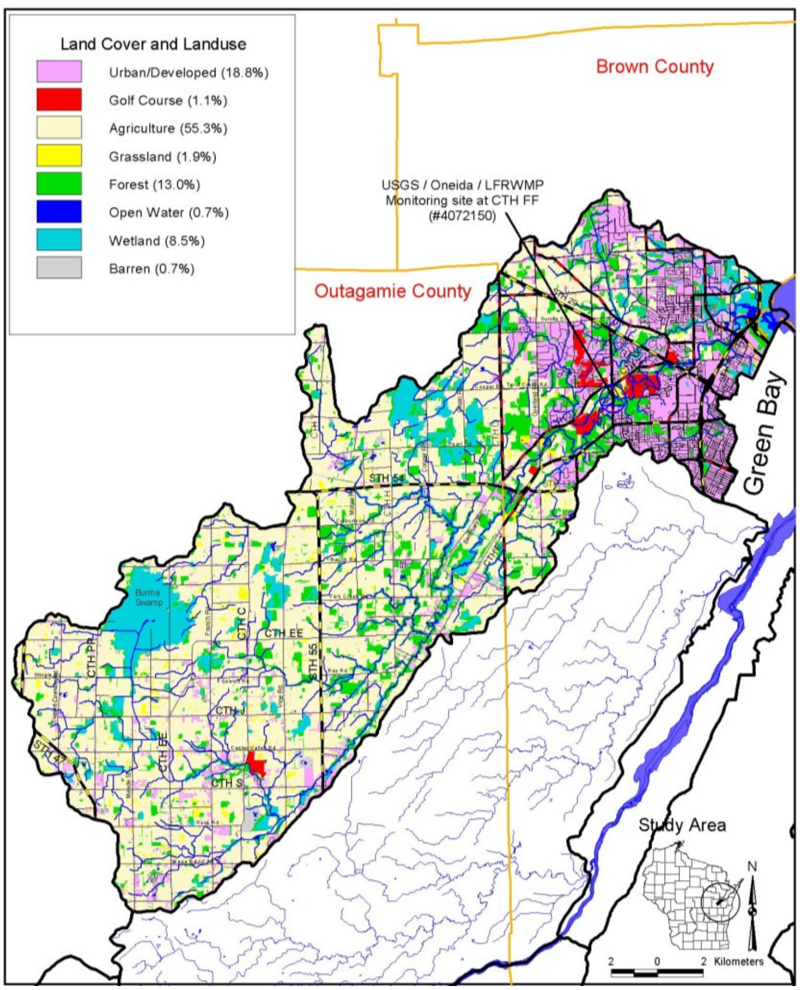

Figure 1.1. Land Cover and Landuse in the Duck Creek Watershed, 2001.

Geology and Soils

Underlying the Duck Creek watershed is the Galena formation of the Sinnipee limestone group. This rock group originates from the latter part of the Paleozoic Era (600 million years ago) and consists of a dolomitic limestone layer, with some chert and shale. The Sinnipee Group is one of several sedimentary and Precambrian rock groups that tilt towards the east at about 30 to 40 ft/mi. (Batten and Bradbury, 1996). Once thought to be impermeable, more recent information indicates that the Sinnipee Dolomite allows water from Duck Creek to flow into underlying sedimentary layers to the water table (written communication, USGS, 1991).

Glaciation has had a profound effect on both the topography and the surface drainage patterns in the watershed. Quaternary glacial till deposits 50 to 200 feet deep overlie the Sinnipee Group (Batten and Bradbury, 1996). The most recent of four glacial advancements, the Wisconsin stage, occurred from 25,000 to 10,000 years ago (Clayton et al., 2006). The first major substage of the Wisconsin advancement, the Cary ice sheet, melted to form present-day Lake Winnebago. As it melted the Cary ice sheet deposited large quantities of sand in the northern portion of the watershed, near the confluence of Duck and Trout Creeks. Years after the Cary ice sheet retreated, the Valders substage occurred. This ice sheet did little to change the existing topography, but did leave significant deposits of red clay till in the southern and middle portions of the watershed (WDNR, 1997). As a result, the soils in the upstream (south-west) portions of the watershed are comprised of fertile reddish-brown calcareous clays and reddish clay-loam mixtures, while the downstream (north-east) areas of the watershed are generally more sands and sandy loams.

Hydrology and Water Quality

Mean annual precipitation at the National Weather Service station in Green Bay, WI was 73.7 cm for 1976-2008, and ranged from 45.4 to 97.5 cm (Appendix A.1, Cibulka, 2009). In this region the majority of rainfall occurs during the months of June-September, though the streams receive considerable water in March and April due to snowmelt.

Historically, Duck Creek may have been a perennial stream. In recent years, Duck Creek has been classified as a warmwater intermittent stream by various investigators. In 1991, the United States Geological Survey (USGS) completed a study of the flow regimes of Duck Creek. The study identified 15 losing reaches (groundwater recharge zones) on the mainstem of the stream. Some reaches have the potential to lose about 390,000 gallons per day to local groundwater storage, depending on river flow conditions (written communication, USGS, 1991). This is likely due to the well-drained soils and permeable Sinnipee dolomite, which allows transport of stream water from the stream to the water table.

The watershed has a rich history of both agricultural use and water quality problems due to agricultural impacts. Reports from the United States Geological Survey (USGS), Wisconsin Department of Natural Resources (WDNR), Oneida Tribe of Indians (OTI), and the United States Fish and Wildlife Service (UWFWS) have classified the Duck Creek watershed's water quality and habitat as "poor" to "fair" (Cogswell, 1998; Santy, 2001; Moren, 2002; Gilmore, 2007; WDNR, 2006).

Section 303(d) of the Environmental Protection Agency's (EPA) Clean Water Act (CWA) requires the states and tribes to establish water quality standards. It also requires the state to identify those bodies of water that are not meeting the standards and places these on an "impaired waters" list. The bodies of water on this list are subject to Total Maximum Daily Load (TMDL) regulations in which assessments of the pollution contributions are made and a remedial plan is developed. Currently 63.5 km of the main stem of Duck Creek are included on Wisconsin's impaired waterways list. Sediment and phosphorus are identified as the primary pollutants causing the impairments (WDNR, 2008). The 20.6 km main stem of Trout Creek is also listed as an impaired surface water because of excess sediment and phosphorus inputs (WDNR, 2008). However, all of Trout Creek, and the middle segment of Duck Creek are proposed to be removed from the list because these stream segments are within the Oneida Tribal boundary, so the Oneida Tribal Nation has authority to regulate these waterways.

In June of 2007, a TMDL committee was formed to set numeric water quality targets for tributary streams in the Lower Fox River basin, as well as the Lower Fox River and Green Bay Area of Concern (AOC). The TMDL Science Team and WDNR reviewed data collected in these water bodies, and calculated reduction targets for total phosphorus (TP) and total suspended solids (TSS) in these water bodies. Preliminary targets are summarized in Table 1.1. These targets are expected to result in many water quality improvements in the bay of Green Bay, including increased water clarity, improved growth of submerged aquatic vegetation, decreased resuspension of sediment particles in the water column, reduced algal growth, and increased dissolved oxygen (Lower Fox River Basin TMDL Executive Summary, unpublished, 2009).

Table 1.1. Preliminary water quality targets established by the Lower Fox River Basin TMDL Science Team and WDNR (Lower Fox River Basin TMDL Executive Summary, unpublished, 2009). Target values are for summer median concentrations. TSS targets for tributaries will be determined based upon the total percent reduction needed to meet the 20 mg/L concentration set for the Green Bay Area of Concern (AOC).

Water Bodies	**TP Target**	**TSS Target**
Lower Fox River Basin Tributary Streams	0.075 mg/L	TBD for each stream
Lower Fox River (outlet of Lake Winnebago to Green Bay) and Green Bay AOC	0.10 mg/L	20 mg/L at Fox River outlet

Water quality management has largely focused on nutrient and sediment loading to streams and other bodies of water. A rich history of research has addressed these pollutants. As far back as the 1950's, the effects of anthropogenic (or man-influenced) sedimentation and its impacts on stream biotic communities were being studied (Tebo, 1955). Suspended sediments result in turbid waters that directly contribute to reducing light penetration and production of aquatic life, along with altering the taste, odor, and temperature of water (Oschwald, 1972). Nutrients such as phosphorus and nitrogen and sediment from land runoff can alter both the biological diversity and habitat of streams when found in excessive amounts. Inputs of nutrients such as phosphorus and nitrogen contribute to eutrophication, which is an accelerated increase of the ecosystem's primary productivity. Aquatic systems experiencing high eutrophication often display adverse effects such as increased growth of algae and aquatic vegetation, which in turn may cause a decrease in dissolved oxygen concentrations, unfavorable conditions for aquatic organisms, and poor aesthetics (Carpenter et al., 1998).

Because the effects of anthropogenic pollution in streams are seen relatively quickly in biotic communities, organisms can be used as an indicator of a streams ecological health. Fish and macroinvertebrates have been used to assess the quality of water because they integrate the effects of environmental stressors (Vannote et al., 1980; Lyons, 1992). Simply put, an organism will not thrive in a stream that displays conditions outside its tolerance range. Organisms that are tolerant of environmental degradation, however, will remain present in this stream. If sensitive species are not found within the stream, it can be concluded that a certain level of degradation has occurred.

Project Objectives

The primary cause of water quality and biotic integrity degradation in the Duck Creek watershed has been pollution in the forms of excessive nutrients and sedimentation from non-point sources. With alteration in land management aimed at reducing non-point pollution, resulting effects should be reflected in the water chemistry and the biotic communities that reside in the streams of the Duck Creek watershed. This research included the following objectives to determine if land management improvement programs in recent years have had substantial effects on improving the health of the streams within the watershed:

1. Characterize changes in land use and land management in the Duck Creek watershed.

2. Analyze relationships between historical water quality and biotic integrity data and recently collected data on Duck Creek.
    a. Examine trends in water quality from 1989-2008.
    b. Explore differences in fish and macroinvertebrate communities in the watershed between 1988-1995 and 2003-2008.

3. Explore the relationship between land use changes and the water quality and biotic condition in Duck Creek.

4. Characterize the water quality at multiple sites within Trout Creek following strategic BMP implementation.

5. Assess the management implications of this watershed analysis, including the potential reintroduction of brook trout to Trout Creek.

This report is substantially based on thesis work conducted by Daniel Cibulka, Environmental Science and Policy Graduate Program at UW-Green Bay (Cibulka, 2009).

Chapter 2 - **CHANGES IN THE DUCK CREEK WATERSHED**

Historical Context

The Duck Creek watershed has seen significant changes in recent years. In Jeanne and Les Rentmeester's book *Memories of Old Duck Creek* (1984), the authors recount early settlers writings of "Riviére aux Canard" (the French name for Duck Creek) and "PAISSACUE" (the Menominee Indian name for Duck Creek) . At the mouth of the stream, vast stretches of wild rice attracted large flocks of ducks. Although these ducks still inhabit the area in smaller populations the wild rice has disappeared, mostly due to increasing urbanization, pollution, and the introduction of carp to the region. Early Duck Creek was much deeper than the stream we know today. Its current was also swifter, making it an ideal site for a sawmill. The first sawmill on the stream, one of the first built in the state, was built on its banks in 1827. The resulting erosion from harvested lands placed silts into the river, gradually filling the deeper pools. As Upper Michigan's iron mines peaked in the mid to late 1800's, deforestation of the region continued. The trees were harvested and burned to supply Green Bay mills with the energy needed for steel production (Rentmeester and Rentmeester, 1984).

The timber industry and deforestation of the area declined with a pivotal event in 1871. The largest fire in the history of the United States, the Peshtigo fire of 1871, tore through more than 1.5 million acres of Wisconsin and Upper Michigan (Hipke, 2009). In time, the region began to regrow some of its forests. The region also acquired a new powerful industry: dairy. From 1895 to 1910, cheese production in the area increased by 3.3 million lbs. per year (Martin, 1913). Agriculture blossomed and the area soon became well known for its dairy, cash crops, and meat production. To this day agriculture still has a strong presence in the region.

The Duck Creek watershed basin has a rich economic history due to the presence of diverse natural resources. Early Native Americans and European settlers alike realized this and moved to the area to take advantage of the rich soils, large forest plots, and plentiful streams. The population of the basin grew rapidly, and continues to do so today. According to data taken from the United States Census Bureau (USCB), the watershed has seen growth in recent years. Population data was accessed at the USCB website (USCB, 2009) at the town level. For towns that were partially in the Duck Creek watershed, population numbers were adjusted for approximate area with the assumption that individuals were equally distributed within the town. It was estimated that the watershed has seen an increase of 3,818 individuals since 1990 – an average annual increase of 1.4 percent. Urban land has likely increased as well, though as previously stated, agricultural land still remains the largest landuse in the watershed.

With agriculture plots and urban neighborhoods now dominating a once entirely forested watershed, the waters of nearby streams now document years of misuse. As discussed in Chapter 1, the water quality of Duck Creek is impaired from anthropogenic pollution, and the biotic communities and their habitats have been affected substantially. In Chapter 2, discussion will focus on the approaches that managers in the watershed have been taking to restore Duck Creek and its tributaries to their original state.

Duck, Apple and Ashwaubenon Creeks Priority Watershed Project

In 1994, the Duck, Apple, and Ashwaubenon Creeks were designated as "priority watersheds" under the Wisconsin Nonpoint Source Water Pollution Abatement Program. This program was created by the State Legislature in 1978 as a means of improving and protecting the water quality of streams, lakes, wetlands, and groundwater by reducing pollutants from urban and rural nonpoint sources (WIS Administrative Code Chapter NR 120). Today, this program is overseen by the WDNR and the DATCP. Following acceptance into the Wisconsin Nonpoint Source Water Pollution Abatement Program, assessments were completed in 1995 and 1996 within the watersheds by numerous entities including the Brown County Land Conservation Department (BCLCD), Outagamie County Land Conservation Department (OCLCD), and Oneida Nation Planning Department (ONPD) in cooperation with the WDNR and DATCP. The purpose of the assessments was to produce detailed inventories of land use and identify general pollution sources. The combined efforts of these groups resulted in a priority watershed plan that outlined the management practices needed to reduce nonpoint pollution within these three watersheds, outline agencies responsible for the various tasks, and determine time frames and budgets for the project (WDNR, 1997). In 1997, the Duck, Apple and Ashwaubenon Priority Watershed Project (DAAPWP) was approved by the aforementioned parties as well as the state of Wisconsin, and scheduled to run through 2009. The detailed report included practices needed to reduce sediment and phosphorus delivery by the stated goal of 50 percent.

DAAPWP Results

Data obtained from the BCLCD and OCLCD documented numerous BMPs being placed within the watershed as a result of the DAAPWP. Information was limited as to their exact location – records were kept for all three watersheds as opposed to each individual watershed and could not be subdivided. Records were also held separately between Brown and Outagamie Counties. Tables 2.1 and 2.2 summarize the BMP placement efforts that have occurred in the Duck, Apple, and Ashwaubenon Creek watersheds as a result of the DAAPWP, with respect to Brown and Outagamie Counties.

Table 2.1. BMPs installed from 1997-2008 within Brown County as a result of the DAAPWP. Results represent placements in the Duck, Apple, and Ashwaubenon watersheds. Data obtained from Jim Jolly (May 2009) of the BCLCD .

DAAPWP Best Management Practice Summary - Brown County		
Practice	**Qty**	**Units**
Barnyard Runoff Control Structure	1	#
Buffers	90	Acre
Conservation Tillage	31,064	Acre
Cover Crops	13,427	Acre
Manure Storage Facilities	2	#
Milkhouse Waste Control	1	#
Nutrient Management	10,275	Acre
Streambank and Shoreline Protection	222	Feet
Well Abandonment	2	#
Wetland Restoration	15	Acre

Table 2.2. BMPs installed from 1997-2008 within Outagamie County as a result of the DAAPWP. Results represent placements in the Duck, Apple, and Ashwaubenon watersheds. Data obtained from Suzan McBurney of the OCLCD.

DAAPWP Best Management Practice Summary – Outagamie County					
Practice	**Qty**	**Units**	**Practice**	**Qty**	**Units**
Access Road	60	#	Prairie Plantings	42	#
Animal Trails and Walkways	150	#	Prescribed Grazing	>67.5	Acre
Barnyard Runoff Management	40	#	Roof Runoff Management	46	#
Buffer	64.5	Acre	Stormwater Basin	9	#
Diversion	253	Feet	Stream Crossings	12	#
Earth Exercise Lot Relocation	1	#	Streambank/Shoreline Protection	380	Feet
Fence	2,100	Feet	Subsurface Drain	18	#
Fertilizer Spill Control Facility	1	#	Surface Drain Field Ditch	55,980	Feet
Grade Stabilization Structure	>2	#	Underground Outlet	51	#
Grassed Waterways	1,924	Acre	Waste Storage Facility	97	#
Heavy Use Area Protection	4	Acre	Water and Sediment control Basin	7	#
Leachate Collection System	1	#	Well Decommissioning	14	#
Lined Waterway or Outlet	660	Feet	Wetland Development/Restoration	98	Acre
Milkhouse Waste Mgt Pond	21	#			

Inventories of sediment and phosphorus delivery in the Duck, Apple, and Ashwaubenon Creek watersheds were calculated using the WDNR's WINHUSLE modeling software. This program calculated annual loading estimates of 111,000 tons of sediment and 228,000 lbs. of phosphorus (WDNR 1997). 11,500 tons of sediment and 19,400 lbs of phosphorus were estimated to come from urban lands in the watersheds, while the remaining majority was associated with rural lands. Reduction estimates were collected from the BCLCD and the OCLCD for their portions of the three streams. Data was not separated between the three watersheds. The results show substantial potential reductions in both sediment and phosphorus delivery to the three streams (Table 2.3). These estimates show that the program appears to have met the total reduction goals. However, the actual numbers should be taken with caution because the inventory and reductions are simulated, rather than measured values. For example, average annual 2004 to 2006 loads from the Duck Creek, Ashwaubenon Creek and Apple Creek monitoring stations were extrapolated by the LFRWMP to estimate loads from the entire area encompassed by the DAAPWP watersheds. The resulting average annual loads were 132,600 lb of phosphorus (60,100 kg) and 18,900 tons of TSS (17,150 metric tons) delivered to the watershed outlets. These values represent 58% and 17% of the TP (228,000 lbs) and TSS (111,000 tons) loads, respectively, which were reported in the DAAPWP (WDNR, 1997).

Managers from Brown and Outagamie County believe the program was a success, and concluded that a major accomplishment of the program was changing the behavior of farmers in the watershed. Farmers received both financial and technical assistance in changing their farming practices to include conservation tillage, nutrient management plans, cover crop planting, and overall conservation-conscious management schemes. Rural "critical sites" were identified and BMPs installed to fix these problematic areas. Urban residents were informed of the impacts of fertilization, storm water controls, leaf collection, pet waste and other acts that affect water quality in nearby streams. In summary, although data from the project cannot be used to directly quantify gains in water quality with certainty, the Duck, Apple, and Ashwaubenon Creek watersheds certainly benefited from implementation of this program.

Table 2.3. Estimated reductions achieved through DAAPWP projects from 1997-2008. Totals represent reductions in Duck, Apple, and Ashwaubenon Creeks combined. Reduction values were calculated using different methods for Brown and Outagamie Counties (WDNR, 1997; Jolly, 2009; McBurney unpublished March 2009).

Pollutant	Source	Inventory Result†	Reduction Goal†	Brown County Reduction‡	Outagamie County Reduction†	Total Reduction
Sediment	Upland Sediment (tons)	91,475	45,738 (50%)	20,149	28,726	48,875
	Streambank erosion (tons)	7,040	704 (10%)	502	1,503	2,005
	Gully erosion (tons)	1,000	250 (25%)	259	516	775
Phosphorus	Ag Upland / Cropland (lbs)	162,826	81,413 (50%)	44,513	54,726	99,239
	Barnyard Runoff (lbs)	9,034	4,517 (50%)	3,215	5,861	9,076
	Nutrient Management (lbs)	36,563	18,282 (50%)	13,170	8,623	21,793

† Results based on WDNR's WINHUSLE model.
‡ Results based on sediment delivery ratio method.

Agricultural Cropland Survey

A survey was conducted in mid-March of 2009 to compare agricultural practices in the Duck watershed to those of previous years. Twenty-eight road-sites in the watershed were chosen, with the criteria that each road site be within agricultural land-use areas (Figure 2.1). Sites were selected from Arc-GIS maps previously created by Paul Baumgart through the Lower Fox River Watershed Monitoring Program (LFRWMP) that articulated areas of agricultural land-use. All but seven sites had agricultural fields on each side of the road, and these seven sites had agricultural land on one side and either restored wetland, pasture, or residential areas on the opposing side of the road. A location description and GPS coordinates were recorded at each site. For each agricultural field, the previous year's crop, fall tillage practice, and estimated residue cover on a scale of 0-5 were determined from roadside observations.

Previous surveys of the watershed were accessed through the Conservation Technology Information Center (CTIC) Conservation Tillage Reports, and summarized on a watershed basis. These surveys were done in 1996, 1999, 2000, 2002 and 2007. Data in the 1999 and 2000 surveys were combined into one category due to limited data in a portion of the watershed. The 2007 survey was only conducted in Brown County, which encompasses only about 33% of the watershed, and even less of the agricultural land area. Therefore, data from the 2007 survey was not directly comparable to the other surveys. To compare the March 2009 survey with previous surveys of the watershed that classified fields in terms of percent residue cover, the 2009 residue cover estimates were fit into four categories on the basis of percent residue cover: conventional tillage (CT: 0-15%), conventional / mulch tillage (CT / MT: 15-30%), mulch tillage (MT: 30-50%) and no till (NT >50%). Residue data that the CTIC placed into the CT / MT category was distributed equally between the CT and MT categories.

