SUITABILITY OF COHO SALMON HABITAT IN MADDOX AND CARPENTER CREEKS: SKAGIT DELTA, WASHINGTON

By

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Abstract

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The Skagit Delta of western Washington has been highly altered from its natural environment over the past century. Anthropogenic activities throughout the watershed have caused increased nutrients and sediments to enter the Skagit River, its tributaries and sloughs leading to poor water quality and reduced native fisheries. Growth of urban and suburban developments is currently impacting the aquatic systems within the Delta. Recently, the Nature Conservancy, working with local agricultural and tribal groups, has begun to address some of these problems in the lower Skagit Delta. For example, the Fisher Slough Restoration Project (FSRP) has been developed to improve water quality and aquatic habitat for species like the coho salmon, *Oncorhynchus kisutch* (Walbaum). In this study, we evaluated baseline water quality conditions in two freshwater creeks (Maddox and Carpenter Creeks) that will be affected by the FSRP. Biological, chemical and physical parameters were used to assess stream environments relative to coho seasonal life cycle requirements. All parameters indicated that the majority of reaches along the study creeks are unlikely to support native coho populations; downstream sites are the most impacted compared to headwater reaches. The FSRP should increase coho populations and enhance access to less impacted upper headwaters by targeting critical spawning and rearing habitat in the lower stream sections. This initial study of physical, biological and chemical water quality parameters will allow for assessment of restoration activities for coho habitats.

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CHAPTER ONE

INTRODUCTION

Overview

Streams in the Pacific Northwest have historically provided high-quality habitat for andronomous salmonids (Benda et al. 1992). Good water quality within freshwater streams is essential for providing suitable habitat for the life cycle of salmonids. Over the past century, many salmonid habitats have been heavily impacted by various anthropogenic activities, reducing water quality and degrading critical freshwater habitat (Bisson et al. 1992). The decrease in habitat, due largely to changes in surrounding land use, has led to diminished and in some cases extinction of salmonid stocks (Nehlsen et al. 1991, Bisson and Gregory 1997).

The Skagit River is the largest river flowing into the Puget Sound. It has an 8,030 km^2 watershed and supports five species of Pacific salmon; Chinook (*Oncorhynchus tshawytscha* Walbaum), chum (*O.*keta Walbaum), coho (*O.kisutch* Walbaum), pink (*O.gorbuscha* Walbaum), and sockeye (*O.nerka* Walbaum) (Hood 2004). The Skagit River Delta, comprised of approximately 32,670 ha, has been significantly altered by anthropogenic changes throughout the past century (Hood 2004). Prior to the 1800s, salmonid habitat within the Skagit basin was primarily in floodplains and deltas (Beechie et al. 2001). Beginning in the 1850s much of the land was converted to agriculture and other forms of development, resulting in isolation of over 90% of the Delta from riverine and tidal influences (Collins and Montgomery 2001). Today, the conversion of agricultural land to domestic and industrial sites is causing increased nutrients and toxic materials to enter the waterways, further reducing critical salmonid habitat (Pess et al. 2003).

Since 1991 there have been steep declines in the number of coho salmon returning to the Puget Sound region due to habitat alterations, poor ocean survival and harvest pressure (Johnson et al. 1997). In the Skagit Delta, coho salmon smolt production has decreased significantly due to the loss of both summer and winter rearing habitat (Beechie et al. 1994). Prior to European settlement, winter rearing habitats produced almost twice as many coho smolts as today (Beechie et al. 2001). In 1994, Beechie et al., estimated production levels of smolts in summer conditions to be 0.98 million (historically estimated at 1.28 million) and 1.17 million (historically estimated at 1.77 million) in winter conditions.

Coho salmon are reliant on low gradient tributaries for spawning and sloughs for rearing habitat (Benda et al. 1992, Nicklelson et al. 1992). Distributary and side channel sloughs produce the largest number of coho smolts within the Skagit Delta, yet these areas are the most threatened by current land use activities (Beechie et al. 1994). Currently smolt production within the Delta has decreased from historic rates by 45% in side channel sloughs and by 64% in distributary sloughs (Beechie et al. 1994). With conversion of agricultural lands to urban and suburban developments the coho population faces the threat of further habitat reduction and population stresses.

Coho may be more sensitive than other salmon species to changes in physical habitat and water quality, because they have a relatively fixed age for smolting and spawning (Waples 2008). Juvenile coho also require a residence time of a year or more before migration to the sea (McMahon 1983, Sandercock 1991, Behnke 2002), longer than most species of Pacific salmon (Behnke 2002). These life requirements of juvenile coho make them susceptible to an amplitude of natural and anthropogenic perturbations during the rearing period (Meehan 1991). However, they consistently respond well to habitat restoration (Roni et al. 2003) and therefore can be useful for indicating if restoration activities are successful.

Project History and Site Description

Recently, the Nature Conservancy, working with tribal and agricultural groups, has developed a project to restore salmonid habitat while also preserving farmland from the threat of urban and suburban development. The Fisher Slough Restoration Project (FSRP) was designed to improve habitat in one critical side channel slough within the Skagit Delta. The hydrologic functions within Fisher Slough have been altered over the past 150 years from the construction of channels, drainage canals and levees for flood control and irrigation. Historically, Fisher Slough was a transitional zone where several freshwater tributaries convened and formed an alluvial fan, before flowing to the Skagit Bay through a floodplain marsh (Tetra Tech 2007). Channel realignment, dredging and grading to reduce flooding for agricultural purposes, have resulted in loss of much of the alluvial fan, riparian floodplain and wetland areas within the Slough (Tetra Tech 2007).

The FSRP site (Fig. 1) is located at the downstream end of the Carpenter Creek watershed and the confluence with Tom Moore Slough, on the South Fork of the Skagit River, south of Conway, WA. (Tetra Tech 2007). Fisher Slough is a tidally influenced freshwater marsh, and the main inflow is from the Skagit River. Fisher Slough is also fed by three freshwater tributaries, Carpenter Creek (also known as Hill Ditch), Big Fisher Creek and Little Fisher Creek (Tetra Tech 2007).

Culverts and other stream crossing structures block important coho habitat within the Skagit River, reducing an estimated 6% of area used for rearing (Beechie et al. 2001). Multiple structures and features also impact hydraulic functions and fish passage within Fisher Slough,

Maddox and Carpenter Creek Study Area

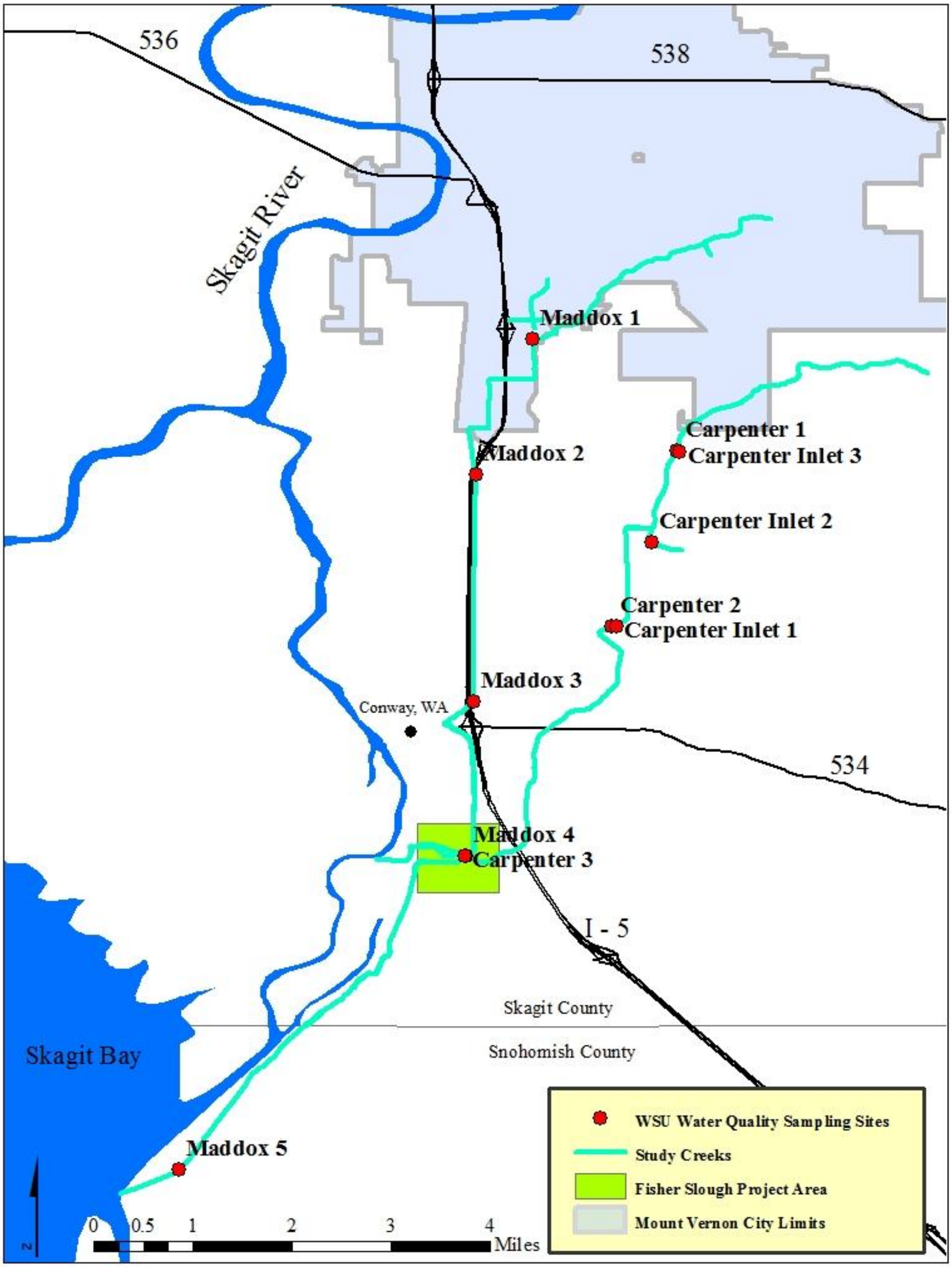

Figure 1. Study Area within the Skagit Delta, with Sampling Locations

such as the primary barrier, the Maddox Creek (also known as Big Ditch) culvert (Tetra Tech 2007). Maddox Creek is lower in elevation than Fisher Slough, so to prevent flooding on surrounding agricultural land, a manmade ditch system and levees were created between 1910 and 1945 (WWAA et al. 2007). The lower reach of Maddox Creek crosses directly underneath Fisher Slough, through the culvert structure, and then continues four miles south to Skagit Bay.

The confluence of Carpenter Creek with Big and Little Fisher Creeks is upstream of the Maddox Creek crossing. Carpenter Creek is channelized upstream of Fisher Slough, where the banks are lined with sedge and grass. Three cold water tributaries, Sandy (Inlet 1), Johnson (Inlet 2) and Bulson (Inlet 3), enter into this portion of Carpenter Creek. At the mouths of these inlets excess sedimentation has built up around the alluvial fans and combined with backwater in Fisher Slough, flooding often occurs. The low gradient of Carpenter Creek is important for coho habitat (Sandercock 1991), but contributes to the sedimentation problem, and frequent dredging of the channel is necessary to maintain hydraulic functioning (Tetra Tech 2007). The excessive sediment entering into Carpenter Creek also decreases the feeding ability and disease resistance of coho (Redding and Schreck 1987).

The FSRP will replace floodgates, realign and remove levees within the slough, modify the Maddox Creek crossing, restoring and enhancing the floodplain through development of secondary side channels, blind tide channels, ponds, wetlands, marshes and riparian areas (Tetra Tech 2007). Restoration of landscape processes and functions within the Fisher Slough is expected to improve water quality and aquatic habitat, and thus enhance native fish populations. The FSRP is expected to create 60 acres of tidal freshwater marsh habitat for juvenile salmonids and allow access to 15 additional miles of high quality spawning streams (TNC 2010). Coho should specifically benefit from the scheduled restoration because of the improvements to low river, off channel slough areas that they rely on for a significant portion of their life (Beechie and Bolton 1999). Local farmers and landowners will also likely prosper from the restoration through improved drainage and flood storage for the upstream tributaries to the South Fork of the Skagit River.

Purpose and Goals of Coho Habitat Assessment

The goal of this study is to determine the suitability of coho salmon habitat in Maddox and Carpenter Creeks in relation to surrounding land use using biological, chemical and physical parameters. Specifically, I want to know the conditions of coho habitat within Maddox and Carpenter Creeks prior to scheduled restoration. Determining the baseline conditions is critical for long term analysis of changes in water quality and aquatic habitats that may result from changing land use patterns, planned restoration activities and altered practices on agricultural lands.

Objectives

Obj. 1 Quantify basic water quality parameters and relate them to coho life requirements.

Obj. 2 Determine ecological conditions with relation to coho life cycle requirements, using benthic invertebrate community composition.

Obj. 3 Determine the amount of suitable physical habitat available at each sampling site using the coho habitat suitability index, to establish baseline conditions prior to restoration.

CHAPTER 2

MATERIALS AND METHODS

Sampling Sites and Locations

Eleven sampling locations were identified before the first sampling event and were used for the duration of the project (Fig.1). Sites were chosen to maximize water quality, biological and hydrologic information in relationship to the Fisher Slough restoration site and their accessibility for field sampling. The inlets flowing into Carpenter Creek were studied because they are less impacted than the downstream Carpenter and Maddox sites and because of their influence on Carpenter. The downstream sites in Carpenter Creek (Carpenter sites 2 and 3) and Maddox (Maddox sites 2, 3, 4 and 5) are more heavily influenced by anthropogenic activities, and Maddox Creek as a whole may be more impacted because it flows through an extensive agricultural area as well as the industrialized zones in the city of Mt. Vernon. Sampling sites located within the main stem of Carpenter and Maddox Creeks were chosen for comparison of less disturbed sites (upstream) to more disturbed sites (downstream). Additionally, the downstream sites are expected to be affected by the Fisher Slough Restoration Project (FSRP). The upstream sections of Maddox (Maddox site 1), Carpenter Creeks (Carpenter site 1) and the inlets will serve as “references” for this project as they will not be affected by the scheduled restoration. Sampling in multiple locations throughout the watershed showed where detrimental inputs of excess nutrients and sediments occur.

Sample Collection and Analysis

Fifteen sampling events were conducted throughout the summers of 2007-2009 (Appendix A). Sampling was timed as best as possible to correspond with daytime high tide, to provide consistent conditions in the lower end of the drainage system.

Water Properties

Temperature, dissolved oxygen, pH and specific conductivity were measured at each site using a Hydrolab, MiniSonde 5, multiprobe (Hach Environmental, Inc.). The MiniSonde was calibrated in the lab 24 hours prior to deployment following methods described by the manufacturer for accurate sensor functioning. Water property readings were taken from the thalweg flow where there were no riffles or pools, to avoid oxygenation from bubbling aeration. The MiniSonde was carefully lowered into the stream so as to not disturb the sediment or move other debris into the sensors.

Water Sampling

Water samples for nitrogen, phosphorus and suspended solid samples were collected in acid-washed 500 mL Nalgene bottles from each sampling location. Bottles and caps were triple rinsed with the sample water, then water was collected from the subsurface to avoid water-air interface and to obtain an integrated collection. Samples were collected upstream of the entry point, away from streamside vegetation and sediments to avoid contamination. Samples were held in the dark and on ice for transport to the laboratory.

Nutrient Analysis

Phosphorus and nitrogen were analyzed on a Seal AutoAnalyzer 3 (AA3), with colorimetric detection. Analytical protocols followed the standard methods (APHA) as modified for the AA3 (Seal Analytical 2008). All reagents and calibrates were National Institute for Standards and Technology (NIST) traceable.

Samples for orthophosphate, nitrate/nitrite, ammonia, and alkalinity were filtered with Millipore 0.45µm filters within 24 hours of sampling. Total phosphorus (TP) samples were not filtered, but were digested prior to analysis with a persulfate digestion (Seal Analytical 2008).

This digestion process uses an autoclave, combining high temperatures, pressure and strong acids to completely convert all forms of phosphorus to orthophosphate (PO_4^{-3}). In an acidic medium, orthophosphate reacts with molybdenum (VI), antimony (III) and ascorbic acid to form a blue complex that is detected colorimetrically at 880nm (Seal Analytical 2008).

Suspended Solids Analysis

Suspended solids were analyzed using modified standard methods (Standard Methods 1975). Sixty mL of water was dried at 103-105°C in a drying oven, than cooled to room temperature before weighing.

Discharge

Stream discharge was measured in the field using standard cross sectional area/velocity methods (Rantz et al. 1991, Noland and Shields 2000) at all sites except Maddox 5, which was stagnant during every sampling event. Velocity was measured with a Swoffer velocity meter (Swoffer Instruments, Seattle WA.).

Benthic Macroinvertebrate Sampling, Identification and Analysis

Benthic invertebrates were collected with a Surber, D-net or Eckman dredge sampler depending on the nature of the site. Three replicate samples were taken from the thalweg at each site (except for Maddox 5). Maddox 5 was not sampled for invertebrates because of the influence of saline, the substrate there is a concrete pad and the nature of the sampling techniques. Replicates were combined into a composite sample for each site. Materials collected in the samplers were removed using tweezers, stored in acid-washed Nalgene bottles and immediately preserved with a 70% ethanol solution.

Invertebrates were sorted in white trays, under bright lights, using a large magnifying glass (hand-crafter's lamp). Individual organisms were picked out with fine forceps and placed into small glass vials then counted and identified to the lowest possible taxonomic unit using appropriate keys. Identifications were performed using the taxon from McCafferty 1983, Merrit and Cummings 1984 and Voshell 2002.

The invertebrate population was first analyzed by calculating the average number of species, by family, for each site. Then percentages of pollution tolerant (Annelida, Gastropoda Bivalvia) and intolerant (Ephemeroptera, Plecoptera and Trichoptera) species were computed. Three water quality metric indexes were also calculated for each site; EPT abundance, the Hilsenhoff biotic index (HBI) and the Shannon-Wiener diversity index. EPT abundance was calculated by summing the total Ephemeroptera, Plecoptera and Trichoptera collected and dividing that number by the total sample size. EPT abundance expressed percentages of pollution intolerant species at each sampling site. The HBI provides a measure of water quality for each sampling site by assigning tolerance values to all arthropod families. The HBI was calculated by multiplying the number of individuals in each family to a maximum of 10, times the family tolerance value, then summing the products, and dividing by the total arthropods collected at each site (Hilsenhoff 1988, Hilsenhoff 1998). The Shannon-Wiener index expressed diversity of the macroinvertebrate community as a function of the total number of species and the distribution of individuals between species:

$$H = -\sum_{i=1}^{s} p_i \ln p_i$$

Where **S** is the total number of taxa, and $\mathbf{p_i}$ is the proportion of **S** making up the ith taxa.

Coho Salmon Habitat Suitability Index

A habitat suitability index (HSI) was calculated for each site based on characteristics and measurements of upstream and downstream reaches for each site, unless it was possible to only establish one reach. A reach was defined as ten times creek width and within each reach, ten evenly spaced transects were established. Water quality, food and cover were assessed at each transect relative to various life requirements of coho (McMahon 1983). A numerical index, based on preference curves developed by McMahon, 1983, was assigned to each parameter and its corresponding life stage for a total of fifteen different indices. HSI values can range from 0.0, representing unsuitable habitat, to a maximum of 1.0, indicating optimal conditions. The values obtained within each reach were averaged together, using the assumption that all variables of the habitat equally contribute to the suitability of each site. For sites with two reaches, the HSI was expressed as an average of both reaches. The HSI values for each system were then averaged together to determine the overall suitability of each creek. Habitats between 0.0-0.19 were considered poor, 0.2-0.49 fair, 0.5-0.79 good and 0.8-1.0 excellent. Habitat under 0.49 was considered unsuitable for coho (McMahon 1983).

Statistical Analysis

Statistical analyses were conducted using Minitab 15 (Minitab Inc. 2010). ANOVA was used to test statistical differences in response means for chemical and physical variables among sampling locations. For biological measurements, the General Linear Model with two treatments and interaction was used. Once found significant, multiple comparisons using Tukey tests were completed for pairwise differences. If interaction was detected between variables, interaction plots and contrasts were used. Main effects were presented if no interactions were detected.

Two sample t-tests were run to determine if the community composition of invertebrates was pollution tolerant or intolerant based on the sampling location. Once the sites were classified as tolerant/intolerant, physical and chemical measurements were analyzed using a 2 sample t-test to see if these variables corresponded to differences in invertebrate community composition. Pearson correlations were calculated between physical and chemical measurements to determine if there was a relationship between nutrient concentrations and the Habitat Suitability Index. Type 1 error rate, α, was controlled at 0.05.

CHAPTER 3

RESULTS

Temperature

Carpenter 1, Maddox 1 and the inlets were all significantly cooler than the downstream sections of Maddox and Carpenter Creek ($P<0.05$). In Maddox Creek, temperatures were recorded at 20°C or higher on seven sampling dates (Table 13, Appendix A). A maximum temperature of 23.1°C was recorded in Maddox 4 on August 18, 2009 (Fig. 2 and Table 13, Appendix A). In Carpenter Creek, water temperatures in excess of 20°C were measured three times, with a maximum temperature of 22.4°C recorded in Carpenter 2 on July 15, 2008 (Fig. 3 and Table 13, Appendix A). Two of the times that temperature was above 20°C occurred in Carpenter site 2. High temperatures are likely associated with this site because it is a stagnant backwater area. With the contribution of cool water from the tributaries, the temperatures were generally lower further downstream. However, on July 15, 2008 temperature in Carpenter 3 was recorded at 20.4°C.

