FINAL REPORT

Lake Crawford Nonpoint Source Loading Study

June 30, 2005

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FINAL REPORT

Lake Crawford Nonpoint Source Loading Study

Prepared as Part of the Paradise Creek Watershed Restoration & Protection Plan

A Brodhead Watershed Association Project

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Photograph of Lake Crawford taken by Edward W. Molesky of Aqua-Link, Inc. in the Spring 2003.

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Executive Summary

The Lake Crawford Nonpoint Source (NPS) Loading Study was performed as part of the Paradise Creek Watershed Assessment and Protection Plan Project. This project was sponsored by the Brodhead Watershed Association and funded through a combination of in-kind services and the Pennsylvania Department of Environmental Protection (PA DEP) through its Growing Greener Grant Program.

The three principle objectives of the Lake Crawford NPS Loading Study were to evaluate and compare NPS loadings to the lake during baseflow and stormflow conditions, to prioritize the two main tributaries to the lake in terms of NPS loadings, and to determine the net removal (retention) of NPS pollutants by the lake itself.

The Lake Crawford study involved the collection and analysis of stream water quality and hydrologic data over a 6-month period in 2003. Three stream stations were established along two tributaries to the lake, Paradise Creek and an unnamed tributary, and below the dam of the lake. Stream water samples were collected manually during baseflow conditions and mechanically using automated sampling equipment during storm events. A selected certified laboratory analyzed all water samples for total phosphorus, total nitrogen and total suspended solids. Water levels (stage) were continuously recorded at each station every thirty minutes during the entire study period. All water level data were then converted to discharge using rating curves developed as part of this study.

Based upon this study, it was determined that the nutrient (phosphorus and nitrogen) and sediment (total suspended solids concentrations) concentrations were considered very high and low, respectively, at the three stream stations during all flow conditions. The total phosphorus and total nitrogen concentrations were generally, slightly lower during storm events. Lower nutrient concentrations during storm events were likely attributed to a dilution effect. Potential sources of nutrients to Paradise Creek are point source discharges (e.g., treated effluent from wastewater treatment plants), illicit discharges to stormwater sewers, malfunctioning on-lot septic systems and streambank erosion during storm events. Conversely, the major source of nutrients to Hatchery Run is likely from an upstream trout hatchery.

In addition, Paradise Creek contributed the highest loadings (quantities or mass) of nutrients to Lake Crawford. Nutrient and sediment loadings were determined by using streamflow data generated as part of this study and water quality data reported by the laboratory. The unnamed tributary, referred to as Hatchery Run, also contributed a substantial amount of nutrients to the lake even though its drainage area is significantly smaller than the drainage area of the Paradise Creek. In contrast, the sediment loadings to the lake were considered low for both Paradise Creek and Hatchery Run.

As part of the Paradise Creek Watershed Assessment and Protection Plan Project, it was determined that Lake Crawford is classified as hyper-eutrophic. Therefore, as part of this study, recommendations were offered to improve and further protect the water quality of Lake Crawford. These recommendations are as follows: to reduce both point and nonpoint source nutrient loadings to the lake via Paradise Creek, to reduce nutrient loadings from the trout hatchery to Hatchery Run, to create a forebay near the confluence of Paradise Creek in order to remove incoming sediments to the lake, and to stabilize severely eroding banks along Paradise Creek using natural stream channel design (NSCD) restoration methods.

1. Introduction

Paradise Falls along Paradise Creek

The Paradise Creek Watershed is a 44.5 square mile (28,480 acre) sub-watershed of the larger 285 square mile Brodhead Watershed within the Delaware River Basin. While most of the Paradise Creek Watershed lies within Paradise Township, headwaters are located in Barrett and Coolbaugh Townships to the north, Tobyhanna Township and Mt. Pocono Borough to the west, and Pocono Township to the south. Rapid growth, changing land uses, and development in these areas represent a potential for degradation of the entire sub-watershed from non-point source pollution. The Paradise Creek Watershed leads to the drinking water sources for the Stroudsburg/Stroud Township areas of Monroe County. Streams within the watershed are all designated either high-quality or exceptional value waters (Debra Brady of Paradise Township, 2005).

The Lake Crawford Nonpoint Source (NPS) Loading Study was performed as part of the Paradise Creek Watershed Assessment and Protection Plan Project. This project was sponsored by the Brodhead Watershed Association and funded through a combination of in-kind services and the Pennsylvania Department of Environmental Protection (PA DEP) through its Growing Greener Grant Program. The final product of this three-year, three-phase project is a Watershed Restoration and Protection Plan to improve and further protect the surface waters and groundwater resources within the Paradise Creek and subsequently the Brodhead Creek watersheds.

The Lake Crawford study involved the collection and analysis of stream water quality and hydrologic data over a 6-month period in 2003. Two stream stations were established along the two main tributaries, Paradise Creek and an unnamed tributary, to the lake (Figure 1.1). In this study, the unnamed stream was referred to as Hatchery Run, which receives water directly from the Paradise Trout Hatchery. The third stream station was installed just below the lake dam along Paradise Creek. During baseflow conditions, stream water samples were manually collected and later analyzed by a contract laboratory for nutrients (phosphorus and nitrogen) and sediments (total suspended solids). Conversely, automated water sampling equipment was used to collect stream water samples during storm events at all three stations. During storms, the automated samplers collected both first flush and composite stream water samples. The first flush samples were collected as single discrete water samples when the stream levels first began to rise. Composite samples represented a series of discrete water samples that were collected over the entire storm hydrographs. Once again, all first flush and composite stream samples were sent to the contract laboratory for nutrient and sediment analysis. In addition to water quality monitoring, stream water levels were continuously recorded using electronic water level logging equipment over the entire study period. At a later time, water level data was converted to stream discharge values using stage to discharge rating curves that were developed as part of this study.

The three principle objectives of the Lake Crawford NPS Loading Study were:

- To evaluate and compare NPS loadings to the lake during baseflow and stormflow conditions,
- To prioritize the two main tributaries to the lake in terms of NPS loadings, and
- To determine the net removal (retention) of NPS pollutants by the lake itself.

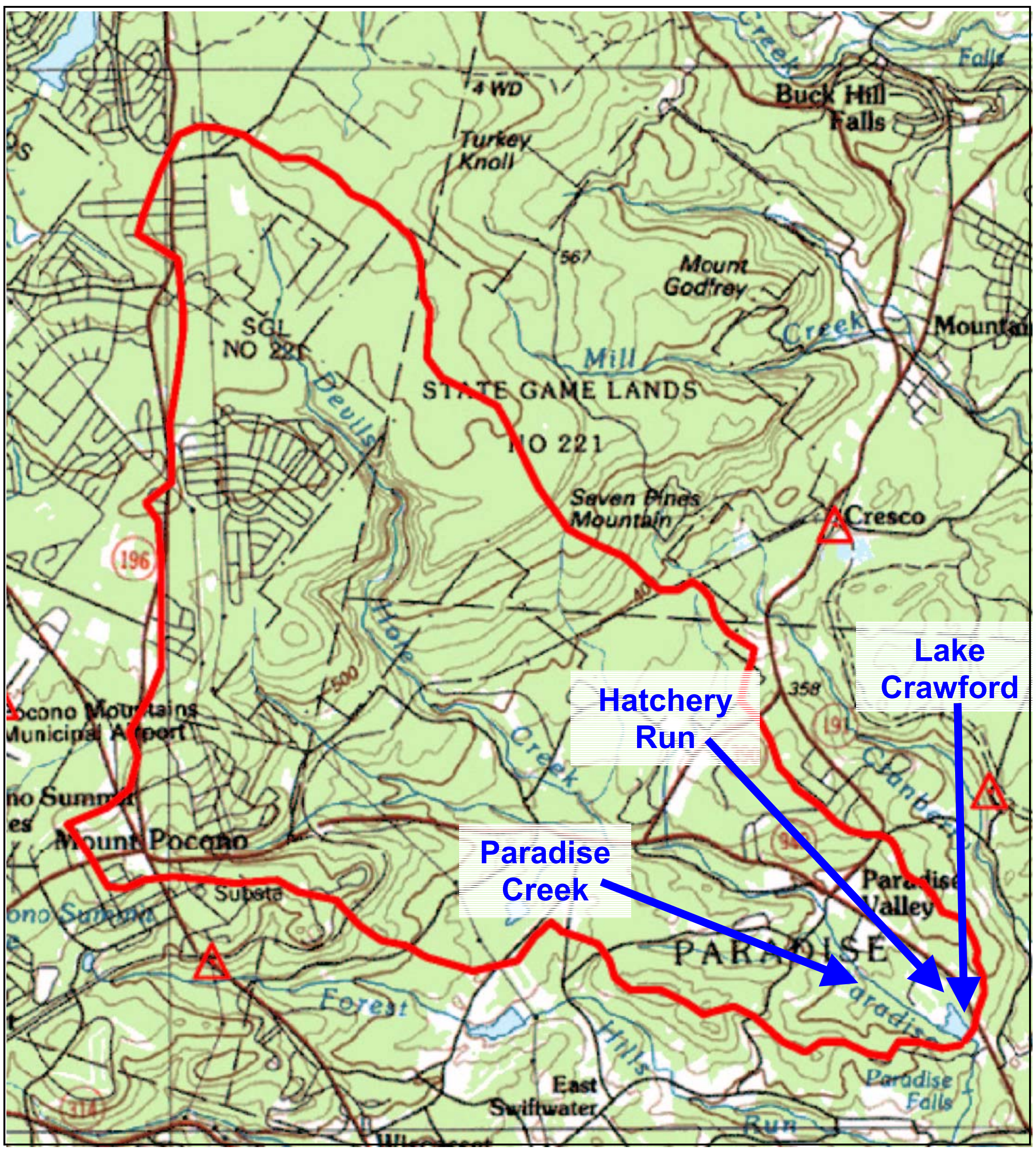


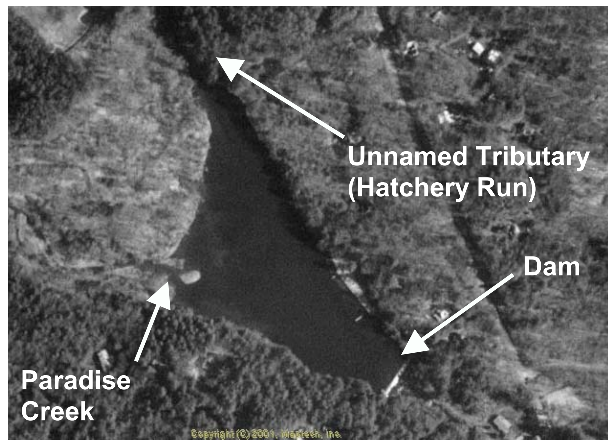
Figure 1.1 Lake Crawford Watershed

2. Lake and Watershed Characteristics

This section primarily discusses the characteristics of Lake Crawford and its surrounding watershed. The information provided below is frequently cited throughout the remainder of this report.