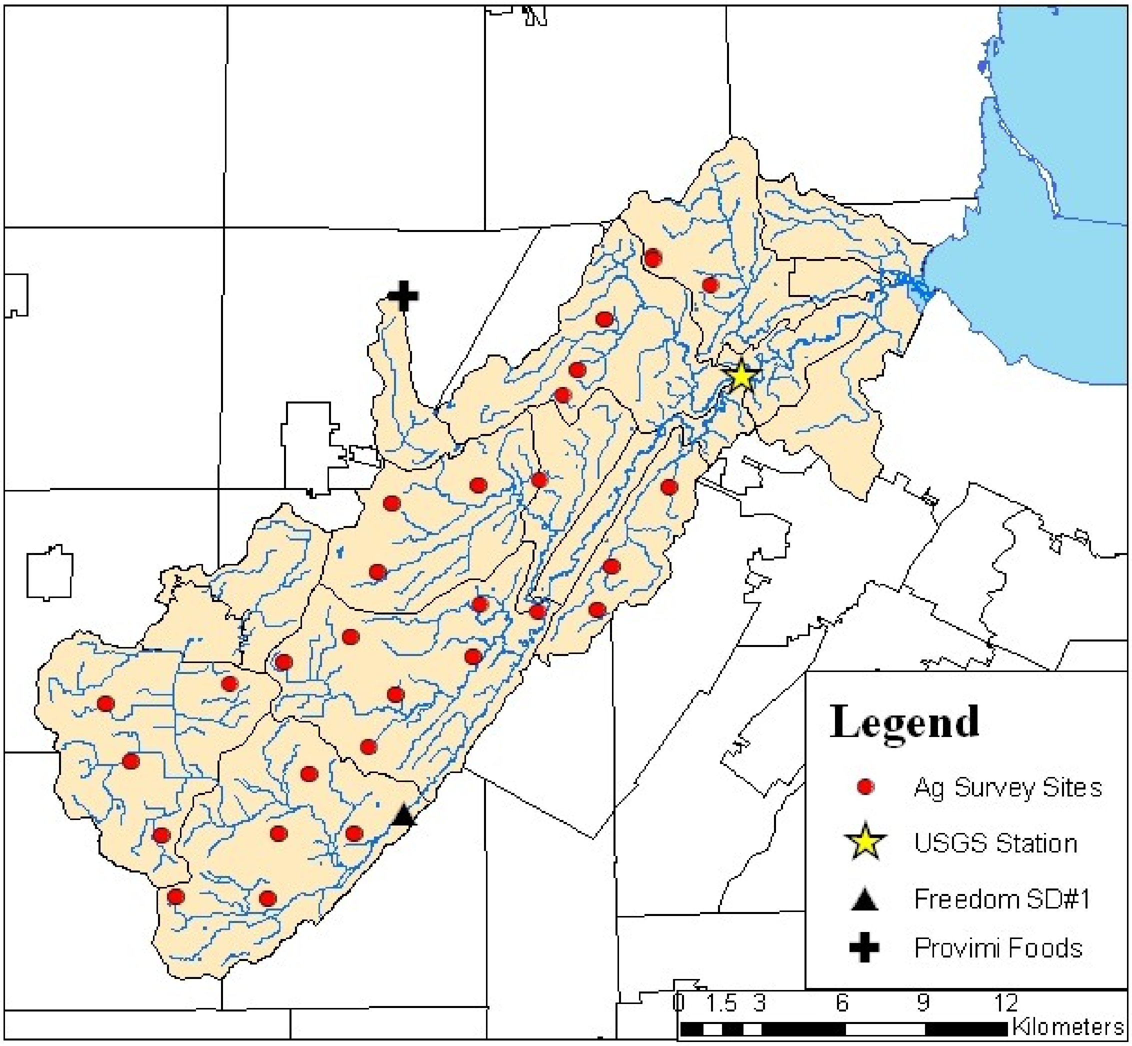

Figure 2.1. Agricultural practice survey sites, permitted point source discharges, and County Road FF USGS monitoring station in the Duck Creek watershed. Agricultural practice survey took place on March 16, 2009.

Overall trends from the surveys indicate an increase in the use of mulch tillage and no till practices, which are sometimes referred to as "conservation tillage" because of the soil and water quality benefits they provide. The results of the survey show that conventional till practices have declined since 1996, with the exception of the year 2002 when 96 percent of the fields in the watershed were classified as having conventional tillage (Table 2.4). This anomaly may be due to changes in tillage practices, crop rotations or market demands, which could have altered which crops were planted and the associated tillage practices used to farm these crops.

Table 2.4. Tillage practices in the Duck Creek watershed, as determined by CTIC (1996, 1999/2000, 2002, 2007) and investigator (2009) transect surveys. The March, 2009 survey was prior to spring tillage and planting, so tillage estimates from this year likely understate the percentage of conventional tillage. The 2007 survey data only includes the Brown County portion of the watershed.

Year	Survey Time	Conventional Till	Mulch Till	No Till	Area
2009	before spring tillage	50.0%	40.9%	9.1%	Duck
2007	after spring planting	68.9%	25.5%	5.7%	Only Brown Cty.
2002	after spring planting	96.0%	4.0%	0.0%	Duck
1999/2000	after spring planting	69.0%	28.8%	2.2%	Duck
1996	after spring planting	74.3%	25.7%	0.0%	Duck

Trends in Dairy Farms

The Program on Agricultural Technology Studies (PATS) at UW-Madison was accessed to gain insight on the trends in dairy farms and cropping trends (PATS, 2009). County and town data from 1989, 1997, and 2000 were accessed via the website, while 2008 data was received from PATS staff (Alan Turnquist, personal communication). To better estimate how this information applied specifically to the Duck Creek watershed the percentages of town, village, or city that resided within the watershed was calculated using Arc-GIS (ESRI, 2009). Town-based dairy numbers from PATS were adjusted by their respective area percentages, with the assumption that dairy farms were distributed evenly throughout the town. In the Duck Creek watershed, the number of dairy farms in Brown County decreased 67 percent from 21 farms in 1989 to 7 farms in 2008, and dairy farms decreased 58 percent from 148 farms in 1989 to 62 farms in 2008 within Outagamie County. As a whole there were 100 fewer dairy farms in the watershed in 2008 compared to 1989, reflecting an overall decrease of 59 percent. At the county level, the total number of dairy cows in Brown County increased 7.9% between 1988 and 2007, while the total number of dairy cows in Outagamie County decreased 19.6% over the same period (USDA, 2009). Most of the reductions (11,500 cows) in Outagamie County occurred prior to 1999.

Agricultural Crop Trends

Potential trends in agricultural cropland between two periods were assessed by comparing differences between the WDNR 1992 WISCLAND land cover image and the USDA NASS 2007 agricultural cropland image (www.nass.usda.gov/research/Cropland/SARS1a.htm). The tabulate areas function in ArcGIS was applied to both images to determine watershed specific cropland areas for all of the watersheds that were upstream of the five LFRWMP monitoring stations. Crop classifications from both raster images were reclassified into three categories: 1) corn; 2) soybean, wheat and other row crops; and 3) forage. Only the results from Duck Creek are reported here. The GIS-derived cropland proportions were checked by applying the same method to the boundaries of both Brown and Outagamie counties, and then comparing the resulting crop proportions to the published statistics for each county and year (USDA, 2009). However, data from Brown County are not included in this report because very little of the Duck Creek watershed above CTH FF is in Brown County. Plus, the eastern WISCLAND scene includes most of Brown County, but it did not include corn as a separate category in the level three land cover classification, just row crops and other row crops.

Results from both of these methods are summarized in Table 2.5 by crop category, year and boundary. The proportion of cropland in corn increased by 9% between 1992 and 2007 in the Duck watershed (upstream of CTH FF); whereas, the proportion of cropland in forage decreased by 7.5%, and the other crops remained nearly the same. The GIS-derived trends between 1992 and 2007 are roughly the same for both the Duck Creek watershed and Outagamie County boundaries. However, statistical data from the NASS for Outagamie County showed a much greater decrease in forage, and a greater increase in soybean, wheat and other crops compared to the GIS-derived estimates for Outagamie County. In addition, the proportion of cropland in corn was greater for the published statistics compared to the GIS-derived estimates for Outagamie County in both 1992 and 2007. Some of these differences may be related to the difference in methodologies between the way the 1992 land cover and 2007 cropland images were classified. Still, the general trend of increasing corn and decreasing forage proportions between 1992 and 2007 is consistent between the different boundaries and methods. All else being equal, this trend may cause an increase in soil erosion because perennial forage crops are more protective of the soil surface than corn, particularly if forage crops like alfalfa are being replaced by corn silage which leaves little residue after harvest.

Table 2.5. Estimated cropland trends between 1992 and 2007 in the Duck Creek watershed upstream of CTH FF (280 km^2), and in Outagamie County. Both GIS-derived estimates (GIS) and USDA NASS statistics (Stats.) show a decrease in alfalfa/forage.

	Corn			**Soybean/wheat/etc**			**Alfalfa/Forage**		
	1992	**2007**	***change***	**1992**	**2007**	***change***	**1992**	**2007**	***change***
Duck watershed at FF - GIS	36.6%	40.0%	*9.2%*	24.3%	23.8%	*-1.8%*	39.1%	36.2%	*-7.5%*
Outagamie County – GIS	38.8%	42.2%	*8.6%*	24.2%	25.0%	*3.2%*	36.9%	32.8%	*-11.1%*
Outagamie County- Stats.	44.6%	47.4%	*6.4%*	18.2%	27.0%	*48.2%*	37.2%	25.6%	*-31.2%*

Oneida Land Use and BMP Implementation

The Oneida Tribe has spent significant resources on improving the Duck Creek watershed. All tribal lands north of State Highway 54 have been buffered, including parts of the Trout Creek, Oneida Creek, and Lancaster Brook watersheds as well as mainstem Duck Creek (Mike Troge, personal communication). The Oneida Nation Farm has implemented a managed intensive rotational grazing plan for beef cattle, with more than 600 acres of pasture. Other management practices include grassed waterways, cattle lanes, stream crossings, roof gutters and grazing paddocks. Throughout the Reservation, over 255 acres of buffers, 266 acres of grassed waterways, and 1070 acres of restored wetlands have been implemented with the intent of enhancing the water quality of nearby streams, benefiting the habitat of native organisms, and providing recreational value for the people of the Oneida Nation (Mike Troge, personal communication).

Nutrient management plans have been implemented for the farmlands owned by the Oneida Tribe, as well as many of the private farms in the Oneida Reservation. Of all the fields under Oneida management in 2002 and 2007, the mean and median soil test phosphorus levels appear to have decreased slightly (Table 2.6). However, in an analysis of available yearly soil test results from all fields under nutrient management, annual mean soil test phosphorus ranged from 22 to 55 ppm between 2001 and 2006. Furthermore, no trend in soil test phosphorus levels could be determined from this analysis of aggregated nutrient management plans supplied from the Oneida Tribe. This lack of trend is most likely due to new fields being acquired each year; plus the same fields were not tested each year for phosphorus content.

Table 2.6. Acreage and soil phosphorus values (Bray P1 in ppm) for Oneida farms in the Duck Creek watershed. Data are based on field values from multiple years as reported in 2002 and 2007 nutrient management plans.

	2002	**2007**
Total Acreage	2,652	5,614
Number of Fields	52	160
Average Field Acreage	51	35
Mean Phosphorus	42	36
Median Phosphorus	30	25
Max Phosphorus	148	161
Min Phosphorus	8	3
Std Dev Phosphorus	31	32
95 Percentile Phosphorus	106	111
90 Percentile Phosphorus	87	78
75 Percentile Phosphorus	54	42
50 Percentile Phosphorus	30	25
25 Percentile Phosphorus	22	15
10 Percentile Phosphorus	12	9

Much of the Oneida's focus has been placed on the Trout Creek watershed. The state farm (~1,200 acres), located near the Sanger B. Powers Correctional Facility in the western basin of the Trout Creek watershed, was a major source of sediment, phosphorus and nitrogen to the stream due to the large cattle herd located there. The Oneida Water Team determined that manure runoff from this herd was the largest stressor to Trout Creek. A manure containment device was placed on the farm in 2002, and all of the banks of Trout Creek were buffered as well. In a before / after study of this project, the Oneida water team monitoring efforts indicated a noticeable decrease in suspended sediments and nutrients as well as a positive shift in the macroinvertebrate communities of Trout Creek (Moren, 2002; Gilmore, 2007). Upstream of the farm, 1850 ft. of the stream was restored to a meandering state in 2003, which slowed down stream flow and allowed for establishment of a diverse community of macroinvertebrates (Snitgen and Melchior, 2008). As part of the restoration of Trout Creek engineered logjams were created at several locations using large woody debris. As the water runs over these logjams, riffles and pools will form. These devices, along with the structures they create, will serve as essential habitat for fish in Trout Creek.

Permitted Point Source Discharges

Although nonpoint sources were identified as the major source of impairments to Duck Creek by the DAAPWP (WDNR, 1997), data was collected from the two permitted point source dischargers located in the Duck Creek watershed and assessed for their potential impact on stream phosphorus concentrations. The Freedom Sanitary District #1 (FSD#1) and Provimi Foods are both located in upstream regions of the watershed (Figure 2.1). The FSD#1 discharges directly into mainstem Duck Creek, while Provimi Foods discharges into an unnamed tributary which flows towards Duck Creek. Data was obtained through the WDNR (Jim Schmidt, personal communication, 2009) for each of these dischargers and compared to recent load estimates calculated by the USGS for Duck Creek. Phosphorus loadings (in kg/year) have declined significantly for both the FSD#1 and Provimi Foods (Figure 2.2). The FSD#1 has decreased annual loads by 68% from 1993 to 2008, while Provimi Foods has reduced annual loads by 98% from 1996 to 2008. The total annual loads at County Road FF averaged 14,800 kg/year from 2004 to 2008, and ranged from 4,900 kg in 2007 to 28,800 kg in 2004. The impact of these point sources in recent years is small, with annual loads from Provimi Foods making up less than 0.5% of the total annual load at County Road FF in 2004-2008, and the Freedom plant only discharging 0.90% to 4.4% of the annual total load during this time. It is likely that these point sources contributed a greater portion (10% or more) of the annual phosphorus load to the creek prior to 1999.

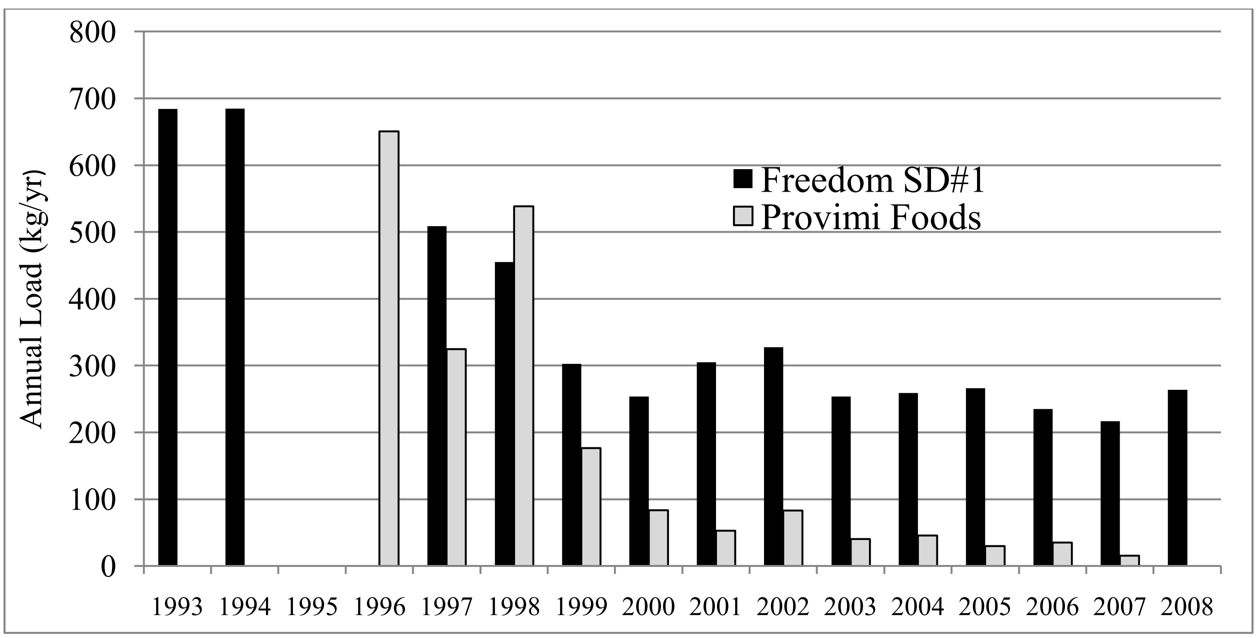

Figure 2.2. Point source phosphorus loads to Duck Creek for the Freedom Sanitary District #1 and Provimi Foods 1993 to 2008 (source WDNR).

Data from the Freedom Sanitary District #1 shows that along with mean annual loads, mean phosphorus concentrations from this discharger have dropped noticeably from the mid to late 1990's, and have fluctuated since then but still display a general decreasing trend. The number of instances that concentrations have reached maximum limits set by Chapter NR 210.05 standards of the Wisconsin Administrative Code (Table 2.7) have dropped considerably from 1999 and, again, show several fluctuations amidst a decreasing trend.

Table 2.7. Annual total phosphorus effluent concentrations from the Freedom Sanitary District #1 Wastewater Treatment Facility 1999 to 2008.

Year	N	Mean (mg/L)	Median (mg/L)	Min (mg/L)	Max (mg/L)	Number of occurrences > 1.0 mg/L
1999	103	1.16	1.15	0.95	1.62	94
2000	102	0.94	0.92	0.70	1.21	19
2001	106	1.00	0.96	0.09	3.80	36
2002	105	0.93	0.82	0.16	2.70	30
2003	104	0.75	0.44	0.02	5.40	23
2004	104	0.67	0.63	0.03	2.50	9
2005	104	0.81	0.61	0.02	3.70	27
2006	104	0.70	0.66	0.21	2.40	9
2007	104	0.63	0.51	0.02	5.40	7
2008	106	0.96	0.62	0.11	34.00	4

Summary

Although the availability of quantitative land management data for the Duck Creek watershed was limited in this study, there have been significant advances in land management that have been documented by numerous entities on a more qualitative basis. Projects such as the DAAPWP made it feasible to implement expensive watershed management practices in the Duck Creek watershed, while some projects targeted actions to restore subwatersheds with specific management goals such as the reintroduction of brook trout in Trout Creek by the Oneida Tribe. A widespread educational effort of farming practices and new legislation to force nutrient management on farms has led to the increased use of conservation tillage and cover crops in the watershed. Consistent with statewide trends in the dairy industry, the number of dairy farms in the watershed has decreased significantly during the last several decades, but the number of cows per farm has increased. With fewer farms, the number of barn yards discharging nutrients and sediment would have also decreased. And finally, point source dischargers have reduced their impact on Duck Creek as well by reducing annual phosphorus loads and mean concentrations from 1993-2008. These changes are likely to have had a positive effect on water quality. In contrast, between 1992 and 2007 the proportion of forage crops such as alfalfa has decreased in the Duck watershed, whereas the proportion of cropland in corn has increased. This change is likely to have had a negative impact on water quality. In Chapter 3 of this document the potential changes in water quality are discussed that have, in part, been influenced by changes in land management practices.

Chapter 3 - DUCK CREEK WATER QUALITY ANALYSIS

Introduction

As discussed in the previous chapter, in the past 20 years there have been substantial efforts to implement BMPs and manage agricultural lands with the goal of protecting water quality in the Duck Creek watershed. In this chapter, the effectiveness of these efforts were evaluated through examination of water quality trends in Duck Creek. A 20 year water quality dataset for a Duck Creek monitoring station was assembled and statistically analyzed to determine if trends in water quality have occurred. Based on an expectation that phosphorus concentrations ought to decrease in response to efforts to improve water quality in Duck Creek, we formulated the following hypotheses to accomplish the objective stated for Research Objective #2(a):

a) Total and dissolved phosphorus concentrations have decreased in recent years compared to the early portion of the water quality record. To test this hypothesis, the null hypothesis H_0 states that phosphorus concentrations either increased or remained the same, and it will be rejected if $p < 0.05$. The alternative hypothesis H_A is that phosphorus concentrations decreased.

b) The fraction of dissolved phosphorus in total phosphorus has not changed. To test this hypothesis, the null hypothesis H_0 states that the dissolved to total phosphorus ratio has remained the same, and it will be rejected if $p < 0.05$. The alternative hypothesis H_A is that the dissolved to total phosphorus ratio has either increased or decreased.

Duck Creek Water Quality Dataset Characteristics

The USGS has collected water quality data from Duck Creek and several tributaries since 1988 and continues today with a gauging station (Station ID# 04072150) located at the County Road FF / Hillcrest Drive bridge located outside of Howard, WI. This station captures 280 km^2 of the 392 km^2 watershed, and is located nearly 11 km upstream from the mouth of Duck Creek. The station on Duck Creek is equipped with several pieces of monitoring equipment. A nitrogen-gas bubbler system is used to measure the water level of the stream. An ISCO 3700R refrigerated automatic sampler (Teledyne Isco, Inc., Lincoln, NE) is used to collect samples at pre-determined criteria, such as defined time intervals or water level heights. Water quality sampling and laboratory analysis of samples at the USGS Duck Creek station have followed methods established by the USGS (Shelton, 1994).

Continuous water-stage and derived discharge have been recorded since the stations inception until present (a 20-year time span), with water quality samples being collected intermittently. Nutrient and suspended sediment sampling intensities have fluctuated throughout the entire monitoring record, likely as a result of funding limitations and varying monitoring objectives and seem to fall into three distinct periods. The sampling protocol for the first period (1989-1995) appeared to be a combination of event-based, low flow and biweekly sampling. Samples collected during the middle period (1996 to 2003) appear to have been primarily collected on a monthly basis. The sampling protocol for the last period (2004-2008) was based on an objective of providing accurate daily loads of TSS and TP, and sampling included a combination of event-based, low flow and biweekly samples (Reckinger, 2007). Sampling and subsequent data analysis during the third period was conducted through the LFRWMP, with funding by the USGS, Oneida Tribe and UWGB.

Of the water quality constituents that were analyzed over the 20-year monitoring record, only total and dissolved phosphorus samples were collected and analyzed at a sufficient frequency throughout the monitored period to conduct statistical trend analysis, and test for differences between sampling periods. Upon analyzing the sediment dataset, it was observed that two methods of suspended sediment analysis were utilized during the 20-year record: total suspended solids (TSS) and suspended sediment concentration (SSC). These data were not utilized to assess long-term trends because: 1) with the exception of 1999, TSS was analyzed only during the third period; 2) only 21 samples were analyzed for SSC in the third period; and 3) although TSS and SSC are both related, their methodologies are different and correlation between the two constituents was not sufficiently strong to substitute one for the other in statistical analysis (R^2=0.505). Distribution of total phosphorus samples, the most regularly sampled parameter during the 20-year monitoring period, can be seen in Figure 3.1.