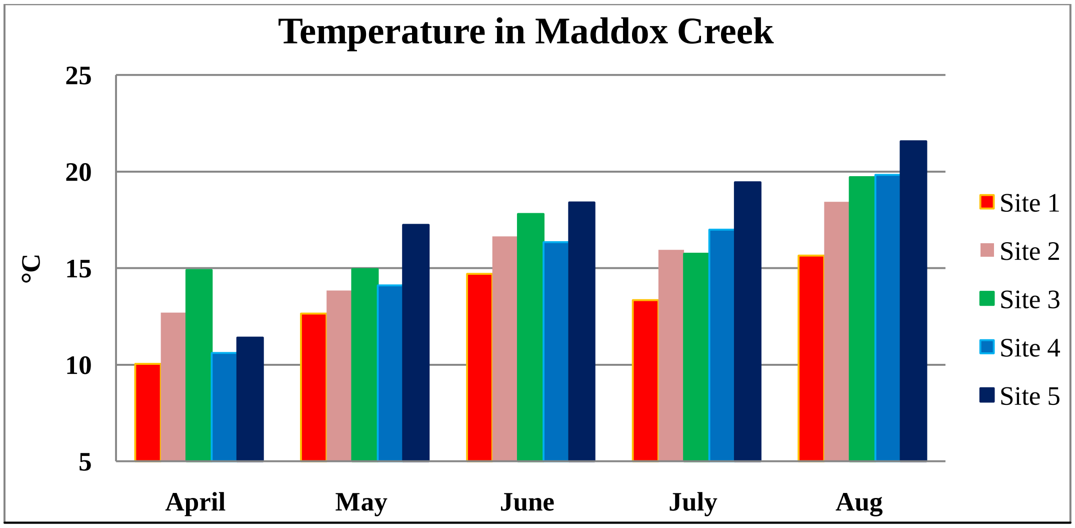

Figure 2. Average Temperature in Maddox Creek by Sampling Site, 2007-2009

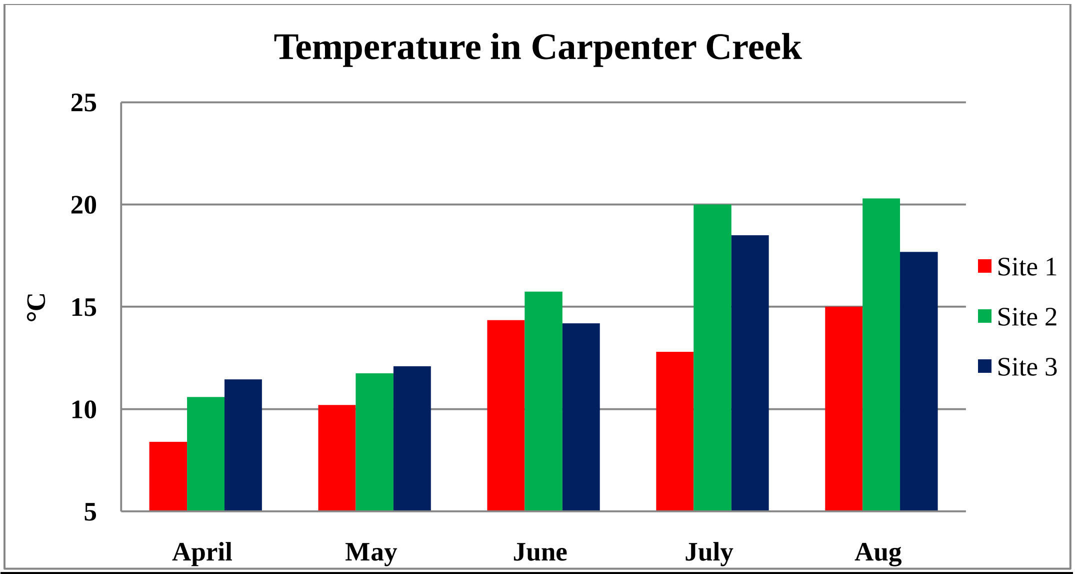

Figure 3. Average Temperature in Carpenter Creek by Sampling Site, 2007-2009

Dissolved Oxygen

Dissolved oxygen (DO) concentrations were significantly higher in Carpenter 1, Maddox 1, Inlet 1, Inlet 2 and Inlet 3 than Carpenter site 2 and Maddox sites 2 and 3 ($P<0.05$). Hypoxic conditions, with DO less than 4 mg/L were recorded seven times in Maddox Creek sites 2-4, and anoxic conditions, with DO levels less than 1 mg/L were recorded two times (Table 14, Appendix A). DO was as low as 0.4 mg/L in Maddox 4 on April 10, 2008 and 0.6 mg/L in Maddox 2 on August 21, 2008. In comparison, dissolved oxygen within Carpenter Creek only fell below 5 mg/L once, at site 2, on September 11, 2007 (4.7 mg/L; Table 14, Appendix A). The lowest DO level recorded in the inlets was 8.8 mg/L at Inlet 2 (November 15, 2007) and Inlet 3 (August 18, 2009; Table 14, Appendix A).

pH

Although there were significant differences between pH across the sampling sites ($P<0.001$), no pattern was established by the pH averages. Median values and seasonal ranges are typically used to assess pH, so the averages used in ANOVA can't be relied on to determine if differences in pH exist. Acidic conditions, with median pH values below 6.5 were recorded in Maddox 2 (pH 6.3), and Carpenter 2 (pH 6.3), in 2007 (Table 1 and Table 16, Appendix A). In respect to the Washington State Department of Ecology (WSDE) standard pH range to support salmonids, the pH range fell below the standard thirteen times over the period of sampling (Washington State Legislature <WSL> 2006). The overall range was above WSDE standards two times at Maddox 4. Maddox 5 was the only site that fell below the WSDE range pH standards each year, with pH measured as low as 5.2 in 2008, indicating acidic conditions.

Table 1. Median Values and Seasonal Ranges of pH in Maddox, Carpenter and Carpenter Inlets

Median pH Values within Maddox, Carpenter and Inlets, 2007-2009								
			2007 August-Nov.		2008 March-Aug.		2009 April-Aug.	
	Annual Median	Annual Range	Median	Range	Median	Range	Median	Range
Maddox 1	7.25	6.5-7.9	6.6	6.5-7.1	7.2	6.7-7.6	7.6	7.4-7.9
Maddox 2	7	6.1-7.3	6.3	6.1-7.2	7.0	6.3-7.3	7.1	7.0-7.2
Maddox 3	7.2	6.2-8.7	6.5	6.2-7.2	7.1	6.6-8.3	7.2	7.0-8.7
Maddox 4	7.7	6.1-9.3	7.6	6.1-9.3	7.3	6.7-8.3	7.5	6.9-9.0
Maddox 5	6.8	5.2-7.6	6.6	6.2-7.2	6.8	5.2-7.4	7.1	6.4-7.6
Carpenter 1	7.6	6.4-7.9	6.8	6.4-7.3	7.5	6.9-7.9	7.7	7.6-7.8
Carpenter 2	7.3	6.1-8.3	6.3	6.2-7.2	7.3	6.1-7.3	7.5	7.4-8.3
Carpenter 3	7.4	6.3-8.0	7.1	6.3-8.0	7.4	6.5-7.5	7.4	7.2-7.6
Inlet 1	7.6	6.5-7.8	6.5	6.5	7.5	6.5-7.7	7.6	7.4-7.8
Inlet 2	7.9	6.9-8.2	7.1	6.9-7.8	8.0	7.6-8.2	8.0	7.8-8.0
Inlet 3	7.6	6.3-8.0	6.4	6.4	7.3	6.3-7.6	7.7	7.6-8.0

Alkalinity

Alkalinity was variable over the course of sampling. Alkalinity was significantly different across sampling sites ($P<0.001$). The highest average alkalinity was measured in Inlet 3 ($P<0.05$). The highest alkalinity measured in the inlets was 216.2 mg/L on August 21, 2008 in Inlet 3 (Table 17, Appendix A). The most alkaline conditions in Maddox Creek were at site 3 on September 11, 2007 (153.4 mg/L; Table 17, Appendix A). In Carpenter Creek, the most alkaline conditions were measured at site 1 on July 14, 2009 (180.8 mg/L). In terms of median values, alkalinity was highest at Inlet 3 (133.4 mg/L) and lowest at Inlet 1 (39.4 mg/L; Table 2). In Maddox Creek the highest median alkalinity was at site 2 (116.0 mg/L) and the lowest was at site 4 (62.2 mg/L; Table 2). The highest median alkalinity within Carpenter Creek was at site 2, (104.9 mg/L) and lowest at site 3 (81.7 mg/L; Table 2).

Table 2. Median Values of Alkalinity, 2007-2009

Maddox 1	76.5
Maddox 2	116.0
Maddox 3	107.5
Maddox 4	62.2
Maddox 5	94.3
Carpenter 1	92.7
Carpenter 2	104.9
Carpenter 3	81.7
Inlet 1	39.4
Inlet 2	105.8
Inlet 3	133.4

Specific Conductivity

Specific conductivity was highest in Maddox Creek at site 5 ($P<0.05$). Although there were no significant differences between specific conductivity at the other sampling sites, values within the disturbed Maddox sites 2-4, were generally higher. In Maddox sites 2-4, specific conductivity was above 300 mS/cm twenty four times and was highest at Maddox 5 on August 15, 2007 (16,424 mS/cm; Table 18, Appendix A). Excluding Maddox site 5, a site highly influenced by saltwater, specific conductivity was highest in the Maddox system at site 2 on August 15, 2007 (769 mS/cm). In Carpenter Creek specific conductivity was only above 300 mS/cm ten times and was highest at site 1, on September 11, 2009 (788 mS/cm; Table 18, Appendix A). Specific conductivity was above 300 mS/cm eleven times in the inlets and was highest at Inlet 3 on August 21, 2008 (416 mS/cm; Table 18, Appendix A).

Nutrients

Nitrate/Nitrite

Generally, the highest nitrate/nitrite concentrations were measured at Maddox 2. Nitrate/nitrite concentrations within Maddox 2 were significantly higher than those in Carpenter 2, Carpenter 3, Inlet 2, Inlet 3, Maddox 1 and Maddox 4 ($P<0.05$). Nitrate/nitrite levels were measured as high as 7.316 mg/L at Maddox site 2 on July 15, 2008. Nitrate/Nitrite was above 1.0 mg/L eleven times in Maddox Creek, two times in Carpenter Creek and two times within the inlets (Table 19, Appendix A). The highest concentration measured in Carpenter Creek was 2.765 mg/L at site 1 on March 12, 2008 (Table 19, Appendix A). The highest concentration measured within the inlets was 1.406 mg/L at Inlet 1 on April 10, 2008 (Table 19, Appendix A).

Ammonia

Ammonia concentrations were highest at the disturbed Maddox sites. Maddox sites 2, 3, 4 and 5 had significantly higher ammonia concentrations than Carpenter 1, Maddox 1 and the three inlets ($P<0.05$). Ammonia was in excess of 0.100 mg/L fifteen times in Maddox Creek, and once in Carpenter Creek (Table 20, Appendix A). Concentrations were measured as high as 0.378 mg/L on March 12, 2008 at Maddox site 4 (Table 20, Appendix A). An ammonia concentration of 0.130 mg/L was measured on May 20, 2008 at Carpenter site 1 (Table 20, Appendix A). The ammonia concentrations within the inlets were never above 0.098 mg/L (Table 20, Appendix A).

Orthophosphorus

Carpenter 3 had significantly higher orthophosphorus concentrations than all other sampling sites ($P<0.05$). Maddox sites 1, 2, 3 and 4 had significantly higher orthophosphorus concentrations than Carpenter 1, Inlet 1 and Inlet 3 ($P<0.05$). Orthophosphorus was measured as high as 0.210 mg/L at Carpenter 3 on September 11, 2007 (Table 21, Appendix A). The highest orthophosphate value recorded in Maddox Creek was 0.151 mg/L at Maddox 3 on April 16, 2009 (Table 21, Appendix A). The highest orthophosphate measured in the inlets was on September 11, 2007 (0.025 mg/L; Table 21, Appendix A).

Total Phosphorus

Total Phosphorus (TP) concentrations were significantly difference across sites ($P<0.001$). TP concentrations were significantly higher in all Maddox sites and Carpenter 3 than in Carpenter 1 and the inlets ($P<0.05$). TP was above 0.200 mg/L four times in Maddox Creek (Table 22, Appendix A). Three of the four times these high TP values occurred in Maddox 3, where concentrations were as high as 0.417 mg/L on July 15, 2008 (Table 22, Appendix A). The highest TP concentration measured in Carpenter Creek also occurred on July 15, 2008 when it was 0.189 mg/L at Carpenter 2 (Table 22, Appendix A). The highest TP concentrations in the inlets were measured on August 15, 2007 at Inlet site 2 (0.054 mg/L; Table 22, Appendix A).

Suspended Solids

Maddox 5 had significantly higher suspended solid concentrations than any other sampling site ($P<0.05$). In Maddox 5, suspended solids were measured in excess of 1.0 mg/L two times (Table 23, Appendix A). In Maddox 5, on April 16, 2009, concentrations were measured at 1.2 mg/L and on August 18, 2009 concentrations were measured as high as 2.0 mg/L (Table 23, Appendix A). Suspended solid concentrations within Maddox sites 4 and 5 were between 0.4 mg/L and 1.0 mg/L ten times (Table 23, Appendix A). In Maddox site 1, concentrations were below 0.2 mg/L, except on July 15, 2008 when concentrations were measured at 0.9 mg/L (Table 23, Appendix A). Only two times were concentrations above 0.4 mg/L in Carpenter Creek, and these both occurred at Carpenter site 1 (Table 23, Appendix A). Suspended solids at Carpenter 1 were measured on August 15, 2007 at 0.4 mg/L and on September 11, 2009 at 0.6 mg/L (Table 23,

Appendix A). The highest suspended solids concentrations within the inlets were measured in Inlet 3 on May 20, 2008 (0.3 mg/L; Table 23, Appendix A).

Discharge

Discharge was much more variable in Carpenter Creek than in Maddox Creek or the inlets. Carpenter 3 had significantly higher discharge than any other sampling site ($P<0.05$). The highest discharge measured at Carpenter 3 was 78.7 cfs on April 10, 2008 (Table 24, Appendix A). The highest discharge measured within the Maddox system was at Maddox 4 on April 16, 2009 at 27.8 cfs (Table 24, Appendix A). The highest discharge measured in the inlets was on April 10, 2008 at Inlet site 1, 7.9 cfs (Table 24, Appendix A).

Benthic Macroinvertebrates

Invertebrate community composition varied significantly among sites ($P<0.001$). There were significantly more pollution tolerant species of benthic macroinvertebrates than pollution intolerant species at all Maddox sites, Carpenter 2 and Carpenter 3 ($P<0.05$). Intolerant species dominated the community composition at Carpenter 1 and all inlet sites ($P<0.05$). In 2007 and 2008, nearly 100% of the invertebrates collected at the highly impacted Maddox sites were pollution tolerant (Fig. 4 and 7). In 2009, several intolerant species were collected from Maddox site 3 and site 4, although pollution tolerant species still made up the majority of the community (Fig. 10). The downstream Carpenter sites also had communities dominated by pollution tolerant species, although there were more intolerant species collected at these sites than the downstream Maddox sites. In 2007, nearly 80% of invertebrates collected in Carpenter 3 (Fig. 5) and 85% in Carpenter 2 were pollution tolerant (Fig. 8). In 2009, over 90% of the benthic invertebrate community was pollution tolerant at these sites (Fig. 11). In comparison, the community composition within Carpenter 1 was dominated by pollution intolerant species, and tolerant species never represented more than 25% of the total population (Fig. 8). Generally, the invertebrates collected within the inlets were pollution intolerant species, with tolerant species comprising 10% or less of the total community (Fig. 6 and 9). However, in 2009, pollution tolerant species comprised nearly 40% of the community within Inlet 1 (Fig. 12).

High phosphorus, ammonia, suspended solids, low dissolved oxygen and high temperatures were significantly associated with impacted sites dominated by pollution tolerant invertebrate populations ($P<0.05$). High HSI values were associated with sites dominated by pollution intolerant invertebrates ($P<0.05$).

The EPT abundance corresponded positively to the pollution intolerant community composition. Pollution intolerant EPT abundance was highest in Carpenter 1 and the inlet sites every year of sampling (Table 3, 4 and 5). The highest EPT abundance was 82% at Inlet 1 in 2007 (Table 3). In 2009 the EPT abundance was measured as low as 27% at Inlet 1 (Table 5); however, generally the EPT abundance was closer to 50% at the less impacted sites. Maddox Creek and the downstream Carpenter sites had much lower EPT abundances. EPT abundance was 0% in Maddox sites 2 and 3 because no Ephemeroptera, Plecoptera or Trichoptera were collected from these locations. The highest percentage of EPT within Maddox Creek was 7% in Maddox 1 in 2008 (Table 4). The highest EPT percentage at the highly impacted Maddox sites was 2% at site 4 in 2009 (Table 5).

The HBI scores ranged from 0 to 10, with lower numbers indicating better water quality. Carpenter site 1 and the inlets generally had the lowest HBI scores, signifying better water quality than Maddox Creek (Table 3, 4 and 5). These four sites always had excellent to good water quality. The lowest HBI score recorded was at Inlet 1 in 2007, 2.43, indicating excellent water quality (Table 3). The highest HBI score recorded within these sites was in 2009 at Inlet 1

4.65, indicating good water quality (Table 5). Carpenter site 2 had very good water quality in 2007 and good water quality in 2009, 3.61 and 3.85 (Table 3 and 5). However, water quality in 2008 at this site was 5.56, indicating fair water quality (Table 4). The highly impacted Maddox sites, 2-4, generally ranged between very poor and good water quality (Table 3, 4 and 5). In 2007, the highest HBI was measured at Maddox site 3, 8.00, indicating very poor water quality (Table 3). Maddox 1 had a low HBI scores in 2007, 3.17, signifying excellent water quality (Table 3). However, in 2008 and 2009 the HBI at Maddox site 1 rose to 4.79 and 4.59, indicating good water quality (Table 4 and 5).

The Shannon H Diversity index did not indicate much variation across sampling sites. The greatest diversity measured was 3.52 in 2007 at Carpenter site 2 (Table 3). In 2007, diversity was also high at Maddox site 3, 3.49, Inlet site 2, 3.15 and Carpenter site 1, 3.13 (Table 3). In 2008 the highest diversity measured was 1.46 at Maddox site 1 (Table 4). In 2009, the highest diversity measured was 1.59 in both Maddox site 3 and Carpenter site 1 (Table 5). The lowest diversity measured was 0.93 at Inlet site 1 in 2009 (Table 5).

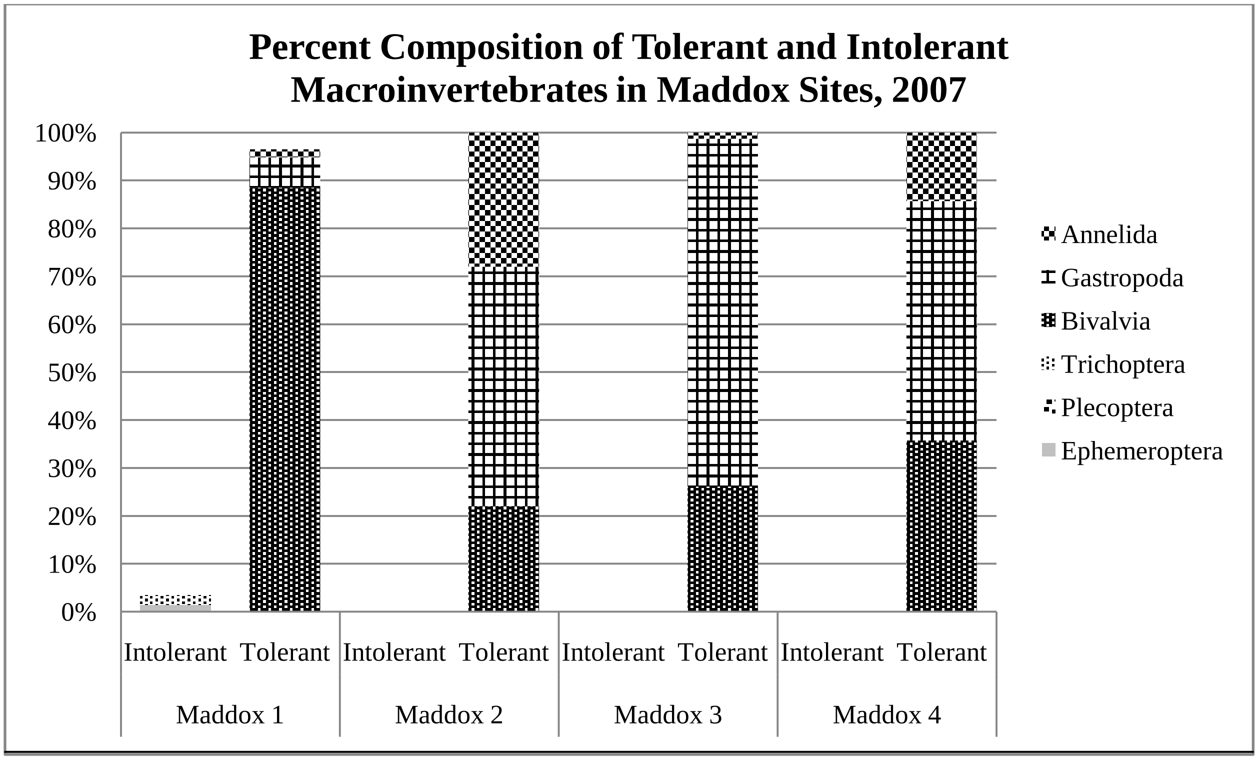

Figure 4. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Maddox Creek by Sampling Site, 2007

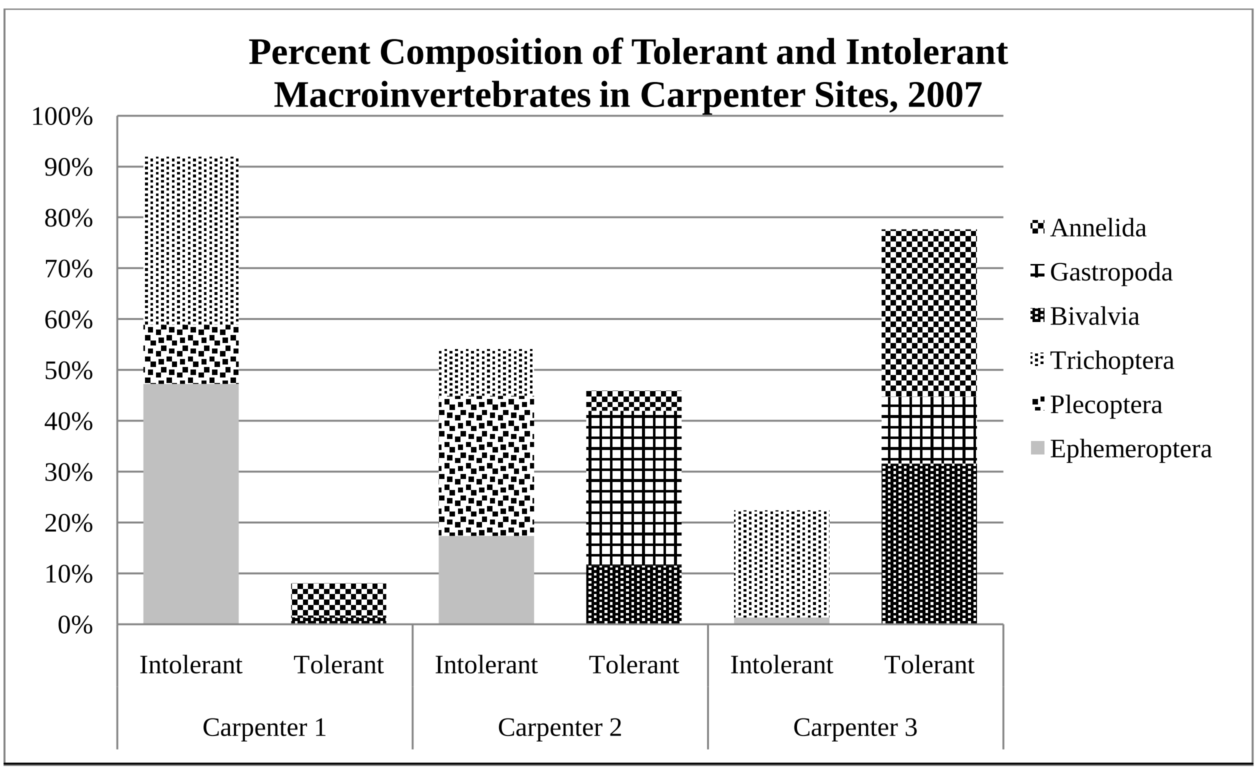

Figure 5. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek by Sampling Site, 2007

