BRITISH COLUMBIA

ENVIRONMENTAL PROTECTION DIVISION

WATER STEWARDSHIP DIVISION

MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for Newcastle Creek Community Watershed

TECHNICAL REPORT

Prepared pursuant to Section 5(e) of the *Environmental Management Act* (2003),

Section 150 (1)(a)(ii) of the *Forest and Range Practices Act* (2002) and

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1.0 INTRODUCTION

The Ministry of Environment is conducting a program to assess water quality in designated community watersheds. Community watersheds are defined under the *Forest Practices Code Act of BC* as "the drainage area above the point of diversion and which are licensed under the *Water Act* for waterworks purposes". These watersheds are generally small (<500 km^2) with short stream response times and minimal opportunities for dilution or settling. The purpose of this program is to accumulate the baseline data necessary to assess water quality and to establish ambient water quality objectives on an individual community watershed basis. Water quality objectives provide policy direction for resource managers, serve as a guide for issuing permits, licences, and orders by the Ministry of Environment (MOE), and establish benchmarks for assessing the Ministry's performance in protecting water quality.

There are over 60 community watersheds within the Vancouver Island Region of the Ministry of Environment. Rather than developing water quality objectives for each of the watersheds on an individual basis, an ecoregion approach has been implemented. The ecoregions are based on the ecosections developed by Demarchi (1996), however, for ease of communication with a wide range of stakeholders the term "ecoregion" has been adopted by Vancouver Island MOE regional staff. Thus, the Vancouver Island Region has been split into 11 terrestrial ecoregions, based on features such as climate, geology, soils and hydrology (Figure 1). Due to accessibility and holding time of samples, only the six ecoregions on Vancouver Island are being considered at this time. Fundamental baseline water quality should be similar in all streams and all lakes throughout each ecoregion. However, the underlying physical, chemical and biological differences between streams and lakes must be recognized. Representative lake and stream watersheds within each ecoregion are selected (initially stream focused) and a three-year monitoring program is implemented to collect water quality and quantity data, as well as biological data. Standard base monitoring programs have been established for use in streams and lakes to maximize data comparability between watersheds and among ecoregions, regardless of location. Watershed objectives will be developed for each of the representative lake and stream watersheds based on this data, and these objectives will also be applied on an interim basis to the remaining lake and stream watersheds within that ecoregion. Over time, other priority watersheds within each ecoregion will be monitored for one year to verify the validity of the objectives developed for each ecoregion and to determine whether the objectives are being met for individual watersheds.

Partnerships formed between the Ministry of Environment and local municipalities and stewardship groups are another key component of the water quality network. Water quality sampling conducted by the public works departments of local municipalities as well as stewardship groups have enabled the Ministry to significantly increase the number of watersheds studied and the sampling regime within each watershed. These partnerships have not only allowed the Ministry to study watersheds over a greater geographic range and in more eco-sections across Vancouver Island, but have also resulted in a strong relationship with stakeholders, provided valuable input and local support and, ultimately, have resulted in a more effective monitoring program.

This report examines the existing water quality of Newcastle Creek and recommends water quality objectives for this watershed based on potential impacts and water quality parameters of concern. Newcastle Creek is a third-order stream, 6.5 km in length. It flows into Johnstone Straight near the community of Sayward, BC on the east coast of Vancouver Island. The portion of the watershed designated as a community watershed includes the upper reaches of Newcastle Creek above the Sayward water intake (Figure 2. Newcastle Creek community watershed.

) which is located approximately 1.5 km upstream from its confluence with Salmon Bay. Anthropogenic land uses within the watershed include timber harvesting and recreation. These activities, as well as natural erosion and the presence of wildlife, can all potentially affect water quality in Newcastle Creek.

Figure 1. Overview of Vancouver Island terrestrial Ecoregions (based on ecosection divisions in Demarchi (1996).

Figure 2. Newcastle Creek community watershed.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

The community watershed portion of Newcastle Creek is approximately 912 ha in area and ranges from approximately 700 m elevation at the Sayward water intake to about 1,200 m in the upper watershed. The creek is approximately 6.5 km long in total, and about 5 km long from the its headwaters near Newcastle Ridge to the Sayward intake. There are a few small, unnamed lakes in the upper reaches of the watershed.

The majority of the watershed falls within the Coastal Western Hemlock (submontane very wet maritime, CWHvm1) biogeoclimatic zone, with higher elevations (above about 950 m) falling within the Mountain Hemlock (windward moist montane, MHmm1) biogeoclimatic zone. Newcastle Creek falls within the Northern Island Mountains (NIM) ecoregion established for Vancouver Island by MOE staff (see Figure 1).

2.2 HYDROLOGY AND PRECIPITATION

The nearest climate station to the watershed for which climate normal data is available is at Campbell River (elevation 105 m, Environment Canada Climate Station 1021261), approximately 60 km southeast of Sayward. Weather patterns are likely quite similar between the two sites, as they are both located on the east coast of Vancouver Island, and both are near sea level. Average daily temperatures in Campbell River ranged from 1.3^{o}C in January to 16.9^{o}C in July and August for the 30-year period between 1971 and 2000. Average total annual precipitation is 1,452 mm, with only 109 mm (water equivalent) (8%) of this falling as snow (Figure). A larger portion of the annual total precipitation occurs as snowfall in the higher-elevation terrain of the watershed. Most of the precipitation (1,091 mm, or 75%) falls between October and March.

Hydrometric data was collected as part of an automated monitoring program between 2003 and 2005, and shows peak water levels occurring between September and January (Figure). Water Survey Canada has not operated a hydrometric station on Newcastle Creek.

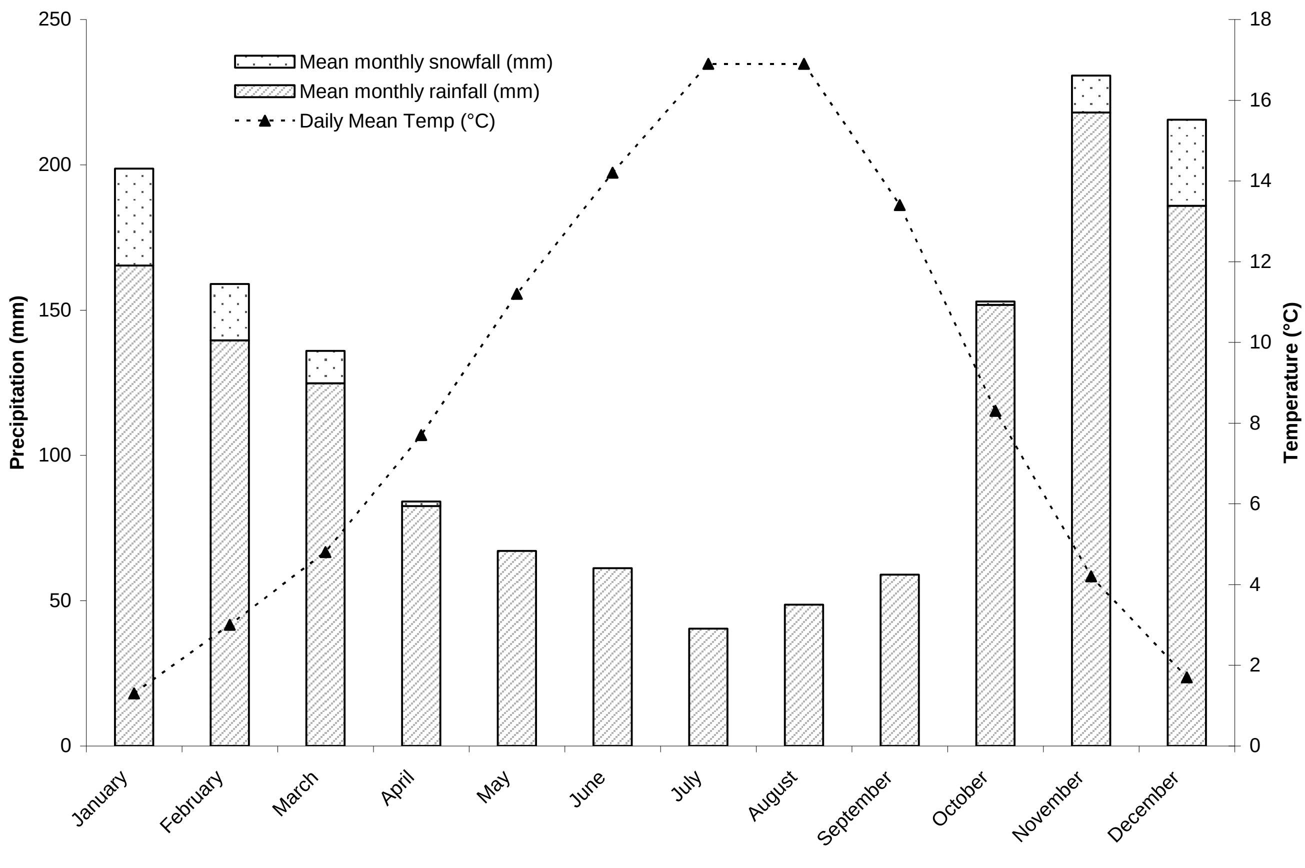

Figure 3. Climate normal data for Campbell River (Environment Canada Climate Station 1021261) for the period 1971 to 2000.

