ANALYSIS OF WATER QUANTITY AND QUALITY IN THE ENGLISHMAN RIVER – AN EXAMINATION OF VULNERABILITY TO LAND USE IMPACTS

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A thesis submitted in partial fulfillment of
The requirements for the degree of

MASTER OF SCIENCE
in

ENVIRONMENT AND MANAGEMENT

We accept this thesis as conforming
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March 2004

Abstract

This thesis examines whether the impact of human activities can be determined, based on the analysis of water samples from the Englishman River. Standard water quality parameters collected from three major sub-basins and the main stem of the Englishman River system are used to address these questions:

- Are there long-term temporal changes in the quantity and quality of the water in the Englishman River?
- Are there correlations between parameter values and water flow?
- Are there spatial differences among the water quality parameters?

Several statistical approaches are employed, including a multivariate analysis technique (cluster analysis) that simultaneously measures the degree of difference between individual water quality parameters, sampling sites and time of year. The approach provides evidence that human activity is having a measurable impact on water quality in the Englishman River and establishes the value of using multivariate analysis to distinguish geographically distinct sub-basins in a coastal watershed.

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CHAPTER ONE
INTRODUCTION

Although the availability of clean, fresh water is a global issue facing human populations everywhere, well documented by de Villiers (2000), there are some aspects of this problem in coastal British Columbia that are noteworthy. In particular, the steep topography, the extremes of seasonal rainfall, and the short residency times have posed challenges for the exploitation of this resource. The growing concern over the potential impacts of global climate change is raising questions as to the possible local effects on watersheds. Water demand, for domestic uses, has increased with population, and will continue to do so, barring a major shift in our daily behaviour as North American consumers. Canadians rank 2nd highest of 29 members of the Organization for Economic Cooperation and Development (OECD), in water consumption per capita (Boyd, 2001).

The recurrence of a few dry summers in the Pacific Northwest and the conservation efforts of individual municipalities have temporarily reduced both supply and demand, but our habits tend to regress with the return of the fall rains. Our life styles continue to put pressure on the quantity and quality of our supplies, generally. High profile cases of contaminated municipal water supplies in Central and Western Canada (BC Ministry of Health, 2001) monopolize media, public, and government attention for short periods of time. Nevertheless, the general causes of contamination are well known and deserve continuing attention. Not surprisingly, people are motivated by their immediate water needs, whether for domestic, agricultural, and industrial uses, or for recreation. Furthermore, there is an increasing awareness that humans should also address the needs of other living organisms including fish, wildlife and their habitats for aesthetic, as well as, ethical reasons (Acreman, 2001). However, the key issue seems to be whether local communities are able and willing to integrate readily available information, regarding the current state of their water supply and the health of the ecosystem that supports it. If they are, then, they should be taking substantive steps to ensure the security and sustainability of their watersheds.

Background of the Problem

Numerous reports have been researched and compiled on watersheds throughout the world (Lal, 2000) and, within the past few decades, even relatively unspoiled watercourses, such as the Englishman River on the southeast coast of Vancouver Island, have been subjected to increased scrutiny (Bocking & Gaboury, 2001; Boom & Bryden, 1994). The pressures of anthropogenic land uses, ranging from forestry to residential development, have had noticeable impacts on both the quantity and quality of the river's water. However, it appears that each of the numerous agencies, involved in monitoring and regulating its use, has a narrow jurisdictional scope that would benefit from a broader perspective.

A more holistic approach could lead to the protection of natural purification processes, which are important aspects of the hydrologic cycle. The aim of this research project is to examine issues, from an integrated perspective, regarding the quantity and quality of water in the Englishman River, specifically, its vulnerability to various land use impacts. This coastal watershed is a good example because it is subjected to three major land use activities (forestry, agriculture, and urbanization), localized in three distinct catchment areas, while being utilized as both a drinking water supply and a salmonid rearing run. By utilizing available data, from multiple sources, potential impacts of the land use activities will be assessed and susceptibilities to continuing anthropogenic influences will be addressed. This process may well reveal possibilities for the preservation and enhancement of watershed health.

Perspectives

Social

Like most North Americans, the inhabitants of mid- Vancouver Island near Parksville, benefit from unfettered access to potable water at the turn of a tap, without undue concern for cost. The long-term sustainability of a safe water supply seems to be of limited interest, provided the water purveyor meets the ratepayers' expectations. Annual average quantities can be misconstrued and lead to a false sense of security regarding the supply. As well, relatively high water quality is often interpreted as an implication that there are few threats, although long time residents have offered anecdotal evidence that observed water quality has deteriorated over the past twenty years (T. Wicks, personal communication, January 18, 2002). The mechanisms of these attributes are not widely understood; however, the matter of watershed protection is now appearing on the public agenda of the Regional District of Nanaimo (2003a) and a source to tap approach is gaining currency. Furthermore, the recent acquisition of riparian land by a consortium of governmental agencies and the Nature Trust of BC was greeted as good news by many local residents (Sutherland, 2003).

Economic

As in other parts of this province, the pre-occupation of mainstream society throughout the 1990s appeared to be growth and development, in order to provide jobs and economic prosperity in the region. Recognition of the need for an urbanization strategy was borne out by the efforts of the Regional District in preparing its Growth Management Plan (Regional District of Nanaimo, 2001a); however, the issue of carrying capacity of water supplies to areas slated for development has yet to be resolved (Regional District of Nanaimo, 2002). It appears as if the pressure of fiscal restraint at all levels of government has led to a climate in which there is, both, an acceptance of the need for a vibrant tax-base, fuelled by growth, and a reluctance to commit major resources to sustainability issues (Wells, 2003), such as watershed security or enhancement. The term security, in this context, refers to both the protection of its integrity and the guarantee of its future availability.

Legal

In Canada, there is no single legislative authority when it comes to surface water, especially rivers, so the issue of jurisdiction is always complex. In British Columbia, there are over a dozen agencies, from the municipal, provincial, and federal levels of government, involved in monitoring and/or legislating the quality of drinking water (BC Ministry of Health, 2001). In addition, there are at least 39 provincial acts affecting watershed management (West Coast Environmental Law, 2003) ranging from straightforward drinking water regulation, under the Water Protection Act, to the relatively obscure provisions of the Land Title Act. The entire Englishman River watershed is within the boundaries of the Regional District of Nanaimo (RDN). However, the situation is complicated by the fact that over two thirds is privately owned, as a legacy of the Esquimalt & Nanaimo Railway land grant at the end of the 19th century.

Environmental

Decades ago, public concern over migrating birds on the estuary and dwindling anadromous fish stocks in the lower reaches, gave rise to early conservation efforts associated with the Englishman River. Henceforth, various environmental non-governmental organizations (ENGOs) have tended to focus on the preservation of selected species. However, the growing awareness of the importance of total ecosystem health, as well as, the realization that riparian habitat is required by many types of wildlife, has played a key role in stimulating these groups. A frequently undervalued aspect of ecosystems is the role they play in natural water purification processes, such as filtration, oxygenation, distillation, and coagulation, which are inherent in the hydrologic cycle. One group of environmentalists, who succeeded in achieving the designation of this area as the Mount Arrowsmith Biosphere Reserve by the United Nations Educational, Science and Cultural Organization in 2001, also produced a video series highlighting the importance of the water cycle (Mount Arrowsmith Biosphere Reserve, 2001a).

Scientific

It appears that the monitoring of many water quality parameters has been primarily based on legal responsibilities. Governmental agencies are rightfully pre-occupied with their legislated mandates; however, there seems to be room for more cross-disciplinary communication (Aron & Zimmerman, 2002). This could be promoted by utilizing common dimensions for all water uses; therefore, it was decided that data in this report would be converted to the metric system. Another impediment to effective communication is the definition of “Water Quality”, which has different meanings depending on the end use category. These include drinking water, aquatic life, wildlife, recreation, agricultural and industrial (BC Ministry of Water, Land, & Air Protection, 1998). This report will attempt to address the overall health of the watershed, as a holistic ecosystem.

Description of Ecologically Healthy Watersheds

From a chapter, entitled Fundamental Elements of Ecologically Healthy Watersheds in the Pacific Northwest Coastal Ecoregion, Naiman (1992) provided the following description: “In ecologically healthy watersheds, interactions between channel geomorphology, hydrological pattern, spatial position of the channel, and riparian forest characteristics produce habitat for terrestrial and aquatic organisms” (p. 56). However, a challenge exists in the identification of those indicators which may portend a degradation in ecological health. Habitat has been irrevocably altered, because of intensive immigration over the past century and a half, resulting in reductions and/or displacement of indigenous wildlife. More recently, reductions in fish stocks have raised ongoing questions regarding aquatic and riparian health (Bocking & Gaboury, 2001). On the other hand, the watershed’s natural purification processes play an important, but perhaps underestimated, role in sustaining water quality.

Available Indicators

While it is understood that biological indicators are, in many ways, effective in determining the health of a river ecosystem (Hewitt, 1991), detailed inventories of the biota in each area of this watershed are not available. Selected physico-chemical parameters are readily available from the federal and provincial governments from continuous monitoring of river levels and regular sampling of river water at four specific sites. Therefore, the focus of this research has been on physical and chemical indicators of water quality that are already being used as part of a monitoring project. It is hypothesized that it may be possible to determine the measurable effects of various land uses on the quantity and quality of the river water, thereby providing an indication of aquatic and riparian ecosystem health. It is hoped that patterns within this set of parameters will be useful indicators of land use perturbations.

Measured Parameters

Water Quantity

The primary source for water quantity data is from the Water Survey of Canada's gauge, 08HB002[BC], near Parksville, which is available online (Water Survey of Canada, 2002). Continuous monitoring of the river level (in meters) is converted to discharge (amount in m^3/s) through the use of a rating curve, which is specific to the river at the location of the gauge. All other agencies rely on this data, compiled to produce daily, mean monthly, as well as the mean annual discharge (MAD). By global standards, the MAD of the Englishman River would appear to be sufficient for a much larger population (Boyd, 2001). However, annual figures do not address the seasonality of supply, in that winter flows greatly exceed demand and summer-fall flows are insufficient to satisfy the needs of all users. A complicating factor is the unknown amount of surface water that leaves the watercourses to recharge ground water sources in the watershed. The fundamental question is whether, or not, there is sufficient flow of river water to ensure a healthy aquatic and riparian ecosystem AND meet the demands of the human population, throughout the entire year; now and into the foreseeable future. Therefore, monthly data gives a better indication of what quantity may be available, during a particular month of the year. Monthly averages have been collated and used in other reports, so they are readily accessible.

Dimensions – Supply and Demand

The river's discharge, expressed in cubic meters per second (m^3/s), is generally accepted as the measure of supply. The amount of water allocated to municipal water utilities is usually expressed in Imperial Gallons per Year (GY), but for domestic and business users it has been in Imperial Gallons per Day (GD). Then, for irrigation, amounts are indicated in acre-feet (AF), which, when calculated in the metric system, are very large quantities. In describing the water flow allocated for conservation, amounts are expressed in cubic feet per second (CS). Therefore, another dimension, used by some agencies, is the Cubic Decameter ($decm^3$ or dam^3).

Dimensional Conversions

To ensure that discussions can be based on a common unit system, the measurements from all sources have been converted to the metric system. Therefore, the standard units used for comparisons in this report are cubic meters for quantity and cubic meters per second for flow.

Water Quality

It seems that existing governmental regulations provide the primary motivation for the current collection of water quality data. The provincial government and the municipality monitor specific parameters in the Englishman River, to determine whether they meet the approved criteria for the specified end use (D. Epps, personal communication, October 2, 2002; G. J. O'Rourke, personal communication, September 10, 2003). Regular sampling is stipulated, but the frequency may not be sufficient to capture a truly representative state of the river's health, especially during high flows immediately following major precipitation events. Furthermore, it is not obvious that the overall health of the ecosystem is being tracked, because, even though six different uses have identified, provincial water quality objectives have yet to be established for this particular watershed.

Anthropocentric values appear to be implicit in the current monitoring schemes. For example, nutrients are measured in relation to current drinking water standards, whereas there is little mention of their role with respect to net primary production (NPP) for other biota. Similarly, dissolved oxygen and temperature, which are significant parameters for fish, but not for humans, are not recorded in the same database. Also, while the impacts of many metals on human health are well documented and their concentrations are monitored, the presence of xenobiotics and persistent organic pollutants (POPs) is not monitored for either ecosystem or human health. While it is acknowledged that the cost of monitoring more complex substances may be an important consideration in deciding which ones are analyzed, there is no readily apparent mechanism or rationale for the decisions as to which are included and which are ignored.

Physical Parameters

The physical parameters addressed in this study are those that are commonly used in assessing water quality: pH, as a measure of acidity or alkalinity (in pH units), specific conductance as a measure of electrical conductance or the concentration of ions (in micro-Sieverts per centimetre or μS/cm), and turbidity as a measure of murkiness (in Nephelometric Turbidity Units or NTUs).

Nutrients

Nutrients are chemicals essential to the health of all biota, starting with primary producers, autotrophs, such as algae. As indicated in a major study by the Government of Canada, two key elements in this category are nitrogen and phosphorus, although carbon, hydrogen, oxygen, and potassium are also classified as macro-nutrients (Chambers, Guy, Roberts, Charlton, Kent, Gagnon et al., 2001). The two key types are both critical to net primary production (NPP), which is a measure of the assimilation of organic material. Therefore, surface waters can be classified as being N-limited or P-limited. Fresh water ecosystems in the forested areas of the Pacific Northwest are typically P-limited (Church & Eaton, 2001), therefore an increase in this substance can promote considerable growth of plant matter.

Not all species of nitrogen and phosphorus are bio-available; nevertheless, when concentrations exceed particular levels, they can upset the “balance of nature” by promoting algal blooms and, in extreme cases, by producing bio-toxins, such as cyanobacter, also known as “blue-green algae”. The excessive growth of algae leads to an increased demand for oxygen, which can cause the eutrophication of a surface water supply. In another example, excessive consumption of nitrates, in human health, can cause the phenomenon of methemoglobinemia (“blue baby syndrome”) (Newman & Unger, 2002). Due to these harmful effects, it is not surprising that nitrates are a regularly monitored parameter, as they may enter the water supply from fertilization or sewage.

In this study, nitrogen is measured as nitrites and as a total of the two species, “Nitrates + Nitrites”, however, it is also present in the chemically reduced form “ammonia”. For phosphorus, orthophosphate, total dissolved phosphorus (TDP) and total phosphorus (TP) are the measured forms. TDP includes combined forms which hydrolize to the bioavailable orthophosphate PO_4^{3-}, during digestion. In addition to providing a future supply of orthophosphate, polyphosphates can act as chelating ligands, which increase the transport of metals. The term Total Phosphorus refers to the aggregate of these species. The following table summarizes the chemical forms, their bioavailability, and the potential sources of some common nutrient species. Although all these forms have natural sources, some land use activities are known to either directly or indirectly result in elevated levels.

Chemical Form	Symbol	Bio-Availability	For.	Agri.	Urb.
ammonia / ammonium	NH_3 / NH_4^+	immediate	I	D	I
Nitrate	NO_3^-	immediate	I	D	I
Nitrite	NO_2^-	latent			
Total Dissolved Nitrogen	Various chemical forms	latent	I/D	D	
Orthophosphate	PO_4^{3-}	immediate	I	D	D
Total Dissolved Phosphorus	PO_4^{3-} & combined forms	latent	I	I/D	I/D

Table I – Forms of nutrients in the environment (water)(Chambers et al., 2001)
Potential Sources include Forestry, Agriculture, Urbanization, and Industry.
D = Direct source (directly applied or released in this chemical form)
I = Indirect source (may be released indirectly as a result of activity)

Microbial Contaminants

Fecal Coliforms and Escherichia Coli (E.Coli) are enteric bacteria associated with human and animal waste. Many types of bacteria are commonly found in the intestines of animals and humans and some of these species are indicative of a number of water borne pathogens capable of causing a number of diseases, such as cholera, typhoid fever, or hepatitis A. During precipitation, E. Coli may be washed into creeks, rivers, lakes or groundwater. When these are used as sources of drinking water (and the water is not treated or inadequately treated), E. Coli may end up in drinking water. Although most strains are harmless and live in the intestines of healthy humans and animals, E. Coli, E 0157:H7, produces a powerful toxin and can cause severe illness.

Total and fecal coliform counts have been used as indicator organisms to monitor water quality (BC Ministry of Health, 2001) and the addition of chlorine has been the most commonly used anti-bacterial treatment, worldwide. However, there are other organisms that can be spread through water, which do not respond to normal disinfection processes. Cattle manure and other animal feces have been identified as sources of enteric parasites, such as giardia and cryptosporidium. These are responsible for impacting human health, and affected water supplies require alternative, multi-barrier, water treatment technologies, other than simple chlorination.

Metals

The metallic elements may occur naturally in rocks and soils, but some deserve particular attention because many have been associated with urban land use and industrial activities. Heavy metals are generally taken to include cadmium, lead, and mercury (although chromium is sometimes included in this group). These species are not known to have any beneficial biological function and are generally considered highly toxic. This is reflected in very low drinking water criteria as depicted below. Heavy metal contamination is often associated with a number of light and heavy industrial activities including, but not limited to, electroplating, metal refining and processing incineration as well as specific products. The metals manganese, iron, nickel, copper and zinc are micro-nutrients, which can become problematic at high concentrations, whereas the criteria for nickel is still in preparation (Health Canada, 2001). The metalloids, aluminium, selenium, antimony, and arsenic, are a special group, which have a range of biological activities and toxicities depending on their chemical form.

The following table summarizes the criteria established for two purposes, aesthetics and drinking:

	Metal or Metalloid	**Symbol**	**Aesthetic Criteria**	**Drinking Criteria**
Heavy Metals	Lead	Pb	-	10 µg/L (max)
	Cadmium	Cd	-	5 µg/L (max)
	Mercury	Hg	-	1 µg/L (max)
	Chromium	Cr	-	50 µg/L (max)
Micro - Nutrients	Manganese	Mn	<or = 50 µg/L	-
	Iron	Fe	<or = 300µg/L	-
	Copper	Cu	<or = 1000µg/L	-
	Zinc	Zn	<or = 5000µg/L	-
Metalloids	Aluminium (dissolved)	Al	-	20 µg/L (dependent on pH)
	Antimony	Sb	-	6 µg/L (proposed)
	Arsenic	As	-	25 µg/L (interim)
	Selenium	Se	-	10 µg/L (max)

Table II – Metals and metalloids in the surface water environment.

The drinking water criteria for lead, according to the BC Approved Water Quality Guidelines, is set at 10 μg/L, which is a relatively low level (BC Ministry of Health, 2001). Arsenic is a metalloid that is also highly toxic and carcinogenic (criteria: < 25 μg / L), but is found naturally in some water supplies in BC, as well as in runoff, due to its use in wood preservatives and pesticides (BC Ministry of Health, 2001; Newman, 1998). Lower on the scale of concern is copper, an essential trace element for human health, similar to iron, but toxic in very high concentrations (e.g. > 15000 μg/day). The criteria for copper is set at < 1000 μg/L, for aesthetic reasons, due to the staining that it produces (BC Ministry of Health, 2001). Zinc is another metal of current (but of lesser) concern, as reflected by the aesthetic criteria of 5000 μg/L (BC Ministry of Health, 2001).

Synthetic Chemical Contaminants

With the host of commercial products available as cleaning solvents, protective coatings, fertilizers and biocides, it is not surprising that some ingredients are toxic to biota when they eventually enter the hydrological cycle, either directly through runoff, or indirectly through evaporation and deposition. In the context of this watershed study, the actual path of any contaminants is not easily determined because the samples, used as the basis for this report, were all taken from the lower reaches of the river and its tributaries.

Some substances are of concern, even at very low concentrations, especially to biota at specific stages in their development. The presence of persistent organic pollutants (POPs), such as organochlorines, or organophosphates is not expected; however, there is no readily accessible database to confirm this assumption. On the other hand, the presence of polycyclic aromatic hydrocarbons (PAHs) is suspected, due to the continued practice of wood burning and the widespread dependence on fossil fuels (Newman, 1998). Tests, to determine the presence and concentration of these substances, will be conducted in Shelly Creek, as part of another monitoring project (D. Epps, personal communication, December 3, 2003). Pharmaceuticals enter watersheds through wastewater and may be present due to runoff from septic fields, but larger quantities would be expected from waste water treatment facilities.

Turbidity

The presence of suspended particles of undissolved solids is measured as turbidity. This results in a lack of clarity, due to the scattering of light by particles > 0.45 μm. The sources of sediment in this watershed are described in the following section on land uses; however, the effects on water quality are noted here. Turbidity affects the ability of biota to access dissolved oxygen, critical to their survival. It also decreases the transmissivity of the water to sunlight and, thereby, leads to increased water temperatures, as well as, reducing the underwater visibility. Both factors are of particular importance to the survival of immature stages of anadromous fish species and have been the subject of a great deal of published research and conference presentations (Waters,1995; Newcombe,1996; McPhee & Novo, 2000). The fry and parr require dissolved oxygen and visible food sources in order to survive; however, both of these essentials are reduced in murky, warmer water. In addition, turbidity impacts treatment of water for micro-organisms by reducing the efficiency of chlorination and ultra-violet disinfection (BC Ministry of Health, 2001).

Land Use Interactions

The interactions between users and watersheds have been examined in detail throughout the world (Best, Bogacka, & Niemirycz, 1997; de Villiers, 2000; Lal, 2000) and the impacts are varied and far-reaching. As noted by Lal (2000), topography, soil types, and vegetation are major factors in how watercourses are affected by human endeavours. Of all the different types of anthropogenic activities, forestry, agriculture and urbanization are the predominant land uses in the area under consideration (Burke, 2002). These activities comprise the essence of human interaction with this watershed, therefore, the relationship of these activities to the quantity and quality of river water is the salient aspect of this research. Non-point source impacts are often subtle and inherently diffuse, requiring long time horizons to distinguish between natural variations and impact trends.