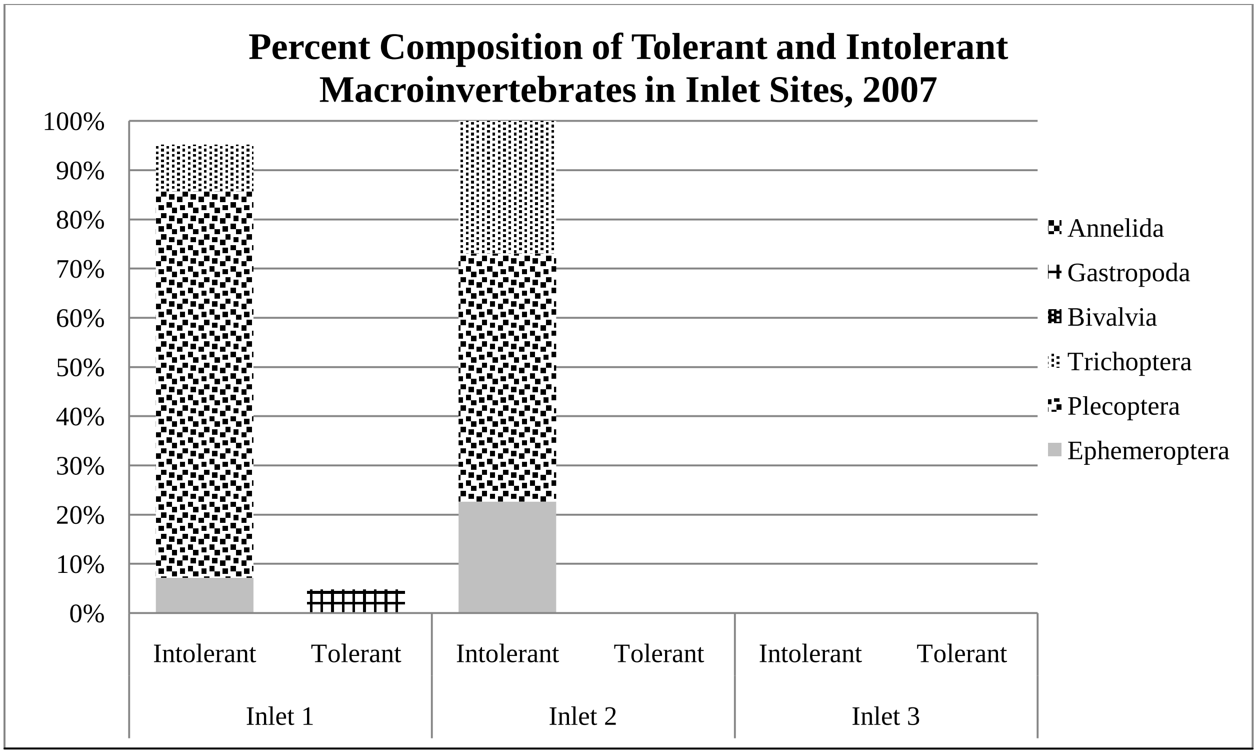

Figure 6. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek Inlets by Sampling Site, 2007

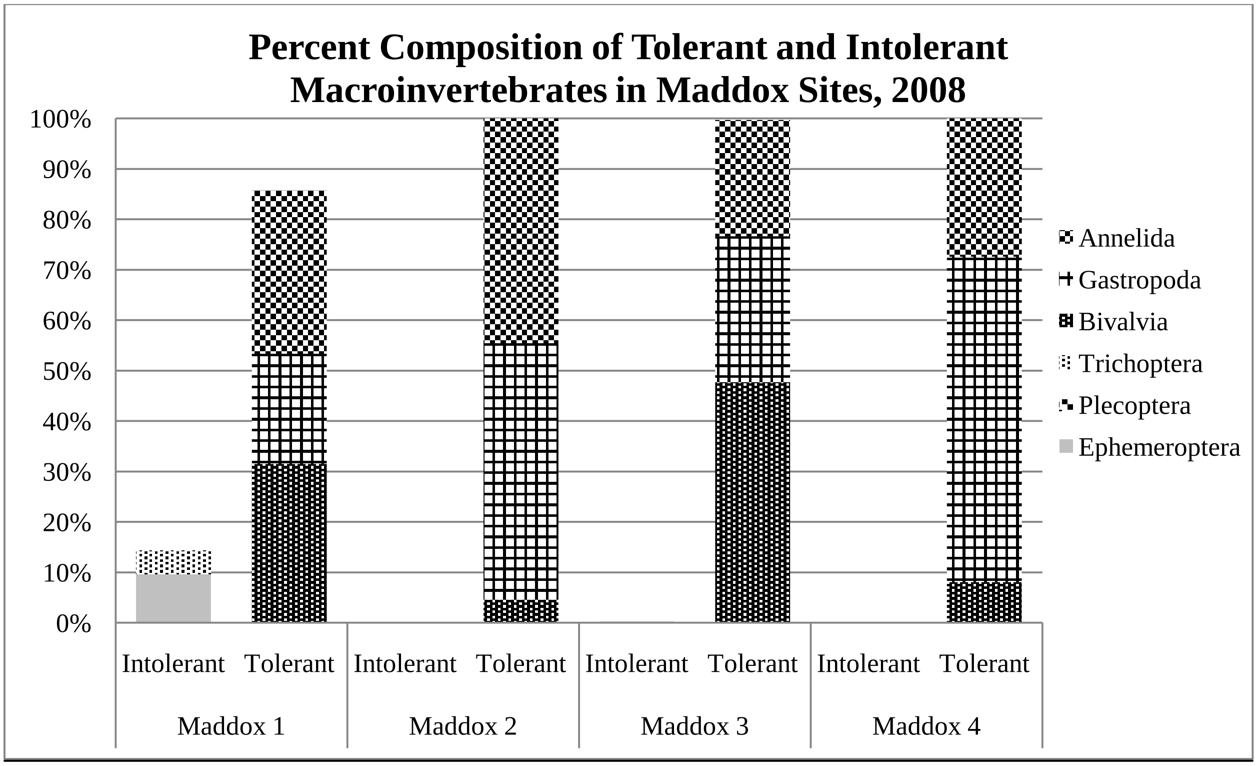

Figure 7. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Maddox Creek by Sampling Site, 2008

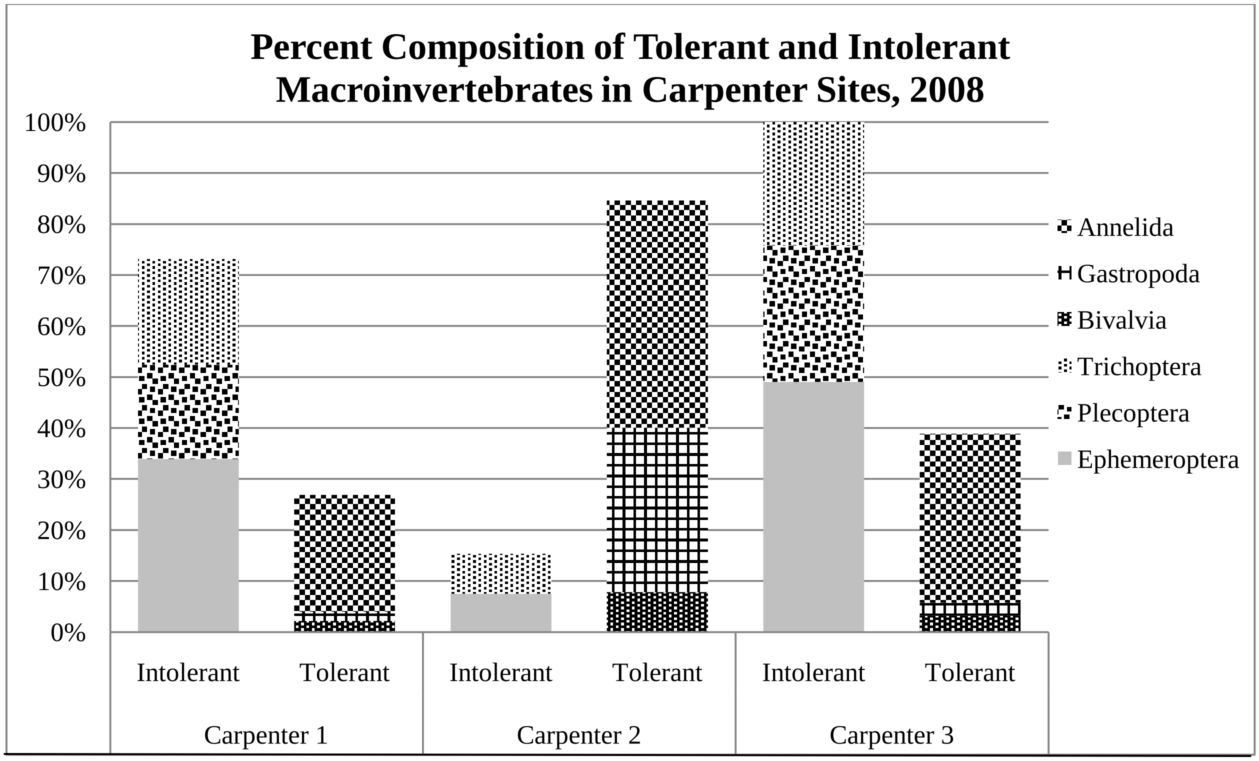

Figure 8. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek by Sampling Site, 2008

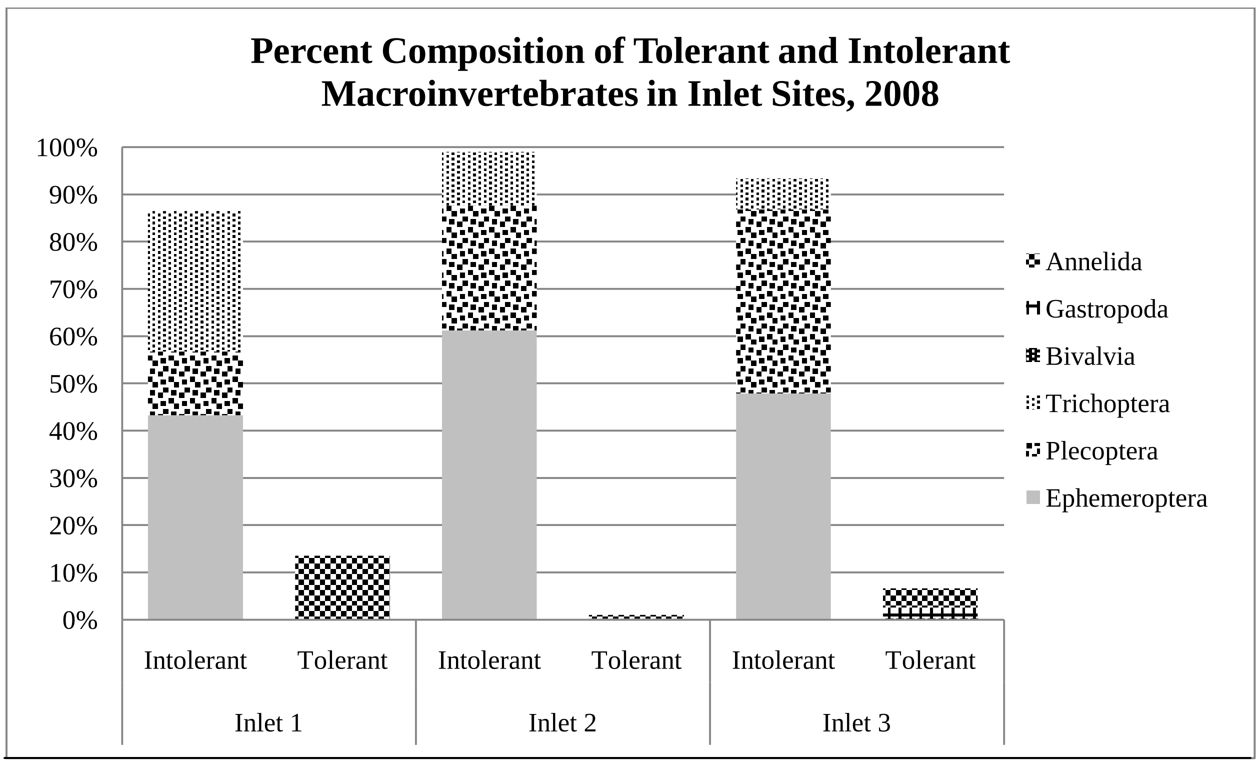

Figure 9. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek Inlets by Sampling Site, 2008

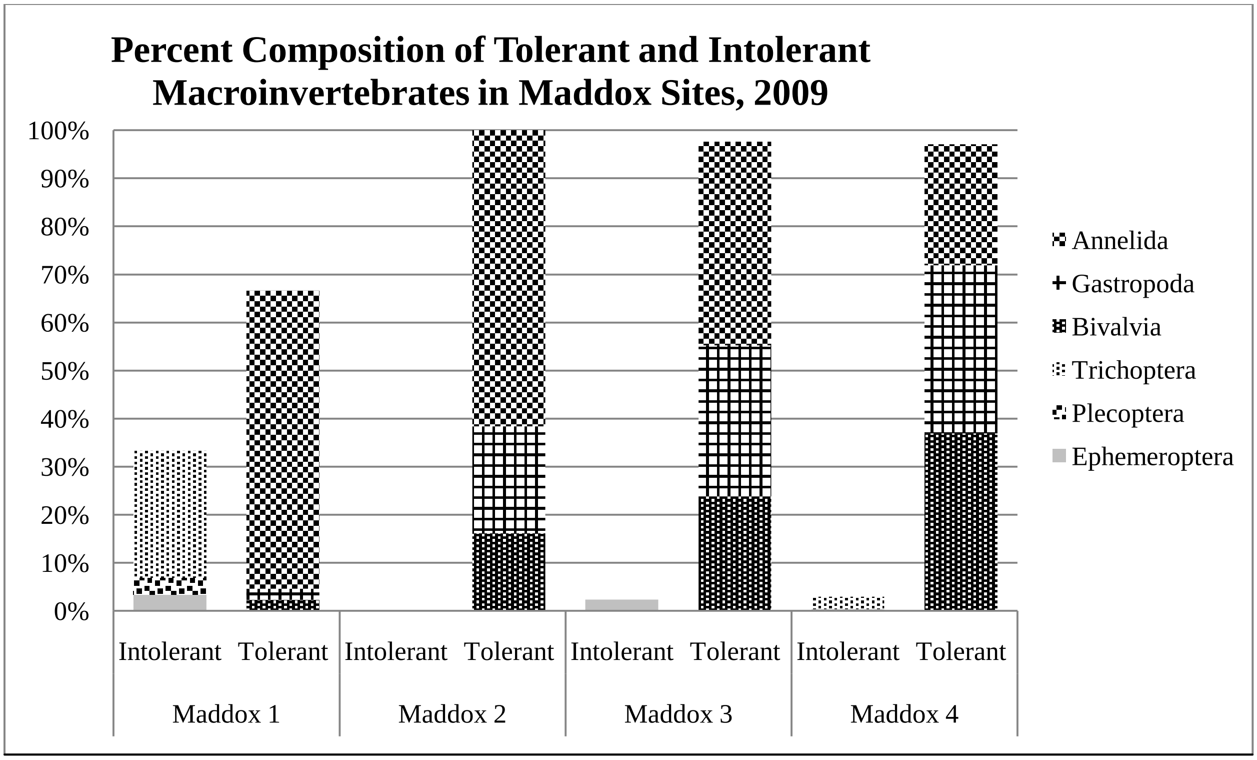

Figure 10. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Maddox Creek by Sampling Site, 2009

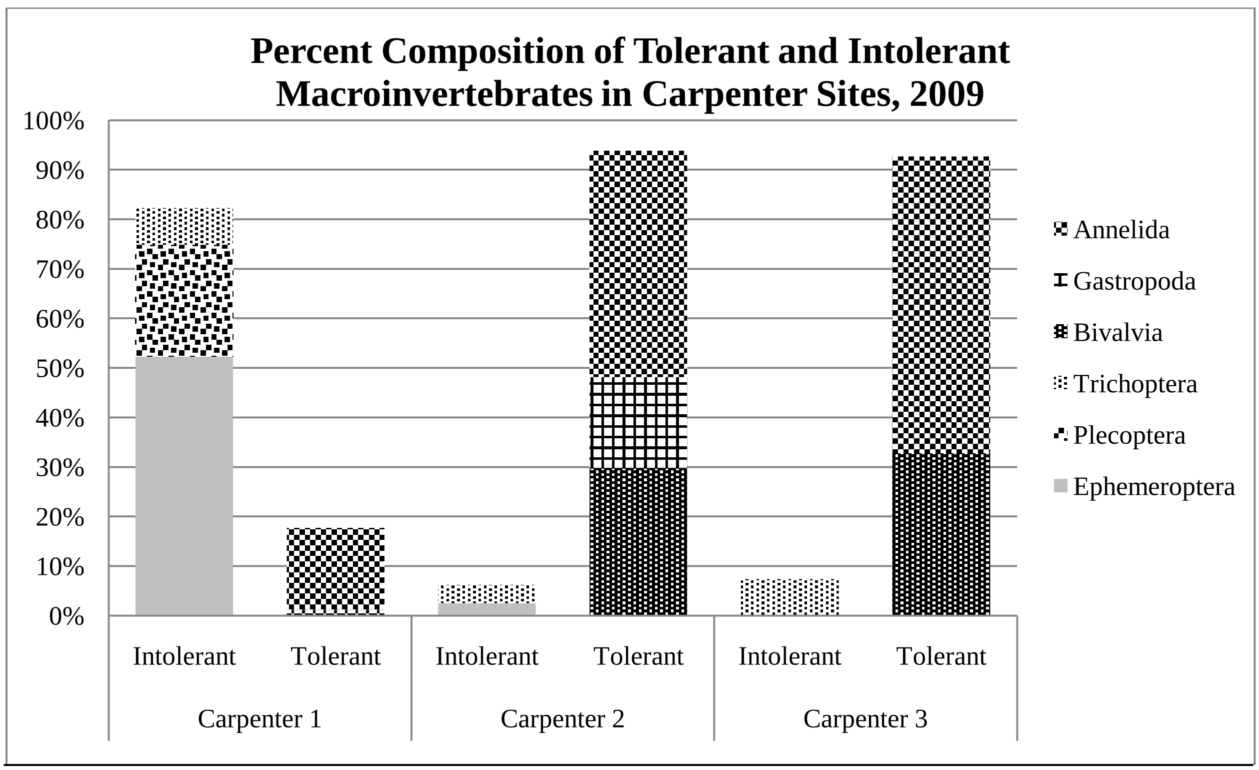

Figure 11. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek by Sampling Site, 2009

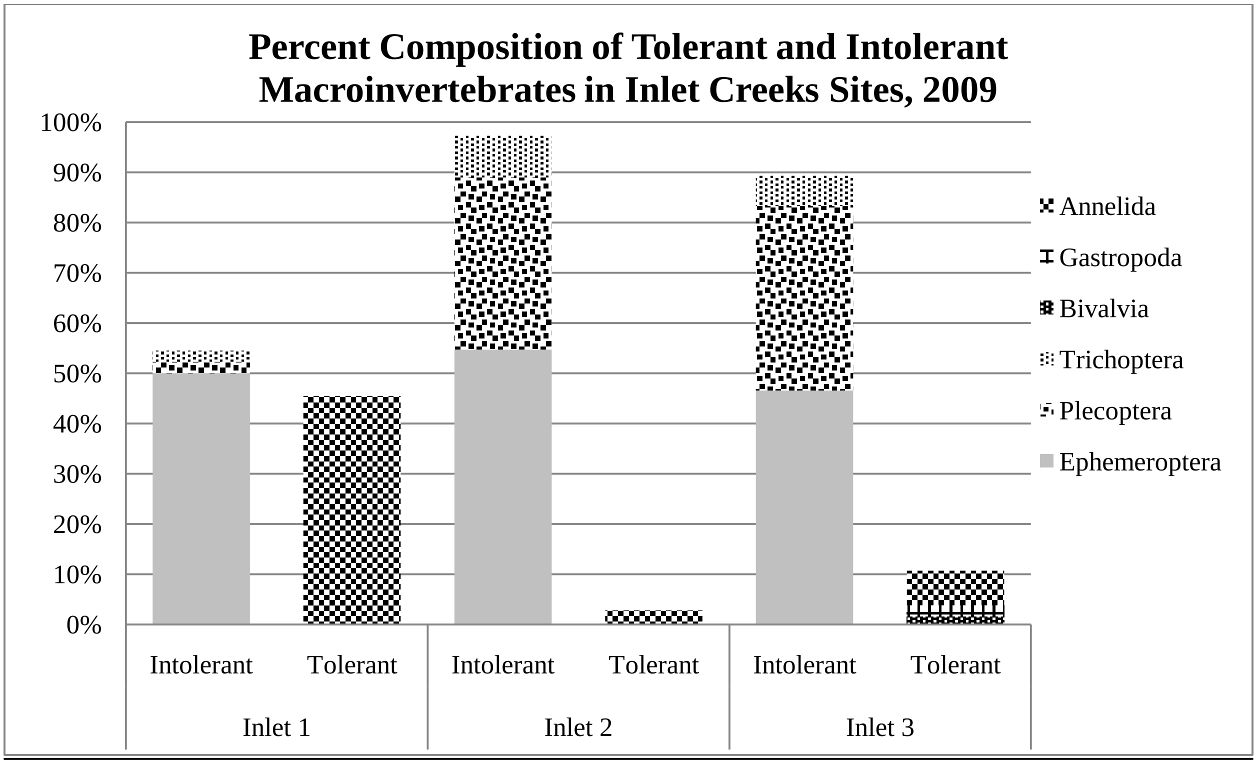

Figure 12. Percentage of Pollution Tolerant and Intolerant Orders of Macroinvertebrates in Carpenter Creek Inlets by Sampling Site, 2009

Table 3. Macroinvertebrate Metric Scores by Sampling Site, 2007

2007 Metric Scores August-November										
	Maddox Creek				Carpenter Creek			Inlet Creeks		
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Total Number	626	232	256	78	595	527	336	49	153	x
Total EPT	21	0	0	0	331	165	17	40	119	x
EPT (%) Abundance	3%	0%	0%	0%	56%	31%	5%	82%	78%	x
Hilsenhoff Biotic Index	3.17	4.00	8.00	5.00	3.42	3.61	3.95	2.43	2.66	x
Shannon H Diversity	0.74	2.52	3.49	1.15	3.13	3.52	1.79	1.05	3.15	x

x = no flow

Table 4. Macroinvertebrate Metric Scores by Sampling Site, 2008

2008 Metric Scores March-August										
	Maddox Creek				Carpenter Creek			Inlet Creeks		
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Total Number	519	511	433	324	311	844	500	49	969	625
Total EPT	34	0	1	0	166	51	40	32	574	367
EPT(%) Abundance	7%	0%	0%	0%	53%	6%	8%	70%	59%	59%
Hilsenhoff Biotic Index	4.79	4.73	4.50	6.67	3.74	5.56	4.22	3.03	3.70	4.07
Shannon H Diversity	1.46	1.15	1.26	1.07	1.04	1.22	0.97	1.38	1.27	1.16

Table 5. Macroinvertebrate Metric Scores by Sampling Site, 2009

2009 Metric Scores April-August										
	Maddox Creek				Carpenter Creek			Inlet Creeks		
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
Total Number	590	240	393	413	453	349	509	118	475	434
Total EPT	29	0	5	9	209	5	13	30	176	284
EPT (%) Abundance	5%	0%	1%	2%	46%	1%	3%	27%	37%	65%
Hilsenhoff Biotic Index	4.59	6.06	5.11	5.57	3.85	3.75	5.22	4.65	4.14	3.1
Shannon H Diversity	1.07	0.98	1.59	1.41	1.59	1.08	1.38	0.93	1.19	1.49

Habitat Suitability Index

The threshold value used to determine if habitat was suitable for coho was 0.50. Maddox 1 was the only site within Maddox Creek rated suitable for coho, with an HSI score of 0.62 (Fig. 4). Carpenter 1 was the only suitable site within Carpenter Creek with an HSI score of 0.74 (Fig. 5). Although conditions began to improve again downstream of Carpenter site 2, Carpenter site 3 was just below the threshold with an HSI score of 0.47. All three Carpenter inlets had HSI scores above 0.49 indicating suitable habitat for coho (Fig. 6).