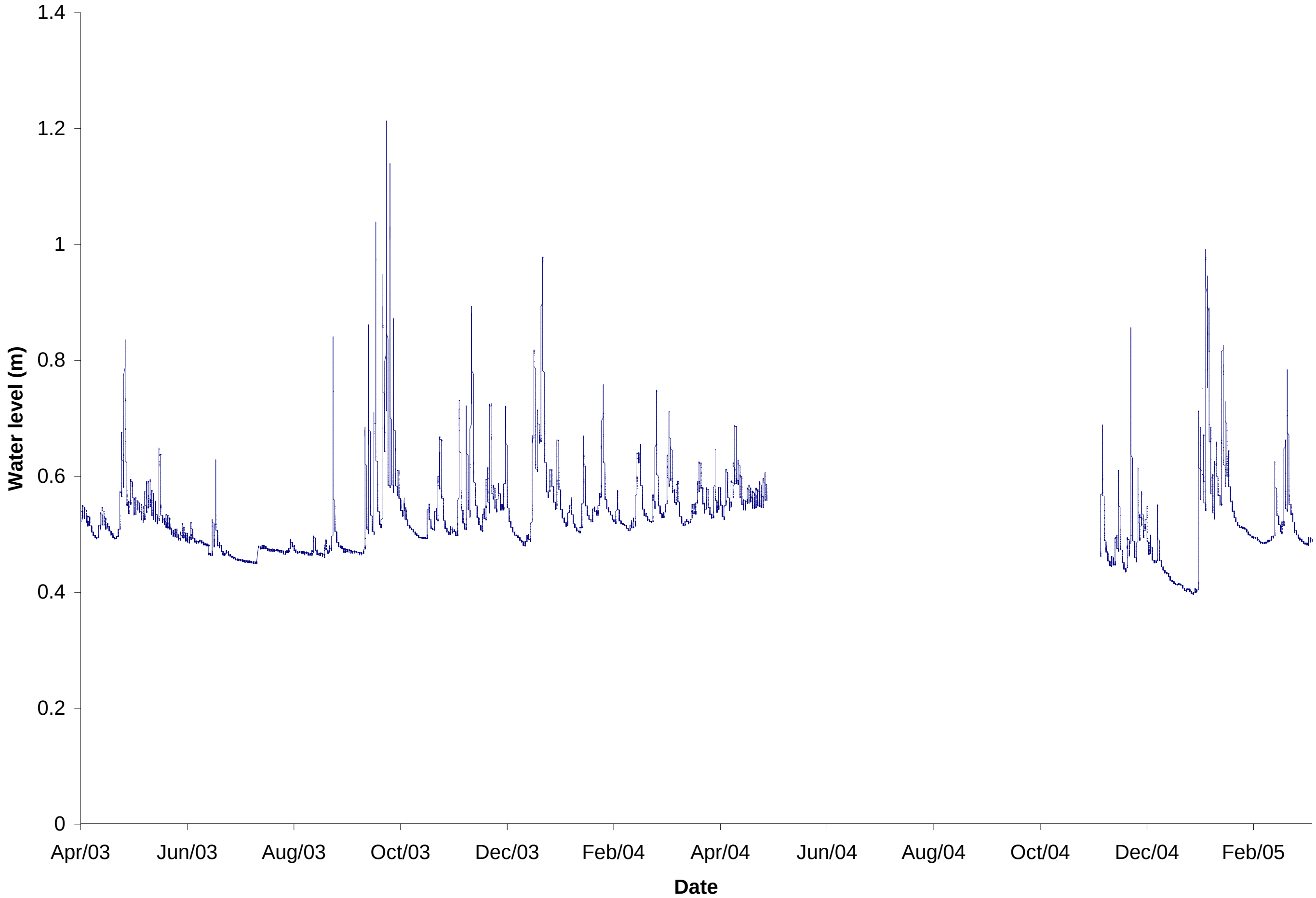

Figure 4. Water level data for EMS Site E229564, Newcastle Creek near the Sayward Intake, 2003 – 2005. Note due to equipment malfunction data was not collected from June to November 2004.

3.0 WATER USES

3.1 WATER LICENSES

Two water licenses have been issued for Newcastle Creek, both to the Village of Sayward under a Waterworks – Local Authority license, with a total allocation of 845 dam^3/year.

3.2 FISHERIES

No fisheries data are available for Newcastle Creek (FISS, 2005). The relatively steep stream gradient and lack of lakes in the watershed suggests that fish habitat is likely limited within the watershed.

3.3 RECREATION

No specific studies have been conducted to determine the recreational use of the Newcastle Creek watershed, but the presence of logging roads throughout the watershed allows recreational access. There are no BC Forest Service recreation sites located in the Newcastle Creek watershed.

3.4 WILDLIFE

The Newcastle Creek watershed provides habitat to a variety of species typical of the west coast of Vancouver Island, including blacktail deer, black bear, cougar, and numerous other small mammals and birds. The BC Conservation Data Centre (CDC) lists one Species of Special Concern, the *anguina* subspecies of ermine (*Mustela erminea anguina*), that has been observed within the watershed boundaries (CDC, 2005).

3.5 DESIGNATED WATER USES

Designated water uses are those water uses that are designated for protection in a watershed or waterbody. Water quality objectives are designed for the substances or conditions of concern in a watershed so that attainment of the objectives will protect the most sensitive designated uses.

The Newcastle Creek community watershed is the primary source of drinking water for the Village of Sayward. As such, the main goal should be to protect water for domestic purposes and recognize aquatic life and wildlife as other designated uses.

4.0 INFLUENCES ON WATER QUALITY

Newcastle Creek is located in Tree Farm Licence 39, managed by Island Timberlands. There are no licensed discharges within the watershed. Recreational use is generally limited to seasonal activities such as hunting, and there are no sanctioned camping areas within the watershed. Therefore, the primary concerns with regards to potential anthropogenic impacts on water quality in Newcastle Creek are associated with forestry activities.

4.1 LAND OWNERSHIP

The community watershed portion of Newcastle Creek consists primarily of Crown Lands. As such, there are no private households located within the community watershed boundaries, and so potential sources of contamination associated with households (such as septic fields) will not impact water quality in the upper Newcastle Creek.

4.2 LICENSED WATER WITHDRAWALS

Water licenses can impact aquatic habitat downstream from the withdrawal, especially during low-flow periods. As mentioned in Section 3.1, there are two licensed water withdrawals from the Newcastle Creek community watershed, with an overall maximum volume of 845 dam^3/year. Assuming water was withdrawn from Newcastle Creek at a constant rate throughout the year (an unlikely scenario), this would result in an average withdrawal rate of 0.027 m^3/s. As no flow data is available for Newcastle Creek, it is uncertain whether this volume of water is likely to impact flows downstream from the intake. Given the location of the watershed, and the amount of rain this area receives, low flows are likely not of great concern.

4.3 FOREST HARVESTING AND FOREST ROADS

Forestry activities can impact water quality both directly and indirectly in several ways. The removal of trees can decrease water retention times within the watershed and result in a more rapid response to precipitation events and earlier and higher spring freshets. The improper construction of roads can change drainage patterns, destabilize slopes and introduce high concentrations of sediment to streams.

The Newcastle Creek community watershed consists primarily of old growth forest; there has been little historical logging within the community watershed boundaries.

4.4 RECREATION

Recreational activities can affect water quality in a number of ways. Erosion associated with 4-wheel drive and ATV vehicles, direct contamination of water from vehicle fuel, and fecal contamination from human and domestic animal wastes (*e.g.*, dogs or horses) are typical examples of potential effects. As no specific studies have been conducted on recreation within the Newcastle Creek watershed, the relative impacts of recreational activities cannot be discussed, but they are likely to be minimal due to the lack of camping areas within the watershed.

4.5 WILDLIFE

Wildlife can influence water quality because warm-blooded animals can carry pathogens such as *Giardia lamblia*, which causes giardiasis or “beaver fever”, and *Cryptosporidium* oocysts which cause the gastrointestinal disease, cryptosporidiosis. Virtually every mammal ever tested can carry *Giardia*, while aquatic mammals and domestic livestock carry *Cryptosporidium*. In addition, warm-blooded animals excrete fecal coliforms in their feces, and can cause elevated levels of this indicator in water. Fecal contamination of water by animals is generally considered to be less of a concern to human health than contamination by humans because there is less risk of inter-specific transfer of pathogens. However, without specific source tracking methods, it is impossible to determine the origins of coliforms.

Because of the variety of wildlife species present in the watershed (Section 3.4), a risk of fecal contamination from natural wildlife populations within the watershed does exist.

4.6 MINING AND PERMITTED DISCHARGES

There are no historical mining activities recorded within the Newcastle Creek watershed, nor are there any reports of mineral prospects (MINFILE 2005). As such, there is a low likelihood of mining activities occurring within the watershed in the foreseeable future. Also, there are no permitted discharges within the Newcastle Creek watershed.

5.0 DESCRIPTION OF WATER QUALITY MONITORING DATA

This report provides an assessment of water quality data collected from 1997 to 2005 in the Newcastle Creek watershed. Key drinking water characteristics such as fecal coliforms, turbidity, colour, pH, phosphorus, nitrate, nitrite and specific conductivity are considered to protect raw drinking water supplies. Drinking water is the most sensitive water use in Newcastle Creek for these characteristics. In addition, based on current knowledge of potential anthropogenic impacts to the watersheds (generally associated with forestry), and the lack of permitted waste discharges to any of the watersheds, these are the water quality parameters most likely to change should impacts occur. Nutrient (nitrate, nitrite and phosphorus) concentrations are also considered as these parameters may be influenced by forestry-related activities.

5.1 WATER SAMPLING PROCEDURES

One water quality monitoring site was selected within the Newcastle Creek watershed: EMS Site #E229564, Newcastle Creek at the water intake (Figure 2).

Water samples were collected at this site a few times in 1998 and 1999 and then on a monthly basis between October 2001 and May 2005. The sampling frequency was increased to weekly during summer low-flows and during fall peak-flows. Samples were collected according to Resource Inventory Standards Committee (RISC) standards (RISC, 1997). Water samples were then sent to a laboratory for analyses of fecal coliforms, *E.*

coli, turbidity, non-filterable residue, temperature, true colour, specific conductivity, pH, nitrate and nitrite, total phosphorus, and metals concentrations.