2.1. Lake Characteristics

Lake Crawford (41.113139° N, 75.2687998° W) is moderately shallow, 10-acre reservoir located in Paradise Township, Monroe County, Pennsylvania. The maximum water depth of the reservoir in 2003 was 10 feet in the vicinity of the dam. The reservoir is owned and maintained by the Paradise Falls Lutheran Association and was created by constructing rock and earthen dam across the Paradise Creek. Presently, the lake is used for fishing, swimming and boating. The Association annually stocks the lake with trout for its membership.



Over the years, Lake Crawford had become very shallow due to sediment loadings transported via its tributaries. This was especially true in the upper end of the reservoir near the confluence of Paradise Creek. In order to restore the lake, the Association hired a contractor to dredge accumulated, unconsolidated sediments from a 7-acre section of the lake. Lake dredging commenced and was completed in 2004.

The water quality of Lake Crawford was assessed as part of the Paradise Creek Watershed Assessment and Protection Plan Project. In this project, members of the Brodhead Creek Watershed Association monitored the water quality of Lake Crawford, Swiftwater Lake, Alpine Lake and Mt. Airy Lake on four different study dates in 2003. On each of the study dates, surface and bottom water samples were collected at one station per lake. All lake water samples were transferred into bottles supplied by the contract laboratory and preserved accordingly in the field. The contract laboratory analyzed all collected lake water samples for alkalinity, hardness, total phosphorus, dissolved reactive phosphorus (often referred to as soluble reactive phosphorus or orthophosphorus), total Kjeldahl nitrogen (TKN), ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total suspended solids and chlorophyll-a (surface water only).

In addition, dissolved oxygen, temperature, pH, conductivity, specific conductance and transparency were monitored in the field on each study date. Dissolved oxygen, temperature, conductivity, specific conductance, pH, total dissolved solids and oxidation-reduction potential (ORP) were measured throughout the water column using electronic monitoring equipment.

Transparency was measured in the field using a 20 cm (8 inch diameter) freshwater Secchi disk, which was quartered black and white.

The 2003 water quality data indicates that all four lakes are classified as highly eutrophic (hyper-eutrophic). The Carlson's Trophic Index values for total phosphorus, Secchi disk transparency and chlorophyll-a for Lake Crawford were 89, 58 and 54, respectively. The lower index values for Secchi disk transparency and chlorophyll-a are likely due to rapid flushing of the reservoir, thereby not allowing the phytoplankton to reach its maximum densities. Rapid flushing (low hydraulic residence time) of the lake is attributed to a small impoundment receiving streamflow from a very large watershed area.

2.2. Watershed Characteristics

The Lake Crawford watershed is approximately 13.6 square miles (8,688 acres) and is drained by Paradise Creek (Figure 1.1). Tank Creek, Yankee Creek and Devils Hole Creek are the major tributaries to Paradise Creek. Tank and Yankee Creeks generally drain the western portion of the watershed. The headwaters of these streams begin in Mount Pocono. Conversely, the headwaters of Devils Hole Creek, which is designated Exceptional Value (EV), are located in State Game Lands No. 221. These game lands are located in the northeastern portion of the Lake Crawford watershed.

Most of the land uses within the Lake Crawford watershed are best described as forest intermixed with residential developments. Paradise Creek receives treated effluent from two NPDES permitted wastewater treatment plants. These facilities currently treat raw municipal wastewater from the Paradise Stream Resort and Monsignor McHugh High School.

Lake Crawford receives streamflow via several tributaries as shown in Figure 2.1. The two largest tributaries to the lake are Paradise Creek and Hatchery Run. The subwatershed areas of Paradise Creek (Inlet) and Hatchery Run are 12.8 and 0.6 square miles, respectively. Hatchery Run is a very small tributary and receives flow directly from the Paradise Trout Hatchery.

The lake surface area to watershed ratio for Lake Crawford is 869 to 1. This ratio is extremely high and indicates that this impoundment will act like a "run-of-the-river" type reservoir having an extremely short hydraulic residence time. Overall, watershed to lake surface area ratios less than 25 are considered low, while ratios greater than 150 are classified as high. In general, lakes with the extremely low hydraulic residence times (i.e., extremely high drainage area to surface area ratios) function like "run-of-the-river" type lake systems. The water quality of these types of lakes can rapidly degrade as a result of high pollutant loadings from their surrounding watersheds. Conversely, lakes with extremely high hydraulic residence times (i.e., extremely low drainage area to surface area ratios) serve as efficient sinks for both incoming nutrients and sediment. The water quality of these types of lakes tends to degrade more slowly in response to high pollutant loadings from the surrounding watersheds.

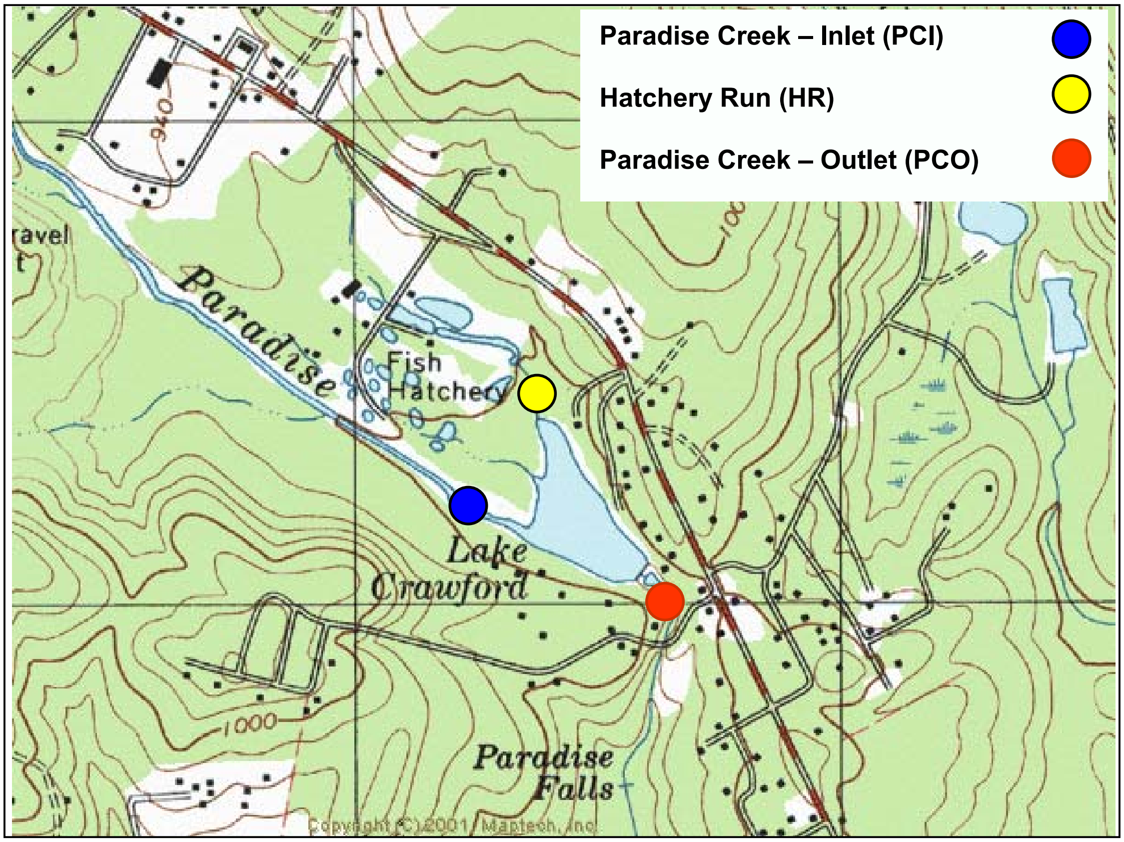


Figure 2.1 Stream Monitoring Stations

3. Overview of the NPS Loading Study

3.1. Primer on Lake Ecology and Watershed Dynamics

A glossary of lake and watershed terms in Appendix A is intended to serve as an aid to understanding this section and contains many of the technical terms used throughout this report.

The water quality of a lake is often described as a reflection of its surrounding watershed. The term lake collectively refers to both reservoirs (man-made impoundments) and natural lake systems. Water from the surrounding watershed enters a lake as streamflow, surface runoff and groundwater. The water quality of these water sources is greatly influenced by the characteristics of the watershed such as geology, soils, topography and land use. Of these characteristics, changes in land use (e.g., forested, agriculture, silviculture, residential, commercial, industrial) can significantly alter the water quality of lakes.

Nutrients (e.g., phosphorus, nitrogen, carbon, silicon, calcium, potassium, magnesium, sulfur, sodium, chloride, iron) are primarily transported to lakes via streamflow, surface runoff and groundwater, while sediments are mainly conveyed by streamflow and surface runoff. As streamflow and surface runoff enter a lake, their overall velocity decreases, which allow transported sediments to settle to the lake bottom. Many of these incoming nutrients may be bound to sediment particles and subsequently will also settle to the lake bottom. Very small sediment particles, such as clays, may resist sedimentation and subsequently pass through the lake without settling.

Once within the lake, water quality is further modified through a complex set of physical, chemical and biological processes. These processes are significantly affected by the lake's morphological characteristics (morphology). Some of the more important morphological characteristics of lakes are surface area, shape, depth, volume and bottom composition. In addition, the hydraulic residence time (i.e., the lake's flushing rate) also greatly affects these processes and is directly related to the lake's volume and the annual volume of water flowing into the lake.

