ENVIRONMENTAL PROTECTION DIVISION

WATER STEWARDSHIP DIVISION

MINISTRY OF ENVIRONMENT

# Water Quality Assessment and Objectives for the China Creek Community Watershed

TECHNICAL REPORT

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# EXECUTIVE SUMMARY

This document presents a summary of the ambient water quality of China Creek, British Columbia, and proposes water quality objectives designed to protect existing and future water uses. The water quality assessment for the creek and an evaluation of the watershed form the basis for the objectives.

China Creek, with a length of 21.4 km, drains into the Alberni Inlet near Port Alberni, BC. The City of Port Alberni withdraws drinking water from China Creek. The water uses to be protected in China Creek include drinking water, wildlife and aquatic life. Upnit Power Corporation has a hydroelectric intake on the creek, logging roads provide recreational access to the watershed, and hunting, ATV use and hiking occurs. These activities, as well as forestry, mining and wildlife, all potentially affect water quality in the creek.

Water quality monitoring was conducted between 1998 and 2005. The results of this monitoring indicated that the overall state of the water quality is very good. All chemical, physical and biological parameters meet provincial water quality guidelines with the exception of turbidity and *Escherichia coli*, which exceeded the drinking water guidelines on occasion. In order to maintain and protect the water quality in China Creek, ambient water quality objectives were set for *E. coli*, turbidity, pH, temperature, true colour, total organic carbon and non-filterable residue (total suspended solids).

Future monitoring recommendations include attainment monitoring every 3-5 years, depending on available resources and whether activities, such as forestry or development, are underway within the watershed. This monitoring should be conducted for one year during the summer low flow and fall flush period (five weekly samples in 30 days) at the City of Port Alberni intake.

**Water Quality Objectives for China Creek**

| Variable | Objective Value |
|---|---|
| ***Escherichia coli*** | ≤10 CFU/100 mL (90th percentile)<br>(based on a minimum 5 weekly samples collected over a 30-day period) |
| **Turbidity** | October to April:<br>5 NTU maximum<br>May to September:<br>2 NTU maximum |
| **pH** | 6.5 – 8.5 pH units |
| **Temperature** | 15°C maximum (long-term) |
| **True Colour** | 15 TCU maximum |
| **Total Organic Carbon** | 4.0 mg/L maximum |
| **Non-Filterable Residue (TSS)** | October to April:<br>28 mg/L maximum in a 24-hour period<br>8mg/L average (based on a minimum of five weekly samples collected over a 30-day period)<br><br>May to September:<br>26 mg/L maximum in a 24-hour period<br>6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period) |

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# ACKNOWLEDGEMENTS

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# 1.0 INTRODUCTION

The British Columbia (BC) Ministry of Environment (MOE) is conducting a program to assess water quality in priority watersheds. The purpose of this program is to accumulate the baseline data necessary to assess both the current state of water quality and long-term trends, and to establish ambient water quality objectives on a watershed specific basis. Water quality objectives provide goals that need to be met to ensure protection of designated water uses. The inclusion of water quality objectives into planning initiatives can help protect watershed values, mitigate impacts of land-use activities, and protect water quality in the context of both acute and chronic impacts to human and aquatic ecosystem health. Water quality objectives provide direction for resource managers, serve as a guide for issuing permits, licenses, and orders by MOE, and establish benchmarks for assessing the Ministry's performance in protecting water quality. Water quality objectives and attainment monitoring results are reported out both to local stakeholders and on a province wide basis through forums such as State of the Environment reporting.

Vancouver Island's topography is such that the many watersheds of the MOE's Vancouver Island Region are generally small (<500 $km^2$). As a result the stream response times can be relatively short and opportunities for dilution or settling are often minimal. Rather than developing water quality objectives for these watersheds on an individual basis, an ecoregion approach has been implemented. The ecoregion areas 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, Vancouver Island has been split into six terrestrial ecoregions, based on similarities in characteristics such as climate, geology, soils, and hydrology (Figure 1).

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. Water quality objectives will be developed for each of the representative lake and stream watersheds, 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.


**Figure 1.** Map of Vancouver Island Ecoregions

Partnerships formed between the MOE, local municipalities, and stewardship groups are a key component of the water quality network. Water quality sampling conducted by the public works departments of local municipalities and stewardship groups has enabled the Ministry to significantly increase the number of watersheds studied and the sampling regime within these watersheds. These partnerships have allowed the Ministry to study watersheds over a greater geographic range and in more ecoregions across Vancouver Island, have resulted in strong relationships with local government and interest groups, provided valuable input and local support, and, ultimately, resulted in a more effective monitoring program.

The China Creek community watershed provides a significant source of drinking water to the local community and has important fisheries values, with chinook, chum, coho and pink salmon, cutthroat and rainbow trout, steelhead, and Dolly Varden char all present at some point during the year (FISS, 2005). Anthropogenic land uses within the watershed include timber harvesting, historical mining, a hydroelectric plant, and recreation. These activities, as well as natural erosion and the presence of wildlife, all potentially affect water quality in China Creek.

This report examines the existing water quality of China Creek and recommends water quality objectives for this watershed based on potential impacts and water quality parameters of concern. China Creek was designated as a community watershed in 1995, as defined under the *Forest Practices Code of British Columbia Act* ("the drainage area above the downstream point of diversion and which are licensed under the *Water Act* for waterworks purposes"). This designation was grandparented and continued under the *Forest and Range Practices Act* (FRPA) in 2004 and infers a level of protection. As the majority of the China Creek community watershed is on private land, the FRPA does not apply to most of the watershed. However, the MOE uses other tools, such as water quality objectives, and legislation, such as the *Private Managed Forest Land Act* and the *Drinking Water Protection Act*, to ensure that water quality within these watersheds is protected and managed in a consistent manner.

# 2.0 WATERSHED PROFILE AND HYDROLOGY

## 2.1 BASIN PROFILE

China Creek is a fourth-order stream, 21.4 km in length, draining into the Alberni Inlet approximately 11 km south from the community of Port Alberni, BC. The community watershed portion includes approximately 14 km of China Creek's length, is 5,750 ha in area, and ranges in elevation from approximately 190 m at the Port Alberni water intake to about 1,575 m elevation in the upper watershed near Mount McQuillan (Figure 2). The intake, where there is adam on the creek, is located approximately 800 m downstream from the confluence of McLaughlin and China creeks. There are two named lakes (Duck Lake at 928 m elevation, and Lizard Lake at 737 m elevation) within the community watershed portion, both draining to Williams Creek (FISS, 2005).

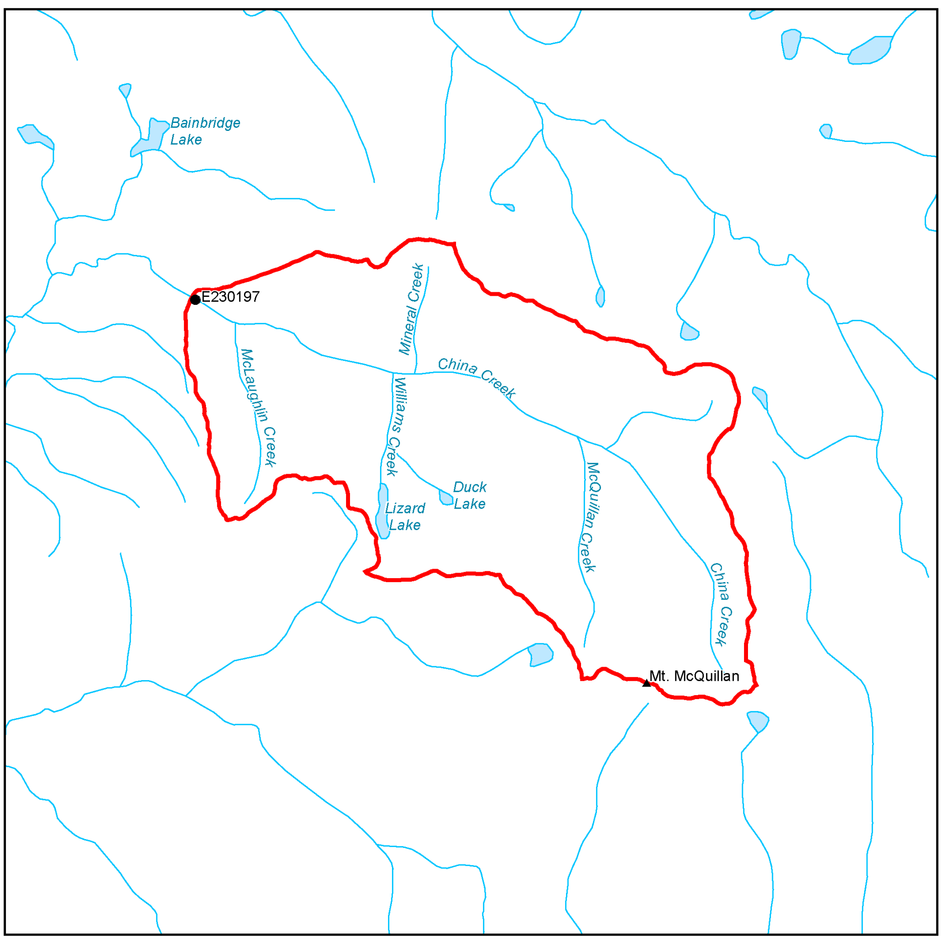


**Figure 2.** Map of China Creek community watershed.

The majority of the watershed lies within the Coastal Western Hemlock (montane moist maritime, CWHmm2) biogeoclimatic zone, with higher elevations (above about 800 m) in the Mountain Hemlock (windward moist montane, MHmm1) biogeoclimatic zone and small areas above 1,400 m composed of Alpine Tundra parkland (ATp). China Creek lies within the Leeward Island Mountains (LIM) ecoregion (see Figure 1) established for Vancouver Island by MOE staff.

The soils of the area consist of glacial deposits, limestone and volcanic rock. Water quality of the eco-section is characterized by neutral to slightly basic pH due to elevated calcium levels from limestone bedrock, with a moderate sensitivity to acidic inputs due to concentrations of calcium and alkalinity (Carmanah Research, 1997). There are known Karst formations in the upper Williams Creek part of the watershed, near Duck Lake (Guthrie, 2005). Karst formations, which develop as a result of dissolving action on soluble bedrock, are highly sensitive, valuable and non-renewable. Special consideration should be given to protection of this very productive landscape that supports diverse ecological systems. They can include underground drainage systems capable of moving large quantities of water over great distances in relatively short periods of time (BC Ministry of Forests, 2003).

### 2.2 HYDROLOGY AND PRECIPITATION

The nearest climate station to the watershed for which climate normal data are available was the Port Alberni station (elevation 2.4 m) (Environment Canada Climate Station 1036206). Average daily temperatures between 1971 and 2000 ranged from 2.1$^{o}$C in January to 17.9$^{o}$C in August. Average total annual precipitation between 1971 and 2000 was 1,911 mm, with only 114 mm (water equivalent) (6%) of this falling as snow (Figure 3). Temperatures at higher elevations in the watershed would be cooler than recorded at sea level. A larger portion of the annual total precipitation occurred as snowfall in the higher-elevation terrain of the watershed. Most precipitation (1,542 mm, or 81%) fell between October and March. A comparison of rainfall at the Port Alberni station with data collected from the City of Port Alberni rain gauge on China Creek showed precipitation was 23% and 34% higher at China Creek than at Port Alberni in1994 and

1996 (Horel, 2001). Thus, the precipitation data shown in Figure 3 likely underestimates the actual precipitation that fell within the China Creek community watershed basin.

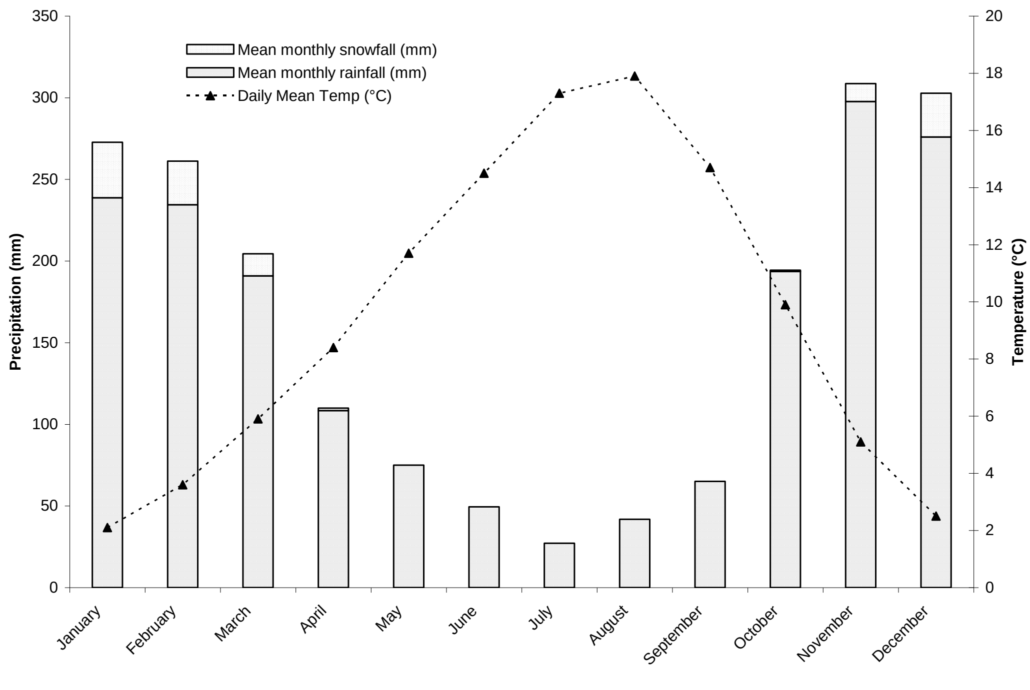


**Figure 3.** Climate data (1971 – 2000) for Port Alberni (Environment Canada Climate Station 1036206).

Water Survey Canada (WSC) operated a hydrometric station on China Creek between 1990 and 1995 (WSC, 2005). Minimum, maximum and average daily flows for this period are shown in Figure 4. Peak flows measured between 1990 and 1995 were approximately 15.2 $m^3/s$, while minimum flows were approximately 0.1 $m^3/s$. While no hydrometric data were available for this site between late October and late March, it is expected that water levels were generally high during this period due to high rainfall (see Figure 3) at lower elevations in the watershed. This theory is supported by hydrometric data collected between 2003 and 2005 as part of this study, with peak water levels occurring between October and January (Figure 5). The uncharacteristic drop in water level in January 2005 (Figure 5) was likely due to water release at the intake dam by the city of Port Alberni.