An automated water quality/quantity monitoring station was also installed at site E229564 to measure water temperature, turbidity, specific conductivity and water levels at 15-minute intervals. The station operated from April 2003 to March 2005.

Benthic invertebrates were collected in the fall of 2004 to provide a picture of the overall ecosystem health of the watershed.

5.2 QUALITY ASSURANCE / QUALITY CONTROL

Water samples were collected in strict accordance with RISC standards, by trained personnel. Quality assurance and quality control was also verified by collecting duplicate samples. Duplicate co-located samples are collected by filling two sample bottles in as close to the same time period as possible (one right after the other) at a monitoring location, and then calculating the percent difference between the laboratory results reported for the various samples. The maximum acceptable percentage difference between duplicate sample results is 25% (results must be at least five times the method detection limit).

Two sets of duplicate samples were collected during the sampling program (Appendix I). In 92% of the instances, relative percent mean differences and relative percent standard deviations were found to be within acceptable limits as discussed above. For the remaining samples, concentrations were almost invariably less than five times the detection limits, and therefore the guidelines for interpreting acceptability do not apply. Based on these samples, the data can be considered to be within acceptable limits for data quality.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

There are two sets of guidelines that are commonly used to determine the suitability of drinking water. The British Columbia water quality guidelines (BC Ministry of Environment, 2006) are used to assess water at the point of diversion into a waterworks system. These BC guidelines are also used to protect other designated water uses such as habitat for aquatic life. The Guidelines for Canadian Drinking Water Quality (Health Canada, 2006) are national guidelines that apply to drinking water at the point of consumption after treatment processes that may include particle removal and bacterial disinfection. The Ministry of Health requires water purveyors to disinfect all surface water as a minimum prior to drinking (*Drinking Water Protection Act* – Drinking Water Protection Regulation 2005).

6.1 COLIFORM BACTERIA

Coliform bacteria are present in large numbers in the feces of warm-blooded animals and, although rarely pathogenic themselves, are used as indicators of fecal contamination in water. Fecal coliforms are quite specific to the feces of warm-blooded animals and *E. coli* are even more specific, whereas total coliforms have many non-fecal sources (e.g. soils, plants), and are thus less indicative of fecal contamination. Coliforms generally do not survive long in cold, fresh water (Brettar and Höfle, 1992), but can survive for prolonged periods in stream sediment, soils or fecal material; when associated with particulate matter; or in warmer water (Howell *et al.*, 1996; Tiedemann *et al.*, 1987). Disturbance of these sediments can therefore result in coliforms appearing in overlying water for extended periods (Jawson *et al.*, 1982; Stephenson and Rychert, 1982). The inclusion of a small piece of fecal matter in a sample can result in extremely high concentrations (>1,000 CFU/100 mL), which can skew the overall results for a particular site. It is therefore important to consider the range of values, as well as the standard deviation, to determine if results are consistently high or if one value "artificially" inflated the mean. For this reason, the 90th percentile is used to determine if the water quality guideline is exceeded, as extreme values would have less effect on the data. Water from Newcastle Creek is chlorinated prior to consumption. The drinking water guideline for raw waters receiving disinfection is that the 90th percentile of at least five weekly samples collected in a 30-day period be less than 10 CFU/100 mL (B.C. Ministry of Environment, 2006).

Fecal coliform concentrations were measured 36 times in Newcastle Creek, with values ranging from below detection limits (<1 CFU/100 mL) to a maximum of 20 CFU/100 mL. Elevated coliform samples typically occurred in October and November each year. Samples were collected with sufficient frequency (a minimum of five weekly samples within 30 days) on four occasions and the 90th percentile for these sets of samples ranged from 4.2 CFU/100 mL to 14.4 CFU/100 mL. Only the maximum 90th percentile fecal coliform value of 14.4 CFU/100mL exceeded the drinking water guideline for the period between October 22 and November 19, 2003. The average for all four 90th percentiles is approximately 8 CFU/100 ml.

E. coli concentrations ranged from below detection limits (< 1 CFU/100 mL) to 18 CFU/100 mL, for 34 samples collected between October 10, 2001 and October 27, 2004. The requisite sampling frequency (at least five weekly samples in 30 days) was met on five occasions, and the 90th percentile ranged from 2.2 CFU/100 mL to 13.0 CFU/100 mL. The average 90th percentile for all five sample periods was 6.0 CFU/100mL. Similar to the fecal coliform results, the maximum 90th percentile *E. coli* value of 13.0 CFU/100 mL exceeded the drinking water guideline for the period between October 22 and November 19, 2003.

The 90th percentile for samples of both fecal coliforms and *E. coli* exceeded the drinking water guideline on one occasion, suggesting that coliforms are occasionally a problem in Newcastle Creek. As there is limited road access to the upper watershed it is likely that the source of these coliforms is the endemic wildlife and the values collected during this three year sampling program are reflective of natural or background concentrations. ***Therefore, it is recommended that the 90th percentile of a minimum of 5 weekly samples collected within a 30-day period must not exceed 10 CFU/100mL for fecal coliforms and/or* E.coli.** These objectives will provide protection from fecal coliform bacteria (including *E. coli*) but not from parasites such as *Cryptosporidium* or *Giardia*.

Sampling for these pathogens falls under the auspices of the water purveyor, in this case the Village of Sayward.

6.2 pH

pH is a measure of the concentration of hydrogen ions (H^+) in water, which can range over 14 orders of magnitude, and is defined on a logarithmic scale between 0 and 14. A pH between 0 and 7 is acidic (the lower the number, the more acidic the water) and a pH between 7 and 14 is alkaline (the higher the number, the more basic the water). The aesthetic objective for drinking water is a pH between 6.5 and 8.5 (B.C. Ministry of Environment, 2006). Corrosion of metal plumbing may occur at both low and high pH outside of this range, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range.

pH in the Newcastle Creek watershed was near-neutral, with values ranging from 6.6 to 7.6 pH units and a mean of 7.1 pH units. All pH values were well within the drinking water guideline, suggesting that pH is not a concern within the Newcastle Creek watershed.

6.1 Temperature

Temperature is considered in drinking water for aesthetic reasons. The aesthetic guideline is 15°C – temperatures above this level are considered to be too warm to be aesthetically pleasing (B.C. Ministry of Environment, 2006). For the protection of aquatic life, the allowable hourly change in temperature is +/-1°C from naturally occurring levels. This guideline is established in situations where wastewater is discharged into a body of water, and therefore does not apply to this watershed. For salmonids and other cold water species, there are a number of guidelines set depending on the species and life stage of the fish. For trout species, the optimum temperature ranges are: 9 – 13°C for incubation; 15 – 19°C for rearing; and 9 – 16.5°C for spawning (B. C. Ministry of Environment, Lands and Parks, 2001). However, as it does not appear that Newcastle Creek provides significant habitat for fish species, these guidelines do not apply. There are provincial guidelines for streams with unknown fish distributions that would apply. However, the drinking water guidelines are still more stringent and would protect aquatic life as well as drinking water.

Water temperatures in Newcastle Creek varied seasonally, with maximum temperatures occurring in mid-August each year. Water temperatures measured by the automated station ranged from near 0°C in the winter months to a maximum of 14.6°C in August 2004 (Figure).

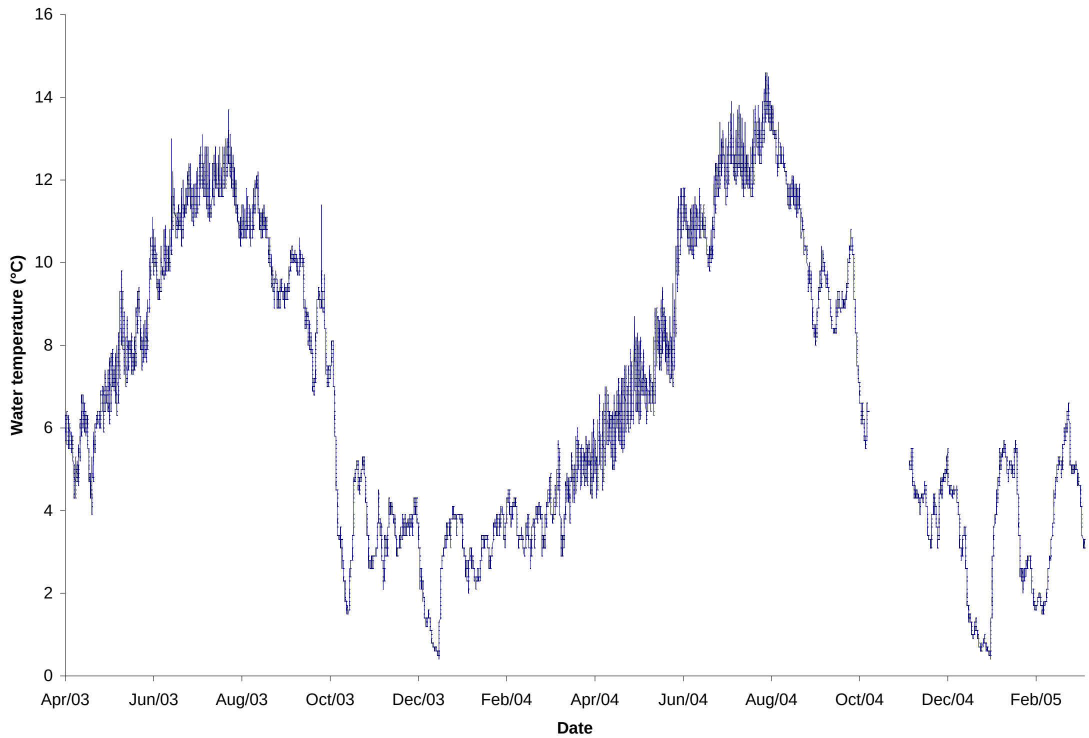

Figure 5. Automated water temperature data collected from Newcastle Creek at the intake between April 2003 and March 2005.