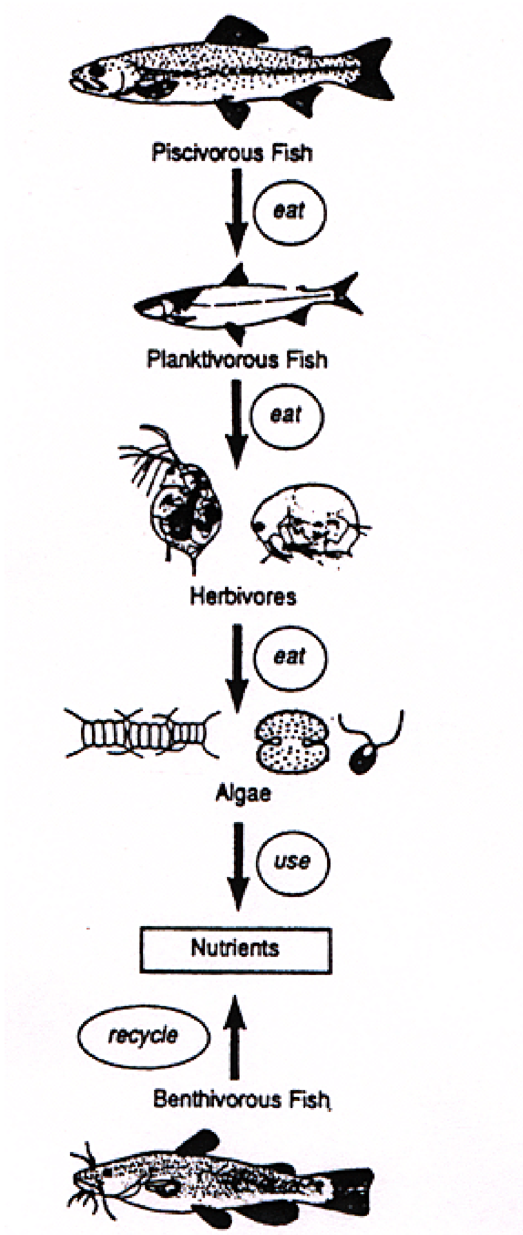
With respect to nutrients, phosphorus and nitrogen are generally considered the most important nutrients in freshwater lakes. Phosphorus and, to a lesser degree, nitrogen typically determine the overall amount of aquatic plants present. Aquatic plants adsorb and convert available nutrients into energy, which is then used for additional growth and reproduction. In lakes, aquatic plants are mainly comprised of phytoplankton (free-floating microscopic plants or algae) and macrophytes (higher vascular plants). The most readily available form of phosphorus is dissolved orthophosphate (analytical determined as dissolved reactive phosphorus), while ammonia (NH_3-N) and nitrate (NO_3-N) are the most readily available forms of nitrogen.

The transfer and flow of energy in lakes is ultimately controlled by complex interactions between various groups of aquatic organisms (both plants and animals). A simplistic diagram of these interactions among aquatic organisms is shown as Figure 3.1. In Figure 3.1, algae (phytoplankton) and aquatic macrophytes (plants) capture energy from the sun and convert this energy into chemical energy through the process known as photosynthesis. During photosynthesis, carbon dioxide, nutrients, water and captured sunlight energy are used to produce organic compounds (chemical energy), which are then used to support further growth and reproduction.

Energy continues to flow upward through the food chain. Algae are primarily grazed upon by zooplankton. Zooplankton are tiny aquatic animals that are barely visible to the naked eye. Next, zooplankton serve as prey for planktivorous (plankton-eating) fish and larger invertebrates (macroinvertebrates). In turn, plankitvores are consumed by piscivorous (fish-eating) fish. Overall, these aquatic organisms (zooplankton, macroinvertebrates and fish) derive energy by breaking down organic matter through the process known as respiration. During respiration, organic matter, water and dissolved oxygen are converted into carbon dioxide and nutrients.

At the bottom of the food chain (Figure 3.1), particulate organic waste products (excrement) from aquatic organisms along with dead aquatic organisms settle to the lake bottom and are subsequently feed upon by other organisms. Organisms that live or reside along the lake bottom are referred to as benthivores. After settling to the lake bottom, dead organic materials and organic waste products are now called detritus. Some benthivorous fish (catfish and carp) and microorganisms (bacteria, fungi and protozoans) feed upon detritus. Aquatic organisms that feed upon detritus in lakes are referred to as decomposers. Decomposers obtain energy by breaking down detritus (dead organic matter) via the process of respiration. During decomposition, some of the nutrients are recycled back into lake water and can now once again be used by algae and aquatic plants for growth and reproduction. Any unused detritus will accumulate and eventually become part of the lake sediments, thereby increasing the organic content of these sediments.

Ultimately, the amount of nutrients in lakes controls the overall degree of aquatic productivity (Figure 3.1). Lakes with low levels of nutrients and low levels of aquatic productivity are referred to as oligotrophic. Oligotrophic lakes are typically clear and deep with low quantities of phytoplankton and rooted aquatic plants. In these lakes, the deeper, colder waters are generally well-oxygenated and capable of supporting coldwater fish such as trout. Conversely, lakes with high nutrient levels and high levels of aquatic productivity are referred to as eutrophic. Eutrophic lakes are generally more turbid and shallower due to the deposition of sediments and the accumulation of detritus. If deep enough, the bottom waters of eutrophic lakes are generally less oxygenated or may be devoid of dissolved oxygen (anoxic). Eutrophic lakes are often capable of supporting warmwater fish such as bluegill and bass. Mesotrophic lakes lie somewhere in between oligotrophic and eutrophic lakes. These lakes contain moderate levels of nutrients and moderate levels of aquatic productivity.



<u>Zooplankto</u>n plus others: macroinvertebrates (clams, snails & aquatic insects) & grazing minnows

<u>Phytoplankto</u>n (def) : microscopic free-floating algae

Plus, microorganisms like bacteria, fungi & protozoans

Figure 3.1 Aquatic Food Web

In some instances, the flow of energy through the food web may be disrupted. In hyper-eutrophic (highly eutrophic) lakes, aquatic productivity is extremely high and is dominated by very large numbers of a few, undesirable species. The phytoplankton community is typically comprised largely by blue-green algae during the summer months. Many species of blue-green algae are not readily grazed upon the zooplankton community. Under these conditions, the blue-green algae community is allowed to flourish due to the lack of predation, while the zooplankton community collapses.

Decreases in zooplankton biomass in a lake may in turn adversely affect the lake's fishery. In addition, shallow lake areas may be completely infested with dense stands of aquatic macrophytes and dominated by common carp, catfish or other rough fish.

3.2. Study Design and Data Acquisition

In May 2003, Aqua-Link, Inc., with the assistance of volunteers of the Brodhead Creek Watershed Association, established three stream monitoring stations for the Lake Crawford NPS Loading Study. The names and locations of these stations are shown in Figure 2.1 and described in Table 3.1. At each station, an automated stormwater sampler (Global Water ™ Model SS201), electronic water level data logger (Global Water ™ Model WL15X) and a metal staff gage (0.0 to 3.33 feet, Style C) were installed.

Table 3.1 Descriptions of Stream Monitoring Stations

Station	Stream	Description
PCI	Paradise Creek	Paradise Creek – Inlet to the lake. Approximately 75 yards upstream of the lake.
PCO	Paradise Creek	Paradise Creek – Outlet of the lake. Approximately 50 yards below the dam of the lake.
HR	Unnamed Tributary referred to as Hatchery Run	Approximately 50 yards upstream of the lake.


Stormwater Sampler & Water Level Logger

The Global Water ™ automated stormwater samplers and water level loggers were programmed by Aqua-Link immediately following their installation. The automated stormwater samplers contained two 4,000 ml bottles that were used to collect a discrete first flush water sample followed by a composite water sample. Each stormwater sampler was activated when rising stream waters made contact with a water sensor. Immediately following its activation, a stormwater sampler completely filled the first bottle and this water sample was designated as the first flush sample.

Next, the sampler was programmed to collect 100 ml discrete samples every hour until the stream level once again fell below the water sensor. The discrete samples were automatically composited together in the second bottle, which represented a composite sample over the entire storm hydrograph. In addition, the water level data loggers were programmed to record the stage of the streams every 30-minutes over a 6-month study period, which extended from June 1 through November 30, 2003.


Station PCO along Paradise Creek

The three stream stations were monitored two times during baseflow conditions and seven times during storm events during the 6-month study period. Under baseflow conditions, discrete stream samples were manually collected using bottles provided by the contract laboratory. During storm events, the programmed automated stormwater samplers collected both the first flush and composite water samples. Thereafter, these samples were transferred to bottles provided by the contract laboratory. All collected water samples were then preserved accordingly in the field, iced and transported to the contract laboratory for analysis. The contract laboratory, Pocono Environmental Laboratories of Pocono, Pennsylvania, analyzed all water samples for nitrate nitrogen, nitrite nitrogen, total Kjeldahl nitrogen, total phosphorus and total suspended solids. Total nitrogen was determined by summing all of the above nitrogen fractions together.

Lastly, incremental stream water depth and velocity data were measured and recorded at established cross sections at each of the stream stations. These incremental data were collected under various flow conditions throughout the study period. All stream velocities and water depths were measured using a hand held stream velocity meter (Global Water ™ Flow Probe FP101). In addition, staff gage and water level logger readings were also recorded immediately following the collection of incremental stream water depth and velocity data. Thereafter, instantaneous stream discharge values were determined using the collected incremental stream water depth and velocity data. Stream rating curves (discharge vs. stage) were determined for each of the stream stations using regression analysis. These rating curves were later used to convert all recorded water level readings, which were collected every 30-minutes, to stream discharge values.

4. Stream Data & Results

4.1. Overview

The stream monitoring program for the Lake Crawford Nonpoint Source (NPS) Study extended from June 1 through November 30, 2003. In this section, water quality, hydrologic and NPS loading data are presented and discussed for the three stream monitoring stations: Paradise Creek Inlet (PCI), Paradise Creek Outlet (PCO) and Hatchery Run (HR) as shown in Figure 2.1. Refer to Section 3.2 for more information about the stream stations, the study design and how all data were acquired.

4.1.1. Water Quality

The mean concentrations of total phosphorus (TP), total nitrogen (TN, sum total Kejldahl nitrogen and nitrate-nitrite nitrogen) and total suspended solids for all stream stations during both baseflow and stormflow conditions are summarized in Table 4.1. All stream water quality data for the three stations are presented in Appendix B.

Table 4.1 Mean Nutrient and Solids Concentrations for All Stream Stations

Station	Flow Regime	Sample Type	TP (mg/l as P)	TN (mg/l as N)	TSS (mg/l)
HR	Base	Grab	0.15	2.09	3.7
HR	Storm	First Flush	0.16	2.85	2.9
HR	Storm	Composite	0.12	2.84	3.1
PCI	Base	Grab	0.10	2.11	1.2
PCI	Storm	First Flush	0.08	3.55	6.4
PCI	Storm	Composite	0.07	1.35	1.7
PCO	Base	Grab	0.15	2.49	6.0
PCO	Storm	First Flush	0.11	3.83	2.2
PCO	Storm	Composite	0.09	1.46	4.5

Overall, the nutrient and the total suspended solids concentrations are considered very high and low, respectively, at all of the stream stations during all flow regimes (Table 4.1). In general, the total phosphorus and total nitrogen were slightly lower during storm events (composite samples). One exception is nitrogen at Station HR where the stormwater composite samples actually contained more nitrogen than in the stream baseflow samples. One plausible explanation for this increase in nitrogen concentration may be attributed to an increased hydraulic loading to the upstream trout hatchery, which released more nitrogen to the stream.

Lower mean nutrient concentrations during storm events (storm composite samples) are likely related to a dilution effect. In other words, stormwater runoff from the surrounding watershed apparently contains lower amounts of nutrients than the streams typically contain during baseflow conditions. Potential sources of nutrients to Paradise Creek are point source discharges (e.g., treated effluent from wastewater treatment plants), illicit discharges to stormwater sewers, malfunctioning on-lot septic systems and streambank erosion during storm events. Conversely, the major source of nutrients to Hatchery Run is likely from an upstream trout hatchery.