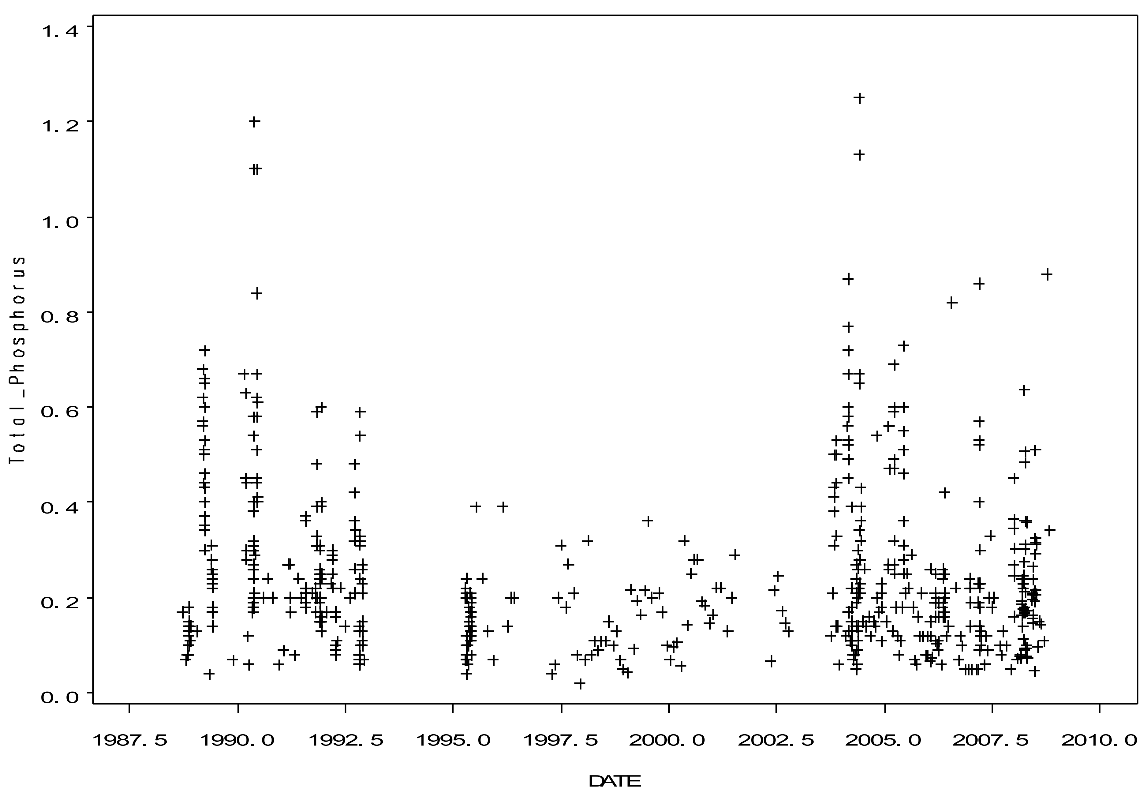

Figure 3.1. Distribution of total phosphorus concentrations (mg/L) in samples collected throughout the 20-year monitoring period (1988-2008). In years 1996-2002, sampling was primarily performed monthly, resulting in fewer samples and no samples of higher concentrations (>0.5 mg/L).

Methodology – Statistical Analysis

The Statistical Analysis Software package (SAS version 9.1.3 © 2002-2003) was utilized to conduct all statistical analysis. Descriptive statistics of the dataset were generated for the 20-year monitoring record and are summarized in Table 3.1. Flow varied widely from periods of no flow to times of extreme event-based flow (3690 cfs). The median TP concentration was 0.20 mg/L with a maximum of 2.79 mg/L. The median dissolved phosphorus (DP) concentration was 0.13 mg/L with a maximum of 0.56 mg/L. The median ratio of DP to TP was 0.78. Maximum TSS and SSC concentrations were roughly 1000 mg/L. Sufficient total phosphorus and dissolved phosphorus samples existed throughout the monitoring period for statistical analysis.

Table 3.1. Simple water quality statistics for samples collected at the USGS monitoring station (ID #04072150) on Duck Creek, 1988-2008.

Variable	N	Median	Mean	Std. Dev.	Min.	Max.	Lower 95% CL for Mean	Upper 95% CL for Mean
Flow (cfs)	7282	6.0	51	153	0.0	3690	47.5	54.5
TSS (mg/L)	267	27	77	136	2.0	956	60.7	93.4
SSC (mg/L)	202	24	58	123	2.0	1080	40.6	74.9
TP (mg/L)	601	0.20	0.28	0.29	0.02	2.79	0.25	0.30
DP (mg/L)	343	0.13	0.16	0.11	0.02	0.56	0.15	0.17
DP / TP	343	0.73	0.68	0.22	0.08	1.00	0.66	0.70

A trend analysis was conducted on total and dissolved phosphorus by using a multiple linear regression model. In order to achieve accurate results with the regression model, various procedures were performed on the dataset to reduce bias. TP outliers (equal to or greater than 1.3 mg/L) were removed from the dataset. Periodically, manual samples and automatic samples were collected at the same time for comparison purposes. These duplicate samples were flagged and subsequently removed. Samples collected during a four month period in 1999 were sampled too frequently to be representative of the sampling regime during that year and contributed disproportionately to serial correlation, so only a single sample per month was kept for analysis. Phosphorus concentrations (both TP and DP) and flow were log-transformed to achieve linearity and normality in the residuals. Flow was transformed in two ways: log-transformed and log of the flow squared (calculated as $[\log(\text{flow})]^2$). All references to log transformed data refer to natural logs, and not base-ten logarithms. Included in the regression analysis were TP and DP as dependent variables and decimal time, log of flow, and log of flow squared as independent variables. Decimal time served as the independent time trend variable of interest, whereby a regression slope for this variable that was significantly different than zero indicated a probable change in the dependent variable over time. For example, if the regression coefficient for decimal time wass negative, and significantly different than zero, then TP or DP were decreasing over time. Decimal time is just the annual date, plus a decimal fraction that represents the time of year (e.g., 1995.4959 is June 30, 1995, or 1995 plus 181/365 days). Flow was included in the regression analysis as an independent variable to account for potential changes in DP and TP that were related to flow. Including flow and other potential exogenous variables in the regression analysis serves to reduce model error and increase the ability of the regression model to detect a trend over time. Sine and cosine functions were included in the regression equation as independent variables to account for seasonal differences in the phosphorus concentrations in the manner recommended by Helsel and Hirsch (1992). Finally, the Cp selection method was utilized to select the best regression model that described the dependent variables over time. The Cp statistic explains as much variation in the independent variable as possible by including all relevant variables. It also minimizes the number of coefficients, which helps to reduce the variance in the estimate (Helsel and Hirsch, 1992).

Multiple Linear Regression Results - Trends

To simplify presentation of the results, only the results from the most meaningful regression equations are included in this report. Other regression equations were generated but not included in this report, often because further analysis indicated that the equations violated the assumptions inherent to linear regression analysis such as normality of residuals. A detailed account of the entire procedure can be found in Cibulka (2009).

The selected regression equation format comes from one of the default options defined in the load estimator program LOADEST (Runkel et al., 2004). In this equation, steps are taken to eliminate collinearity. Collinearity occurs when two or more variables in a multiple regression are highly correlated. For example, if streamflow and precipitation are used as variables in the same regression, the results may be inaccurate because streamflow and precipitation are highly related to each other. Runkel et al. (2004) suggests centering explanatory variables to reduce this problem. In the centering process the center of the independent variable, as defined by Cohn et al. (1992), is subtracted from the original values. The result is a "centered" model. The LOADEST model centers the flow as well as time (in decimal format). The regression equation is as follows:

$$\text{LN-constituent} = a0 + a1\ \text{LN\_Q} + a2\ \text{LN\_Q}^2 + a3\ \text{SIN}(2\pi\text{DEC\_TIME}) + a4\ \text{COS}(2\pi\text{DEC\_TIME}) + a5\ \text{DEC\_TIME}$$

Where a0 is the intercept, a1 to a5 are the regression parameters of each of the independent variables, LN_Q is the log of flow, LN_Q^2 is the log of flow squared, DEC_TIME is decimal time, SIN_DAY and COS_DAY are the sine and cosine curves that describe the seasonal phase shift, and LN-constituent is the natural log transformed constituent of interest (e.g., LN_TP, LN_DP). This equation also coincided with the equation that was chosen as the best equation by the Cp selection method in SAS.

Regression Analysis over the 20 year monitoring record

Initially, the regression models that were applied over the entire monitoring period appeared to be good predictors of log-transformed TP and log-transformed DP concentrations. The adjusted R^2 value for the TP and DP models was 0.34 and 0.23, respectively. The model estimated an apparent decrease of 2% per year for TP and 3% per year for DP over the 20-year period. The slope of decimal time was significantly different than zero, with $P<0.0001$ for both models. However, an analysis of the residuals (error between predicted and observed) found that the TP and DP regression models violated key assumptions that are a prerequisite to valid linear regression models. The data shown in Figure 3.2 seems to show a fairly sharp downward trend in TP concentrations during the first period, followed by a leveling off period, and then a potential decrease during the last year of the third period. A similar change was observed with log-transformed DP. The relationship between TP and DP concentrations over time was not stationary. Consequently, the regression models were not valid when applied over the entire 20 year record.

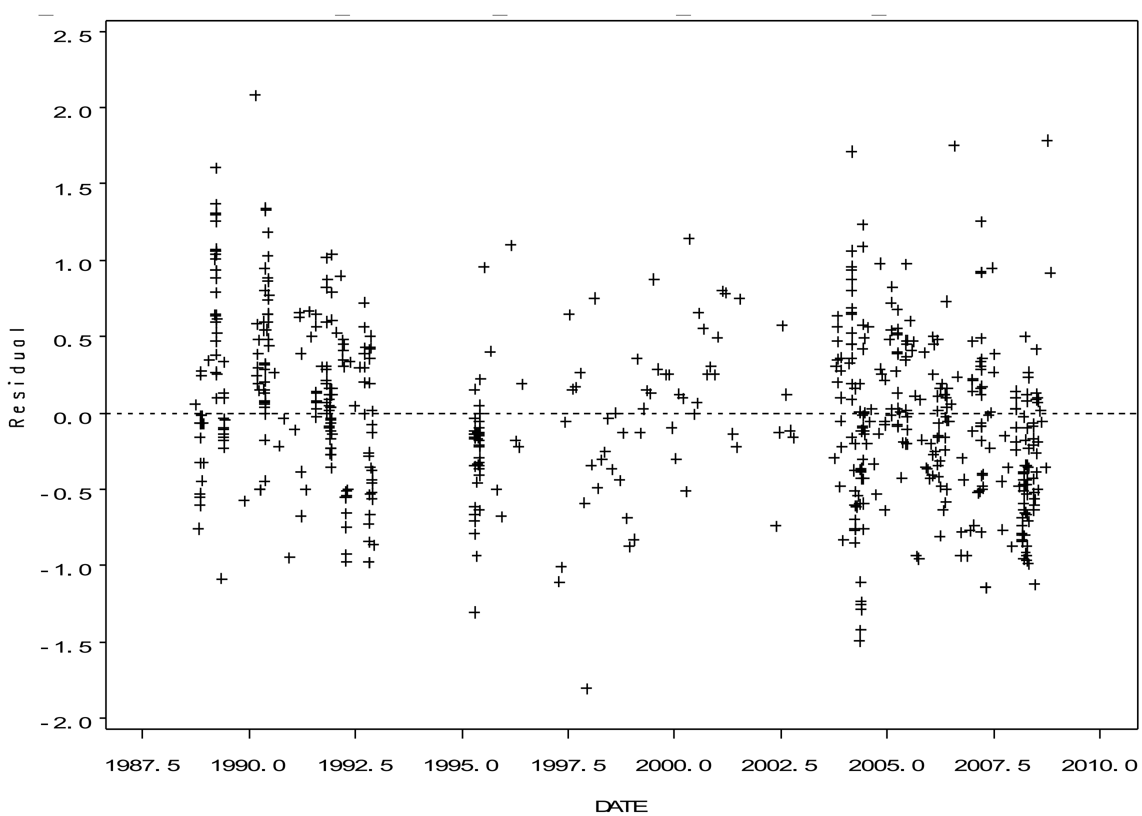

Figure 3.2. Flow and seasonally-adjusted residuals of log-transformed TP during the 20-year USGS monitoring record (USGS water years 1989-2008).

Period-Specific Regression Analysis

The linear regression models were rejected when applied over the entire monitoring record largely because the apparent trends seemed to take place primarily within the first period rather than a steady decline over all periods. Therefore, potential trends within the 20-year dataset were examined by applying the same regression model to Period 1(1989-1995) and Period 3 (2004-2008). Parameter estimates for the TP and DP regression models are summarized in Table 3.2 for Period 1. In Period 1, decimal time was a highly significant explanatory variable for log-transformed TP concentrations ($p < 0.0001$). The slope was much greater (-0.1044) than for the 20 year regression model, indicating a greater decrease in TP concentrations of about 10% per year over Period 1. Concentrations of log-transformed DP saw a significant decrease ($p=0.0001$) as well. The slope was larger (-0.11421) than the 20 year regression model, which translates to an 11% decrease in DP concentrations per year over Period 1. The adjusted R^2 values for the log transformed TP and DP regression models were 0.38 and 0.37, respectively. Both models were highly significant ($p < 0.0001$).

Residual trends for flow and seasonally-adjusted log-transformed TP and DP concentrations are plotted for Period 1 in Figures 3.3 and 3.4. Residuals, or model error, essentially remove the effect of flow and seasonality on log-transformed TP and DP concentrations. Therefore, the residuals express the variation in log-transformed TP and DP over time, over and above the variation due to flow and seasonality (Helsel and Hirsch, 1992). If there were no change in phosphorus concentrations over time, the residuals of the flow and seasonally-adjusted phosphorus regression models would show no apparent trend over time because the residuals would be evenly distributed along the zero axis. However, Figures 3.3 and 3.4 show a clear downward trend over time, rather than a parallel cluster along the zero axis. Therefore, time is an important explanatory variable to include in the regression models. Figure 3.5 shows the relationship between the observed and predicted log-transformed TP concentrations, where the predicted values are based on the five parameter regression model which includes LN_Q, LN_Q^2, SIN_DAY, COS_DAY and DEC_TIME. Most of the points in Figure 3.5 lie within a uniform, but relatively loose cluster indicating that the regression model was able to reasonably predict log-transformed TP concentrations.

Table 3.2. Regression model estimates, standard errors, and P-values of the coefficients in the Duck Creek log-transformed total phosphorus (LN_TP) and dissolved phosphorus (LN_DP) regression models for Period 1 (USGS water years 1989-1995).

		Intercept (a0)	**LN_Q (a1)†**	**LN_Q^2 (a2)**	**SIN_DAY (a3)**	**COS_DAY (a4)**	**DEC_TIME (a5)‡**	**N**
LN_TP	**Coefficient (a0 to a5)**	-1.80091	0.20243	0.0264	0.18764	-0.22828	-0.10439	243
	t-value	-40.38	9.49	3.47	3.31	-3.85	-6.12	
	std error	0.0446	0.0213	0.0076	0.0568	0.0594	0.0171	
	VIF§		1.37	1.11	1.34	1.74	1.13	
	P value	*<.0001*	*<.0001*	*0.0006*	*0.0011*	*0.0002*	*<.0001*	
LN_DP	**Coefficient (a0 to a5)**	-2.11239	0.10258	0.03534	0.0716	-0.21273	-0.11421	177
	t-value	-38.13	3.74	3.63	0.95	-3.17	-5.82	
	std error	0.0554	0.0274	0.0097	0.0752	0.0670	0.0196	
	VIF		1.27	1.09	1.47	1.23	1.13	
	P value	*<.0001*	*0.0003*	*0.0004*	*0.3422*	*0.0018*	*<.0001*	

† LN_Q was centered by subtracting 3.38 and 3.605 from the actual LN_Q for the LN_TP and LN_DP regression models, respectively.
‡ DEC_TIME was centered by subtracting 1992.242 and 1992.5 from the actual DEC_TIME for the LN_TP and LN_DP regression models, respectively.
§ VIF = variance inflation factor

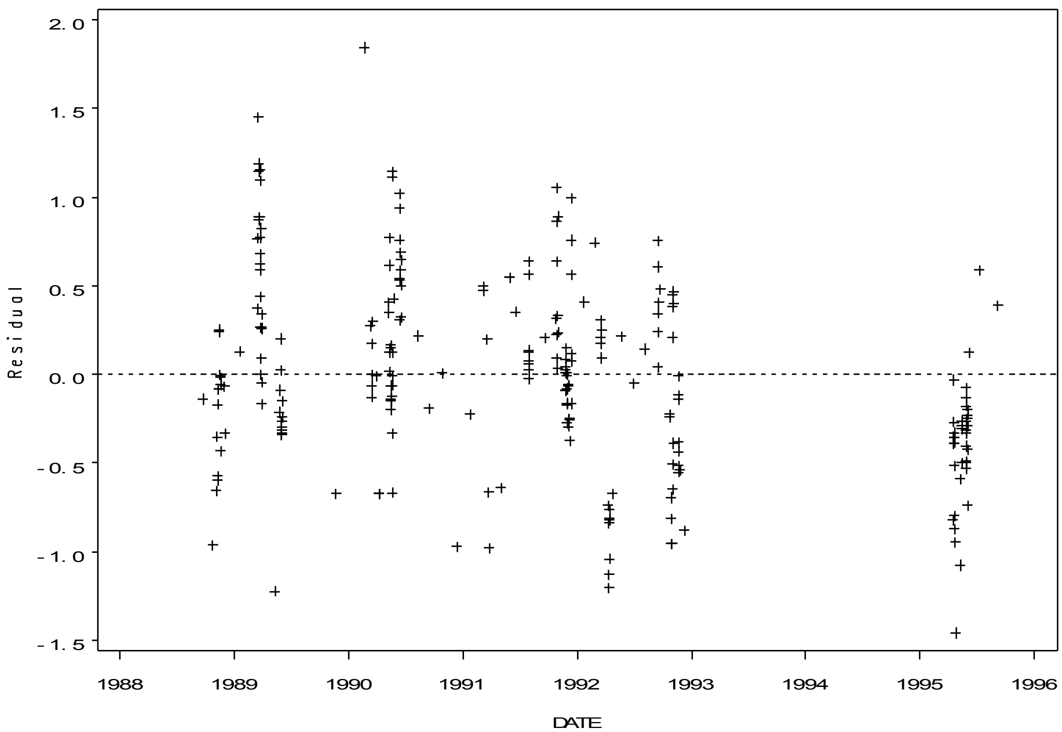

Figure 3.3. Decreasing trend of flow and seasonally-adjusted residuals of log-transformed total phosphorus during Period 1 (USGS water years 1989-1995).

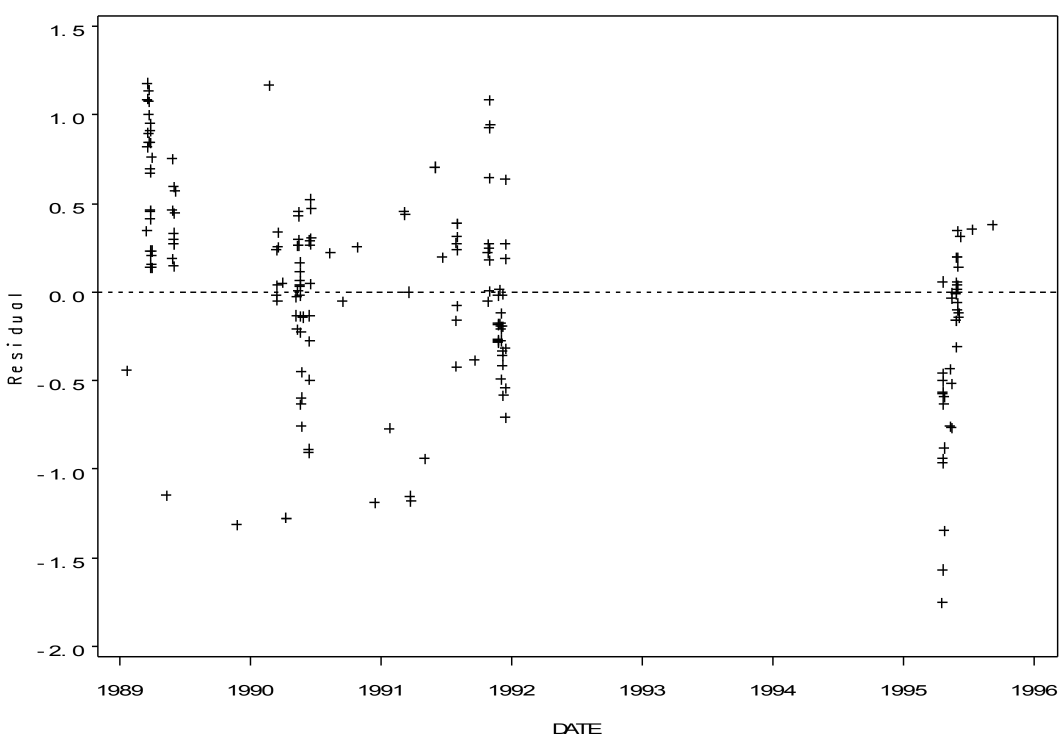

Figure 3.4. Flow and seasonally-adjusted residuals of log-transformed dissolved phosphorus during Period 1 (USGS water years 1989-1995).