Forestry

The role of forestry in the hydrology of watersheds has been well documented with respect to both quantity and quality. In the initial period of several years following clear-cut logging, the water yield increases due to less evapotranspiration (Church & Eaton, 2001), although the direct linkage between peak stream-flows and equivalent clear-cut area (ECA) is still under discussion (Hudson, 2002). Nevertheless, the greater amount of water has an impact on water quality because logging and the associated road-building are major contributors to soil erosion, and, therefore, to sedimentation. This change to the hydrology affects physical aspects such as stream velocity and temperature and can produce detrimental impacts on the amounts of turbidity and dissolved oxygen. The contact time with the soil horizon influences the total dissolved solid content and the dissolved organic carbon levels.

As noted in the previous section, sediment can affect aquatic life (McPhee & Novo, 2000; Newcombe, 1996) as well as the effectiveness of water treatment processes (BC Ministry of Health, 2001). Although forestry practices in British Columbia are intended to mitigate these impacts, there have been recommendations for even more effective measures (Church & Eaton, 2001). An important symposium was held in Seattle in 1990 on New Perspectives for Watershed Management in the Pacific Northwest and a published collection of the contributions focused on global & national perspectives, integrated watershed management and innovative approaches to mitigation and restoration (Naiman, 1992). Other papers have been written on the effects of forestry on watersheds in this region, notably at the University of British Columbia (UBC) (Church & Eaton, 2001) and the Center for Streamside Studies at the University of Washington (U of W) (Mote, Parson, Hamlet, Keaton, Lettenmaier, Mantua et al., 2003). Of particular relevance, is recent work regarding forestry's effects in increased streamflows (Hudson, 2002), nutrients (Collins, Feller, Klinka, & de Montigny, 2001), and turbidity (McPhee & Novo, 2000). These reports indicate that the higher flows alter the amount and types of sediment in the watercourses, frequently destroying fish rearing habitat, as well as, reducing their food sources. Also, the higher temperatures, observed following logging can have a detrimental impact on the availability of food and habitat for all aquatic biota (Church & Eaton, 2001). This project examines some of the impacts that may be attributable to this significant utilization of a considerable portion of the watershed area.

Agriculture

Intensive agriculture is known to influence the quantity and quality of river water and is being subjected to intense scrutiny (Berka, Schreier, & Hall, 2001). Animal husbandry produces waste products, which may contain pharmaceuticals used for pest control or to enhance growth. Crop production may result in fertilizers, pesticides and herbicides being added to the runoff. Even the basic activity of tilling the soil will affect the hydrology and sediment of local creeks (Koteen, Alexander, & Loomis, 2002). The withdrawal of bulk water for irrigation is bound to have an impact on the quality and quantity of surface water in the sub-basin. Therefore, the licensed allocations are examined, in addition to the potential effects of nutrients (Chambers et al., 2001) and sedimentation (Waters, 1995). It is noted that farming in this watershed has taken place in areas that were once wetlands and, therefore, required draining rather than the clearing of first growth trees and stumps (P. Mullen, personal communication, November 27, 2003). This area is frequently under water during the winter and, therefore, the runoff from the fields produces noticeable effects downstream, ranging from increased turbidity to an increase in nutrients. Information on other parameters is reviewed; however, documentation on the use of pesticides and herbicides is not readily available for this particular area.

Urbanization

Daily living, in 21st century North America, entails activities that require large amounts of fresh water (Boyd, 2001), placing significant demands on water supplies. In 2001, more than 10,000 people depended on water from the Englishman River and the projected growth rate is 2.8% per year (Regional District of Nanaimo, 2003b), with a concomitant increase in water consumption. Then, there is the impact of domestic and industrial activities, which alter water quality. In both suburban and semi-rural neighbourhoods, run-off from septic systems, roadside ditches, and storm sewers has the potential to contaminate surface water with synthetic substances and coliforms (Wicks, 1998). The man-made contaminants from these sources may include hydrocarbons (including PAHs), pesticides, household cleaning products, and some heavy metals. In addition, the effluent from major urban populations is often a concern (even if it is treated), because it frequently re-enters surface water sources with altered water quality parameters and added substances, such as pharmaceuticals; however, this is not a major hazard in the current case, because the outflow from the nearest treatment plant is into Georgia Strait, not into the watershed area.

Goals

The Englishman River is a valuable resource with many beneficiaries. This project examines some of the conflicting requirements associated with the uses of this resource and, potentially, will assist decision-makers in addressing water issues for the benefit of all users. In this context, the goals of this research project are to:

- Summarize existing information on water quantity and quality and identify knowledge gaps;
- Examine correlations between several land-uses and existing water quality data at four sampling sites; and
- Promote an interdisciplinary framework in an effort to protect the long-term sustainability of the Englishman River watershed.

CHAPTER TWO
LOCAL FACTORS AND RESEARCH METHODOLOGY

Study Area

Geographic Factors

The Pacific Northwest region of North America is characterized by its mountainous terrain, coniferous forests and a moderate climate (Abell, 2000). Drainage basins are comparatively small and characterized by steep terrain and numerous tributaries. Many coastal river systems are short, energetic and tend to experience large fluctuations in water flows due to the fall-winter freshet and the relatively dry summers (Rosenau & Angelo, 2003). These large variations can have a significant effect on physical characteristics of the river's morphology as well as the river's water, notably temperature and turbidity. In comparison to many other watersheds in North America, water chemistry of small coastal river systems tends to be less influenced by subterranean geologic contributions. Exceptions can be due to mining activities, such as coal and copper (e.g. the Tsolum River, downstream from the copper mine at Mount Washington). Water chemistry in coastal streams is proportionately more influenced by surface and shallow sub-surface inputs. Consequently, both natural and anthropogenic sources of nutrient ions (such as nitrate, ammonium & phosphates), as well as, dissolved gases (O_2 & CO_2) and dissolved organic matter (C & N) can make a noticeable impact on water quality parameters.

Climatic Factors

On south-eastern Vancouver Island, watersheds are classified as either rain-driven or snow-and-rain-driven (Wade, Martin, & Whitfield, 2001). The Englishman River can be considered rain-driven because the snowmelt from Mount Arrowsmith is insufficient to cause an apparent summer freshet like many higher watersheds. The cycle of rainy winters, followed by relatively dry summer-fall seasons is well known and there is data available from the past century that confirms this phenomenum (Water Survey of Canada, 2002). On average, winter runoff accounts for 77% of the annual total in the Englishman, according to a recent climatological study (Wade et al., 2001). Reynolds, a recent Masters of Environment and Management graduate of Royal Roads University (RRU), conducted research on the predicted impact of climate change on five rivers in the Georgia Basin, including the Englishman River (Reynolds, 2002). He concluded that the Englishman river will experience more frequent major precipitation events, primarily in the form of rainfall rather than snow, during the winters, and that the dry season will be extended by several weeks.

Local Perspectives

The Englishman River is a small steep watercourse (a drop of ~1200 m in 40km) that exhibits rapid and dramatic increases in flow immediately following a major rainfall in the watershed. Its morphology has been significantly altered due major floods and the transport of sediment. For instance, about 100 years ago, the estuary was two kilometres to the East of its current location (T. Wicks, personal communication, June 24, 2003). The Mean Annual Discharges for 1915 & 1916 are comparable to those from recent years (Water Survey of Canada, 2002). Nevertheless, it must be noted that even within the range of what could be considered as historic variability, there have been years when the rate of flow has been very high, resulting in extended periods when the turbidity has been detrimental to water quality, for both fish and humans. Available measurements are insufficient to determine the frequency and duration of these high-turbidity events. On the other hand, the extent of the low flow periods for the past thirty years is well documented (Water Survey of Canada, 2002). Therefore, it is not unexpected that issues associated with low flows might be relatively straightforward, when compared to the multi-faceted issues of water quantity and quality, during the high flow periods.

Land Uses

Question on Land Uses

What are the dominant land-use activities in the watershed, as a whole, and in each of the three major sub-basins that are likely to influence water quantity/quality?

Overview

Over the past 100 years, logging provided the initial motivation for intensive human incursions, followed by agriculture and habitation. Burke (2002), a retired professional engineer who volunteered his time and effort on behalf of the Arrowsmith Watersheds Coalition Society, prepared a comprehensive and detailed report on the land uses in the local area. His report included the following summary: “The Englishman River watershed contained in Areas F and G (of the RDN) and a small segment of the City of Parksville is the second largest of the defined watersheds after the Little Qualicum River Watershed. …Its area as defined in this report is 8,313 hectares, predominantly Forest Lands (66%). Agriculture Lands comprise 12% of the total. Approximately one third of the Agriculture Lands are in large commercial farms, concentrated at the upper ends of Morison and Swane Creeks. Park and Residential Lands each account for 7%-8% of the total” (Burke, 2002, p. 3).

Sampling Sites and Land Use Interactions

Four water-sampling locations were selected by the BC Ministry of Water, Land and Air Protection (the ministry), in 2002, for a three year project to provide data upon which to develop provincial water quality objectives for the Englishman River (D. Epps, personal communication, October 2, 2002). This researcher participated in a couple of the sample collection events and has received electronic copies of the analysis conducted by the BC Provincial Laboratory. Samples were taken at the Old Island Highway Bridge in Parksville, Morison Creek (near the confluence with the Englishman River), the main stem of the Englishman River (near Morison Creek), and the South Englishman River (near the confluence with Centre Creek). The names assigned to the sites are **HWY**, **Morison**, **Eng R MS** and **South Fork**, respectively. These sampling sites are located such that the samples can be considered representative of selected areas of the watershed as delineated in Figure 1. This means that an observed parameter may be associated with a particular tributary and/or with the entire watershed, in the case of the **HWY** site. Furthermore, it was anticipated that it might be possible to correlate some water quality parameters with specific land uses, due to their presence at specific sites.

HWY Site – Combined Flows

The best-known sampling site is within Parksville city limits at the Old Island Highway Bridge, which is also the location of the water level gauge maintained by the Water Survey of Canada. This site is the furthest downstream and is, therefore, the recipient of waters from all of the river's tributaries. In addition to the three main contributors, there is also Shelley Creek that emanates from the sub-urban area of the eastern part of the city. While many stressors are present in run-off from urbanized areas, their contribution may be diminished, in this case, due to the relatively small size of the impacted watershed (i.e. 7% park & residential, 4% rural, & 3% urban). Nevertheless, parking areas, roadways, and buildings all contribute to the contamination of run-off. Furthermore, within this part of the watershed there are auto-wreckers, a cemetery, and a closed landfill site. Hydrocarbons associated with vehicle usage, fertilizers and pesticides used in gardening, as well as bacteria from septic fields and pet feces collect in sediments. Unfortunately, chemical species normally associated with vehicular traffic, such as Polycyclic Aromatic Hydrocarbons (PAHs) are not subject to analysis under the current sampling project. However, a more recent initiative is expected to analyse water from Shelley Creek for PAHs (D. Epps, personal communication, December 3, 2003). Therefore, at this time, the contributions of this land use may not be distinguishable from other non-point sources of contamination.

Morison Site – Agriculture & Rural-Residential Land Use

The Morison Creek watershed covers ~ 49 km^2 and accounts for 15% of the entire watershed (Boom & Bryden, 1994) including Swane Creek, where low intensity farms and rural-residential acreages predominate. Water licences for irrigation have been issued on both creeks, contributing to the total withdrawals from the river system. Some impacts of working and fertilizing the soil can be inferred from measurements taken at Morison Creek, near the confluence with the main stem. The readings for turbidity and nutrients at this site should be of interest, as both of these parameters have shown a relationship to agriculture in other regions of North America (Waters, 1995; Chambers et al., 2001). In the area under study, other factors, expected to affect water quality, are septic field break-outs and manure from livestock (not only from chickens, pigs and cattle, but also from dogs and horses on the numerous hobby farms). Contamination from these sources may be most noticeable after the first significant rain event in the fall, or after a major flood. Nevertheless, all of these factors are potential causes of increased coliform counts in the river.

Englishman River Main Stem Site – Forestry & Semi-Rural Land Use

The dominant land uses for the sub-basin represented by the **ER MS** site include forestry and a small amount of 'rural residential' area, due to the small acreages known as Englishman River Estates just downstream from Englishman River Falls Provincial Park. The upper reaches of the Englishman River are part of privately owned holdings of the major forestry company in the region, Weyerhauser. This area has been logged during the past century, but is not currently being harvested. Therefore, the primary land use of this major sub-basin, accounting for approximately half of the watershed area, is sylviculture.

South Fork Site - Forestry

This sub-basin, which drains the South Englishman River, is predominantly second growth forest and uninhabited. It comprises ~78 km^2 and accounts for 24% of the watershed area (Boom & Bryden, 1994). All of this area is owned Weyerhaeuser and TimberWest, a very small portion of which is being actively logged (estimated to be ~5%), as most of this forest is not yet ready for harvesting. Forestry's impact on streamflow, nutrients and turbidity have been documented in the regional context, however, specific effects on the Englishman River have not been measured. Initial increases in run-off due to reduced forest cover have been documented on the Sunshine Coast (Hudson, 2002), however, the actual change in the amount of water retained in this watershed cannot be easily determined. On the other hand, it is known that after clear-cutting, the increased temperature and moisture content of the forest floor lead to an increased rate of decomposition of organic matter (Hudson & Tolland, 2002). This can be expected to produce increased levels of dissolved organic carbon and nitrogen in the form of ammonia, nitrates, nitrites and organic-N. Furthermore, urea is applied as a fertilizer to enhance sylviculture at certain stages of growth (S. Higman, personal communication, December 9, 2002), therefore, depending on when and where it is applied, an increase in nitrogen-based nutrients might be anticipated in water samples from the South Englishman River (Chambers et al., 2001). The roads associated with logging are known to be important sources of sediment (Waters, 1995), however, the total impact of this activity on the total sediment load in this river is difficult to assess. Without a detailed assessment of the extent and effects of logging in this particular watershed, land use impacts due to forestry may only be described in general terms.

Figure 1 – Englishman River watershed and sub-basins (Bocking & Gaboury, 2001) (with permission of LGL Limited)

Sampling sites:
1. **HWY** – Old Island Highway Bridge in Parksville;
2. **Morison** – Morison Creek near the confluence with the river;
3. **ER MS** – Englishman River mainstem upstream from confluence with Morison Creek; and
4. **South Fork** – South Englishman River near the confluence with Centre Creek.

Three Basic Questions

Long Term Temporal Changes

An often-asked question regarding the quantity and quality of water in the Englishman River is: **Whether there have been any long term changes to the quality of the water over time?** Due to the sporadic and infrequent monitoring and the seasonal variation among parameters, this may be a difficult question to answer.

Correlations Between Concentrations and Flow

Question on Correlation

Given the usual seasonal variations in the quantity of water flow, it is instructive to ask: **Whether there are correlations between measured concentrations of substances and the amount of water flow?** This question has been answered through the analysis of two separate data sets. The first data set involves two five weekly sampling periods chosen during high and low flow seasons. The second data set involves monthly samplings throughout the year-long study period. Continuous flow data is available from the Water Survey of Canada website (Water Survey of Canada, 2002).

Low & High Flow Measurements

The Ministry undertook two sets of five weekly measurements during the August-September and October-November time frames in 2002, in order to determine whether there are correlations between concentrations and flow. These were the only periods during which analysis for metals was conducted. Analysis of bacterial parameters was also conducted during these samplings, in addition to the regular monthly samples. Therefore, a specific data set is available for these two periods, which includes metals, fecal coliforms and E. Coli. A series of box plots were created in order to display the relationship between the low and high flow and four parameters (copper, zinc, fecal coliforms, and E. Coli).

Regular Monthly Parameter and Flow Rate Measurements

The monthly water quality parameters and flow data were graphed in the same frame with different axes, in order to display potential relationships during the annual variation (July 2002 – June 2003). With the available software programs, it was not feasible to display parameter measurements for all four sites, plus water flow, in the same graph, therefore, individual parameters were graphed for each of the four sites, along with the monthly flow rate at the highway bridge. This flow was assumed to be proportional to that at each sampling site, due to the close proximity of the sub-basins within this relatively small watershed.

Spatial Differences

The question that originally triggered the author's interest in this research was **Given the geographic separation of the four sampling locations, are there discernable differences in the sets of water quality parameters, measured at each of the four sites?** Although the answer appeared to be intuitive, based on local knowledge of the tributaries, the concentrations of all substances were quite low and seasonal variations at individual sites were often larger than the discernable differences between sites. Therefore, an immediate answer to this question was not obvious. Annual and seasonal data were used to generate box plots for each parameter at each site were constructed and compared. Box plots illustrate the mean value, statistical spread and extrema for a given parameter at a given site. Finally, a statistical software application was used to perform multivariate analysis and generate cluster plots known as dendrograms.

Measured Parameters

Parameters of Quantity

With respect to quantity, the Water Survey of Canada has records of water levels, from the early part of the 20th century, as well as detailed data on water levels and discharge from 1971 onwards. One of the graphs produced from their website shows a comparison of the averages 1913-1917 and 1997-2001 (Water Survey of Canada, 2002) This indicates an overall change in the number and frequency of high flow events in the winter months and the lengthening of the low flow periods in summer and fall. The trend is borne out by Reynolds (2002), who forecasts similar, but accentuated, patterns for three 21-year time slices in the 21st century.

In 1994, the (then) Ministry of Environment, Lands and Parks prepared the Englishman River Allocation Plan (Boom & Bryden, 1994), a seminal document, which raised a question as to the adequacy of the watershed to meet the demand. The new crown corporation, Land and Water BC Inc. (2003) now maintains a website of all current water licences, but does not provide any overall findings regarding the supply and demand within the watershed. This project reviews the discharge data and provides some insight into the relationship between allocations and available supply, as well as the implications for sustainability.

Definitions of Water Quality

As previously mentioned, water quality has more aspects than just the impact on human health. Other parameters, such as temperature and dissolved oxygen are critical to the survival of fish. All of these parameters (and more) are mentioned in the provincial water quality guidelines, as well as the listing of criteria for six major uses: Drinking Water, Aquatic Life (freshwater and marine), Wildlife, Recreation and Aesthetics, Agriculture (Irrigation and Livestock Watering), and Industrial (e.g. Food Processing Industry) (BC Ministry of Water, Land and Air Protection, 1998). A comparison of the observed concentrations with the approved criteria is easily conducted. However, a more interesting question that has arisen during this project is whether standard water quality parameters can be useful as determinants of land-use impacts, or predictors of future changes in water quality.

Water Quality Parameters

Of twenty different parameters, analysed and forwarded by the Ministry of Water, Land, and Air Protection for each water sample, ten were selected as showing noticeable variation, worthy of closer scrutiny. One water quality parameter with particular implications for the overall health of a river is turbidity, which has been observed to peak shortly after periods of heavy precipitation. Other parameters of potential concern include nitrates and nitrites, based on extensive studies of nutrients in the environment (some focussing on the Canadian context) (Chambers et al., 2001). The various forms of phosphorus (including orthophosphate, TDP and TP) have the potential to alter the health of the river. Fecal Coliforms and Escherichia Coli (E.Coli) are examined due to their potential to affect human health. The metals, copper and zinc, mentioned in the previous chapter, were selected as these were the only metals from the data set with consistently detectable quantities (> 1 µg/L).

Description of Methodology

Temporal Analysis of Water Quality Parameters

The temporal analysis was conducted in two dimensions, comparing the quantitative value for the individual parameters on the basis of time of sampling. Long-term trends over the period 1986 – 2003, for several water quality parameters, were plotted as X-Y scatter plots for each of several measured parameters for the **HWY** site. This approach was also applied to the more complete data set for monthly samplings for the year's worth of data, July 2002 – June 2003, at all four sites. In both cases, ten separate water quality parameters were treated. For the 2002/03 monthly data set, each of eight parameters at the four sampling sites was plotted as a time series bar chart along with the monthly mean water flows generating a total of 32 graphs. To compare the seasonal variations among the four sampling sites, a series of X versus multiple Y scatter plots were generated (one for each of the eight water quality parameters).

Quantitative Analysis of Water Quality Parameters

Over the summer and fall, ten parameters were plotted as functions of time, to display each parameter at each of the four sites, for 12 monthly samples. This technique highlighted the seasonal variations over the course of one year, but only provided a linkage between the individual parameters and the sampling locations. Standard box plots were created using the graphing software, Kaliedograph®. Within each plot, the vertical dimension of the box represents 50% of the values with a horizontal line displaying the mean value. The whiskers or lines extending from the top and bottom of the box represent the maximum and minimum values, respectively. Outliers are displayed as individual points beyond the extrema. Traditional X-Y scatter plots are also used to display the annual variation of parameter values and water flow. This provides a sense of the relationships between variables and is summarized in a correlation table.

Multi-Dimensional Analysis

In May 2003, a preliminary attempt to determine whether there was any correlation between the data sets, from the four sampling locations, was conducted. The question asked was whether there was a difference in the water quality data from the various sites, based on five parameters measured in each of nine months. An initial effort involved a comparison of mean values of individual parameters and their associated standard deviations. This was unsuccessful in revealing any conclusive differences between the sites, possibly due to the relatively high seasonal variability in the parameters, which in some cases was greater than the variability between sites.

Subsequent attempts involved using several different multivariate analysis techniques with a statistical software application known as KyPlot®. The original water quality data sets were screened to remove samples, which were not analyzed for all parameters, and parameters, which were not analyzed for all samples. Measured values, which were reported below the analytical method detection limits, were arbitrarily set to one half of the method detection. The remaining data set was then normalized (z-scored) using standard routines within Excel and exported to a KyPlot® spreadsheet. Principal component and hierarchical cluster analysis were preformed and showed similar trends although only the results of the cluster analysis are presented here. Hierarchical cluster analyses were preformed by Ward’s method of incremental sum of squares using standardized Euclidean distance measures.

In January 2004, readily discernable patterns in selected parameters from the tributaries during specific seasons were observed by using multivariate analysis. The technique was validated, by creating a cluster plot from 17 samples from a single site using 10 water quality variables. It succeeded in reducing a large amount of information to a more readily discernable pattern of relationships.