Evaluation of all sites within one creek as a whole indicated if the stream had the habitat capacity to support coho. Maddox Creek was rated as unsuitable with an HSI score of 0.39 (Fig. 7). The overall HSI in Carpenter Creek was 0.51, indicating that coho may have enough habitat capacity to survive in this creek. The inlets, the least impacted sites in the study area, had an average HSI of 0.71, suggesting good coho habitat.

High HSI scores were negatively correlated with phosphorus, nitrogen, ammonia, temperature and suspended solids ($P<0.05$). These correlations indicate that higher nutrient concentrations, parameters not used in this study to assign HSI scores, are associated with those sites that had low HSI scores. Due to the low degree of freedom, it was not possible to compare sites to one another through statistical analysis.

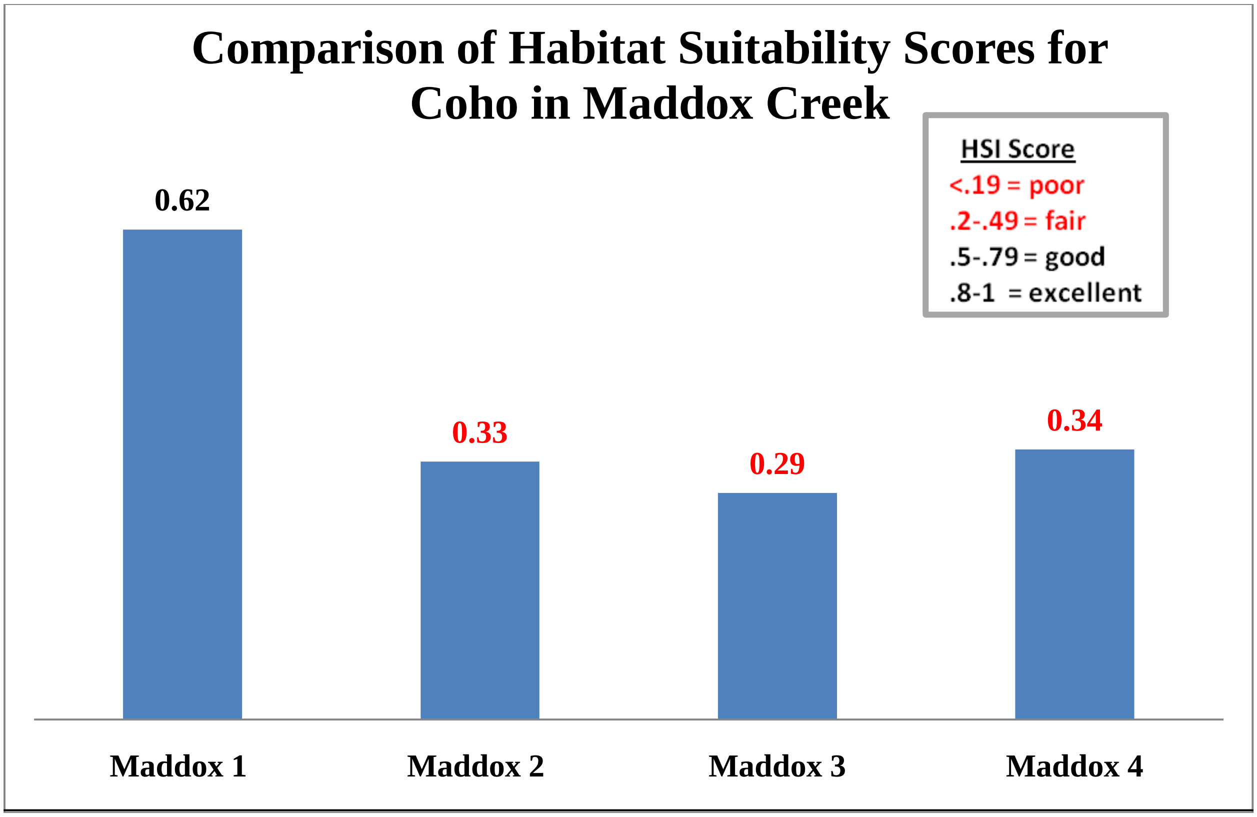

Figure 13. Habitat Suitability Index Scores within Maddox Creek by Sampling Site, 2007-2009

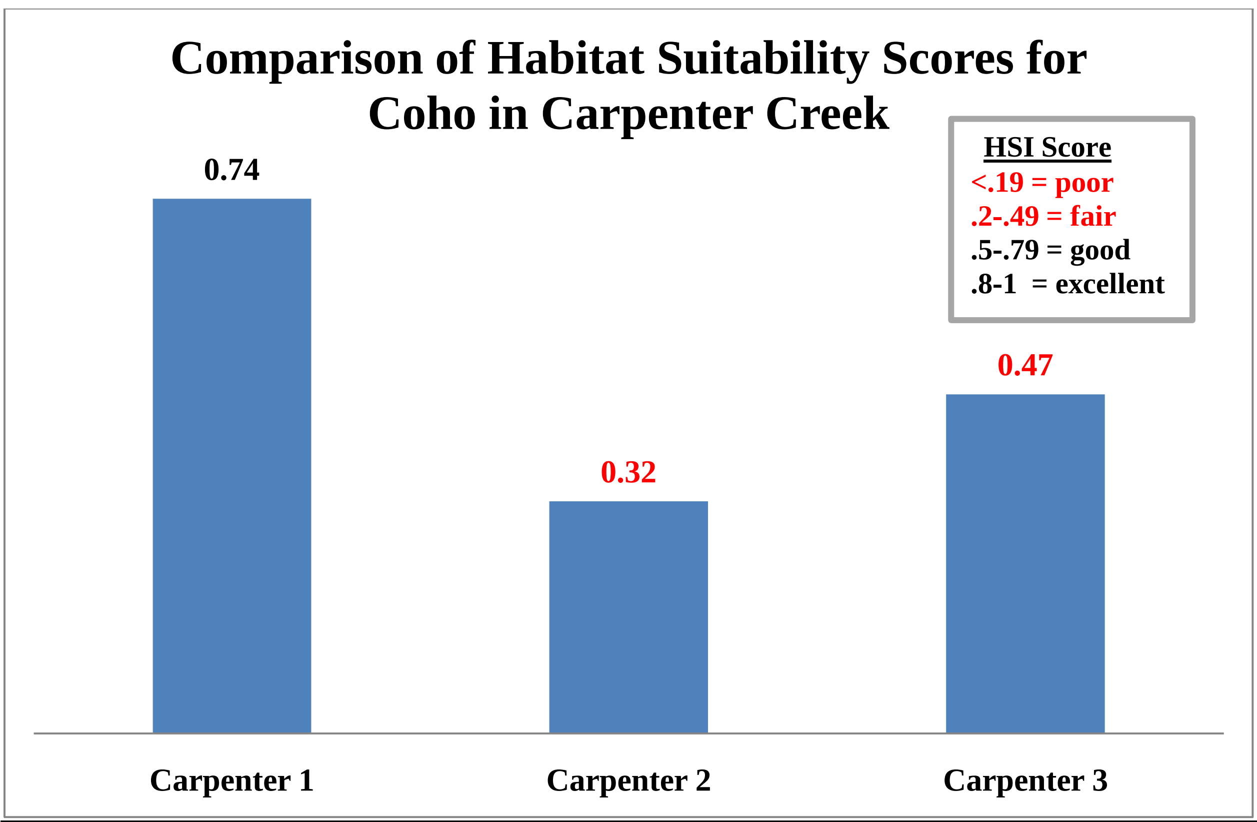

Figure 14. Habitat Suitability Index Scores within Carpenter Creek by Sampling Site, 2007-2009

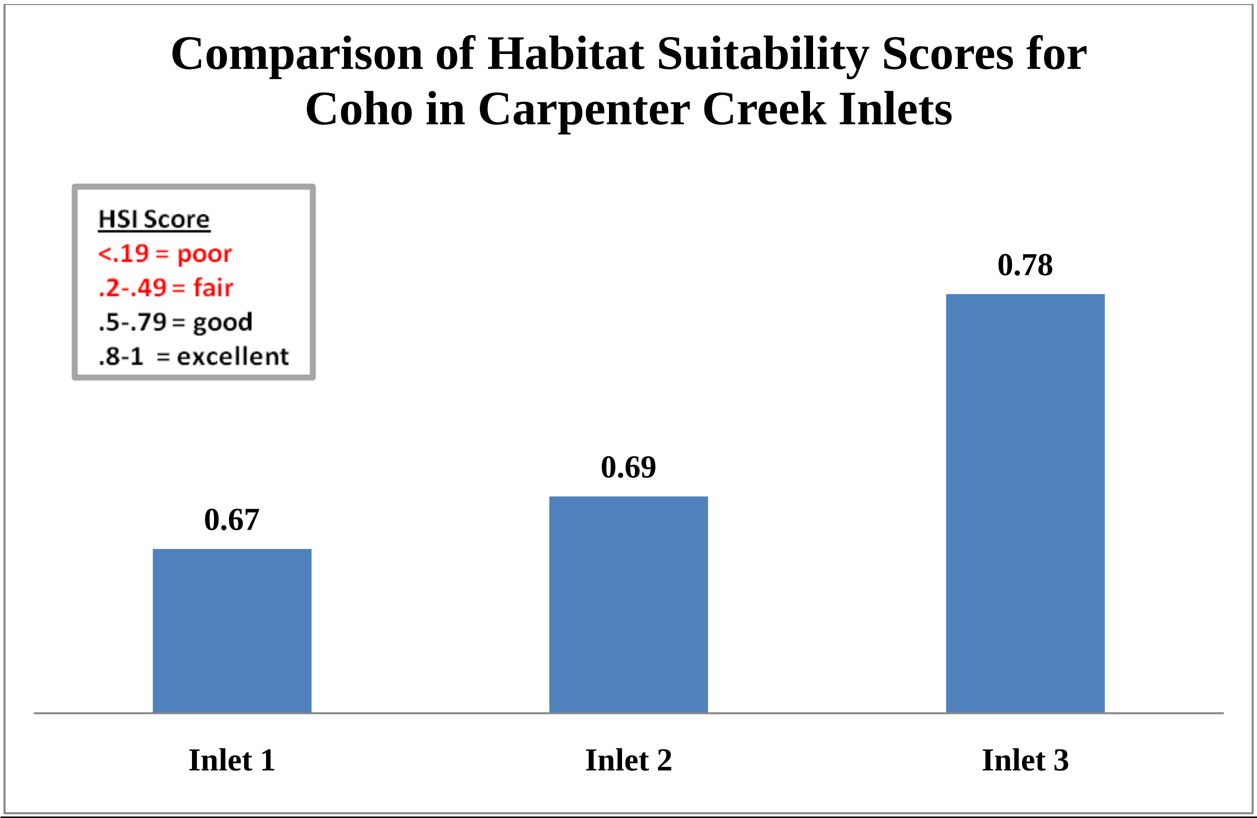

Figure 15. Habitat Suitability Index Scores for Carpenter Creek Inlets, 2007-2009

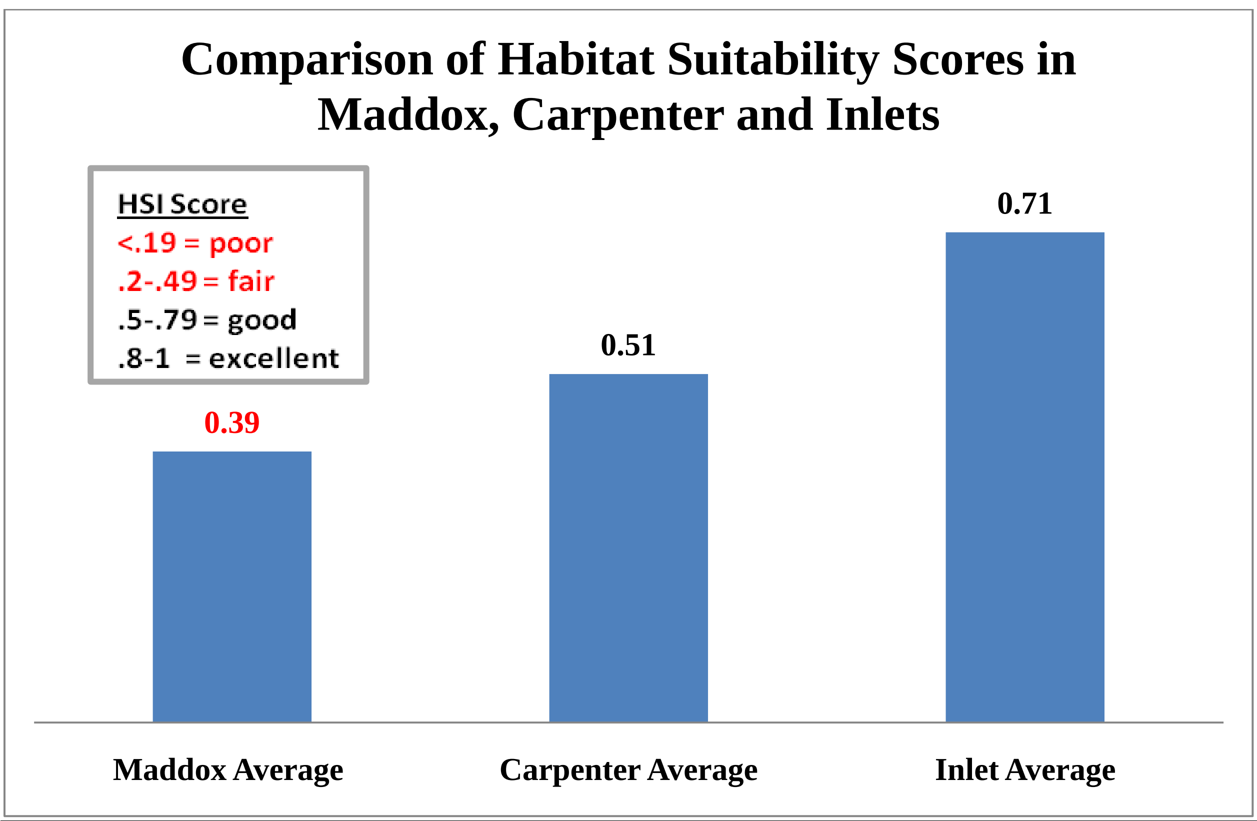

Figure 16. Average Habitat Suitability Index Scores for Maddox, Carpenter and Carpenter Creek Inlets, 2007-2009

CHAPTER 4

DISCUSSION

Coho habitat quality varied among the sampling sites, with differences evident across biological, chemical and physical parameters. The sites nearer to the headwaters and the inlets have better water quality and more adequate habitat than the downstream sites. These sites represent the most natural ecosystems of all sampling locations and are also less impacted by current suburban and urban developments. Reduced amounts of suitable habitat within Maddox Creek and lower Carpenter Creek may be attributed to current land use practices within the Skagit Delta.

Water quality near Maddox Creek headwaters was generally good and deteriorates as the water moves downstream. Maddox Creek is highly channelized, flowing through industrial and agricultural areas. As the water flows downstream it is exposed to more sediment and nutrients, decreasing water quality. Carpenter Creek is much less influenced by anthropogenic development, flowing through more forested areas. Carpenter Creek water quality also deteriorates as it flows downstream from the headwaters, but improves again as several clean, cold water tributaries enter the main stem. Contribution of good quality water from the tributaries and less impact from anthropogenic activities may be responsible for the better overall water quality within Carpenter Creek.

Poor water quality in Maddox Creek was especially noticeable in the highly impacted Maddox stations 2 through 4. Almost all water quality parameters measured at these sites repeatedly indicated poor water quality and aquatic habitat. Carpenter site 2 often had the lowest measured water quality of all Carpenter sites, possibly from surrounding land use, and because it is a backwater area that is stagnant throughout the summer. Tidal influence at Maddox 5 may affect all measured parameters, so data from this location needs to be used with caution.

Cool temperatures and high dissolved oxygen are important for the coho life cycle and for maintaining biological habitat. Elevated water temperature and low dissolved oxygen can lead to early onset of smoltification, resulting in premature seaward migration of coho smolts (McMahon 1983). Summertime temperatures over 20°C can adversely affect swimming speed and growth of coho parr (Griffiths and Alderice 1972, Bell 1973). Temperature in the downstream Maddox and Carpenter Creeks was measured above 20° C multiple times, signifying poor water quality and adverse habitat conditions for coho. In contrast, the upstream sites and the inlets generally exhibited optimal temperatures (between 10 and 15°) for summertime rearing habitat (McMahon 1983).

The Washington State dissolved oxygen standard for salmonid spawning, rearing and migration is 8mg/L in freshwater, 6 mg/L in marine water and 9.5 mg/L for core summer salmonid habitat (WSL 2006). Every station in Maddox Creek fell below the state freshwater core summer salmonid habitat standard; downstream sites were below the standards more often than the site nearer to the headwaters. Overall, Carpenter Creek had higher dissolved oxygen levels, although both sites 2 and 3 fell below the state standards at least once. The inlets had high dissolved oxygen concentrations and never fell below the Washington State standards (WSL 2006).

For salmonid spawning, rearing and migration habitat, pH must be between 6.5 and 8.5 (WSL 2006). Although the pH at all stations ranged near neutral, there were multiple times that levels were outside the ranges. Basic or acidic water can increase toxicity of certain compounds such as ammonia (WSDE 2010). The pH values dropped below the range suitable to support biological communities in both Maddox and Carpenter Creeks. Downstream Maddox sites tended to have the lowest pH of all sampling locations, representing more acidic conditions and poorer water quality than Carpenter Creek.

Streams with low alkalinity are more susceptible to changes in pH. However, high alkalinity in streams can be attributed to various landscape parameters, including geologic settings, deciduous riparian zones and exposure to high nitrates or organic residues from agricultural areas (Kreuger and Waters 1983). Carpenter Inlet 3 often had the highest alkalinity of all sampling sites, possibly due to large inputs of detritus from the surrounding deciduous riparian area. Median alkalinity values within Maddox and Carpenter Creeks were highest at site 2 within each creek. Positive correlations were calculated between alkalinity and total phosphorus, orthophosphorus and ammonia (Appendix D). These correlations indicate that higher alkalinity can be associated with higher nutrient concentrations. Since both Maddox and Carpenter site 2 had minimal riparian areas, were close to agricultural areas, and had high nutrient concentrations, the high alkalinity at these sites may be associated with surrounding land use activities.

The trend in downstream Maddox sites included low pH and dissolved oxygen; however, on August 18, 2009 these sites had the highest observed dissolved oxygen and pH of any sampling location. On this date the water was observed as cloudier and greener than during other sampling events. Combined with high pH and oxygen, these conditions indicate the presence of excessive periphyton. Periphyton are prone to occur in streams with little shade, warm temperatures, sandy or silty beds and exposure to high nutrient concentrations (Quinn et al. 1997, Chetelat et al. 1999). Excessive periphyton often indicate eutrophication of a lotic system with blooms occurring in nutrient rich waters (Chetelat et al. 1999). Periphyton blooms temporarily lead to high oxygen, but eventually die off, rapidly decreasing oxygen and pH.

Fluctuations in oxygen and pH stress biological communities; shifting the type of food available to invertebrate communities (Cuffney et al. 2000), and further reducing habitat in an already polluted system. Excessive periphyton in downstream Maddox sites, are another indicator of poor water quality within this system.

Nutrient concentrations were also highest in Maddox Creek. The highest phosphorus measured was at Maddox site 3. Maddox site 4 had the highest concentrations of nitrogen and ammonia. There appeared to be a problem with organic matter washing into the creek near Maddox site 3 from a small drainage ditch just upstream of the site. For example, on March 10, 2007, thick, conglomerated organic material was observed entering Maddox Creek from this ditch, giving the stream a murky brown appearance with frothy aggregates of organic material. These inputs are probably affecting nutrient concentrations in the downstream Maddox sites. Even small amounts of nutrients in runoff during summertime conditions of low dissolved oxygen and high temperature can cause eutrophication. These higher nutrient concentrations at the downstream Maddox sites appear to be negatively impacting water quality and likely contributed to the summer 2009 periphyton bloom. In contrast, Carpenter Creek and the inlets had much lower nutrient values and also had better overall water quality than Maddox Creek.

Suspended solid concentrations were consistent with other water quality conclusions. Although lotic bodies of water naturally contain sediments due to erosion and other natural processes, the amount of solid matter entering creeks increases with anthropogenic activities (Alabaster 1972). In Maddox Creek sites 2-4, suspended solid concentrations were generally higher than in Maddox site 1, the Carpenter Creek system and the inlets. These high concentrations indicate that excessive sediments, possibly from non natural processes, are entering the Maddox Creek system. Excessive suspended solids can adversely affect the survival, growth and reproduction of fish through a decrease in food supply (Alabaster 1972), negatively impacting fresh water fish populations. These high concentrations of suspended solids may be one cause of the higher nutrient levels measured at the downstream Maddox sites.