Water temperatures remained consistently below the aesthetic guideline of 15°C over the course of the monitoring program. However, it is possible that activities such as forest harvesting (especially along the stream bank, where cover is reduced) could cause increases in water temperature to the point where this guideline is occasionally exceeded. ***For this reason, a water quality objective is proposed for temperature in Newcastle***

Creek. The objective is that maximum instantaneous water temperatures should not exceed 15°C during the summer months, and the maximum hourly temperature change should not exceed 1°C. Attaining this objective will also protect aquatic life in streams with unknown fish distributions.

6.2 True Colour

Colour in water is caused by dissolved and particulate organic and inorganic matter. True colour is a measure of the dissolved colour in water after the particulate matter has been removed, while apparent colour is a measure of the dissolved and particulate matter in water. Colour can affect the aesthetic acceptability of drinking water, and the aesthetic guideline is a maximum of 15 true colour units (TCU) (B.C. Ministry of Environment, 2006). However, this drinking water guideline only applies to systems in which background color levels are less than or equal to 15 TCU. Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products such as trihalomethanes.

Colour in Newcastle Creek ranged from 10 TCU to 45 TCU, with an average of 20 TCU for 11 samples collected. Most of the samples had colour values exceeding the aesthetic guideline of 15 TCU. It is likely that colour in the watershed is a result of natural processes (high concentrations of organics in the boggy portions of the upper watershed) rather than anthropogenic activities, but it is possible that human activities may cause further increases in true colour. During the monitoring period there has been little or no activity in the watershed and, as such, color values are relatively constant but are subject to some fluctuations during rain storm events. This suggests that the data collected actually reflects background levels. Based on the 90th percentile of the data set the true color background levels are 22.5 TCU, which indicates that the drinking water supply guideline for raw water based on aesthetics considerations does not apply to Newcastle Creek.

High color values are usually associated with higher levels of organic matter (see Section 6.5 Total Organic Carbon) which can increase the level of disinfection by-products being produced after chlorination. These disinfection by-products can be a risk to human health. Therefore, the water purveyor, in this case, the District of Sayward, needs to consider additional water treatment methods, prior to chlorination, to remove the organics and reduce disinfection by-product formation.

To protect aquatic life, the true colour guideline is stated that the average of 5 weekly samples in 30 days not exceed the background level by more than 5 TCU in clear water systems (background levels less that or equal to 20 TCU) or by more than 20% in colored systems (background levels greater than 20 TCU) (B.C. Ministry of Environment, 2006). Given that background levels exceed 20 TCU**,** an objective has been developed based on the 90th percentile of the data set (background) plus 20% background to reflect natural variability. ***Thus, an objective of 27 TCU is proposed based on the mean of 5 weekly samples in 30 days to reflect no further increases to true color concentrations from any future activities in the watershed.***

6.3 TOTAL ORGANIC CARBON

Most waters contain organic matter that can be measured as total organic carbon (TOC). Sources of organic carbon in fresh waters include living material (plants and animals), waste materials and effluents. Total organic carbon consists of dissolved (DOC) and particulate organic carbon (POC) and is therefore affected by pronounced fluctuations in suspended solids in riverine systems. Elevated TOC levels (above 4.0 mg/L) can result in higher levels of disinfection by-products in finished drinking water if chlorination is used to disinfect the water (BC Ministry of Environment, 2006). As the Village of Sayward uses chlorine to disinfect their drinking water, TOC concentrations were monitored.

Concentrations of TOC ranged from 1.1 mg/L to 8.8 mg/L with an average of 4.5 mg/L for 14 samples collected, suggesting that TOC may be a concern in Newcastle Creek. As with true colour, it may be that anthropogenic activities are not impacting TOC levels in Newcastle Creek and the higher concentrations found in the creek are due to natural conditions within the watershed. During the monitoring period there has been little or no activity in the watershed and as such TOC values have been maintained at a relatively constant level with some fluctuations during rain storm events. This suggests that the data collected actually reflects background levels and as such the objective for TOC was developed based on the 90th percentile of the data set. ***Therefore, an objective is proposed for the Newcastle Creek community watershed, such that TOC concentrations at the Sayward Intake should not exceed 6.5 mg/L based on the mean of 5 weekly samples collected over a 30-day period. It is recognized that this objective exceeds the provincial drinking water guideline of 4.0 mg/L, however, it reflects natural background levels. This value is meant to ensure no further increase to total organic carbon concentrations from future activities in the watershed.*** If there are concerns over the naturally high TOC values (and corresponding high true color values), and the subsequent higher potential for the formation of disinfection by-products, the raw water should be treated to remove organics prior to chlorination.

It should be noted that while drinking water supply is the most sensitive use for this parameter (guideline value of 4.0 mg/L), there is also a water quality guideline for TOC for the protection of aquatic life, which is based on the 30-day median ± 20% of the median background concentration. Assuming that the data collected reflects background levels as mentioned above, TOC data in this equation also produces an objective of 6.5 mg/L. Therefore the proposed TOC objective of 6.5 mg/L will protect all uses in the watershed.

6.4 CONDUCTIVITY

Conductivity refers to the ability of a substance to conduct an electric current. The conductivity of a water sample gives an indication of the amount of dissolved ions in the water. The more ions dissolved in a solution, the greater the electrical conductivity. Because temperature affects the conductivity of water (a 1ºC increase in temperature results in approximately a 2% increase in conductivity), specific conductivity is used (rather than simply conductivity) to compensate for temperature. For drinking water a maximum specific conductivity of 700 μS/cm is allowed (BC Ministry of Environment, 2006). Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 μS/cm), while interior watersheds generally have higher values. Increased flows resulting from precipitation events or snowmelt tends to dilute the ions, resulting in decreased specific conductivity levels with increased flow levels. Therefore, water level and specific conductivity tend to be inversely related. However, in situations such as landslides where high levels of dissolved and suspended solids are introduced to the stream, specific conductivity levels tend to increase. As such, significant changes in specific conductivity can be used as an indicator of potential impacts.

In Newcastle Creek, laboratory results for specific conductivity values ranged from < 2 µS/cm to 37 µS/cm, with an average of 24 µS/cm (n = 40). Automated monitoring data showed slightly lower results with values ranging from 1 µs/cm to 28 µS/cm and an average of 11 µS/cm. Values were closely correlated with flows, with the highest conductivity occurring during low flows (when dilution was lowest) and conductivity values dropping during the winter (when dilution from rainfall was highest) (Figure). All values were well below the drinking water guideline of 700 µs/cm, and no objective is proposed for specific conductivity.

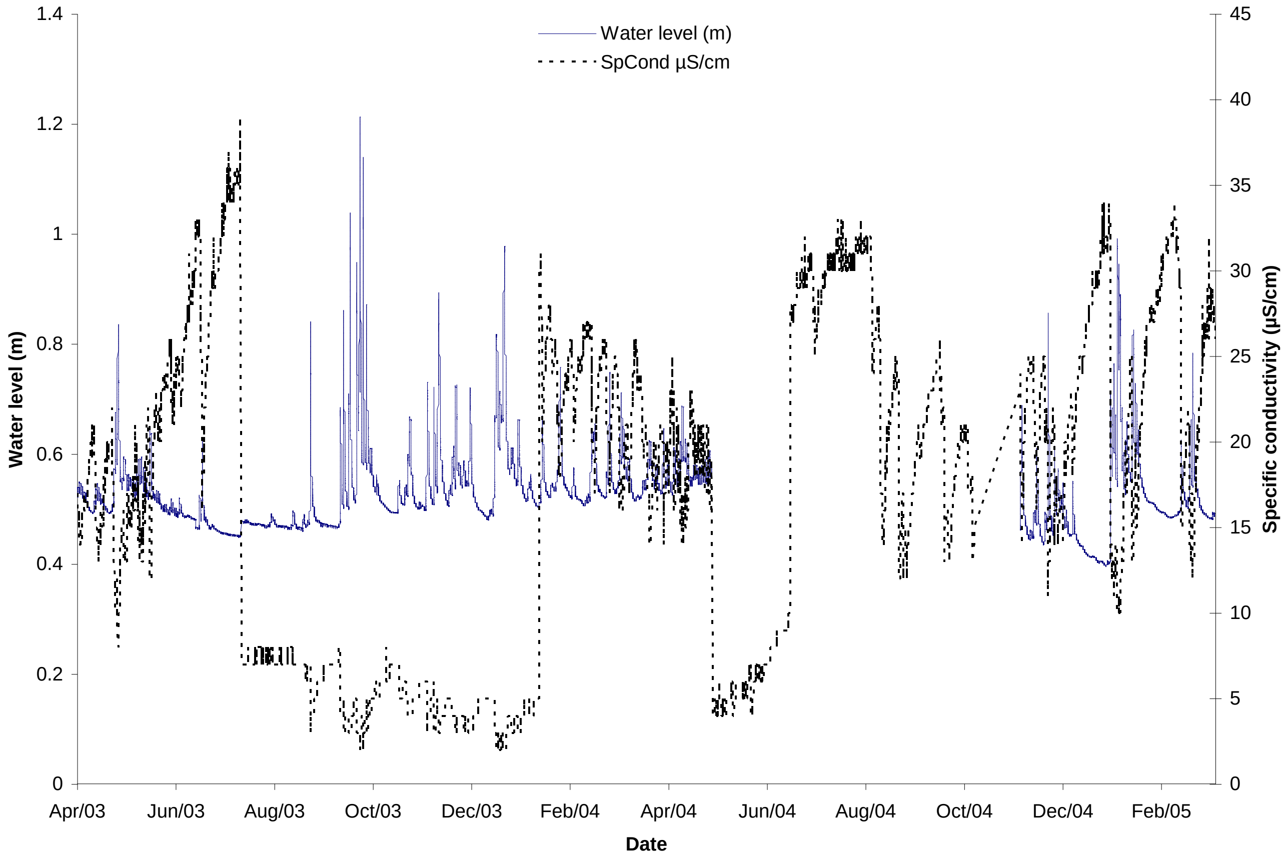

Figure 6. Specific conductivity and water level measured at the Ministry of Environment automated monitoring station between April 2003 and March 2005.