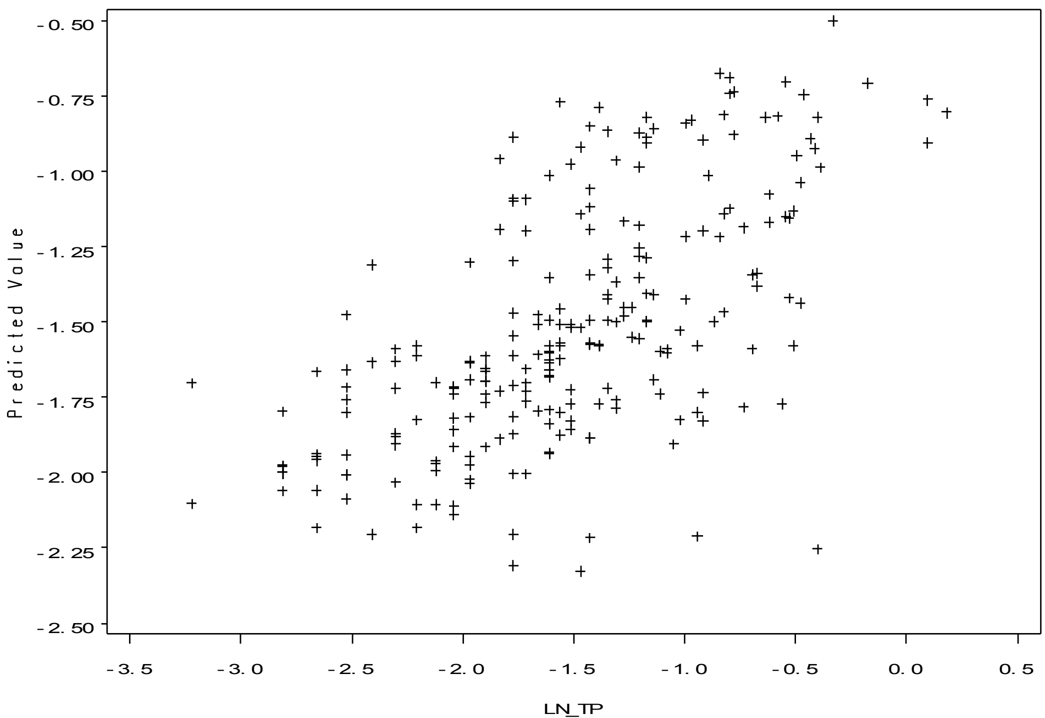

Figure 3.5. Observed and predicted log-transformed total phosphorus (LN_TP) concentrations during Period 1 with the selected best fit regression model (adjusted $R^2 = 0.38$). Pattern indicates regression model reasonably predicts TP concentration in Period 1.

To test how sensitive the regression model was to changing the range of data included during Period 1, data from some of the years was added or removed to see if there was a substantial change in the regression model coefficients and level of significance. In addition, there was a gap in the data during the first period because phosphorus was not analyzed from 1993 or 1994, so the data set was not continuous. Overall, only small changes were observed with regards to decimal time, slope or level of significance when 1995 data was excluded, or when data from 1996, 1996-1997, and 1996-1998 data were added. The latter ranges were also added, but without the 1995 data. Again, little change was observed; thereby increasing confidence in the observed trend of decreasing log-transformed TP.

In Period 3, two regressions were run. An initial regression model was conducted without data from 2008. Following formal certification of the data by the USGS, the new dataset which included 2008 was modeled. The initial model showed no significant decrease of log-transformed TP concentrations over time (p=0.786). However with the 2008 data, the results changed dramatically. Decimal time became a significant explanatory variable (p=0.0007), and model results indicated a fairly large decrease in TP concentrations. Similar results were found for log-transformed DP, although the results when 2008 data was removed came close to showing a significant decrease with time (p = 0.084). Because the two regressions run on the third period show dramatically different results, the 2008 data may be an outlier. Indeed, graphical analysis of the flow and seasonally-adjusted residuals of log-transformed TP and DP showed no decrease until 2008. There were about as many TSS samples as TP samples in the third period, so the same regression model was applied, but with log-transformed TSS as the dependent variable. The results were even more pronounced as TSS concentrations remained fairly level until there was an abrupt decline in 2008. It is not likely that this decrease is related to recent implementation of BMP's because the expected effect on a watershed the size of Duck Creek should not be so sudden. It seems more likely that this apparent decrease is related to the rain-less large snow melt event in 2008, sampling bias or other factors. We therefore conclude that we were unable to detect a decreasing trend in log transformed TP or DP concentrations in Period 3. A detailed explanation is provided in Cibulka (2009).

Further Investigation

Period 1 vs Period 3 Comparison: non-parametric tests

The results from the regression analysis strongly suggest that phosphorus concentrations have decreased from Period 1 to Period 3. To further verify the regression results, the non-parametric Wilcoxon Rank sum test was applied to compare the first and third periods with regards to TP, DP, DP/TP and flow. When all data were included in the analysis, TP ($p=0.049$) and DP ($p<0.0001$) concentrations were found to be significantly lower in Period 3. These results are summarized in Table 3.3 under the second column (all flows, all years).

The flow associated with samples was significantly different between the first and third periods (Wilcoxon Rank sum test, $p<0.0001$) for the data subsets, with the third period having greater flow than the first period. This result does not conflict with the finding that phosphorus concentrations were lower in the third period, because TP is correlated with flow ($r=0.43$ for the first period, $r=0.46$ for the third period). So, as flow increases, phosphorus concentrations should generally increase as well. In this situation, both TP and DP concentrations are decreasing from periods one to three, while the flow associated with their sampling is increasing. Therefore, the small but significant difference in flows associated with the samples from the two periods seems to simply support the previous evidence for decreasing phosphorus concentrations. However, high flows in the third period could also be the result of relatively clean snow melt or groundwater recharge, which might tend to dilute phosphorus concentrations in the stream.

To determine how sensitive these results might be to potential outliers or non-representative dataset, the non-parametric Wilcoxon Rank sum test was performed on phosphorus data with regards to various flow and data-censoring scenarios for the following reasons. As shown in Figure 3.6, the distribution of stream flow was different between periods one and three. There were only 7 samples collected when flow was greater than 1,000 cfs in Period 1 compared to 23 samples in Period 3. The proportion of samples collected with flows less than 75 cfs were also greater in Period 1 compared to Period 3. The distribution of collected samples and their respective flows can be seen in Figure 3.7. In this graph, the low-flow Period 2 samples are easily distinguished from the moderate flow Period 1 and the relatively high-flow Period 3 samples. This phenomenon is likely due to a difference in sampling protocols.

The previous regression analysis showed that a substantial decrease in phosphorus concentrations occurred by 1995. The sharp decrease during Period 1 may indicate that 1995 is at the end of this apparent change. In addition, there were no samples collected during 1993 and 1994, so there was a significant break in the data record. Due to the sharp drop-off in phosphorus concentrations in 1995, data from 1995 was omitted in all but one of the period comparison scenarios because data from 1995 might be better categorized as belonging with data from an extended leveling off period, which includes Period 2 and Period 3.

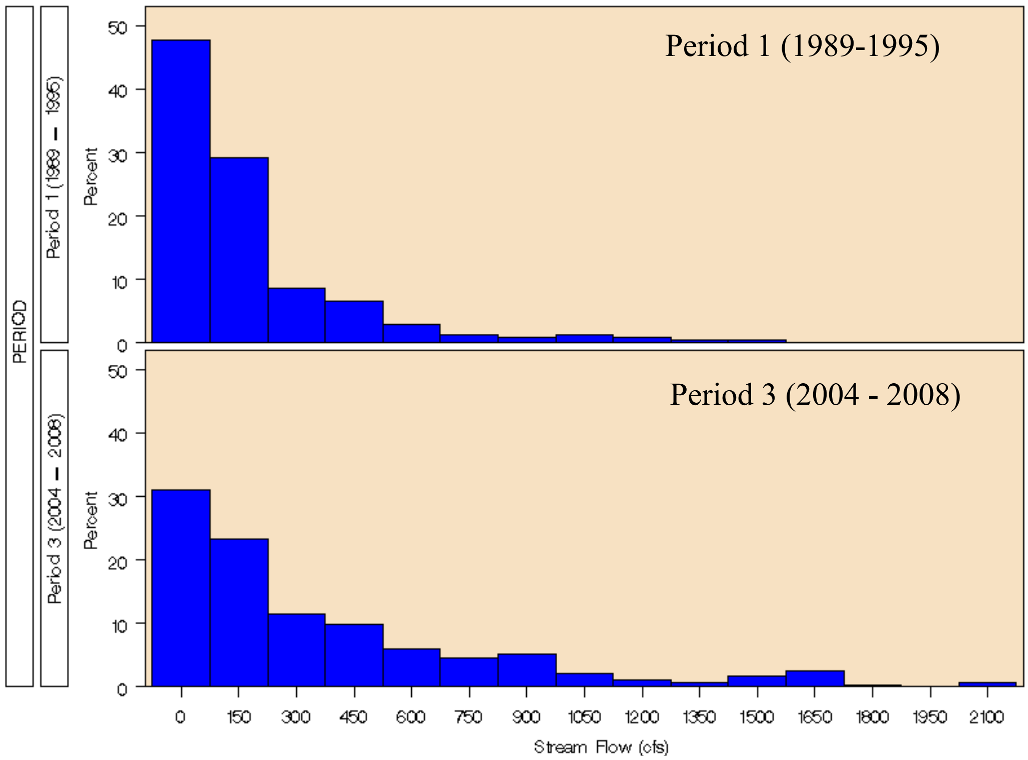

Figure 3.6. Histogram of stream flow during phosphorus sampling between periods one (1989-1995) and three (2004-2008). Proportionally fewer samples were taken at higher flows (>675 cfs) during Period 1, while fewer samples were collected at low flow (<75 cfs) during Period 3.

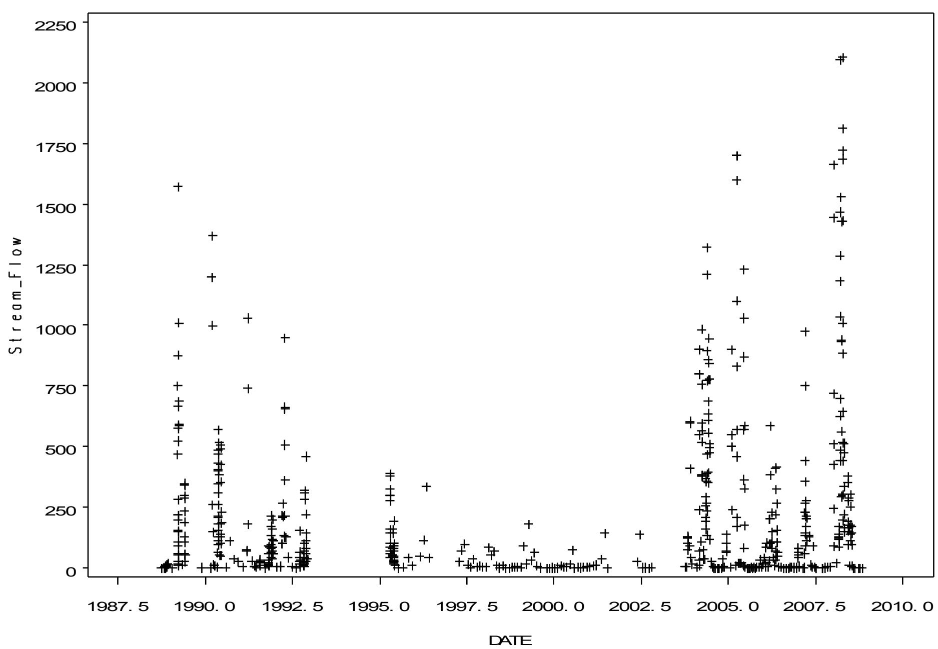

Figure 3.7. Measured stream flow (cfs) during phosphorus sampling from 1988-2008 at the Duck Creek USGS monitoring station. Three distinguishable periods are apparent, which coincide with different sampling protocols.

Wilcoxon Rank sum test results are summarized in Table 3.3 for various flow and water year censoring scenarios which were created to analyze the difference between phosphorus concentrations during Period 1 and Period 3 under several flow regimes, and with the removal of year 1995 data. Under all of these scenarios, the concentrations of both TP and DP were significantly greater in Period 1 compared to Period 3 ($p < 0.05$). The DP/TP ratio was essentially not significantly different between the two periods ($p > 0.05$), although it was barely significant for the particular situation where data from all flow scenarios was included, but data from 1995 was excluded from the analysis ($p = 0.048$). Therefore, the analysis indicates that DP/TP ratios have not changed significantly.

Table 3.3. Non-parametric Wilcoxon Rank sum test (t-approximation) for several constituents under different flow and data censoring scenarios: Period 1 vs Period 3. Flow scenarios (in cfs) were created to account for differing sampling protocols and unusual weather events that occurred over the 20-year record. All flow scenarios omit water-year 1995, except the column labeled "All Years". NOTE: P1 indicates Period 1 (USGS water years 1989 to 1995), P3 indicates Period 3 (USGS water years 2004 to 2008). To reflect the different null hypotheses, statistical tests for TP and DP were one-sided, whereas tests for DP/TP and flow were two-sided.

	All Flow	**All Flow**	**Flow < 1000**	**Flow < 750**	**Flow < 500**	**Flow < 250**	**Flow < 75**	**Flow > 75 and < 750**	**Flow > 75 and < 750 without 2008**
Variable	**All Years**	**------ without data from 1995 ------**							
TP	P1>P3 p=0.049	P1>P3 p=0.0015	P1>P3 p=0.0003	P1>P3 p=0.0001	P1>P3 p=0.0001	P1>P3 p=0.0001	P1>P3 p=0.0026	P1>P3 p<0.0001	P1>P3 p=0.0031
DP	P1>P3 p<0.0001	P1>P3 p<0.0001	P1>P3 p<0.0001	P1>P3 p<0.0001	P1>P3 p<0.0001	P1>P3 p<0.0001	P1>P3 p<0.0019	P1>P3 p<0.0001	P1>P3 p<0.0001
DP/TP	P1=P3 p=0.059	P1>P3 p=0.048	P1=P3 p=0.098	P1=P3 p=0.450	P1=P3 p=0.996	P1=P3 p=0.99	P1=P3 p=0.84	P1=P3 p=0.082	P1=P3 p=0.15
Flow	P3>P1 p<0.0001	P3>P1 p<0.0001	P3>P1 p<0.0001	P3>P1 p<0.074	P3>P1 p<0.017	P3=P1 p=0.9	P1>P3 p=0.0003	P1=P3 p=0.18	P1=P3 p=0.24
N for TP	243 – P1 288 – P3	205 288	199 264	196 237	182 210	157 167	98 89	97 148	97 102

Mid-Month and Mid-Week Sub-Sampled Statistical Comparison

When sampling frequency is relatively high, serial correlation amongst samples from hydrologic data such as the Duck Creek data set can pose problems because the samples are not likely to be independent of one another; thereby, violating a key assumption of most statistical tests. The Durbin-Watson test is a common method used to check a model for serial correlation (Draper and Smith, 1998). The Durbin-Watson statistic was significant for all of the aforementioned regression models indicating that some degree of serial correlation is influencing the results. However the 1st order autocorrelation values were moderate rather than strong for the LN_TP (0.499) and LN_DP (0.414) Period 1 regression models, suggesting that the highly significant regression models may still be valid

To reduce potential serial correlation to a minimum, the full data set was sub-sampled on a once/month basis whereby only a single sample collected closest to the middle of each month was retained for further statistical analysis. The median TP concentration of this sub-sampled data set was 0.18 mg/L during Period 1 compared to 0.13 mg/L during Period 3 (n = 43 and 53, respectively). The median DP concentration of the sub-sampled data set was 0.14 mg/L during the Period 1 compared to 0.09 mg/L during the Period 3 (n = 43 and 54, respectively). The non-parametric Wilcoxon Rank sum test was performed on the sub-sampled data set to test for differences in TP and DP concentrations, DP/TP ratio and flow between Period 1 and Period 3. The results of this analysis are summarized in Table 3.4. The concentrations of both TP and DP were found to still be significantly greater in Period 1 compared to Period 3 (p = 0.023 for both; one-sided tests using the normal approximation). The median flow of this sub-sampled data set was 18 cfs during Period 1 and 4.9 cfs during Period 3; and the mean flows were 102 cfs and 97 cfs, respectively. However, the flow was not significantly different between the two periods (p = 0.143; two-sided tests with normal approximation). Similar results were found when data from 1995 were excluded from the first period, as was done in the previous section. The concentrations of both TP (p = 0.0337) and DP (p = 0.0249) were still significantly greater in Period 1 compared to Period 3 (both one-sided tests with normal approximation). The ratio of DP to TP was not significantly different between Period 1and Period 3 for the sub-sampled data set, with or without data from 1995 (p > 0.8, two sided test with normal approximation).

The full data set was also sub-sampled on a once/week basis whereby only a single sample collected closest to the middle of each week was retained for further statistical analysis. The results of this analysis were similar to the mid-month analysis, except the significance levels were improved for TP and DP primarily because of the larger data set (Table 3.4). The concentrations of both TP and DP were again significantly greater in Period 1 compared to Period 3 (p = 0.012 and p = 0.002, respectively; one-sided tests with normal approximation).

Regression analysis was also performed on the monthly sub-sampled data sets with the same five parameter regression model that was used earlier. Decimal time was not a significant explanatory variable for log-transformed TP or DP, for either Period 1 (p = 0.557, 0.789) or Period 3 (p = 0.874, 0.149). This result is contrary to that found for the whole data set. One possible explanation is that the number of samples is simply too low to provide enough statistical power given the variability of the TP and DP data. Regression analysis was then performed on the weekly sub-sampled data sets with the same regression formula that was used earlier. Decimal time was not a significant explanatory variable for log-transformed TP for either Period 1 (p = 0.350) or Period 3 (p = 0.168). Decimal time was a significant explanatory variable for log-transformed DP for Period 3 (p = 0.022), but not for Period 1 (p = 0.213). However, when data from 2008 were excluded from Period 3 for reasons stated earlier, decimal time was no longer a significant explanatory variable for either the five parameter log-transformed DP regression model (p = 0.104) or a two parameter regression model (p = 0.056) with only LN_Q and DEC_TIME as independent variables.

Table 3.4. Non-parametric Wilcoxon Rank sum test (t-approximation) of TP, DP, DP/TP and flow data between Period 1 and Period 3. Data were sub-sampled under a once-per-month and once-per-week basis to increase independence between samples and to reduce serial correlation. USGS water-year 1995 was omitted from some of the analysis for comparison purposes. NOTE: P1 indicates Period 1 (USGS water years 1989 to 1995), P3 indicates Period 3 (USGS water years 2004 to 2008). Significant results are in bold. To reflect the different null hypotheses, statistical tests for TP and DP were one-sided, whereas tests for DP/TP and flow were two-sided.

		Mid-month			**Mid-week**		
		Median & number of samples		**Wilcoxon Rank-Sum**	**Median & number of samples**		**Wilcoxon Rank-Sum**
Variable		**Period 1**	**Period 3**	**Test**	**Period 1**	**Period 3**	**Test**
TP (mg/L)	with 1995	0.18 mg/L n = 43	0.13 mg/L n = 53	**P3 < P1** **p = 0.023**	0.20 mg/L n = 68	0.14 mg/L n = 121	**P3 < P1** **p = 0.012**
	without 1995	0.19 mg/L n = 38	same	**P3 < P1** **p = 0.034**	0.20 mg/L n = 60	same	**P3 < P1** **p = 0.009**
DP (mg/L)	with 1995	0.14 mg/L n = 28	0.09 mg/L n = 23	**P3 < P1** **p = 0.023**	0.14 mg/L n = 45	0.10 n = 59	**P3 < P1** **p = 0.002**
	without 1995	0.14 mg/L n = 23	Same	**P3 < P1** **p = 0.025**	0.15 n = 37	Same	**P3 < P1** **p = 0.0006**
DP/TP ratio	with 1995	0.72 n = 28	0.74 n = 23	P3 = P1 p = 0.81	0.74 n = 45	0.73 n = 59	P3 = P1 p = 0.91
	without 1995	0.75 n = 23	Same	P3 = P1 p = 0.93	0.75 n = 37	Same	P3 = P1 p = 0.83
Flow (cfs)	with 1995	18 n = 43	4.9 n = 53	P3 = P1 p = 0.15	35.5 n = 68	18 n = 121	P3 = P1 p = 0.25
	without 1995	22.5 n = 38	Same	P3 = P1 p = 0.12	33.5 n = 60	Same	P3 = P1 p = 0.22

Trend Analysis Summary

The results from five statistical procedures that were applied to examine the USGS Duck Creek dataset for trends in TP and DP are summarized below:

- A 20-year multiple linear regression trend analysis was performed with TP and DP water concentrations. However, the results were deemed invalid because the observed declines occurred in a non-linear fashion, primarily during the first period, thereby violating assumptions inherent to linear regression analysis.
- A multiple linear regression trend analysis was conducted on Period 1 (1989-1995) and Period 3 (2004-2008) within the 20-year dataset. This test found that TP concentrations decreased 10% per year and DP concentrations decreased 11% per year in Period 1. A decrease in TP and DP concentrations was observed in Period 3 only when data from 2008 was included. However, further analysis indicated that it is more likely that this decrease was due to unusual climate or sampling problems in 2008, rather than an abrupt change in the watershed between 2007 and 2008.
- A Wilcoxon Rank sum test was applied to TP and DP concentrations between Periods 1 and 3 under a variety of data censoring and flow scenarios. In all cases, TP and DP concentrations were significantly lower in Period 3 than in Period 1 ($p < 0.05$). In general, the DP/TP ratio was not significantly different between the two periods.
- A Wilcoxon Rank sum test was performed on a subset of data that was based on one sample per month, taken in the middle of the month to reduce potential serial correlation bias. This test found that TP and DP concentrations were significantly lower in Period 3 compared to Period 1 ($p < 0.05$). Similar results were obtained for TP and DP concentrations when the data set was sub-sampled on a once per week basis ($p < 0.05$). The DP/TP ratio was not significantly different between the two periods ($p > 0.80$).
- A multiple linear regression analysis was performed on the monthly and weekly sub-sampled data sets. Decimal time was not a significant explanatory variable for log-transformed TP or DP, for either Period 1 or Period 3 (excluding data from 2008).
- Overall, the weight of evidence from the statistical analyses is sufficient to conclude that it is likely that TP and DP concentrations have decreased during the 20-year record.