Specific conductivity is a general indicator of the amount of dissolved material in water (USGS 2010). Although specific conductivity varies among geographical regions, it can be a useful indicator to measure if restoration improves water quality. In streams impacted by anthropogenic activities, specific conductivity tends to be higher and more variable (Roy et al. 2003). This was especially true in Maddox Creek. Maddox site 1 tended to have low specific conductivity, but as the water moved downstream to sites more impacted by humans, the specific conductivity increased. Specific conductivity usually was much lower in Carpenter Creek than in the Maddox Creek system. Although Carpenter site 1 had high specific conductivity on two sampling dates, generally, Carpenter 2 (the most disturbed site within the system) had the highest specific conductivity within Carpenter Creek. These high specific conductivity concentrations once again illustrate the poor water quality in the highly impacted Maddox sites and Carpenter site 2. If specific conductivity decreases in the highly disturbed sites after restoration, the baseline data can be useful in indicating if water quality has improved.

Urbanization of the Skagit Delta may increase discharge as more impervious surfaces are developed. This discharge threatens to increase sediment runoff, turbidity and nutrient concentrations within the sample creeks (Schoonover et al. 2005) further impacting salmonid habitat. In the baseline study discharge was much more variable in Carpenter Creek than Maddox Creek, possibly due to the increased watershed area and tributary inputs to Carpenter Creek. At Carpenter 3, discharge was highest, probably due to tidal influence and the number of clean water tributaries entering the system. Although Maddox 3 also can have a considerable volume of discharge, it is likely from the irrigation ditch just upstream of this site. This irrigation ditch is not only increasing discharge at this site but it appears to be contributing poor quality water to the stream. resulting in reduced water quality parameters at Maddox sites 3 and 4.

The community structure of benthic invertebrates is useful for evaluating biological conditions in streams because their low motility does not allow them to escape pollution entering their environment (Wilhm and Dorris 1968). Previous studies have shown reductions in dissolved oxygen, elevated temperatures and excessive nutrient inputs from activities on surrounding land can alter stream invertebrate communities (Suckling 1982, Quinn and Hickey 1990, Quinn et al. 1997, Dauer et al. 2000). Pollution and excess sedimentation can alter the macroinvertebrate community structure from one dominated by species sensitive to poor water conditions like Ephemeroptera, Plecoptera and Trichoptera to more pollution tolerant species such as Annelida, Bivalvia and Gastropoda (Lenat 1988, Karr and Chu 1999). Due to the sensitivity of certain species to variations in chemical and physical water quality, the community composition of benthic invertebrates can be used to determine changing biological conditions within streams (Lenat 1988). The composition of invertebrates within a stream not only indicates habitat conditions but can affect available aquatic prey (Wipfli 1997), impacting the salmonid populations that feed off of them (Nielson 1992, Giannico 2000).

The composition of the benthic macroinvertebrate community in this study was statistically linked to physical and chemical water quality parameters. Sites dominated by the pollution tolerant species had higher concentrations of nutrients, lower dissolved oxygen and higher temperatures. Corroborating the general water quality conclusions, pollution tolerant species such as Annelida, Bivalvia and Gastropoda dominated the fauna in Maddox sites 2-4 and

Carpenter sites 2 and 3. Pollution tolerant species indicate that various perturbations have occurred within the lower Maddox and Carpenter systems. In Carpenter Creek and its inlets, the macroinvertebrate community includes pollution intolerant organisms that require clean water to survive. However, pollution tolerant amphipods became much more abundant in downstream sampling locations within Carpenter Creek. Lack of pollution intolerant species at the downstream sites suggests that these invertebrates cannot survive in the current water quality conditions.

The EPT abundance index also supports the findings of poor water quality within the disturbed Maddox and Carpenter sites. Carpenter site 1 and the inlets support large populations, by percentage, of Ephemeroptera, Plecoptera and Trichoptera and very few pollution tolerant species. The large presence of these three orders at Carpenter 1 and the inlet sites indicate stable areas, good water quality and the ability of these locations to support very sensitive biological communities. Lack of these pollution intolerant organisms in Maddox Creek and the lower Carpenter sites signify that the water quality at these sites is not good enough to support sensitive biological species such as coho.

The Hilsenhoff Biotic Index (HBI) provides a measure of water quality health and the general status of organic pollution within the streams, based on families of invertebrates collected at the sampling sites (Hilsenhoff 1988). The HBI demonstrated similar results to the other water quality parameters measured for the baseline study. Carpenter site 1 and the inlets have the best water quality of the sampling locations, shown by their low HBI scores. The highly impacted downstream Maddox sites had generally poor water quality indicating that organic pollution is present at these sites.

The Shannon Diversity Index is frequently used to characterize the species diversity within a given community. The number of invertebrates collected at the different sites likely affected the differences in diversity values. For example, the low diversity in Inlet 1 is probably attributed to the small sample size. Inlet 1 was sampled fewer times than the other sites due to no flow in the summertime months. Although there did not seem to be distinct differences between the sites using this metric score, the baseline values can be used in the future to measure if species diversity changes with scheduled restoration.

In terms of physical habitat, the HSI indicated downstream areas of Maddox and Carpenter Creeks have less capacity to support coho than the inlets and sites nearer to the headwaters. According to the coho Habitat Suitability Index, sites that have higher HSIs are expected to support more coho (McMahon 1983). It is unlikely that there is enough suitable habitat to support coho in most of Maddox Creek, because HSI values were under 0.49 in all sites downstream of Maddox 1. Although Carpenter Creek, as a whole, has more suitable habitat than Maddox, the downstream sites do not provide adequate habitat for coho life requirements. The inlets and sites nearer to the headwaters represent the best coho habitat. These sites are the least impacted by anthropogenic activities and also represent the most natural ecosystem when compared to the downstream portions of Maddox and Carpenter Creeks. Comparing the HSI scores to the nutrient data shows that high HSI scores are correlated with low nutrients concentrations and suspended sediment. Although neither of these attributes were used when computing HSI scores, it would be useful in the future to incorporate these parameters into a suitability index as these conditions have a strong impact on the physical environment on which coho depend.

Biological integrity within lotic systems is determined and influenced by chemical, physical and biological factors, along with the interaction between these processes (Karr 1991, Yoder and Rankin 1998). Determining the status of these factors, and the relationship between them provided a synoptic view of the water quality within the study creeks. Almost every measured parameter shows the sites most impacted by human activities have the poorest water quality and the worst salmonid habitat. Channelization of both creeks, inputs of excess nutrients and reduction of riparian habitat have likely contributed to the reduced water quality in all of the downstream sections of these creeks. Since anadromous salmonids use the entire range of habitats encountered throughout their life cycle (Spence et al. 1996), and coho depend on good quality freshwater for the first year of their life, the adverse water quality conditions at the downstream Maddox and Carpenter sites indicate that these sites do not provide adequate habitat for coho.

It is the interaction between the poor physical, chemical and biological parameters at the highly impacted sites of Maddox and Carpenter Creek that are degrading water quality and causing unsuitable coho habitat. Only by improving the water quality conditions at the downstream sites within Maddox and Carpenter Creeks will the streams be able to support larger coho populations. Without changes in surrounding landscape activities, it is likely that water quality will likely be further degraded, critical habitat will continue to decline and these creeks will not be able to support populations of coho salmon.

CHAPTER 5

MANAGEMENT IMPLICATIONS

The indications of poor habitat suitability in Maddox and lower Carpenter Creeks have important implications for habitat management. Floodplain habitats, currently isolated by levees and other structures cannot be recovered by natural processes; therefore without management interventions these areas cannot improve (Beechie et al. 2001). Although restoration to pristine conditions is not possible, the FSRP is expected to allow disturbance and recovery processes to take place more naturally (Bisson et al. 1997), therefore improving coho habitats.

This study established a baseline data set that can be used to measure alterations in coho habitat due to changing landscape functions. It was previously known that many areas within the Skagit Delta were not sufficient for salmonid habitat (Beechie et al. 1994). The specific areas within Maddox and Carpenter Creeks that are unsuitable for coho habitat were determined based on chemical, biological and physical factors. It is expected that the downstream sites in both Maddox and Carpenter Creeks will benefit from the scheduled restoration. Currently, the habitat is not sufficient to support populations of coho and only through restoration and altered land use practices is it possible for these areas to be improved. Defining the specific areas of critical coho habitat threatened by current land use activities will allow for evaluation of how restoration improves the stream environments within Carpenter and Maddox Creeks.

Continuation of monitoring during and after restoration will provide valuable information to managers, allowing them to effectively evaluate the progress of restoration in terms of water quality and coho habitat (Yoder and Rankin 1998). The ecological effects of restoration may enhance ecosystem function years after intended responses are observed (Marshall et al. 2006); therefore continued monitoring within Maddox and Carpenter Creeks is necessary to understand how physical, chemical and biological attributes change over time. Performing successful restoration partly depends on this future monitoring to evaluate whether the functional state of the slough and tributaries have been improved (Gray et al. 2002). Although monitoring restoration plans is quite costly, without interpreting how these activities impact aquatic habitat it will be difficult to guide future projects for other areas within the Delta (Mitsch and Wilson 1996, Roni et al. 2003). A consistent process and set of principles is necessary for a systematic evaluation of the restoration processes to understand the components of the project that were successful (Beechie 2003). Therefore, the priority for future monitoring should follow the same methods as the baseline study.

In addition to continuing with the parameters monitored for the baseline study, I recommend analyzing the diet of coho to determine if available food resources change with restoration. Coho diet analysis can be an effective measure of restoration since biological responses are important indicators of successful restoration (Roni et al. 2002). Available food resources can be determined by examining the diets of coho through stomach content analysis. Gastric lavage, also referred to as stomach pumping, safely removes food from fish without harming them (Light et al. 1983). Stomach content analysis can show if alterations to the aquatic systems result in changing diets, reflecting the conditions of coho habitat. Although not reported here, fish lavage was conducted in the summer of 2009 to analyze the diets of coho salmon, prior to restoration. Having lavage contents before, during and after restoration will show how coho diets have been impacted by restoration. This information will go beyond assessing only water quality to understand habitat conditions by looking at available prey resources in disturbed areas.

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APPENDIX A

Water Quality Data

Table 13. Temperature in degrees Celsius for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	13.8	15.9	10.1	9.1	6.1	9.8	12.9	13.5	13.5	15.1	10.3	12.4	15.9	13.2	18.1
Maddox #2 Culvert/freeway 1	17.4	13.1	9.9	9.8	7.5	11.6	13.7	15.8	16.5	15.7	13.8	14.0	17.5	15.4	22.2
Maddox #3 Culvert/freeway 2	17.6	16.7	9.9	9.4	7.7	13.8	13.7	19.4	15.2	19.8	16.0	16.2	16.2	16.3	21.7
Maddox #4 Siphon	19.7	19.7	9.7	8.8	x	x	11.8	19.2	18.9	16.7	10.6	16.4	13.5	15.1	23.1
Maddox #5 Estuary	22.4	16.7	11.6	8.1	9.2	11.3	18.0	19.0	21.4	20.4	11.5	16.5	17.8	17.5	21.9
Carpenter #1 Headwaters	15.0	13.1	9.6	8.9	7.3	x	10.5	15.0	12.6	15.3	8.4	9.9	13.7	13.0	14.7
Carpenter #2 Bridge	18.3	14.0	11.0	7.9	7.5	x	12.9	13.6	22.4	20.7	10.6	10.6	17.9	17.6	21.9
Carpenter #3 Fisher Slough	16.2	15.9	10.9	8.0	7.4	8.4	11.6	9.9	20.4	17.8	14.5	12.6	18.5	16.6	19.1
Carpenter Inlet #1 by bridge @ Carp. #2	nf	nf	nf	8.7	6.7	x	10.5	10.3	12.1	nf	9.3	9.3	12.5	12.9	nf
Carpenter Inlet #2 perennial stream Sandy Creek	14.6	12.7	9.4	8.5	6.6	x	9.8	9.8	11.9	14.5	7.6	9.1	12.9	12.9	14.6
Carpenter Inlet #3 ephemeral stream	x	x	x	10.4	6.9	*x*	10.8	10.4	11.3	12.3	7.5	9.9	10.8	14.7	13.3

(x) Represents Hydrolab malfunctions and (nf) represents periods of no flow

Table 14. Dissolved oxygen concentrations in mg/L for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	7.8	7.3	10.3	9.3	12.6	12.4	11.0	9.6	9.9	x	12.3	10.5	8.2	8.2*	7.7
Maddox #2 Culvert/freeway 1	2.5	6.6	8.2	4.9	8.0	8.0	9.2	11.1	5.4	0.6	8.2	9.0	9.4	7.6*	6.4
Maddox #3 Culvert/freeway 2	1.4	6.8	8.2	6.3	6.8	2.2	10.1	12.0	3.9	3.5	14.2	15.3	9.5	5.3*	13.0
Maddox #4 Siphon	8.6	15.8	8.1	9.8	x	0.4	6.2	9.7	13.9	7.4	12.0	10.9	13.3	8.7*	15.0
Maddox #5 Estuary	9.1	8.3	8.4	14.3	7.7	x	7.1	9.9	7.9	6.6	9.5	6.8	8.2	7.6*	9.2
Carpenter #1 Headwaters	8.8	8.5	11.3	10.9	12.0	x	12.0	11.1	13.8	11.3	12.3	11.4	10.3	10.3*	8.7
Carpenter #2 Bridge	5.7	4.7	10.9	6.5	10.4	x	7.4	6.8	8.9	5.2	12.7	9.7	8.4	4.6*	6.5
Carpenter #3 Fisher Slough	10.3	11.5	8.8	8.5	10.5	9.9	9.5	10.1	8.9	8.7	14.2	10.7	6.2	8.4*	9.8
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	10.5	12.1	x	12.0	11.3	10.5	nf	11.8	11.5	9.4	10.2*	nf
Carpenter Inlet #2 perennial stream (Sandy Creek)	8.9	9.8	10.9	13.1	12.2	x	12.4	11.6	12.7	11.8	12.4	11.7	10.2	9.8*	8.8
Carpenter Inlet #3 ephemeral stream	x	x	x	8.8	10.2	x	10.2	10.0	10.7	11.4	10.6	9.5	10	9.2	7.7

(x) Represents Hydrolab malfunctions and (nf) represents periods of no flow. (*) Represents incorrect Hydrolab calibration.

Table 15. Percent saturation of dissolved oxygen for each sampling location

	2007				2008						2009				
	8/15	9/11	10/4	11/15	3/12	4/10	5/20	6/16	7/15	8/21	4/16	5/19	6/17	7/14	8/18
Maddox #1 Headwaters	75	73	99	78	101	100	105	91	92	x	107	97	83	77*	80
Maddox #2 Culvert/freeway 1	25	63	78	42	65	70	88	111	54	5	80	86	97	74*	72
Maddox #3 Culvert/freeway 2	14	68	79	55	56	21	97	128	39	36	140	154	94	53*	144
Maddox #4 Siphon	93	172	75	84	x	4	57	103	147	72	106	109	126	84*	173
Maddox #5 Estuary	110	88	84	115	63	x	74	104	90	71	86	69	84	78*	106
Carpenter #1 Headwaters	86	80	106	93	98	x	108	97	122	110	100	99	98	96*	84
Carpenter #2 Bridge	58	43	64	54	86	x	70	64	100	57	112	84	86	47*	73
Carpenter #3 Fisher Slough	102	114	76	68	86	88	86	99	97	93	137	99	65	85*	105
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	89	97	x	107	98	97	nf	100	96	87	94*	nf
Carpenter Inlet #2 perennial stream Sandy Creek	88	87	102	108	97	x	109	101	114	114	101	100	95	91*	79
Carpenter Inlet #3 ephemeral stream	x	x	x	78	82	x	92	86	97	107	87	83	87	90*	83

(x) Represents Hydrolab malfunctions and (nf) represents periods of no flow. (*) Represents incorrect Hydrolab calibration.

Table 16. Recorded pH for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	7.1	6.6	6.5	6.6	6.7	7.2	7.6	7.6	7.0	x	7.9	7.6	7.6	7.3	7.4
Maddox #2 Culvert/freeway 1	7.2	6.4	6.1	6.1	6.3	6.9	7.3	7.3	6.7	7.0	7.2	7.1	7.1	7.0	7.0
Maddox #3 Culvert/freeway 2	7.2	6.6	6.2	6.3	6.5	6.9	7.2	7.6	6.7	7.4	7.2	7.2	7.7	7.0	8.7
Maddox #4 Siphon	8.6	9.3	6.1	6.5	x	x	6.9	7.7	8.3	6.6	6.9	7.2	8.4	7.7	9.0
Maddox #5 Estuary	7.2	6.7	6.4	6.2	5.2	6.7	7.2	7.4	6.7	6.8	6.4	7.1	7.6	7.0	7.6
Carpenter #1 Headwaters	7.3	6.4	6.9	6.7	7.0	x	7.8	7.9	7.5	6.9	7.8	7.8	7.7	7.8	7.6
Carpenter #2 Bridge	7.2	6.4	6.2	5.9	6.1	x	7.3	7.3	7.0	7.3	7.6	7.4	7.5	7.5	8.3
Carpenter #3 Fisher Slough	8.0	7.5	6.3	6.6	6.5	7.4	7.3	7.5	7.0	7.4	7.2	7.4	7.3	7.4	7.6
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	6.5	6.5	x	7.6	7.7	7.3	nf	7.8	7.6	7.6	7.4	nf
Carpenter Inlet #2 perennial stream Sandy Creek	7.8	6.9	7.2	6.9	7.8	x	8.0	8.2	7.6	8.0	8.0	8.0	8.0	7.9	7.8
Carpenter Inlet #3 ephemeral stream	x	x	x	6.4	7.3	x	7.6	7.7	7.2	6.3	7.6	7.6	8.0	7.7	7.7

(x) Represents Hydrolab malfunctions and (nf) represents periods of no flow

Table 17. Alkalinity measured in mg/L for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	x	109.4	42.3	86.0	64.5	58.9	62.9	79.0	107.5	51.4	73.9	54.2	92.2	100.6	101.6
Maddox #2 Culvert/freeway 1	x	151.7	28.4	125.2	100.43	97.2	43.9	125.9	145	151.5	106.7	65.0	136.4	83.4	150.5
Maddox #3 Culvert/freeway 2	x	153.4	28.1	x	119.3	125.6	100.1	141.6	38.3	107.5	142.3	90.5	33.8	18.2	139.8
Maddox #4 Siphon	x	100.5	27.0	117.5	50.3	139.5	62.2	135.2	25.4	25.4	147.9	82.5	17.4	131.6	58.5
Maddox #5 Estuary	x	88.0	x	100.6	119.6	107.8	132.5	125.1	44.1	48.3	115.9	81.1	22.0	131.7	62.1
Carpenter #1 Headwaters	x	124.6	61.7	90.1	50.3	49.5	56.0	77.1	99.9	101.8	50.8	125.6	95.3	180.8	112.6
Carpenter #2 Bridge	x	180.2	110.9	107.5	62.9	63.7	72.5	83.1	132.8	168.3	68.2	67.8	126.8	102.3	159.4
Carpenter #3 Fisher Slough	x	124.1	117.7	90.0	50.3	46.4	49.8	58.0	109.1	126.2	56.3	73.3	99.5	147.6	32.8
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	57.9	30.6	29.2	28.5	43.8	x	nf	35.7	39.4	101.0	128.1	nf
Carpenter Inlet #2 perennial stream Sandy Creek	x	187.0	x	105.8	67.9	58.0	71.3	78.8	134.6	130.7	65.1	71.0	124.1	131.4	156.6
Carpenter Inlet #3	x	x	x	165.9	123.0	116.4	132.1	150.4	185.1	216.2	113.2	74.3	164.5	134.7	195.1

(x) Represents periods of no data and (nf) represents periods of no flow.