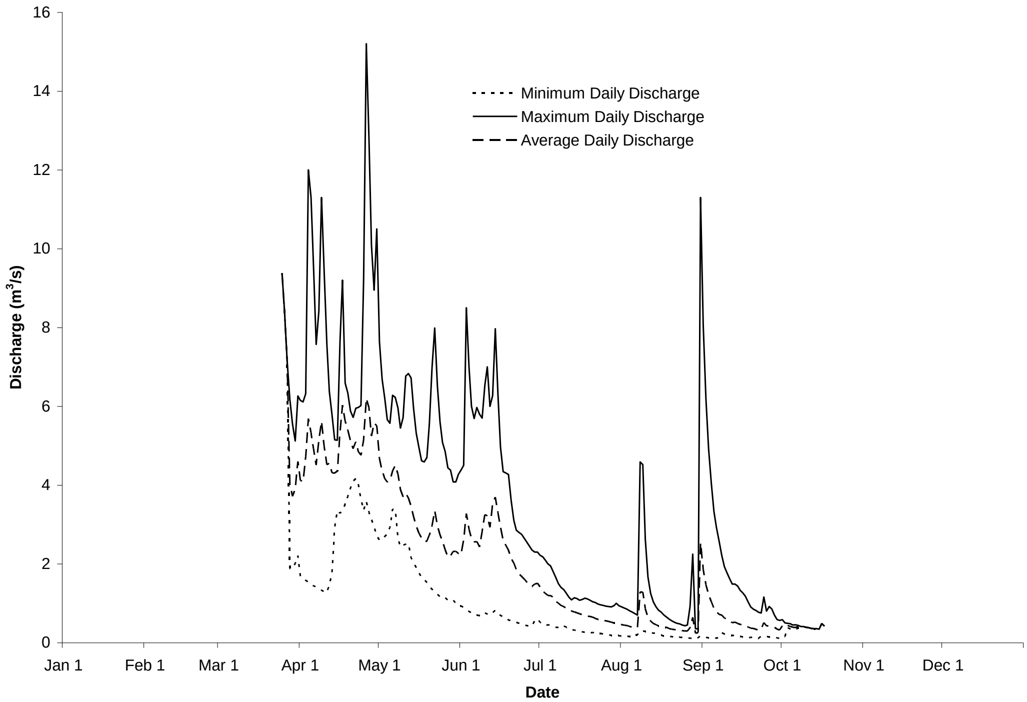


**Figure 4.** Minimum, maximum and average daily discharge data for China Creek below McFarland Creek (Water Survey Canada Station 08HB077) between 1990 and 1995 (WSC, 2005).

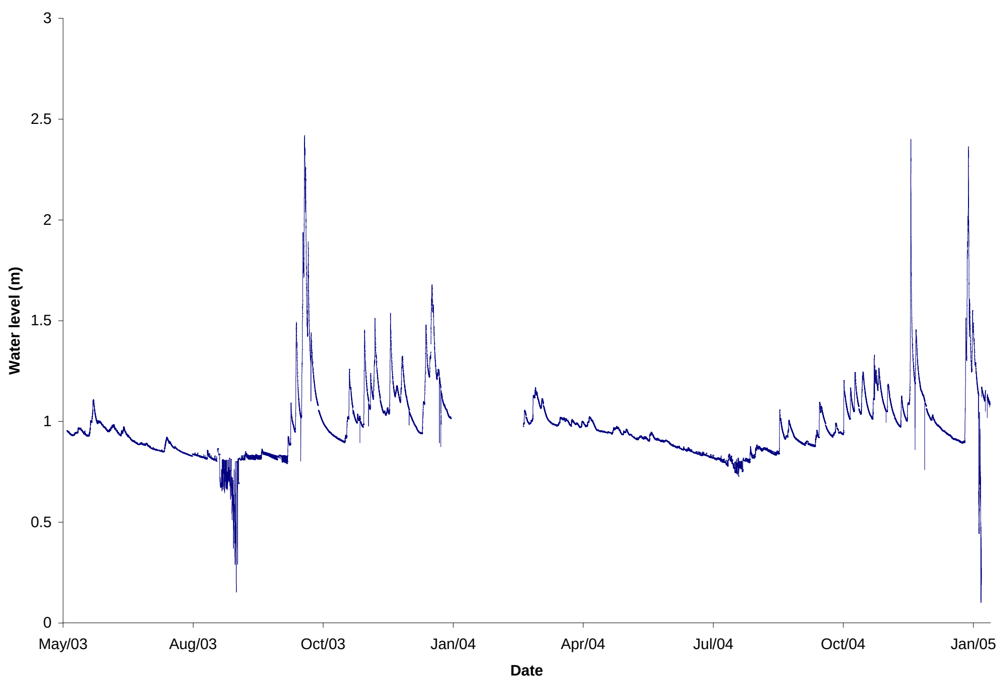


**Figure 5.** Water level data collected by the Ministry of Environment at EMS Site E230197, China Creek near the Port Alberni Intake, 2003 – 2005.

# 3.0 WATER USES

## 3.1 WATER LICENSES

Six water licenses have been issued for the China Creek mainstem, but only two of these are located within the community watershed boundaries. The City of Port Alberni has a license to remove 8,936 $dam^3$/year (cubic decametres/year, where 1 $dam^3$ = 1,000 $m^3$) of water for domestic use under a "Waterworks – Local Authority" license. During winter months, they typically withdraw approximately 9 $dam^3$/day, while in summer months they withdraw approximately 18 $dam^3$/day (Streamline Environmental Consulting Ltd. and Ostapowich Engineering Services Ltd., 2005). As well, Upnit Power Corporation has a license to remove 16,396 $dam^3$/year from the mainstem, approximately 2.5 km upstream from the City of Port Alberni intake, for the purposes of generating power. The water is then released back into the mainstem approximately 2.9 km downstream from the City of Port Alberni intake. The City of Port Alberni also has a license to store 645 $dam^3$/year in Lizard Lake, which they use to relieve summer low-flows.

## 3.2 FISHERIES

China Creek has high fisheries values, and species present include chinook (*Oncorhynchus tshawytscha*), pink (*O. gorbuscha*), coho (*O. kisutch*) and chum (*O. keta*) salmon, as well as cutthroat trout (*O. clarkii*), Dolly Varden char (*Salvelinus malma*), rainbow trout (*O. mykiss*), and steelhead (*O. mykiss*) (FISS, 2005). As well, Lizard Lake is reported to contain rainbow trout, while Duck Lake contains cutthroat trout (FISS, 2005).

## 3.3 RECREATION

There is a popular 5 km-long hiking trail within the China Creek watershed, but it is in the lower portion of the watershed, below the community watershed boundaries. No specific studies have been conducted to determine the recreational use of the China Creek watershed, but the presence of logging roads throughout the upper watershed allows recreational access. The area is utilized primarily by hunters and hikers, as well as all-terrain vehicle (ATV) users. There is a significant network of ATV trails located in the upper watershed which are utilized on a regular basis (Higman, pers. comm., 2005).

### 3.4 FLORA AND FAUNA

The China Creek watershed provides valuable habitat to a wide variety of species including blacktail deer (*Odocoileus hemionus columbianus*), black bear (*Ursus americanus*), cougar (*Puma concolor*), and numerous other small mammals and birds. The watershed is composed mainly of high value Douglas-fir (*Pseudotsuga menziesi)*, western red Cedar (*Thuja plicata*), Amabilis fir (*Abies amablilis*) and western Hemlock (*Tsuga heterophylla*) (Epps, pers. comm., 2009). McLaughlin Ridge, located on the north side of China Creek between Debeaux Creek and Mineral Creek, consists of old-growth Douglas-fir. This provides very high value winter range for blacktail deer and habitat for the Queen Charlotte goshawk (*Accipiter gentilis laingi*), a species included on the BC Red List (composed of species legally designated as endangered or threatened), and considered by the Committee On the Status of Endangered Species In Canada (COSEWIC) to be threatened. There have been historical observations of the endangered Vancouver Island marmot (*Marmota vancouverensis*) in the sub-alpine portions of the watershed, although the last sighting occurred in 1938 (CDC, 2005). However, both Douglas Peak and Mt. McQuillan are viable sites for reintroduction of this red-listed and COSEWIC endangered species (Chatwin, pers. comm., 2005). Other threatened species include the Vancouver Island water shrew (*Sorex palustris brooksi*, red-listed) and the red-legged frog (*Rana aurora*, blue listed and on the COSEWIC Special Concern list) (Chatwin, pers. comm., 2005). As well, the *saxatilis* subspecies of white-tailed ptarmigan (*Lagopus leucura saxatilis*, blue-listed) has also been observed at higher elevations in China Creek as recently as 1995 (CDC, 2005).

### 3.5 DESIGNATED WATER USES

Designated water uses are those identified for protection in a specific 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 preceding discussion demonstrates that water uses to be protected should include drinking water, wildlife and aquatic life.

# 4.0 INFLUENCES ON WATER QUALITY

## 4.1 LAND OWNERSHIP

The community watershed portion of China Creek is located primarily on private land owned and managed byIsland Timberlands Limited Partnership (LP), with a small portion owned and managed by TimberWest Forest Corp. There are small areas of Crown Land remaining within the watershed, and these are managed by Western Forest Products under Tree Farm Licence (TFL) 44. The community watershed contains no private households located within its boundaries, and so potential sources of contamination associated with households (such as runoff, septic fields, fertilizers and pesticides) are not an issue.

## 4.2 LICENSED WATER WITHDRAWALS

There is a maximum licensed water withdrawal from the China Creek community watershed of 25,331 $dam^3$/year. Assuming water was withdrawn from China Creek at a constant rate throughout the year (an unlikely scenario), the average withdrawal rate would be 0.80 $m^3$/s. Average daily flows between 1990 and 1995 ranged from 0.24 $m^3$/s during the mid-summer to 9.38 $m^3$/s during spring rain on snow events, and water consumption is highest during the summer months. As a result, water withdrawals from China Creek could potentially impact summer water levels between Upnit Power Corporation's hydroelectric intake and the site downstream from the Port Alberni intake where the water is returned from the hydroelectric project (see Section 3.1). However, the storage capacity of Lizard Lake and the ability of the City of Port Alberni to regulate flow from this lake may mitigate these low-flow situations. As well, the hydroelectric plant is not expected to operate during August and September due to low flows, and Upnit is required to allow a bypass flow of at least 0.51 $m^3$/s when possible (Streamline Environmental Consulting Ltd. and Ostapowich Engineering Services Ltd., 2005).

Though the regulated flow from Lizard Lake may help to settle suspended matter in the water column and help to improve water quality during peak flow events, the construction of the water intake for the hydro project has resulted in a road right-of-way for a buried penstock being built for approximately 2 km along China Creek between the City of Port Alberni intake and the hydroelectric intake. Construction of the hydroelectric plant occurred from December, 2004 through November, 2005 (Lewis *et al*., 2009). The right-of-way is travelled weekly by an operator on an ATV from November through March, but not by any licensed vehicles (Jones pers.comm., 2007). Due to its proximity to the creek, the right-of-way will likely be a source of turbidity.

### 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 rain on snow events in spring. The improper construction of roads can change drainage patterns, destabilize slopes, and introduce high concentrations of sediment to streams.

The China Creek watershed consists of private lands, managed primarily by Island Timberlands LP (5,327 ha), TimberWest Forest Corp (401 ha) well as Crown Land within TFL 44, managed by Western Forest Products (Horel, 2001). The most recent watershed assessment procedure (WAP) was completed in February, 2005 (Streamline Environmental Consulting Ltd. and Ostapowich Engineering Services Ltd., 2005). The following information is summarized from that report, and the calculations do not include data for private land not managed by Island Timberlands.

Of the area managed by Island Timberlands LP, approximately 66% has been harvested, primarily in the 1930’s and 1940’s, and the equivalent clearcut area (ECA) was 7% to the end of 2004. This was predicted to decrease to 4% by the end of 2009 with a rate of recovery of about 47 ha/yr. By the end of 2004, the total length of roads in the China Creek community watershed was 123.2 km. Of this, 7.2 km was considered to have a high sediment delivery potential, 10.9 km was considered to have a moderate sediment delivery potential, 5.7 km a low sediment delivery potential and the remainder (99.4 km) a very low sediment delivery potential.

With the exception of a few short reaches, the mainstem of China Creek has been harvested to the stream bank. This has resulted in a large number of aging alder growing along the stream bank, a number of which will likely fall into the stream over the next decade. While this will increase the volume of large woody debris within the creek (which is currently quite low) and therefore lend some channel stability, trap sediment, and increase fish habitat, it may also result in debris jams which would divert water into the stream bank, potentially causing erosion and increased turbidity.