Discussion

Statistical methods to analyze long-term water quality trends are becoming more robust and more common as monitoring datasets grow. They are, however, not without complex problems that may lead to misinterpretation of results. It was discovered during this investigation that point sources are likely not contributing towards a decreasing trend in Duck Creek phosphorus concentrations. Beyond removing this potential contributing factor, other factors influencing water quality statistical trend analysis are many and quite complicated. They may include natural variability, management practices of different degrees, and seasonal and climatic variations (Johnson et al., 2009). The time lag between watershed changes and water quality effects is often difficult to identify as well. Richards et al. (2008) report that changes occurring within 5 years of land-use management efforts should be ignored in trend detection studies due to the aforementioned factors. Landers (2005) suggests that datasets reflect at least 10 years of monitoring to adequately assess if watershed changes are responsible for a given water quality trend. The 20-year monitoring record also experienced factors such as changing sampling regimes, changing sampling methods, and several years in which no monitoring took place. Although these considerations may have complicated the procedures, a robust statistical analysis was able to be performed.

The 20-year Duck Creek water quality dataset was scrutinized in a variety of ways to account for some of the recognized factors that may bias the trend analysis. What started as a relatively straightforward 20-year trend analysis quickly evolved into a comprehensive investigation in which several statistical tests were used to analyze micro trends occurring within the larger dataset. Four out of the five statistical procedures that were applied indicated that TP and DP concentrations have decreased over the 20-year record, primarily within Period 1 of this timeframe. This conclusion does not mean that phosphorus concentrations decreased solely during Period 1; only that there was insufficient evidence to conclude that a significant decrease in phosphorus concentrations occurred after Period 1.

Chapter 4 - BIOLOGICAL INTEGRITY OF THE DUCK CREEK WATERSHED

Introduction

The stated objective of the Clean Water Act is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C. § 1251 (a), CWA § 101(a)). Title I of the act lists the protection of aquatic organisms as a major goal, stating that:

> "It is the national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water be achieved..."

Thus, there is a legal basis for ensuring the waters of the Duck Creek watershed are hospitable to aquatic organisms. The CWA is based upon years of research on aquatic systems which has identified pollutants and their impacts. Two of the most researched pollutant areas have been nutrient and sediment input.

Phosphorus and nitrogen are considered critical because as "limiting" nutrients they control photosynthesis in aquatic systems. As these nutrient concentrations increase, they stimulate phytoplankton and aquatic macrophyte growth. Excessive nutrients can lead to excessive organic material, which leads to an increased oxygen demand as microbes decompose the material. Thick mats of phytoplankton or macrophytes may also disrupt vertical mixing of aquatic systems, reducing oxygen in this manner. The results of lowered dissolved oxygen can be detrimental to aquatic organisms. In a study examining nutrient concentrations on stream biotic communities (periphytic diatoms, macroinvertebrates, and fish), Robertson et. al. (2006) found that nutrient concentrations are important in controlling the biotic health of streams. Specifically, their study suggests that phosphorus has more control over the health in biotic communities than nitrogen.

Sedimentation in aquatic systems is considered one of the greatest causes of water quality impairment by the USEPA (2003). Besides the aesthetic impairments that result from excessive suspended sediment (turbidity,) the pollutant can clog filtration mechanisms in invertebrates, impair ingestion rates in mussels, reduce available light for aquatic macrophytes, interfere with physiological functions in fish, as well as alter aquatic habitat and nesting sites (Berry et al., 2003). The effects of organic matter, nutrient and sediment pollution on aquatic organisms have been extensively researched (e.g., Lyons 1992; 2006) and methods to quantitatively describe these impacts have been developed. In this chapter, trends in the biological integrity of Duck Creek are statistically and quantitatively investigated using a variety of established methods. Fish and macroinvertebrates, two biological indicators of environmental stress, have been surveyed by numerous entities in the Duck Creek watershed. Data from these surveys were collected and analyzed for temporal trends that may have occurred in these sensitive biological communities.

Biological Indices

Biological Assessment of Fish Communities

The term "healthy" biotic community may seem somewhat arbitrary if not defined. For the purpose of management goals, standardized methods of assessing biological communities have been developed for numerous aquatic communities (e.g., Lyons, 1992; 2006; others). In 1986, Karr et. al. (1986) developed a method to measure the biological integrity of fish communities in Midwestern U.S. streams. Karr's Index of Biological Integrity (IBI) has since been modified for the streams of Appalachia, Ontario, North Carolina, Colorado, Tennessee, Idaho, Missouri, and Mexico, larger streams in Oregon, France, Ohio, Australia, Africa, Belgium, and India, as well as Tennessee river reservoirs and Great Lakes bays (Simon and Lyons, 1995; Hughes and Oberdorff, 1998). IBI's are useful management tools because they reflect vital components of a fish community: taxonomic richness, habitat and trophic guild composition, and individual health and abundance.

In 1992 Lyons calibrated the Karr IBI system to Wisconsin warmwater, wadeable streams (Lyons, 1992). The Wisconsin IBI was developed using 10 metrics, with an additional 2 "correction factors". Lyons later took this same concept and developed an IBI specifically tailored towards wadeable, warmwater intermittent streams (Lyons, 2006). Intermittent streams are defined as streams without continuous flow – they may naturally be reduced to a series of isolated pools or go completely dry during summer months. These stream systems can be harsh environments, and may naturally have chemical and physical parameters that severely impact fish survival, growth, and reproduction (Zale et al., 1989). The fish that do exist in these systems tend to display several common characteristics such as being small-bodied, short-lived, fast maturing, capable of rapid population increase, and tolerant of physiochemical extremes (Lyons, 2006). The intermittent stream IBI relies upon different metrics than Lyons' 1992 IBI, and as a result is better suited for evaluating these types of streams.

While an IBI is a useful method of determining whether a stream fish community is degraded due to environmental stressors, the total score cannot identify what stressor is causing the biological response. To investigate the relationship of anthropogenic stresses on a fish community, one method is to explore trends in the individual metrics of the IBI instead of the total IBI score itself (O'Reilly et al., 2007). By analyzing these components of a fish community, one may speculate as to what kind of environmental stressors are occurring. For example, a decrease in darter species may indicate a change in habitat, as members of this species prefer hunting aquatic insects in stream riffles or runs. Simple lithophilous spawners require clean substrates for spawning, so a decrease in this metric may indicate embeddness of rocky substrates (O'Reilly et al., 2007).

Biological Assessment of Macroinvertebrate Communities

Macroinvertebrates may respond to environmental stressors faster than fish species due to their limited mobility. In addition, because species or groups of macroinvertebrates have specific or particular tolerance ranges for pollutants they can be monitored to analyze the biotic health of streams. A well-known and often used index for measuring macroinvertebrate health in streams is the Hilsenhoff Biotic Index (HBI) (Hilsenhoff, 1987). The HBI evaluates water quality and degree of organic pollution based upon tolerance levels of macroinvertebrates. The degree of organic pollution strongly influences dissolved oxygen levels in the stream. As a result, only invertebrates that require dissolved oxygen for respiration are used in the calculation of the HBI.

The HBI is calculated using macroinvertebrates identified to either the genus or species level. The formula for calculating the HBI is:

$$HBI = \sum (x_i * t_i) / (n)$$

where x_i is the number of individuals within a genus or species, t_i is the tolerance value of a genus or species, and n is the total number of organisms in the sample. Organisms that are sensitive to low concentrations of dissolved oxygen are assigned low tolerance values, and organisms that have a higher tolerance are assigned a higher tolerance value. A sample dominated by many species/individuals with a low tolerance for low oxygen levels would have a low overall HBI score and indicate a higher water quality rating. Computed values range within a scale of 0 to 10, and coincide with varying degrees of organic pollution (Table 4.1.)

Although the HBI is a useful tool in assessing macroinvertebrate communities' response to organic pollution, it is sometimes difficult to perform, as macroinvertebrates must be identified to the genus and species level. This can be very time consuming and requires a high level of expertise with macroinvertebrate identification. In 1988, Hilsenhoff created the Family Biotic Index (FBI) as a way to more rapidly assess macroinvertebrate communities (Hilsenhoff, 1988). This method involves the identification of macroinvertebrates to the Family level. Although the FBI does sacrifice some accuracy and specificity, it allows for sufficient evaluation of stream sites by novice investigators in a timely manner. It is similar to the HBI equation except instead of assigning tolerance values to insect genera, species taxa are assigned a tolerance value at the family level. The number of individuals within a taxon are weighted by a tolerance value of the taxon (t_i), summed and normalized by the total number of organisms in the sample (n). Again, similar to the HBI, the values range from 0 to 10 and describe the levels of organic pollution a stream has received in (Table 4.1.)

Table 4.1. Evaluation of water quality based upon biotic indices associated with macroinvertebrate communities (Hilsenhoff 1987 and 1988).

HBI Value	FBI Value	Water Quality	Degree of Organic Pollution
0.00-3.50	0.00-3.75	Excellent	Organic pollution unlikely
3.51-4.50	3.76-4.25	Very good	Possible slight organic pollution
4.51-5.50	4.26-5.00	Good	Some organic pollution probable
5.51-6.50	5.01-5.75	Fair	Fairly substantial pollution unlikely
6.51-7.50	5.76-6.50	Fairly poor	Substantial pollution likely
7.51-8.50	6.51-7.25	Poor	Very substantial pollution likely
8.51-10.00	7.26-10.00	Very poor	Severe organic pollution likely

A third commonly used macroinvertebrate metric is EPT (Ephemeroptera-Plecoptera-Tricoptera) Richness, generally expressed as a percentage of the sample. This metric represents insects from the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies). Insects in these orders are particularly sensitive to organic pollution. As a result, their numbers should decrease as pollution increases (Lillie et al., 2003).

Methods

Fish Methods

Fish data were collected from several agencies that have performed surveys on Duck Creek. These agencies included the Lower Fox River Watershed Monitoring Program, the Oneida Tribe of Indians, the USGS through the NAWQA Program, the WDNR and Kirby Kohler, a graduate student at the University of Wisconsin – Stevens Point. The agencies had all surveyed Duck Creek with the intention of using the data in Lyons' 1992 IBI calculation, so it was assumed that sampling methodology was consistent with the methods described in Lyons (1992). The as-delivered data was in various forms – some agencies delivered basic survey data only, while others delivered basic survey data and IBI values. For all datasets, 1992 and 2006 IBI values were calculated using the criteria in Lyons (1992) and Lyons (2006). Individual IBI metrics were calculated for each sampling event using both IBI methods as well. The total dataset included 12 sites along the mainstem of Duck Creek, sampled through 148 surveys from 1993 to 2007. Due to potential seasonal differences in fish communities, the dataset was limited to those sampling dates occurring from late April to early October, as recommended by Lyons (2006). This limited the dataset to 91 surveys (Table 4.2).

The resulting dataset was somewhat limited in that many survey sites had few surveys performed, and often during a short time span. In order to examine long-term trends in the fisheries data, several modifications had to be made. First, the data was aggregated into three time periods that coincided with the changing water quality sampling objectives at the USGS monitoring station and also coincided with land management and monitoring program initiatives (i.e. the DAAPWP and LFRWMP). The three periods were 1988-1995 (Period 1), 1996-2002 (Period 2), and 2003-2008 (Period 3). Secondly, the location of each survey site was entered into an ArcGIS database of the watershed. The twelve survey sites were then aggregated into three spatial classes of Upstream, Midstream, and Downstream reaches (Figure 4.1) to minimize potential influences of stream flow and duration variability between sites.

Fish survey IBI and individual metrics, along with total abundance of each survey was compiled in Microsoft Excel and then analyzed using SAS (version 9.1.3 © 2002-2003). Boxplots showing the median, minimum, maximum and 25th and 75th quartiles for each metric are presented in Appendix C.1 of Cibulka (2009). In the statistical analysis many of the metrics displayed non-normal tendencies which could not be alleviated with transformations. Therefore, the non-parametric Wilcoxon Rank Sum Test (exact p-value option) was used to test for significant differences in the medians of each metric between Period 1 and Period 3 of the fisheries data. These periods roughly represent time periods "before and after" the implementation of management activities in the watershed. Period 2 was considered a transitional stage.

Table 4.2. Fish survey dataset for mainstem Duck Creek, WI. Data was collected from several agencies and was reduced to summer (late April through early October) sampling dates only.

Location	Site†	N	Sampling Range	Sources‡
Upstream	CTY Rd. S	5	1995-2004	Kohler, NAWQA
	Center Valley Rd.	7	1995-2005	Kohler, Oneida
	CTY Rd. J	6	1995-1996	Kohler
	Tip Rd.	4	1995-1996	Kohler
Mid-Stream	CTY Rd. EE	10	1998-2006	Oneida, LFRWMP
	Seminary Rd.	17	1993-2008	NAWQA, Kohler, Oneida
	CTY Rd. U and E	4	1995-1996	Kohler
Downstream	CTY Rd. GE	4	1995-1996	Kohler
	CTY Rd. FF	4	2003-2007	LFRWMP
	D/S of CTY FF	4	1995-1996	Kohler
	Oneida G&C Club	13	1995-2008	Kohler, Oneida
	Pamperin Park	13	1995-2008	Kohler, Oneida

† D/S: downstream.
‡ Kohler, 1997; NAWQA: USGS National Water Quality Assessment Program; Oneida: Oneida Environmental, Health and Safety Division; LFRWMP: Lower Fox River Watershed Monitoring Program, UW-Green Bay and UW-Milwaukee.

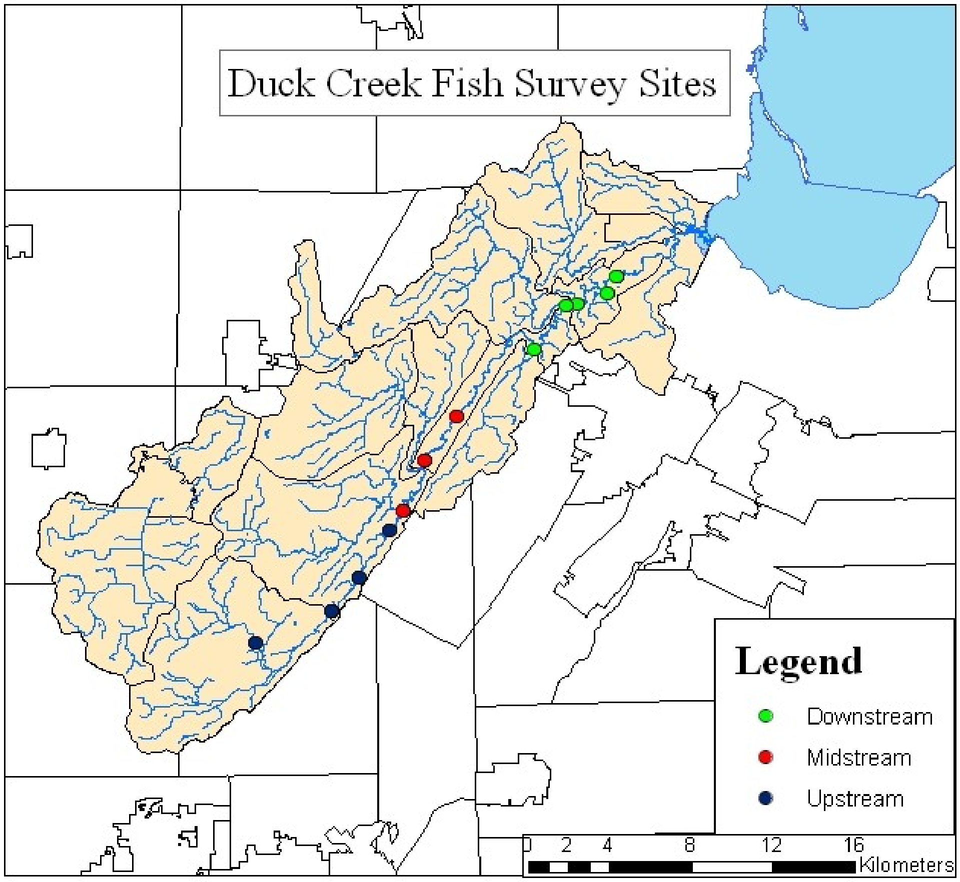

Figure 4.1. Fish survey locations within the Duck Creek watershed. 12 locations were combined into categories of Downstream, Midstream, and Upstream based upon the entry of tributary streams to the mainstem of Duck Creek.

Macroinvertebrate Methods

Data were pooled from several agencies that performed macroinvertebrate surveys on the mainstem of Duck Creek including the LFRWMP, the Oneida Tribe of Indians, USGS (through the NAWQA program) and the UWSP aquatic entomology lab, which is an analysis lab and repository for macroinvertebrate data collected primarily by the WDNR. Although these agencies may have used different yet relatively similar techniques to collect the organisms it was assumed that any differences in macroinvertebrate samples were the result of varying stream conditions, and not of the agency field collection and processing methods. This assumption was based upon Lenz and Millers (1996) study which found that although four different macroinvertebrate sampling techniques by four separate government agencies produced a collection of different total abundances and proportions of individual taxa, the water quality ratings from calculated indices (HBI, FBI, etc.) were similar. Two of the agencies compared in this study, the USGS (NAWQA program) and WDNR, have provided the majority of the data for this Duck Creek analysis. The remaining two agencies (LFRWMP and Oneida Tribe) have used generally accepted methods for macroinvertebrate collection.

Macroinvertebrate monitoring in Duck Creek has varied over the past 20 years, both in terms of watershed location and years of sampling. It appears that most of the sampling done by all agencies has been the result of watershed specific projects, and not with the intent of examining long term trends. The location of macroinvertebrate surveys are shown in Figure 4.2.

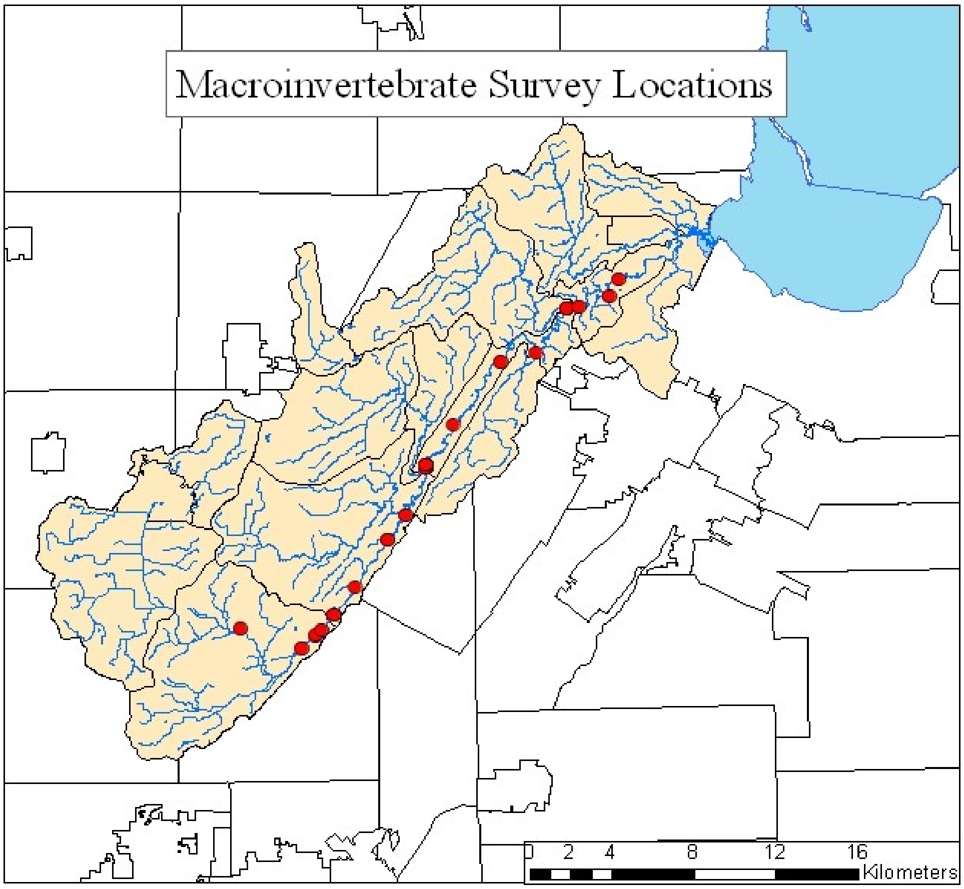

Figure 4.2. Location of macroinvertebrate survey sites included in this study. All locations are located on the main stem of Duck Creek.

Macroinvertebrate data were analyzed using the UWSP BUG Biomonitoring Program, developed by Dr. Stanley Szczytko's aquatic entomology lab at the University of Wisconsin Stevens Point (Lillie et al., 2003). This program calculates 25 macroinvertebrate community metrics that are commonly used for bioassessments of water quality. Although many metrics are reported, the most commonly utilized metrics (# of species, HBI, FBI, and EPT%) were emphasized due to their widespread use and acceptance (Lillie et al., 2003). It was discovered during the investigation that, due to the nature of the data, some benthic data could not be analyzed with the BUG Program. For example, the LFRWMP samples were identified only to the Family taxonomic level, with the intent of analyzing FBI and EPT% for these sampling periods. The HBI metric, which applies tolerance values to a specific genus or species, and the Species # metric, which counts the number of species, could not be applied to these samples. As a result, HBI and Species # metrics were calculated for a smaller dataset, while FBI and EPT% were calculated for all collected data.

Fish Community Trend Results

There were 20 significant changes in fisheries metrics between the first and third time periods within the three watershed locations. For each metric, it was determined if the metric value increased or decreased. These changes were related to either a positive or negative response in the fish community, based upon the nature of the metrics (Table 4.3). Metrics that exhibited a statistically significant change (either positive or negative) are presented in Table 4.4.

Table 4.3. Metric categories for Lyons' 1992 and 2006 IBI classification system, and their tendencies under increasingly stressful situations.

Metric	Lyons' Indices	Expected Response with Increasing Human Impact
Total Abundance	Neither	Decrease
Number of Native Species	Both	Decrease
Number of Intolerant Species	Both	Decrease
Number of Native Minnows	2006	Decrease
Number of Sucker Species	1992	Decrease
Number of Sunfish Species	1992	Decrease
Number of Darter Species	1992	Decrease
Number of Headwater Species	2006	Decrease
Percentage Insectivores	1992	Decrease
Percentage Omnivores	1992	Increase
Percentage Top Carnivores	1992	Decrease
Percentage Simple Lithophils	1992	Decrease
Percentage Tolerants	1992	Increase
Catch of Non Tolerants	2006	Decrease
Catch of Brook Stickleback	2006	Decrease
1992 IBI	1992	Decrease
2006 IBI	2006	Decrease

Table 4.4. Fish metrics with significant change (P<0.05) between Periods 1 and 3, their locations in the watershed, the direction of change, and fish community implication in Duck Creek. The bottom portion of the table summarizes the number of positive and negative changes for each watershed location.