Table 18. Specific conductivity for each sampling location measured in microSiemens/cm

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	257	264	178	244	196	181	158	198	266	x	203	175	257	279	283
Maddox #2 Culvert/freeway 1	769	451	122	341	303	297	139	334	493	451	335	252	429	272	415
Maddox #3 Culvert/freeway 2	455	455	122	394	486	474	321	497	103	342	525	330	58	57	427
Maddox #4 Siphon	295	300	110	588	x	x	366	x	45	52	160	426	42	51	179
Maddox #5 Estuary	16,424	13,457	190	12,928	842	858	737	1941	1759	2025	435	761	68	270	3910
Carpenter #1 Headwaters	766	788	219	297	202	x	220	233	306	269	182	210	289	329	572
Carpenter #2 Bridge	370	360	318	299	181	x	180	194	312	380	208	198	312	361	413
Carpenter #3 Fisher Slough	769	252	254	193	160	144	118	140	241	206	782	146	240	203	67
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	148	89	x	78	106	246	nf	123	102	312	286	nf
Carpenter Inlet #2 perennial stream Sandy Creek	347	364	251	233	168	x	148	164	280	261	157	162	262	288	342
Carpenter Inlet #3 ephemeral stream	x	x	x	389	320	x	282	331	381	416	262	291	354	263	409

(x) Represents Hydrolab malfunctions and (nf) represents periods of no flow

Table 19. Nitrate/nitrate nitrogen concentration measured in mg/L for each sampling location

	2007				2008						2009				
	8/15	9/11	10/4	11/15	3/12	4/10	5/20	6/16	7/15	8/21	4/16	5/19	6/17	7/14	8/18
Maddox #1 Headwaters	0.041	0.033	0.025	0.025	0.318	0.471	0.042	<DL	0.019	0.009	0.500	0.346	0.636	0.755	0.409
Maddox #2 Culvert/freeway 1	0.025	0.09	0.033	0.148	0.217	0.470	0.143	0.216	7.316	2.534	0.674	0.527	0.849	0.866	0.248
Maddox #3 Culvert/freeway 2	0.008	0.049	0.041	x	1.345	1.304	0.669	0.387	2.054	0.618	0.733	0.733	0.218	0.018	0.002
Maddox #4 Siphon	0.14	0.082	0.033	0.21	x	2.069	1.007	0.767	<DL	<DL	0.710	0.752	0.275	0.010	0.006
Maddox #5 Estuary	0.041	0.025	0.06	0.08	2.256	2.656	1.372	1.031	<DL	<DL	0.719	0.776	0.310	0.020	0.006
Carpenter #1 Headwaters	0.033	0.008	0.041	0.008	2.765	1.853	0.647	0.777	0.336	0.127	0.710	0.132	0.775	0.790	0.903
Carpenter #2 Bridge	0.041	0.033	0.016	0.041	0.912	0.798	0.265	0.235	<DL	<DL	0.710	0.794	0.276	0.132	0.001
Carpenter #3 Fisher Slough	0.033	0.016	0.09	0.025	0.926	0.941	<DL	0.062	0.004	<DL	0.676	0.528	0.330	0.206	0.048
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.025	1.255	1.406	0.333	0.672	x	nf	0.721	0.717	0.790	0.526	nf
Carpenter Inlet #2 perennial stream Sandy Creek	0.016	<DL	x	0.008	0.995	0.884	0.299	0.354	0.094	<DL	0.673	0.703	0.524	0.526	0.407
Carpenter Inlet #3 ephemeral stream	x	x	x	0.008	0.376	0.056	<DL	<DL	<DL	0.103	0.227	0.143	0.167	0.375	0.298

(x) Represents periods of no data,(nf) represents periods of no flow and (<DL) represents amounts too low for detection (.002 mg/L and lower)

Table 20. Ammonia concentration measured in mg/L for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	0.050	0.040	0.030	0.030	0.047	0.025	0.004	0.042	0.037	0.001	0.013	0.011	0.028	0.022	0.069
Maddox #2 Culvert/freeway 1	0.030	0.110	0.040	0.180	<DL	0.039	0.084	0.003	0.157	0.035	0.014	0.015	0.020	0.029	0.344
Maddox #3 Culvert/freeway 2	0.010	0.060	0.050	x	0.288	0.002	0.132	0.010	0.019	0.096	0.011	0.011	0.015	0.070	0.047
Maddox #4 Siphon	0.170	0.10	0.040	0.260	x	0.378	0.283	0.021	0.005	0.016	0.015	0.017	0.013	0.041	0.064
Maddox #5 Estuary	0.050	0.030	0.070	0.100	0.208	0.153	0.110	0.021	0.012	0.006	0.012	0.009	0.016	0.064	0.052
Carpenter #1 Headwaters	0.040	0.010	0.050	0.010	0.042	0.004	0.130	0.003	0.009	0.009	0.002	0.008	0.008	0.010	0.009
Carpenter #2 Bridge	0.050	0.040	0.020	0.050	0.003	0.008	0.017	0.004	0.009	0.038	0.004	0.003	0.004	0.009	0.059
Carpenter #3 Fisher Slough	0.040	0.020	0.110	0.030	0.006	0.008	0.099	0.069	0.006	0.026	0.013	0.014	0.020	0.026	0.048
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.030	0.015	0.008	0.047	0.007	x	nf	0.022	0.031	0.006	0.007	nf
Carpenter Inlet #2 perennial stream Sandy Creek	0.02	<DL	x	0.010	0.003	0.028	0.098	0.019	0.006	0.005	0.014	0.004	0.064	0.026	0.033
Carpenter Inlet #3 ephemeral stream	x	x	x	0.010	0.001	0.004	0.010	0.006	0.001	0.003	0.004	0.023	0.006	0.027	0.012

(x) Represents periods of no data,(nf) represents periods of no flow and (<DL) represents amounts too low for detection (.002 mg/L and lower)

Table 21. Orthophosphorus concentrations measured in mg/L for each sampling location

	2007				2008						2009				
	8/15	9/11	10/4	11/15	3/12	4/10	5/20	6/16	7/15	8/21	4/16	5/19	6/17	7/14	8/18
Maddox #1 Headwaters	x	0.052	0.027	0.021	0.004	0.004	0 .004	0.006	0.024	0.022	0.012	0.017	0.039	0.049	0.034
Maddox #2 Culvert/freeway 1	x	0.010	0.060	0.017	0.019	0.016	0.006	0.013	0.009	0.008	0.049	0.003	0.006	0.055	0.006
Maddox #3 Culvert/freeway 2	x	0.014	0.056	x	0.030	0.042	0.010	0.020	0.001	0.005	0.151	0.019	0.004	0.022	0.003
Maddox #4 Siphon	x	0.019	0.017	0.016	x	0.023	0.011	0.008	0.002	0.003	0.082	0.031	0.008	0.022	0.029
Maddox #5 Estuary	x	0.001	x	0.006	0.018	0.019	0.008	0.011	0.021	0.001	0.051	0.022	0.006	0.030	0.000
Carpenter #1 Headwaters	x	0.007	0.016	0.004	0.008	0.003	0.004	0.006	0.013	0.009	0.004	0.000	0.007	0.003	0.009
Carpenter #2 Bridge	x	0.003	0.017	0.011	0.004	0.002	0.004	0.005	0.008	0.009	0.004	0.002	0.017	0.011	0.078
Carpenter #3 Fisher Slough	x	0.210	0.012	0.069	0.005	0.003	0.004	0.010	0.068	0.151	0.015	0.004	0.070	0.016	0.001
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.004	0.002	0.001	0.001	0.002	x	nf	0.001	0.002	0.004	0.010	nf
Carpenter Inlet #2 perennial stream	x	0.025	x	x	0.004	0.003	0.006	0.004	0.008	0.004	0.001	0.004	0.001	0.009	0.024
Carpenter Inlet #3 ephemeral stream	x	x	x	0.005	0.003	0.003	0.004	0.004	0.005	0.006	0.002	0.005	0.002	0.001	0.002

(x) Represents periods of no data and (nf) represents periods of no flow.

Table 22. Total phosphorus concentrations measured in mg/L for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	0.104	0.092	x	0.052	x	0.048	0.095	0.087	0.234	0.070	0.060	0.057	0.089	0.107	0.064
Maddox #2 Culvert/freeway 1	0.118	0.054	x	0.081	x	0.106	0.091	0.065	0.052	0.057	0.147	0.095	0.257	0.168	0.120
Maddox #3 Culvert/freeway 2	0.066	0.064	x	0.102	x	0.158	0.127	0.092	0.417	0.163	0.324	0.329	0.130	0.056	0.154
Maddox #4 Siphon	0.042	0.045	x	0.062	x	0.145	0.093	0.106	0.100	0.033	0.192	0.102	0.049	0.057	0.098
Maddox #5 Estuary	x	0.045	x	0.060	x	0.109	0.111	0.080	0.129	0.018	0.144	0.125	0.060	0.073	0.036
Carpenter #1 Headwaters	0.046	0.039	x	0.027	x	0.026	0.095	0.036	0.046	0.030	0.063	0.044	0.047	0.047	0.026
Carpenter #2 Bridge	0.040	0.043	x	0.041	x	0.024	0.034	0.072	0.189	0.077	0.057	0.046	0.073	0.111	0.108
Carpenter #3 Fisher Slough	0.333	0.271	x	0.097	x	0.034	0.076	0.065	0.114	0.185	0.061	0.071	0.119	0.183	0.009
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.027	x	0.018	0.043	0.021	x	nf	0.025	0.029	0.036	0.049	nf
Carpenter Inlet #2	0.054	0.051	x	0.042	x	0.019	0.090	0.044	0.031	0.029	0.034	0.037	0.043	0.063	0.019
Carpenter Inlet #3 ephemeral stream	x	x	x	0.026	x	x	0.030	0.041	0.032	0.034	0.036	0.041	0.046	0.038	0.030

(x) Represents periods of no data and (nf) represents periods of no flow.

Table 23. Suspended solids in mg/L for each sampling location

	2007				2008						2009				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.1	0.9	0.1	0.1	0.1	0.1	0.1	0.2
Maddox #2 Culvert/freeway 1	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.5	0.2	0.3	0.2	0.3
Maddox #3 Culvert/freeway 2	0.3	0.3	0.1	0.3	0.3	0.3	0.2	0.3	0.1	0.2	0.4	0.3	0.0	0.0	0.3
Maddox #4 Siphon	0.2	0.2	0.1	x	x	0.5	0.2	0.4	0.0	0.0	0.5	0.2	0.0	0.0	0.1
Maddox #5 Estuary	x	0.1	0.1	0.4	0.5	0.5	0.5	0.5	0.1	0.7	1.2	0.5	0.0	0.2	2.0
Carpenter #1 Headwaters	0.4	0.6	0.2	0.2	0.1	0.1	0.4	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.4
Carpenter #2 Bridge	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.3	0.2	0.1	0.1	0.1	0.2	0.2
Carpenter #3 Fisher Slough	0.2	0.1	0.2	0.2	0.1	0.0	0.1	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.3
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.2	0.1	0.1	0.2	x	x	nf	0.1	0.1	0.1	0.2	nf
Carpenter Inlet #2 perennial stream	0.2	0.2	x	0.1	0.1	0.1	0.2	0.1	0.2	x	0.1	0.1	0.2	0.2	0.2
Sandy Creek **Carpenter Inlet #3** ephemeral stream	x	x	x	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2

(x) Represents periods of no data and (nf) represents periods of no flow.

Table 24. Stream discharge estimates for Maddox and Carpenter Creek stations-all values are in cubic feet per second, (cfs)

	2007				**2008**						**2009**				
	8/15	**9/11**	**10/4**	**11/15**	**3/12**	**4/10**	**5/20**	**6/16**	**7/15**	**8/21**	**4/16**	**5/19**	**6/17**	**7/14**	**8/18**
Maddox #1 Headwaters	0.03	0.0	1.9	0.2	1.3	3.1	2.4	0.2	0.0	x	0.6	1.7	0.02	0.01	x
Maddox #2 Culvert/freeway 1	0.34	0.6	x	5.3	2.8	3.9	3.8	x	x	x	1.0	5.4	3.9	0.5	0.3
Maddox #3 Culvert/freeway 2	0.66	1.4	9.3	5.0	7.3	4.5	8.9	x	x	10.4	0.8	7.3	1.2	0.4	0.1
Maddox #4 Siphon	x	x	x	x	x	12.7	8.4	10.5	14.8	2.4	27.8	11.6	5.1	x	x
Maddox #5	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Estuary	x	5.5	x	6.1	6.0	x	x	x	x	x	x	x	x	x	x
Carpenter #1 Headwaters	0.01	0.1	0.4	0.3	2.1	5.3	x	2.0	1.0	x	12.1	5.4	1.3	0.15	x
Carpenter #2 Bridge	0.06	x	3.1	x	x	x	x	x	x	x	5.6	18.8	2.8	0.6	x
Carpenter #3 Fisher Slough	1.57	0.3	29.1	4.4	58.8	78.7	14.0	6.3	x	x	3.1	40.8	0.9	2.3	5.4
Carpenter Inlet #1 by bridge at Carp. #2	nf	nf	nf	0.4	3.1	7.9	6.5	1.0	x	nf	1.5	1.7	0.1	x	nf
Carpenter Inlet #2 perennial stream	0.08	0.0	0.4	0.6	1.2	3.4	5.2	1.1	2.3	1.7	2.5	1.7	0.2	0.2	x
Sandy Creek **Carpenter Inlet #3** ephemeral stream	x	x	x	0.2	0.4	1.4	3.1	0.5	0.2	x	0.74	0.18	0.1	0.01	x

(x)- represents sites for which adequate discharge could not be determined and (nf) represents sites with no flow.

APPENDIX B

Benthic Macroinvertebrate Data

2007 Invertebrate Averages

August-November											
Pollution Tolerant	**Order**	**Maddox Creek**				**Carpenter Creek**			**Inlet Creeks**		
		Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
YES	Annelida	3	16	1	2	6	3	8	0	0	x
YES	Bivalvia	2	12	13	5	1	9	8	0	0	x
	Crustacea	133	20	2	19	4	6	54	0	1	x
NO	Coleoptera	0	0	2	0	0	3	1	0	1	x
Moderate	Diptera	5	1	27	45	55	45	27	7	10	x
NO	Ephemeroptera	2	0	0	0	43	13	0	3	9	x
YES	Gastropoda	10	28	37	7	0	23	3	2	0	x
YES	Hemiptera	0	0	0	0	0	0	0	0	0	x
Moderate	Megaloptera	0	0	0	0	0	0	1	0	0	x
	Mysidacea	0	0	0	0	0	0	3	0	0	x
NO	Plecoptera	0	0	0	0	11	21	0	33	20	x
NO	Trichoptera	3	0	0	0	30	7	5	4	11	x
Moderate	Odonata	0	0	4	0	0	2	0	0	0	x
	Unknown	0	0	0	0	0	0	1	0	0	x
Tolerant Total		15	56	51	14	7	35	19	2	0	0
Intolerant Total		5	0	2	0	84	44	6	40	41	0

2008 Invertebrate Averages

March-August Pollution Tolerant	Order	Maddox Creek				Carpenter Creek			Inlet Creeks		
		Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
YES	Annelida	13	32	15	11	9	25	14	2	3	3
YES	Bivalvia	13	3	31	3	1	4	4	0	0	0
	Crustacea	28	5	0	18	8	12	22	0	0	0
NO	Coleoptera	0	1	0	0	1	0	0	0	2	0
Moderate	Diptera	18	7	20	47	4	72	46	5	61	38
NO	Ephemeroptera	4	0	0	0	13	4	0	7	59	31
YES	Gastropoda	9	37	19	27	1	18	5	0	0	2
YES	Hemiptera	0	0	1	0	0	1	0	0	0	0
Moderate	Megaloptera	0	0	0	0	0	0	0	0	0	0
	Mysidacea	0	0	0	0	0	0	0	0	0	0
NO	Plecoptera	0	0	0	0	7	0	3	3	26	26
NO	Trichoptera	2	0	0	0	8	4	5	6	11	4
Moderate	Odonata	1	0	0	2	0	0	0	0	0	0
	Unknown	0	0	0	0	0	0	0	1	0	0
Tolerant Totals		35	72	66	41	11	48	23	2	3	5
Intolerant Totals		6	1	0	0	29	8	8	16	98	61

2009 Invertebrate Averages

April-August Pollution Tolerant	Order	Maddox Creek				Carpenter Creek			Inlet Creeks		
		Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 1	Site 2	Site 3
YES	Annelida	11	12	18	15	8	9	27	5	1	4
YES	Bivalvia	0	3	10	23	0	6	15	0	0	1
	Crustacea	36	0	16	2	0	7	40	0	0	1
NO	Coleoptera	2	0	1	0	22	1	0	1	4	9
Moderate	Diptera	62	26	17	17	17	59	43	16	54	13
NO	Ephemeroptera	1	0	1	0	27	1	0	6	20	30
YES	Gastropoda	0	4	13	21	0	4	1	0	0	1
YES	Hemiptera	0	1	0	0	0	0	0	0	0	0
Moderate	Megaloptera	0	0	2	1	0	1	1	0	0	0
	Mysidacea	0	0	0	0	0	0	0	0	0	0
NO	Plecoptera	1	0	0	0	11	0	0	0	12	23
NO	Trichoptera	5	0	0	2	4	1	3	2	3	4
Moderate	Odonata	0	0	1	1	0	0	0	0	0	0
	Unknown	0	0	0	0	0	0	0	0	0	1
Tolerant Totals		11	20	41	59	8	19	43	5	1	6
Intolerant Totals		9	0	2	2	64	3	3	9	39	66

APPENDIX C

Habitat Suitability Index Data

HSI Scoring Components

V_1	Max. temp during upstream migration
V_2	Min. dissolved oxygen during upstream migration
V_3	Max. temp from spawning to emergence of fry
V_4	Min. dissolved oxygen from spawning to emergence of fry
V_5	Substrate composition in riffle/run areas
V_6	Max. temp during rearing (parr)
V_7	Min. dissolved oxygen during rearing (parr)
V_8	% Vegetative canopy over rearing stream
V_9	Vegetation index of riparian zone during summer
V_{10}	% pools during summer low flow period
V_{11}	Proportion of pools during summer that are large & have sufficient canopy
V_{12}	% Instream and bank cover present during summer low flow period
V_{13}	% of total area consisting of quiet backwaters and deep pools
V_{14}	Max. temp during winter/spring early summer
V_{15}	Min. dissolved oxygen during early summer

Maddox 1

	Upstream		Downstream		Average	
V_1	0.25	fair	0.23	fair	0.24	Fair
V_2	N/A	N/A	N/A	N/A	N/A	N/A
V_3	0.84	Excellent	N/A	N/A	0.84	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.025	Poor	0.28	Poor	0.15	Poor
V_6	N/A	good	0.12	Poor	0.12	Good
V_7	N/A	N/A	N/A	N/A	N/A	N/A
V_8	1.00	Excellent	0.64	Good	0.82	Excellent
V_9	0.91	Excellent	1.00	Excellent	1.00	Excellent
V_{10}	0.10	Poor	0.10	Poor	0.10	Poor
V_{11}	0.20	Poor	0.20	poor	0.20	Fair
V_{12}	1.00	Excellent	1.00	Excellent	1.00	Excellent
V_{13}	1.00	Excellent	1.00	Excellent	1.00	Excellent
V_{14}	0.87	Excellent	N/A	N/A	0.87	Excellent
V_{15}	1.00	Excellent	N/A	N/A	1.00	Excellent
				total	**7.30**	
				average	**0.56**	**GOOD**

Maddox 2

	Upstream		Downstream		Average	
V_1	N/A	N/A	0.23	Fair	0.23	Fair
V_2	N/A	N/A	0.00	Poor	0.00	Poor
V_3	N/A	N/A	0.72	Good	0.72	Good
V_4	N/A	N/A	0.00	Poor	0.00	Poor
V_5	N/A	N/A	0.33	Fair	0.33	Fair
V_6	N/A	N/A	0.50	Good	0.50	Good
V_7	N/A	N/A	0.00	Poor	0.00	Poor
V_8	N/A	N/A	0.00	Poor	0.00	Poor
V_9	N/A	N/A	0.58	Good	0.58	Good
V_{10}	N/A	N/A	0.20	Fair	0.20	Fair
V_{11}	N/A	N/A	0.20	Fair	0.20	Fair
V_{12}	N/A	N/A	0.20	Fair	0.20	Fair
V_{13}	N/A	N/A	0.20	Fair	0.20	Fair
V_{14}	N/A	N/A	0.50	Good	0.50	Good
V_{15}	N/A	N/A	0.57	Good	0.57	Good
				total	**4.23**	
				average	**0.28**	**FAIR**

Maddox 3

	Upstream		Downstream		Average	
V_1	0.04	Poor	N/A	N/A	0.04	Poor
V_2	0.00	Poor	N/A	N/A	0.00	Poor
V_3	0.50	Good	N/A	N/A	0.50	Good
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.33	Fair	N/A	N/A	0.33	Fair
V_6	0.18	Poor	N/A	N/A	0.18	Poor
V_7	0.00	Poor	N/A	N/A	0.00	Poor
V_8	0.00	Poor	N/A	N/A	0.00	Poor
V_9	0.58	Good	N/A	N/A	0.58	Good
V_{10}	0.20	Fair	N/A	N/A	0.20	Fair
V_{11}	0.20	Fair	N/A	N/A	0.20	Fair
V_{12}	0.23	Fair	N/A	N/A	0.23	Fair
V_{13}	0.20	Fair	N/A	N/A	0.20	Fair
V_{14}	0.55	Good	N/A	N/A	0.55	Good
V_{15}	0.60	Good	N/A	N/A	0.60	Good
				total	**3.60**	
				average	**0.24**	**FAIR**

Maddox 4

	Upstream		Downstream		Average	
V_1	0.07	Poor	N/A	N/A	0.07	Poor
V_2	0.00	Poor	N/A	N/A	0.00	Poor
V_3	1.00	Excellent	N/A	N/A	1.00	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.33	Fair	N/A	N/A	0.33	Fair
V_6	0.33	Fair	N/A	N/A	0.33	Fair
V_7	0.00	Poor	N/A	N/A	0.00	Poor
V_8	0.00	Poor	N/A	N/A	0.00	Poor
V_9	0.58	Good	N/A	N/A	0.58	Good
V_{10}	0.20	Fair	N/A	N/A	0.20	Fair
V_{11}	0.20	Fair	N/A	N/A	0.20	Fair
V_{12}	0.20	Fair	N/A	N/A	0.20	Fair
V_{13}	0.20	Fair	N/A	N/A	0.20	Fair
V_{14}	0.49	Fair	N/A	N/A	0.49	Fair
V_{15}	0.84	Excellent	N/A	N/A	0.84	Excellent
				total	**4.44**	
				average	**0.30**	**FAIR**

Carpenter 1

	Upstream		Downstream		average	
V_1	N/A	N/A	N/A	N/A	N/A	N/A
V_2	0.21	Fair	N/A	N/A	0.21	Fair
V_3	1.00	Excellent	N/A	N/A	1.00	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	1.00	Excellent	1	Excellent	1.00	Excellent
V_6	0.48	Fair	N/A	N/A	0.48	Fair
V_7	N/A	N/A	N/A	N/A	N/A	N/A
V_8	0.50	Good	0.78	Good	0.64	Good
V_9	0.59	Good	1	Excellent	0.80	Good
V_{10}	0.10	Fair	0.7	Good	0.40	Fair
V_{11}	0.20	Fair	0.83	Excellent	0.52	Good
V_{12}	1.00	Excellent	1	Excellent	1.00	Excellent
V_{13}	1.00	Excellent	1	Excellent	1.00	Excellent
V_{14}	0.70	Good	N/A	N/A	0.70	Good
V_{15}	1.00	Excellent	N/A	N/A	1.00	Excellent
				total	**8.74**	
				average	**0.67**	**GOOD**

Carpenter 2

	Upstream		Downstream		average	
V_1	N/A	N/A	0.00	Poor	0.00	Poor
V_2	0.05	Poor	N/A	N/A	0.05	Poor
V_3	0.84	Excellent	N/A	N/A	0.84	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.01	Poor	0.00	Poor	0.00	Poor
V_6	0.24	Fair	N/A	N/A	0.24	Fair
V_7	N/A	N/A	0.00	Poor	0.00	Poor
V_8	0.00	Poor	0.00	Poor	0.00	Poor
V_9	0.58	Good	0.58	Good	0.58	Good
V_{10}	0.20	Fair	0.20	Fair	0.20	Fair
V_{11}	0.20	Fair	0.20	Fair	0.20	Fair
V_{12}	0.20	Fair	1.00	Excellent	0.60	Good
V_{13}	0.20	Fair	0.20	Fair	0.20	Fair
V_{14}	0.50	Good	N/A	N/A	0.50	Good
V_{15}	0.94	Excellent	N/A	N/A	0.94	Excellent
				total	**4.36**	
				average	**0.29**	**FAIR**

Carpenter 3

	Upstream		Downstream		average	
V_1	0.00	Poor	1.00	Excellent	0.50	Good
V_2	0.07	Poor	0.05	Poor	0.06	Poor
V_3	1.00	Excellent	N/A	N/A	1.00	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.00	Poor	0.00	Poor	0.00	Poor
V_6	0.30	Fair	0.25	Fair	0.28	Fair
V_7	0.00	Poor	1.00	Excellent	0.50	Good
V_8	0.28	Fair	0.20	Fair	0.24	Fair
V_9	0.40	Fair	0.74	Good	0.57	Good
V_{10}	0.20	Fair	0.20	Fair	0.20	Fair
V_{11}	1.00	Excellent	0.43	Fair	0.72	Good
V_{12}	1.00	Excellent	0.26	Fair	0.63	Good
V_{13}	1.00	Excellent	0.20	Fair	0.60	Good
V_{14}	0.50	Good	N/A	N/A	0.50	Good
V_{15}	1.00	Excellent	N/A	N/A	1.00	Excellent
				total	**6.79**	
				average	**0.45**	**FAIR**