6.5 TURBIDITY

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water as nephelometric turbidity units (NTU). Elevated turbidity levels can decrease the efficiency of disinfection, allowing pathogens to enter the water system. As well, there are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures. The guideline for raw drinking water of exceptional clarity (i.e. < 5NTU) that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU and a maximum turbidity of 5 NTU at any time (BC Ministry of Environment, Lands and Parks, 1997). In general, it is assumed that turbidity values greater than 2 NTU will compromise disinfection efficiency (VIHA pers. comm. 2006).

At the intake site, turbidity values ranged from < 0.1 NTU to 0.83 NTU, with an average of 0.23 NTU for the 47 samples collected between 1998 and 2005.

Turbidity values were also measured by the automated water quality monitoring station situated at the Sayward intake dam. Here, a McVan analyte turbidity sensor was installed within the stream flow and polled every 15 minutes by a FWS-12 datalogger. A summary of turbidity data collected between May, 2003 and February, 2005 is given in Table 1 and Figure 7. The distribution of data shows that about 98% of values were below 1 NTU, and that only about 1.6% of the time, or about 254 of the 16,000 hours when turbidity was measured over the course of the study, did turbidity values exceed the drinking water guideline of 5 NTU.

Table 1. Summary of automated turbidity data measured at Newcastle Creek at Sayward intake station between April 2003 and March 2005.

	Number	Percentage	Cumulative %
Number Turbidity ≤ 1 NTU	62,178	97.8%	97.8%
Number Turbidity > 1, ≤ 5 NTU	365	0.6%	98.4%
Number Turbidity > 5, ≤ 10 NTU	124	0.2%	98.5%
Number Turbidity > 10, ≤ 50	375	0.6%	99.1%
Number Turbidity > 50	550	0.9%	100.0%
Totals	**63,592**	**100**	

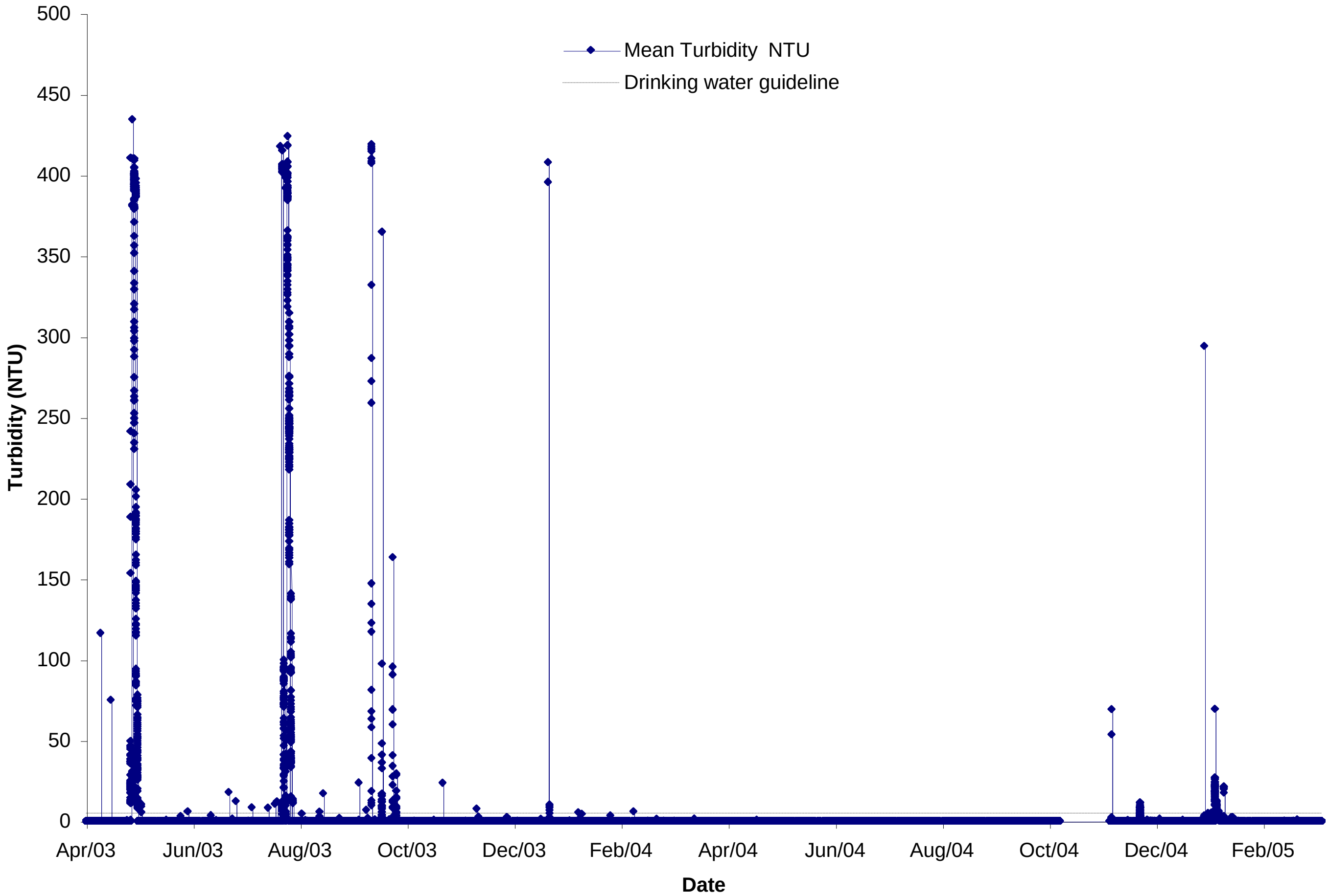

Figure 7. Turbidity levels in Newcastle Creek between April 2003 and March 2005 as measured on 15-minute intervals by the automated water quality monitoring station near the Sayward intake.

It is important to consider not only the total amount of time the criterion was exceeded, but also how long each exceedence lasted. For example, high turbidity levels for five consecutive hours are more likely to impact drinking water quality than five one-hour events separated by a few hours of low-turbidity water. Figure 7 shows a summary of the intensity and duration of turbidity events occurring at the automated station between 2003 and 2005. A turbidity event, for the sake of this summary, is defined as a number of consecutive turbidity values measured at 15-minute intervals exceeding the 5 NTU threshold. The recovery time is the length of time that has passed since the previous turbidity event (*i.e.*, since the turbidity last exceeded 5 NTU). For the sake of brevity and ease of reading, Table 2 includes only the longest-duration events (*i.e.*, events over 6 hours in length) – the remainder of the summary is included as Appendix III, arranged in chronological order. The longest turbidity event was over 85 hours in length, with maximum values of over 400 NTU. The majority of turbidity events (especially the longer events) occurred in 2003. This may be due to variations in environmental conditions during that year (heavy rainfalls, etc.).

Table 2. Summary of turbidity events exceeding 6 hours in duration reported by automated turbidity meter at Ministry of Environment station between 2003 and 2005.

Start Date	Start Time	Recovery Time (hrs)	Water Level (m)	Change in water level (m)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
22/08/2003	12:45	1	0.467	0.002	9.25	57.9	0	39.4	9.3
18/08/2003	19:15	0.5	0.472	0	9.75	63.8	2.5	29.3	19.9
21/01/2005	15:45	14	0.794	0.002	11.75	27	4.8	14.5	6.8
28/05/2003	9:15	7	0.583	-0.01	12.25	78.3	0	44.1	21.7
17/08/2003	19:15	0.5	0.474	-0.002	18.75	100	4.3	46.8	37.0
21/08/2003	13:45	1	0.47	-0.002	22.25	270.9	0	139.0	75.2
19/08/2003	21:45	16	0.472	-0.002	39.25	424	4.2	334.9	69.1
24/05/2003	13:15	1	0.695	-0.109	85.25	434.4	0	166.1	159.8

Turbidity is notoriously difficult to measure accurately with automated equipment due to the wide variety of factors that can affect measurements, including fish and other aquatic organisms, algae and air bubbles. Appendix IV shows a comparison of laboratory results compared with the automated data collected at the same time. These data show that in all instances, turbidity values reported by the laboratory and by the automated equipment were within 2 NTU, which is an acceptable range. However, all of the samples were collected when turbidity was very low (< 1 NTU), and are therefore not indicative of the occasional turbidity events that occur in this watershed. Future monitoring should focus on collecting water samples following significant rain events, in order to try and capture these occasional elevated turbidity levels.

During the monitoring period there has been little or no activity in the watershed suggesting that the data collected actually reflects background levels. The turbidity levels during this period have remained at a constant level (98% of values were below 1 NTU) with only minor fluctuations during rain storm events. ***Therefore the recommended***

objective for turbidity measured at the intake is a mean of ≤2 NTU, based on five weekly samples collected within a 30-day period, and no results exceeding 5 NTU at any time. It should be noted that turbidity values above 2.0 NTU are considered likely to affect disinfection in a chlorine-only system. An alternative to the average objective of 2.0 NTU would be to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency.

6.6 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS) (also referred to as non-filterable residue or NFR) include all of the undissolved particulate matter in a sample. This value is usually closely correlated with the turbidity value, however, unlike turbidity it is not measured by optics. Instead, a quantity of the sample is filtered, and the residue is dried and weighed so that a weight of residue per volume is determined. No guideline has been established for drinking water at this time, however for the protection of aquatic life the induced TSS concentrations should not exceed background levels by more that 25 mg/L during any 24 hour period, when background is less than or equal to 25 mg/L, and the average TSS concentrations (five weekly samples in 30 days) should not exceed background by more than 5 mg/L (B.C. Ministry of Environment, 2006).