Metric	P-Value	Location†	Change	Implication
Abundance	0.0057	DS	Increase	Positive
	0.0424	US	Increase	Positive
No. of Native Species	<0.0001	DS	Increase	Positive
	0.0201	MS	Increase	Positive
No. of Darters	0.0022	DS	Increase	Positive
No. of Suckers	0.0019	DS	Decrease	Negative
No. of Sunfish	0.0394	US	Increase	Positive
No. of Intolerant Species	0.0356	MS	Decrease	Negative
% Tolerant Species	0.0263	DS	Increase	Negative
% Insectivores	0.0071	DS	Increase	Positive
% Top Carnivores	0.0148	DS	Decrease	Negative
	0.0154	MS	Decrease	Negative
1992 IBI	0.0452	DS	Increase	Positive
No. of Minnow Species	<0.0001	DS	Increase	Positive
	0.0028	MS	Increase	Positive
Catch of Non-Tolerant Species	0.0037	DS	Increase	Positive
	0.0439	MS	Increase	Positive
	0.0394	US	Increase	Positive
Catch of Brook Stickleback	0.0122	MS	Increase	Positive
2006 IBI	0.0045	DS	Increase	Positive

Summary by Watershed Location

Location	Significant Changes	Positive	Negative
DS	11	8	3
MS	6	4	2
US	3	3	0

† DS: downstream, US: upstream, MS: midstream.

Macroinvertebrate Trend Results

The Duck Creek macroinvertebrate dataset was limited in several ways. Sampling locations varied throughout the watershed over time, with many samples being collected in site-specific locations for various projects, such as the assessments for the DAAPWP. The LFRWMP consistently sampled the same two locations for several years, but only during the recent time period and this information was limited to only the family level of macroinvertebrate identification. The various sampling locations were not lumped together into "watershed areas" as was done with the fish data because of the limited mobility and habitat specific nature of macroinvertebrates. As a result, several commonly used macroinvertebrate metrics were calculated on the given data, and no detailed trend analysis was performed.

Metrics were calculated for all applicable survey samples. The Appendix D.1 table in Cibulka (2009) details these metrics, along with site locations. BUG Program descriptions are identified in Appendix D.2 and output for all locations is listed in Appendix D.3 (Cibulka, 2009). There were a substantial number of surveys completed at two locations on mainstem Duck Creek – at Seminary Rd. and County Rd. FF. Figure 4.3 shows calculated metrics for all survey data, in all locations of the watershed, with respect to time. Seminary Rd. surveys are distinguished from all other sites (labeled as “other”) for all four metrics, while County Rd. FF, which had numerous data points collected through the LFRWMP, is isolated from “other” sites and Seminary Rd. sites for the FBI and EPT% metrics.

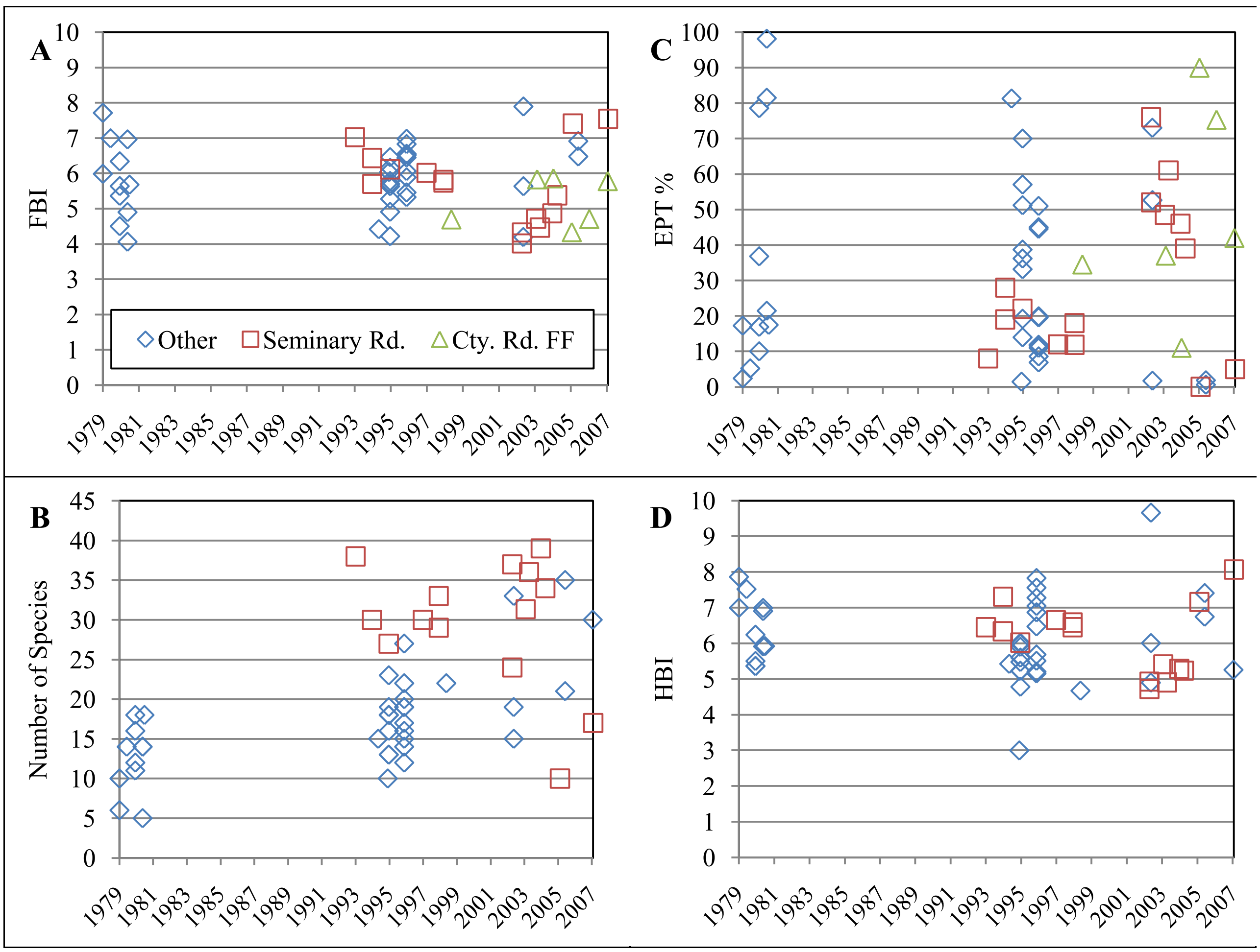

Figure 4.3. Calculated metrics for Duck Creek macroinvertebrate surveys. Metrics include FBI (A), Number of Species (B), EPT% (C), and HBI (D) for Seminary Rd., County Rd. FF and all other watershed locations with respect to time.

For all Duck Creek locations between 1979 and 2007, FBI values ranged from 4 (water quality “very good”) to 8 (water quality “very poor”), and the mean value was 5.7 (“Fair” water quality). Mean values were similar for the Seminary Rd. site (5.8 – close to 5.7 yet included in the "Fairly Poor" category) and the County Rd. FF site (5.2). The number of species varied widely as well, ranging from 5 to 40 species. The mean number of species at all sites (without data from the LFRWMP) was 21, while the Seminary Rd. site averaged more diversity in the number of macroinvertebrates (30). The percent of the count that were Ephemeroptera, Plecoptera, and Tricoptera varied the most, ranging from 0 to 100%, though average values were similar between all sites (32%), the Seminary Rd. sites (30%), and the County Rd. FF sites (48%). HBI values included several potential outliers at 3 and 10 (water quality ratings of "Excellent" and "Very Poor"), while averages for all sites and the Seminary Rd. location each averaged 6.1 (water quality "Fair"). There were no apparent trends when these metric values were analyzed with respect to time or location in the watershed.

Summary

Management practices have been implemented within the Duck Creek watershed with the goal of not only reducing sediment and nutrient export to the streams, but also to improve habitat conditions for aquatic organisms that live in these streams. As the water quality of Duck Creek improves, the biotic communities in the stream are expected to exhibit signs of improvement as well.

For this study, a dataset consisting of 91 fish surveys conducted by several entities at 12 different sites in Duck Creek from 1988 to 2008 was assembled. The data were aggregated into three spatial groups and three time periods. Temporal changes in fish community indices and IBI metrics were analyzed. Twenty metrics and indices were significantly different between the first (1988-1995) and third time periods (2003-2008). Fifteen of the significant differences indicated a positive response in the fish community, while five indicated a negative response.

A macroinvertebrate survey dataset was also assembled and analyzed in this study. This 20-year dataset was limited because sampling locations varied throughout the watershed over time. Apparently the sampling that was conducted by various entities was done for watershed specific projects and not with the intent of examining long term trends. Based on an assessment of several macroinvertebrate biotic indicies and metrics calculated from the dataset, the water quality rating for Duck Creek is "fair" but ranged from "very good" to "very poor." There were no apparent trends in the metrics with respect to time or location.

Discussion

Individual IBI metrics can be used to infer habitat conditions and presence of environmental degradation. Lyons (1992) and Gatz and Harig (1993) reports that low numbers of simple lithophilous species such as the common shiner (Notropis cornutus) and creek chub (Semotilus atromaculatus) and benthic species such as darters and suckers are typically present where siltation and loss of coarse substrate has occurred. In Duck Creek, although the numbers of darter species has increased downstream, the number of sucker species has decreased, and the number of simple lithophils has not changed ($P = 0.2789$) in any of the three watershed locations. This may indicate that Duck Creek is still experiencing heavy siltation in riffle and run areas of the stream, which would result in a loss of habitat and reproductive opportunity for these indicator species. Lyons (1992) also reports that top carnivores and sunfish species favor deep pools and instream cover habitats. The top carnivores metric significantly decreased in the mid and downstream reaches of Duck Creek, while the number of sunfish increased significantly in only the upstream locations. This may suggest lower reaches of the stream have lost the critical habitat required for predatory fish such as rock bass, smallmouth bass, and pike, while the upstream areas may still have this essential habitat. Minnow species and intolerant species have significantly increased in the watershed, which may indicate organic pollution has decreased, allowing these sensitive species to recover.

Several of the metrics may be more encompassing than others with respect to Duck Creek. Total abundance of fish species and the number of native species have increased in two of the three watershed locations. These trends indicate that the fish communities are not only becoming more diverse, but also more prolific. And finally, the 1992 and 2006 overall IBI values have increased in the downstream portions of the creek.

Overall, the fish communities of Duck Creek have begun to show signs of improvement in all areas of the watershed. In the downstream reaches, 73% of all significant metric changes were in a positive direction, while midstream and upstream reaches show 67% and 100% positive changes, respectively. The downstream reaches showed the largest number of both positive and negative changes (8 positive and 3 negative). This stream section may exhibit more community adjustments because it encompasses more of the watershed than the upstream and midstream reaches, and therefore is more reflective of overall conditions.

The macroinvertebrate data was assessed with respect to time, yet further analysis was unable to be performed due to the lack of consistent site-based monitoring through the analysis period. The current data set shows great variability, especially in the EPT % index. This index may be the most vulnerable to sampling bias due to the macroinvertebrates in these families being very selective of habitat. With multiple agencies contributing data for this analysis, it is possible that differing sampling methodology is responsible for this variability. The number of species may also be influenced by using different sampling methods for invertebrate collection for this same reason. However, even though these metrics displayed much variability, the Biotic Indices developed by Hilsenhoff (1987; 1988) seem to show greater consistency, just as Lenz and Millers (1996) had discovered. Some outlier values exist, yet values seem to be centered fairly well over the means of the HBI and FBI, which are consistent in their water quality counterpart (both values indicate “Fair” to “Fairly Poor” water quality).

It is unfortunate that the macroinvertebrate dataset was limited. In order for trends to be investigated on this biotic community, it is important that studies be completed in the same locations year after year, using a similar sampling protocol. Macroinvertebrates are highly limited in terms of their mobility, and very selective of habitat. Sampling in one location followed by a location downstream would not be ideal for comparison purposes due to the nature of these organisms. However, the efforts at analyzing the dataset were not without merit because these surveys were further characterized through the use of the BUG Program, and several possible long-term trend sites have been established (Seminary Rd. and County Rd. FF).

Chapter 5 - **TROUT CREEK WATER QUALITY ANALYSIS**

Introduction - Establishing a Trout Fishery

Trout Creek is one of several coldwater tributaries that flow into Duck Creek. The Trout Creek sub-watershed is located in the northern portion of the Duck Creek watershed and is located partly within the Oneida Reservation. It consists of a main perennial stream, a northern and western perennial branch, and many unnamed intermittent tributaries. The perennial portion of the stream flows 12.8 km until it spills into Duck Creek near County Rd. FF, and drains 50.5 km^2 of land (WDNR, 1997). The North Branch of Trout Creek runs through primarily forested land, while the West Branch of the stream drains considerably more agricultural land (Figures 1.1 and 5.1). In 1997 the sub-watershed composition was 77 percent agricultural, 18 percent wetland and wooded and 5 percent urban (WDNR, 1997).

In the DAAPWP assessment study, officials noted that Trout Creek was one of the few streams in the region to have "good flow" throughout the year (WDNR, 1997). The geology of this small watershed is likely the reason this stream flows continuously. Approximately 14,000 years ago, the Cary ice sheet retreated in several phases, leaving behind recessional moraines through modern day Bonduel, Cecil and Black Creek, WI. It melted further and eventually paused on the eastern side of the creek basin. In doing this, it formed another moraine that impounded a portion of glacial Lake Oshkosh between this eastern boundary and the moraine in Bonduel. Early Lake Oshkosh was fairly shallow and deposited large quantities of sand in its place (Dorney et al., 1973). Later on, the ice melted further and the drainage systems of the watershed developed. These sandy deposits still dominate the watershed soils today.

According to Nelson and Fassbender (1972), the waters of Trout Creek were once considered to have a marginal trout fishery. However in the mid 1990s, habitat, dissolved oxygen levels, HBI, EPT and IBI evaluations ranged from "poor" to "fair" (WDNR, 1997). Following these monitoring studies, the authors concluded that intolerant aquatic life was likely stressed in the creek. What was once a trout stream became an impaired stream holding only redside dace, white suckers, johnny darters, and other forage species (WDNR, 1997). The Oneida Tribe of Indians has focused much effort towards restoring this culturally significant stream. Many BMPs were implemented to address the major water quality problems established by the DAAPWP – streambank erosion, phosphorus from barnyard animal lots and sediment runoff from croplands. In addition to these BMPs, the tribe has restored habitat within the stream to coincide with their effort to reintroduce brook trout in the future.

Brook trout (*Salvelinus fontinalis)* are a cold-water fish species that inhabits lakes and streams in most of North America and Canada, and have been introduced to temperate regions of other continents. They are the most generalized and adaptable of the trout species and are associated with cold temperate climates, though research has demonstrated the species does display preferred habitat and environmental conditions (Table 5.1).

Table 5.1. Environmental tolerance and optimal habitat of brook trout species. Conditions may vary due to regional or genetic differences.

	Optimal Conditions	Range	Source
D.O.	>7mg/L @ <15C >9mg/L at >15C to saturation	5 mg/L to saturation	Raleigh 1982
Temperature	11-16C	0-24C	Raleigh 1982
Turbidity	0-30 NTUs	0-130 NTUs	Sykora et al. 1972
pH	6.5-8.0	3.5-9.8	Daye and Garside 1975
Flow	7-11 cm/sec	<25 cm/sec	Wesche 1974
Habitat	Clear, cold spring-fed water Approx. 1:1 pool-riffle ratio Areas of slow, deep water Well vegetated stream banks Abundant instream cover Overhanging vegetation Water surface turbulence		Raleigh 1982, Giger 1973

With the possible re-introduction of brook trout to Trout Creek by the Oneida Tribe of Indians, it is important to understand the nature of the waters these fish will inhabit. The waters of Trout Creek were assessed for nutrients and physical characteristics in 2008 at two locations, with this re-introduction in mind. This chapter presents results of a comparison in phosphorus and sediment concentrations between an upstream and downstream location on Trout Creek and documents temperature, DO and other characteristics at the two sites in 2008. An interpretation of the findings is also presented in the context of potential problems regarding the survival of brook trout, a particularly sensitive species.

Trout Creek Water Quality Analysis - Methods

Monitoring Locations and Nutrient and Sediment Monitoring

Two Trout Creek locations were monitored in this portion of the study– at the stream crossing of County Rd. FF / Hillcrest Drive (TC1) and off of Oak Ridge Rd. near the former Desjardin Farm (TC2) (Figure 5.1). Bi-weekly and rain event samples were collected at the downstream TC1 site, which accounted for the entire Trout Creek watershed. At the upstream site, TC2, bi-weekly samples were collected within one hour of collection of the TC1 samples. At this location only one event sample was collected.

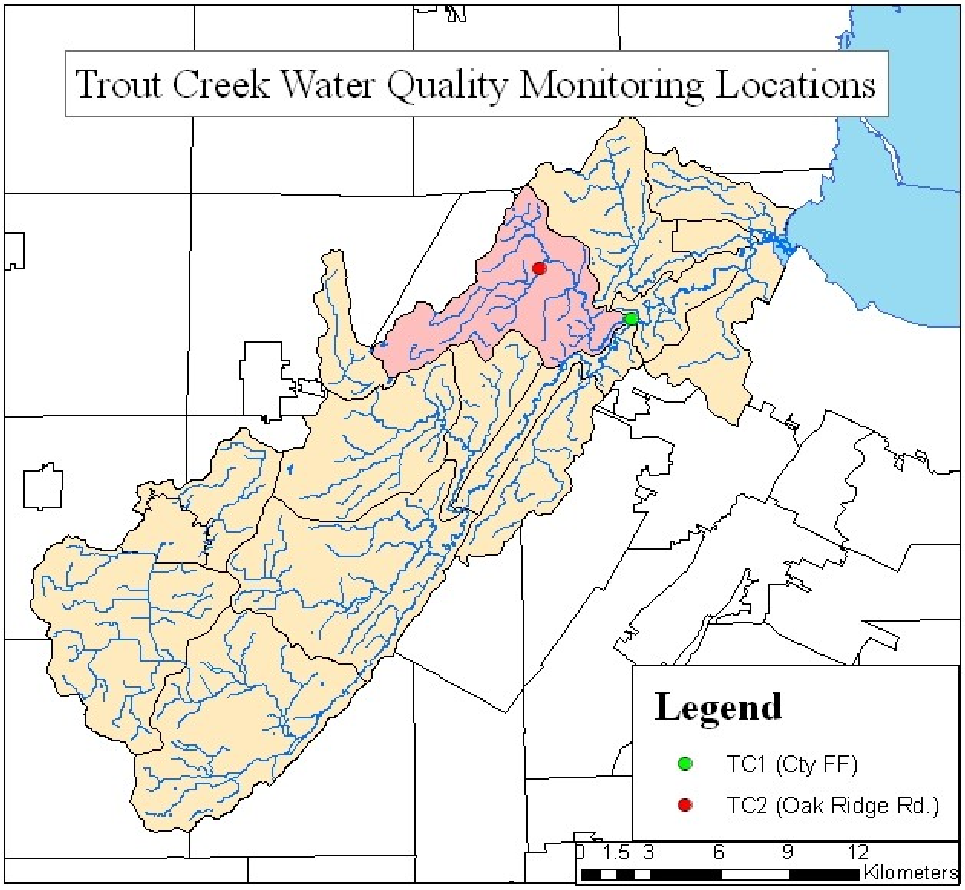

Figure 5.1. Location of the Trout Creek watershed and two water quality monitoring locations. Nutrient and physical water quality parameters were measured at TC1 (downstream) and TC2 (upstream) during 2008.

Bi-weekly water quality samples were collected through the use of equal width interval sampling devices. Event samples of higher flow were sampled through the use of siphon samplers (Gracyk et al., 2000). All samples were transported to the UWGB water quality lab and then divided into smaller quantities using a Teflon cone splitter, which allowed several parameters to be tested on one sample. Samples were analyzed for TP, DP, and TSS concentration. Samples for DP analysis were filtered through a 0.45 µm membrane filter to remove particulate matter. Both TP and DP samples were preserved with diluted sulfuric acid (3:1 concentration) and refrigerated until analysis at the Green Bay Metropolitan Sewerage District (GBMSD). Total phosphorus and DP analyses followed USEPA's Automated Block Digester Method 365.4 (USEPA 1983). Total Suspended Solids samples were also analyzed at the GBMSD using Standard Method 240 D (Clesceri et al., 1988).

Physical Water Quality Monitoring

In addition to nutrient and sediment sampling, physical water quality parameters (temperature, pH, conductivity, depth, turbidity, dissolved oxygen) were measured with continuously recording YSI 6600 EDS Sondes (YSI Inc, Yellow Springs, OH). The sondes were deployed at site TC1 from June 6 through November 21 and at site TC2 from July 2 through

October 31. Each parameter was measured and recorded at 10 minute intervals. The sondes were removed from the field and re-calibrated about once every 2-3 weeks to ensure accuracy of the collected data. A number of QA/QC procedures were implemented on the dataset. Dissolved oxygen values were removed when the charge of the oxygen probe strayed outside of its recommended limits (a charge of 25 to 75). The erroneous DO data often occurred when the DO probe membrane was damaged. Damage to the membranes was likely caused by crayfish crawling over the sonde. Raw turbidity data was adjusted by adding the lowest negative reading (if any) for a deployment period to each turbidity reading for that respective period. On two occasions the monitoring probes experienced battery related errors, resulting in several days of missing data. Data were extracted from the sondes and compiled using Ecowatch (YSI Inc, Yellow Springs, OH) analysis software. Daily and monthly summary statistics were estimated for each parameter following the previously mentioned QA/QC procedures.

Gage height and stream water temperature at County Rd. FF were continuously (10 min. intervals) recorded with an atmospheric pressure-compensated pressure transducer and a temperature probe connected to a CR-10 datalogger (Campbell Scientific, Inc., Logan, UT). This datalogger was in operation from May 1 through November 21 and recorded several moderate flow events that were missed with the YSI sondes. The datalogger and a 75 mm PVC pipe which housed the probes were attached to a USGS crest gage on the downstream side of the County Rd. FF culvert. The USGS crest gage served as a reference point for establishing stream gage height. The upper lip of the cap at the bottom of the crest gage pipe was assumed to be at 10 feet, to be consistent with the markings on the wood staff inside the pipe. Readings from the water depth probe were adjusted to coincide with the crest gage readings by adding 8.90 feet to the recorded water height.