The resulting cluster plots or dendrograms display the degree of 'relatedness' among a set of selected objects (in this case, water samples) in terms of a set of selected variables (in this case, water quality parameters). The composition of the object 'families' together with the distance measured along the Y-axis provide a two dimensional representation of the differences among objects in a multi-dimensional data set by comparing the magnitudes of all parameters from all sample site locations over the time span of the samplings, simultaneously.

Limitations of the Methodology

Selection of Parameters

The analysed water quality parameters are those selected by sections within the Ministry of Water, Land and Air Protection, which may or may not include all of the physical and chemical indicators of potential concern. Based on a standard list of thirty to forty water quality parameters, that can be analyzed by the provincial laboratory, a group of twenty physical, chemical and bacterial parameters were chosen (see Table III below), due either to their potential impact on human health or to the fact that the levels observed in previous grab samples had detectable concentrations. Other agencies collect data for their own specific needs, such as temperature and dissolved oxygen for fisheries; however, it is not obvious that this information is shared among databases. It should also be noted that specific analytes that might prove more indicative of a particular land-use impact (such as individual xenobiotic compounds) were not included in this monitoring project, presumably due to the prohibitive expense of analysis.

Physical Parameter	**Chemical Parameter**	**Metal**	**Bacterial Parameter**
pH (pH units)	Nitrite+Nitrate (mg/L)	Arsenic (µg/L)	Fecal Coliforms (Col./100ml)
Specific Conductance (µS/cm)	Nitrite (mg/L)	Cadmium (µg/L)	E. Coli (Col./100ml)
Total Suspended Solids (mg/L)	Ammonia (mg/L)	Chromium (µg/L)	
Turbidity (NTU)	Dissolved Organic Carbon (mg/L)	Copper (µg/L)	
	Ortho-Phosphate (mg/L)	Lead (µg/L)	
	Total Dissolved Phosphorus (mg/L)	Nickel (µg/L)	
	Total Phosphorus (mg/L)	Zinc (µg/L)	

Table III – Twenty Selected Water Quality Parameters from WLAP (D. Epps, personal communication, October 2, 2002).

Time slice and duration

The primary limitation is the short duration of the study. Given that only 12 months of data was available, this analysis should be considered preliminary and followed up after the full three-year data set is completed. Nevertheless, when dealing with any time series involving annual variations, longer time frames, often on the order of decades, are required to identify trends resulting from diffuse land use impacts. . The data from a dozen sporadic grab-samples from the Englishman river at the Highway are available for some dates between March 1986 and May 2002, but are incomplete data sets. A visual inspection of the data suggests few (if any) significant trends are discernable. Seasonal fluctuations alone can account for the variation observed among these grab-samples.

Frequency of Sampling

Another important aspect of data collection, that affects the accuracy of the findings of this report, is the frequency of sampling. Monthly intervals may reflect a general pattern of variability throughout the year, but gaps can occur due to the absence of data during major precipitation events. After a heavy rainfall, the effects of a particular plume of runoff, and the subsequent dilution of potential contaminants are not likely to be captured by monthly sampling. Cost is always a factor in establishing sampling regimes; however, the value of more frequent or on-line water sample data, which can provide a more complete and accurate representation of river water quality, should also be considered.

CHAPTER THREE
STUDY FINDINGS

Analysis of Water Quantity

Water Flow Data

Discharge Volumes

As reported by the Mount Arrowsmith Biosphere Reserve: “Discharge volumes are relatively low in comparison to major mainland rivers (e.g., Fraser and Squamish Rivers) draining into the eastern side of Georgia Strait. With the Englishman, average annual flow is only 14 m^3/s, with maximum and minimum average monthly flows of 30 m^3/s in December and 1 m^3/s in August, respectively (Inland Waters Directorate 1991). Water flow is greatly affected by recent rainfalls and is subject to rapid fluctuation over short time periods. Within 10-15 h following a major rainfall, discharge volume of the Englishman can increase to a peak flow for typically 4-12 h, and then return to a normal seasonal level within a few days. The recorded maximum instantaneous discharge is 460 m^3/s and the average total annual discharge is 439,000 dam^3” (Mount Arrowsmith Biosphere Reserve, 2001b, ¶ 2). The average monthly flows (along with the standard deviation) for the ten year period, 1993-2002, are shown in Table IV, followed by the monthly average flow for the specific period of this study. From the data in this table, as well as the full data set in Appendix B, the water flow can nominally be divided into two five month periods; a low flow (dry season - June through October) and a high flow (wet season – December through April). The shoulder months of May (10.9 ± 4. 8 m^3/s) and November (23.1 ± 13.3 m^3/s) were not labeled as either wet or dry, due to the variability during these months as shown by the large relative standard deviation.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993-2003 Mean Monthly Flow (m^3/s)	27.4	21.4	19.2	13.1	10.9	6.8	2.9	1.6	1.5	6.9	23.1	27.7
Std Dev	(12.0)	(10.)	(8.8)	(4.3)	(4.8)	(4.5)	(3.0)	(1.3)	(1.6)	(8.1)	(13.)	(10)
2002	-	-	-	-	-	-	2.14	1.72	1.58	1.1	22.4	26.8
2003	42.0	7.72	36.5	18.6	5.98	3.82	-	-	-	-	-	-

Table IV – Englishman River Mean Monthly Flow 1993-2002.
Flow in m^3/s. All values based on levels at the Highway near Parksville (Water Survey of Canada, 2002).

Summer Flows and Storage

The quantity of water flow during the summer season is an ongoing issue from both the municipal water supply and the fisheries perspectives. A decade ago, the Englishman River Water Allocation Plan (Boom & Bryden, 1994) acknowledged the possibility that the amount of water allocated for domestic purposes might adversely affect local fish enhancement efforts. The authors recognized that there was “not sufficient storage developed or proposed to maintain and support the existing and projected water demands through the low flow period” (Boom & Bryden, 1994, p. 19). Over the past decade, the Regional

District of Nanaimo undertook the construction of the Arrowsmith Dam, completed in 2000, which was intended to address this issue by providing additional water storage for municipal and fisheries use (Regional District of Nanaimo, 2001b). An algorithm was developed to regulate the release of water to mitigate summertime shortages. However, it would appear that the demand for humans and fisheries has exceeded the available quantities (using the current discharge algorithm) during each of the past three summers, since the additional quantity stored above the dam was not available the first year and had been released before the end of the dry season in 2002 and 2003.

Allocations

Annual Total Allocations

An examination of the total maximum daily allocations, from this watershed authorized by BC's water authority (Land and Water BC Inc., 2003) indicates that *270,000* m^3/d, which is approximately *22%* of the Average Annual Flow of *~1,210,000* m^3/d is currently allocated. Of that total, it appears that *20%* is allocated for storage by the Arrowsmith Water Service (AWS), which is a collaborative effort of the Regional District of Nanaimo, the City of Parksville, and the Town of Qualicum Beach. This is the authorized amount stored behind the Arrowsmith Dam. Remarkably, less than *2% (~22,000* m^3/d*)* is authorized for direct daily human withdrawal and consumption; whereas, less than *4% (~52,000* m^3/d*)* is designated for fisheries purposes (see Appendix A).

The average annual flow does not reflect the real effects of the paucity of water during the summer 'low flow' period. In the summers, when flow has been observed to drop below 1 m^3/s *(~86,400 m^3/d)*, there may not be enough for either fish or humans. Furthermore, the morphology of the Englishman River has changed greatly over the past century, due, in part, to sedimentation (Weston, 2003). This means that, in many places, the river has become wider and shallower, thereby reducing the available habitat for juvenile salmonids.

Impact of Total Withdrawals

An important factor is the total amount of the withdrawals, which negatively impacts the fish-rearing potential of the river and its tributaries. This is supported by the conclusions of the most recent report of the Pacific Fisheries Resource Conservation Council (PFRCC), which also recommends: 1) a specific regime for the release of the stored water from the Arrowsmith Dam. 2) The initiation of a compliance-assessment of existing water licenses. 3) Facilitating a hydrological-budgeting exercise for the watershed. 4) Restricting the issuance of further water licenses unless supported by off-channel storage. 5) The investigation of new or innovative options to provide more water in tributary streams, including the storage of more water for release during dry periods (Rosenau & Angelo, 2003). The amount of summertime flow recommended by the PFRCC is 2.76 m^3/s, which is over seven times the amount suggested by an independent hydrologist (0.375 m^3/s) as being sustainable from the existing storage capacity (Nuttall, 1998).

Adequacy of Stored Capacity

Furthermore, the report by the Pacific Fisheries Resource Conservation Council recommends several actions to increase the summer-fall flows in the tributaries and the main stem to enhance the recovery of steelhead and salmon stocks (Rosenau & Angelo, 2003). However, the recurrence of warm, dry summers, over the past decade, has cast doubt as to the adequacy of the actual stored capacity, as mentioned above. Therefore, it would appear that there is currently insufficient capacity in the Arrowsmith Dam to meet the present needs of both the human and the fish populations during the low flow period, especially during August and September (see Appendix B). In the broader context, there is no report suggesting just how much water should be made available to maintain a healthy ecosystem in this watershed; nevertheless, enough to ensure adequate year-round flow for fish might be a start.

Mean Monthly Flows

In keeping with the comments on the difference between summer and winter flows, it is instructive to note that, based on the collected data (Water Survey of Canada, 2002), the mean monthly discharge of the Englishman River in August – September is approximately 10% of the MAD; whereas, in November – February it is typically from 150% to 200 % of the MAD. This could conceivably produce variations in the total amounts of measured substances of roughly one order of magnitude because, although the concentrations may not vary appreciably, the total amount of water in the river at the time of sampling may have changed significantly. This would be particularly significant in any attempts to estimate the mass transport of suspended solids and/or export of nutrients.

Temporal Analysis of Water Quality Parameters

Long-Term Temporal Changes

The collection of “grab samples” from the Englishman River at the Old Island Highway (**HWY**) was conducted on a sporadic basis by the provincial government. About a dozen samples were collected over the period from 1986 to the beginning of the current sampling program in July 2002. Although the available data is very intermittent, there appears to be a gradual increase in both the pH and the specific conductance over this 16-year period. Since these samples were collected at various times during the year, the data displayed in Figures 2 and 3 have been divided into high and low flow periods. There was no specified time of year for these samples; however, eight of the first eleven sets were taken during the wet months of November through March. Based on an examination of the seven remaining water quality parameters analyzed over this time frame, it is difficult to identify any significant trends. As noted, the comprehensive sampling regime was initiated in 2002, which explains the more numerous data points over the past two years. This will establish the inter-seasonal variation and may lead to a more conclusive detection of trends in the future.

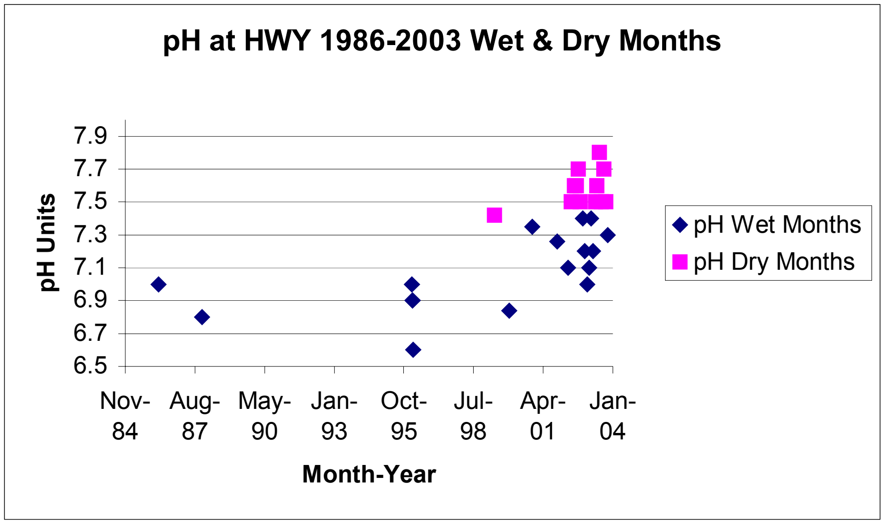

Figure 2 – Long-term observation of pH at the Highway site, 1986 – 2003.

Power + Hydrogen (pH)

It can be observed in Figure 2 that the pH tends to be higher during the low flow period. The average of 12 dry season measurements (1998-2003) is 7.6 as compared to 7.1, for the wet season measurements, over the same time frame. The average of five pH measurements (wet season, 1986-1996) was 6.9, which is somewhat lower than measurements obtained in the past five years. Although there is no cause for concern of the pH values themselves, long-term trends are often associated with land use changes.

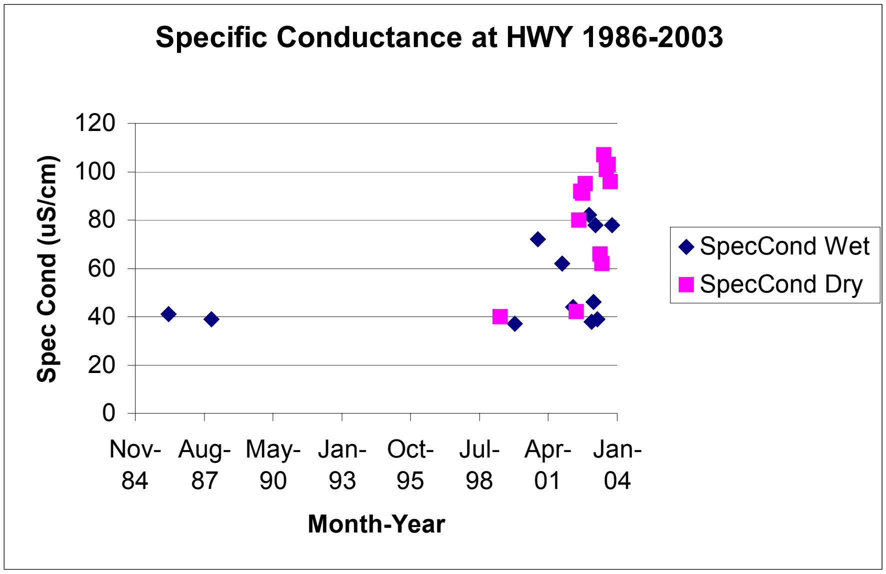

Figure 3 – Long-term observation of Specific Conductance at the Highway site, 1986 - 2003.

Specific Conductance

Over the same period, there appears to have been a noticeable change in the specific conductance. Although there is very little pre-1998 data, the mean value for the ten "Wet Months" during 1998-2003 is 55 µS/cm, which is an increase over the data obtained in the mid-1980s. Furthermore, the average of the twelve "Dry Months" during 1998-2003 is 81 µS/cm, which is considerably higher than many of the earlier measurements. Again, the data is inconclusive, but warrants continued monitoring as it too may be associated with land use changes.

Annual Temporal Variations – Seasonality

The seasonal variations, for each of seven water quality parameters (pH, specific conductance, turbidity, DOC, nitrite/nitrate, orthophosphate and TDP), are clearly observed in the bar graphs in Appendix C, which also depict the mean monthly water flows. Metal concentrations and bacteriological counts were measured in two five-week sampling periods to coincide with low and high water flows. The seasonal variations for these parameters are depicted in the box plots showed in Figures 4 and 5. As there is a great deal of information to be derived from all of the data, it became apparent that the cluster analysis feature of the multivariate analysis tool is one way of simplifying the portrayal of the interrelationships. This technique provides further insight into the seasonality of the measurements, as demonstrated in the test case discussed in Section B.4. and shown at Figure 10. A discussion of these observations follows:

Selected Parameters

As previously indicated, twenty different water quality parameters are available from the data set of the monthly water samples, for each of the four sites. There are a total of twelve samples for most substances, except the metals, which were analysed weekly in two five-week blocks. These two blocks were expected to cover the low and high flow periods (primarily for fisheries officials). The data are presented in Box Plots and in the Summary Tables, in the following sections. A preliminary visual review confirmed that all measurements (with one exception, i.e. a single fecal coliform reading) were well within the criteria established by the BC Approved Water Quality Guidelines (BC Ministry of Water, Land and Air Protection, 1998). Then, the ten substances that appeared to have noticeable concentrations were graphed to highlight those measurements.

Physical Parameters

The mean annual data set, for three physical parameters (pH, specific conductance and turbidity), is summarized in Table V. The pH measurements were all between 6.8 and 8.0 pH units, with annual average readings of 7.4 or 7.5 pH units for all four locations. There was a slight dip in the readings, for January and February (to approx 7 pH units). This phenomenon is not fully understood, although it is suspected that the dilution by rainwater may be a factor. The specific conductance measurements are lower in January and February than most other times of the year, regardless of location. On the other hand, turbidity did not appear to be equally dependent on season at all four sites. It was most evident in the measurements from **Morison** for December 2002 through June 2003. Although the readings did not exceed the BC Approved Criteria of 5 Nephelometric Turbidity Units (NTUs), it was between 2 and 3 on four separate occasions in this tributary. This phenomenon was also observed, to a lesser degree, at **HWY** but was not present in the samples from **ER MS** or **South Fork**. These consistently higher readings raise the question as to the possible causes, which, based on predominant land uses, might be either agriculture and/or semi-rural residential development.

Site		**pH**	**Specific Conductance**	**Turbidity**
			(uS/cm)	(NTU)
Hwy	mean (s.d.)	**7.4** (0.2)	**75** (27)	**0.49** (0.25)
	range	7.0 - 7.7	38 - 131	0.25 - 1.14
Morison	mean (s.d.)	**7.5** (0.3)	**71** (25)	**1.54** (1.23)
	range	6.9 - 7.9	32 - 108	0.28 - 3.70
ER MS	mean (s.d.)	**7.4** (0.2)	**72** (25)	**0.31** (0.22)
	range	7.1 - 7.6	40 - 124	0.13 - 0.91
South Fork	mean (s.d.)	**7.5** (0.4)	**133** (95)	**0.39** (0.43)
	range	6.9 - 8.0	37 - 304	0.13 - 1.57

Table V – Summary of the annual average physical parameters,
for 12 monthly samples in 2002-2003, taken at the four sites.

Chemical Parameters

Two chemical indicators showed noticeably higher levels for the period January – June 2003. These were nitrate+nitrite and dissolved organic carbon (summarized in Table VI). The graphs for these three parameters display marked temporal variation, showing higher values for the high flow period. The one exception is **South Fork,** where nitrates+nitrites were well below the levels at the other sampling locations, during the winter and spring.

Site		NO2+NO3 (mg/L N)	DOC (mg/L C)	SRP (mg/L P)	TDP (mg/L P)	TP (mg/L P)
Hwy	mean (s.d.)	**0.046** (0.048)	**2.2** (0.9)	**0.002** (0.001)	**0.005** (0.003)	**0.004** (0.002)
	range	0.005 - 0.153	0.7 - 3.7	0.001 - 0.004	0.003 - 0.010	0.002 - 0.008
E MS	mean (s.d.)	**0.054** (0.063)	**1.5** (0.7)	**0.002** (0.001)	**0.004** (0.002)	**0.006** (0.009)
	range	0.002 - 0.197	0.3 - 2.8	0.001 - 0.004	0.002 - 0.007	0.002 - 0.024
Morison	mean (s.d.)	**0.101** (0.065)	**5.2** (2.1)	**0.006** (0.003)	**0.012** (0.004)	**0.016** (0.005)
	range	0.004 - 0.198	2.0 - 7.7	0.001 - 0.010	0.005 - 0.019	0.007 - 0.025
So. Fork	mean (s.d.)	**0.038** (0.044)	**2.4** (1.2)	**0.003** (0.001)	**0.004** (0.002)	**0.004** (0.001)
	range	0.006 - 0.129	1.1 - 4.1	0.001 - 0.005	0.002 - 0.007	0.002 - 0.006

Table VI – Summary of the annual average chemical parameters,
for 12 monthly samples in 2002-2003, taken at the four sites.

Metals During Low and High Flow Periods

A special sampling regime was established for metals (and bacteriological parameters) during two five-week periods, which were selected by the ministry to represent the low and high flow periods. A comparison between these two sampling periods are best shown in the box plots, see Figures 4 and 5 for Copper and Zinc, respectively). All values are well below the BC Approved Water Quality Guidelines Criteria; nevertheless, the seasonal variation at all sites is noteworthy. In general, the metal concentrations appear to be somewhat higher in the high flow (wet season) as compared to the low flow (dry) season.

Furthermore, the metal concentrations are more highly variable during periods of high flow as compared to low flow. For copper, there is greater variability during the wet period, at all sites. **Morison** appears to have the highest concentration of copper, whereas **Eng R MS** appears to have the highest concentration of zinc. The seasonal variability for zinc is much greater during high flow and is also more noticeable at **Eng R MS**, compared to the other sites. Therefore, these two metals (Cu & Zn) may be useful variables to discriminate between locations, in the multivariate analysis.