There have been 142 landslides within the China Creek community watershed (2.5 landslides/km$^2$), the majority (95) of which were due to natural causes. Of the remaining 47 landslides, 23 were attributed to logging activities and 24 to road construction. All of the landslides attributed to logging are now vegetated and no longer produce sediment, and only three of the 24 landslides attributed to road construction are thought to continue to produce sediment. The frequency of landslides on harvested steep terrain was 3.3/km$^2$, which is considered to be moderate.

Due to the relatively high concentration of roads within the watershed, and especially adjacent to the creek, runoff from these roads has the potential to impact turbidity levels in the creek, particularly during periods of road grading or road construction. Potential impacts from these roads will decrease as roads are deactivated and reclaimed.

Improvements in harvesting practices over the past 20 years, coupled with increased legislation and enforcement (for example, the *Water Act* and the *Private Managed Forest Land Act*), suggests that the potential for impacts to water quality will decrease as hydrologic recovery continues.

### 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 China Creek watershed, the relative impacts of recreational activities cannot be discussed, but they are likely to occur due to the high use of the area by ATV vehicles and other recreational users.

### 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 (Health Canada, 2004). In addition, warm-blooded animals excrete fecal coliforms and *Escherichia coli* in their feces, and can cause elevated levels of these microbiological indicators 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-species transfer of pathogens. However, without specific source tracking methods, it is impossible to determine the origins of coliforms.

China Creek contains valuable wildlife habitat and provides a home for a wide variety of warm-blooded species. Therefore, the risk of contamination from endemic wildlife exists.

### 4.6 MINING

Mining activities can impact water quality by introducing high concentrations of metals and other contaminants (e.g., sulphate) to waterbodies. The leaching of waste rock or adit discharges can also contribute to acidification of the water. Mining activities generally include road construction and land-clearing, which can change water movement patterns and result in increased turbidity levels.

There are four closed/abandoned mines, one prospect, and one developed prospect within the China Creek community watershed, as well as historical placer mining operations in the mainstem (Table 1) (MINFILE, 2004). Metals mined included gold, silver, copper, lead, zinc, and arsenic.

**Table 1.** Summary of mining activities within the China Creek community watershed.

| Mine Type | Mine Name | Metals Mined | Most Recent Exploration |
|---|---|---|---|
| Abandoned/Closed | Grizzly | Arsenic, silver, gold | 1924 |
| Abandoned/Closed | Gillespie | Gold, silver, copper, lead, zinc | 1936 – 39 |
| Abandoned/Closed | Havilah | Gold, silver, copper, lead, zinc | 1936 |
| Abandoned/Closed | Debbie | Gold, silver, copper, zinc | 1989 |
| Placer | China Creek | Gold | 1895 |
| Developed prospect | 900 | Gold | 1987 |
| Prospect | Regina | Gold, silver, copper, lead, zinc | 1987 |

# 5.0 STUDY DETAILS

One water quality monitoring location was established within the China Creek watershed: Environmental Monitoring System (EMS) site E230197 is located on China Creek at the main water intake (see Figure 2). The project consisted of four phases: collecting water quality data, gathering information on water use, determining land use activities that may influence water quality, and establishing water quality objectives.

Water quality data were collected from 1998 to 2005. Drinking water is one of the designated water uses in China Creek and so water quality variables relevant to the protection of raw drinking water supplies were included. Based on the current knowledge of potential anthropogenic impacts to the sub-watersheds (generally associated with forestry, mining, recreation and the hydroelectric plant), natural features (wildlife), and the lack of authorized waste discharges within the watershed, the following water quality variables were included:

- Physical: pH, true color, specific conductivity, turbidity, non-filterable residue (total suspended solids);
- Carbon: dissolved organic carbon;
- Nutrients: total phosphorus, orthophosphate, nitrate, nitrite;
- Microbiological indicators: fecal coliforms, *E. coli*;
- Total metals concentrations.

To represent the worst case scenario, water samples were collected at the site on a weekly basis for five consecutive weeks during the summer low flow and fall high flow periods from 2002 to 2004, and usually on a monthly basis for the remainder of the year from June 2002 to June 2005. Additional sampling was conducted at the site twice in early 1998 as part of a pre-2002 sampling program.

Grab samples were collected at the water surface in strict accordance with Resource Inventory Standards Committee (RISC) standards (BC MOE, 2003) by trained personnel including City of Port Alberni public works staff. Water chemistry analyses were conducted by Maxxam Analytics Inc. in Burnaby, BC. Bacteriological analyses were conducted by Cantest Laboratories in Burnaby, BC. Summary statistics were calculated on all available data, and $90^{th}$ percentiles were calculated using data from a minimum of 5 weekly samples in 30 consecutive days for each site. Data are summarized in Appendix I.

An automated water quality/quantity monitoring station was also installed at the site from May 2003 to January 2005 to measure and log water temperature, turbidity, specific conductivity and water level. Here, a McVan analyte SDI-12 turbidity sensor was installed within the stream flow and polled every 15 minutes by a FWS-12 datalogger.

# 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 BC MOE water quality guidelines (available at http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html) are used to assess water at the point of diversion of the natural stream into a waterworks system. These BC guidelines are also used to protect other designated water uses such as recreation and habitat for aquatic life. Water quality guidelines provide the basis for the development of water quality objectives for a specific waterbody, which can be integrated into an overall fundamental water protection program designed to protect all uses of the resource, including drinking water sources.

The *BC Drinking Water Protection Act* sets minimum disinfection requirements for all surface supplies as well as requiring drinking water to be potable. The Vancouver Island Health Authority (VIHA) determines the level of treatment and disinfection required based on both source and end of tap water quality. As such, VIHA requires all surface water supply systems to provide two types of treatment processes. Currently the City of Port Alberni only treats through chlorine disinfection prior to distribution (Environment Canada, 2001; Meunier, pers. comm., 2006). To effectively treat the water for viruses and parasites, such as *Cryptosporidium* and *Giardia*, the City of Port Alberni may be required to provide additional disinfection, such as UV or ozone, and/or treatment, such as filtration. The following sections describe the characteristics considered in assessing the water quality of China Creek.

## 6.1 PH

pH measures the concentration of hydrogen ions ($H^+$) in water. The concentration of hydrogen ions in water can range over 14 orders of magnitude, so pH 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 (McKean and Nagpal, 1991). 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 China Creek was consistently slightly alkaline, with values ranging from 7.3 to 8.2 pH units and a mean of 7.8 pH units (Appendix I) for 42 samples collected. All pH values were well within the drinking water guideline, suggesting that pH is not presently a concern within the China Creek watershed. However, the history of mining activities within the watershed, coupled with the possibility of future mining, suggest that acid rock drainage may be a concern and pH should be monitored on an ongoing basis. ***Therefore, an objective is proposed for pH in China Creek. The objective is that the pH of China Creek should remain between 6.5 and 8.5 pH units at all times.***

### 6.2 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 (Oliver and Fidler, 2001). For the protection of aquatic life in streams, the allowable hourly change in temperature is +/-1°C. The optimum temperature ranges for salmonids are based on species-specific life history stages such as incubation, rearing, migration, and spawning. For steelhead, which are present in China Creek, the optimum temperature ranges are: 10 – 12°C for incubation; 16 – 18°C for rearing; and 10 – 15.5°C for spawning (Oliver and Fidler, 2001). Each salmon species also has its own optimum temperature range. Chum salmon, which are present in China Creek, are the most sensitive salmonid to warmer temperatures (12-14°C for rearing); however, the juveniles are not present in the river during the summer months. Steelhead and coho, which have similar temperature thresholds, are the species in the watershed for the longest periods of time, including the summer.

Water temperatures in China Creek varied seasonally, with maximum temperatures occurring in late July through the end of August. Water temperatures measured by the automated station ranged from near 0°C in the winter months to a maximum of 14.6°C in July 2003 (Figure 6).

Water temperatures remained consistently below the aesthetic guideline of 15°C and below aquatic life guidelines for the spawning, incubation and rearing periods for salmonids over the course of the monitoring program. However, it is possible that activities such as forest harvesting, the micro hydroelectric project just upstream from the intake, and climate change could increase water temperature to the point where this guideline is occasionally exceeded. ***For this reason, a water quality objective is proposed for temperature in China Creek. It is recommended that maximum instantaneous water temperatures should not exceed 15°C during the summer months.***

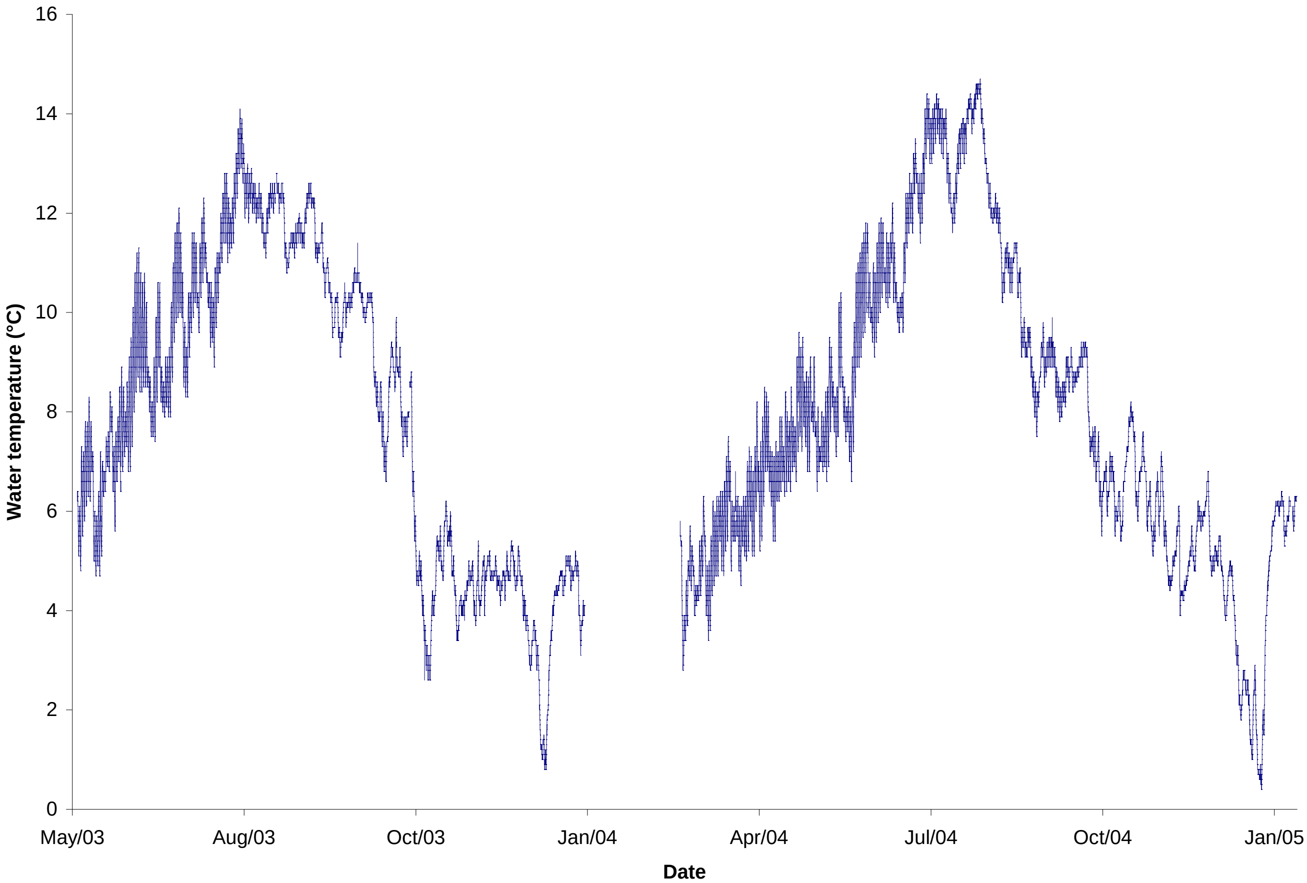


**Figure 6.** Automated water temperature data collected from China Creek at the Port Alberni intake between May 2003 and January 2005. Due to equipment malfunction, data gaps exist for the winter of 2004.

### 6.3 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. As 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. Coastal systems, with high annual rainfall values and typically short water retention times, generally have low specific conductivity (<80 microsiemens/centimeter (µS/cm)), while interior watersheds generally have higher values. Increased flows resulting from precipitation events or snowmelt tend 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 China Creek, specific conductivity values in the discrete samples ranged from 48µS/cm to 148 µS/cm, with an average of 104 µS/cm for 37 samples collected (Appendix I). At the automated station, values ranged from 7 µS/cm to 152 µS/cm, with an average of 84 µS/cm. Values were correlated with flows, with the highest conductivity levels occurring during low summer flows (when dilution was lowest) and decreasing conductivity during the winter (when dilution from rainfall was highest) (Figure 7). As there is no BC Water Quality Guideline for specific conductivity, and the average specific conductivity observed was within 25 µS/cm of what is typical of coastal systems, no objective is proposed for specific conductivity.