Trout Creek Water Quality Analysis - Results

Flow and Physical Water Quality Parameters

Weather in 2008 was anomalous in several respects. Many areas of the state reported record snowfalls in the winter of 2007 – 2008. Green Bay received 90 cm more snowfall than the 30-yr average (NWS, 2009). Total January-April, water-equivalent precipitation was nearly double the 30-yr. average (+16 cm). Early spring (March and April) was characterized by rapid snowmelt and few rain events. Water levels in Trout Creek receded throughout May, a month in which rainfall was about one-half the typical amount (Fig. 5.2). On June 8, 2008, 3.5 cm of rain was recorded at the Duck Creek USGS monitoring station. Water levels in nearby Trout Creek rose nearly two feet (60 cm) in response to this rain storm (Fig. 5.2). The rest of the summer was characterized by smaller (< 2.5 cm) rain events with the exception of July 2nd, in which a rainfall of 3.0 cm was recorded at the Duck Creek USGS monitoring station. Water levels in Trout Creek dropped to their lowest values in August in response to less than one cm of rainfall for the month (Figure 5.2). Total rainfall from August through November was about 15 cm below average resulting in modest flow increases following the growing season.

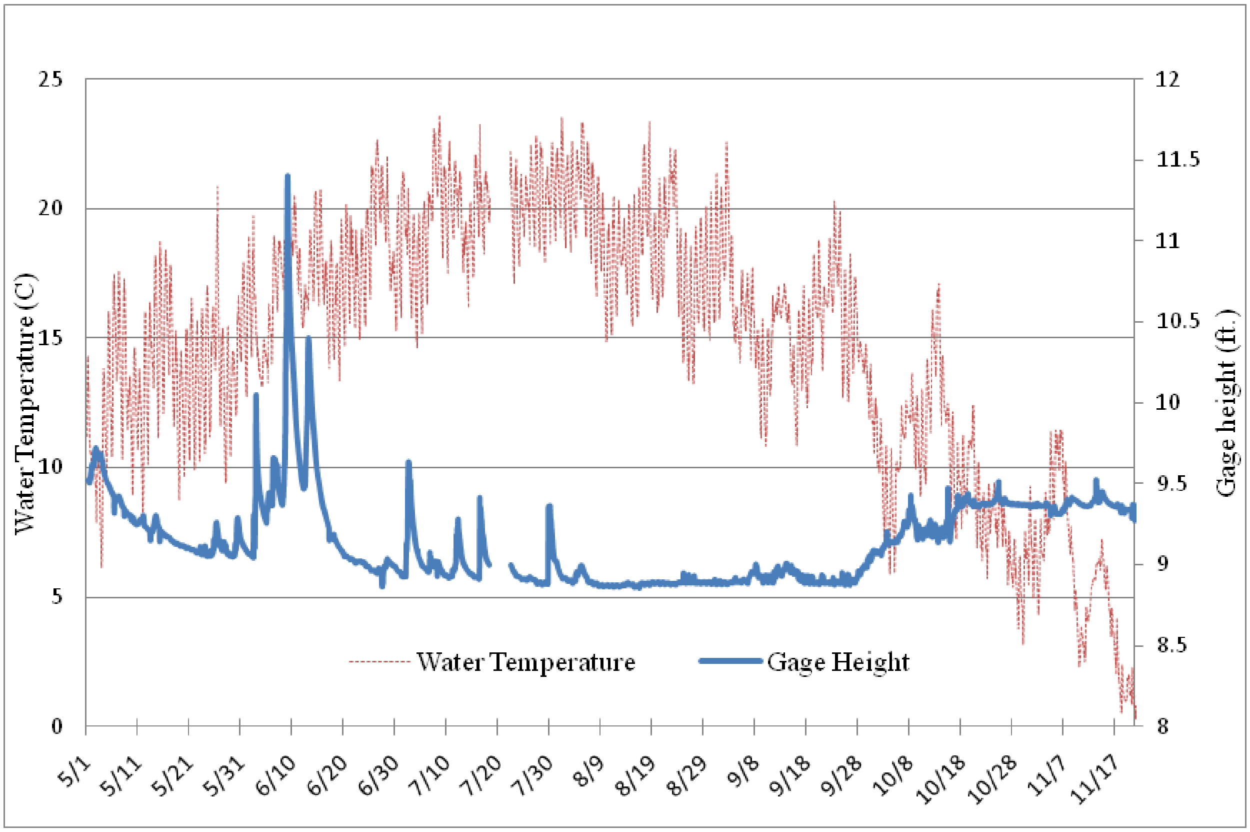

Figure 5.2. Gage height and water temperature for Trout Creek during May-November of 2008. Data was recorded at County Road FF using a datalogger, pressure transducer and thermocouple.

The downstream (TC1) and upstream (TC2) multiparameter sondes were operational from July through October. Limited data were collected at site TC1 in June and early November. Daily mean, maximum and minimum from 10 minute data for each monitoring site are presented in Appendices E.1 and E.2 (Cibulka, 2009). Monthly data are summarized in Table 5.2. Table 5.3 summarizes the optimal ranges of four parameters reported for brook trout as well as those ranges observed in Trout Creek during two periods in 2008.

Maximum water temperatures occurred during July at both sites (Fig. 5.2 and Table 5.2). Recorded measurements at TC1 were similar to previous temperature data collected by the Oneida Tribe (Stacy Gilmore, personal communication) and the USGS (USGS online database, http://nwis.waterdata.usgs.gov/nwis/qwdata/?site_no=04072185&). The maximum temperature at TC1 in 2008 was 23.0 degrees C on July 8. A maximum temperature of 26.8 degrees C was recorded at this site by the USGS in the afternoon of July17, 2002. Temperatures were either the same or slightly lower at TC2.

Table 5.2. Monthly physical water quality parameter statistics for Trout Creek at County Rd. FF (site TC1) and at Oak Ridge Road (site TC2). Data was continuously collected at 10 min. intervals using a multiparameter sonde.

		June	July		August		September		October		Nov.
		TC1	TC1	TC2	TC1	TC2	TC1	TC2	TC1	TC2	TC1
Temp (C)	Mean	17.4	19.5	18.9	18.4	17.8	15.2	14.8	8.3	8.7	4.7
	Max	20.6	23.0	22.9	22.8	22.3	20.8	21.2	15.9	16.0	10.9
	Min	14.9	14.4	14.8	13.6	13.5	10.7	10.7	2.2	2.4	-0.2
pH	Mean	8.2	8.3	7.9	8.4	7.9	8.3	7.9	7.9	7.7	7.7
	Max	8.3	8.5	8.1	8.6	8.1	8.5	8.2	8.2	7.9	7.9
	Min	7.9	6.7	7.5	8.2	7.6	8.2	7.7	7.6	7.6	7.6
D.O. (mg/L)	Mean	7.9	9.0	7.2	9.1	8.4	9.3	7.8	9.7	7.6	10.1
	Max	9.7	11.0	9.6	13.1	11.5	11.3	11.8	14.1	11.2	14.5
	Min	6.0	7.0	5.2	7.2	5.6	7.2	5.7	4.7	3.1	5.8
D.O. %	Mean	83	98	78	97	88	92	78	82	65	78
	Max	103	122	107	138	124	110	118	111	91	101
	Min	60	75	56	75	61	78	56	45	29	51
Spc. Cond (mS/cm)	Mean	0.598	0.724	0.553	0.789	0.801	0.782	0.799	0.848	0.828	0.849
	Max	0.818	0.817	0.841	0.817	0.846	0.812	0.844	0.881	0.869	0.922
	Min	0.318	0.447	0.254	0.712	0.645	0.689	0.654	0.791	0.692	0.753
Turbidity (NTU)	Mean	26	11	22	12	7	10	10	4	10	6
	Max	222	302	934	48	107	23	382	21	55	33
	Min	3	1	0	2	2	4	2	2	3	2.0
Depth (m)	Mean	0.38	0.21	0.18	0.09	0.20	0.14	0.17	0.28	0.21	0.17
	Max	0.66	0.62	0.48	0.16	0.29	0.27	0.29	0.40	0.35	0.36
	Min	0.11	0.00	0.08	0.00	0.10	0.00	0.05	0.07	0.00	0.00

Table 5.3. Published ranges of four parameters for brook trout, along with daily mean and 95% confidence intervals measured in Trout Creek at locations TC1 and TC2 in 2008.

			July, August, September Daily Means ± 95% CI		October Daily Means ± 95% CI	
Parameter	Optimal Conditions	Range	TC1	TC2	TC1	TC2
D.O. (mg/L)	7.0 to 9.0	5.0 to Sat.	9.2 ± 0.7	7.8 ± 0.6	10.1 ± 1.5	7.6 ± 1.3
Temperature (C)	11 to 16	0 to 24	16.1 ± 2.1	17.2 ± 1.0	4.7 ± 2.6	8.6 ± 1.8
pH	6.8 to 8.0	3.5 to 9.8	8.2 ± 0.2	7.9 ± 0.1	7.7 ± 0.05	7.7 ± 0.1
Turbidity (NTU)	0 to 30	0 to 130	11 ± 4.5	7 ± 2	6 ± 2.8	9.8 ± 2.0

Dissolved oxygen concentration and percentage fluctuated widely during the monitoring period, both seasonally and diurnally. The stream water remained well oxygenated through the hot summer months of June, July, August and September. However, oxygen levels dropped below 5.0 mg/L at the TC1 site for approximately 7 hours during the early morning hours of October 14th, before returning to the monthly average of 9.7 mg/L later in the day. At TC2, oxygen concentrations dropped below 5.0 mg/L on two occasions, once on October 13th for a 9-hour period, and then again that same day onward for a duration of 64 hours. During this time concentrations ranged from 3.1 mg/L to 4.9 mg/L (Appendix E.2, Cibulka, 2009).

The pH and conductivity at the two Trout Creek monitoring sites are not different from those measurements taken by the Oneida Tribe or USGS. The WDNR (2006) reports that the northeastern region of Wisconsin typically has higher pH and specific conductivity due to the carbonate rich bedrock groups in the area. The pH levels remained slightly alkaline (>7) for both locations during the monitoring period and reached maximums of 8.5 and 7.9 for TC1 and TC2, respectively. The mean pH also dropped slightly during the period at both sites. Specific conductance means increased from the early, wet summer months to the drier fall months. The observed trend in pH and specific conductance was expected as the proportion of the water in the stream shifted to become more groundwater dominated, instead of mostly rainwater.

Daily mean turbidity at both sites was fairly low, rarely exceeding 25 NTU (Tables 5.2 and 5.3). Daily mean turbidity exceeded 130 NTU in early July at TC2 and had a maximum of more than 900 NTU's. This maximum value lasted only briefly (10 minutes) though the stream remained fairly turbid (100-400 NTU) during the 20 hours that followed this sharp turbidity peak. These readings were taken on July 2nd and July 3rd during an isolated rain event. In general turbidity values less than 130 NTU occurred immediately following rainfall events, and only remained that high for a few hours.

Although the descriptive statistics indicate that depth reached a minimum level of 0.0 meters, this was not observed at any time during the monitoring period. A depth value of 0.0 should indicate that water levels had decreased to the sonde unit itself, however this also was not observed at anytime. YSI reports that the accuracy range of the sonde's depth probe is ± 0.02 meters (YSI 6600 Sonde Specification manual 0103 E33-02). Although flow decreased in the late summer / early fall months, field reports indicate that considerable flow was observed in the driest of times at TC1, even when nearby Duck Creek dried up completely at the County Road FF bridge. It was noted on October 3rd that at TC2 flow decreased to the point where water appeared to be standing in the center channel of the stream and moving at only a small trickle.

Nutrient and Sediment Monitoring Results

Descriptive statistics for water quality samples collected at the two sampling sites are presented in Table 5.4. Sample dates, times and analytical results for individual samples from each site are given in Appendix E.3 of Cibulka (2009). Recall that bi-weekly samples were collected at both sites for site comparison purposes. In addition, rain event samples were also collected at site TC1.

Table 5.4. Summary statistics for water quality samples collected at two Trout Creek locations in 2008. All concentrations are in mg/L.

	TC1 - County FF			TC2 - Oak Ridge Rd.		
	TSS	TP	DP	TSS	TP	DP
N	18	18	17	10	10	10
Mean	198	0.296	0.057	64	0.224	0.073
Median	49	0.161	0.044	4	0.095	0.055
Max	1490	1.160	0.156	442	0.830	0.210
Min	2	0.015	0.015	2	0.015	0.015

The bi-weekly low flow samples were isolated from the dataset to perform a statistical comparison between sites (Table 5.5). Samples were arranged pairwise and analyzed statistically with the Statistical Analysis Software package (SAS version 9.1.3 © 2002-2003). Samples that were recorded below the GBMSD lower detection level of 2.2 mg/L for TSS and 0.015 mg/L for phosphorus were treated as that lower detection limit. TSS, TP, and DP were log-transformed to achieve normality. Log-transformed TP showed a strong, significant correlation between TC1 and TC2 (Pearson's r = 0.84, p = 0.009) and log-transformed DP also showed this same relationship (Pearson's r = 0.79, p=0.02). Log-transformed TSS showed a weak correlation (Pearson's r = 0.27) that was not significant (p=0.5). This was likely due to several outliers in the relatively small dataset (Table 5.5).

Table 5.5. Summary of bi-weekly low flow water quality samples collected at two locations on Trout Creek in 2008, and analyzed for TSS, total phosphorus and dissolved phosphorus.

	6/25/2008	**7/22/2008**	**8/19/2008**	**9/8/2008**	**9/18/2008**	**10/3/2008**	**10/31/2008**	**11/21/2008**
Site	**Total Suspended Solids (mg/L)**							
TC1	16	9.8	8.9	3.2	3.2	2.5	<2.2	2.1
TC2	7	3	4	2.2	2.9	14	<2.2	2
	Total Phosphorus (mg/L)							
TC1	0.113	0.083	0.073	0.035	0.064	0.043	<0.015	<0.015
TC2	0.133	0.151	0.085	0.074	0.07	0.105	0.046	<0.015
	Dissolved Phosphorus (mg/L)							
TC1	0.06	0.044	0.058	0.016	0.048	0.038	<0.015	<0.015
TC2	0.092	0.064	0.049	0.05	0.048	0.059	0.017	<0.015

A Paired T-Test was run on log-transformed TSS, TP, and DP to determine if a difference existed in the mean concentrations between the two sites. Significant differences were seen between the two locations for log-transformed TP (p=0.0163) and log-transformed DP (p=0.0031), but not for TSS (p=0.5421) (Table 5.6). Both phosphorus forms were found in higher concentrations at the upstream site (TC2).

Table 5.6. Simple statistics and p-values for a paired t-test performed on three water quality parameters monitored at two sites in Trout Creek (N=8).

	TSS (mg/L)		TP (mg/L)		DP (mg/L)	
	TC1	TC2	TC1	TC2	TC1	TC2
Mean	6.0	4.7	0.060	0.085	0.037	0.049
Min	2.1	2.0	0.015	0.015	0.015	0.015
Max	16.0	14.0	0.113	0.151	0.060	0.092
Std Dev	5.1	4.1	0.034	0.044	0.019	0.025
p-value	0.5421		0.0163		0.0031	

Discussion

Based on 2008 intensive monitoring and historical data collected by the Oneida Tribe and USGS, daily water temperature means of 17 to 19 degrees C seem to be the norm in Trout Creek during summer months(appendix E in Cibulka, 2009; Gilmore 2007). A peak temperature of 23 degrees C occurred at TC1 in July during the hottest part of summer2008.

Oxygen is a critical factor to aquatic life. At TC1, mean DO levels were close to saturation during the entire monitoring period (means ranging from 81% to 98%) while the upstream site (TC2) displayed lower DO saturation levels (65% to 88%). Bottom substrate likely played a key role in oxygen concentration differences between the two sites. The downstream monitoring site is located near an artificially created riffle/pool/riffle series, whereas TC2 has a primarily smooth, sandy bottom. Thus, there is more physical mixing at TC1 and aeration of the water. Dissolved oxygen was depleted below a critical level of 5 mg/L twice for an extended period of time (9 and then 64 hours) at TC2, whereas there was only one 7-hour period at site TC1 when the DO level fell below this threshold.

The Oneida Tribe of Indians has a water quality standard of 0.1 mg/L for total phosphorus concentrations in Trout Creek and other tributary streams (Gilmore 2007). Thirty eight percent of samples collected at TC1 met this standard, while 50% did so at the upstream (TC2) site. However, more “event” based samples were collected at the downstream site. Of the baseflow samples collected, 7 of the 8, TC1 samples met the Oneida Water Quality Standard and 6 of the 8, TC2 samples met the standard. A comparison of low-flow TP and DP samples between the two sites in Trout Creek revealed that upstream concentrations of both parameters were significantly higher than downstream concentrations. While measured TSS means were higher at the downstream site, a significant difference was not detected between sites.

Although the element of hydrology was partially minimized by sampling during summer and fall baseflow conditions, there may be several other factors influencing these results. Within short distances the stream changes from flat pools to short, swift riffles. The width of the stream changes as well, allowing for diverse riparian areas which may alter the flow and nutrient concentration of the stream. Bilby and Likens (1980) found that in-stream structure can trap particulate matter and Bencala (1984) determined that storage of dissolved constituents may occur in pools, side channels, and subsurface spaces. Studies have shown that phosphorus uptake by organisms can occur in less than 100 m, and that if this nutrient is not adequately resupplied to the streamwater, phosphorus availability downstream will decline (Mulholland et al., 1990, Munn and Meyer, 1990). Mulholland and Rosemond (1992) discovered that instream processes were primarily responsible for longitudinal depletion of phosphorus. Furthermore, water inputs may influence nutrient concentrations in streams. A smaller tributary (north branch of Trout Creek) flows through heavily wooded areas and eventually enters the mainstem of Trout Creek shortly downstream of the TC2 site. This tributary may be causing a "dilution effect" in which well-filtered, relatively cleaner water is diluting the downstream portions of Trout Creek. Thus, a number of hydrologic and biotic mechanisms may be responsible for the dilution, transient storage, or uptake of phosphorus as it moves downstream.

As of May 2008, the Oneida Tribe began stocking Trout Creek with brook trout in several locations. The collected sonde data shows that conditions appear to be suitable in Trout Creek for survival of this species. Monthly and daily means of dissolved oxygen, temperature, pH, and turbidity at both Trout Creek locations fell within the optimal ranges reported for brook trout (Tables 5.2 and 5.3). However, brook trout survival in the Trout Creek watershed may be influenced by sedimentation. Unlike most of the Duck Creek watershed, this sub-watershed contains significant sand deposits from the previous glaciation. Alexander and Hansen (1986) found through experimental introduction of suspended sand sediments that concentrations of only 80 mg/L significantly decreased vital habitat, physical parameters such as dissolved oxygen, and brook trout populations. Several studies have found that brook trout can be highly stressed due to sedimentation, primarily during the early life stages (Alexander and Hansen, 1986; Curry and MacNeill, 2003). In late March of 2008 temperatures climbed rapidly, allowing a record-setting winter snowfall to melt in a relatively short period of time. This melting was followed by 40.6 mm of rain on 3/31/08 and 88.4 mm of precipitation, mostly as rain, between 4/7/08 and 4/12/08 at the Duck Creek monitoring station near County Road FF. In response to saturated soil conditions and these rain fall events, Trout Creek rose over the streambank at least once and left deposits of sand on the forest floor surrounding the stream near County Road FF that were observed during regular visits to the Trout Creek monitoring station. Relatively deep sandy sediment deposits (~100 mm) were also observed on the Trout Creek stream bed downstream of County Road FF. High-flow events such as those that occurred in 2008 raise questions about how the biotic communities in the stream are impacted by harsh conditions.

Chapter 6 – **PROJECT SUMMARY**

This study was undertaken with the intention of linking water quality trends and biotic community indices with substantial efforts by multiple agencies to restore this anthropogenically degraded watershed. The specific objectives were previously stated in Chapter 1. In this chapter, each of the objectives is addressed in order. Difficulties experienced during the course of the study are examined and significant findings are highlighted.

Objective 1 – Land Management Analysis

Despite rapid population increases in recent years, agricultural lands still dominate the Duck Creek watershed. The DAAPWP was initiated in 1997 with several goals in mind, including identification of "critical" areas in the watershed and reducing runoff pollution from rural and urban areas to the streams in the three watersheds. The program appears to be a success, though lack of detailed record keeping and use of different methods to quantify nutrient and sediment reductions has resulted in somewhat incomplete results. However, the underlying mission of reducing runoff pollution, fixing critical locations/problems, and increasing awareness of water quality issues was ultimately accomplished.

The agricultural survey of the watershed indicated an increase in the use of conservation tillage, though data were somewhat limited and these results should be taken with caution. There is a general belief that more land managers are becoming aware of the benefits of conservation tillage (both environmental and economic) and are incorporating this method where applicable. The Oneida Tribe has also comprehensively implemented nutrient management plans on their farms in the watershed.

Farm numbers have decreased in the watershed substantially. In Brown County the number of cows has increased while Outagamie County has seen a sharp decrease in cows. This decrease took part primarily during 1989-1998. It is likely that national trends have affected northeastern Wisconsin as well and smaller farms are closing down in favor of larger operations. Recent trends show an increase in the number of dairy cows in Outagamie County, with current numbers similar to the early 1990s.

The Oneida Tribe has spent tremendous effort restoring the lands within the reservation. Their focus has not only been on BMP implementation, restoring native lands, and intensive nutrient management, but also on creating habitat for fish, invertebrates, birds, and other wildlife. Although their efforts have been taking place for quite some time, quantitative data was only available for recent years.

Objective 2 – Trend Analysis of Water Quality and Biotic Data

The statistical trend analysis of water quality produced several interesting results. First, it was determined that an analysis of suspended solids was not achievable. Differences in the laboratory processing of suspended solid samples prevented a distinguishable relationship between TSS and SSC, and the two methods were utilized at different times within the data analysis record. This is unfortunate as many of the efforts aimed at restoring the Duck Creek watershed have focused on reducing sediment erosion to the stream.