Concentrations of total suspended solids were generally below method detection limits (47 of 52 measurements were <1 mg/L) with a maximum value of 4 mg/L. Based on the samples that have been collected, it does not appear that suspended solids are a concern in Newcastle Creek at this time. However, suspended solids can be related to turbidity and color values, for which objectives have been recommended. During the monitoring period there has been little or no activity in the watershed, and as such the total suspended solids have remained at a constant level suggesting that the data collected actually reflects background levels. Based on the 90^{th} percentile of the data collected background TSS levels for both maximum and 30 day average for Newcastle Creek is 1 mg/L. ***Therefore, it is recommended that maximum total suspended solids measured at the intake should not exceed 26.0 mg/L at any time and the mean of five weekly samples in a 30 day period should not exceed 6.0 mg/L.*** This reflects an induced level above background as recommended from the guidelines. The objective is meant to apply to situations which result from human activities within the watershed.

6.7 NUTRIENTS (NITRATE, NITRITE AND PHOSPHORUS)

The concentrations of nitrogen (including nitrate and nitrite) and phosphorus are important parameters, since they tend to be the limiting nutrients in biological systems. Productivity is therefore directly proportional to the availability of these parameters. Nitrogen is usually the limiting nutrient in terrestrial systems, while phosphorus tends to be the limiting factor in freshwater aquatic systems. In watersheds where drinking water is a priority, it is desirable that nutrient levels remain low to avoid algal blooms and foul tasting water. Similarly, to protect aquatic life, nutrient levels should not be too high or the resulting plant and algal growth can deplete oxygen levels when it dies and begins to decompose, as well as during periods of low productivity when plants consume oxygen (*i.e.*, at night and during the winter under ice cover). The guideline for the maximum concentration for nitrate in drinking water is 10 mg/L as nitrogen and the guideline for nitrite is a maximum of 1 mg/L as nitrogen (B.C. Ministry of Environment, 2006). When both nitrate and nitrite are present, their combined concentration must not exceed 10 mg/L as N.

For the protection of aquatic life, the BC MOE guideline (developed in 1986), for nitrate is a maximum concentration of 200 mg/L as N and an average of less than or equal to 40 mg/L as N. More recently the CCME (2002) has developed a nitrate guideline for aquatic life as a maximum concentration of 13 mg/L. The guideline for nitrite for the protection of freshwater aquatic life is a maximum concentration of 0.06 mg/L as nitrogen (CCME, 2002). The provincial nitrite guideline for nitrite is chloride dependent and varies from a maximum of 0.06 mg/L with a chloride values of less than 2 mg/L to 0.60 mg/L with chloride concentrations greater than 10 mg/L (BC Ministry of Environment, 2006) .

Nitrogen concentrations were measured in terms of dissolved nitrite (NO_2) and dissolved nitrate (NO_3). Dissolved nitrate concentrations ranged from below detectable limits (< 0.002 mg/L as nitrogen) to a maximum of 0.053 mg/L as nitrogen for 32 samples, while dissolved nitrite concentrations ranged from below detectable limits (< 0.002 mg/L as nitrogen) to a maximum of 0.005 mg/L as nitrogen. All values of both nitrate and nitrite species as N were well below the aquatic life guidelines.

Total phosphorus concentrations ranged from below detectable limits (< 0.002 mg/L) to a maximum of 0.023 mg/L for 40 samples collected during the program. There are no guidelines for P concentrations in streams, but P concentrations in Newcastle Creek are not likely to be a concern.

As concentrations of both nitrogen and phosphorus are generally low in Newcastle Creek, no objectives are proposed for these parameters.

6.8 METALS

Total metals concentrations were measured on 35 occasions in Newcastle Creek. The concentrations of most metals were below detectable limits, and well below guidelines for drinking water and aquatic life. However, the concentration of dissolved aluminum exceeded the drinking water guideline of 0.2 mg/L on one occasion, with a maximum concentration of 0.271 mg/L. It is likely that the occasional slightly elevated dissolved aluminum value is due to the natural geography of the area and not anthropogenic impacts, and unlikely to cause significant problems for drinking water quality. Therefore, no water quality objectives are proposed for metals concentrations in Newcastle Creek.

Metal speciation determines the biologically available portion of the total metal concentration. Only a portion of the total metals level is in a form which can be toxic to aquatic life. Naturally occurring organics in the watershed can bind substantial proportions of the metals which are present, forming metal complexes which are not biologically available. The relationship will vary both seasonally and depending upon the metal (e.g. copper has the highest affinity for binding sites in humic materials). Levels of organics as measured by dissolved organic carbon (DOC) vary from ecoregion to ecoregion. To aid in future development of metals objectives, DOC has been included in the Newcastle Creek monitoring program.

7.0 MONITORING RECOMMENDATIONS

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, freshet and summer low-flow) we recommend that a minimum of five weekly samples be collected within a 30-day period between August and September, as well as between November and February. Samples collected during the winter months should coincide with rain events whenever possible. In this way, the two critical periods (minimum dilution and maximum turbidity), will be monitored. Samples should be analyzed for general water chemistry (including TSS, turbidity, true colour, and DOC/TOC) as well as bacteriology (including fecal coliforms and *E. coli*). One of the samples collected during both the high-flow and low-flow period should also be analyzed for total and dissolved metals concentrations. Given the high levels of organics and subsequent higher true color values, it is also recommended that trihalomethanes be sampled, after chlorination at three locations within the distribution system (first tap, midway and end of system) on a quarterly basis. This sampling falls under the responsibility of the water purveyor, District of Sayward, and the local health authority (VIHA).

7.1 BENTHIC INVERTEBRATES

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. Biological data have been underutilized due to the highly specialized interpretation required and the difficulty in applying the data quantitatively. Notwithstanding this problem, with few exceptions, the most sensitive use of our water bodies is aquatic life. Therefore biological objectives need to be incorporated into the overall objectives development program.

In streams, benthic invertebrates have been accepted as a very important assessment tool. Considerable progress has been made in the development of benthic invertebrate indices, which can be incorporated into impact assessments and water quality objectives. On Vancouver Island, benthic sampling has been conducted at a limited number of sites over the past three years. The dataset at present is too limited to be able to make a sound judgment as to the state of the ecosystem health. To be able to apply and test the benthic invertebrate approach, Vancouver Island regional staff will be collecting more data at a broad range of both reference and test sites. Once all the data has been compiled and analyzed, biological objectives and/or indices will be developed for those watersheds where water quality objectives have already been developed.

8.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES AND MONITORING SCHEDULE

Table 3. Summary of proposed water quality objectives for Newcastle Creek community watershed (Site E229564).

Variable	Objective Value
Fecal Coliform Bacteria	≤10 CFU/100 mL (90th percentile based on a minimum of five weekly samples collected over a 30-day period)
Escherichia coli	≤10 CFU/100 mL (90th percentile based on a minimum of five weekly samples collected over a 30-day period)
Turbidity	2 NTU average (based on a minimum 5 weekly samples collected over a 30-day period) 5 NTU maximum
True Colour	≤ 27 TCU average (based on a minimum of five weekly samples collected over a 30-day period)
Total Suspended Solids	26 mg/L maximum in a 24-hour period 6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Total Organic Carbon	≤ 6.5 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)
Temperature	≤15°C (long-term) with hourly rate of change not exceeding 1°C

Designated water uses: drinking water, aquatic life, and wildlife

Table 4. Proposed schedule for future water quality and benthic invertebrate monitoring in Newcastle Creek.

Frequency and timing	Parameters to be measured
August – September (low-flow season): five weekly samples in a 30-day period	TSS, turbidity, DOC/TOC, true colour, fecal coliforms and *E. coli*
November – February (high-flow season): five weekly samples in a 30-day period	TSS, turbidity, DOC/TOC, true colour, fecal coliforms and *E. coli*
Once each during low-flow and high-flow season	Total and dissolved metals, nutrients (total phosphorus, nitrate, nitrite) and pH
Once every five years	Benthic invertebrate sampling

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Appendix I Summary of Duplicate Samples

Summary of duplicate samples collected from Newcastle Creek*.

Parameter	22-Oct-03		Relative % Difference
Ag-D (mg/L)	< 0.0001	< 0.0001	0%
Ag-T (mg/L)	< 0.0001	< 0.0001	0%
Al-D (mg/L)	0.0827	0.0775	6.5%
Al-T (mg/L)	0.0781	0.0759	2.9%
As-D (mg/L)	< 0.0001	< 0.0001	0%
As-T (mg/L)	< 0.0001	< 0.0001	0%
Ba-D (mg/L)	< 0.001	< 0.001	0%
Ba-T (mg/L)	0.0009	0.0009	0%
Be-D (mg/L)	< 0.0005	< 0.0005	0%
Be-T (mg/L)	< 0.0005	< 0.0005	0%
Bi-D (mg/L)	< 0.0005	< 0.0005	0%
Bi-T (mg/L)	< 0.0005	< 0.0005	0%
Cd-D (mg/L)	< 0.0001	< 0.0001	0%
Cd-T (mg/L)	< 0.0001	< 0.0001	0%
Co-D (mg/L)	< 0.0001	< 0.0001	0%
Co-T (mg/L)	< 0.0001	< 0.0001	0%
Cr-D (mg/L)	0.0004	0.0003	**28.6%**
Cr-T (mg/L)	0.0007	0.0006	15.4%
Cu-D (mg/L)	0.0007	0.001	**35.3%**
Cu-T (mg/L)	< 0.001	< 0.001	0%
Li-D (mg/L)	< 0.0001	< 0.0001	0%
Li-T (mg/L)	< 0.0001	< 0.0001	0%
Mn-D (mg/L)	0.0015	0.0013	14.3%
Mn-T (mg/L)	0.0014	0.0013	7.4%
Mo-D (mg/L)	< 0.0001	< 0.0001	0%
Mo-T (mg/L)	< 0.0001	< 0.0001	0%
Ni-D (mg/L)	0.0004	0.0002	**66.7%**
Ni-T (mg/L)	0.0004	0.0003	**28.6%**
Pb-D (mg/L)	< 0.0001	< 0.0001	0%
Pb-T (mg/L)	< 0.0001	< 0.0001	0%
NFR (mg/L)	< 1	< 1	0%
Sb-D (mg/L)	< 0.0001	< 0.0001	0%
Sb-T (mg/L)	< 0.0001	< 0.0001	0%
Se-D (mg/L)	0.0003	0.0002	**40.0%**
Se-T (mg/L)	0.0002	0.0002	0%
Sn-D (mg/L)	< 0.0001	< 0.0001	0%
Sn-T (mg/L)	< 0.0001	< 0.0001	0%
Sr-D (mg/L)	0.0061	0.0057	6.8%
Sr-T (mg/L)	0.006	0.0059	1.7%
Tl-D (mg/L)	< 0.0001	< 0.0001	0%
Tl-T (mg/L)	< 0.0001	< 0.0001	0%
U--D (mg/L)	< 0.000001	< 0.000001	0%
U--T (mg/L)	< 0.000001	< 0.000001	0%
V--D (mg/L)	0.0004	0.0004	0%
V--T (mg/L)	0.0005	0.0004	22.2%
Zn-D (mg/L)	0.0004	0.0004	0%
Zn-T (mg/L)	0.0007	0.0008	13.3%