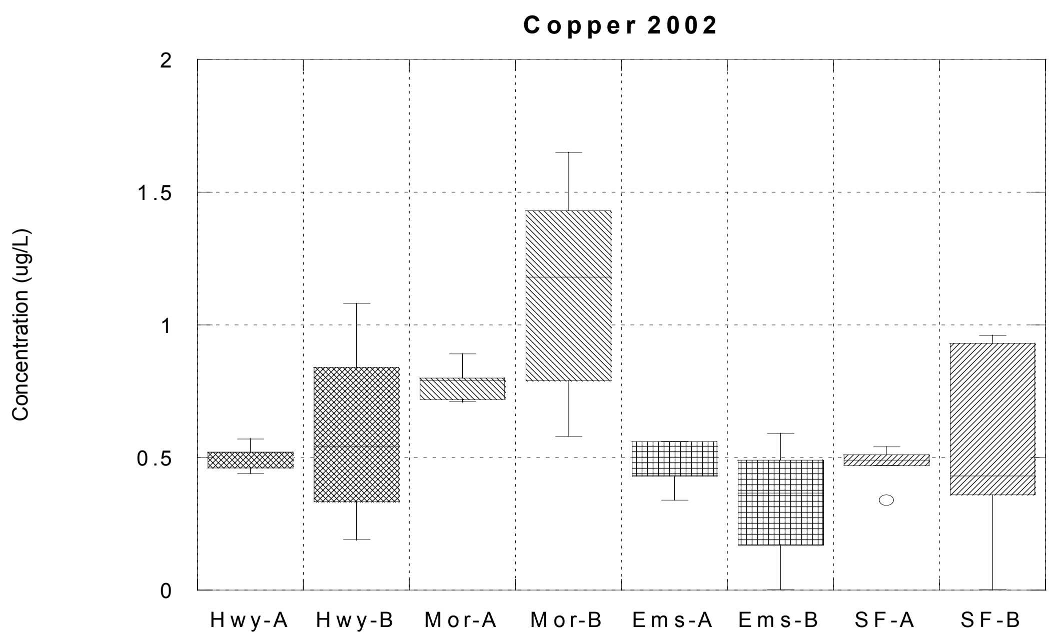

Figure 4 - Box plots of Copper concentrations
at four sampling sites during:
A- Aug-Sep02 (5 samples) – low water flow: 1.72 m^3/s; and
B- Oct-Nov02 (5 samples) – high water flow: 22.4 m^3/s.

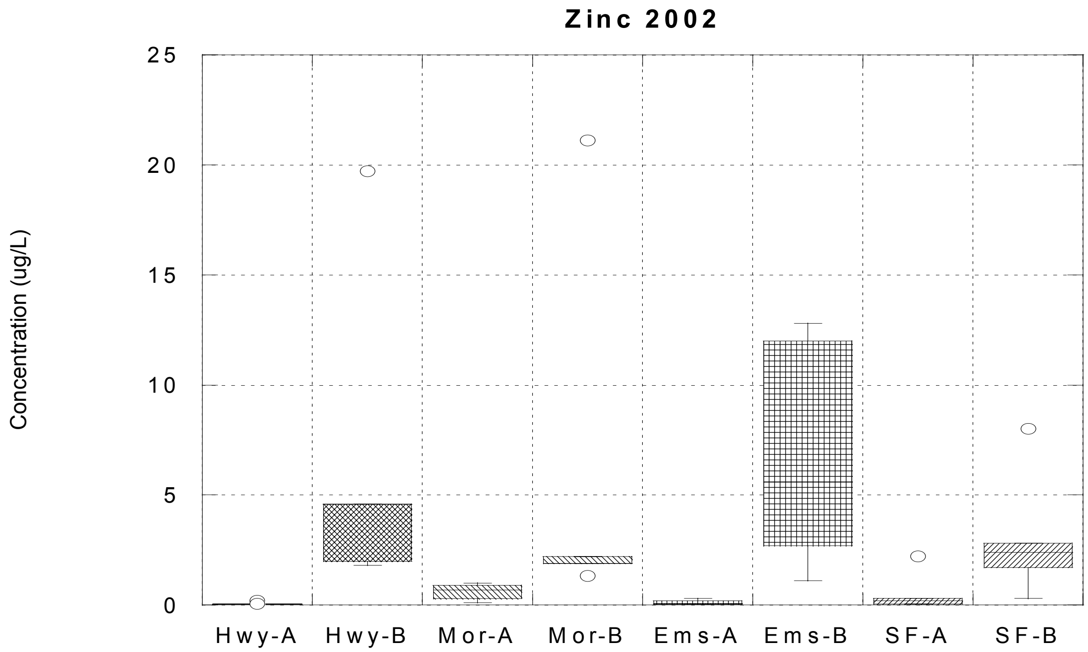

Figure 5 - Box plots of Zinc concentrations
at four sampling sites during:
A- Aug-Sep02 (5 samples) – low water flow: 1.72 m^3/s; and
B- Oct-Nov02 (5 samples) – high water flow: 22.4 m^3/s.

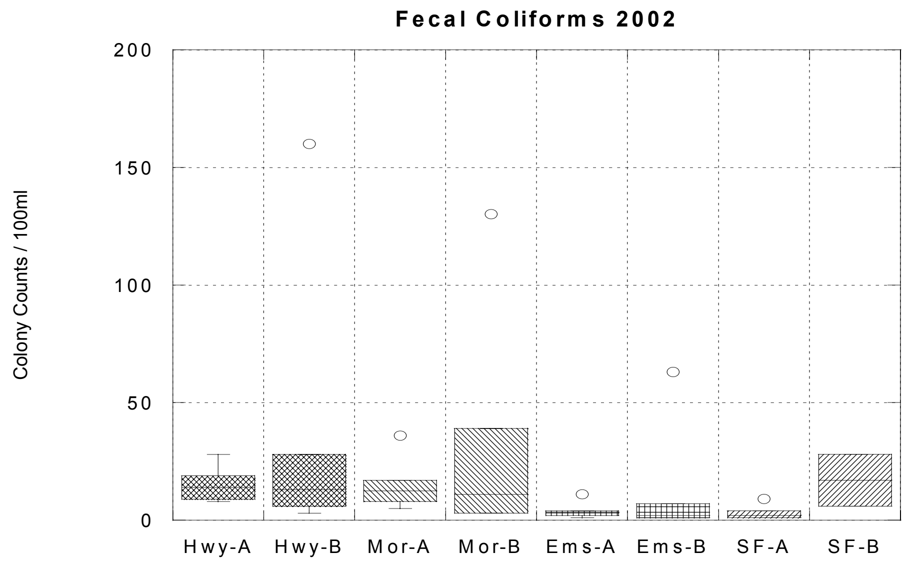

Figure 6- Box plots of colony counts of Fecal Coliforms

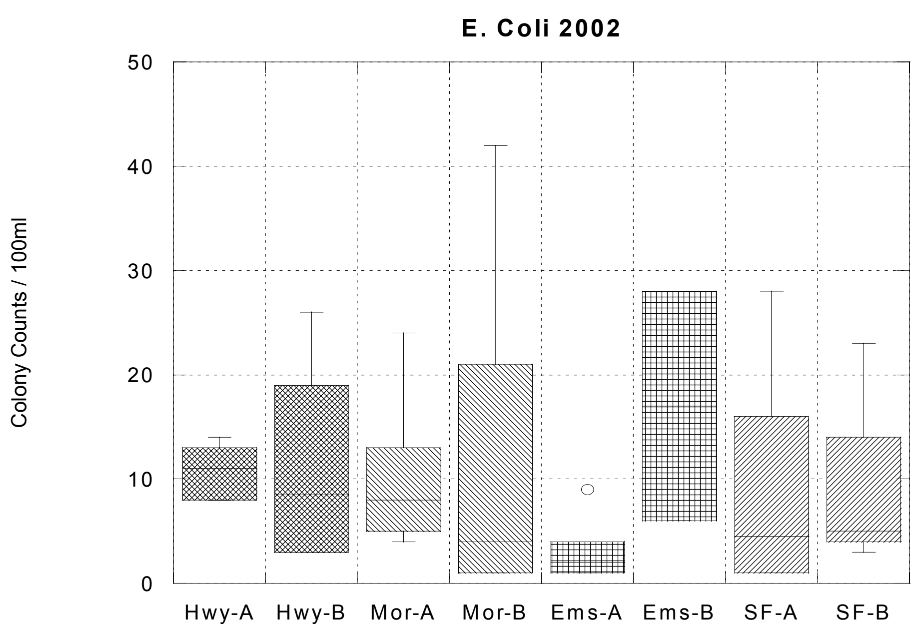

Figure 7- Box plots of colony counts of E. Coli

A. Aug-Sep02 (6 samples) – low water flow: 1.72 m^3/s.; and

B. Oct-Nov02 (6 samples) – high water flow: 22.4 m^3/s.

Bacterial Parameters

The highest bacterial counts and the greatest variability in these counts are generally observed during high flow periods as seen in Figures 6 and 7. As previously mentioned, Total and Fecal Coliforms have been commonly used as indicators of potential risk of waterborne diseases (BC Ministry of Health, 2001). In this case study, the measurements of Fecal Coliforms and Esherichia Coli (E. Coli) were very high in several monthly samples. The highest reading of Fecal Coliforms (160 Col. / 100 ml) was taken in October 2002 at **HWY**, when salmon carcasses were observed in the river, which is a naturally recurring event. The highest E. Coli reading was 87 Col. / 100 ml on May 12, 2003 at **Morison**, during a month in which there was below average flow. The presence of either of these bacteria exceeds the criteria for Raw Drinking Water without treatment. Even with disinfection, according to the drinking water guidelines, there is a limitation on the number of readings, above 10 Col. / 100 ml, that are considered acceptable within a 30 day period (90^{th} percentile)(BC Ministry of Health, 2001). These findings are shown in Figures 6 & 7 and are summarized in Table VII, below.

Site		Fecal Coliforms (col/100ml)	Escherichia Coli (col/100 ml)
Hwy	mean (s.d.)	**11** (12)	**10** (13)
	Range	1.0 - 40	1.0 - 40
E MS	mean (s.d.)	**2** (3)	**2** (3)
	Range	1.0 - 11	1.0 - 9
Morison	mean (s.d.)	**17** (24)	**16** (28)
	Range	1.0 - 75	1.0 -87
So. Fork	mean (s.d.)	**11** (17)	**5** (9)
	Range	1.0 - 42	1.0 - 28

Table VII – Summary of the annual average bacteriological parameters, for 12 monthly samples in 2002-2003, taken at the four sites.

Temporal Variation of Parameters Among Sites

A straightforward way of displaying data from several sites is in the form of X-multiple Y scatter plots. The quantity of particular parameter at each site is plotted along the Y-axis and the date of the samples is plotted along the X-axis. This was done, separately, for seven parameters that showed noticeable variations. Two graphs that warrant comment are for turbidity (Figure 8) and dissolved organic carbon (Figure 9). Similar plots for the remaining parameters are included in Appendix F.

Turbidity at Four Sites Over One Year

The general trend at two of the four sites is an increase in turbidity readings during the wetter months of December through April, which is not unexpected since sediment is transported by erosion following precipitation events. The samples for **Morison** show an increase, up to four times higher than **Eng R MS** and **South Fork**, which are less heavily impacted by land uses. The lesser increase at **HWY** may simply reflect the contribution of the sediment emanating from **Morison**. This is shown at Figure 8, below.

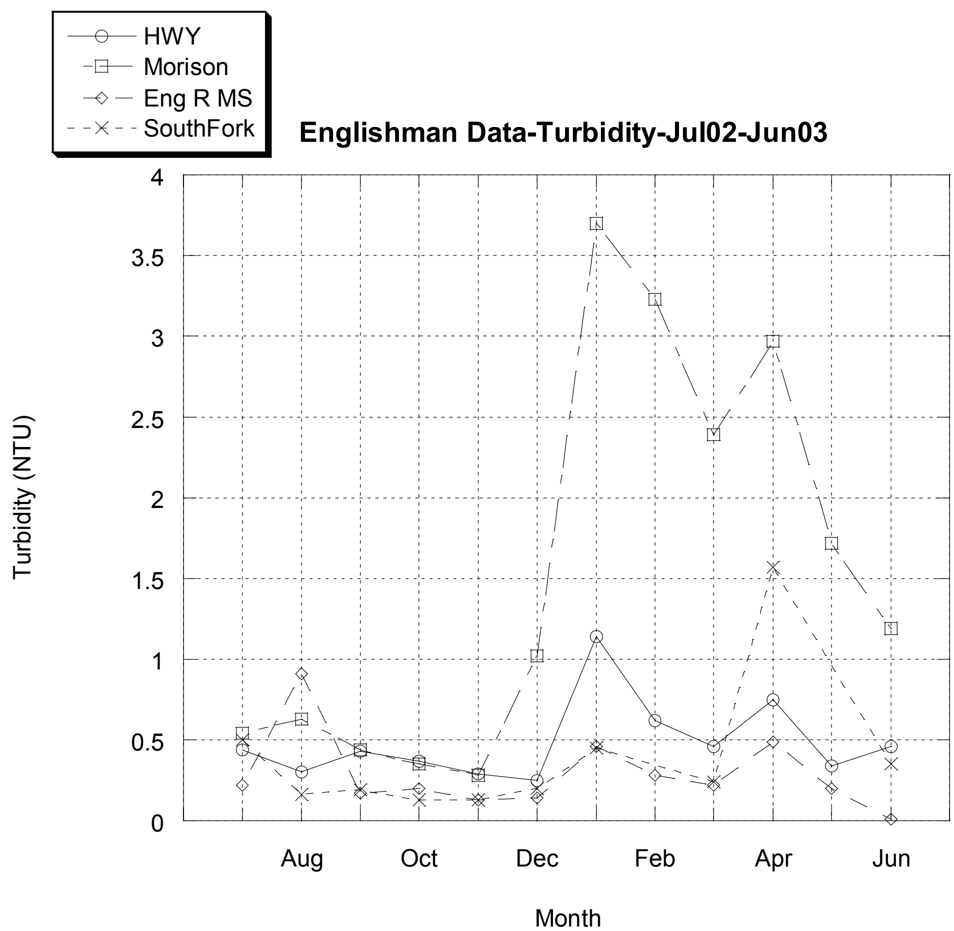

Figure 8 – Turbidity at four sites for one year.

Dissolved Organic Carbon (DOC) at Four Sites Over Eleven Months

The measurements for DOC also show an increase during the wetter months (see Figure 9 below), similar to the variation in turbidity (above) and nitrate+nitrite (Appendix F2). This phenomenon will be discussed in greater detail in the section on spatial variations.

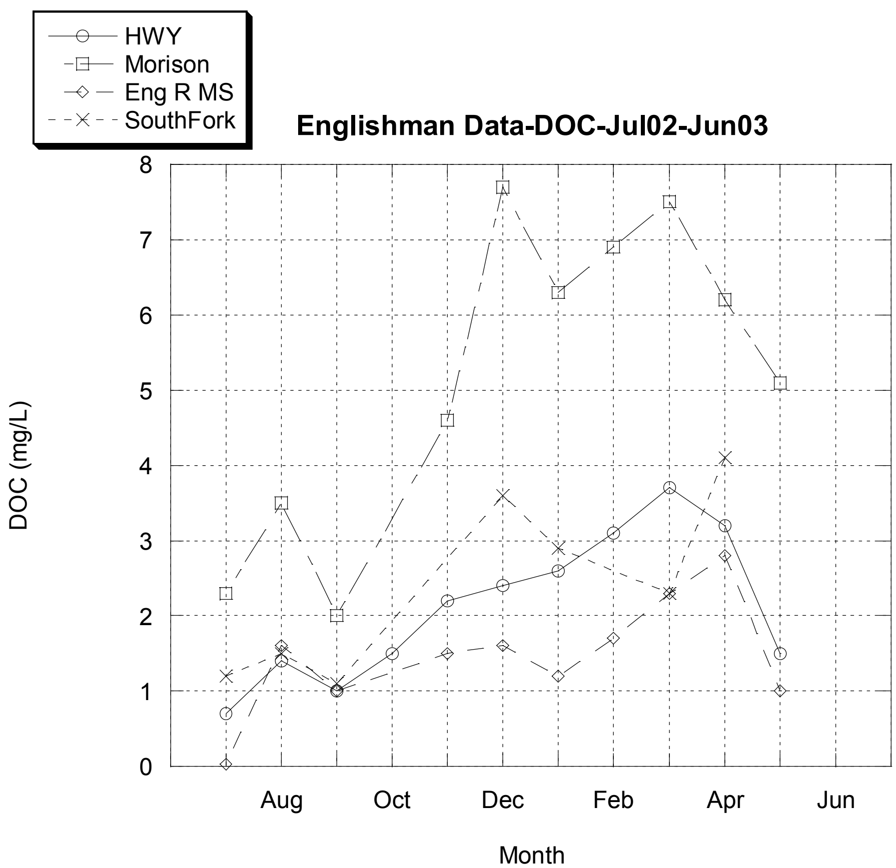

Figure 9 – Dissolved Organic Carbon at four sites over eleven months.

Multivariate Cluster Analysis – Test Case

Cluster analysis is used to reduce large multi-dimensional data sets into more readily discernable patterns in two-dimensional representations. The dendrogram (Figure 10, below) is presented as a test case to establish the validity of this technique. It was generated by treating 17 Englishman River (ER) **HWY** samples (collected Jul 02 – Nov 03) as objects to be grouped together using the degree of dissimilarity among eight water quality (WQ) variables simultaneously. The samples cluster into two distinct groupings, which are well separated in terms of the distance measure indicated on the Y-axis. A tight grouping of samples collected during wet months are clustered together on the right side of the diagram, whereas samples collected during dry months are clustered on the left. It is important to note that flow data was not used in this analysis. The significance of this result is that it displays the degree of 'relatedness' among samples, based solely on the relative magnitude of water quality parameters. It clearly shows a correlation between the relationship among water quality parameters and the date the sample was collected, without expressly incorporating the water flow. In other words, the relative magnitudes of several water quality parameters can be used to discriminate between high and low flow periods (i.e., the seasonality).

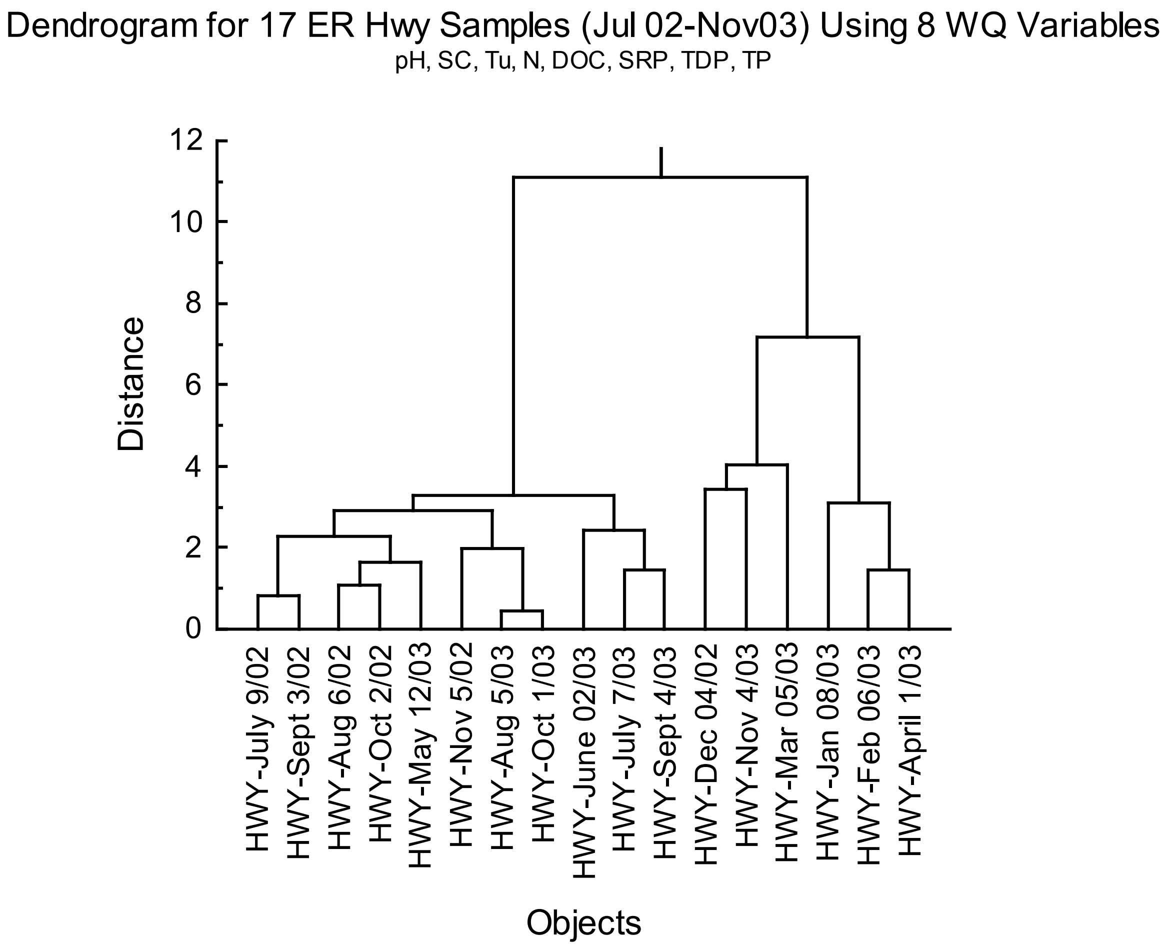

Figure 10 – Dendrogram - test case

Spatial Variation of Water Quality Data

Distinct Character of Tributaries

One way of illustrating spatial differences between the tributaries is to display the annual means and statistical spreads for each parameter as a series of box plots. Figures 11 and 12 display the box plots for DOC and TDP, which clearly show the distinctness of Morison Creek. Also at **Morison**, the measurements of orthophosphate (Appendix F2) and total dissolved phosphorus were consistently higher than at the other three sites, throughout the entire year. The average concentrations were 6 and 12 μg P/ L, which were two to three times higher than at the other three sites. Nevertheless, none of the levels exceeded the BC Approved Water Quality Guidelines and were not in excess of the expected values for similar streams in the Pacific Northwest (Naiman, 1992).