The mean nutrient and suspended solids concentrations for the first flush samples are typically similar to the mean values reported for the composite stormwater samples at all stations. The only possible "first flush effect" that occurred in this study was for nitrogen at Stations PCI and PCO. For these stations, the total nitrogen concentrations were slightly higher than the mean concentrations reported for baseflow and stormflow (composite sample) conditions.

4.1.2. Hydrology

A hydrologic budget balances the amount of water to and from a lake system. Water inputs to a lake are from tributaries, direct runoff from lands immediately surrounding the lake (i.e., the direct drainage area), precipitation to the surface of the lake and groundwater. Water outputs are via the lake's outlet, evaporation from the surface of the lake and groundwater. The hydrologic budget for any lake system is generally presented as an input-output type equation as listed below:

1. $V_{outlet} = V_{tributaries} + V_{direct\ drainage} + V_{precipitation} - V_{evaporation} \pm V_{groundwater} \pm V_{storage}$

Where,

V_{outlet}	volume of water released from the lake at the outlet,
$V_{tributaries}$	volume of water entering the lake via major tributaries,
$V_{direct\ drainage}$	volume of water entering the lake from lands adjacent to the lake and unmonitored tributaries to the lake,
$V_{precipitation}$	volume of precipitation to the surface of the lake,
$V_{evaporation}$	volume of water evaporated from the surface of the lake,
$V_{groundwater}$	net volume exchange of groundwater through the lake bottom, and
$V_{storage}$	change in storage capacity of the lake.

In order to simplify this equation, the following assumptions were made for this study. Shallow groundwater to the lake is assumed to be included as part of the estimates for $V_{tributaries}$. The $V_{direct\ drainage}$ and $V_{groundwater}$ variables were assumed to be negligible since the lake has very large watershed and subsequently most of the water to the lake will be from inflowing tributaries. The $V_{precipitation}$ and $V_{evaporation}$ variables are assumed to be insignificant since the lake surface area is only

10 acres. Lastly, the $V_{storage}$ variable is assumed to be negligible since water continuously flows over the dam year round. Based on these assumptions, Equation No. 1 is simplified to the following equation:

2. $V_{outlet} = V_{tributaries}$ *[Paradise Creek (PCI) + Hatchery Run (HR)]*

For this study, hydrographs for the two main tributaries (Stations PCI and HR) were developed using the collected stage (water level) data and the calculated rating curves as discussed in Section 3.2 and presented in Appendix C. It should be noted that a hydrograph for Station PCO was not directly determined because of equipment failure. More specifically, the water level data logger at this station stopped recording data on several different occasions, thereby resulting in an incomplete hydrograph. First for Stations PCI and HR, rating curves (discharge vs. stage relationships) were developed using regression analysis for all collected incremental stream water depth and velocity data and stream stage data. Next, the rating curves were used to convert all stream stage data (water level measurements) to discharge values. For more information on the rating curves and the stream hydrologic data, refer to Appendix C of this report.

The hydrographs for the three stream stations are shown in Figure 4.1. The hydrograph for Station PCO was determined by combining the individual hydrographs for Stations PCI and HR (refer to Equation 2 as discussed above). Next, the hydrographs for each station were separated into baseflow and stormflow as presented in Figures 4.2 through 4.3.

Next, the hydrographs, as shown in Figures 4.2 through 4.4, were used to calculate the total water volumes contributed by each station. These hydrographs were also used to quantify the baseflow and stormflow components of the total water volumes. The total, baseflow and stormflow water volumes for Stations PCI, HR and PCO along with the estimated mean discharge (Q) are presented in Table 4.2. By far, the most significant source of water to Lake Crawford is Paradise Creek, which accounted for about 80 percent of its total flow. Furthermore, most of the streamflow at the three stations occurred as baseflow during the 6-month study period.

Table 4.2 Hydrologic Characteristics of Streams

Station	Mean Q (cfs)	Total Volume (cubic ft)	Baseflow Volume (cubic ft.)	Stormflow Volume (cubic ft.)
PCI	31.8	474,906,982	392,364,582	82,542,400
HR	7.8	120,505,310	117,639,771	2,865,539
PCO	39.6	595,412,292	510,004,353	85,407,939