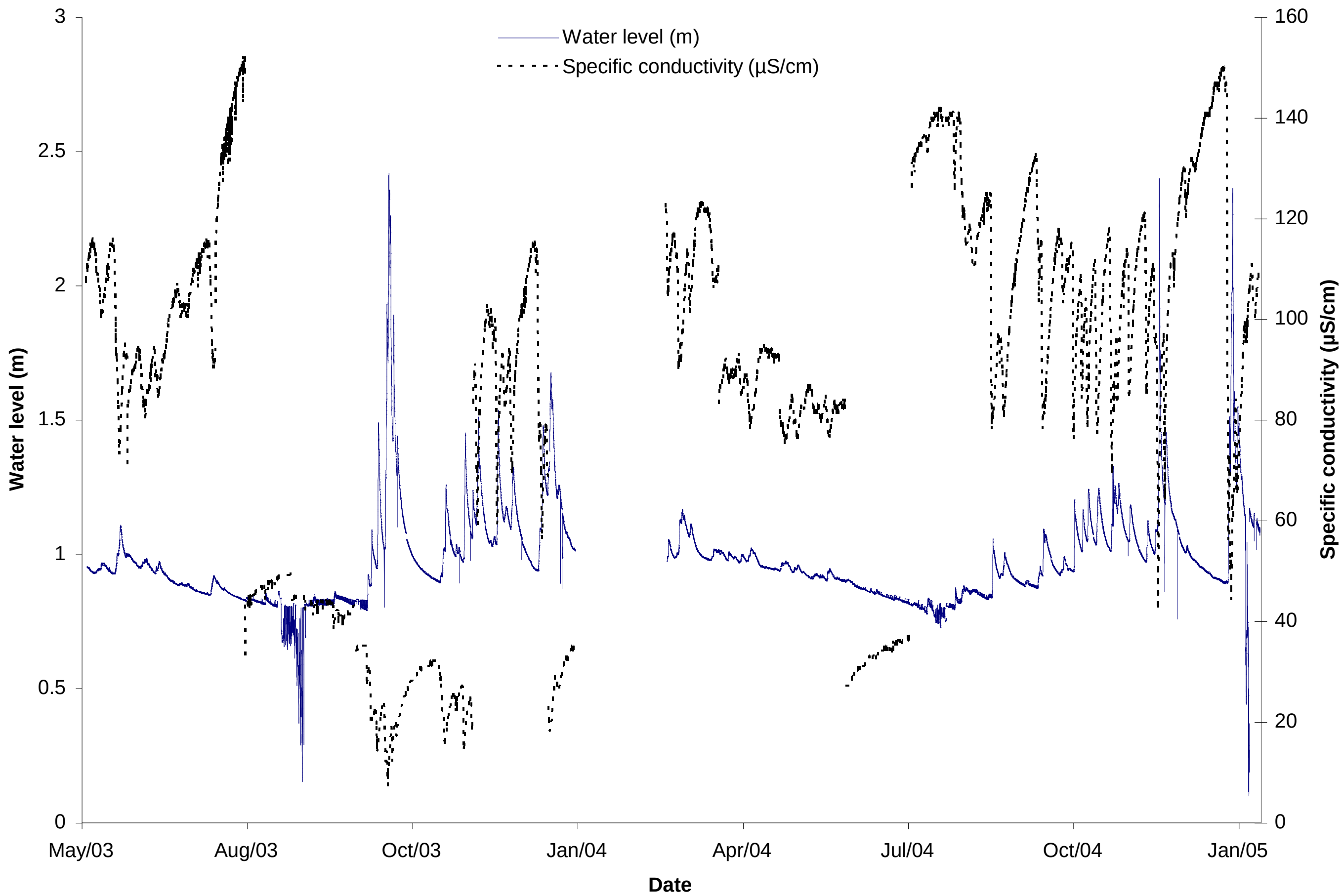


**Figure 7.** Specific conductivity and water levels measured in China Creek near Port Alberni intake between May 2003 and January 2005. Due to equipment malfunction, data gaps exist for the winter of 2004.

### 6.4 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 microbiological contaminants 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 drinking water that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU when background is less than 5 NTU, and a maximum of 5 NTU (during turbid flow periods) (Caux *et al.*, 1997). VIHA's goal for surface source drinking water for systems that do not receive filtration, such as China Creek, is that it demonstrate 1 NTU turbidity or less (95% of days) and not above 5 NTU on more than 2 days in a 12 month period when sampled at the intake (Enns, pers. comm., 2009).

Turbidity is a significant water quality concern in China Creek, as elevated turbidity levels force the City of Port Alberni to switch to an alternative water source (either from Bainbridge Lake or the Somass River). The City of Port Alberni utilizes these alternative water sources when turbidity levels in China Creek exceed 0.4 NTU (Muenier, pers.comm., 2006). Turbidity can result both from natural landslides as well as those induced by human activities, such as timber harvesting.

At the intake site, turbidity values ranged from < 0.1 NTU to 5.5 NTU, with an average of 0.6 NTU for the 43 samples collected between 1998 and 2005 (Appendix I). In general, turbidity values were quite low, with only four values exceeding 1 NTU and one value exceeding 5 NTU (5.5 NTU, recorded on April 6, 2005). The highest turbidity values occurred between the months of October and April. Forestry activity and the construction of the hydroelectric plant had started in the watershed by December 2004 and only values prior to this are considered to be background. Average turbidity was 0.6 NTU when calculated using only the 34 values prior to December 2004. As average turbidity at this site was < 1 NTU and the maximum value prior to anthropogenic activity in the watershed was < 5 NTU, BC Water Quality Guidelines for drinking water in the watershed specify a maximum of 5 NTU and an induced (caused by athropogenic activities) maximum turbidity of 2 NTU.

Turbidity was also measured by the City of Port Alberni on a daily basis. Between 1994 and 1997, maximum monthly turbidity values exceeded 5 NTU on nine occasions, always between the months of October and March when peak flows occur, with a maximum value of 50 NTU recorded in November 1995.

A summary of turbidity data collected at the automated water quality monitoring station between May 2003 and Jan 2005 is given in Table 2. The distribution of data shows that over 94% of values were below 1 NTU, and over 96% of values were below 5 NTU.

Therefore, only about 3.7% of the time, or about 518 of the 14,000 hours when turbidity was measured over the course of the study, did turbidity values exceed the maximum BC MOE drinking water guideline of 5 NTU. 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. In this study, values greater than 50 NTU (1.1% of values, or 593 samples) were likely affected by such factors, which were exacerbated by the location of the deployment tube.

**Table 2.** Summary of automated turbidity data measured at China Creek at City of Port Alberni intake station between May 2003 and February 2005.

| | Number | Percentage | Cumulative % |
|---|---|---|---|
| Number Turbidity <=1 NTU | 52,933 | 94.4% | 94.4% |
| Number Turbidity >1, <=5 NTU | 1,066 | 1.9% | 96.3% |
| Number Turbidity >5, <=10 | 442 | 0.8% | 97.1% |
| Number Turbidity >10, <=50 | 1,016 | 1.8% | 98.9% |
| Number Turbidity >50 | 593 | 1.1% | 100.0% |
| **Totals:** | **56050** | **100.0%** | |

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. Turbidity events in China Creek tended to be of relatively short duration and occurred primarily during the fall and winter (Figure 8).

Table 3 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 3 includes only the longest-duration events (*i.e.*, events over 8 hours in length) – the remainder of the summary is included as Appendix II, arranged in chronological order. The longest turbidity event was almost 45 hours in length, with a maximum value of over 400 NTU. Almost 99% of the turbidity events occurred between October and March.

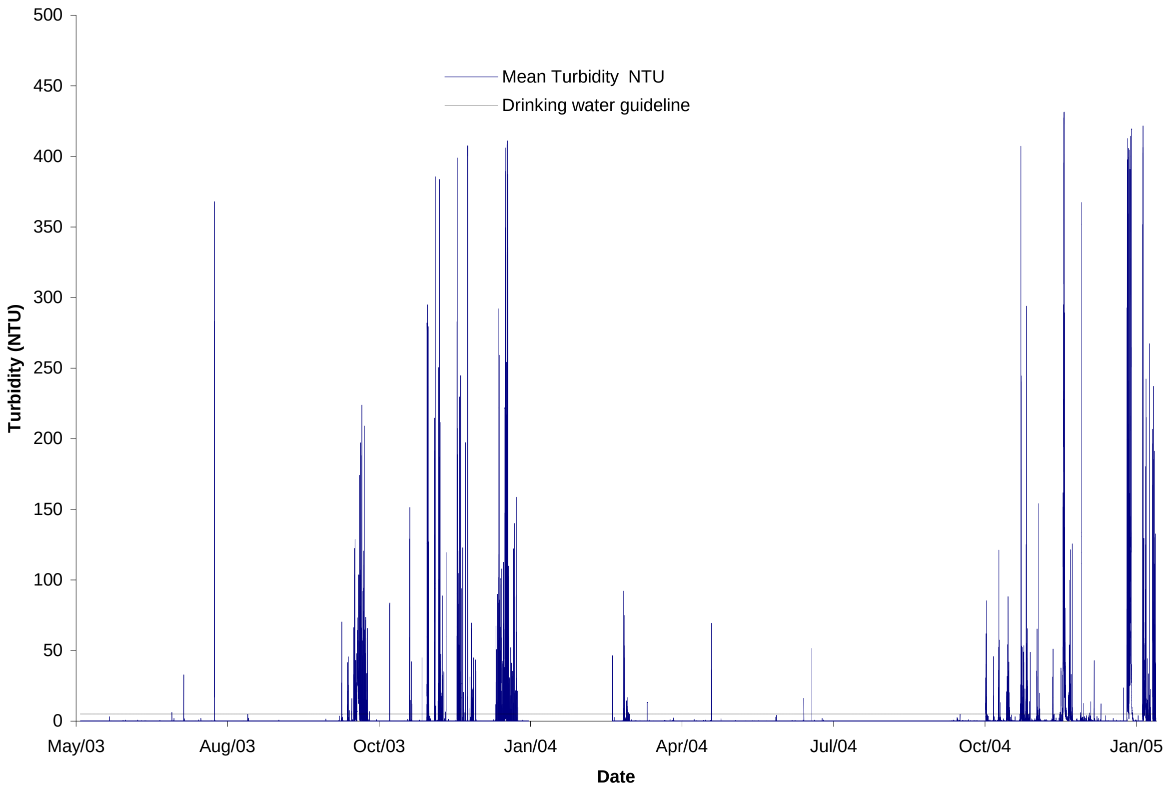


**Figure 8.** Turbidity levels in China Creek between May 2003 and January 2005 as measured on 15-minute intervals by the automated water quality monitoring station near the City of Port Alberni intake. Due to equipment malfunction, data gaps exist for the winter of 2004.

**Table 3.** Summary of turbidity events exceeding 8 hours in duration reported by automated turbidity meter near the Port Alberni intake 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. |
|---|---|---|---|---|---|---|---|---|---|
| 14/12/2004 | 4:00 | 0.5 | 1.365 | 0.044 | 10.25 | 99.8 | 5 | 18 | 20.2 |
| 27/01/2005 | 19:00 | 0.25 | 0.758 | -0.556 | 16 | 180.3 | 4.1 | 37 | 30.7 |
| 17/01/2005 | 7:15 | 45.75 | 1.034 | 0.278 | 25.75 | 412.7 | 4.1 | 97.2 | 111.7 |
| 10/12/2004 | 5:45 | 0.75 | 1.219 | 0.192 | 35.75 | 431.4 | 3.1 | 87.1 | 107.6 |
| 17/10/2003 | 18:45 | 1.5 | 1.896 | -0.14 | 37.25 | 174.1 | 4.1 | 27.8 | 20.2 |
| 18/01/2005 | 11:45 | 0.5 | 1.352 | 0.171 | 44.75 | 419.3 | 2.5 | 104.7 | 117.5 |

Table 4 shows a comparison of grab sample laboratory results compared with the automated data collected at the same time. In those instances where laboratory samples were not collected on the 15-minute interval, automated data from immediately before and immediately after the lab sample was collected is shown. This table shows that in 16 of 19 instances, turbidity values reported by the laboratory and by the automated equipment were within 2 NTU, which is an acceptable level (RISC, 2006), while the remaining values differed by 2.1, 3.4 and 8.7 NTU. However, most of the laboratory 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. In the event of a significant turbidity event (*i.e.*, turbidity values exceeding 5 NTU for a period of at least 24 hours), grab-samples should be collected at other monitoring sites within the system to determine the origin of the problem.

**Table 4.** 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) |
|---|---|---|---|
| 03/06/2003 11:48 | 0.18 | 0 | 0.18 |
| 23/07/2003 9:00 | 0.2 | 0 | 0.2 |
| 05/08/2003 11:00 | 0.17 | 0 | 0.17 |
| 02/10/2003 9:43 | <0.1 | 0 | <0.1 |
| 03/11/2003 9:25 | <0.1 | 0 | <0.1 |
| 01/12/2003 9:45 | 0.38 | 0 | 0.38 |
| 18/03/2004 9:00 | 0.3 | 0 | 0.3 |
| 01/04/2004 8:30 | 0.15 | 0 | 0.15 |
| 04/05/2004 8:30 | 0.19 | 0 | 0.19 |
| 02/06/2004 9:20 | 0.22 | 0 | 0.22 |
| 05/07/2004 8:30 | 0.22 | 0 | 0.22 |
| 02/09/2004 12:08 | 0.22 | 0 | 0.22 |
| 04/10/2004 16:00 | 0.64 | 0 | 0.64 |
| 24/10/2004 16:00 | 2.09 | 0.1 | 2.08 |
| 02/11/2004 11:20 | 0.73 | 0.9 / 4.1 | - 0.17 / - 3.37 |
| 02/12/2004 9:30 | 0.19 | 0 | 0.19 |
| 06/12/2004 9:00 | 0.23 | 0 | 0.23 |
| 06/01/2005 8:20 | 0.33 | 0 | 0.33 |
| 02/02/2005 9:20 | 0.25 | 0.4 / 8.9 | - 0.15 / - 8.65 |

The turbidity levels during this period have been maintained at a consistent level (below 1.0 NTU for 94% of the data) with fluctuations during rain storm events. These occasional occurrences of elevated turbidity data were observed prior to any recent anthropogenic activities in the watershed and are thus considered natural; however, they are a significant concern at the Port Alberni intake***. Therefore, to protect drinking water quality, it is recommended that from October to April (when turbid flows can occur) turbidity measured at the Port Alberni intake should not exceed a maximum of 5 NTU; during the remainder of the year (clear flow periods) turbidity measured at the Port Alberni intake should not exceed a maximum of 2 NTU (1 NTU above ambient levels, as measured prior to anthropogenic disturbance in the watershed).*** It should be noted that turbidity values above 2.0 NTU are considered likely to affect disinfection effectiveness in a chlorine-only system (Anderson, pers. comm., 2006). To meet the clear flow objective of 2 NTU it may be necessary to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency. In accordance with VIHA's protocol for whether filtration is required, the City of Port Alberni, as water purveyors, should continue to sample turbidity levels at the water intake location to ensure that the appropriate treatment methods are applied.