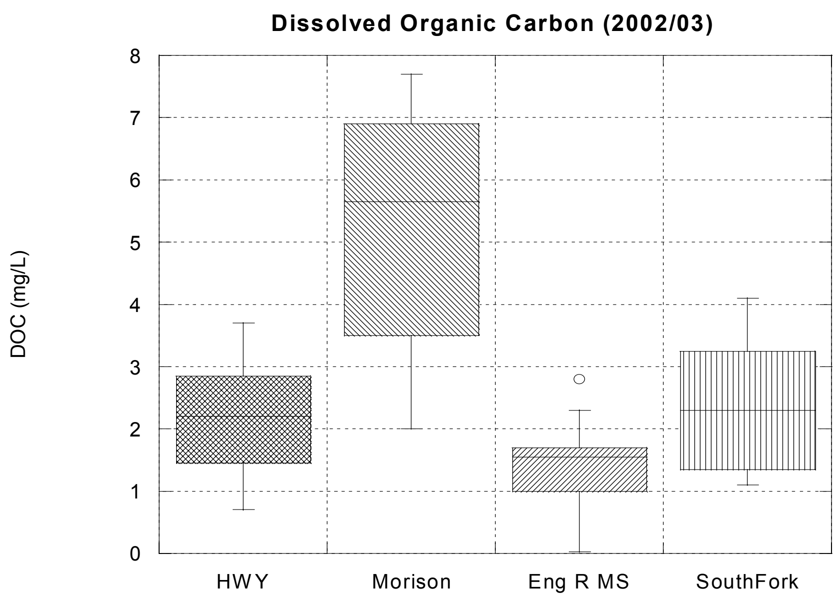

Figure 11 – Dissolved Organic Carbon at four sites (12 monthly samples)

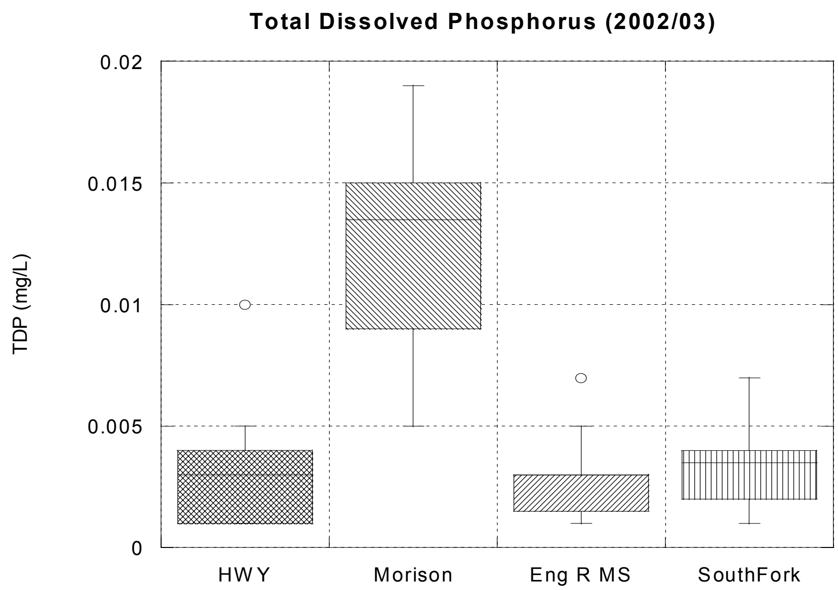

Figure 12 –Total Dissolved Phosphorus at four sites (12 monthly samples)

Correlation Between Parameters and Water Flow

Due to the difficulty in displaying more than four variables on a single graph, a series of graphs were created in which one of seven parameters [pH, specific conductance, turbidity, nitrate + nitrite (NO_2 +NO_3), dissolved organic carbon (DOC), orthophosphate, and total dissolved phosphorus (TDP)], as well as water flow were graphed versus time, for each of the four sites. The assumption was made that the flow at each of the sites is directly proportional to the flow measured at the Old Island Highway (**HWY**) as was done by Boom & Bryden (1994). This is considered reasonable due to the geographical proximity of the four sites (all are within 5 km of each other and are likely to receive similar precipitation) and the fact that no other major tributaries enter the river system within this area.

The correlation table, Table VII below, summarizes the correlations between the concentration of a given parameter and water flow. The seven sets of graphs, from which the table was derived, are shown in Appendix C. Table VII clearly shows the inverse correlation between pH and flow rate (correlations ≥ **I - 0.70 I**), whereas, the nutrients are more or less directly correlated to the flow rate, depending on location.

Sample Site	**HWY**	**Morison**	**Eng R MS**	**South Fork**
pH	**-0.70**	**-0.76**	**-0.71**	**-0.88**
Specific Conductance	-0.21	**-0.50**	-0.13	**-0.50**
Turbidity	+0.49	**+0.56**	-0.08	+0.11
DOC	**+0.72**	**+0.71**	+0.27	**+0.62**
$NO_2 + NO_3$	**+0.53**	**+0.72**	**+0.53**	**-0.72**
Orthophosphate	**+0.85**	**+0.62**	**+0.54**	**-0.65**
TDP	+0.43	+0.45	-0.23	+0.42

Table VII – Correlation table of individual parameters and water flow at four sites.
Any 'r' values ≥ **±0.5** are presented in bold type and arbitrarily considered to be moderately correlated.

Correlation of Physical Parameters

It can be seen that pH is obviously negatively correlated to flow at all four locations, whereas specific conductance shows a weak negative correlation to flow, notably, at **Morison** and at **HWY**. This may be due to dilution by rainwater after precipitation events. Turbidity shows a moderate positive correlation with flow at the Morison Creek and Highway sampling sites. Dissolved organic carbon is also positively correlated at those two sites as well as at **South Fork**. This appears to support the conventional wisdom that Morison Creek receives considerable run-off from low-lying agricultural land and is backed up by similar observations elsewhere in North America (Waters, 1995).

Correlation of Nutrients

The nutrients nitrate+nitrite and orthophosphate are positively correlated to flow at three sites, **HWY**, **Morison** & **Eng R MS**, whereas they are both negatively correlated at **South Fork**. If the land use results in increased surface loading of nutrients species, it is understandable that these nutrients tend to rise with the increase in surface runoff. On the other hand, the amount of precipitation will affect the sub-surface hydrology perhaps providing greater contact time with nutrient rich soil horizons. The inverse correlation at **South Fork** is interesting and may reflect the largely unperturbed nature of the mature second growth forest. This hypothesis requires further examination, as this observation is not fully understood. Finally, total dissolved phosphorus may be weakly correlated to flow at **Morison**, **South Fork** and **HWY**, but is not notably correlated at **Eng R MS**.

Differences Between Tributaries

Turbidity, Nitrate + Nitrite, Dissolved Organic Carbon, Orthophosphate, and Total Dissolved Phosphorus all appear in noticeably higher concentrations at **Morison**, as shown in Appendices C, E and F. However, taken collectively the relationships between the values of the parameters, the date of the sample and its source location is shown by the results of the cluster analysis. All variables are treated independently, so that it is the patterns of relationships, rather than the pair-wise relationships themselves, that are displayed in a dendrogram. Nine water quality parameters were treated as independent variables used to group 35 samples taken from three tributaries (**Morison**, **South Fork** and **Eng R MS**) together as objects in the cluster analysis. This was done in an effort to see if it is possible to distinguish between the tributaries based solely on the relative magnitudes of the parameters in the existing data set. The dendrogram shown in Figure 13 using 9 water quality variables shows the groupings of the sample measurements into three distinct families based on their source tributary and seasonality.

The most noticeable grouping is on the far right hand side of the graph, where six samples from **Morison** during wet months are closely linked as a family, quite distinct from all of the other samples. This segregation is based on the similarity of the actual quantitative data (no other source information is used to identify the sample). This is also readily seen in a similar dendrogram for 46 ER Samples (no **HWY**) using 6 water quality variables shown in Appendix D2.

The distinctness of the tributaries was evident in other cluster analyses conducted for the low flow period, July 2002 through September 2002, and repeated for the high flow period October 2002 through December 2002. However, the most notable groupings were displayed for cluster analyses for the high flow periods: January 2003 through March 2003, as well as, April 2003 through June 2003. In particular, **Morison** and, to a lesser extent, **South Fork** stand out as the most distinct watersheds. Which is not surprising, due to our knowledge of the land uses in each of these areas.

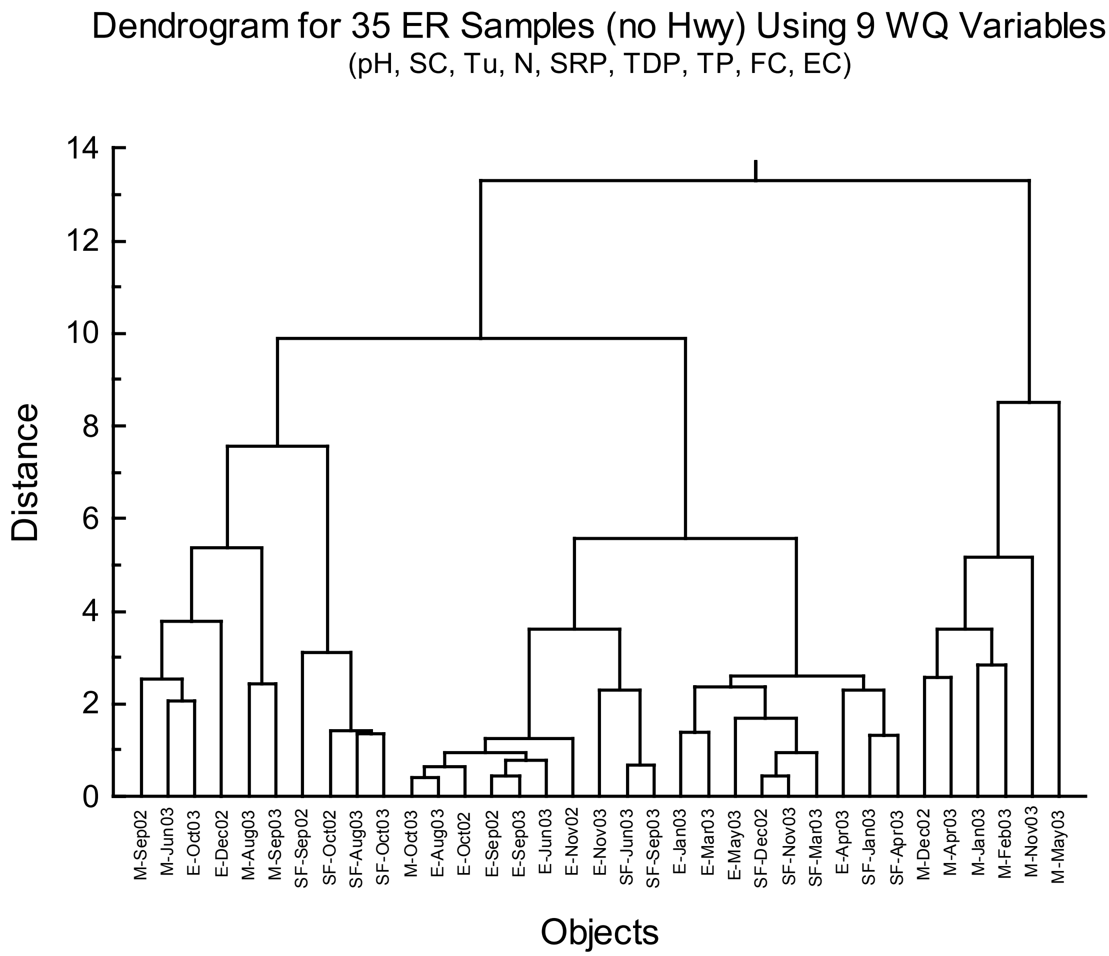

Figure 13 –Dendrogram showing clusters of samples taken from three tributaries over a 15-month period (Sept02-Nov03)
(M= Morison, E = Englishman Main Stem, SF = South Fork)

Discussion of Findings

Caveats

Based on the monthly samples analysed by the provincial laboratory, it appears that all chemical criteria, stipulated in the Approved Water Guidelines for measured substances, have been met. Therefore, there is no evidence for an immediate health concern due to the physical and chemical parameters monitored in this project. On the other hand, the values for bacteriological parameters have exceeded the guidelines for untreated drinking water, on several occasions, and are cause for concern. Moreover, it is important to determine the source/s of this input in order to mitigate the potential effects. Otherwise, it seems as if there is no substantive reason for concern based on the accepted “safe levels” for specific parameters. However, what has not been determined is: 1. Whether the total loading of a substance during a particular time of year may be of concern, but not observed due to dilution by high flow; or, 2. Whether there are other substances, which may not have been measured, that might indicate a change in the health of the river.

Potential Significance

Potential Sources of Substances

The higher measurements of turbidity, nitrates + nitrites, dissolved organic carbon, orthophosphates and total phosphorus are all consistent with agricultural activity. Therefore, an obvious possibility is that agriculture is responsible for the higher concentrations of nutrients and turbidity in the area upstream from the **Morison** sampling site. Especially, as current farming practices include the spreading of manure on fields (P. Mullen, personal communication, November 27, 2003). Nevertheless, nutrients could also emanate from septic fields associated with human habitation, so it is possible that the rural residential land use is contributing to increases in these parameters. The higher turbidity may be associated with all three major land uses in the area, because, recently, there has been ongoing farming, logging to clear land, as well as, development, in the form of house building and local road construction.

Bacteriological Indicators

The presence of the two measures of bacteria, Fecal Coliforms and E. Coli, in various samples is not surprising, based on possible natural causes and on anthropogenic land uses. Spawning salmon, as well as healthy and dead wildlife, can contribute to the amount of bacteria as evidenced by the spike at the Highway in October 2002; however, the presence of higher readings of E. Coli in **Morison** samples is likely to be the result of agricultural activity and/or improperly functioning septic fields. The use of manure from livestock as fertilizer on forage crops is a possible cause.

Unexpected Measurements

Based on a literature review of studies of similar land uses in the Pacific Northwest, higher levels of nutrients might have been anticipated in water samples from the South Englishman River sub-basin (**South Fork**). Higher values of nitrates + nitrites might have been interpreted as being associated with the effects of clear-cutting and subsequent fertilization. However, there was no observed increase in the levels of nutrients from this tributary, which may be due to the current average age of the forest stands in this area. It will be important to continue monitoring these parameters at this site if further activity is anticipated.

A Puzzling Parameter

Higher levels of specific conductance were observed in samples from **South Fork** (115 - 304 μS/cm compared to an average ~ 70 μS/cm at the other three locations), for the period from August – November 2002. No other parameter showed a concomitant variation for the same period. Measurements of other ions in the water samples would be required in order to explain the full significance of this observation. However, a possible explanation for this occurrence is offered in the current literature, in that higher levels of dissolved ions have been observed during low flow periods, in the first two years following logging (Church & Eaton, 2001). **South Fork** was also the only site that showed a negative correlation between nutrients and flow. Another possibility could be ground-water inflow, which can have a higher concentration of ionized species.

CHAPTER FOUR
STUDY RESULTS

Quantity of Available Water Flow

Observations Regarding Quantity

Although the causes of low flows are primarily climatological, there is little doubt that this is exacerbated by the withdrawals. The demand may increase, based on the projected human population growth, by approximately 3% per year (Regional District of Nanaimo, 2003), unless a major conservation effort is undertaken. As previously noted, the effects of global climate change are predicted to prolong the summertime low flow periods; therefore, the issue of available flow for both human and fisheries purposes will be exacerbated. The major knowledge gap appears to be just how much water flow is needed to maintain a healthy aquatic ecosystem, while meeting the needs of a growing human population. Without an effective regulatory infrastructure, there will soon be even less supply for some of the approved uses of the river's water. The problem of insufficient flow for fish was raised by the provincial Water Allocation Report (Boom & Bryden, 1994) in 1994 and this same message has been repeated nearly a decade later. The report to the Pacific Fisheries Resource Conservation Council has made the recommendation that the minimum flow needed to protect anadromous fish stocks is 2.76 m^3/s, which is more than double the current minimum monthly flow during the low flow period (Rosenau & Angelo, 2003).

Potential Solutions to Water Quantity

Two obvious solutions to water shortages are to make better use of the currently available supply, through conservation, and to provide additional storage capacity for some of the water that flows directly into Georgia Strait during the high flow events each winter. However, it is essential to acknowledge the gaps in the current assortment of available information. For instance, there is an accessible database for the available quantity of water, but the way it is presented and used could be improved. An important first step would be to recognize that annual allocations are misleading, because of the extreme variation in the quantity of available water between summer and winter, it would be prudent to base allocations on mean monthly rather than mean annual flows. Then, a more informed dialogue could take place on the need for more stringent conservation efforts or greater storage capacity. This issue should be expanded to incorporate the needs of the ecosystem of the watershed to include intrinsic natural values, in order to safeguard its health. This is the approach being taken by the State of Washington’s Department of Ecology (2004) in 17 watersheds with vulnerable salmon and trout populations and would certainly be appropriate for application to the Englishman River.

Water Quality Concerns

General

The general conclusions drawn from the results of this study are a result of the short time-line (one year) and the frequency of water sampling. Also, the lack of sampling for certain substances must be noted. Reduced N species, NH_3 & organic-N (perhaps associated with nutrient enrichments from sylvicultural practises) as well as specific markers of domestic wasterwater, such as detergents, whiteners etc, associated with leaking septic fields and selected pest/herbicides associated with agriculture and urban lawn beautification would add another dimension to the monitoring. It should be remembered that this report is based on the available data for the first year (2002/03) of a three year (2002/03 – 2004/05) monitoring program. The central question about the observed impacts on the watershed and it’s tributaries resulting from land-use practices will need to be addressed using the three-year data set, when it becomes available.

Meanwhile, the three questions raised in this thesis have been answered with varying degrees of success. The first, regarding long-term changes over time, has not been fully answered, due to the sporadic nature of the water sampling over the previous two decades. The small increases in pH and specific conductance may indicate the start of a trend, and if this is so, it would be worthwhile knowing the reason why.

Observations Regarding the Analysis of Quality

The temporal analysis, conducted in two dimensions, provided a level of interpretation of the data that is generally understood, through the integrative capacity of the human mind. The levels of specific parameters at various times of the year are readily observed in the graphs and people have ascribed various reasons for the changes in the values. The question of long-term variation could be answered more conclusively by the results of X-Y scatter plots, if there were more regular data for a longer period.

The question of seasonal variation is partially addressed by the X-Y box plots for the measurements of selected parameters taken during the low and high flow periods. However, the multivariate analysis provides an additional level of sophistication, based on dynamical systems theory (Capra, 1996). The cluster analysis of 17 samples of eight water quality parameters, taken at the Highway Bridge (see Figure 10) clearly shows that the readings taken during the wet months of December-April are closely associated as a distinct family. Then, by using the same technique on 35 samples of nine parameters at three sites, the patterns of relatedness between all of the parameters, all three sites, and all the months of the sampling can be displayed on one dendrogram. This showed the distinctness of readings taken at **Morison**, both during the wet season (see Figure 13).

Particular Indicators

Human Health

At those locations where water is withdrawn for domestic and municipal uses, monitoring is required by regulation. While the assessment of risk is beyond the scope of this thesis, the presence of bacterial colonies, such as Fecal Coliforms and E. Coli, in the river water upstream should raise the level of concern of decision makers. The presence of these organisms is generally taken to be an indication of contamination that can have serious health implications for the end user, if left untreated. The widely fluctuating concentrations and colony counts observed during the high flow period suggests the greatest vulnerability to water quality is associated with precipitation events in the winter and spring months. Also, it should be noted that **Morison** and **Eng R MS** contribute the highest recorded Fecal Coliform and E. Coli measurements. Quite apart from the immediate concern for human health, is the issue of anthropogenic land use impact. As shown by the clustering of samples into groups associated with different source waters, taken together with the different dominant land uses, human activity is having a measurable (albeit subtle) effect on the overall water quality.

Ecological Health

Although, it is not known whether the effects of Persistent Organic Pollutants (POPs) by long-range airborne transport, are having much effect in the local region, it seems short sighted to abrogate responsibility by not investigating the local impacts of this global issue. Meanwhile, there are other substances, used locally, such as fertilizers for fields and forests, which could be monitored on a more frequent and comprehensive basis. While the impact of nutrients on water quality is known, it would be useful to verify whether their application in specified areas is directly responsible for affecting water quality.

Physico-Chemical Parameters

While the current levels of the measured physical parameters are not of concern, there are noticeable changes, both in time and space, affecting these indicators. The water samples taken during the low flow periods exhibit higher levels of pH and specific conductance, than those taken during the high flow winter-spring period. Turbidity, on the other hand, does show a marked increase during the high flow period, but seems to be quite dependent on the location of the sample. This is particularly noticeable in areas where anthropogenic land uses predominate.

Similarly, the chemical parameters, especially the nutrients, do show a positive correlation with flow rates. Not surprisingly, the most significant increases were observed in samples from **Morison,** which are probably associated with the most intensive levels of land use of the three tributaries.

Land Use Impacts

Of the three tributaries, the upper reaches of the Englishman River main stem and the South Englishman River watersheds are the least impacted by human land uses. At this time, it is estimated that less than 5% of these areas are being logged. However, Morison Creek and its Swane Creek sub-basin are without doubt the most heavily impacted watersheds, due to the long standing agricultural community and the more recent proliferation of rural-residential habitation. This has, no doubt, had an impact on the water quality parameters. However, without further investigation it is not possible to determine the exact cause of the changes.

Potential Improvements to Water Quality

Prevention

Since most of the higher readings of substances occur in the high flow period of the year, the total loading is definitely related to higher flows of runoff, following major precipitation events. Therefore, awareness of the effect of heavy rains and the saturation of the soil could help mitigate land use impacts by following best practices in logging, farming and building. Turbidity is probably the most obvious example, because the transport of sediments is certainly worse during and after heavy rainfalls. Therefore, if certain activities were curtailed during these periods, the effects could be diminished.

Protection

Greater protection of the watershed would be one way of achieving improved river water quality. In the past, many municipalities were able to establish authority over their watersheds. This was done in eras when governments, at all three levels, had more clout and the anticipated public good was readily accepted as a worthwhile and achievable goal. The intervening years have seen limitations on governmental authority and their ability to undertake major infrastructure-related initiatives, due in part to fiscal restraint. This issue is not trivial, since the vast majority of the land in the Englishman River watershed is privately owned. That said, there are legislative measures, which might be taken to enhance the health of the water supply. An ideal solution would be the intervention of a single authority on all issues relating to the water supply. With the recent amendment of the legislation (BC Ministry of Health, 2003), the Provincial Health Officer has been accorded a position of authority relating to drinking water from source to tap. However, references to overall protection of watersheds are not explicit in the act and, as this is a recent development, the ability and willingness to cross over jurisdictional boundaries has yet to be put to the test, even for drinking water.