Inlet 1

	Upstream		Downstream		average	
V_1	N/A	N/A	N/A	N/A	N/A	
V_2	1.00	Excellent	N/A	N/A	1.00	Excellent
V_3	1.00	Excellent	N/A	N/A	1.00	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.42	Fair	0.11	Poor	0.27	Fair
V_6	N/A	N/A	N/A	N/A	N/A	N/A
V_7	1.00	Excellent	N/A	N/A	1.00	Excellent
V_8	0.34	Fair	0.22	Fair	0.28	Fair
V_9	0.78	Good	0.79	Good	0.79	Good
V_{10}	0.70	Good	0.10	Poor	0.40	Fair
V_{11}	0.20	Fair	0.20	Fair	0.20	Fair
V_{12}	1.00	Excellent	1.00	Excellent	1.00	Excellent
V_{13}	1.00	Excellent	0.40	Fair	0.70	Good
V_{14}	0.75	Good	N/A	N/A	0.75	Good
V_{15}	1.00	Excellent	N/A	N/A	1.00	Excellent
				total	**8.38**	
				average	**0.64**	**GOOD**

Inlet 2

	Upstream		Downstream		average	
V_1	0.25	Fair	0.25	Fair	0.25	Fair
V_2	1.00	Excellent	N/A	N/A	1.00	Excellent
V_3	1.00	Excellent	N/A	N/A	1.00	Excellent
V_4	0.00	Poor	N/A	N/A	0.00	Poor
V_5	0.61	Good	0.74	Good	0.68	Good
V_6	0.88	Excellent	0.88	Excellent	0.88	Excellent
V_7	1.00	Good	N/A	N/A	1.00	Excellent
V_8	0.83	Excellent	0.50	Good	0.67	Good
V_9	1.00	Excellent	0.57	Good	0.79	Good
V_{10}	0.10	Poor	0.10	Poor	0.10	Poor
V_{11}	0.20	Fair	0.20	Fair	0.20	Fair
V_{12}	1.00	Excellent	1.00	Excellent	1.00	Excellent
V_{13}	1.00	Excellent	1.00	Excellent	1.00	Excellent
V_{14}	0.82	Excellent	N/A	N/A	0.82	Excellent
V_{15}	1.00	Excellent	N/A	N/A	1.00	Excellent
				total	**10.38**	
				average	**0.69**	**GOOD**

Inlet 3

	Upstream		Downstream		average	
V_1	N/A	N/A	0.42	Fair	0.42	Fair
V_2	N/A	N/A	1.00	Excellent	1.00	Excellent
V_3	N/A	N/A	1.00	Excellent	1.00	Excellent
V_4	N/A	N/A	0.00	Poor	0.00	Poor
V_5	N/A	N/A	0.93	Excellent	0.93	Excellent
V_6	N/A	N/A	1.00	Excellent	1.00	Excellent
V_7	N/A	N/A	1.00	Excellent	1.00	Excellent
V_8	N/A	N/A	1.00	Excellent	1.00	Excellent
V_9	N/A	N/A	1.00	Excellent	1.00	Excellent
V_{10}	N/A	N/A	0.10	Poor	0.10	Poor
V_{11}	N/A	N/A	0.20	Fair	0.20	Fair
V_{12}	N/A	N/A	1.00	Excellent	1.00	Excellent
V_{13}	N/A	N/A	1.00	Excellent	1.00	Excellent
V_{14}	N/A	N/A	0.87	Excellent	0.87	Excellent
V_{15}	N/A	N/A	1.00	Excellent	1.00	Excellent
				total	**11.52**	
				average	**0.77**	**GOOD**

APPENDIX D

Statistical Analysis

Two-Sample T-Test for Pollution Tolerant and Intolerant Benthic Invertebrates

CARPENTER 1	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	45	15.9	16.3	2.4
Tolerant	45	3	4.84	0.72
	DF	**T Value**	**P Value**	
T-Test of Diff.	51	5.11	0	

CARPENTER 2	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	42	5.3	15.2	2.3
Tolerant	42	11.8	**16.7**	2.6
	DF	**T Value**	**P Value**	
T-Test of Diff.	81	-1.89	0.063	

CARPENTER 3	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	36	1.94	7.22	1.5
Tolerant	36	9.6	2.58	0.53
	DF	**T Value**	**P Value**	
T-Test of Diff.	40	-3.29	0.002	

MADDOX 1	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	45	1.87	3.76	0.56
Tolerant	45	7	10	1.5
	DF	**T Value**	**P Value**	
T-Test of Diff.	56	-3.23	0.002	

MADDOX 2	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	*	*	*	*
Tolerant				
	DF	**T Value**	**P Value**	
T-Test of Diff.	*	*	*	

Two-Sample T-Test for Pollution Tolerant and Intolerant Benthic Invertebrates

MADDOX 3	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	39	0.154	0.812	0.13
Tolerant	39	17.3	14.5	2.3
	DF	**T Value**	**P Value**	
T-Test of Diff.	38	-7.35	0	

MADDOX 4	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	27	0.333	0.679	0.13
Tolerant	27	16.4	17.5	3.4
	DF	**T Value**	**P Value**	
T-Test of Diff.	26	-4.79	0	

INLET 1	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	24	4.33	7.22	1.5
Tolerant	24	1.13	2.58	0.53
	DF	**T Value**	**P Value**	
T-Test of Diff.	28	2.05	0.05	

INLET 2	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	42	20.7	27.8	4.3
Tolerant	42	1.31	1.31	0.2
	DF	**T Value**	**P Value**	
T-Test of Diff.	41	4.7	0	

INLET 3	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	33	19.5	21.3	3.7
Tolerant	33	1.82	2.91	0.51
	DF	**T Value**	**P Value**	
T-Test of Diff.	33	4.73	0	

Pearson Correlations

	T. Phosphorus	O. Phosphorus	Nitrogen	Ammonia	Temperature
O. Phosphorus	0.51				
P-Value	0				
Nitrogen	0.111	-0.086			
P-Value	0.003	0.017			
Ammonia	0.069	-0.005	0.23		
P-Value	0.052	0.886	0		
Temperature	0.292	0.196	-0.062	0.024	
P-Value	0	0	0.081	0.475	
Dissolved Oxy.	-0.08	-0.037	-0.2	-0.31	-0.271
P-Value	0.026	0.297	0	0	0
pH	-0.087	-0.079	-0.118	-0.21	0.329
P-Value	0.016	0.025	0.001	0	0
Alkalinity	0.083	0.187	0.023	0.122	0.193
P-Value	0.023	0	0.522	0	0
SPC	-0.056	-0.068	-0.072	0.055	0.165
P-Value	0.12	0.055	0.045	0.108	0
Suspended Solids	0.116	0.062	0.073	0.164	0.2
P-Value	0.001	0.76	0.036	0	0
Discharge	0.025	-0.04	0.224	0.028	-0.175
P-Value	0.561	0.331	0	0.483	0
HSI	-0.442	-0.232	-0.075	-0.307	-0.428
P-Value	0	0	0.038	0	0

Pearson Correlations

	Dissolved Oxy.	pH	Alkalinity	SPC	Suspended Solids	Discharge
O. Phosphorus						
P-Value						
Nitrogen						
P-Value						
Ammonia						
P-Value						
Temperature						
P-Value						
Dissolved Oxy.						
P-Value						
pH	0.372					
P-Value	0					
Alkalinity	-0.222	-0.041				
P-Value	0	0.244				
SPC	0.024	-0.12	0.022			
P-Value	0.477	0	0.525			
Suspended Solids	-0.112	-0.147	0.172	0.211		
P-Value	0.001	0	0	0		
Discharge	0.05	-0.099	-0.185	-0.205	-0.095	
P-Value	0.208	0.014	0	0	0.018	
HSI	0.398	0.215	0.068	-0.068	-0.077	-0.218
P-Value	0	0	0.056	0.053	0.029	0

Two Sample T-Tests for Benthic Invertebrates and all Other Water Quality Parameters

T. PHOSPHORUS	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	264	0.0393	0.0158	0.00097
Tolerant	468	0.1078	0.077	0.0036
	DF	**T Value**	**P Value**	
T-Test of Diff.	533	-18.56	0	

O. PHOSPHORUS	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	282	0.00543	0.00516	0.00031
Tolerant	492	0.025	0.0349	0.0016
	DF	**T Value**	**P Value**	
T-Test of Diff.	527	-12.24	0	

NITRITE/NITRATE	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	270	0.524	0.531	0.032
Tolerant	486	0.502	0.92	0.042
	DF	**T Value**	**P Value**	
T-Test of Diff.	752	0.43	0.669	

AMMONIA	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	294	0.0194	0.0244	0.0014
Tolerant	522	0.0534	0.0744	0.0033
	DF	**T Value**	**P Value**	
T-Test of Diff.	693	-9.56	0	

TEMPERATURE	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	288	11.09	2.48	0.15
Tolerant	522	14.38	4.09	0.18
	DF	**T Value**	**P Value**	
T-Test of Diff.	800	-14.21	0	

DISSOLVED OXY.	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	2.88	10.76	1.34	0.079
Tolerant	522	8.68	3.17	0.14
	DF	**T Value**	**P Value**	
T-Test of Diff.	766	13.08	0	

Two Sample T-Tests for Benthic Invertebrates and all Other Water Quality Parameters

pH	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	288	7.465	0.496	0.029
Tolerant	516	7.167	0.655	0.029
	DF	**T Value**	**P Value**	
T-Test of Diff.	731	7.24	0	

ALKALINITY	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	288	102.6	48.6	2.9
Tolerant	498	92.1	40.9	1.8
	DF	**T Value**	**P Value**	
T-Test of Diff.	520	3.09	0.002	

SPC	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	288	281	141	8.3
Tolerant	510	285	157	7
	DF	**T Value**	**P Value**	
T-Test of Diff.	649	-0.33	0.743	

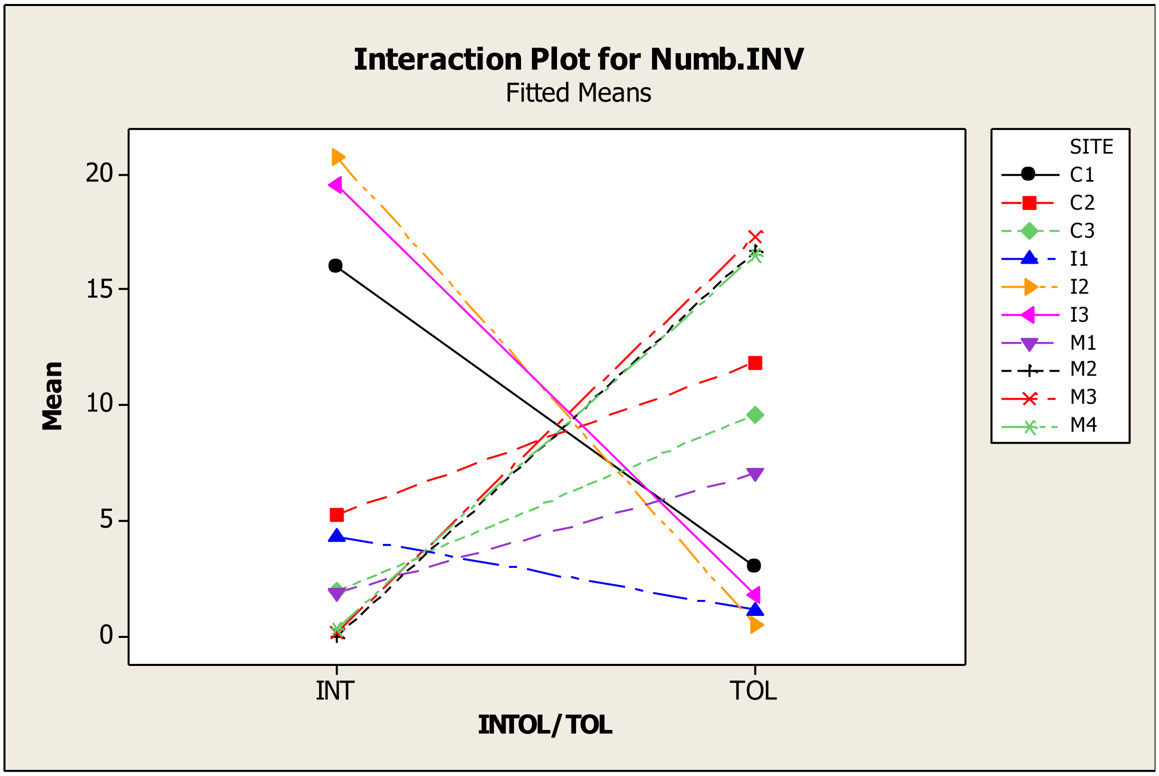
SUSPENDED SOLIDS	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	288	0.1845	0.0907	0.0053
Tolerant	528	0.2	0.126	0.0055
	DF	**T Value**	**P Value**	
T-Test of Diff.	754	-2.09	0.037	

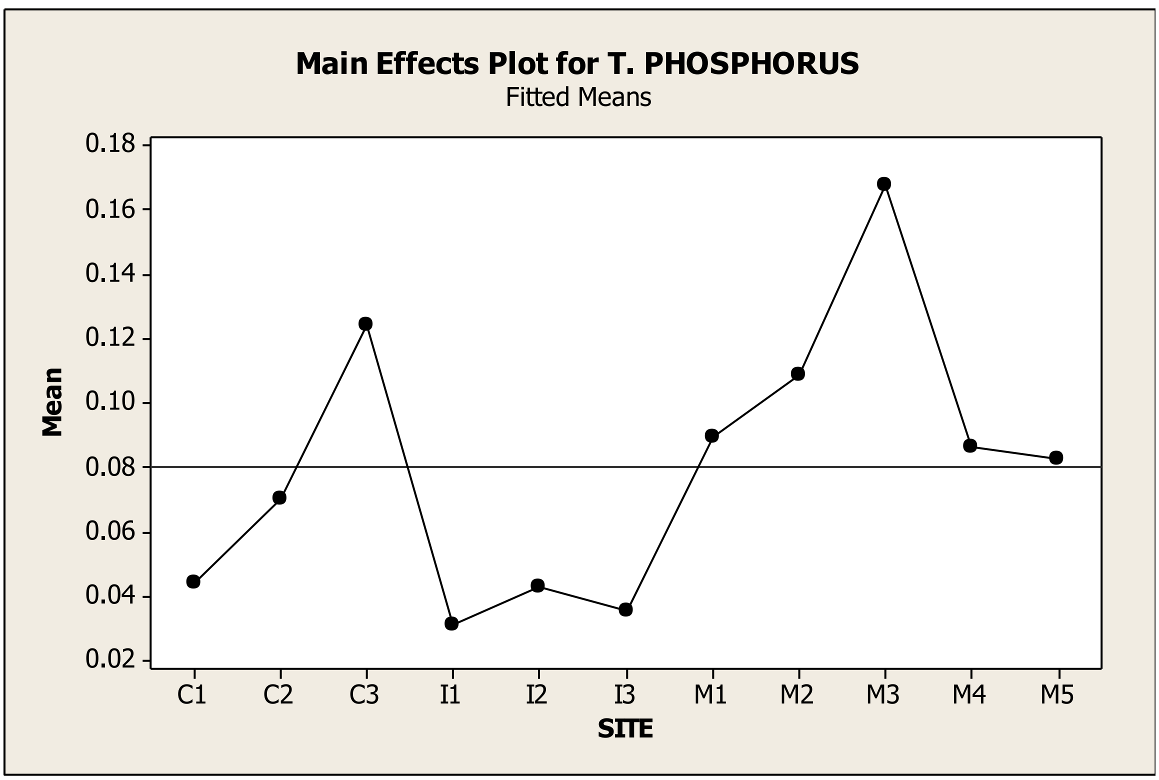
DISCHARGE	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	264	1.81	2.45	0.15
Tolerant	384	7.3	13.4	0.69
	DF	**T Value**	**P Value**	
T-Test of Diff.	419	-7.8	0	

HSI	**N**	**Mean**	**St. Dev**	**SE Mean**
Intolerant	360	0.72	0.0431	0.0023
Tolerant	539	0.395	0.116	0.005
	DF	**T Value**	**P Value**	
T-Test of Diff.	736	59.3	0	

APPENDIX E

Main Effects Plots and Interaction Plots


Interaction Plot for Numb.INV
Fitted Means
Mean
20
15
10
5
0
INT
TOL
INTOL/TOL
SITE
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4