The trend analysis focused on phosphorus. Total and dissolved phosphorus had been monitored continuously throughout the 20-year period by the USGS and others using the same collection and laboratory procedures. However, as previously discussed, the timing and frequency in which these samples were collected varied according to specific monitoring goals and financial constraints that changed during the period. Numerous data analysis approaches were researched and attempted to mitigate this dilemma before deciding on the procedures discussed in Chapter 3. Four of the statistical procedures employed in this study led to the same general conclusion that both TP and DP concentrations have decreased significantly during the past 20 years, although not at a steady rate. Decreases occurred primarily in the beginning (1989-1995) of this 20-year period. Overall, concentrations were larger at the beginning of the 20 year record and lower towards the end. These differences in TP and DP concentrations were observed regardless of how the dataset was segmented by the level of flow.

The fish communities in Duck Creek have likely adapted to changing water quality. When IBI metrics of the communities in three watershed localities were examined, it was found that 11 metrics changed significantly in the downstream portions of the watershed, 73% of which were positive changes. The midstream portion experienced 6 changes (67% were positive), and the upstream portion experienced 3 changes (all positive). The overall conclusion is that fish communities are showing more diversity in Duck Creek, and that species sensitive to organic pollution are becoming more prevalent.

The macroinvertebrate analysis was limited by the number of surveys conducted at similar locations in the watershed. Biotic index calculations from these surveys were rated as "Poor" to "Fair" with several "Good" assessments, indicating that macroinvertebrates are experiencing a fair amount of organic pollution or other stressors. Although it is important to continue site-specific macroinvertebrate collections for the purposes of individual projects, it is recommended that several reference sites be established in the watershed, so that in the future long-term trends may be examined for macroinvertebrates.

Objective 3 – Relationships among Land-Use, Water Quality, and Biotic Condition

It is especially difficult to determine the effects of BMP placement and other land management activities on water quality unless the project design is such that influential variables are controlled. For watersheds undergoing a "treatment" (i.e. BMP additions or other land management changes), the USEPA recommends a Paired Watershed Study design (USEPA 1993). This design calls for a minimum of two watersheds (a control and treatment) and two periods of study (a calibration and treatment). Using this method, year-to-year or seasonal climate variations are accounted for. Year-to-year variations in climate were certainly a factor in the Duck Creek watershed during the study period, and unfortunately the nearest watershed of similar size and climate (Popple Creek watershed in Florence County, WI) did not have sufficient data (water quality or biotic community surveys) for comparison purposes to Duck Creek. This coupled with the fact that BMP and land management quantitative and spatial data were difficult to obtain, makes creating a link between land management and water quality extremely problematic.

There was a significant decrease in TP and DP between the beginning and end of the 20 year Duck Creek monitoring record. Several factors identified in this study may have supported this decreasing trend. The increase in BMP implementation through the DAAPWP has likely produced substantial reductions in both sediment and phosphorus delivery to Duck Creek from both Brown and Outagamie Counties, though the exact results are debatable. Education about cropland and general land management was also an important outcome of the DAAPWP. The decrease in the number of barnyards in both counties may have played a role in reducing phosphorus concentrations, particularly in the dissolved form. Based on information provided by the UW-Extension and the BCLCD, Baumgart (2005) assumed that manure incorporation within the Lower Fox River sub-basin generally increased from about 28% in 1992 to 50% in 2000, which should have reduced TP export to the stream. It is also likely that winter-spreading of manure decreased in response to mandated restrictions and increased manure storage capacity. Finally, the reductions in permitted point source discharges have certainly contributed towards this trend, with the two permitted dischargers reducing annual phosphorus loads significantly since 1993.

If a large decrease was only observed following the years of BMP implementation and land management activities, it may be easier to assume the water quality has changed due to these factors. However with large decreases occurring before the defined "transitional period", this assumption cannot be made. Although it is likely that these efforts have not been in vain and have contributed to a decrease in phosphorus concentrations in Duck Creek, climatic conditions such as dry years and years with above average snowfall are a major contributing factor to these trends, and the decrease in phosphorus concentrations cannot be linked to land-use and land-management changes alone.

Objective 4 – Characterization of Trout Creek Water Quality

Trout Creek is a cool-water tributary stream that originates in the northeastern part of the Duck Creek watershed before flowing into Duck Creek. During baseflow conditions, the waters of the stream carry concentrations of total and dissolved phosphorus that met the Oneida Tribe of Indians Water Quality standard 81% of the time between the two sampling locations. The concentration exceeded this standard during most rain events. Sediment concentrations were found to be relatively high during moderate flow events, possibly due to the larger sand particles that were visually observed in this watershed. The two sites monitored displayed different habitat settings and also different water quality characteristics. The instream structure and overhead canopy at County Road FF as well as the likely dilution effect from the north branch of Trout Creek accounted for the differences seen in the phosphorus concentrations, temperature, and dissolved oxygen between these sites.

The high TSS concentrations and the relatively deep stream bed deposits of sand which were observed in this study may be problematic with respect to brook trout suitability to these waters, as fine-grained sediments (< 2 mm) limited brook trout habitat in 8 of 11 Wisconsin streams studied by Scudder et. al. (2000). Trout Creek appears to be hospitable to this species in terms of other physical water characteristics. Temperature, dissolved oxygen, pH, and turbidity daily means during the 2008 monitoring period all fall within ranges that are either optimal or tolerable to this species. In addition, the efforts by the Oneida Tribe to re-create crucial habitat (logjams, riffles and pools, streambank stability, etc.) in the stream, should significantly improve the likelihood of establishing brook trout in the stream.

Objective 5 – Management Implications and Recommendations

A stream like Duck Creek, that is classified as intermittent in some portions is difficult to manage for aquatic organisms, aesthetic value or recreational opportunity. Common conservation practices have been implemented on this stream, but there are specific management actions that could be improved upon for Duck Creek. In March of 2008 spring snowmelt caused Duck Creek's flow to soar to 2,000 cfs. Because this intermittent stream experiences wide fluctuations in flow, restoring native streambank vegetation will play an important role in mitigating erosion. Streambank vegetation or other riparian zone stability plays a critical role in preventing the stream from eroding the shoreline. Roads, trails or other crossings should be routed over or around the stream and associated buffer areas. Particularly in dry periods, livestock must not be permitted to enter the stream channel or riparian zones. Besides the nutrient input that results from stock animals, the erosion that takes place during times of no/low flow settles to the streambed rather than being transported downstream. This will contribute directly to the loss of pools in the stream.

Additional alteration to the natural hydrological regime of the watershed should be minimized. This would include the effects of urbanization on the stream. Increased urban landscapes near Duck Creek would reduce infiltration within the watershed, contributing to the "flashiness" of the stream. Small man-made barriers (weirs, culverts, dams) should be prevented as much as possible, as these devices can restrict access to pools of water which may serve as refuge habitats for organisms during times of low flow.

It is of great importance that the management of Duck Creek include a plan for long-term monitoring. With continuing efforts to conserve this resource being implemented, it is necessary to be able to quantify and document success stories that may occur as a result. Changes in land management (BMP's, field tillage transitions, land-use changes etc.) should be well documented. The USGS monitoring station on County Rd. FF has enabled collection of 20 years of reliable and diverse data, and should remain in operation in order to continue monitoring of long term trends. The biological communities are likely to change both annually and seasonally in an unstable system such as Duck Creek, but nevertheless it is important to establish reference monitoring sites in the watershed that can be used for long term trend analysis. And, finally, the information collected from management and monitoring efforts in the Duck Creek watershed needs to be fully disclosed, so everyone has the opportunity to contribute to the conservation of this unique resource.

Chapter 7 - **REFERENCES**

Alexander, G.R. and E.A. Hansen. 1986. Sand Bed Load in a Brook Trout Stream. North American Journal of Fisheries Management. 6:9-23.

Baumgart P. 2005. Source Allocation of Suspended Sediment and Phosphorus Loads to Green Bay from the Lower Fox River Sub-basin Using the Soil and Water Assessment Tool (SWAT) - Lower Green Bay and Lower Fox Tributary Modeling Report. Joint Conference: Lake Michigan, State of the Lake and Great Lakes Beach Association, Green Bay, Wisconsin, November 2-3, 2005.

Batten, W.G. and K.R. Bradbury. 1996. Regional Groundwater Flow System Between the Wolf and Fox Rivers near Green Bay, Wisconsin. University of Wisconsin-Extension Information Circular 75.

Bencala, K.E. 1984. Interactions of Solutes and Streambed Sediment: A Dynamic Analysis of Coupled Hydrologic and Chemical Processes that Determine Solute Transport. Water Resources Research. 20:1804-1814.

Berry, W., N. Rubinstein, B. Melzian, and B. Hill. 2003. The Biological Effects of Suspended and Bedded Sediment (SABS) in Aquatic Systems: A Review. USEPA Internal Report. Available: http://www.epa.gov/waterscience/criteria/sediment/pdf/appendix1.pdf.

Bilby, R.E., and G.E. Likens. 1980. Importance of Organic Debris Dams in the Structure and Function of Stream Ecosystems. Ecology. 6:1107-1113.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, and V.H. Smith. 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. Ecological Applications. 8(3):559-568.

Cibulka, D. 2009. Temporal Assessment of Management Practices and Water Quality in the Duck Creek Watershed, Wisconsin. M.S. Thesis, Environmental Science and Policy, Univ. Wisconsin – Green Bay.

Clayton, L., J.W. Attig, D.M. Mickelson, M.D. Johnson, and K.M. Syverson. 2006. Glaciation of Wisconsin. University of Wisconsin Extension Education Series 36. Third edition.

Clesceri, L.S., A.E. Greenberg, and R.R. Trussell. 1998. Standard Methods for the Examination of Water and Wastewaters. 20th ed. Washington, D.C.: American Public Health Association.

Cogswell, S. 1998. Fishery Surveys on Five Tributaries in the Oneida Indian Reservation, Wisconsin, 1997. U.S. Fish and Wildlife Service Report No. 98-1.

Cohn, T.A., D.L. Caulder, E.J. Gilroy, L.D. Zynjuk, and R.M. Summers. 1992. The Validity of a Simple Statistical Model for Estimating Fluvial Constituent Loads – An Empirical Study Involving Nutrient Loads Entering Chesapeake Bay. Water Resources Research. 28(9):2353-2363.

Curry, R.A. and W.S. MacNeill. 2003. Population-Level Responses to Sediment During Early Life in Brook Trout. Journal of the North American Benthological Society. 23(1):140-150.

Daye, P.G. and E.T. Garside. 1975. Lethal Levels of pH for Brook Trout, Salvelinus fontinalis. Canadian Journal of Zoology. 53(5):639-641.

Dorney, J.R., C.D. Jenquin, and L.J. Lofland. 1973. Trout Creek Study. Green Bay – Brown County Planning Commission Document. 61 p.

Draper, N.R. and H. Smith. 1998. *Applied Regression Analysis.* 3rd Edition. pp. 69-70. New York: Wiley.

Gatz, A.J. Jr. and A.I. Harig. 1993. Decline in the Index of Biotic Integrity of Delaware Run, Ohio, Over 50 Years. Ohio Journal of Science. 4:95-100.

Giger, R.D. 1973. Streamflow Requirements of Salmonids. Oregon Wildlife Commission Research Division Report AFS-62-1. 117 p.

Gilmore, S. 2007. 2006/2007 Water Resources Report for the Oneida Reservation. Oneida Environmental, Health & Safety Division, Water Resources Program, Oneida, WI.

Gracyzk, D.J., Robertson, D.M., Rose, W.J. and J.J. Steuer. 2000. Comparison of Water Quality Samples Collected by Siphon Samplers and Automatic Samplers in Wisconsin. USGS Fact Sheet FS-067-00. Helsel, D.R., and R.M. Hirsch. 1992. Statistical Methods in Water Resources. Amsterdam, Elsevier Publishers. 524 p.

Hilsenhoff, W.L. 1987. An Improved Biotic Index of Organic Stream Pollution. Great Lakes Entomologist. 20:31-39.

Hilsenhoff, W.L. 1988. Rapid Field Assessment of Organic Pollution with a Family-level Biotic Index. J. N. Am. Benthol. Soc. 7(1):65-68.

Hipke, D.C. 2009. The Great Peshtigo Fire of 1871. Available http://www.peshtigofire.info/. Accessed May 12, 2009.

Johnson, H.O., S.C. Gupta, A.V. Vecchia, and F. Zvomuya. 2009. Assessment of Water Quality Trends in the Minnesota River Using Non-Parametric and Parametric Methods. Journal of Environmental Quality. 38:1018-1030.

Karr, J.R., Fausch, K.D., Angermeier, P.L., Yant, P.R., and Schlosser, I.J. 1986. Assessing Biological Integrity in Running Waters: A Method and its Rationale. Ill. Nat. Hist. Surv. Spec. Publ. No. 5.

Kohler, K. 1997. Fish Community Characteristics and Fish-Habitat Relations of Duck Creek, Wisconsin. University of Wisconsin-Stevens Point Master of Science Thesis.

Landers, M.N. 2005. Seasonality and Trends in Stream Water Quality in Gwinnett County, Georgia, 1996-2003. Proceedings of the 2005 Georgia Water Resources Conference.

Lenz, B.N. and M.A. Miller. 1996. Comparison of Aquatic Macroinvertebrate Samples Collected Using Different Field Methods. USGS NAWQA Fact Sheet FS-216-96.

Lillie, R.A., Szczytko, S.W., and M.A. Miller. 2003. Macroinvertebrate Data Interpretation Guidance Manual. Wisconsin Department of Natural Resources PUB-SS-965. Madison, WI.

Lyons, J. 1992. Using the Index of Biotic Integrity (IBI) to Measure Environmental Quality in Warmwater Streams of Wisconsin. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, General Technical Report NC_149, St Paul, MN.

Lyons, J. 2006. A Fish-based Index of Biotic Integrity to Assess Intermittent Headwater Streams in Wisconsin, USA. Environmental Monitoring and Assessment. 122:239-258.

Martin, D.B. 1913. History of Brown County Wisconsin: Past and Present. S.J. Clarke Publishing Company, Chicago, Illinois. 357 p.

Minnesota Department of Agriculture (MDOA). 2009. Water and Sediment Control Basin. Conservation Practices: Minnesota Conservation Funding Guide. Minnesota Department of Agriculture Website (http://www.mda.state.mn.us/protecting/conservation/practices/wscob.htm). Accessed May 10, 2009.

Moren, M.M. 2002. 2002 Water Resources Report for the Oneida Reservation. Oneida Environmental, Health & Safety Division, Water Resources Program. Oneida, WI.

Mulholland, P.J., A.D. Steinman, and J.W. Elwood. 1990. Measurement of Phosphorus Uptake Length in Streams: Comparison of Radiotracer and Stable PO4 Releases. Canadian Journal of Fisheries and Aquatic Sciences. 47:2351-2357.

Mulholland, P.J. and A.D. Rosemond. 1992. Periphyton Response to Longitudinal Nutrient Depletion in a Woodland Stream: Evidence of Upstream-Downstream Linkage. Journal of the North American Benthological Society. 11(4):405-419.

Munn, N.L. and J.L. Meyer. 1990. Habitat-Specific Solute Retention in Two Small Streams: An Intersite Comparison. Ecology. 71:2069-2082.

Nelson, L.M. and F.L. Fassbender. 1972. Surface Water Resources of Brown County, Lake and Stream Classification Project. Wisconsin Department of Natural Resources, Madison

NOAA. 2009. Monthly Precipitation Data. National Weather Service Weather Forecast Office. Green Bay, WI.

Oberdorff, T., and R.M. Hughes. 1992. Modification of an Index of Biotic Integrity Based on Fish Assemblages to Characterize Rivers of the Seine Basin, France. Hydrobiologia, 228:117-130.

O’Reilly, N., T.J. Ehlinger, and R. Shaker. 2007. The Development and Evaluation of Methods for Quantifying Risk to Fish in Warm-water Streams of Wisconsin Using Self-Organized Maps: Influences of Watershed and Habitat Stressors. Center for Urban and Environmental Studies, Northeastern University. Technical Report No. 14. Boston, MA.

Oschwald, W.R. 1972. Sediment-Water Interactions. Journal of Environmental Quality. 1:360-366.

Program on Agricultural Technology Studies. 2009. Land Use Data – Brown and Outagamie Counties. Accessed March 2009 available: http://www.pats.wisc.edu/landuse/tables.htm

Raleigh, R.F. 1982. Habitat Suitability Index Models: Brook Trout. U.S. Department of the Interior, Fish and Wildlife Service. FWS/OBS-82/10.24.

Reckinger, N. 2007. Comparison of Phosphorus Forms at Different Spatial Scales and Assessment of an Area-Weighted P-Index to Multi-Field Watersheds. M.S. Thesis, Environmental Science and Policy, Univ. Wisconsin – Green Bay.

Rentmeester, J. and L. Rentmeester. 1984. Memories of Old Duck Creek. Village of Howard, WI.

Rentmeester, J. and L. Rentmeester. 1989. Early Duck Creek History. Village of Howard, WI.

Richards, R.P., D.B. Baker, J.P. Crumrine, J.W. Kramer, D.E. Ewing, and B.J. Merryfield. 2008. Thirty-Year Trends in Suspended Sediment in Seven Lake Erie Tributaries. Journal of Environmental Quality. 37:1894-1908.

Robertson, D.M, D.J. Graczyk, P.J. Garrison, L. Wang, G. LaLiberte, and R. Bannerman. 2006. Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin. USGS Professional Paper 1722.

Runkel, R.L., C.G. Crawford, and T.A. Cohn. 2004. Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers. USGS Techniques and Methods Book 4, Chapter A5. 75 p.

Ryberg, K.R. and A.V. Vecchia. 2006. Water-Quality Trend Analysis and Sampling Design for the Devils Lake Basin, North Dakota, January 1965 Through September 2003. USGS Scientific Investigations Report 2006-5238.

Santy, K.L. 2001. Lower Fox River Basin Integrated Management Plan. Wisconsin Department of Natural Resources. PUBL WT-666-2001. Madison, WI. 106 p.

Scudder, B.C., J.W. Selbig, and R.J. Waschbusch. 2000. Determination of the Effects of Fine-Grained Sediment and Other Limiting Variables on Trout Habitat for Selected Streams in Wisconsin. USGS Open-File Report 00-435.

Shelton, L.R. 1994. Field Guide for Collection and Processing Stream-Water Samples for the National Water-Quality Assessment Program. United States Geological Survey Open-File Report 94-455, Sacramento, CA.

Simon, T.P., and J. Lyons. 1995. Application of the Index of Biotic Integrity to Evaluate Water Resource Integrity in Freshwater Ecosystems. *In* Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. *Edited by* W.S. Davis and T.P. Simon. Lewis Press, Boca Raton, Fla. p. 245-262.

Snitgen, J.L. and M.J. Melchior. 2008. From Headwaters to Mouth: Tribal Stream and Wetland Restoration as a Top-Down Model for Successful Watershed Restoration. Oneida Environmental Health and Safety Division Internal Presentation.

Sykora, J.E. and M. Synak. 1972. Effects of Lime Neutralized Iron Hydroxide Suspensions on Juvenile Brook Trout, Salvelinus fontinalis, Mitchill. Water Resources. 6:935-950.

Tebo, L.B. 1955. Effects of Siltation, Resulting from Improper Logging, On the Bottom Fauna of a Small Trout Stream in the Southern Appalachians. The Progressive Fish Culturist. 17:64-70.

Thornton, J.A., W. Rast, M.M. Holland, G. Jolankai, and S.O. Ryding. 1999. Assessment and Control of Nonpoint Source Pollution of Aquatic Ecosystems: A Practical Approach. New York, NY: The Parthenon Publishing Group, Inc.

Tong, S.T.Y. and W. Chen. 2002. Modeling the Relationship Between Land Use and Surface Water Quality. Journal of Environmental Management. 66(4):377-393.

United States Census Bureau (USCB). 2009. American FactFinder. Accessed March 4, 2009.

United States Department of Agriculture (USDA) National Agricultural Statistics Service. 2009. Quick Stats. Wisconsin County data (http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/)

United States Environmental Protection Agency (USEPA). 1983. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020. USEPA Environmental Monitoring and Support Laboratory. Cincinnati, OH

USEPA. 1993. Paired Watershed Study Design. Office of Water Publication EPA-841-F-93-009.

USEPA. 2001. Functions and Values of Wetlands. Office of Wetlands, Oceans and Watersheds publication EPA 843-F-01-002c.

USEPA. 2003. National Water Quality Report to Congress (305(b) report). Available: http://www.epa.gov/OWOW/305b/.

United States Geological Survey (USGS). 2000. Surface-Water Quality, Oneida Reservation and Vicinity, Wisconsin, 1997-1998. Water-Resources Investigations Report 00-4179.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The River Continuum Concept. Canadian Journal of Fisheries and Aquatic Sciences. 37:130–137.

Wang, L., J. Lyons, P. Kanehl, and R. Gatti. 1997. Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams. American Fisheries Society. 22(6):6-12.

Wang, L., Lyons, J., Kanehl, P., and R. Bannerman. 2001. Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales. Environmental Management. 28(2):2001.

Wesche, T.A. 1974. Evaluation of Trout Cover in Smaller Streams. Proceedings of the Western Association of State Game and Fish Commissioners. 54:286-294.

Wisconsin Department of Natural Resources (WDNR). 1997. Nonpoint Source Control Plan for the Duck, Apple and Ashwaubenon Creeks Priority Watershed Project. PUBL WT-493-97. Madison, WI.

WDNR. 2006. Duck Creek Watershed (LF05). Wisconsin Department of Natural Resources website. Available: http://dnr.wi.gov/org/gmu/lowerfox/surfacewaterfiles/watersheds/lf05.html.

WDNR. 2006. Wisconsin's Long Term Trend Water Quality Monitoring Program for Rivers. WDNR Bureau of Watershed Management, River Long Term Trends Work Group. Madison, WI. 51 p.

WDNR. 2008. Wisconsin's Impaired Waters Program. Accessed 11-April-2009. Available: http://www.dnr.state.wi.us/org/water/wm/wqs/303d/2008/2008Updates.htm

Zale, A.V., D.M. Leslie, W.L. Fisher, and S.G. Merrifield. 1989. The Physiochemistry, Flora, and Fauna of Intermittent Prairie Streams: A Review of the Literature. Biological Report 89(5). U.S. Fish and Wildlife Service, Washington D.C.