Compliance

The water in the Englishman River is vulnerable to non-point-source pollution from the various land uses examined in this study. Although no concentrations of chemical substances were observed to have exceeded the BC Approved Water Quality Guidelines, there is the potential for some species, such as nutrients, to approach the established criteria. However, in the interest of effectiveness (as well as the precautionary principle) it would be preferable to undertake preventive, rather than remedial action. While best practices can contribute to improved stewardship, enforced legal responsibilities provide powerful incentives for adherence. On the other hand, there are already regulations for the proper operation of septic fields, which do not appear to be consistently enforced. In order to ensure the protection of the water supply, a more pro-active stance is required on the part of all stakeholders. The presence of the Fecal Coliforms and Escherichia Coli in samples from the watershed, should give rise to increased vigilance, particularly in the water of Morison Creek. Although this does not necessarily mean that human health is at risk, it is an indication that careful monitoring would be prudent, especially for the dozen, or so, domestic users licenced to draw water directly from the river (Land and Water BC Inc, 2003). The conscientious adherence to rules and regulations regarding the protection of the watershed would certainly enhance the security of this water supply.

CHAPTER FIVE
CONCLUSIONS

General Observation

When faced with an imminent threat to their well-being, human societies often react with vigour and determination. However, in the absence of such an obvious impetus, communities appear to be reluctant to safeguard their future health, if it means potentially costly expenditures. This seems to be the situation facing the users of the Englishman River watershed. The extent of the situation may be up for debate, but indicators are already present that should motivate decision makers and the public at large to take a greater interest in the security of their water supply. Various members of civil society, including stewardship and conservation groups, have already recognized the issues. Unfortunately, it may take an obvious crisis to generate sufficient political will to change the current ‘laissez-faire’ attitude.

Shortfalls – Quantity

If the figures for the supply and demand of river water are representative of the reality, is there really any reason for concern? It is the contention of the author that there is, in fact, some cause for concern, based on several reasons. As previously stated the total amount of water represented by the annual flow could easily support a vibrant ecosystem, as it did prior to the massive influx of humans into this area. From the total Mean Average Discharge (14 m^3/s), it would appear that the 20% (2.76 m^3/ s) recommended (by PFRCC) for fish and the 2% needed by humans is possible throughout most of the year. The problem is that the seasonality of the natural flow would preclude that amount during the period July-October in most years. This has been exacerbated by the continued withdrawals for anthropogenic purposes. Therefore, either increased conservation measures or increased storage capacity is required in the watershed, in order to satisfy all of the sanctioned uses.

Shortcomings – Quality

It appears as if the lack of an integrated perspective may be adversely affecting all users of the Englishman River. The watershed is being impacted to a greater degree than ever before and some effects may be gradually progressing, inconspicuously at present, but significantly in the longer term. While not intending to be alarmist, this study has identified a few parameters that should be of potential concern to decision makers. In 2003, the chemical and physical indicators appear to be at levels where there is little immediate risk to human health, but the consequences of the existing concentrations of nutrients to the health of the aquatic ecosystem remain undetermined. The presence of bacterial indicators is of greater concern to human health because, while it can be addressed by disinfection to produce potable water, it could become a concern for the recreational users of the river and, eventually, could impact the drinking water supply. If, as the data analysis suggests, the land use activities in the Morison Creek sub-basin (mostly agricultural) are influencing the concentrations of the measured parameters, then it would be prudent to monitor for other selected contaminants associated with this land use. It would further the objectives of this study to target better practises and public education where they are likely to have the greatest impact on remediation or prevention.

With a view towards future research and monitoring, it is recommended that an ‘unimpacted’ sampling location be established in the upper reaches of the main stem, to provide a baseline for this watershed. While the costs associated with such an initiative might deter governmental officials, it should be remembered that the legacy we leave for our children will have a major impact on the security of their water supplies.

Research Methods

Initially, a conventional approach was taken to the analysis, during this project. The more familiar statistical methods were used with limited success due to the characteristics of the data sets. However, the use of multivariate analysis added significant insight into the level of correlation between parameters, sample dates and sampling sites. It is concluded that this was an appropriate use of the technique. As described by Capra in The Web of Life, “The new mathematics… is one of relationships and patterns. It is qualitative rather than quantitative and thus embodies the shift of emphasis that is characteristic of systems thinking – from objects to relationships, from quantity to quality, from substance to pattern” (Capra, 1996). Nevertheless, it may be challenging to achieve general acceptance of such an innovative technique, if the conclusions drawn from its use, alone, were to imply the need for sizable expenditure of capital funds. Therefore, it is likely that a combination of conventional and new mathematical techniques will continue to be needed in future analyses.

Recommendations

As human intervention in natural processes has become progressively more intrusive, the need to monitor the potential impacts has become more acute. It is no longer sufficient to simply check a few key water quality parameters, to verify that concentrations of substances in the water are not an immediate threat to human health. Transdisciplinary interpretation of the available data should be taking place. A more integrated approach to the health of the watershed as a whole would take into account all available water quality (and quantity) indicators in an attempt to preclude negative impacts. With more detailed monitoring of the indicators, on a more frequent basis, it would be possible to determine the sources of the added substances, with greater confidence. Furthermore, given that approved guidelines have been established to protect six different uses, it would seem appropriate for measures to be implemented to verify that none of these uses is imperilled.

There is a definite need for greater and more open dialogue regarding the vulnerability of the Englishman River to land use impacts in the watershed. In many ‘grass-roots’ segments of the community, there is a need for greater awareness of the impact of many current practices in forestry, agriculture, and development, on river water quality. This can be addressed in part by education, within the three key sectors; however, enforced laws and regulations might well have a better chance of initiating a change in human behaviour. The crucial importance of a secure supply of water in the Englishman River, for a healthy ecosystem, including humans, is surely worthy of the concerted efforts of all segments of the population.

Epilogue

On the global scale, these problems cannot be considered acute; however, they are chronic and could become severe. The human communities, involved in the Englishman River watershed, do have the wherewithal to protect and manage this most basic necessity of life – water. It simply requires the will and perseverance of all stakeholders, on behalf of the current and future generations who stand to benefit from a healthy watershed.

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APPENDICES

Appendix A - Water Allocations from the Englishman River System

Appendix B - Recent Monthly Flows in the Englishman River

Appendix C - 7 Sets of Graphs of Parameters and Flow versus Month

Appendix D – 2 Dendrograms of ER Samples using 18 & 46 Samples

Appendix E – 7 Sets of Box Plots of 12 Samples at 4 Sites

Appendix F – 5 Scatter Plots at four sites for one year

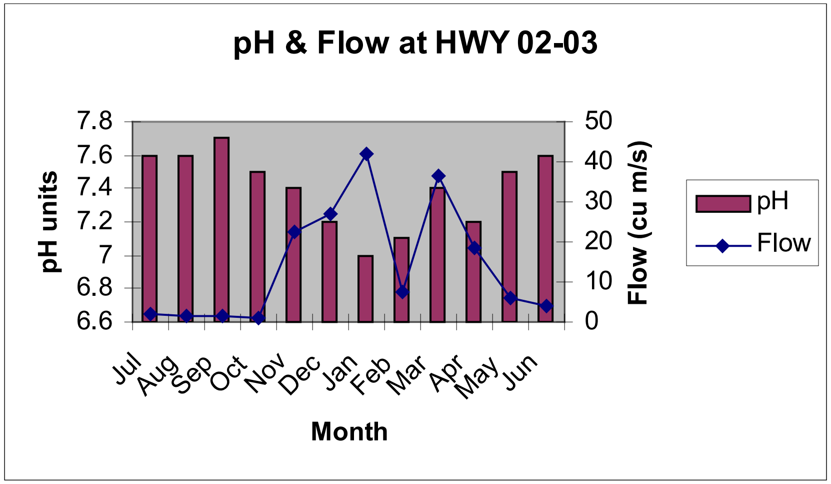
Appendix A – Allocations (Land and Water BC Inc, 2003)

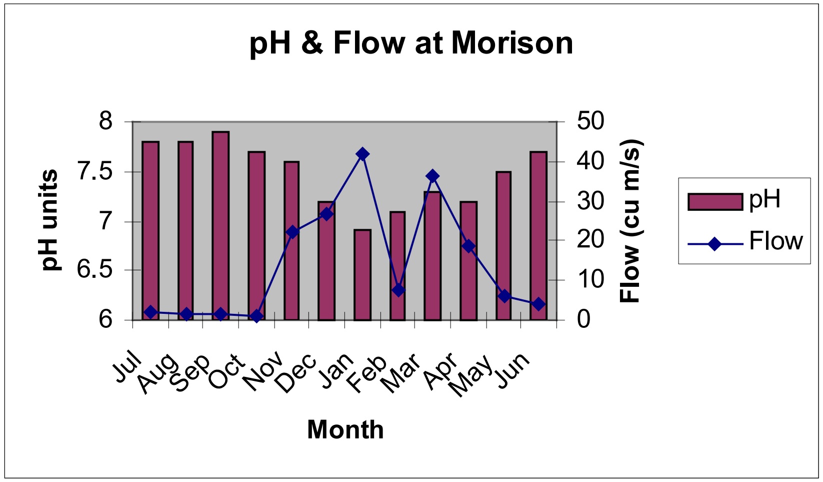
Englishman River Water Licences		**Annual Allocation**	**Maximum Daily Allocation**		**Ave metric demand**
Waterworks Local Authorities		**ImpGal / Yr (GY)**	**ImpGal per Day GD**		**cu m / d**
City of Parksville		193,500,000	530000	div by 2*	1204
Arrowsmith Water Service (AWS)		1,540,000,000	4220000	div by 2*	9590
(RDN, City of P'ville, & Town of QB)					
AWS - Storage	7300 AF->	1,980,000,000	54300000		247000
	Total				257794
Miscellaneous			23000	div by 2*	104
(Water Delivery, Enterprise, Domestic)					
*asumes that municipal and domestic demand is the authorized max daily licenced qty divided by 2 to est ave daily demand X365=>annual demand					
Irrigation	68AF	271472 Imp Gal/365d/y			230
Total Allocations from Watershed			59100000		269000
Average Daily Demand from Eng R					51445
Average Annual Flow	14cu m/s	X 220 Imp Gal X 86400s/d	266000000		1210000
Maximum Average Monthly Flow	30 cu m/s	X 220 Imp Gal X 86400s/d	570240000		2590000
Minimum Average Monthly Flow	1 cu m/s	X 220 Imp Gal X 86400s/d	19008000		86400
Conservation	(Non-consumptive)				
DFO	21CS	X 6.23 Imp Gal X 86400s/d	11300000		51540

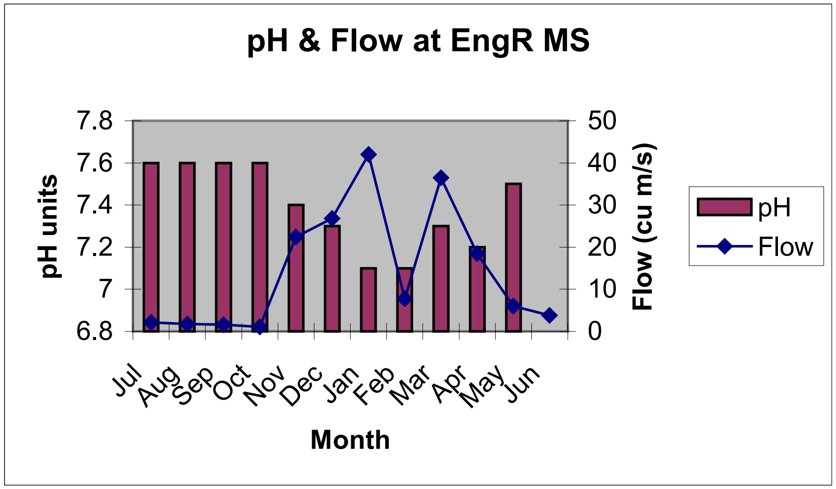
Appendix B – Recent Monthly Flows from the Water Survey of Canada (2002)

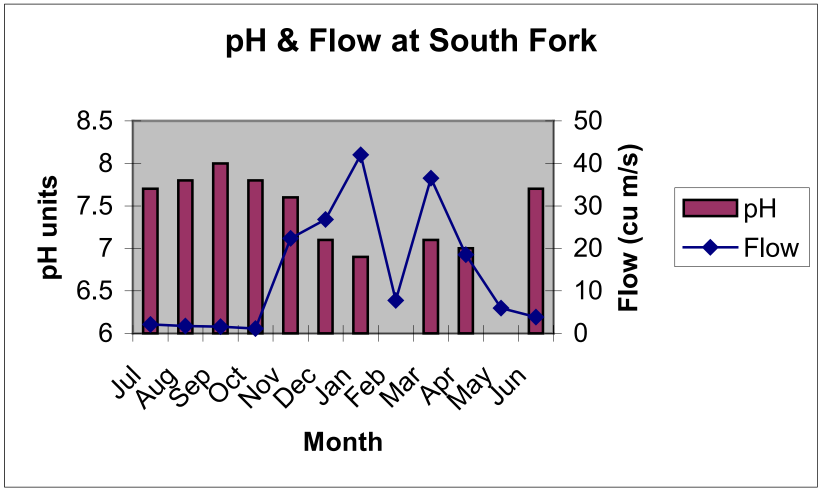
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	12.6	11	21.8	14.2	11.1	6.17	1.34	0.498	0.248	1.13	3.59	25.5
1994	25.6	20.7	32.4	11.5	5.55	4.06	1.14	0.477	0.462	3.36	15.6	41.8
1995	25.2	34.1	21.9	9.33	7.95	4.09	1.62	0.905	0.345	7.49	44.6	41.2
1996	28.5	26.8	11.3	15.2	8.05	3.41	1.16	0.326	0.496	8.29	11.5	13.7
1997	43.4	15.1	34.5	19.9	19.6	9.48	5.37	1.98	5.62	28.4	28.1	23.8
1998	42.6	27.9	14.6	6.35	8.35	4	1.63	0.394	0.338	2.34	36.9	38.8
1999	37.1	37.9	21.4	17.5	19.2	18	10.5	4.38	2.11	4.87	34	26.9
2000	9.4	16.3	13.2	10.9	10.9	8.5	2.59	2.29	1.58	8.58	8.38	15.5
2001	16.1	6.71	10.6	9.36	7.91	3.51	1.52	2.51	1.72	3.27	26.3	23.2
2002	33.7	17.9	10.2	17.2	10.6	6.83	2.14	1.72	1.58	1.1	22.4	26.8
Ave	**27.42**	**21.44**	**19.19**	**13.14**	**10.92**	**6.81**	**2.90**	**1.55**	**1.45**	**6.88**	**23.14**	**27.72**
Std Dev	12.02	10.04	8.83	4.34	4.78	4.48	2.95	1.30	1.62	8.06	13.31	9.95