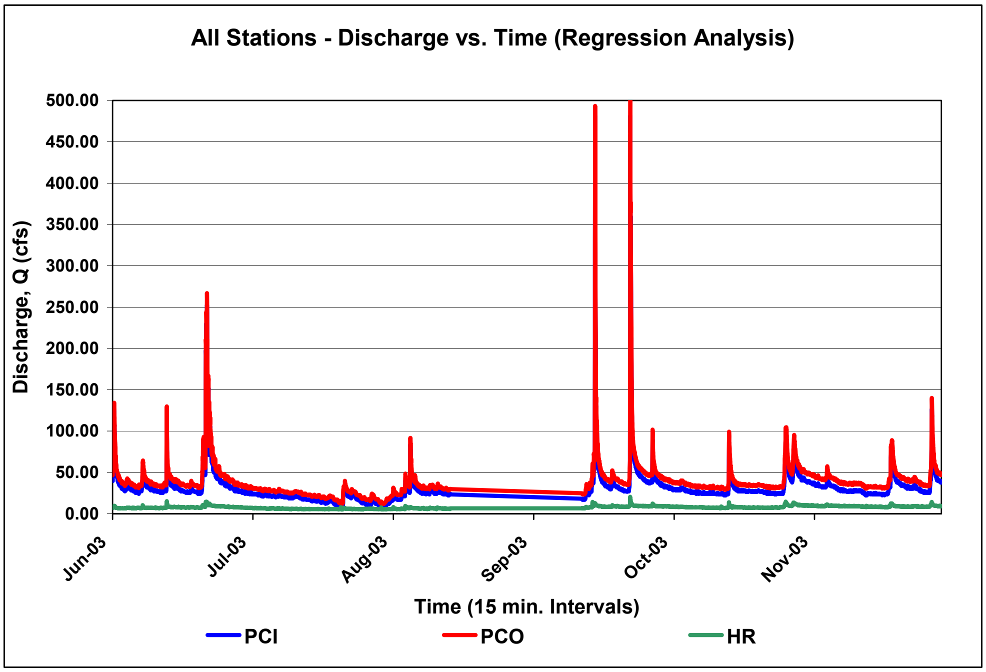


Figure 4.1 Hydrographs for Three Stream Stations

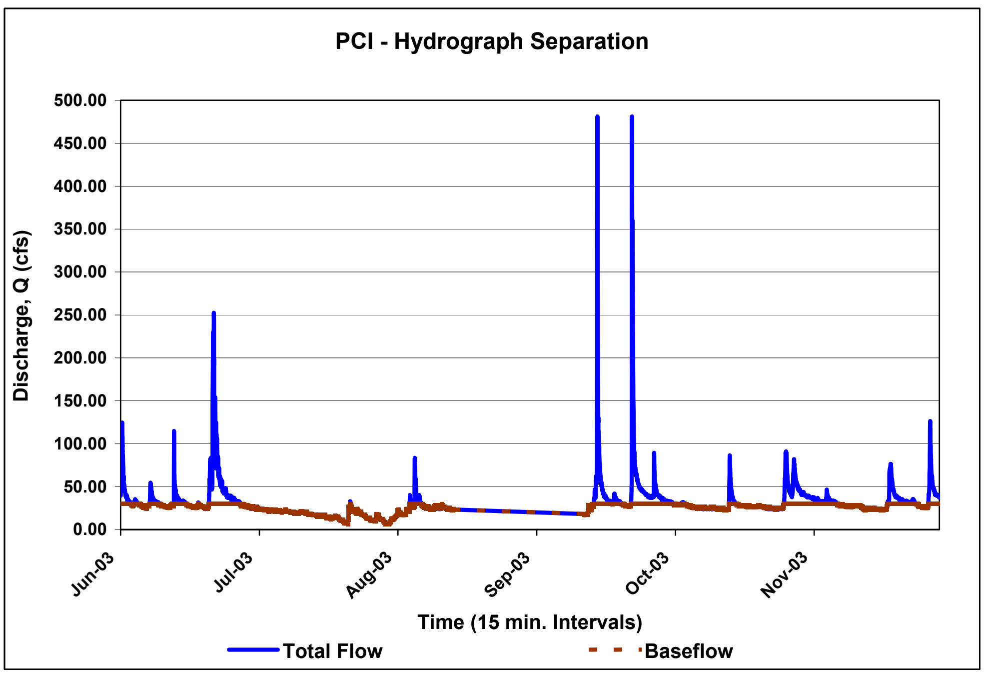


Figure 4.2 Hydrograph for Station PCI

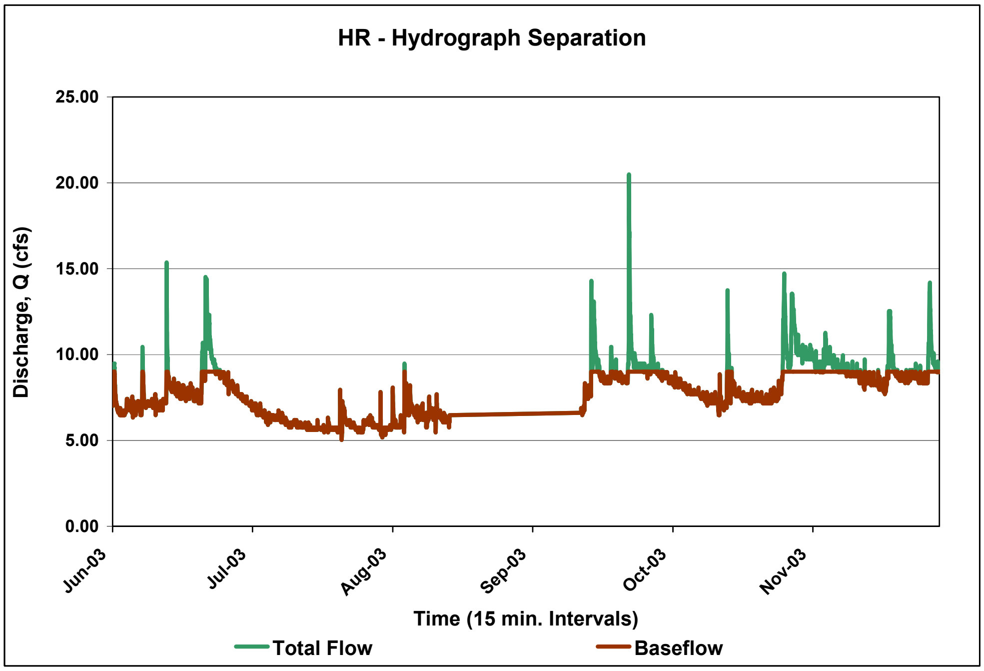


Figure 4.3 Hydrograph for Station HR

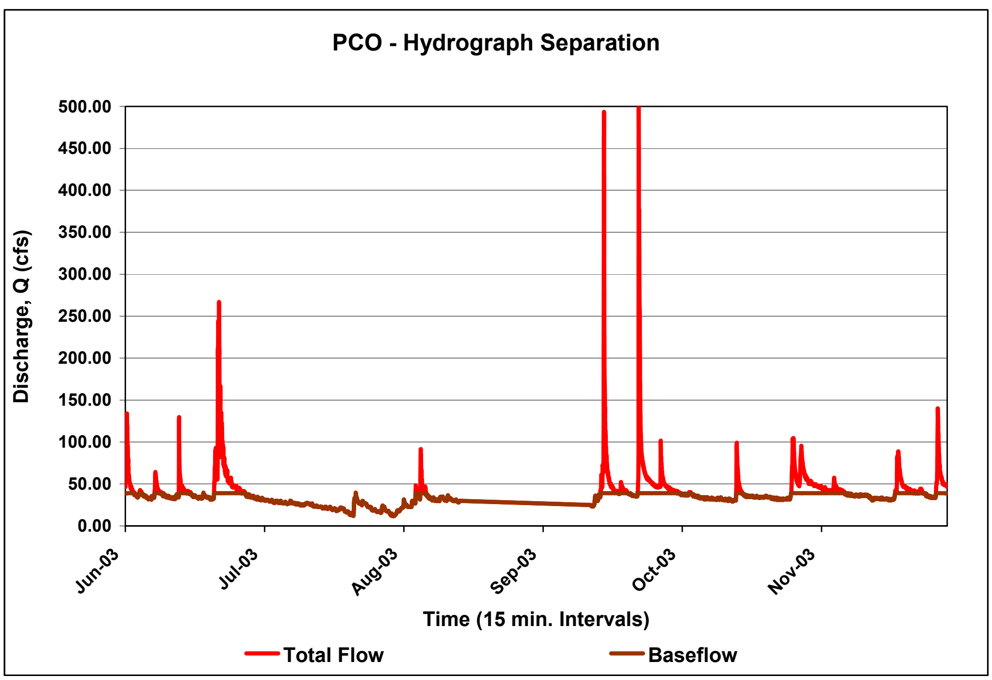


Figure 4.4 Hydrograph for Station PCO

4.1.3. NPS Loadings

Nutrient (total phosphorus and total nitrogen) and sediment (total suspended solids) loadings for the three stream stations are presented in Table 4.3. These loadings were determined by utilizing both water quality data reported by the contract laboratory and hydrologic data presented in Section 4.1.2. More specifically, the nutrient and sediment loadings for each of the three stations during baseflow conditions were estimated by multiplying the mean baseflow concentrations (Table 4.1) multiplied by their corresponding total baseflow water volumes (Table 4.2). Similarly, the nutrient and sediment loadings during stormflow conditions were estimated by multiplying the mean stormflow concentrations (Table 4.1) by their corresponding total stormflow water volumes (Table 4.2). Next, the total nutrient and sediment loadings for the three stations were determined by combining their individual baseflow and stormflow loadings. For additional information, refer to Appendix D.

Table 4.3 Nutrient and Sediment Loadings for Three Stream Stations

Station	Total Phosphorus* (kg)	Total Nitrogen* (kg)	Total Suspended Solids* (kg)
PCI	1,216	26,564	17,239
HR	493	7,176	12,413
PCI + HR *(Input)*	1,709	33,740	29,652
PCO *(Output)*	2,315	39,453	97,637

* All loadings represent a 6-month period (June – November 2003)

Paradise Creek (Station PCI) contributed the highest amounts of nutrients (phosphorus and nitrogen) and sediments (total suspended solids) to Lake Crawford as shown in Table 4.3. Hatchery Run (Station HR) also contributed a substantial amount of nutrients to the lake even though its drainage area is significantly smaller that the drainage area for the Paradise Creek Inlet (Station PCI). As noted in Section 2.2, the drainage areas for Stations PCI and HR are 12.8 and 0.6 square miles, respectively. In addition, the nutrient and sediment loadings at Station PCO are greater than the combined loadings for Stations PCI and HR. The differences between the input and output loadings suggest that the lake may actually be serving as a source of nutrients and sediments for downstream waters. For example, nutrients (as orthophosphorus and ammonia nitrogen) are frequently released via in-lake sediments if severe anoxia occurs at the water – sediment interface (referred to as internal sediment loading). Higher sediments at the outlet of the lake may be attributed to the production of phytoplankton in the lake that are washed downstream as a result of the lake's rapid flushing rate.

5. Conclusions and Recommendations

The conclusions and recommendations of the Lake Crawford Nonpoint Source (NPS) Loading Study are presented and discussed below. This study was performed as part of the Paradise Creek Watershed Assessment and Protection Plan Project and in part, this project determined that this 10-acre impoundment is highly eutrophic (hyper-eutrophic). The Carlson's Trophic Index values for total phosphorus, Secchi disk transparency and chlorophyll-a for Lake Crawford were 89, 58 and 54, respectively.

Based upon this study, Aqua-Link's conclusions regarding Lake Crawford and its tributaries are summarized below:

<u>*Water Quality*</u>

1. The lake surface area to watershed area ratio for Lake Crawford is 869 to 1. This ratio is extremely high and indicates that this impoundment will act like a "run-of-the-river" type reservoir having an extremely short hydraulic residence time. This short hydraulic residence time (rapid flushing rate) is largely responsible for the reservoir having better than expected transparency values due to the rapid flushing out of phytoplankton.

2. The nutrient (phosphorus and nitrogen) concentrations and the sediment (total suspended solids concentrations) are considered very high and low, respectively, for all stream stations during baseflow and stormflow conditions.

3. The total phosphorus and total nitrogen were generally, slightly lower during storm events (composite samples). Lower mean nutrient concentrations during storm events (storm composite samples) are likely related to a dilution effect. In other words, stormwater runoff from the surrounding watershed apparently contains lower amounts of nutrients than the streams typically contain during baseflow conditions.

4. Potential sources of nutrients to Paradise Creek are point source discharges (e.g., treated effluent from wastewater treatment plants), illicit discharges to stormwater sewers, malfunctioning on-lot septic systems and streambank erosion during storm events. Conversely, the major source of nutrients to Hatchery Run is likely from an upstream trout hatchery.

5. The mean nutrient and suspended solids concentrations for the first flush samples are similar to the mean values reported for the composite stormwater

samples at all stations. The only possible "first flush effect" that occurred in this study was for nitrogen at Stations PCI and PCO.

<u>Hydrology</u>

1. The most significant source of water to Lake Crawford is Paradise Creek, which accounted for about 80 percent of its total flow.

2. Most of the streamflow at the two main tributaries, Paradise Creek and Hatchery Run, occurred as baseflow during the study period.

<u>NPS Loadings</u>

1. Paradise Creek (Station PCI) contributed the highest amounts of nutrients (phosphorus and nitrogen) and sediments (total suspended solids) to Lake Crawford.

2. Hatchery Run (Station HR) also contributed a substantial amount of nutrients to the lake even though its drainage area is significantly smaller than the drainage area for the Paradise Creek Inlet (Station PCI).

3. Nutrient and sediment loadings at Station PCO were greater than the combined loadings for Stations PCI and HR. The differences between the input and output loadings suggest that the lake may actually be serving as a source of nutrients and sediments for downstream waters.

   For example, nutrients (as orthophosphorus and ammonia nitrogen) are frequently released via in-lake sediments if severe anoxia occurs at the water – sediment interface (referred to as internal sediment loading). Conversely, higher sediments at the outlet of the lake may be attributed to the production of phytoplankton that are rapidly flushed out of the lake.

The following is a list of recommendations offered by Aqua-Link to improve and further protect the water quality of Lake Crawford:

1. Reduce the nutrient loadings to the lake via Paradise Creek. High nutrient loadings during baseflow conditions suggest that point source loadings (e.g., wastewater treatment facilities and possibly illegal discharges to stormwater sewers) are likely very important for this stream. Other sources of nutrients during baseflow conditions may be attributed

to malfunctioning on-lot septic systems.

2. Reduce the nutrient loadings to the lake via Hatchery Run. This can possibly involve some modifications to the trout hatchery itself or its operation. For example, waters discharged from the hatchery can be pretreated in order to remove additional nutrients before being discharged into Hatchery Run.

3. Create a forebay at the confluence of Paradise Creek. The forebay should be designed to serve as an inline sedimentation basin. Based upon this study, it is expected that bed load and not suspended solids is the major source of sediments to the lake. Field observations confirm that most of the upper lake was filled in with larger cobbles as opposed to finer sediment particles. Thereafter, the lake association should perform maintenance dredging of the forebay on an as-needed basis as opposed to more costly, lake dredging.

4. Stabilize severely eroding banks along Paradise Creek using a natural stream channel design (NSCD) restoration method. It is likely the streambank instability is a significant source of bed load sediments to Lake Crawford via this stream.

APPENDIX A

Glossary of Lake and Watershed Management Terms

Glossary

Algae - Mostly aquatic, non-vascular plants that float in the water or attach to larger plants, rocks, and other substrates. Also called phytoplankton, these individuals are usually visible only with a microscope. They are a normal and necessary component of aquatic life, but excessive numbers can make the water appear cloudy and colored.

Alkalinity - The acid-neutralizing capacity of water. It is primarily a function of the carbonate, bicarbonate, and hydroxide content in water. The lower the alkalinity, the less capacity the water has to absorb acids without becoming more acidic.

Ammonia (NH3) - A nitrogen-containing substance which may indicate recently decomposed plant or animal material.

Benthos - The communities of aquatic life which dwell in or on the bottom sediments of a water body.

Chlorophyll - Pigments (mostly green) in plants, including algae, that play an important part in the chemical reactions of photosynthesis. A measurement of chlorophyll-a (one type of chlorophyll) is commonly used as a measure of the algae content of water.

Conductivity (Cond) - A measure of water's capacity to convey an electric current. It is related to the total amount of dissolved charged substances in the water. Therefore, it can be used as a general indicator of the quality of the water and can also suggest presence of unidentified material in the water. It is often used as a surrogate for salinity measurements.

Combined Sewer Overflow (CSO) -Discharges of combined sewage and stormwater into water bodies during very wet or storm weather. These discharges occur to relieve the sewer system as it becomes overloaded with normal sewer flow and increased storm run-off. The term is also used to denote a pipe that discharges those overflows.

Dissolved oxygen (DO) - Oxygen that is dissolved in the water. Certain amounts are necessary for life processes of aquatic animals. The oxygen is supplied by the photosynthesis of plants, including algae, and by aeration. Oxygen is consumed by animals and plants at night, and bacterial decomposition of dead organic matter (plant matter and animal waste).