### 6.5 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS), or non-filterable residue (NFR), include all of the undissolved particulate matter in a sample. This value should be 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 sources at this time. For the protection of aquatic life, the maximum concentration allowed is an induced TSS concentration over background of 25 mg/L at any one time in 24 hours when background is less than or equal to 25 mg/L (clear flows) and an induced TSS concentration of 5 mg/L over background concentrations at any one time for a duration of 30 days (clear flows). Initially, less frequent monitoring may be appropriate to determine the need for more extensive monitoring (Caux *et al.,* 1997).

Concentrations of TSS ranged from below detectable limits (<1 mg/L) (45 of 53 measurements) to 11 mg/L (on November 12, 2002 after a winter rain event). TSS values were consistently low with elevated fluctuations only occurring during rain storm events during the months October to April. To determine average background levels, a minimum of five weekly samples within 30 days were collected on only two occasions: summer 2002 (mean TSS of 1 mg/L) and fall 2004 (mean TSS of 2 mg/L). The fall 2002 samples captured the first fall flush period (mean of 4 mg/L), and the summer 2004 mean of 1 mg/L) captured the last summer low flow period, providing useful information for determination of a TSS objective; therefore, these data were also included but are based on 4 instead of 5 weekly samples in 30 days. Prior to December 2004 there were little or no anthropogenic activities occurring in the watershed, suggesting that data up to December 2004 reflect background levels. Thus, average background summer TSS levels are 1 mg/L and fall TSS levels are 3 mg/L. Using these values, BC Water Quality Guidelines for aquatic life in the watershed specify a maximum of 26 mg/L in the summer and 28 mg/L in the fall (25 mg/L over background) at any one time in 24 hours, and of maximum of 6 mg/L in the summer and 8 mg/L in the fall (5 mg/L over background) at any one time for a duration 30 days.

It is evident that occasional high concentrations of TSS can occur, and for this reason a water quality objective for TSS is proposed. The objective is meant to apply to situations which are not natural but may have been triggered by human activities. ***It is recommended that TSS measured at the Port Alberni intake during the months October to April (when turbid flows can occur) should not exceed 28.0 mg/L at any time and the mean of five weekly samples in 30-days in this period should not exceed 8.0 mg/L. It is also recommended that during the remainder of the year (clear flow period) TSS measured at the intake should not exceed 26 mg/L at any time and the mean of five weekly samples in 30 days (primarily during May to September) should not exceed 6 mg/L***. Means of five weekly samples in 30 days were chosen (rather than maximum values of 30 samples in a 30 day period, as recommended in the guideline) considering the practicality of, and resources available for, monitoring, as well as local hydrology and the fact that Vancouver Island streams have clear flows for most of the year.

### 6.6 COLOUR AND TOTAL ORGANIC CARBON

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 water quality guideline is a maximum of 15 true colour units (TCU) (Moore and Caux, 1997). Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it can produce disinfection by-products (DBPs) such as trihalomethanes, which may pose a risk to human health.

Colour was only measured during the fall of 2001 in China Creek. Colour ranged from 3 TCU to 13 TCU, with an average of 9 TCU for 6 samples collected (Appendix I) and does not appear to be an aesthetic concern in the China Creek system. However, levels occasionally approach the guideline, and, while it is likely that elevated colour is a result of natural conditions within the watershed rather than anthropogenic activities, we recommend an objective to ensure that this parameter continues to be monitored. ***It is***

***recommended that maximum colour values should not exceed 15 TCU at the Port Alberni intake.***

Elevated total organic carbon (TOC) levels (above 4.0 mg/L) can result in higher levels of DBPs in finished drinking water if chlorination is used to disinfect the water (Moore, 1998). As Port Alberni uses chlorine to disinfect their drinking water, TOC concentrations should be monitored. During the study period, TOC was only sampled 8 times, and concentrations in these samples ranged from <0.5 mg/L to 2.1 mg/L. Instead, dissolved organic carbon (DOC) values were measured. TOC consists of two fractions: DOC and particulate organic carbon, with the majority generally as DOC. Concentrations of DOC at the China Creek sample site ranged from <0.5 to 3.4 mg/L for 35 samples. ***For this reason, and for the reasons listed above, a water quality objective for total organic carbon is proposed. It is recommended that maximum TOC values should not exceed 4.0 mg/L at the Port Alberni intake.***

### 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 in surface water 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. When both nitrate and nitrite are present, their combined concentration must not exceed 10 mg/L as N. For the protection of freshwater aquatic life, the nitrate guidelines are a maximum concentration of 31.3 mg/L and an average concentration of 3 mg/L. Nitrite concentrations are dependent on chloride; in low chloride waters (i.e., less than 2 mg/L) the maximum concentration of nitrite is 0.06 mg/L and the average concentration is 0.02 mg/L. Allowable concentrations of nitrite increase with ambient concentrations of chloride (Meays, 2009). There are no BC guidelines for phosphorus in streams.

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 N) to a maximum of 0.169 mg/L as N for 29 samples, while dissolved nitrite concentrations ranged from below detectable limits (<0.002 mg/L as N) to a maximum of 0.006 mg/L as N for 31 samples. All values of both nitrate and nitrite species were well below the existing aquatic life guidelines (Appendix I). As concentrations of nitrogen are generally low in China Creek, no objective is proposed for this parameter.

Total phosphorus concentrations ranged from below detectable limits (< 0.002 mg/L) to a maximum of 0.016 mg/L for 44 values. Phosphorus concentrations in China Creek are generally low and not likely to be a concern. Thus, no objective is proposed for this parameter at this time. The need for an objective should be re-evaluated after the next attainment monitoring period. The Vancouver Island Region of the MOE is working towards developing an interim phosphorous objective for Vancouver Island streams that will be available for use during future attainment periods.

### 6.8 METALS

Total metals concentrations were measured on 38 occasions in China Creek (Appendix I). The concentrations of most metals were below detection limits, and well below guidelines for drinking water and aquatic life. The exception was for total chromium (chromium I-VI); two samples (0.0014 mg/L on August 28th, 2003 and 0.0023 mg/L on November 3, 2003) were higher than the aquatic life working guideline (a maximum of0.001 mg/L chromium VI). Sampling specific to chromium VI is necessary to determine if the chromium VI working guideline is actually exceeded. As well, the validity of a value so close to the detection limit (0.001 mg/L) should be questioned. These occasional slightly elevated levels are not likely associated with any anthropogenic activities or are of significant concern to aquatic life. Additionally, there is no known source for chromium in the watershed.

Due to significant historical mining activities, as well as relatively recent exploration, it is possible that elevated metals concentrations due to leaching may occur in China Creek. For this reason, continued monitoring for metals is recommended, but no water quality objectives are proposed for metals concentrations in China 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 that are not biologically available. The relationship will vary seasonally, depending on the metal under consideration (e.g.,copper has the highest affinity for binding sites in humic materials). Levels of organics as measured by DOC vary from ecoregion to ecoregion. To aid in future development of metals objectives, DOC has been included in the China Creek monitoring program. As increasing water hardness can decrease the toxicity of copper and some other metals to some organisms, hardness has also been included in the China Creek monitoring program.

### 6.9 MICROBIOLOGICAL INDICATORS

Fecal contamination of surface waters used for drinking and recreating can result in high risks to human health from pathogenic microbiological organisms as well as significant economic losses due to closure of beaches (Scott *et al*., 2002). The direct measurement and monitoring of pathogens in water, however, is difficult due to their low numbers, intermittent and generally unpredictable occurrence, and specific growth requirements (Krewski *et al*., 2004; Ishii and Sadowsky, 2008). To assess risk of microbiological contamination from fecal matter, resource managers commonly measure fecal indicator bacteria levels (Field and Samadpour, 2007; Ishii and Sadowsky, 2008). The most commonly used indicator organisms for assessing the microbiological quality of water are the total coliforms, fecal coliforms (a subgroup of the total coliforms more appropriately termed thermotolerant coliforms as they can grow at elevated temperatures), and *E. coli* (a thermotolerant coliform considered to be specifically of fecal origin) (Yates, 2007).

There are a number of characteristics that suitable indicator organisms should possess. They should be present in the intestinal tracts of warm-blooded animals, not multiply outside the animal host, be nonpathogenic, and have similar survival characteristics to the pathogens of concern. They should also be strongly associated with the presence of pathogenic microorganisms, be present only in contaminated samples, and be detectable and quantifiable by easy, rapid, and inexpensive methods (Scott *et al*., 2002; Field and Samadpour, 2007; Ishii and Sadowsky, 2008).

Total and fecal coliforms have traditionally been used in the assessment of water for domestic and recreational uses. However, research in recent years has shown that there are many differences between the coliforms and the pathogenic microorganisms they are a surrogate for, which limits the use of coliforms as an indicator of fecal contamination (Scott *et al*., 2002). For example, many pathogens, such as enteric viruses and parasites, are not as easily inactivated by water and wastewater treatment processes as coliforms are. As a result, disease outbreaks do occur when indicator bacteria counts are at acceptable levels (Yates, 2007; Haack *et al*., 2009). Additionally, some members of the coliform group, such as *Klebsiella*, can originate from non-fecal sources (Ishii and

Sadowsky, 2008) adding a level of uncertainty when analyzing data. Waters contaminated with human feces are generally regarded as a greater risk to human health, as they are more likely to contain human-specific enteric pathogens (Scott *et al*., 2002). Measurement of total and fecal coliforms does not indicate the source of contamination, which can make the actual risk to human health uncertain; thus, it is not always clear where to direct management efforts.

The BC-approved water quality guidelines for microbiological indicators were developed in 1988 (Warrington, 1988) and include *E. coli*, enterococci, *Psudomonas aeruginosa*, and fecal coliforms. The monitoring programs of the BC MOE have traditionally measured total coliforms, fecal coliforms, *E. coli* and enterococci, either alone or in combination, depending on the specific program. As small pieces of fecal matter in a sample can skew the overall results for a particular site the 90$^{th}$ percentiles (for drinking water) and geometric means (for recreation) are generally used to determine if the water quality guideline is exceeded, as extreme values would have less effect on the data. The BC MOE drinking water guideline for raw waters receiving disinfection only is that the 90$^{th}$ percentile of at least five weekly samples collected in a 30-day period should not exceed 10 CFU/100 mL for either fecal coliforms or *E. coli* (Warrington, 2001).

Fecal coliform concentrations in China Creek ranged from below detectable limits (<1 CFU/100 mL) to a maximum of 41 CFU/100 mL for 30 samples (Appendix I). In those instances (fall 2001 and summer 2002) when at least five samples were collected within a 30-day period, a 90$^{th}$ percentile value was calculated, and these are summarized in Table 5. The fall 2002 and 2003 sample periods had only 4 weekly samples in 30 days, while the summer 2003 sample period had 5 samples in a 34 day period. Though these could not be directly compared to BC water quality guidelines, they were useful in understanding sample period trends and are included in Table 5.

*E. coli* concentrations ranged from below detectable limits (< 1 CFU/100 mL) to 48 CFU/100 mL for 32 samples. On the three occasions (fall 2001, summer 2002, and fall 2004) when the requisite sampling frequency was met, a 90$^{th}$ percentile value was calculated (Table 5). Only one of these 90$^{th}$ percentiles (30 CFU/100mL in fall 2004) was over the drinking water guideline of 10 CFU/100 ml, a result of one of the 5 weekly samples having a value of 48 CFU/100mL. As with fecal coliforms, the fall 2002 and 2003 sample periods had only 4 weekly samples in 30 days, while the summer 2003 sample period had 5 samples in a 34 day period. These were not directly comparable to BC water quality guidelines, but were useful in understanding sample period trends and were also included in Table 5. It was apparent that these non-comparable data sets captured the summer low flow conditions and the first fall flush periods and thus were included in calculations for the determination of an objective. The mean of 90$^{th}$ percentile *E. coli* values for the summer was 7 CFU/100 ml and for the fall was 12 CFU/100mL. Though the fall mean exceeded the drinking water guidelines, elevated fall flush values in areas of no impact are considered natural and have been observed in other Vancouver Island watersheds. For example, in the untouched watershed of McKelvie Creek, an objective of 60 CFU/100 ml (90$^{th}$ percentile for 5 samples in 30 days) was recommended to reflect natural variability within the watershed (Epps, 2007).