Main Effects Plot for T. PHOSPHORUS
Fitted Means
Mean
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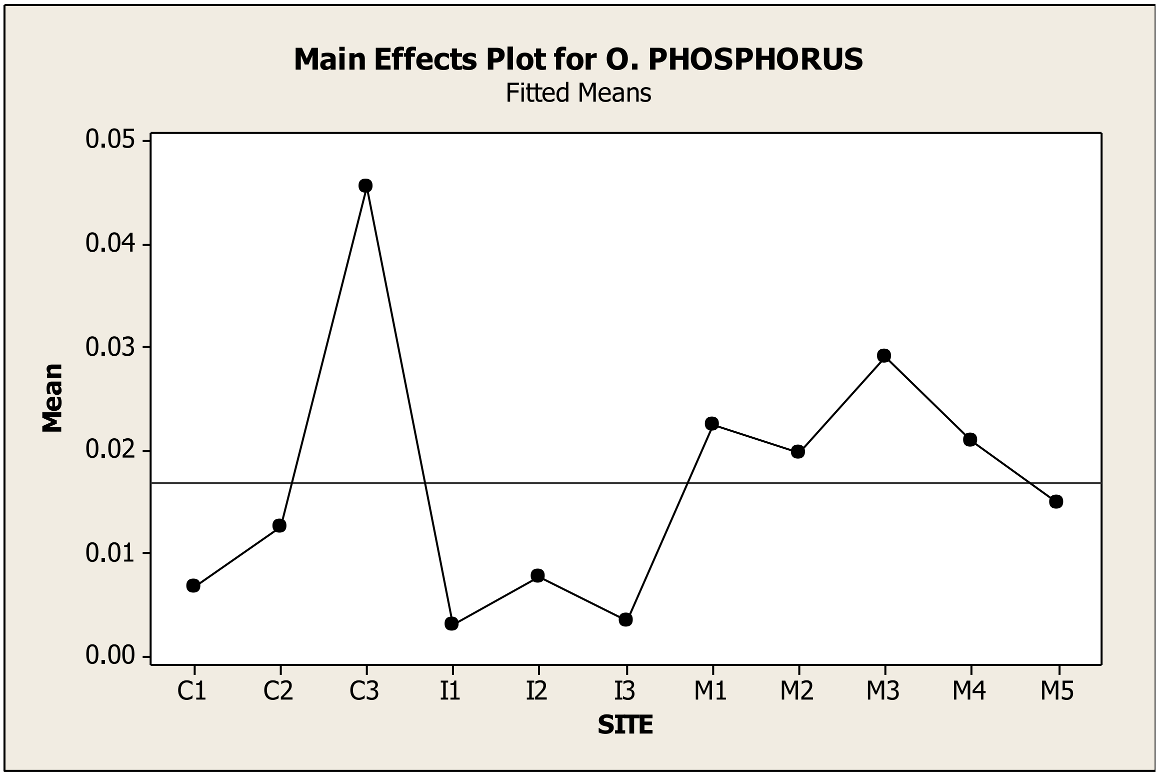
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for O. PHOSPHORUS
Fitted Means
Mean
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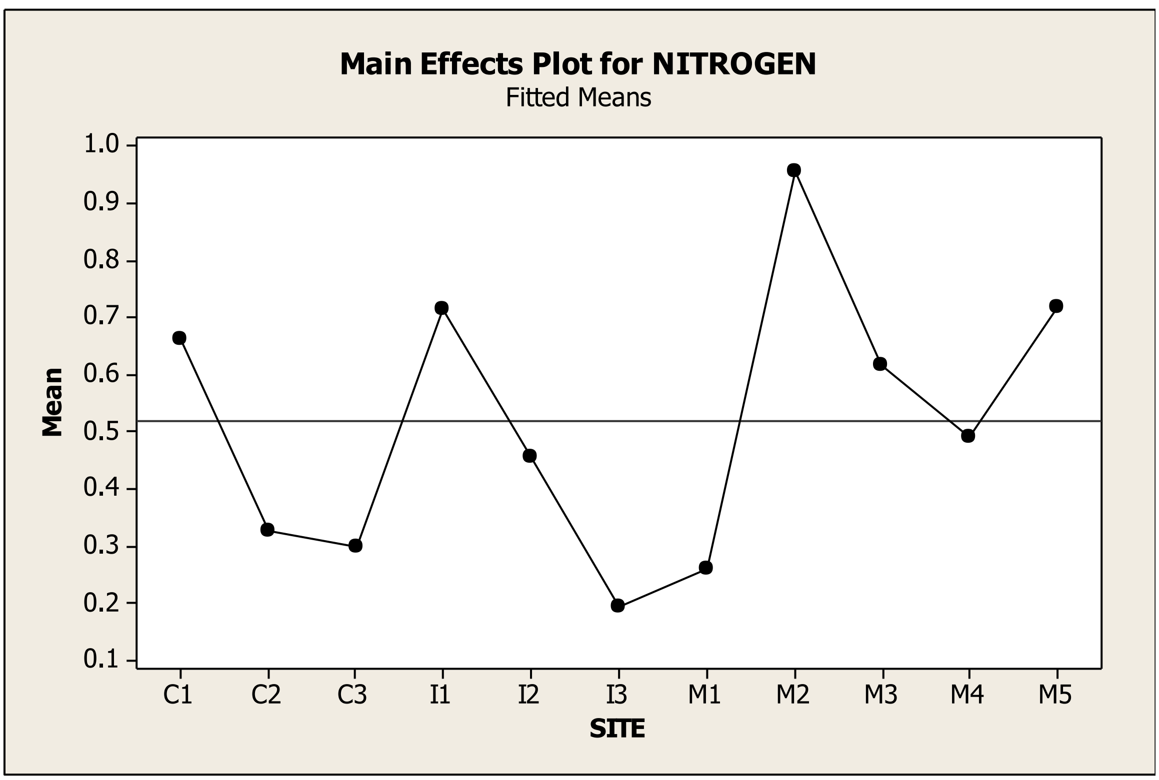
0.04
0.03
0.02
0.01
0.00
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for NITROGEN
Fitted Means
Mean
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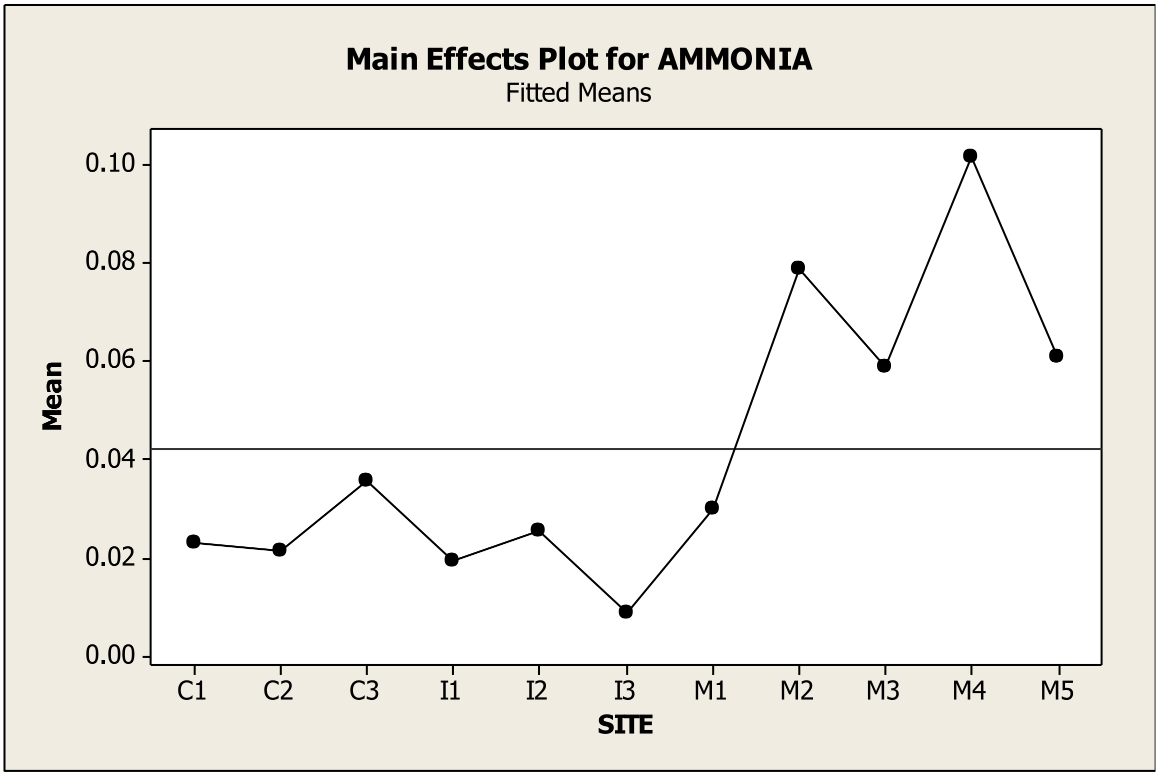
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for AMMONIA
Fitted Means
Mean
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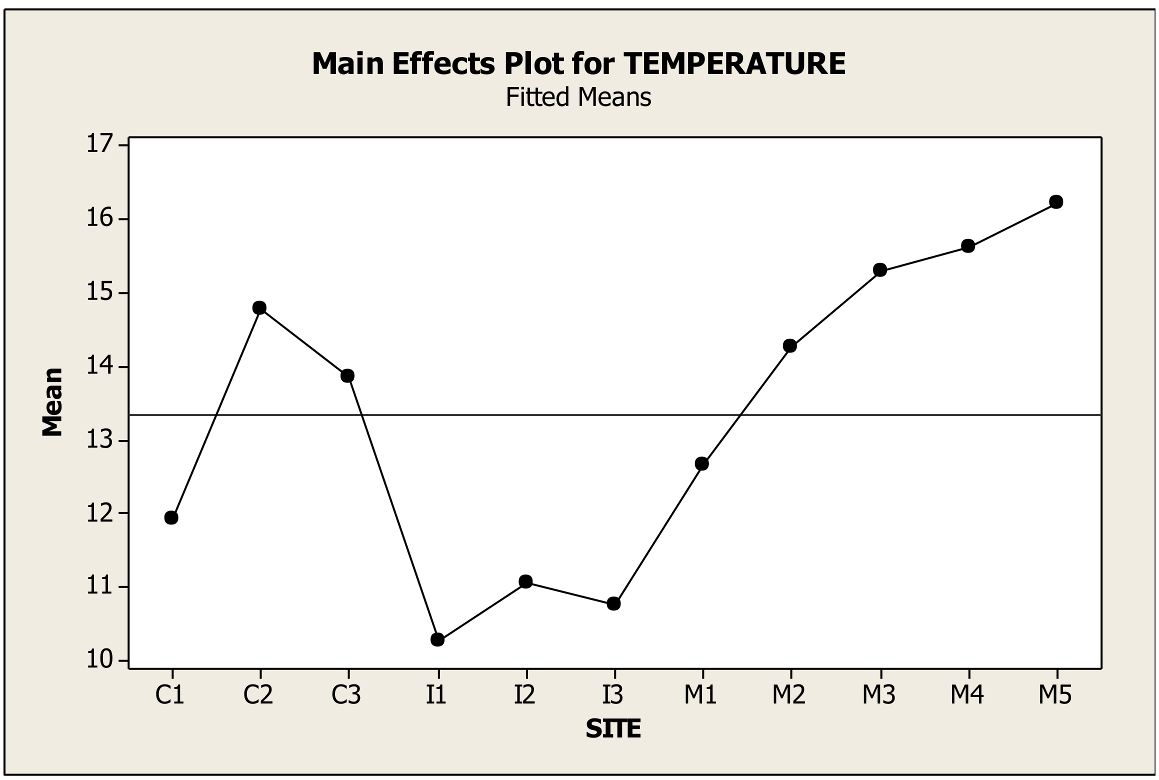
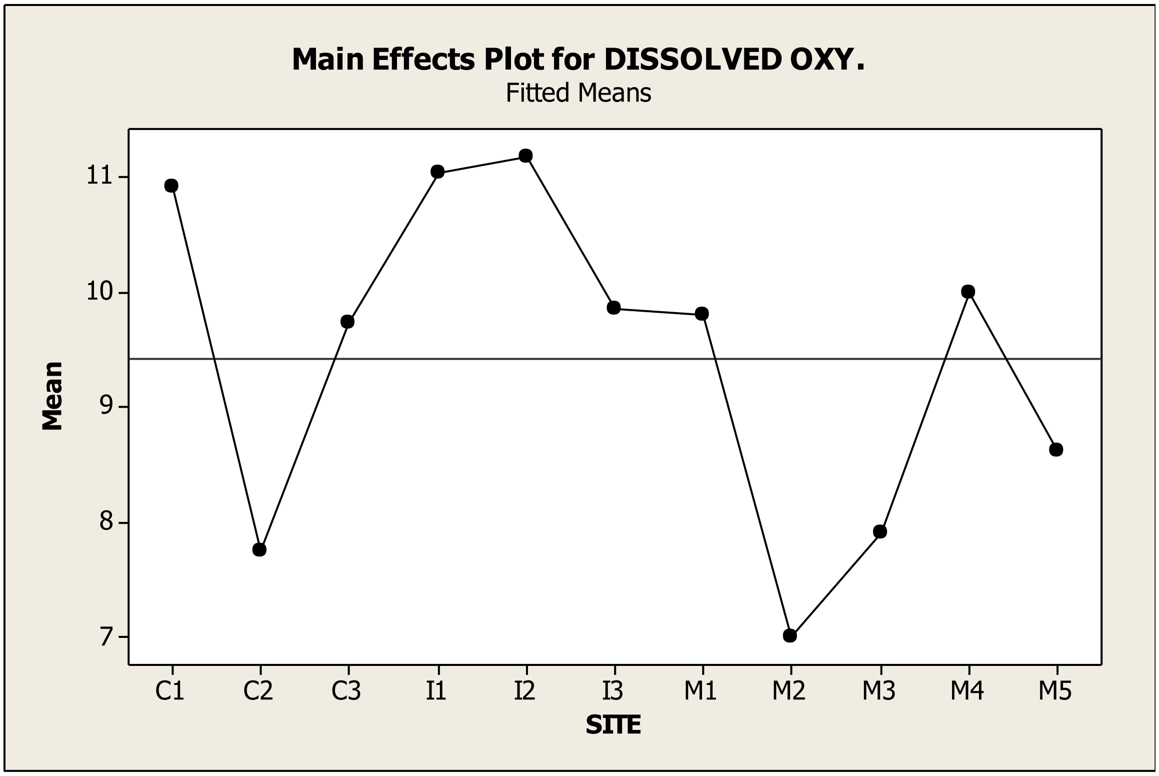
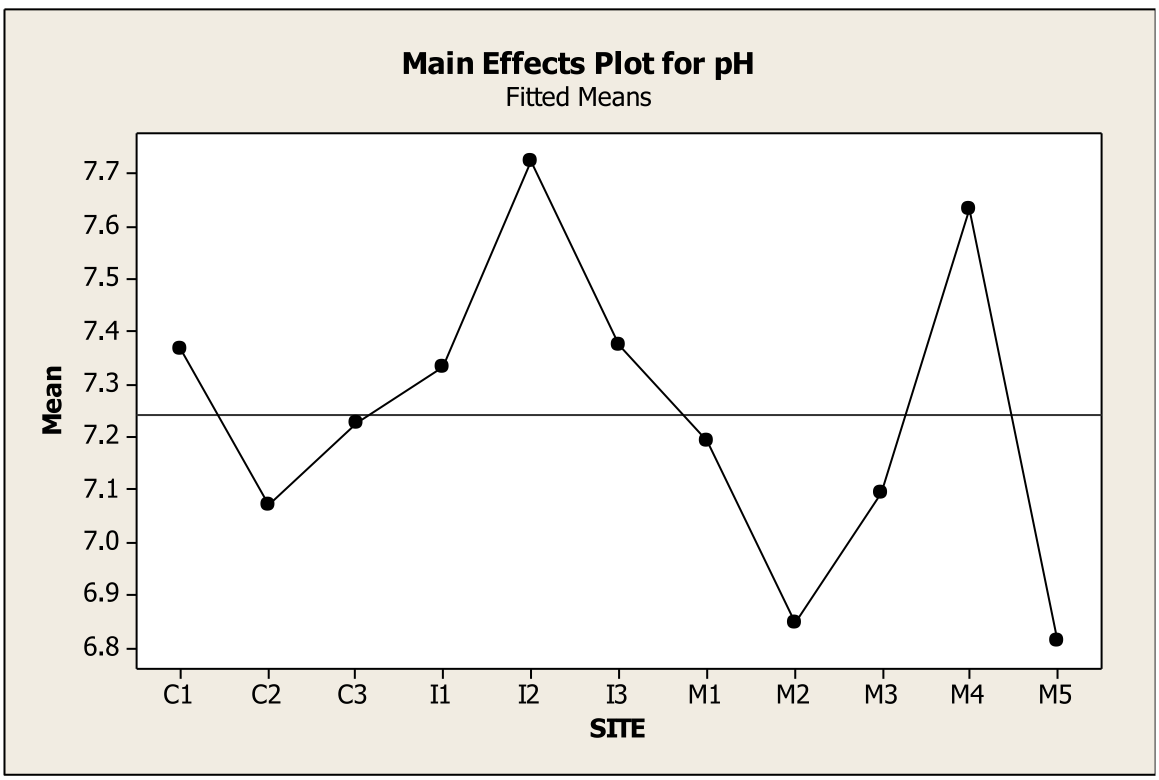
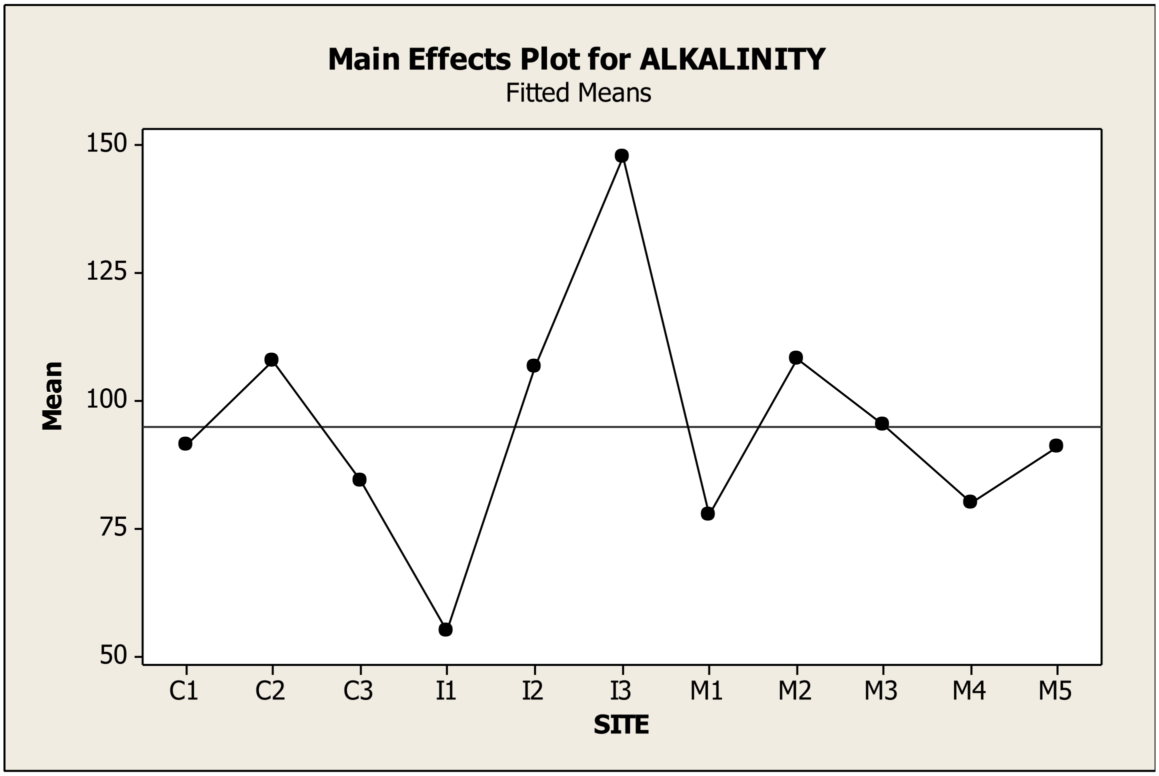
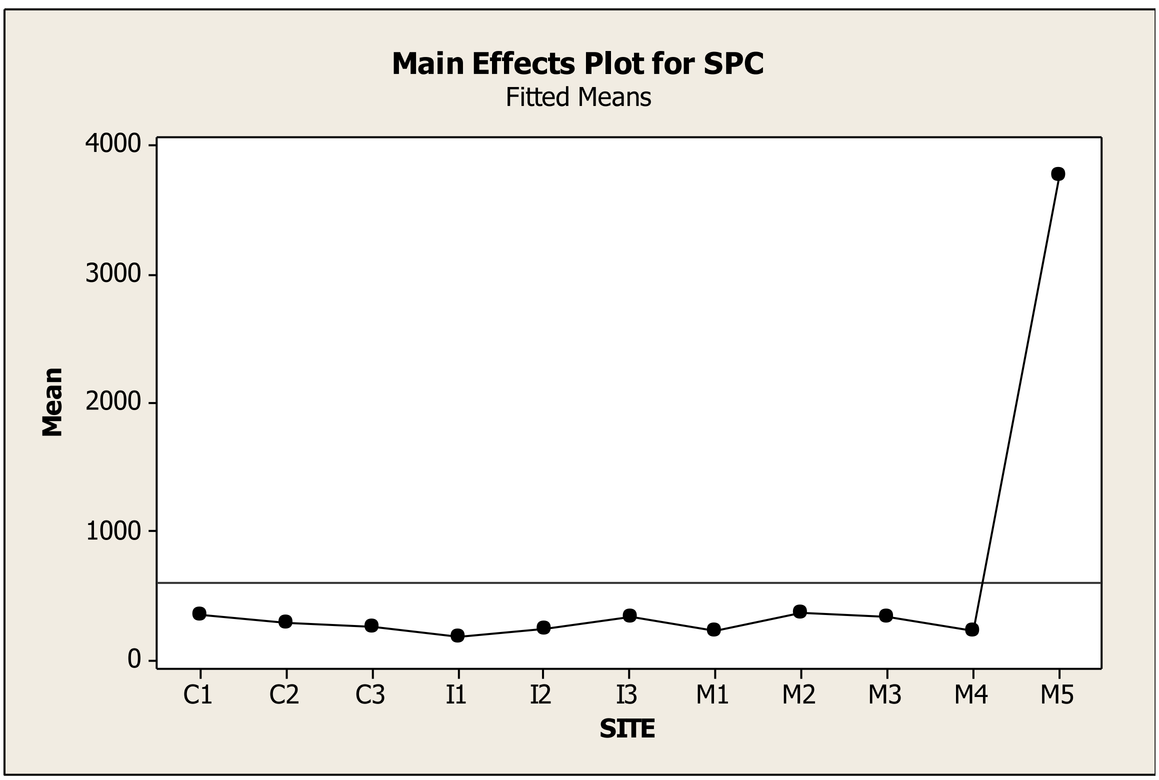
0.08
0.06
0.04
0.02
0.00
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE

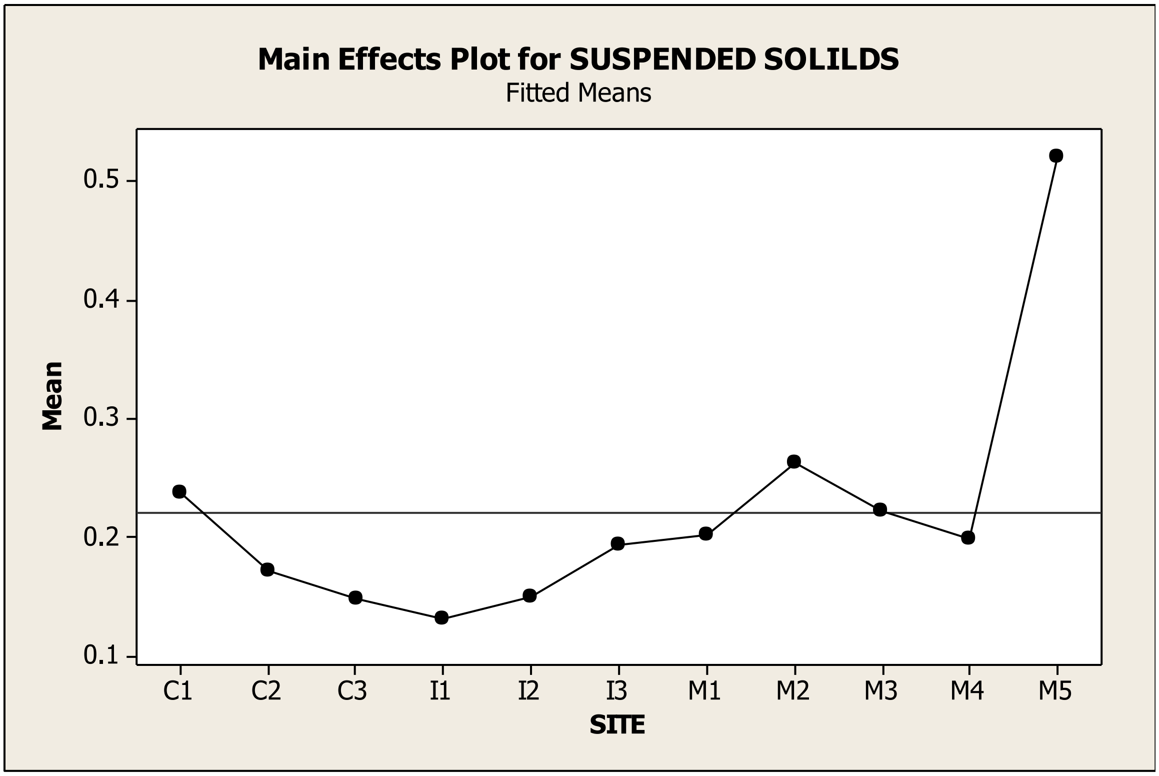

Main Effects Plot for TEMPERATURE
Fitted Means
Mean
17
16
15
14
13
12
11
10
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE

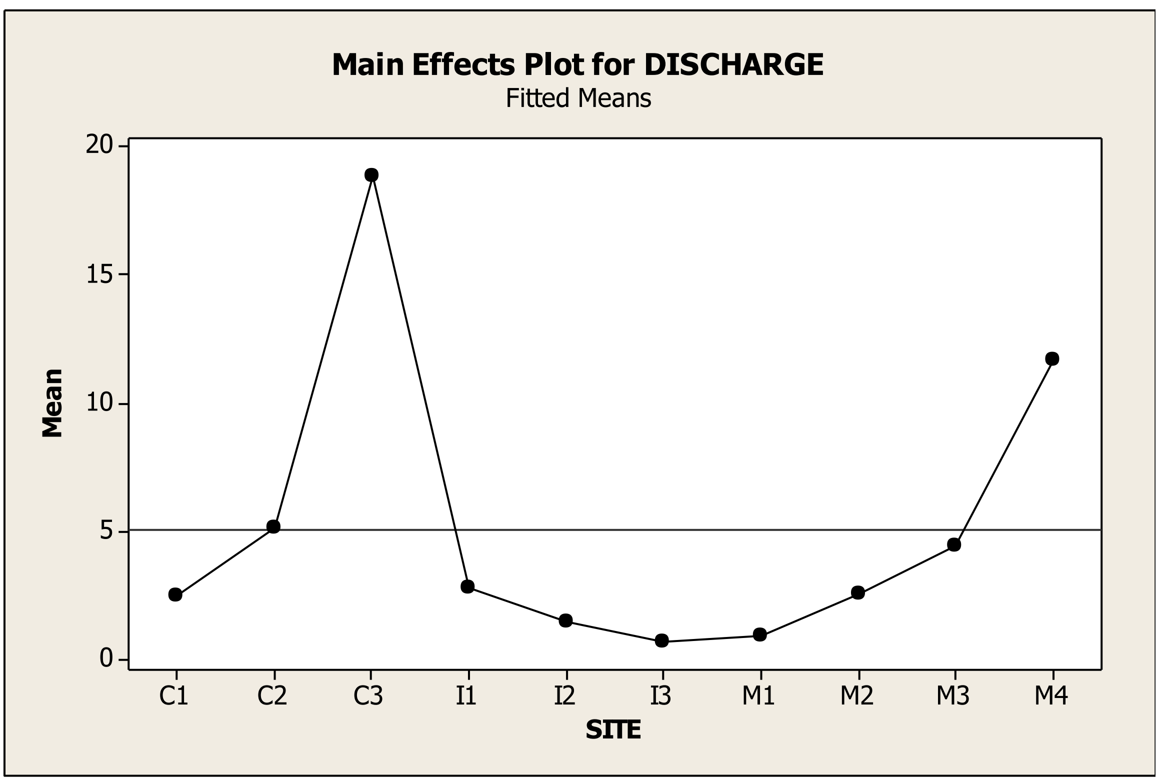

Main Effects Plot for DISSOLVED OXY.
Fitted Means
Mean
11
10
9
8
7
C1 C2 C3 I1 I2 I3 M1 M2 M3 M4 M5
SITE


Main Effects Plot for pH
Fitted Means
Mean
7.7
7.6
7.5
7.4
7.3
7.2
7.1
7.0
6.9
6.8
C1 C2 C3 I1 I2 I3 M1 M2 M3 M4 M5
SITE


Main Effects Plot for ALKALINITY
Fitted Means
Mean
150
125
100
75
50
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for SPC
Fitted Means
Mean
4000
3000
2000
1000
0
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for SUSPENDED SOLILDS
Fitted Means
Mean
0.5
0.4
0.3
0.2
0.1
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
M5
SITE


Main Effects Plot for DISCHARGE
Fitted Means
Mean
20
15
10
5
0
C1
C2
C3
I1
I2
I3
M1
M2
M3
M4
SITE