*Bold numbers denote exceedences of acceptable limits of % relative differences (duplicates: 25%)

Parameter	01-Feb-05		Relative % Difference
Carbon Dissolved Organic (mg/L)	4	4.7	16.1%
Nitrate (NO_3) Dissolved (mg/L)	0.008	0.007	13.3%
Nitrate + Nitrite Diss. (mg/L)	0.01	0.009	10.5%
Nitrogen - Nitrite Diss. (mg/L)	<0.002	<0.002	0%
Ortho-Phosphate Dissolved (mg/L)	0.001	<0.001	0%
Phosphorus - T (mg/L)	<0.002	<0.002	0%
Phosphorus Tot. Dissolved (mg/L)	<0.002	<0.002	0%
Residue Non-filterable (mg/L)	<1	<1	0%
Specific Conductance (µs/cm)	18	18	0%
Turbidity (NTU)	0.29	0.25	14.8%
UV Absorbance 250nm (AU/cm)	0.14	0.12	15.4%
UV Absorbance 254nm (AU/cm)	0.13	0.12	8.0%
UV Absorbance 310nm (AU/cm)	0.06	0.05	18.2%
UV Absorbance 340nm (AU/cm)	0.03	0.03	0%
UV Absorbance 360nm (AU/cm)	0.02	0.02	0%
UV Absorbance 365nm (AU/cm)	0.02	0.02	0%
pH (pH units)	6.9	6.9	0%

*Bold numbers denote exceedences of acceptable limits of % relative differences (duplicates: 25%)

APPENDIX II SUMMARY OF WATER QUALITY DATA

Summary of general water chemistry at Site E229564, Newcastle Creek at Intake.

Variable	Minimum	Maximum	Average	Std Dev	No. of samples
Ammonia Dissolved (mg/L)	0.008	0.009	0.009	0.001	2
Carbon Diss. Inorganic (mg/L)	1.4	2	1.7	0.2	6
Carbon Dissolved Organic (mg/L)	0.7	5.6	2.8	1.1	35
Carbon Total Dissolved (mg/L)	4.9	6.1	5.5	0.5	6
Carbon Total Inorganic (mg/L)	1.6	2	1.7	0.2	6
Carbon Total Organic (mg/L)	1.1	8.8	4.5	1.6	14
Ca-D (mg/L)	2	3.07	2.4	0.4	6
Ca-T (mg/L)	2.1	2.59	2.3	0.2	6
Color True (Col.unit)	10	45	20.1	8.6	11
C--T (mg/L)	4.8	7.7	5.9	1.0469	6
Hardness Total (D) (mg/L)	6.4	9.5	7.6	1.0	10
Hardness Total (T) (mg/L)	6.9	8.3	7.6	0.6	6
Nitrate (NO3) Dissolved (mg/L)	< 0.002	0.053	0.021	0.015	32
Nitrate + Nitrite Diss. (mg/L)	0.002	0.055	0.024	0.016	40
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	0.005	0.002	0.001	33
Nitrogen Total (mg/L)	0.15	0.15	0.15	0	2
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.005	0.002	0.001	36
pH (pH units)	6.6	7.6	7.1	0.2	47
Phosphorus Tot. Dissolved (mg/L)	< 0.002	0.006	0.003	0.001	34

Variable	Minimum	Maximum	Average	Std Dev	No. of samples
P--T (mg/L)	< 0.002	0.023	0.003	0.003	40
Residue Non-filterable (mg/L)	< 1	< 4	1.1	0.6	52
Specific Conductance (uS/cm)	< 2	37	23.8	7.9	40
Turbidity (NTU)	< 0.1	0.83	0.23	0.14	47
Fecal coliforms (CFU/100mL)	< 1	20	3.2	4.0	36
E Coli (CFU/100mL)	< 1	18	2.5	3.6	32
Enterococci (CFU/100mL)	< 1	< 1	< 1	0	8
Streptococci (CFU/100mL)	1	7	4	4.2	2
UV Absorbance 250nm (AU/cm)	< 0.01	0.21	0.10	0.06	12
UV Absorbance 254nm (AU/cm)	< 0.01	0.2	0.10	0.06	12
UV Absorbance 310nm (AU/cm)	< 0.01	0.09	0.05	0.03	12
UV Absorbance 340nm (AU/cm)	< 0.01	0.05	0.03	0.01	12
UV Absorbance 360nm (AU/cm)	< 0.01	0.04	0.02	0.01	12
UV Absorbance 365nm (AU/cm)	< 0.01	0.03	0.02	0.01	12
Ag-D (mg/L)	< 0.0001	0.0001	0.0001	0	35
Ag-T (mg/L)	< 0.0001	0.0001	0.0001	0	35
Al-D (mg/L)	0.0214	0.271	0.0787	0.0536	39
Al-T (mg/L)	0.0277	0.435	0.0888	0.0722	39
As-D (mg/L)	< 0.0001	0.0003	0.0001	0.0000	35
As-T (mg/L)	< 0.0001	0.0002	0.0001	0.0000	35
Ba-D (mg/L)	0.0007	0.0018	0.0011	0.0002	35
Ba-T (mg/L)	0.0008	0.0018	0.0011	0.0002	35
B--D (mg/L)	0.001	0.001	0.001	0	2
Be-D (mg/L)	< 0.0005	0.0005	0.0005	0	35
Be-T (mg/L)	< 0.0005	0.0005	0.0005	0	35
Bi-D (mg/L)	< 0.0005	0.0005	0.0005	0	35
Bi-T (mg/L)	< 0.0005	0.0005	0.0005	0	35
B--T (mg/L)	0.001	0.001	0.001	0	2
Cd-D (mg/L)	< 0.0001	0.0004	0.0001	0	35
Cd-T (mg/L)	< 0.0001	0.0001	0.0001	0	35
Co-D (mg/L)	< 0.0001	0.0001	0.0001	0	35
Co-T (mg/L)	< 0.0001	0.0002	0.0001	0	35
Cr-D (mg/L)	< 0.0002	0.0006	0.0002	0	35
Cr-T (mg/L)	< 0.0002	0.0007	0.0002	0	35
Cu-D (mg/L)	0.0003	0.0043	0.0011	0.0008	35
Cu-T (mg/L)	0.0003	0.0024	0.0010	0.0004	35
Fe-D (mg/L)	0.013	0.025	0.018	0.005	4
Fe-T (mg/L)	0.015	0.033	0.024	0.008	4
Li-D (mg/L)	< 0.0001	0.0013	0.0002	0.0003	35
Li-T (mg/L)	< 0.0001	0.0013	0.0002	0.0003	35
Mg-D (mg/L)	0.441	0.446	0.444	0.004	2
Mg-T (mg/L)	0.447	0.456	0.452	0.006	2
Mn-D (mg/L)	0.0006	0.0094	0.0025	0.0022	39
Mn-T (mg/L)	0.0004	0.0152	0.0030	0.0031	39
Mo-D (mg/L)	< 0.0001	0.0002	0.0001	0.0000	35
Mo-T (mg/L)	< 0.0001	0.0001	0.0001	0.0000	35

Variable	Minimum	Maximum	Average	Std Dev	No. of samples
Ni-D (mg/L)	< 0.0001	0.0006	0.0003	0.0002	35
Ni-T (mg/L)	< 0.0001	0.0007	0.0003	0.0002	35
Pb-D (mg/L)	< 0.0001	0.003	0.0003	0.0005	35
Pb-T (mg/L)	< 0.0001	0.0011	0.0002	0.0003	35
Sb-D (mg/L)	< 0.0001	0.0002	0.0001	0	33
Sb-T (mg/L)	< 0.0001	0.0001	0.0001	0	33
Se-D (mg/L)	< 0.0002	0.0008	0.0002	0.0001	33
Se-T (mg/L)	< 0.0002	0.0003	0.0002	0.0000	33
Si-D (mg/L)	0.37	2.29	1.66	0.67	6
Si-T (mg/L)	0.37	2.04	1.62	0.63	6
Sn-D (mg/L)	< 0.0001	0.0003	0.0001	0	35
Sn-T (mg/L)	< 0.0001	0.0001	0.0001	0	35
Sr-D (mg/L)	0.004	0.0099	0.0067	0.0017	39
Sr-T (mg/L)	0.0046	0.0098	0.0070	0.0016	39
Tl-D (mg/L)	< 0.0001	0.0001	< 0.0001	0	35
Tl-T (mg/L)	< 0.0001	0.0001	< 0.0001	0	35
U--D (mg/L)	< 0.000001	0.000001	0.000001	0	35
U--T (mg/L)	< 0.000001	0.000001	0.000001	0	35
V--D (mg/L)	< 0.0001	0.0007	0.0004	0.0001	35
V--T (mg/L)	< 0.0001	0.0007	0.0005	0.0001	35
Zn-D (mg/L)	< 0.0001	0.0133	0.0014	0.0023	35
Zn-T (mg/L)	0.0001	< 0.005	0.0014	0.0013	39