Appendix C1 - pH & Flow versus Month at four sampling sites

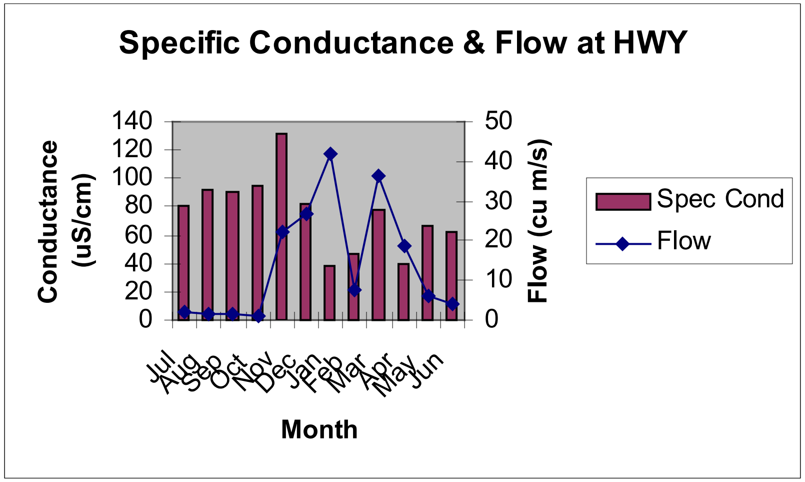


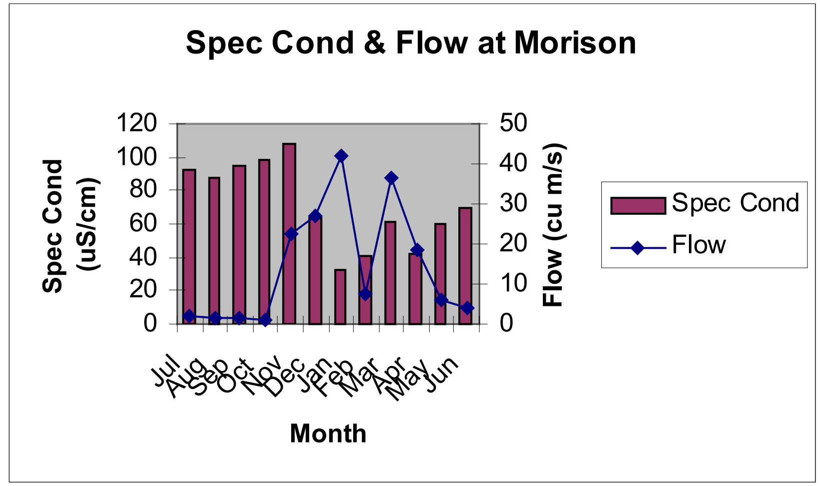


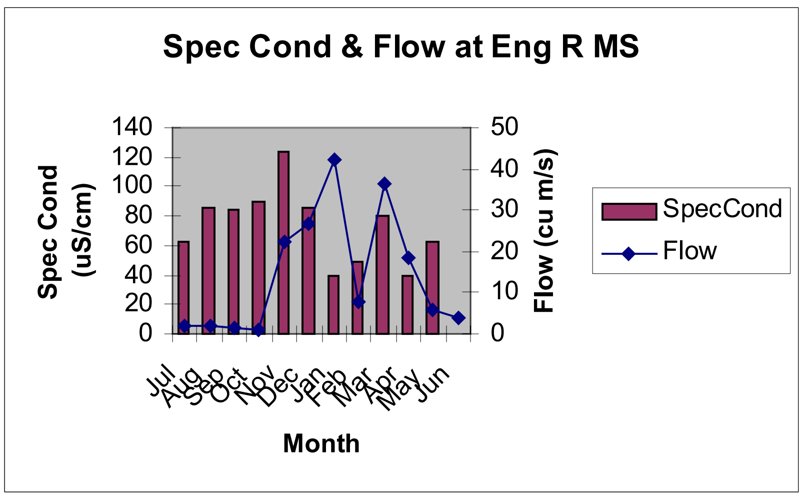


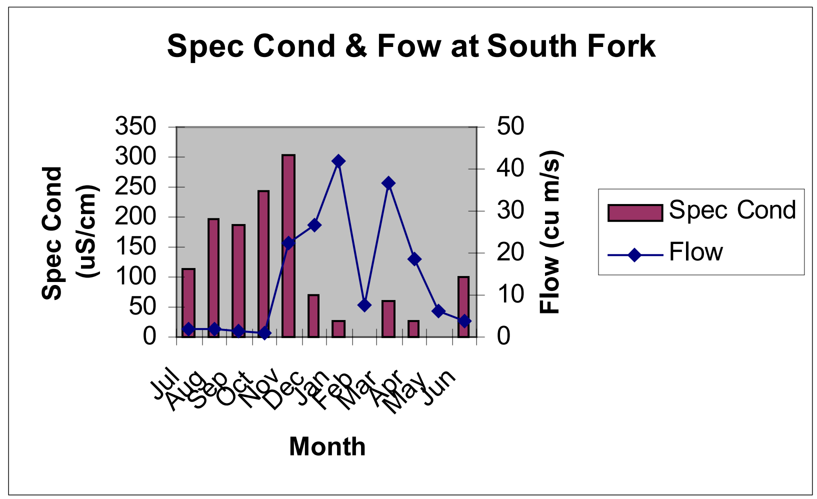


Appendix C2 - Specific Conductance & Flow versus Month

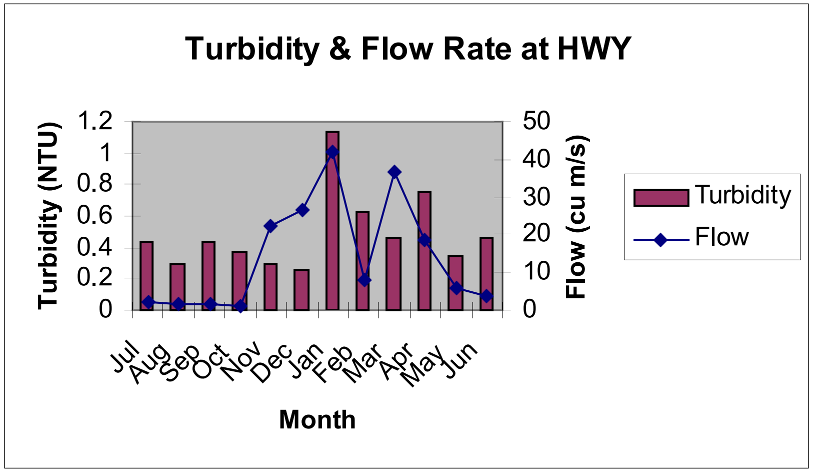


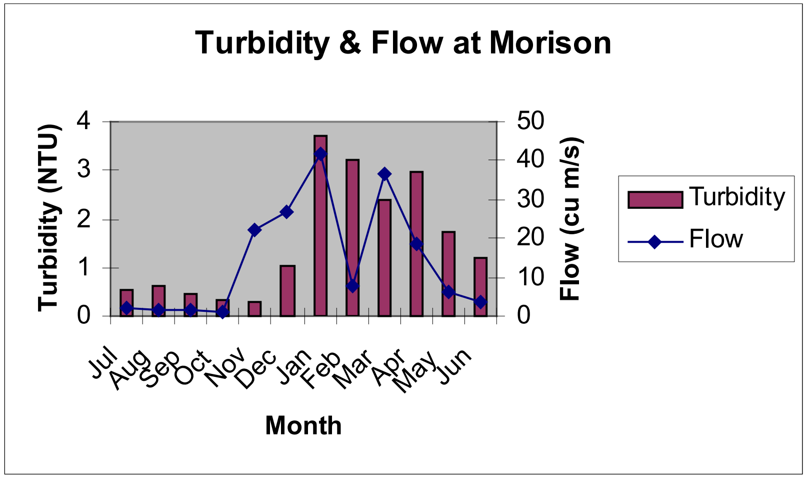


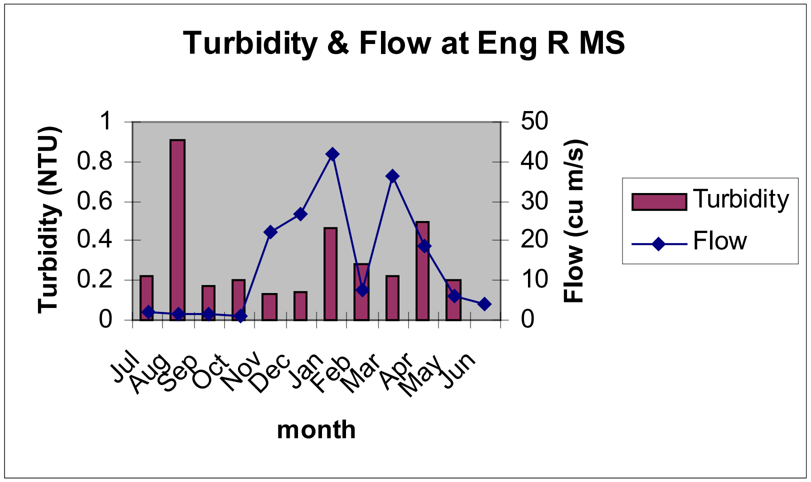


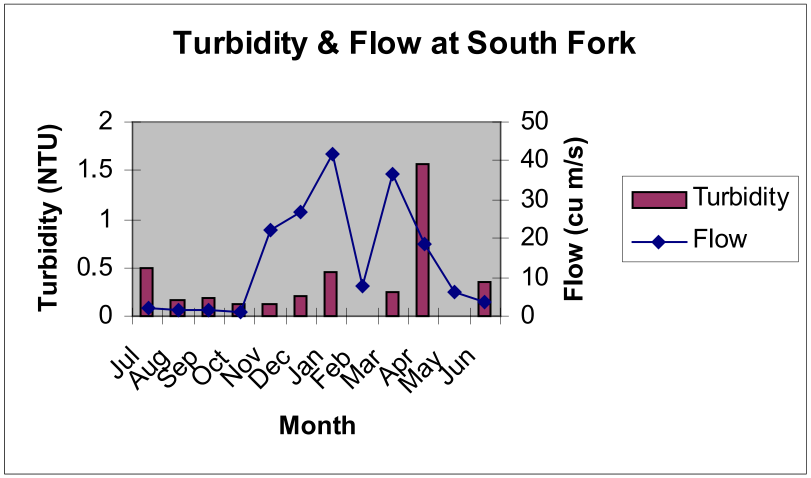


Appendix C3 - Turbidity & Flow Versus Month

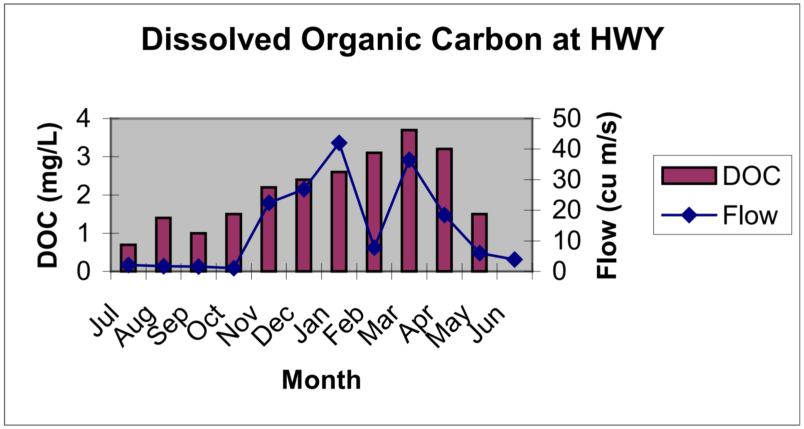


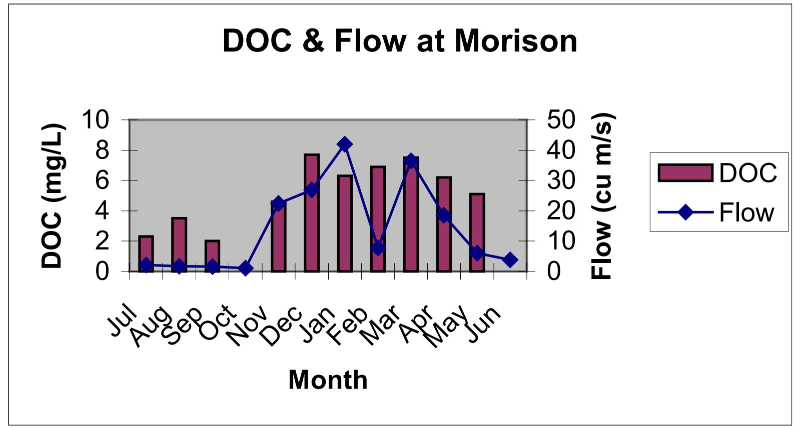


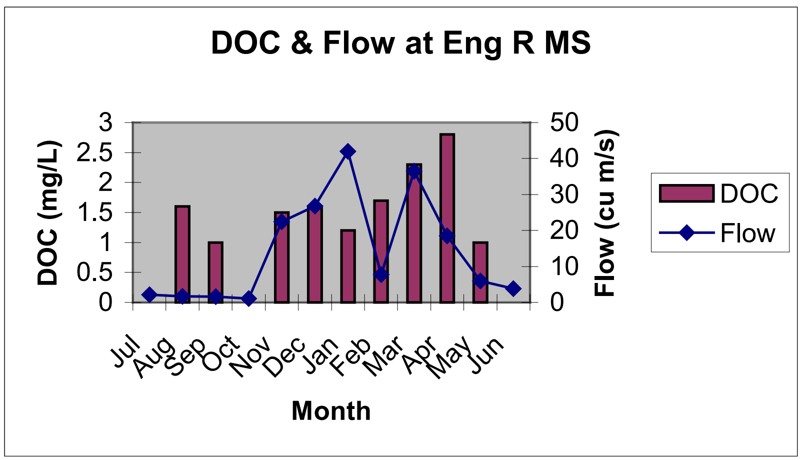


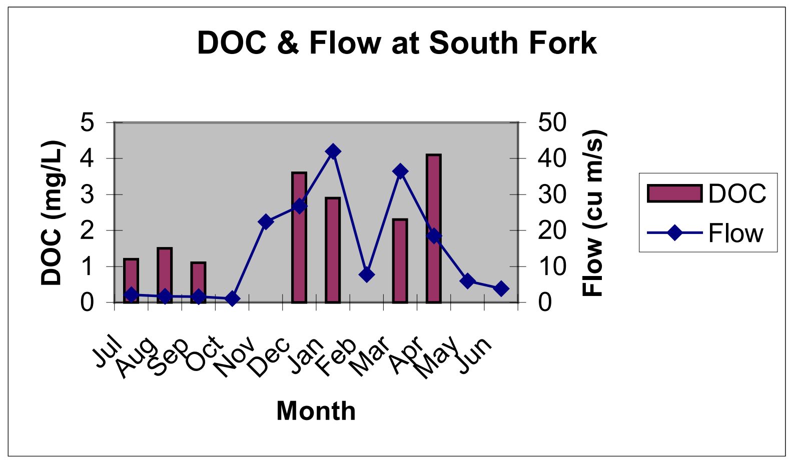


Appendix C4 - Dissolved Organic Carbon & Flow versus Month

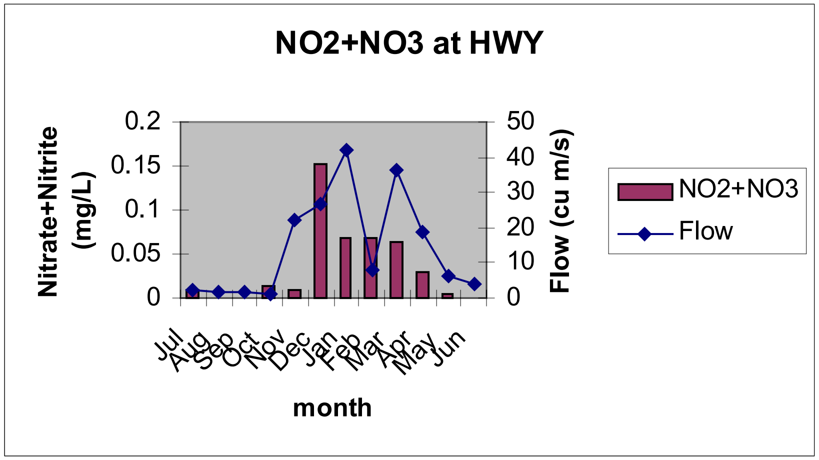


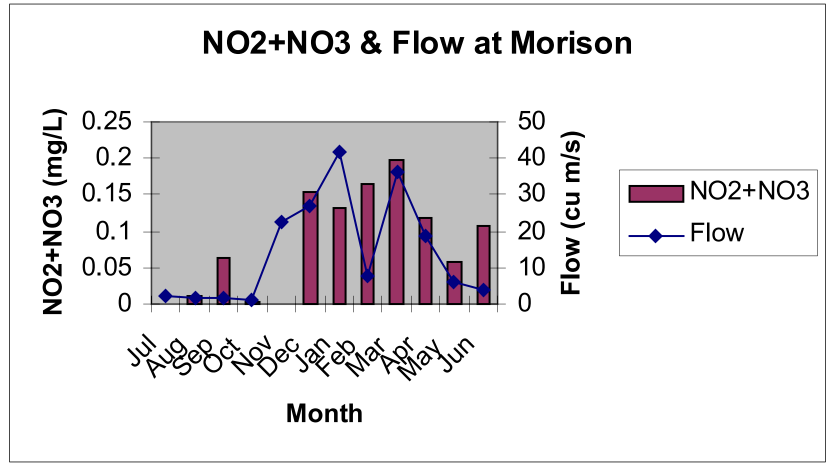


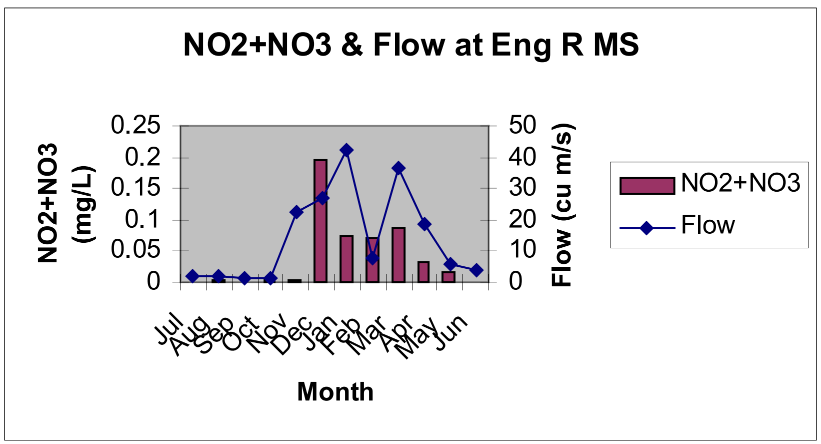


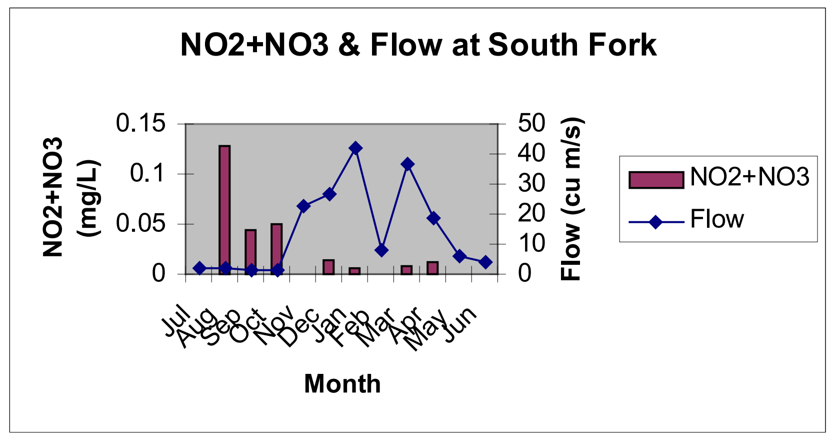


Appendix C5 - Nitrate + Nitrite & Flow versus Month

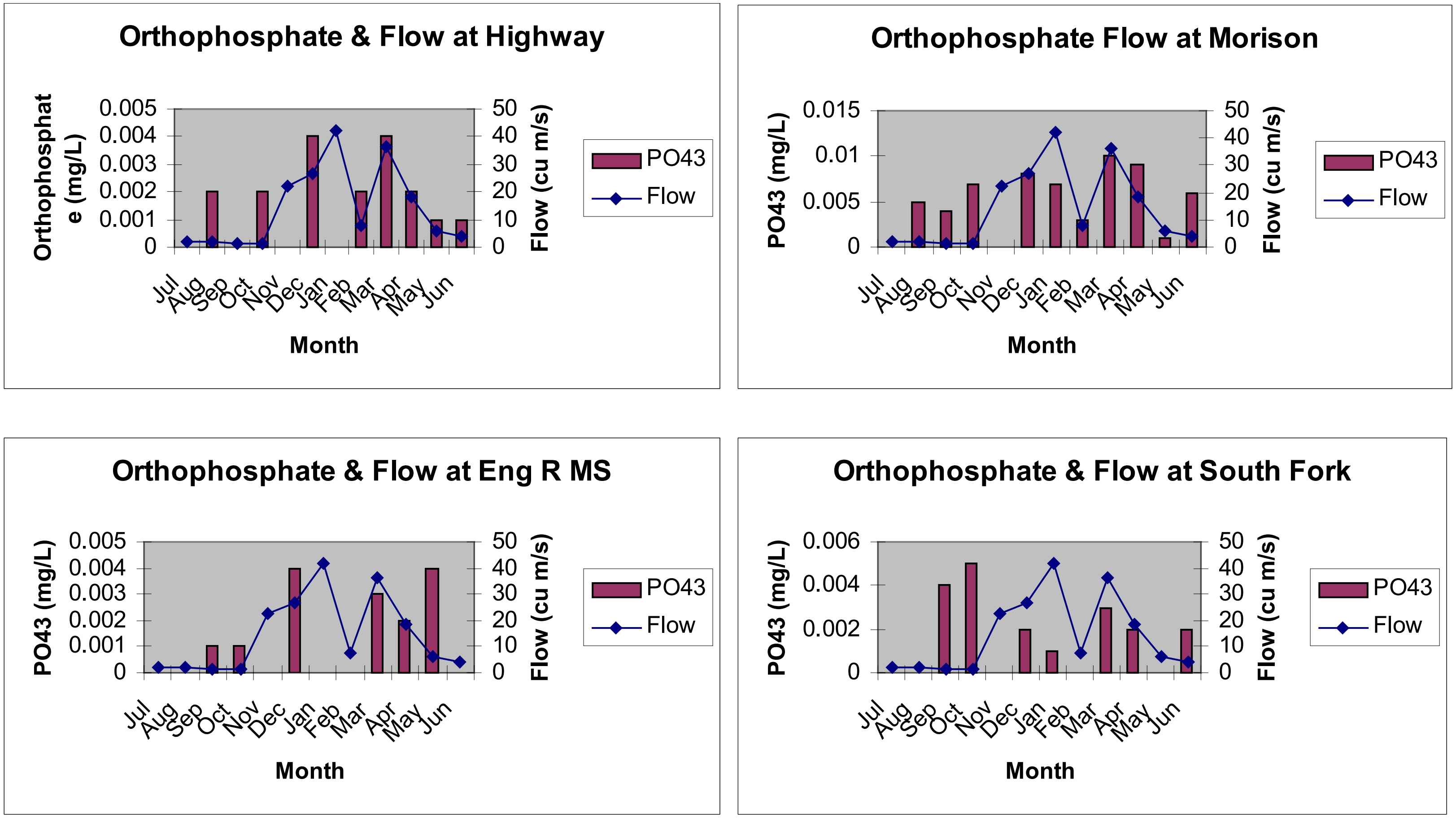




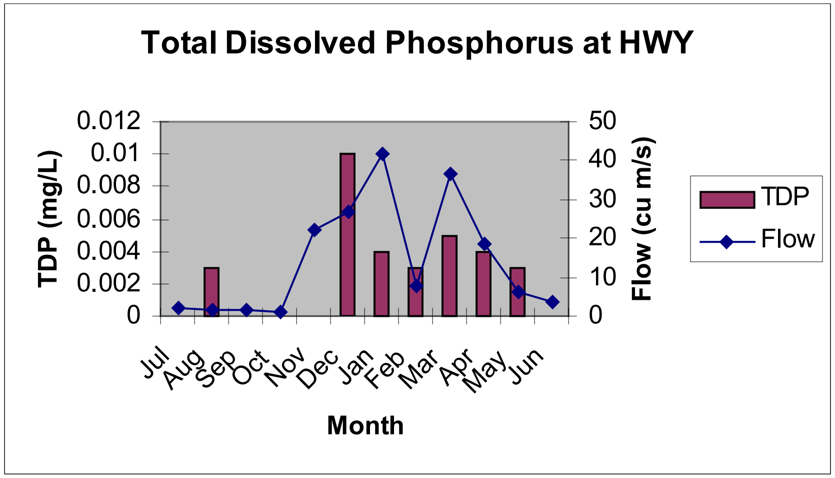


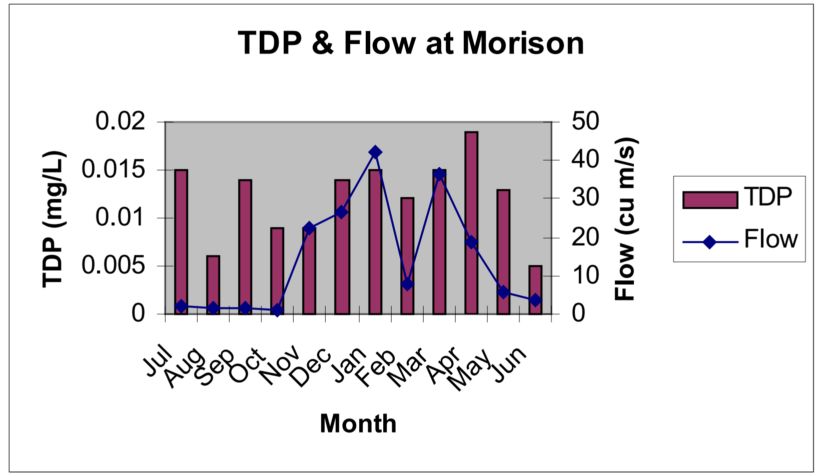


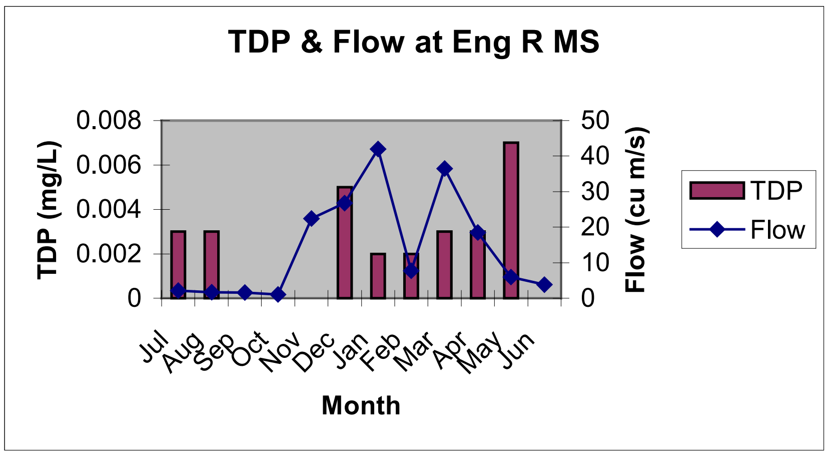
Appendix C6 - Orthophosphate & Flow versus Month