Effluent - Liquids discharged from sewage treatment plants, septic systems, or industrial sources to surface waters.

Epilimnion - The warmer, well-lit surface waters of a lake that are thermally separated from the colder (hence denser), water at the bottom of the lake when a lake is stratified.

Eutrophication - The acceleration of the loading of nutrients to a lake by natural or human-induced causes. The increased rate of delivery of nutrients results in increased production of algae and consequently, poor water transparency. Human-induced (cultural) eutrophication may be caused by input of treated sewage to a lake, deforestation of a watershed, or the urbanization of a watershed.

Fecal Coliform Bacteria - Bacteria from the intestines of warm-blooded animals. Most of the bacteria are not in themselves harmful, so they are measured or counted as an indicator of the possible presence of harmful bacteria.

Groundwater - Water stored beneath the surface of the earth. The water in the ground is supplied by the seepage of rainwater, snowmelt, and other surface water into the soil. Some groundwater may be found far beneath the earth surface, while other groundwater may be only a few inches from the surface. Groundwater discharges into lowland streams to maintain their baseflow.

Hydrology -The science dealing with the properties, distribution and circulation of water. The term usually refers to the flow of water on or below the land surface before reaching a stream or man-made structure.

Hypolimnion - The dark, cold, bottom waters of a lake that are thermally separated from the warmer (hence less dense) surface waters when a lake is stratified.

Invertebrates - Animals without internal skeletons. Some require magnification to be seen well, while others such as worms, insects, and crayfish are relatively large. Invertebrates living in stream and lake sediments are collected as samples to be identified and counted. In general, more varied invertebrate communities indicate healthier water bodies.

Limiting nutrient - The nutrient that is in lowest supply relative to the demand. The limiting nutrient will be exhausted first by algae which require many nutrients and light to grow. Inputs of the limiting nutrient will result in increased algal production, but as soon as the limiting nutrient is exhausted, growth stops. Phytoplankton growth in lake waters of temperate lowland areas is generally phosphorus limited.

Limnology - Scientific study of inland waters.

Littoral zone - portion of a water body extending from the shoreline lakeward to the greatest depth occupied by rooted plants.

Loading rate - Addition of a substance to a water body; or the rate at which the addition occurs. For example, streams load nutrients to lakes at various rates as in "500 kilograms per year (500 kg/yr)" or "227 pounds per year (227 lb/yr)."

Macrophytes - rooted and floating aquatic plants, larger (macro-) than the phytoplankton.

Mesotrophic - A condition of lakes that is characterized by moderate concentrations of nutrients, algae, and water transparency. A mesotrophic lake is not as rich in nutrients as a eutrophic lake, but richer in nutrients than an oligotrophic lake.

Monomictic - A lake which has one mixing and one stratification event per year. If a lake does not freeze over in the winter, the winter winds will mix the waters of the lake. In summer, the lake resists mixing and becomes stratified because the surface waters are warm (light) and the bottom waters are cold (dense). Deep lakes in the Puget lowlands are monomictic lakes.

Nitrate, nitrite (NO3, NO2) - Two types of nitrogen compounds. These nutrients are forms of nitrogen that algae may use for growth.

Nitrogen - One of the elements essential as a nutrient for growth of organisms.

Non-point source pollution - Pollution that originates from diffuse areas and unidentifiable sources, such as agriculture, the atmosphere, or ground water.

Nutrients - Elements or compounds essential for growth of organisms.

Oligotrophic - A condition of lakes characterized by low concentrations of nutrients and algae and resulting good water transparency. An oligotrophic lake has less nutrients than a mesotrophic or eutrophic lake.

Pathogens -Microorganisms that can cause disease in other organisms or humans, animals, and plants. Pathogens include bacteria, viruses, fungi, or parasites found in sewage, in runoff from farms or city streets, and in water used for swimming. Pathogens can be present in municipal, industrial, and nonpoint source discharges.

Pelagic Zone - Deep, open water area of a lake away from the edge of the littoral zone towards the center of the lake.

pH - Measure of the acidity of water on a scale of 0 to 14, with 7 representing neutral water. A pH less than 7 is considered acidic and above 7 is basic.

Phosphorus - One of the elements essential as a nutrient for the growth of organisms. In western Washington lakes, it is usually the algae nutrient in shortest supply relative to the needs of the algae. Phosphorus occurs naturally in soils, as well as in organic material. Various measures of phosphorus in water samples are made, including total-phosphorus (TP) and the dissolved portion of the phosphorus (orthophosphorus).

Photic zone - The lighted region of a lake where photosynthesis occurs.

Phytoplankton - Floating, mostly microscopic algae (plants) that live in water.

Point-source Polution - An input of pollutants into a water body from discrete sources, such as municipal or industrial outfalls.

Primary Treatment - The first stage of wastewater treatment involving removal of debris and solids by screening and settling.

Pump Station -A structure used to move wastewater uphill, against gravity.

Regulator -A structure that controls the flow of wastewater from two or more input pipes to a single output. Regulators can be used to restrict or halt flow, thus causing wastewater to be stored in the conveyance system until it can be handled by the treatemnt plant.

Salmonids - Salmon, trout, char and whitefish species of fish.

Secchi depth - Measure of transparency of water obtained by lowering a 10 cm black and white disk into water until it is no longer visible.

Secondary Treatment - Following primary treatment, bacteria are used to consume organic wastes. Wastewater is then disinfected and discharged through an outfall.

Separation -A method for controlling combined sewer overflow whereby the combined sewer is separated into both a sanitary sewer and a storm drain, as is the practice in new development.

Sewage -That portion of wastewater that is composed of human and industrial wastes from homes, businesses, and industries.

Standard - A legally established allowable limit for a substance or characteristic in the water, based on criteria. Enforcement actions by the appropriate agencies can be taken against parties who cause violations.

Stratification of lakes - A layering effect produced by the warming of the surface waters in many lakes during summer. Upper waters are progressively warmed by the sun and the deeper waters remain cold. Because of the difference in density (warmer water is lighter), the two layers remain separate from each other: upper waters "float" on deeper waters and wind induced mixing occurs only in the upper waters. Oxygen in the bottom waters may become depleted. In autumn as the upper waters cool, the whole lake mixes again and remains mixed throughout the winter, or until it freezes over.

Stormwater -Water that is generated by rainfall and is often routed into drain systems.

Thermocline - Depth in a stratified lake where the greatest change in temperature occurs. Separates the epilimnion from the hypolimnion

Total suspended solids (TSS) - Particles, both mineral (clay and sand) and organic (algae and small pieces of decomposed plant and animal material), that are suspended in water.

Toxic -Causing death, disease, cancer, genetic mutations, or physical deformations in any organism or its offspring upon exposure, ingestion, inhalation, or assimilation.

Transparency - A measure of the clarity of water in a lake, which is measured by lowering a standard black and white Secchi disk into the water and recording the depth at which it is no longer visible. Transparency of lakes is determined by the color of the water and the amount of material suspended in it. Generally in colorless waters of the Puget lowland, the transparency of the water in summer is determined by the amount of algae present in the water. Suspended silt particles may also have an effect, particularly in wet weather.

Trophic status - Rating of the condition of a lake on the scale of oligotrophic-mesotrophic-eutrophic (see definition of these terms).

Turbidity - Cloudiness of water caused by the suspension of minute particles, usually algae, silt, or clay.

Wastewater -Total flow within the sewage system. In combined systems, it includes sewage and stormwater.

Water Column - Water in a lake between the surface and sediments. Used in vertical measurements used to characterize lake water.

Watershed - The areas that drain to surface water bodies, including lakes, rivers, estuaries, wetlands, streams, and the surrounding landscape.

Water of Statewide Significance - Legal term from the state Shoreline Management act, which recognizes particular bodies of water and sets criteria and standards for their protection.

Zooplankton - Small, free swimming or floating animals in water, many are microscopic.

Source: King County, Washington (http://dnr.metrokc.gov/wlr/waterres/lakes/glossary)

APPENDIX B

Stream Water Quality Data

Stream Stations - Proceeding Downstream to Upstream

Station	Stream	Gage Installed	Description
HR	Hatchery Run	Yes	Upstream of lake confluence
PCI	Paradise Creek Inlet	Yes	Upstream of lake confluence
PCO	Paradise Creek Outlet	Yes	Immediately below dam of Crawford Lake

Paradise Creek: Crawford Lake Nutrient & Sediment Loading Study **Prepared by Aqua-Link, Inc.**
Stream Moitoirng Data
ALI Project No. 1030-01

Water Quality Data

Station	Date	Flow Regime	Sample Type	TP (mg/l as P)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)	TSS (mg/l)
HR	07/05/03	Base	c	0.21	0.59	0.050	2.11	2.75	4.7
HR	08/26/03	Base	c	0.08	0.06	0.640	0.72	1.42	2.6
	Base	**Min**		0.08	0.06	0.050	0.72	1.42	2.6
		Max		0.21	0.59	0.640	2.11	2.75	4.7
		Mean		0.15	0.33	0.345	1.42	2.09	3.7
		Median		0.15	0.33	0.345	1.42	2.09	3.7
		Stds		0.09	0.37	0.417	0.98	0.94	1.5
		Std		0.07	0.27	0.295	0.70	0.67	1.1
		Count		2	2	2	2	2	2
HR	07/23/03	Storm	c	0.27	1.72	0.110	1.94	3.77	< 1.0
HR	08/02/03	Storm	c	0.12	0.84	0.050		0.89	1.7
HR	09/02/03	Storm	c	0.11	0.16	< 0.005	0.99	1.16	1.5
HR	09/14/03	Storm	c	0.17	0.82	0.040	7.58	8.44	< 1.0
HR	09/19/03	Storm	c	0.05	0.63	0.050	1.06	1.74	< 1.0
HR	09/24/03	Storm	c	0.06	0.48	0.050	0.80	1.33	13.0
HR	10/05/03	Storm	c	0.09	0.99	0.050	1.49	2.53	2.7
	Storm	**Min**		0.05	0.16	0.005	0.80	0.89	1.0
		Max		0.27	1.72	0.110	7.58	8.44	13.0
		Mean		0.12	0.81	0.051	2.31	2.84	3.1
		Median		0.11	0.82	0.050	1.28	1.74	1.5
		Stds		0.08	0.49	0.031	2.61	2.66	4.4
		Std		0.07	0.45	0.029	2.39	2.46	4.1
		Count		7	7	7	6	7	7

Paradise Creek: Crawford Lake Nutrient & Sediment Loading Study **Prepared by Aqua-Link, Inc.**
Stream Moitoirng Data
ALI Project No. 1030-01