**Table 5.** Summary of 90th percentile values for fecal coliforms (CFU/100 mL) and *E. coli* (CFU/100 mL) at China Creek Intake, calculated when a minimum of five samples were collected within a 30-day period.

| Parameter | Fall 2001 | Summer 2002 | Fall 2002 * | Summer 2003** | Fall 2003* | Summer 2004 | Fall 2004 | Summer Mean | Fall Mean |
|---|---|---|---|---|---|---|---|---|---|
| Fecal coliform | 7 | 9 | 29 | 12 | 7 | no data | too few samples | 10 | 15 |
| *E. coli* | 5 | 8 | 8 | 5 | 5 | no data | 30 | 7 | 12 |

* based on 4 samples in 30 days

**based on 5 samples in 34 days

For China Creek, the results for both fecal coliforms and *E. coli* were not consistently similar. Studies have shown that *E. coli*, a component of the fecal coliforms group, is the main thermo-tolerant coliform species present in human and animal fecal samples (94%) (Tallon *et al*., 2005) and at contaminated bathing beaches (80%) (*Davis et al.*, 2005). In cases where fecal coliform counts were greater than *E. coli*, we can assume a high likelihood of contributions from non-fecal sources. Thus, the value added benefit of measuring both groups is limited.

In the periods sampled with sufficient frequency (5 weekly samples in 30 days), the drinking water guideline (10 CFU/100 mL) was exceeded in only the fall of 2004 and only for *E. coli*. The remaining sample data (collected fewer than 5 weekly samples in 30 days) suggest that, while coliform concentrations are relatively low the majority of the time, occasional high concentrations (e.g. Fall 2002) associated with rainstorm events may be a concern for both fecal coliforms and *E. coli*. While the source of these bacteria is not known and may not be related to anthropogenic activities within the watershed, microbiological indicator concentrations should continue to be monitored and assessed. Given the uncertainty in linking thermotolerant (i.e. fecal) coliforms to human sources of sewage, we recommend using *E. coli* as the microbiological indicator for China Creek. Therefore, a water quality objective is proposed for E. coli in China Creek. Though the mean fall 90$^{th}$ percentile value was 12 CFU/100 mL, this value is so close to the BC drinking water guideline (10 CFU/100 mL) that the guideline will be used as the objective. ***The objective is that the 90$^{th}$ percentile of a minimum of five weekly samples collected within a 30-day period must not exceed 10 CFU/100 mL at the Port Alberni intake for*** **E. coli.** The fall 2004 value in exceedence of the objective highlights the need for water purveyors to provide adequate treatment prior to consumption. Meeting these objectives will provide protection from most pathogens 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 City of Port Alberni.

# 7.0 MONITORING RECOMMENDATIONS

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, fall flush 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 October and November. 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 pH, specific conductivity, TSS, turbidity, colour, DOC, TOC, and total phosphorous), as well as bacteriology (including *E. coli*), and field measurements of temperature should be taken. At least one of the samples collected during the both the high-flow and low-flow period should also be analyzed for total and dissolved metals concentrations (low level analysis) and hardness.

## 7.1 BIOLOGICAL MONITORING

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. Biological data has been under-utilized 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 with water quality objectives, where possible.

# 8.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES AND MONITORING SCHEDULE

In BC, water quality objectives are based mainly on approved or working water quality guidelines. These guidelines are established to prevent specified detrimental effects from occurring with respect to a designated water use. Designated water uses for China Creek that are sensitive and should be protected are drinking water, aquatic life and wildlife. The water quality objectives recommended here (Table 6) take into account background conditions, impacts from current land use and any known potential future impacts that may arise within the watershed. These objectives should be periodically reviewed and revised to reflect any future improvements or technological advancements in water quality assessment and analysis.

**Table 6.** Summary of proposed water quality objectives for China Creek Community Watershed.

| Variable | Objective Value |
|---|---|
| ***Escherichia coli*** | ≤10 CFU/100 mL (90th percentile)<br>(based on a minimum 5 weekly samples collected over a 30-day period) |
| **Turbidity** | October to April:<br>5 NTU maximum<br>May to September:<br>2 NTU maximum |
| **pH** | 6.5 – 8.5 pH units |
| **Temperature** | 15°C maximum (long-term) |
| **True Colour** | 15 TCU maximum |
| **Total Organic Carbon** | 4.0 mg/L maximum |
| **Non-Filterable Residue (TSS)** | October to April:<br>28 mg/L maximum in a 24-hour period<br>8mg/L average (based on a minimum of five weekly samples collected over a 30-day period)<br><br>May to September:<br>26 mg/L maximum in a 24-hour period<br>6 mg/L average (based on a minimum of five weekly samples collected over a 30-day period) |

The recommended water quality monitoring program for China Creek is summarized in Table 7. It is recommended that future attainment monitoring occur once every 3-5 years based on staff and funding availability, and whether activities, such as forestry or development, are underway within the watershed.

**Table 7**. Proposed schedule for future water quality and benthic invertebrate monitoring in China Creek.

| Frequency and timing | Characteristic to be measured |
|---|---|
| August – September (low-flow season): once per week for five consecutive weeks | Temperature, pH, specific conductivity, TSS, turbidity, colour, total phosphorous, DOC, TOC, and *E. coli* |
| October – November (high-flow season): once per week for five consecutive weeks | Temperature, pH, specific conductivity, TSS, turbidity, colour, total phosphorous, DOC, TOC, and *E. coli* |
| Once each during low-flow and high-flow season | Total and dissolved metals, hardness |
| Once every five years | Benthic invertebrate sampling |

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# APPENDIX I. SUMMARY OF WATER QUALITY DATA

**Table 8.** Summary of general water chemistry at Site E230197, China Creek at Intake.

| Parameter | Minimum | Maximum | Average | Std Dev | Count |
|---|---|---|---|---|---|
| C--T (mg/L) | <8.9 | 11.9 | 10.0 | 1.7 | 3 |
| Ca-D (mg/L) | 11 | 19.2 | 15.1 | 3.2 | 8 |
| Ca-T (mg/L) | 11 | 18.1 | 14.8 | 3.1 | 8 |
| Carbon Diss. Inorganic (mg/L) | 7.3 | 8.2 | 7.8 | 0.6 | 2 |
| Carbon Dissolved Organic (mg/L) | <0.5 | 3.4 | 1.2 | 0.7 | 35 |
| Carbon Total Dissolved (mg/L) | <8.7 | 9 | 8.9 | 0.2 | 2 |
| Carbon Total Inorganic (mg/L) | 7.4 | 11.3 | 9.0 | 2.0 | 3 |
| Carbon Total Organic (mg/L) | <0.5 | 2.1 | 1.2 | 0.7 | 8 |
| Mg-D (mg/L) | 0.444 | 1.148 | 0.912 | 0.211 | 14 |
| Mg-T (mg/L) | 0.483 | 1.156 | 0.909 | 0.244 | 8 |
| Na-D (mg/L) | 0.8 | <2 | 1.6 | 0.5 | 8 |
| Na-T (mg/L) | 0.9 | <2 | 1.5 | 0.5 | 8 |
| Nitrate (NO3) Dissolved (mg/L) | 0.013 | 0.169 | 0.049 | 0.032 | 29 |
| Nitrate + Nitrite Diss. (mg/L) | <0.002 | 0.171 | 0.047 | 0.031 | 37 |
| Nitrogen - Nitrite Diss. (mg/L) | <0.002 | 0.006 | 0.002 | 0.001 | 31 |
| Ortho-Phosphate Dissolved (mg/L) | <0.001 | 0.006 | 0.002 | 0.002 | 37 |
| P--T (mg/L) | <0.002 | <0.3 | 0.0 | 0.1 | 44 |
| Phosphorus Tot. Dissolved (mg/L) | <0.002 | <0.3 | 0.0 | 0.1 | 42 |
| | | | | | |
| Color True (Col.unit) | 3 | 13 | 9.3 | 4.3 | 6 |
| Hardness Total (D) (mg/L) | 30.1 | 52.6 | 42.1 | 8.5 | 14 |
| Hardness Total (T) (mg/L) | 29.7 | 49.8 | 40.7 | 8.5 | 8 |
| pH (pH units) | 7.27 | 8.2 | 7.77 | 0.21 | 42 |
| Residue Non-filterable (mg/L) | <1 | 11 | 1.8 | 2.3 | 53 |
| Specific Conductance (uS/cm) | 48 | 148 | 104.1 | 24.1 | 37 |
| Turbidity (NTU) | <0.1 | 5.5 | 0.6 | 1.1 | 43 |
| UV Absorbance 250nm (AU/cm) | <0.01 | 0.06 | 0.02 | 0.01 | 16 |
| UV Absorbance 254nm (AU/cm) | <0.01 | 0.06 | 0.02 | 0.01 | 16 |
| UV Absorbance 310nm (AU/cm) | <0.01 | 0.02 | 0.01 | 0.00 | 16 |
| UV Absorbance 340nm (AU/cm) | <0.01 | 0.01 | 0.01 | 0 | 16 |
| UV Absorbance 360nm (AU/cm) | <0.01 | 0.01 | 0.01 | 0 | 16 |
| UV Absorbance 365nm (AU/cm) | <0.01 | 0.01 | 0.01 | 0 | 16 |
| | | | | | |
| Coli:Fec (CFU/100mL) | <1 | 41 | 5.5 | 8.2 | 30 |
| E Coli (CFU/100mL) | <1 | 48 | 4.3 | 8.4 | 32 |
| Entercoc (CFU/100mL) | <1 | 1 | 1.0 | 0.0 | 6 |
| Strepcoc (CFU/100mL) | 12 | 51 | 31.5 | 27.6 | 2 |
| | | | | | |
| Ag-D (mg/L) | <0.00001 | 0.00003 | 0.00002 | 0.000003 | 37 |
| Ag-T (mg/L) | <0.00001 | <0.00002 | 0.00002 | 0.000002 | 38 |
| Al-D (mg/L) | 0.0021 | <0.05 | 0.0161 | 0.0160 | 43 |
| Al-T (mg/L) | 0.0026 | 0.1495 | 0.0202 | 0.0313 | 38 |
| As-D (mg/L) | 0.0004 | 0.001 | 0.0008 | 0.0001 | 37 |
| As-T (mg/L) | 0.0005 | 0.0011 | 0.0008 | 0.0001 | 38 |
| B--D (mg/L) | 0.005 | 0.011 | 0.008 | 0.002 | 8 |
| B--T (mg/L) | 0.005 | 0.011 | 0.008 | 0.002 | 8 |
| Ba-D (mg/L) | 0.00548 | 0.0148 | 0.01038 | 0.00268 | 43 |
| Ba-T (mg/L) | 0.00611 | 0.0149 | 0.01108 | 0.00259 | 38 |

| Parameter | Minimum | Maximum | Average | Std Dev | Count |
|---|---|---|---|---|---|
| Be-D (mg/L) | <0.000002 | <0.0005 | 0.000044 | 0.000111 | 37 |
| Be-T (mg/L) | <0.000002 | <0.0005 | 0.000044 | 0.000109 | 38 |
| Bi-D (mg/L) | <0.00002 | <0.0005 | 0.00005 | 0.00011 | 37 |
| Bi-T (mg/L) | <0.00002 | <0.0005 | 0.00005 | 0.00011 | 38 |
| Cd-D (mg/L) | <0.00001 | 0.00058 | 0.00005 | 0.00011 | 37 |
| Cd-T (mg/L) | <0.00001 | 0.00008 | 0.00002 | 0.00002 | 38 |
| Co-D (mg/L) | <0.000005 | <0.0001 | 0.000017 | 0.000024 | 37 |
| Co-T (mg/L) | <0.000005 | 0.000134 | 0.000027 | 0.000037 | 38 |
| Cr-D (mg/L) | <0.00002 | 0.0016 | 0.00032 | 0.00026 | 37 |
| Cr-T (mg/L) | <0.00002 | 0.0023 | 0.00039 | 0.00040 | 38 |
| Cu-D (mg/L) | <0.0001 | <0.005 | 0.0012 | 0.0016 | 43 |
| Cu-T (mg/L) | <0.00005 | 0.00297 | 0.00056 | 0.00053 | 38 |
| Fe-D (mg/L) | <0.005 | <0.03 | 0.015 | 0.010 | 8 |
| Fe-T (mg/L) | 0.015 | 0.233 | 0.058 | 0.072 | 8 |
| Hg-D (mg/L) | <0.00001 | <0.00001 | 0.00001 | 0 | 2 |
| Hg-T (mg/L) | <0.00001 | 0.00001 | 0.00001 | 0 | 2 |
| K--D (mg/L) | <0.1 | <2 | 0.6 | 0.9 | 8 |
| K--T (mg/L) | <0.1 | <2 | 0.6 | 0.9 | 8 |
| Li-D (mg/L) | <0.00005 | 0.00165 | 0.00088 | 0.00037 | 37 |
| Li-T (mg/L) | <0.00005 | 0.0024 | 0.00094 | 0.00042 | 38 |
| Mn-D (mg/L) | <0.000005 | 0.00143 | 0.000408 | 0.000361 | 43 |
| Mn-T (mg/L) | 0.000113 | 0.0125 | 0.001045 | 0.002156 | 38 |
| Mo-D (mg/L) | <0.00005 | 0.00029 | 0.00010 | 0.00005 | 37 |
| Mo-T (mg/L) | <0.00005 | 0.00026 | 0.00009 | 0.00004 | 38 |
| Ni-D (mg/L) | <0.00005 | 0.00091 | 0.00016 | 0.00024 | 37 |
| Ni-T (mg/L) | <0.00005 | 0.00188 | 0.00019 | 0.00034 | 38 |
| Pb-D (mg/L) | <0.00001 | <0.05 | 0.00703 | 0.01751 | 43 |
| Pb-T (mg/L) | <0.00001 | 0.00039 | 0.00008 | 0.00008 | 38 |
| S--D (mg/L) | 0.42 | 0.89 | 0.70 | 0.19 | 6 |
| S--T (mg/L) | 0.4 | 0.85 | 0.64 | 0.18 | 6 |
| Sb-D (mg/L) | <0.000005 | 0.000064 | 0.000044 | 0.000012 | 37 |
| Sb-T (mg/L) | <0.000005 | 0.000077 | 0.000045 | 0.000012 | 38 |
| Se-D (mg/L) | <0.0002 | <0.001 | 0.0003 | 0.0002 | 37 |
| Se-T (mg/L) | <0.0002 | <0.001 | 0.0003 | 0.0002 | 38 |
| Si-D (mg/L) | 1.34 | 1.83 | 1.59 | 0.20 | 8 |
| Si-T (mg/L) | 1.31 | 1.87 | 1.58 | 0.18 | 8 |
| Sn-D (mg/L) | <0.00001 | <0.0001 | 0.00002 | 0.00002 | 37 |
| Sn-T (mg/L) | <0.00001 | <0.0001 | 0.00002 | 0.00002 | 38 |
| Sr-D (mg/L) | 0.0172 | 0.0573 | 0.0398 | 0.0115 | 43 |
| Sr-T (mg/L) | 0.0171 | 0.0569 | 0.0424 | 0.0115 | 38 |
| Ti-D (mg/L) | <0.002 | <0.01 | 0.004 | 0.004 | 8 |
| Ti-T (mg/L) | <0.002 | <0.01 | 0.005 | 0.004 | 8 |
| Tl-D (mg/L) | <0.000002 | <0.00005 | 0.00000 | 0.00001 | 37 |
| Tl-T (mg/L) | <0.000002 | <0.00005 | 0.00001 | 0.00001 | 38 |
| U--D (mg/L) | <0.000002 | <0.00001 | 0.00000 | 0.00000 | 37 |
| U--T (mg/L) | <0.000002 | <0.000011 | 0.000005 | 0.000003 | 38 |
| V--D (mg/L) | 0.00012 | 0.00108 | 0.00040 | 0.00024 | 37 |
| V--T (mg/L) | 0.00014 | 0.00103 | 0.00044 | 0.00024 | 38 |
| Zn-D (mg/L) | <0.0001 | 0.004 | 0.0010 | 0.0010 | 43 |
| Zn-T (mg/L) | <0.0001 | 0.0029 | 0.0006 | 0.0006 | 38 |