APPENDIX III SUMMARY OF TURBIDITY EVENTS >0.5 HOURS IN DURATION MEASURED BY AUTOMATED STATION

Start Date	Start Time	Recovery Time (hrs)	Water Level (m)	Change in water level (m)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
07/05/2003	13:30	193.25	0.497	0	0.5	116.4	0	58.2	82.3
13/05/2003	6:45	137	0.518	0	0.5	75.1	0	37.6	53.1
24/05/2003	11:15	1	0.713	-0.015	1.25	28.7	0	20.0	11.4
24/05/2003	8:30	265.5	0.73	-0.012	2	410.5	0	206.4	150.5
24/05/2003	13:15	1	0.695	-0.109	85.25	434.4	0	166.1	159.8
28/05/2003	9:15	7	0.583	-0.01	12.25	78.3	0	44.1	21.7
30/05/2003	3:15	30	0.545	-0.003	1.25	10.6	0	6.2	4.1
25/06/2003	23:15	641	0.502	-0.001	0.5	6	0	3.0	4.2
18/07/2003	6:00	533.75	0.47	-0.001	0.5	18	0	9.0	12.7
22/07/2003	6:30	96.25	0.465	0	0.5	12.4	0	6.2	8.8
31/07/2003	8:30	217.75	0.452	0.002	0.5	8.6	0	4.3	6.1
09/08/2003	18:15	201.25	0.48	0	0.5	8.3	0	4.2	5.9
13/08/2003	10:00	87.5	0.474	-0.001	0.5	10.7	0	5.4	7.6
14/08/2003	10:45	24.5	0.473	-0.001	0.5	12.3	0	6.2	8.7
16/08/2003	14:30	51.5	0.473	-0.001	0.5	417.9	0	209.0	295.5
17/08/2003	14:45	24	0.474	0	4.25	415.3	0.3	383.1	98.8
17/08/2003	19:15	0.5	0.474	-0.002	18.75	100	4.3	46.8	37.0

Start Date	Start Time	Recovery Time (hrs)	Water Level (m)	Change in water level (m)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
18/08/2003	16:45	3	0.472	0	2.25	41.1	2.4	30.1	11.1
18/08/2003	19:15	0.5	0.472	0	9.75	63.8	2.5	29.3	19.9
19/08/2003	5:00	0.25	0.472	0	1	6.1	4.5	5.5	0.7
19/08/2003	21:45	16	0.472	-0.002	39.25	424	4.2	334.9	69.1
21/08/2003	13:45	1	0.47	-0.002	22.25	270.9	0	139.0	75.2
22/08/2003	22:45	1	0.469	0.001	3.25	15.2	0	12.0	3.9
22/08/2003	12:45	1	0.467	0.002	9.25	57.9	0	39.4	9.3
07/09/2003	0:15	358.5	0.471	-0.001	0.5	5.9	0.2	3.1	4.0
09/09/2003	19:00	66.5	0.466	0	0.5	17.2	0	8.6	12.2
29/09/2003	16:30	476.25	0.469	0.001	0.5	23.9	0	12.0	16.9
03/10/2003	22:30	101.75	0.468	0	0.5	7	0	3.5	4.9
06/10/2003	10:15	59.5	0.496	0.029	1.25	81.2	0	54.1	31.4
06/10/2003	12:00	0.75	0.536	0.137	5.5	419.1	0	230.6	169.6
12/10/2003	5:15	132	0.914	0.034	0.5	5.7	1.7	3.7	2.8
12/10/2003	10:00	0.5	0.942	-0.029	0.5	16.7	4	10.4	9.0
12/10/2003	5:45	0.25	0.948	0.011	4	364.8	3.8	45.6	88.3
18/10/2003	20:15	1.5	1.02	-0.03	0.5	8.8	0.2	4.5	6.1
18/10/2003	15:30	149.25	1.098	-0.021	3.5	163.5	0	50.4	44.8
20/10/2003	12:15	0.5	1.049	-0.037	0.5	14.1	2.4	8.3	8.3
20/10/2003	13:00	0.5	0.995	-0.03	0.5	8.3	0.4	4.4	5.6
20/10/2003	13:45	0.5	0.952	-0.042	0.5	29.4	0.3	14.9	20.6
20/10/2003	8:15	35.75	1.031	-0.018	0.75	7.7	5	6.0	1.5
20/10/2003	10:00	1.25	1.061	0.008	2	28.5	2	12.4	8.6
15/11/2003	3:30	612.75	0.544	0	0.5	23.7	0	11.9	16.8
04/12/2003	19:45	472	0.611	0.004	0.5	7.7	0	3.9	5.4
13/01/2004	15:00	955	0.724	0.006	0.5	407.8	0	203.9	288.4
13/01/2004	20:30	5.25	0.791	0.01	0.5	395.6	0	197.8	279.7
14/01/2004	4:45	1.75	0.973	0.002	0.5	8.4	0.1	4.3	5.9
14/01/2004	6:45	1.75	0.978	0	0.5	6.8	0.1	3.5	4.7
14/01/2004	2:30	5.75	0.961	0.009	0.75	10.3	0.5	6.7	5.4
30/01/2004	9:15	386.25	0.553	-0.001	0.5	5.4	0	2.7	3.8
01/03/2004	19:30	753.25	0.512	-0.001	0.5	6.1	0	3.1	4.3
24/11/2004	12:30	5722	0.686	-0.006	0.5	69.3	1.4	35.4	48.0
24/11/2004	15:00	2.25	0.65	-0.007	0.5	53.6	1.2	27.4	37.1
10/12/2004	12:15	381	0.746	0.031	0.5	5.5	4.2	4.9	0.9
10/12/2004	13:00	0.5	0.79	0.003	4.5	11.6	3.6	7.9	2.0
15/01/2005	14:30	861	0.406	0	0.5	294.1	3.5	148.8	205.5
17/01/2005	16:15	49.5	0.677	0.016	0.5	5.2	1.7	3.5	2.5
19/01/2005	9:00	40.5	0.758	0.003	0.5	5.3	4.3	4.8	0.7
19/01/2005	9:30	0.25	0.761	0.003	0.5	5.3	4.5	4.9	0.6
19/01/2005	10:00	0.25	0.764	-0.002	0.5	5.1	4.3	4.7	0.6
19/01/2005	11:30	1.25	0.759	-0.008	0.5	5.1	3.6	4.4	1.1
21/01/2005	0:45	37	0.551	-0.006	1.25	69.5	0	21.4	27.5
21/01/2005	15:45	14	0.794	0.002	11.75	27	4.8	14.5	6.8
22/01/2005	8:45	0.25	0.857	-0.006	0.5	5.2	4.2	4.7	0.7
22/01/2005	9:15	0.25	0.851	-0.005	0.5	5.2	3.1	4.2	1.5
22/01/2005	11:00	1.5	0.848	-0.001	0.5	5.4	3.7	4.6	1.2

Start Date	Start Time	Recovery Time (hrs)	Water Level (m)	Change in water level (m)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
22/01/2005	11:30	0.25	0.847	-0.01	0.5	5.9	4.5	5.2	1.0
22/01/2005	7:45	4.5	0.851	0.006	1	10	3.3	6.3	2.8
22/01/2005	20:15	8.5	0.853	-0.011	4.75	12.9	5	8.7	2.8
23/01/2005	6:30	5	0.85	0.008	0.5	6.4	3.7	5.1	1.9
23/01/2005	8:30	1.75	0.888	-0.006	0.5	5.2	3.6	4.4	1.1
23/01/2005	9:30	0.75	0.876	-0.003	0.5	5.1	5	5.1	0.1
23/01/2005	1:00	0.25	0.842	-0.018	0.75	6.3	4.3	5.2	1.0
26/01/2005	16:15	0.75	0.609	0	0.5	17.6	0	8.8	12.4
26/01/2005	10:15	72.5	0.528	0.082	4.25	21.5	0	19.8	5.1

APPENDIX IV Comparison of turbidity values reported by laboratory analyses and automated turbidity probe.

START DATE	Laboratory Result (NTU)	Automated Sensor Result (NTU)	Difference (Laboratory - Automated) (NTU)
06/05/2003 13:00	0.63	0	0.63
04/06/2003 14:00	0.17	0	0.17
07/07/2003 15:30	0.17	0	0.17
05/08/2003 14:30	0.33	0	0.33
03/09/2003 11:00	0.24	0	0.24
01/10/2003 14:00	0.11	0	0.11
04/11/2003 14:00	< 0.1	0	0.1
09/12/2003 14:30	0.26	0	0.26
13/01/2004 13:30	0.3	0	0.3
03/02/2004 13:00	< 0.1	0	0.1
02/03/2004 15:30	0.11	0	0.11
31/03/2004 14:00	0.13	0	0.13
12/05/2004 15:00	0.15	0	0.15
02/06/2004 14:00	0.26	0	0.26
06/07/2004 15:30	0.11	0	0.11
18/08/2004 15:30	0.22	0	0.22
08/09/2004 16:00	0.2	0	0.2
04/10/2004 15:00	0.23	0	0.23
26/10/2004 10:00	0.43	0	0.43
26/10/2004 10:05	0.4	0	0.4
08/12/2004 15:00	0.21	0	0.21
01/02/2005 13:00	0.29	0	0.29
01/03/2005 14:00	0.5	0	0.5