Water Quality Data

Station	Date	Flow Regime	Sample Type	TP (mg/l as P)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)	TSS (mg/l)
HR	07/23/03	Storm	ff	0.31	0.52	0.170	0.55	1.24	4.0
HR	08/02/03	Storm	ff	0.15	1.58	0.160		1.74	4.8
HR	09/02/03	Storm	ff	0.14	0.52	0.080	1.12	1.72	1.8
HR	09/14/03	Storm	ff	0.25	1.08	0.100	8.35	9.53	1.8
HR	09/19/03	Storm	ff	0.06	0.64	0.060	1.02	1.72	< 1.0
HR	09/24/03	Storm	ff	0.07	0.50	0.050	0.86	1.41	3.6
HR	10/05/03	Storm	ff	0.12	1.04	0.060	1.51	2.61	3.2
	Storm	**Min**		0.06	0.50	0.050	0.55	1.24	1.0
		Max		0.31	1.58	0.170	8.35	9.53	4.8
		Mean		0.16	0.84	0.097	2.24	2.85	2.9
		Median		0.14	0.64	0.080	1.07	1.72	3.2
		Stds		0.09	0.41	0.049	3.01	2.98	1.4
		Std		0.09	0.38	0.046	2.75	2.76	1.3
		Count		7	7	7	6	7	7
PCI	75//2003	Base	c	0.11	< 0.10	< 0.005	2.51	2.62	1.4
PCI	08/26/03	Base	c	0.08	0.45	0.020	1.13	1.60	1.0
	Base	**Min**		0.08	0.10	0.005	1.13	1.60	1.0
		Max		0.11	0.45	0.020	2.51	2.62	1.4
		Mean		0.10	0.28	0.013	1.82	2.11	1.2
		Median		0.10	0.28	0.013	1.82	2.11	1.2
		Stds		0.02	0.25	0.011	0.98	0.72	0.3
		Std		0.02	0.18	0.008	0.69	0.51	0.2
		Count		2	2	2	2	2	2

Water Quality Data

Station	Date	Flow Regime	Sample Type		TP (mg/l as P)	Nitrate (mg/l as N)		Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)		TSS (mg/l)
PCI	07/23/03	Storm	c		0.12	0.58	<	0.005	0.73	1.32		5.1
PCI	08/02/03	Storm	c		0.14	0.65		0.020		0.67		1.0
PCI	09/02/03	Storm	c		0.09	0.16	<	0.005	1.04	1.21	<	1.0
PCI	09/14/03	Storm	c		0.04	0.38	<	0.005	0.90	1.29	<	1.0
PCI	09/19/03	Storm	c		0.04	0.24	<	0.005	1.30	1.55	<	1.0
PCI	09/24/03	Storm	c		0.03	0.15		0.010	1.02	1.18	<	1.0
PCI	10/05/03	Storm	c	<	0.02	0.63		0.010	1.59	2.23		1.6
	Storm	**Min**			0.02	0.15		0.005	0.73	0.67		1.0
		Max			0.14	0.65		0.020	1.59	2.23		5.1
		Mean			0.07	0.40		0.009	1.10	1.35		1.7
		Median			0.04	0.38		0.005	1.03	1.29		1.0
		Stds			0.05	0.22		0.006	0.31	0.47		1.5
		Std			0.04	0.20		0.005	0.28	0.44		1.4
		Count			7	7		7	6	7		7

Station	Date	Flow Regime	Sample Type		TP (mg/l as P)	Nitrate (mg/l as N)		Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)		TSS (mg/l)
PCI	07/23/03	Storm	ff		0.20	0.51		0.050	15.1	15.66		26.0
PCI	08/02/03	Storm	ff		0.05	0.73		0.040		0.77	<	1.0
PCI	09/02/03	Storm	ff		0.19	0.29	<	0.005	1.08	1.38		1.0
PCI	09/14/03	Storm	ff		0.02	0.56		0.020	0.90	1.48	<	1.0
PCI	09/19/03	Storm	ff	<	0.02	0.34		0.010	1.34	1.69	<	1.0
PCI	09/24/03	Storm	ff		0.03	0.30		0.020	1.12	1.44		2.8
PCI	10/05/03	Storm	ff		0.06	0.90		0.040	1.48	2.42		12.0
	Storm	**Min**			0.02	0.29		0.005	0.90	0.77		1.0
		Max			0.20	0.90		0.050	15.10	15.66		26.0
		Mean			0.08	0.52		0.026	3.50	3.55		6.4
		Median			0.05	0.51		0.020	1.23	1.48		1.0
		Stds			0.08	0.23		0.017	5.68	5.36		9.5
		Std			0.07	0.22		0.016	5.19	4.97		8.8
		Count			7	7		7	6	7		7

Water Quality Data

Station	Date	Flow Regime	Sample Type	TP (mg/l as P)	Nitrate (mg/l as N)		Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)		TSS (mg/l)
PCO	07/05/03	Base	c	0.15	0.31		0.005	3.19	3.51	<	1.0
PCO	08/26/03	Base	c	0.14	0.47		0.040	0.96	1.47		11.0
	Storm	**Min**		0.14	0.31		0.005	0.96	1.47		1.0
		Max		0.15	0.47		0.040	3.19	3.51		11.0
		Mean		0.15	0.39		0.023	2.08	2.49		6.0
		Median		0.15	0.39		0.023	2.08	2.49		6.0
		Stds		0.01	0.11		0.025	1.58	1.44		7.1
		Std		0.00	0.08		0.018	1.12	1.02		5.0
		Count		2	2		2	2	2		2
PCO	07/23/03	Storm	c	0.18	0.71	<	0.005	0.73	1.45		7.0
PCO	08/02/03	Storm	c	0.08	0.83		0.020		0.85	<	1.0
PCO	09/02/03	Storm	c	0.13	0.20	<	0.005	0.93	1.14		1.8
PCO	09/14/03	Storm	c	0.09	0.42	<	0.005			<	1.0
PCO	09/19/03	Storm	c	0.09	0.39		0.010	2.15	2.55	<	1.0
PCO	09/24/03	Storm	c	0.04	0.19	<	0.005	1.34	1.54		11.0
PCO	10/05/03	Storm	c	0.03	0.57		0.020	0.65	1.24		9.0
	Storm	**Min**		0.03	0.19		0.005	0.65	0.85		1.0
		Max		0.18	0.83		0.020	2.15	2.55		11.0
		Mean		0.09	0.47		0.010	1.16	1.46		4.5
		Median		0.09	0.42		0.005	0.93	1.34		1.8
		Stds		0.05	0.24		0.007	0.61	0.59		4.3
		Std		0.05	0.23		0.007	0.55	0.54		4.0
		Count		7	7		7	5	6		7

Paradise Creek: Crawford Lake Nutrient & Sediment Loading Study **Prepared by Aqua-Link, Inc.**
Stream Moitoirng Data
ALI Project No. 1030-01

Water Quality Data

Station	Date	Flow Regime	Sample Type	TP (mg/l as P)	Nitrate (mg/l as N)	Nitrite (mg/l as N)	TKN (mg/l as N)	TN* (mg/l as N)	TSS (mg/l)
PCO	07/23/03	Storm	ff	0.27	0.29	0.050	6.08	6.42	4.3
PCO	08/02/03	Storm	ff	0.08	0.74	0.030		0.77	2.9
PCO	09/02/03	Storm	ff	0.15	0.22	0.010	0.86	1.09	1.7
PCO	09/14/03	Storm	ff	0.08	0.06	0.020	14.00	14.08	< 1.0
PCO	09/19/03	Storm	ff	0.12	0.36	0.030	1.98	2.37	< 1.0
PCO	09/24/03	Storm	ff	0.05	0.20	< 0.005	0.72	0.93	2.1
PCO	10/05/03	Storm	ff	0.04	0.34	0.030	0.76	1.13	2.6
	Storm	**Min**		0.04	0.06	0.005	0.72	0.77	1.0
		Max		0.27	0.74	0.050	14.00	14.08	4.3
		Mean		0.11	0.32	0.025	4.07	3.83	2.2
		Median		0.08	0.29	0.030	1.42	1.13	2.1
		Stds		0.08	0.21	0.015	5.28	4.94	1.2
		Std		0.07	0.20	0.014	4.82	4.57	1.1
		Count		7	7	7	6	7	7

Notes:

"g" denotes grab sample collected manually
"ff" denotes first flush sample collected using an automated water sampler unit
"c" denotes composite sample collected over storm hydrograph using an automated water sampler unit
Data removed - PCO composite storm sample with TKN value of 56.4 mg/l on 9/14/03

Paradise Creek: Crawford Lake Nutrient & Sediment Loading Study
Stream Moitoirng Data
ALI Project No. 1030-01