# APPENDIX II. 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. |
|---|---|---|---|---|---|---|---|---|---|
| 25/07/2003 | 05:45 | 439.5 | 0.847 | 0 | 1.25 | 368 | 0 | 176.7 | 162.9 |
| 12/10/2003 | 04:15 | 0.25 | 1.315 | 0.035 | 0.75 | 41.6 | 3.8 | 17.9 | 20.6 |
| 12/10/2003 | 14:45 | 1.75 | 1.422 | -0.02 | 0.75 | 45.6 | 0.4 | 22.4 | 22.6 |
| 15/10/2003 | 23:45 | 0.25 | 1.031 | 0.003 | 0.75 | 66.3 | 0 | 24.7 | 36.2 |
| 16/10/2003 | 15:45 | 0.75 | 1.495 | 0.025 | 0.75 | 128.7 | 1.3 | 76.2 | 66.6 |
| 16/10/2003 | 20:00 | 0.25 | 1.599 | 0.05 | 1 | 21.7 | 1.6 | 9.9 | 8.7 |
| 16/10/2003 | 16:30 | 0.25 | 1.52 | 0.041 | 2 | 87.7 | 1.3 | 33.8 | 29.7 |
| 16/10/2003 | 21:30 | 0.75 | 1.69 | 0.135 | 8 | 43 | 3.4 | 13.2 | 7.3 |
| 17/10/2003 | 18:45 | 1.5 | 1.896 | -0.14 | 37.25 | 174.1 | 4.1 | 27.8 | 20.2 |
| 19/10/2003 | 08:00 | 0.25 | 1.756 | -0.021 | 0.75 | 5.7 | 4.6 | 5.3 | 0.6 |
| 19/10/2003 | 10:30 | 0.25 | 1.679 | -0.013 | 0.75 | 13 | 4.4 | 7.5 | 4.8 |
| 19/10/2003 | 11:15 | 0.25 | 1.666 | -0.016 | 0.75 | 103.5 | 1.8 | 37.2 | 57.5 |
| 19/10/2003 | 14:15 | 0.75 | 1.609 | -0.011 | 0.75 | 16.9 | 1.3 | 8.1 | 8.0 |
| 19/10/2003 | 16:00 | 1.25 | 1.572 | -0.022 | 0.75 | 81.6 | 0.2 | 30.2 | 44.7 |
| 19/10/2003 | 18:45 | 1.5 | 1.534 | -0.024 | 0.75 | 30.4 | 1.2 | 18.7 | 15.4 |
| 19/10/2003 | 12:45 | 1 | 1.635 | -0.023 | 1 | 25.2 | 1.4 | 10.5 | 10.3 |
| 19/10/2003 | 20:00 | 0.75 | 1.511 | -0.013 | 1 | 12.5 | 0.2 | 9.4 | 6.2 |
| 20/10/2003 | 09:00 | 0.25 | 1.537 | 0.064 | 0.75 | 37 | 0.4 | 14.9 | 19.5 |
| 20/10/2003 | 11:00 | 0.25 | 1.694 | 0.034 | 0.75 | 66 | 2 | 30.8 | 32.5 |
| 20/10/2003 | 12:45 | 0.25 | 1.74 | 0.011 | 0.75 | 17.9 | 1.7 | 9.1 | 8.2 |
| 20/10/2003 | 22:00 | 1.5 | 1.671 | -0.025 | 0.75 | 58.9 | 0.8 | 26.7 | 29.6 |
| 20/10/2003 | 22:45 | 0.25 | 1.646 | -0.018 | 0.75 | 26.7 | 0.7 | 11.9 | 13.4 |
| 20/10/2003 | 01:30 | 0.25 | 1.446 | -0.004 | 1 | 197.2 | 0.1 | 69.3 | 88.5 |
| 20/10/2003 | 17:30 | 0.25 | 1.837 | -0.037 | 1 | 223.9 | 4.1 | 65.6 | 105.7 |
| 20/10/2003 | 07:30 | 1.25 | 1.451 | 0.086 | 1.5 | 188 | 0.5 | 52.2 | 70.0 |
| 20/10/2003 | 14:00 | 0.75 | 1.785 | 0.074 | 3 | 26.1 | 2.8 | 9.4 | 6.8 |
| 21/10/2003 | 00:00 | 0.75 | 1.628 | -0.02 | 0.75 | 27 | 0.3 | 11.7 | 13.8 |
| 21/10/2003 | 05:45 | 3.5 | 1.523 | -0.015 | 0.75 | 57 | 0 | 25.7 | 28.9 |
| 21/10/2003 | 08:30 | 0.25 | 1.483 | -0.012 | 0.75 | 91.9 | 1.5 | 61.8 | 52.2 |
| 21/10/2003 | 17:00 | 1.75 | 1.398 | -0.012 | 0.75 | 15.6 | 0 | 8.7 | 7.9 |
| 21/10/2003 | 21:45 | 0.5 | 1.358 | -0.005 | 0.75 | 78 | 0 | 37.2 | 39.1 |
| 22/10/2003 | 03:00 | 2 | 1.327 | 0 | 0.75 | 209.1 | 0 | 72.3 | 118.6 |
| 22/10/2003 | 07:00 | 0.5 | 1.312 | -0.01 | 0.75 | 48.4 | 4.4 | 20.7 | 24.1 |
| 22/10/2003 | 22:15 | 7.5 | 1.389 | -0.003 | 0.75 | 71.5 | 0 | 27.7 | 38.4 |
| 23/10/2003 | 00:00 | 1.25 | 1.375 | -0.018 | 1 | 58.8 | 0 | 27.3 | 28.3 |
| 23/10/2003 | 04:30 | 1.75 | 1.339 | 0.002 | 1 | 11.3 | 4.1 | 7.3 | 3.0 |
| 23/10/2003 | 15:15 | 0.25 | 1.288 | -0.01 | 1 | 33.7 | 0 | 22.2 | 15.9 |
| 06/11/2003 | 06:45 | 280.5 | 0.937 | -0.001 | 1.25 | 83.7 | 0 | 63.9 | 35.9 |
| 18/11/2003 | 05:00 | 0.5 | 1.251 | -0.008 | 0.75 | 80.8 | 0.2 | 36.9 | 40.8 |
| 18/11/2003 | 06:15 | 0.75 | 1.235 | -0.008 | 0.75 | 151.4 | 3.5 | 74.2 | 74.2 |
| 18/11/2003 | 03:45 | 1.5 | 1.258 | -0.002 | 1 | 129 | 0.6 | 63.8 | 54.5 |
| 28/11/2003 | 22:15 | 0.25 | 1.357 | -0.011 | 0.75 | 55.7 | 0.4 | 27.6 | 27.7 |
| 28/11/2003 | 15:15 | 0.25 | 1.442 | 0.012 | 1 | 104.6 | 3 | 66.9 | 45.4 |
| 28/11/2003 | 21:15 | 0.25 | 1.366 | -0.009 | 1 | 237.2 | 5 | 100.1 | 98.1 |

| 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. |
|---|---|---|---|---|---|---|---|---|---|
| 28/11/2003 | 13:30 | 0.5 | 1.399 | 0.043 | 1.75 | 215 | 3.1 | 126.2 | 85.4 |
| 28/11/2003 | 23:15 | 0.5 | 1.35 | -0.032 | 2 | 211.2 | 0.1 | 44.4 | 69.2 |
| 28/11/2003 | 09:45 | 0.75 | 1.236 | 0.155 | 3.5 | 282 | 0.2 | 96.7 | 93.9 |
| 28/11/2003 | 16:15 | 0.25 | 1.454 | -0.065 | 3.75 | 294.9 | 0.8 | 85.7 | 84.2 |
| 29/11/2003 | 04:15 | 0.25 | 1.291 | -0.002 | 0.75 | 49.1 | 0 | 18.4 | 26.8 |
| 29/11/2003 | 11:30 | 0.25 | 1.242 | -0.005 | 0.75 | 11.9 | 0.1 | 7.4 | 6.4 |
| 29/11/2003 | 05:15 | 0.5 | 1.287 | -0.008 | 1 | 279.5 | 0.5 | 103.2 | 128.7 |
| 29/11/2003 | 02:00 | 1 | 1.314 | -0.014 | 1.25 | 76.8 | 0 | 61.4 | 34.3 |
| 02/12/2003 | 19:30 | 0.5 | 1.214 | 0.024 | 0.75 | 35 | 0 | 18.1 | 17.5 |
| 02/12/2003 | 18:15 | 74.25 | 1.145 | 0.062 | 1 | 56.1 | 0.1 | 42.1 | 28.0 |
| 02/12/2003 | 20:15 | 0.25 | 1.238 | -0.006 | 1 | 132 | 0 | 55.4 | 61.5 |
| 02/12/2003 | 21:15 | 0.25 | 1.232 | -0.022 | 2.75 | 214.7 | 3.3 | 65.4 | 64.6 |
| 03/12/2003 | 00:00 | 0.25 | 1.21 | -0.005 | 0.75 | 63.7 | 1.1 | 24.6 | 34.1 |
| 03/12/2003 | 02:15 | 0.25 | 1.19 | 0.001 | 0.75 | 31.4 | 0 | 14.1 | 15.9 |
| 03/12/2003 | 04:30 | 0.5 | 1.186 | -0.008 | 0.75 | 78.2 | 0 | 49.3 | 42.9 |
| 03/12/2003 | 01:15 | 0.25 | 1.201 | -0.011 | 1 | 186.3 | 0.9 | 90.3 | 77.3 |
| 03/12/2003 | 07:15 | 1.75 | 1.172 | 0 | 1 | 385.6 | 0 | 144.3 | 167.1 |
| 05/12/2003 | 06:15 | 1.75 | 1.24 | 0.017 | 0.75 | 20.5 | 0.5 | 8.7 | 10.5 |
| 05/12/2003 | 16:00 | 0.25 | 1.305 | 0.008 | 0.75 | 13.3 | 2 | 6.8 | 5.8 |
| 05/12/2003 | 23:00 | 0.25 | 1.477 | -0.014 | 0.75 | 164.3 | 0.7 | 70.7 | 84.3 |
| 05/12/2003 | 11:45 | 0.25 | 1.289 | 0.006 | 1 | 28.9 | 2.5 | 12.1 | 11.7 |
| 05/12/2003 | 16:45 | 0.25 | 1.313 | 0.021 | 1 | 67.5 | 0.1 | 27.2 | 31.0 |
| 05/12/2003 | 19:15 | 0.5 | 1.398 | 0.082 | 1.5 | 187.1 | 0.6 | 73.8 | 66.6 |
| 05/12/2003 | 10:00 | 1 | 1.291 | -0.002 | 1.75 | 250.4 | 0.1 | 85.7 | 98.8 |
| 05/12/2003 | 20:45 | 0.25 | 1.48 | -0.003 | 2.25 | 383.7 | 0.3 | 78.9 | 123.7 |
| 06/12/2003 | 04:00 | 0.25 | 1.393 | -0.001 | 0.75 | 67.5 | 0 | 25.4 | 36.7 |
| 06/12/2003 | 06:15 | 0.25 | 1.366 | -0.002 | 0.75 | 211.6 | 1.1 | 84.8 | 111.7 |
| 06/12/2003 | 07:15 | 0.5 | 1.357 | 0 | 0.75 | 14.3 | 0.3 | 9.3 | 7.8 |
| 06/12/2003 | 05:00 | 0.5 | 1.382 | -0.016 | 1.25 | 42.8 | 0 | 19.1 | 15.8 |
| 06/12/2003 | 01:15 | 0.25 | 1.429 | -0.036 | 2.75 | 99.4 | 0.1 | 29.1 | 30.6 |
| 07/12/2003 | 14:00 | 1.25 | 1.222 | -0.004 | 0.75 | 88.8 | 0 | 39.7 | 45.1 |
| 07/12/2003 | 17:45 | 3.25 | 1.213 | 0 | 0.75 | 29.4 | 0 | 14.0 | 14.8 |
| 08/12/2003 | 01:00 | 2.75 | 1.189 | -0.002 | 0.75 | 35.2 | 2.8 | 18.4 | 16.2 |
| 09/12/2003 | 18:00 | 6.75 | 1.093 | 0 | 1.5 | 119.5 | 0 | 33.5 | 47.5 |
| 16/12/2003 | 11:30 | 0.5 | 1.364 | 0.015 | 0.75 | 49.8 | 0 | 28.0 | 25.5 |
| 16/12/2003 | 13:00 | 1 | 1.4 | 0.047 | 0.75 | 188.8 | 0.3 | 66.8 | 105.8 |
| 16/12/2003 | 06:00 | 154.75 | 1.21 | 0.048 | 1 | 282.9 | 0.1 | 109.9 | 121.5 |
| 16/12/2003 | 15:30 | 0.25 | 1.528 | -0.005 | 1 | 73.5 | 3.5 | 23.4 | 33.6 |
| 16/12/2003 | 08:30 | 0.75 | 1.316 | 0.031 | 1.25 | 77.5 | 0.2 | 29.3 | 32.0 |
| 16/12/2003 | 09:45 | 0.25 | 1.347 | 0.015 | 1.5 | 399 | 0 | 119.3 | 156.0 |
| 16/12/2003 | 17:45 | 0.5 | 1.496 | -0.036 | 1.75 | 65.4 | 0.2 | 23.8 | 27.0 |
| 16/12/2003 | 21:00 | 1.75 | 1.442 | -0.045 | 3.25 | 120.6 | 1.2 | 45.0 | 38.2 |
| 17/12/2003 | 18:00 | 1.25 | 1.248 | 0.003 | 0.75 | 229.6 | 3.7 | 92.3 | 120.5 |
| 17/12/2003 | 20:45 | 2.25 | 1.24 | -0.003 | 0.75 | 35 | 0.1 | 21.6 | 18.8 |
| 17/12/2003 | 03:00 | 0.25 | 1.361 | -0.001 | 1 | 54.1 | 0 | 28.2 | 22.7 |
| 17/12/2003 | 01:15 | 0.5 | 1.385 | -0.012 | 1.25 | 83 | 1 | 24.8 | 33.6 |
| 18/12/2003 | 03:00 | 5.75 | 1.213 | -0.002 | 0.75 | 9.1 | 0 | 5.8 | 5.1 |
| 18/12/2003 | 11:15 | 4.75 | 1.183 | 0.001 | 0.75 | 244.7 | 0 | 108.1 | 124.8 |