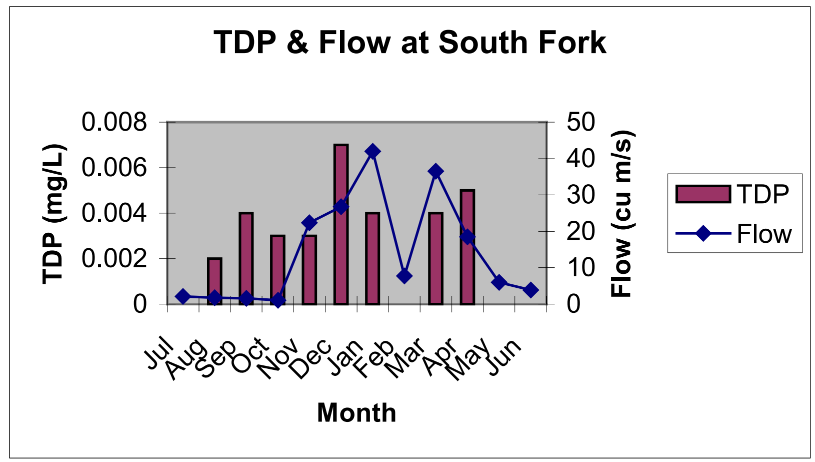


Appendix C7 - Total Dissolved Phosphorus & Flow versus Month

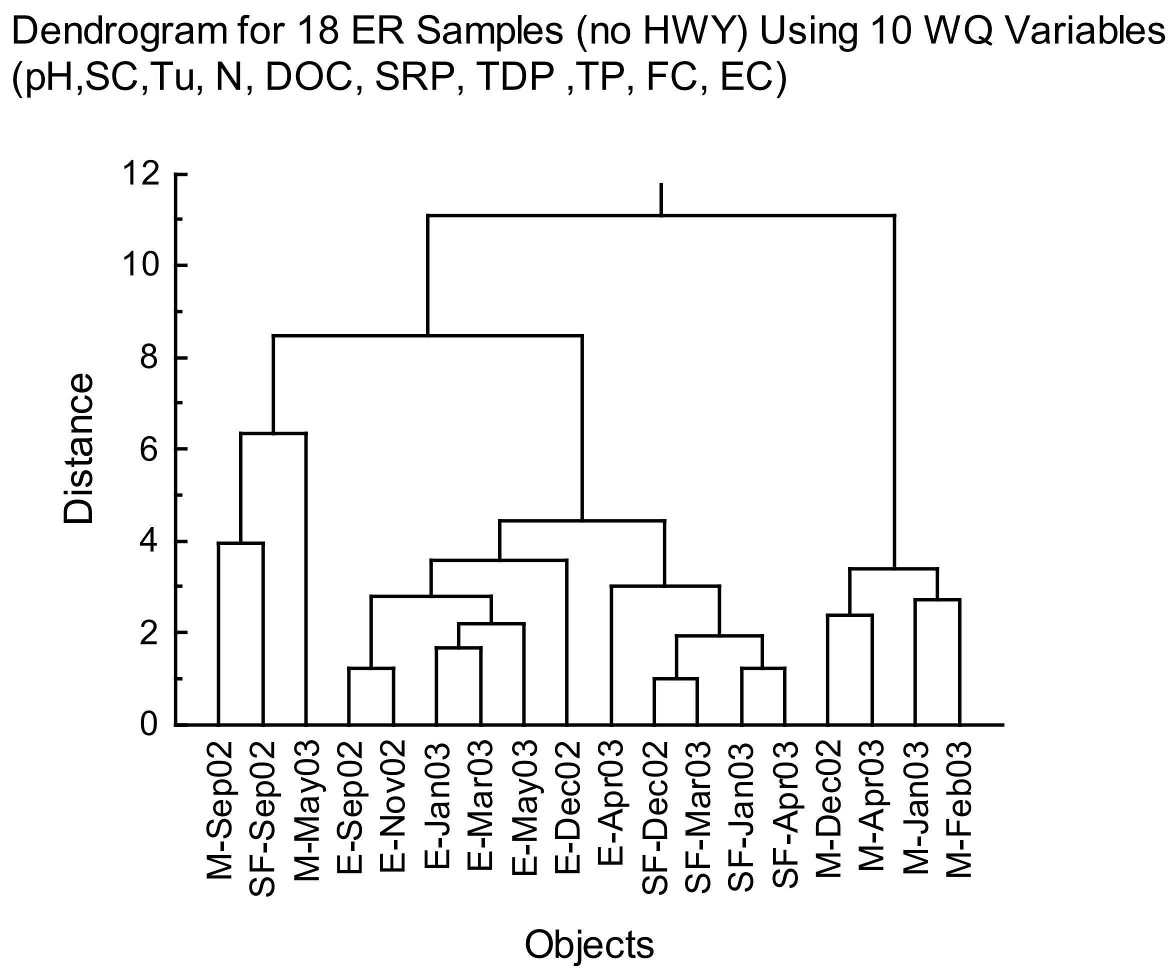






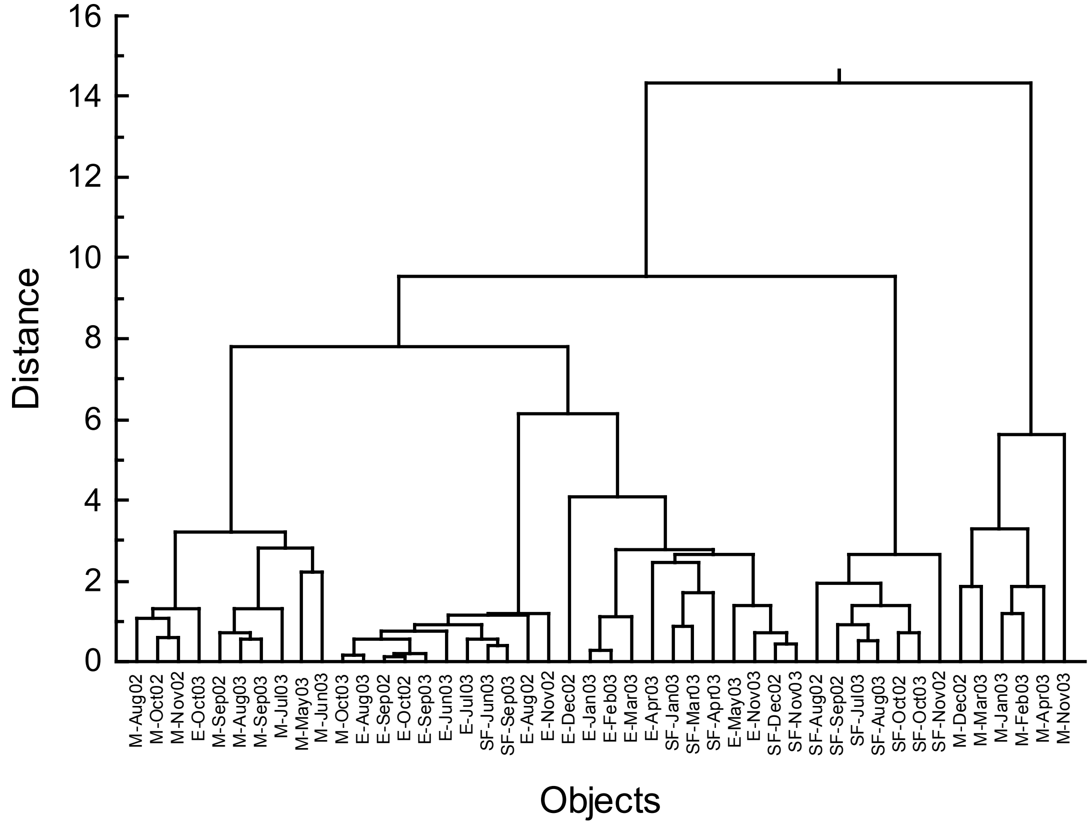


Appendix D1 – Seasonality Cluster Plot

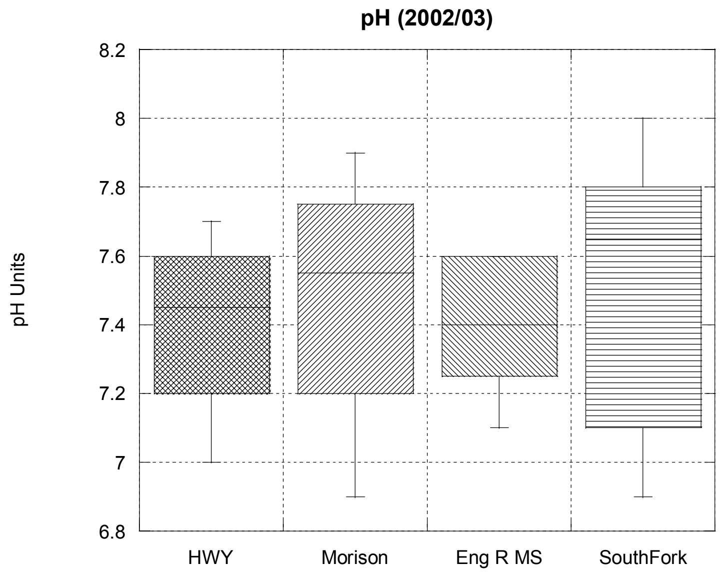


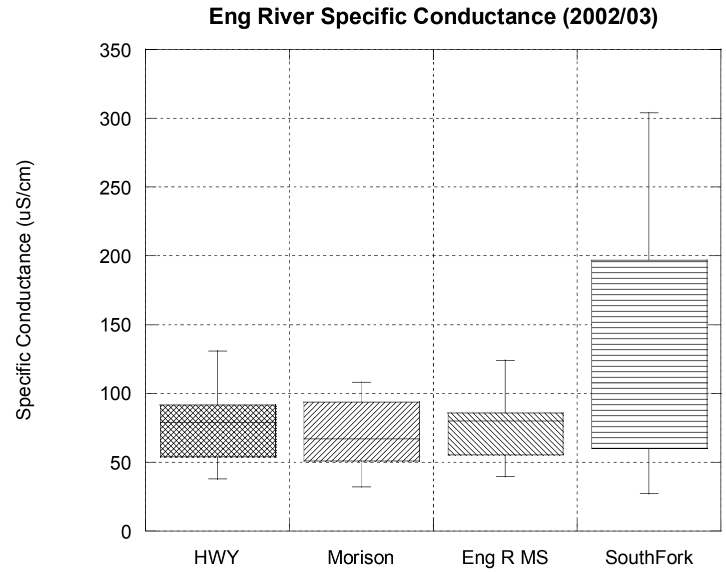
Appendix D2 – Spatial Correlation Cluster Plot

Dendrogram for 46 ER Samples (no Hwy) Using 6 WQ Variables
(pH, SC, Tu, N, TDP, TP)

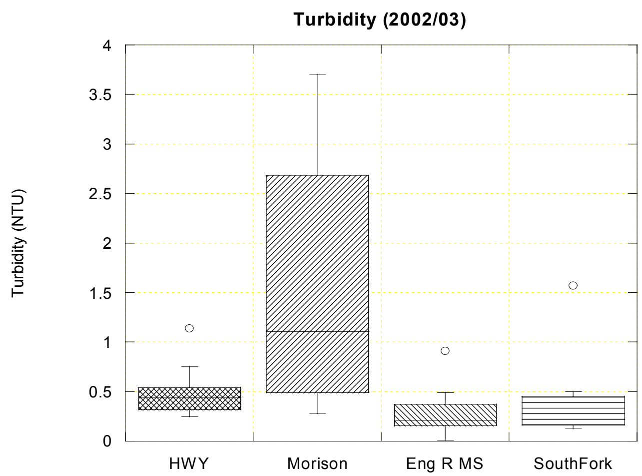


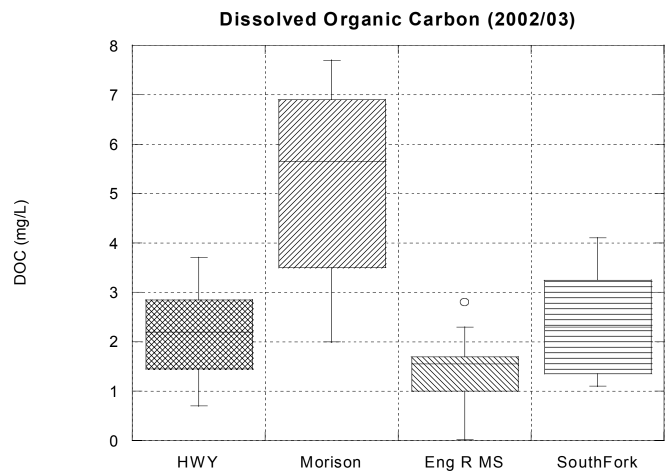
Appendix E1 – Box Plots – pH & Specific Conductance



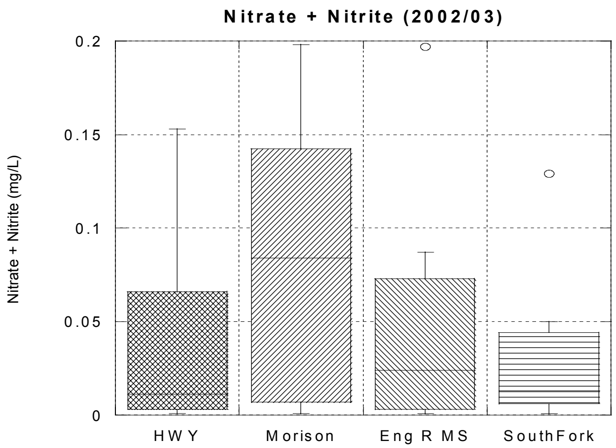


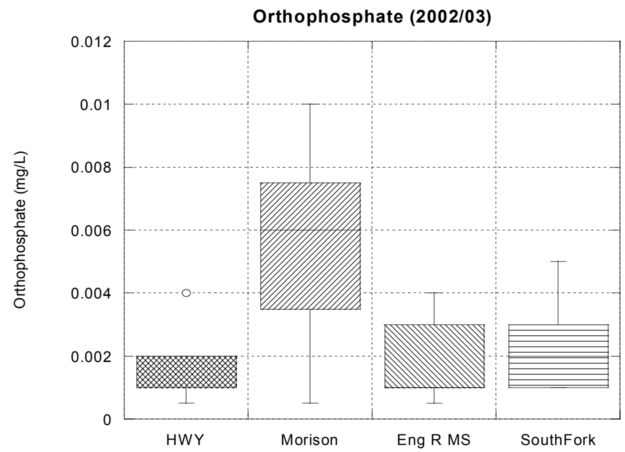
Appendix E2 – Turbidity & Dissolved Organic Carbon



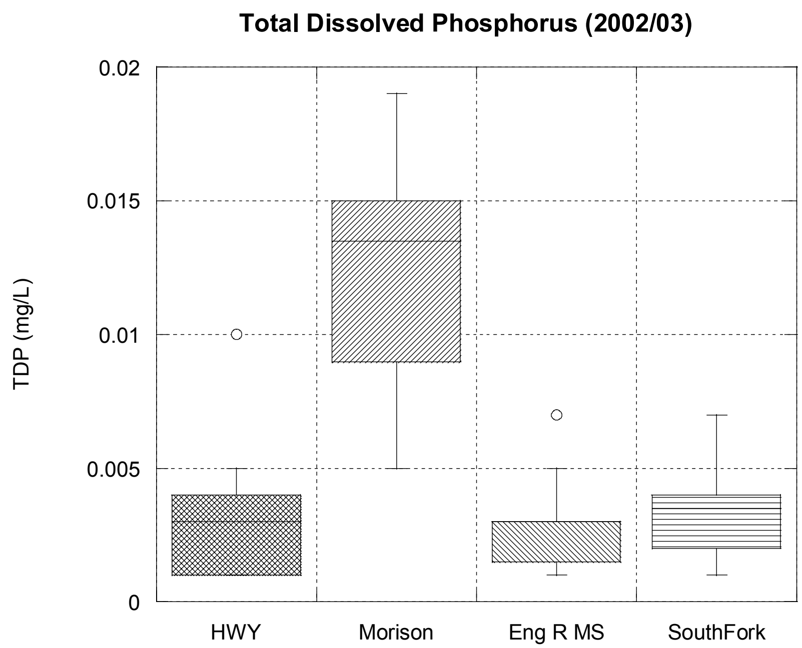


Appendix E3 – Nitrate + Nitrite & Orthophosphate

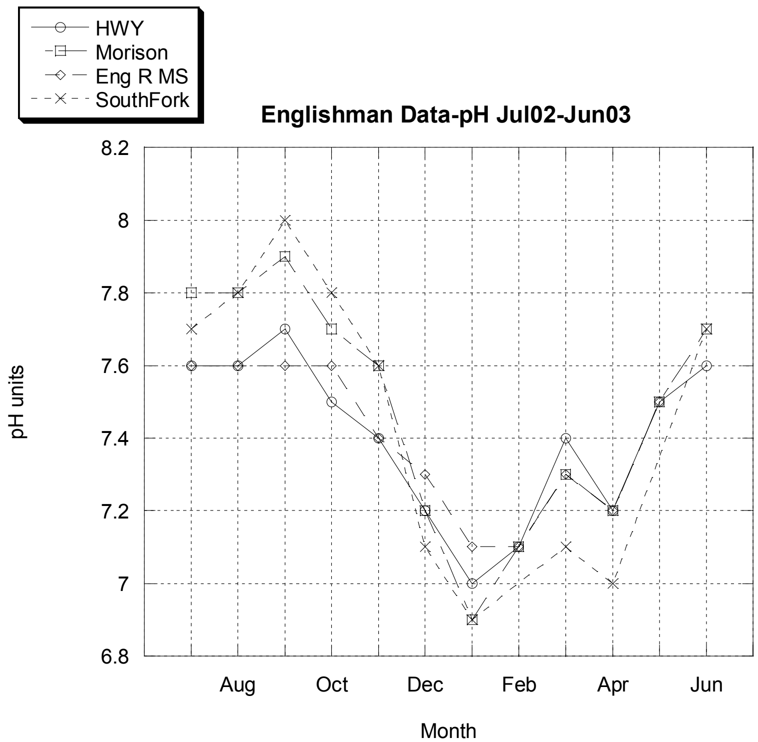


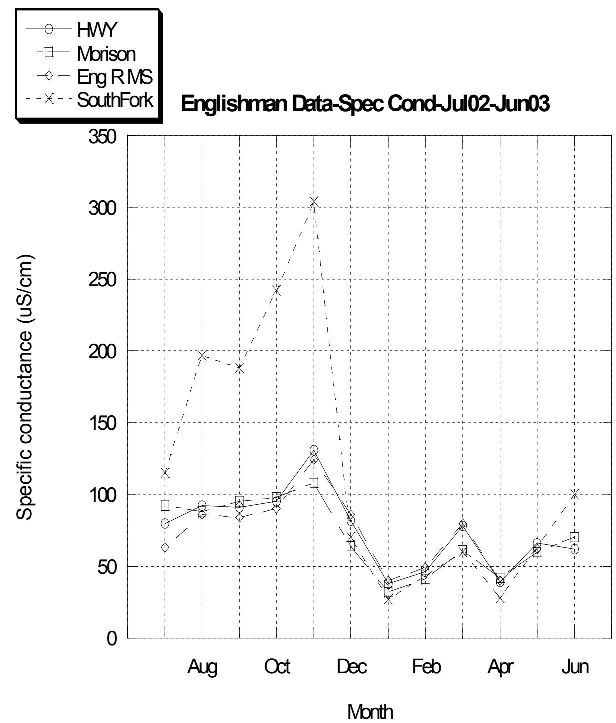


Appendix E4 – Total Dissolved Phosphorus

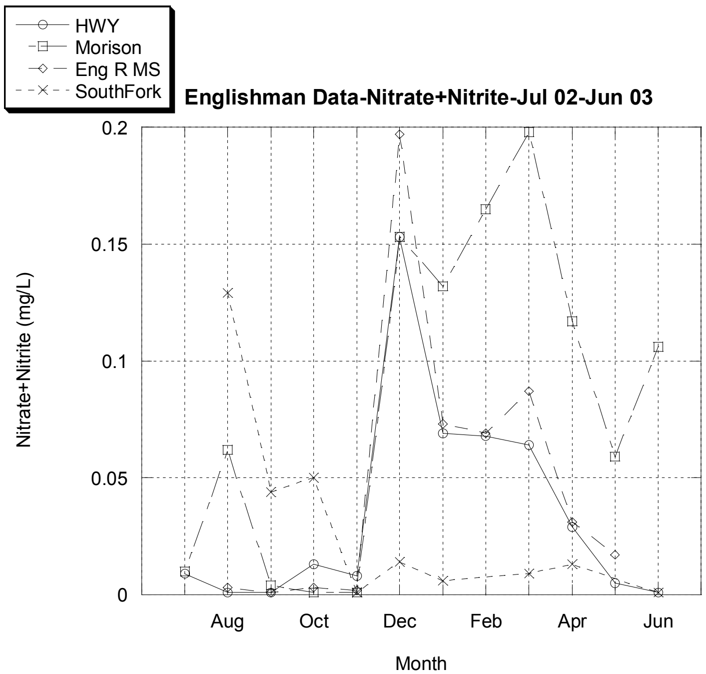


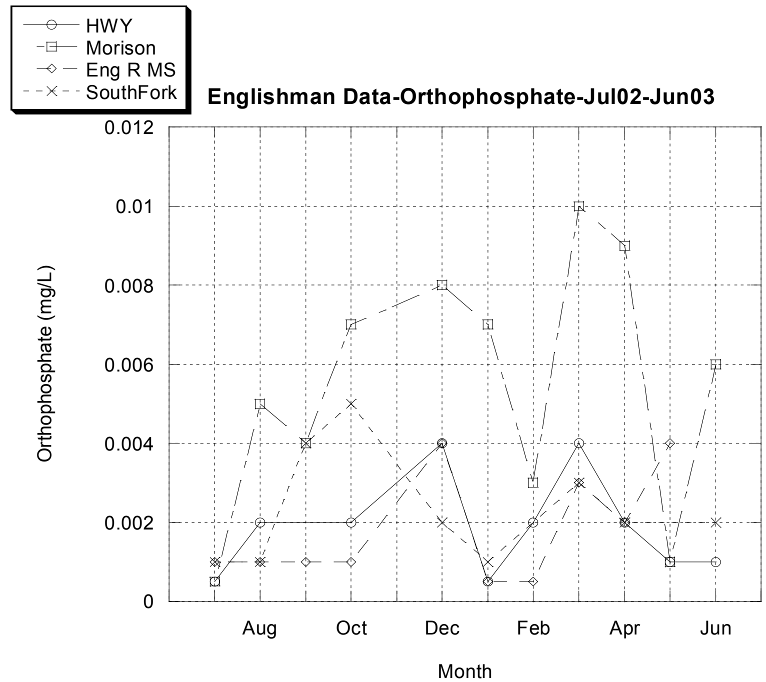
Appendix F1 - pH & Specific Conductance at four sites for one year





Appendix F2 – Nitrate+Nitrite & Orthophosphate at four sites for one year





Appendix F3 – Total Dissolved Phosphorus at four sites for one year