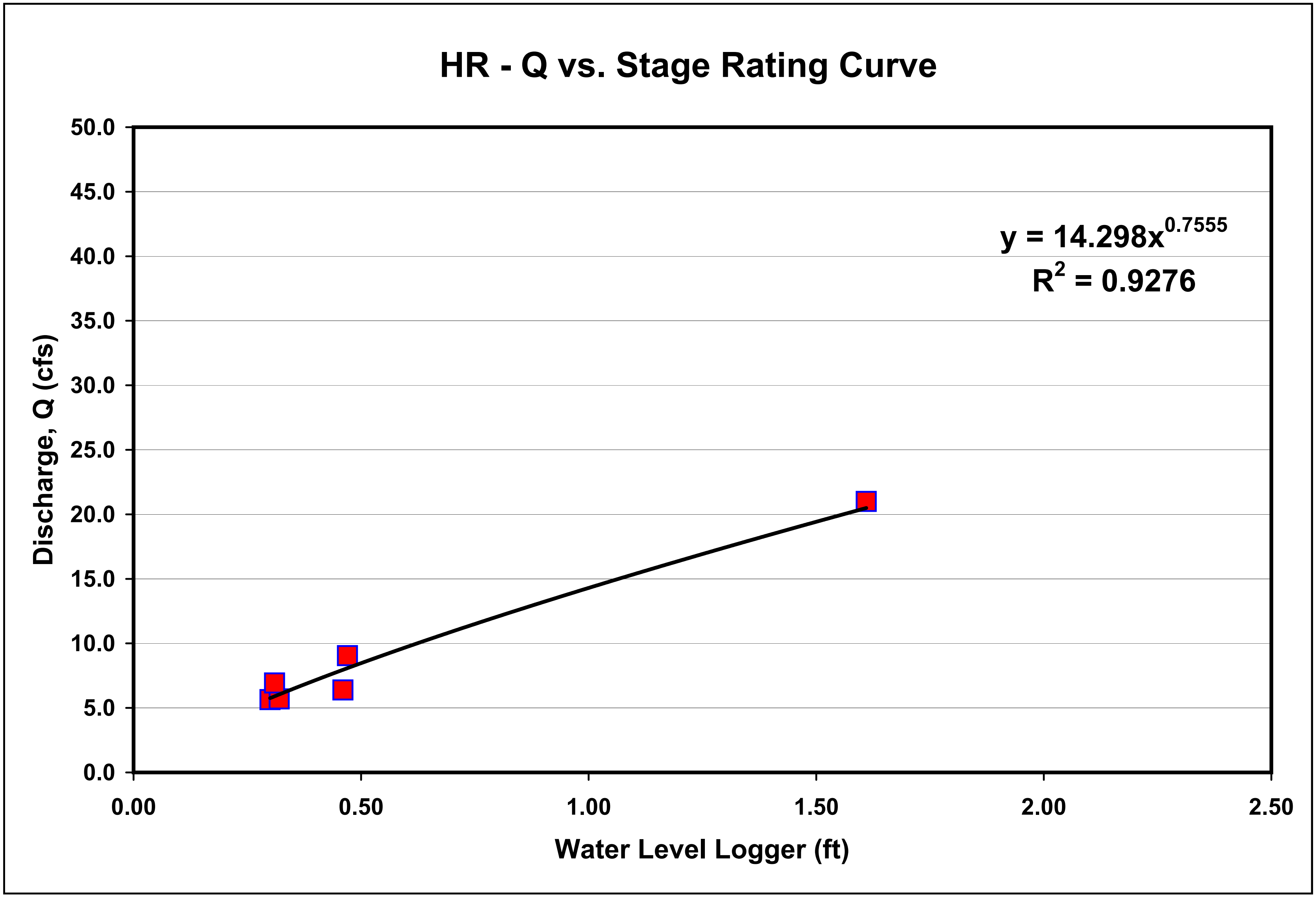
Comparison of Mean Water Quality Data

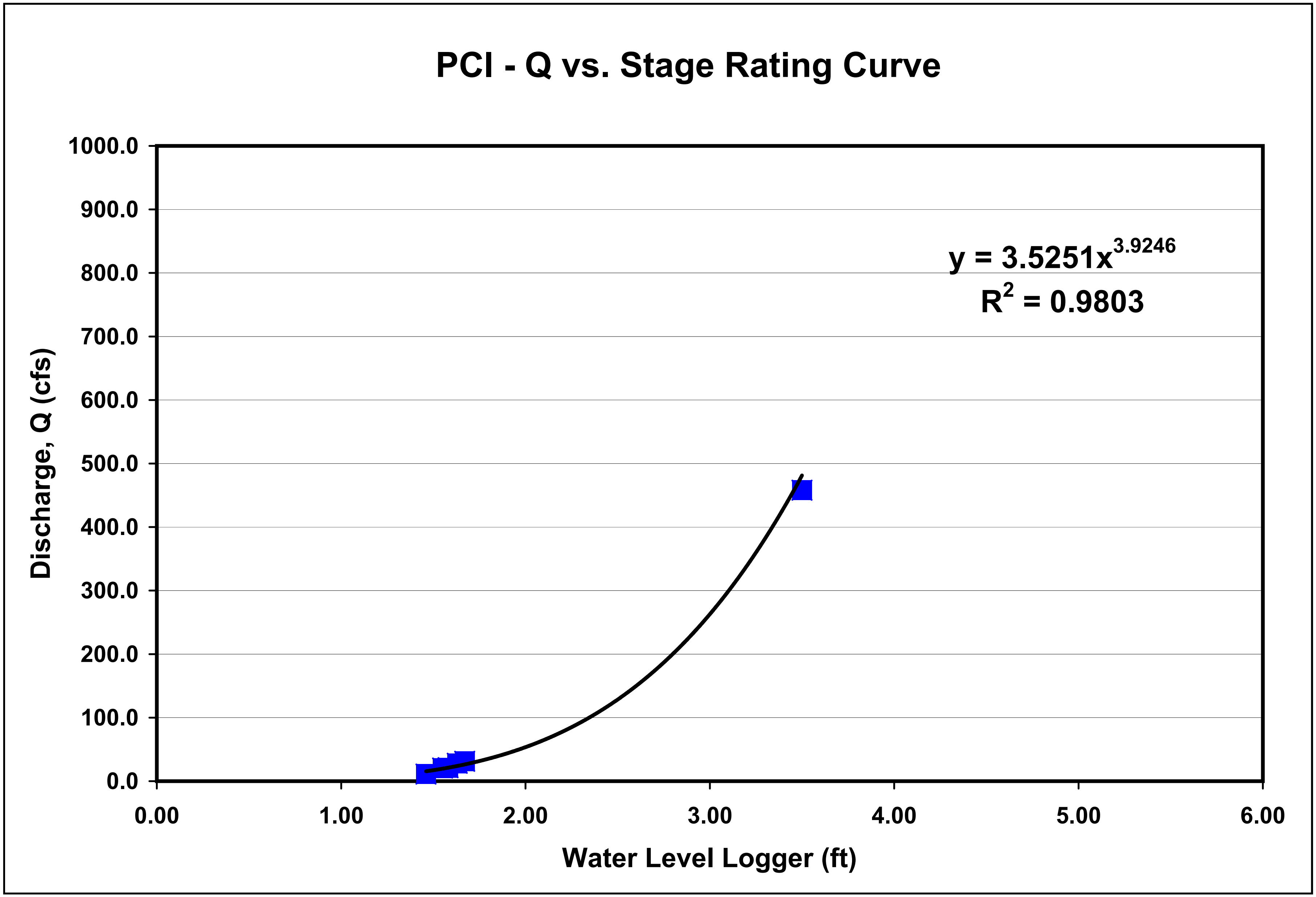
Station	Flow Regime	Sample Type	TP (mg/l as P)	TN* (mg/l as N)	TSS (mg/l)
HR	Base	g	0.15	2.09	3.7
HR	Storm	ff	0.16	2.85	2.9
HR	Storm	c	0.12	2.84	3.1
PCI	Base	g	0.10	2.11	1.2
PCI	Storm	ff	0.08	3.55	6.4
PCI	Storm	c	0.07	1.35	1.7
PCO	Base	g	0.15	2.49	6.0
PCO	Storm	ff	0.11	3.83	2.2
PCO	Storm	c	0.09	1.46	4.5

Notes: "g" denotes grab sample collected manually
"ff" denotes first flush sample collected using an automated water sampler unit
"c" denotes composite sample collected over storm hydrograph using an automated water sampler unit

APPENDIX C

Hydrologic Data


HR - Q vs. Stage Rating Curve
y = 14.298x^0.7555
R^2 = 0.9276
Discharge, Q (cfs)
Water Level Logger (ft)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0.00
0.50
1.00
1.50
2.00
2.50


PCI - Q vs. Stage Rating Curve
y = 3.5251x^3.9246
R^2 = 0.9803
Discharge, Q (cfs)
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0.00
1.00
2.00
3.00
4.00
5.00
6.00
Water Level Logger (ft)

Paradise Creek - Crawford Lake Pollution Budget **Aqua-Link, Inc.**
Project No. 1035-02

Q vs Stage Data - Sorted

Date	Site	Flow (cfs)	Staff Gage (ft)	Data Logger (ft)	Stream Width (ft)	SG - DL (ft)
8/26/2003	HR	5.64	0.70	0.30	21.7	0.40
7/23/2003	HR	5.70	0.71	0.32	20.7	0.39
11/20/2003	HR	6.39	0.81	0.46	21.8	0.35
8/4/2003	HR	6.93	0.74	0.31	20.8	0.43
10/5/2003	HR	9.05	0.86	0.47	22.3	0.39
9/23/03 Est.	**HR**	**21.00**		**1.61**		
8/26/2003	PCI	11.20	2.38	1.46	51.8	
7/23/2003	PCI	20.62	2.39	1.55	51.7	0.84
8/4/2003	PCI	21.27	2.44	1.58	52.8	0.86
11/20/2003	PCI	28.19	2.61	1.63	64.4	0.98
10/5/2003	PCI	31.23	2.68	1.67	55.4	1.01
9/23/03 Est.	**PCI**	**458.00**		**3.50**		
8/26/2003	PCO	20.35	0.87	1.55	34.7	
7/23/2003	PCO	27.65	0.95	1.64	34.8	-0.69
11/20/2003	PCO	34.39	1.02	1.70	35.7	
8/4/2003	PCO	40.12	0.97	1.65	35.2	
10/5/2003	PCO	57.29	1.16	1.84	36.7	-0.68

Notes:

1. Data logger values estimated using staff gage & data logger relationship: PCI on 8/26, PCO on 8/26, 11/20 & 8/4

2. Large storm event at three stations & Brodhead Creek (BHC) @ Analomick on 9/23/03.
Used max. data logger values to estimated Q using BHC Q/watershed area relationship for 9/23/03.
The max. instanteneous Q on 9/23/03 at BHC was 2,360 cfs.

3. The watershed area for BHC @ Analomick (USGS Station No. 01440400) is 65.9 sq. miles.
The watershed area for Station PCI is 12.8 sq. miles.
The watershed area for Station HR is 0.6 sq. miles.

Station PCI (Paradise Creek Inlet)
ALI Project No. 1030-01

Discharge Summary:

Station	Stream Volumes (cubic ft.) Total Flow	Baseflow	Stormflow	% Baseflow
PCI	474,906,982	392,364,582	82,542,400	82.6
HR	120,505,310	117,639,771	2,865,539	97.6
Sum	**595,412,292**	**510,004,353**	85,407,939	85.7
PCO	595,412,292	510,004,353	(Check)	

APPENDIX D

NPS Loading Data

Paradise Creek: Crawford Lake Nutrient & Sediment Loading Study
Stream Moitoirng Data
ALI Project No. 1030-01

Calculated NPS Loadings:

Station	Flow Regime	Sample Type	TP (mg/l as P)	TN* (mg/l as N)	TSS (mg/l)	Stream Volume (ft^3)	TP (kg)	TN* (kg)	TSS (kg)
HR	Base	g	0.15	2.09	3.7	117,639,771	483	6,946	12,159
HR	Storm	c	0.12	2.84	3.1	2,865,539	10	230	254
						120,505,310	**493**	**7,176**	**12,413**
PCI	Base	g	0.10	2.11	1.2	392,364,582	1,056	23,415	13,333
PCI	Storm	c	0.07	1.35	1.7	82,542,400	160	3,149	3,907
						474,906,982	**1,216**	**26,564**	**17,239**
							1,709	**33,740**	**29,652**
PCO	Base	g	0.15	2.49	6.0	510,004,353	2,094	35,924	86,650
PCO	Storm	c	0.09	1.46	4.5	85,407,939	221	3,529	10,987
						595,412,292	**2,315**	**39,453**	**97,637**

Notes: "g" denotes grab sample collected manually
"ff" denotes first flush sample collected using an automated water sampler unit
"c" denotes composite sample collected over storm hydrograph using an automated water sampler unit