| 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. |
|---|---|---|---|---|---|---|---|---|---|
| 18/12/2003 | 12:15 | 0.5 | 1.184 | -0.006 | 1 | 16.5 | 0.1 | 12.4 | 8.2 |
| 18/12/2003 | 20:00 | 3.75 | 1.16 | -0.002 | 1.25 | 94 | 0 | 34.7 | 35.1 |
| 19/12/2003 | 17:15 | 20.25 | 1.122 | 0 | 0.75 | 122.8 | 0 | 42.7 | 69.4 |
| 22/12/2003 | 15:30 | 2.25 | 1.117 | -0.006 | 1 | 407.6 | 0 | 303.8 | 202.5 |
| 24/12/2003 | 14:45 | 13 | 1.309 | 0.006 | 0.75 | 65.5 | 0.6 | 25.3 | 35.1 |
| 27/12/2003 | 13:00 | 6 | 1.122 | 0 | 1.5 | 35.4 | 0 | 16.7 | 11.3 |
| 09/01/2004 | 08:45 | 0.75 | 1.158 | 0.001 | 0.75 | 89.9 | 0.2 | 32.8 | 49.6 |
| 09/01/2004 | 14:45 | 5.5 | 1.22 | 0.006 | 0.75 | 33.4 | 2.6 | 20.2 | 15.9 |
| 09/01/2004 | 15:30 | 0.25 | 1.226 | 0.007 | 0.75 | 10.4 | 0 | 5.7 | 5.3 |
| 09/01/2004 | 23:45 | 0.25 | 1.427 | 0.033 | 0.75 | 11.1 | 0.5 | 7.1 | 5.7 |
| 09/01/2004 | 16:15 | 0.25 | 1.233 | 0.009 | 1.25 | 101.8 | 0 | 39.9 | 39.8 |
| 09/01/2004 | 18:15 | 0.5 | 1.248 | 0.022 | 1.25 | 292.2 | 0.2 | 107.9 | 138.5 |
| 10/01/2004 | 02:15 | 0.5 | 1.48 | -0.002 | 0.75 | 33.8 | 2.8 | 23.4 | 17.9 |
| 10/01/2004 | 08:30 | 3.25 | 1.432 | -0.003 | 0.75 | 55.2 | 3.7 | 22.4 | 28.5 |
| 10/01/2004 | 21:15 | 3 | 1.32 | 0.001 | 0.75 | 96.7 | 0 | 35.3 | 53.4 |
| 10/01/2004 | 15:15 | 2.5 | 1.369 | -0.008 | 1.25 | 58.9 | 0 | 21.1 | 23.0 |
| 10/01/2004 | 22:15 | 0.5 | 1.311 | -0.001 | 1.25 | 100.7 | 0 | 80.6 | 45.0 |
| 11/01/2004 | 01:15 | 1 | 1.295 | 0.003 | 0.75 | 66.6 | 2.5 | 26.9 | 34.7 |
| 11/01/2004 | 04:15 | 2.5 | 1.283 | -0.006 | 0.75 | 50 | 0 | 27.2 | 25.3 |
| 11/01/2004 | 22:15 | 5 | 1.238 | -0.004 | 1.25 | 107.9 | 0 | 43.4 | 41.7 |
| 12/01/2004 | 03:00 | 3.75 | 1.231 | -0.001 | 0.75 | 9.4 | 0.1 | 5.5 | 4.8 |
| 12/01/2004 | 11:00 | 6.75 | 1.225 | -0.005 | 0.75 | 42.4 | 0 | 16.2 | 22.9 |
| 12/01/2004 | 21:15 | 0.75 | 1.313 | -0.004 | 0.75 | 44.3 | 0 | 25.5 | 22.9 |
| 12/01/2004 | 22:00 | 0.25 | 1.309 | 0.005 | 0.75 | 112.5 | 2.5 | 67.2 | 57.5 |
| 13/01/2004 | 06:30 | 1.25 | 1.318 | 0 | 1 | 221.7 | 4.5 | 167.4 | 108.6 |
| 13/01/2004 | 16:00 | 1 | 1.445 | 0.022 | 1 | 38 | 0.4 | 18.0 | 15.5 |
| 13/01/2004 | 19:45 | 0.75 | 1.545 | 0.007 | 1 | 18 | 2.6 | 10.2 | 6.3 |
| 13/01/2004 | 21:15 | 0.75 | 1.548 | 0.016 | 1 | 7.1 | 1.5 | 5.7 | 2.8 |
| 13/01/2004 | 17:30 | 0.25 | 1.485 | 0.036 | 1.75 | 147.4 | 0 | 51.0 | 49.6 |
| 13/01/2004 | 22:15 | 0.25 | 1.564 | 0.048 | 4 | 389.4 | 4.8 | 126.8 | 124.5 |
| 14/01/2004 | 18:00 | 0.5 | 1.561 | 0.003 | 0.75 | 217 | 1.6 | 93.6 | 111.1 |
| 14/01/2004 | 21:45 | 0.5 | 1.555 | 0.003 | 1 | 151.6 | 0 | 51.1 | 69.0 |
| 14/01/2004 | 16:30 | 0.25 | 1.58 | -0.018 | 1.25 | 55.4 | 0.1 | 22.9 | 21.4 |
| 14/01/2004 | 10:00 | 0.25 | 1.653 | -0.005 | 1.75 | 408.3 | 4.9 | 173.8 | 162.2 |
| 14/01/2004 | 19:45 | 0.25 | 1.543 | 0.012 | 1.75 | 254.3 | 1.2 | 91.0 | 100.4 |
| 14/01/2004 | 11:45 | 0.25 | 1.648 | -0.014 | 2 | 208.5 | 2.3 | 70.8 | 67.1 |
| 14/01/2004 | 02:15 | 0.25 | 1.612 | 0.021 | 2.25 | 128.3 | 2.8 | 44.7 | 40.5 |
| 14/01/2004 | 05:00 | 0.25 | 1.625 | 0.042 | 2.5 | 304.4 | 2.2 | 76.3 | 100.7 |
| 14/01/2004 | 07:30 | 0.25 | 1.667 | -0.014 | 2.5 | 406 | 2.6 | 172.2 | 158.7 |
| 14/01/2004 | 13:45 | 0.25 | 1.634 | -0.054 | 2.75 | 51.1 | 2.5 | 20.3 | 17.0 |
| 15/01/2004 | 00:45 | 1.25 | 1.546 | 0.004 | 0.75 | 51.1 | 0 | 27.8 | 25.9 |
| 15/01/2004 | 16:00 | 0.5 | 1.452 | 0.004 | 0.75 | 102.6 | 0.3 | 47.7 | 51.6 |
| 15/01/2004 | 18:30 | 0.75 | 1.437 | -0.004 | 0.75 | 109.8 | 0.7 | 57.3 | 54.7 |
| 15/01/2004 | 01:30 | 0.25 | 1.55 | 0.006 | 1 | 411 | 3.7 | 121.6 | 193.8 |
| 15/01/2004 | 12:00 | 1.5 | 1.506 | -0.015 | 1 | 195.4 | 0 | 84.0 | 90.8 |
| 15/01/2004 | 21:30 | 1.25 | 1.402 | -0.002 | 1 | 22.1 | 0 | 15.4 | 10.5 |
| 15/01/2004 | 14:00 | 1.25 | 1.477 | -0.009 | 1.25 | 335.4 | 0 | 82.8 | 142.3 |
| 15/01/2004 | 09:00 | 0.75 | 1.534 | -0.014 | 1.75 | 387.3 | 0.2 | 110.1 | 147.0 |

| 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. |
|---|---|---|---|---|---|---|---|---|---|
| 15/01/2004 | 04:00 | 1.25 | 1.558 | -0.004 | 3.75 | 411 | 3.2 | 100.0 | 137.5 |
| 16/01/2004 | 05:15 | 3.5 | 1.348 | -0.006 | 1 | 13.6 | 0.1 | 6.2 | 5.6 |
| 17/01/2004 | 05:00 | 3 | 1.236 | -0.001 | 1 | 52.1 | 0 | 20.7 | 22.3 |
| 19/01/2004 | 09:30 | 8.5 | 0.893 | 0.325 | 0.75 | 140.1 | 0.2 | 67.6 | 70.1 |
| 19/01/2004 | 00:15 | 2 | 1.25 | 0 | 1 | 71.2 | 0 | 21.4 | 33.4 |
| 20/01/2004 | 09:30 | 8 | 1.041 | -0.046 | 1.75 | 89.5 | 1.8 | 39.0 | 30.7 |
| 20/01/2004 | 12:00 | 0.5 | 0.992 | -0.003 | 1.75 | 158.6 | 1.1 | 43.3 | 52.6 |
| 24/03/2004 | 07:15 | 160.25 | 1.112 | 0.012 | 0.75 | 92.2 | 0 | 35.6 | 49.6 |
| 24/03/2004 | 23:45 | 0.25 | 1.132 | -0.001 | 0.75 | 44.9 | 0.3 | 18.7 | 23.3 |
| 24/03/2004 | 22:30 | 1.25 | 1.127 | 0.005 | 1.25 | 53.4 | 0 | 18.7 | 20.3 |
| 25/03/2004 | 00:45 | 0.5 | 1.13 | -0.003 | 1 | 75 | 2.7 | 22.7 | 35.0 |
| 07/04/2004 | 05:15 | 266.75 | 0.988 | 0.001 | 1.5 | 13.2 | 0 | 11.0 | 5.4 |
| 15/05/2004 | 13:45 | 1.75 | 0.945 | 0 | 0.75 | 69.4 | 0 | 29.7 | 35.8 |
| 25/10/2004 | 23:30 | 7.75 | 1.135 | -0.003 | 0.75 | 85.3 | 0 | 33.3 | 45.6 |
| 25/10/2004 | 09:15 | 2474.5 | 1.097 | 0.08 | 5.25 | 62 | 2.8 | 16.2 | 14.2 |
| 01/11/2004 | 22:15 | 68.75 | 1.197 | 0.019 | 0.75 | 20.7 | 1.1 | 9.0 | 10.3 |
| 01/11/2004 | 23:00 | 0.25 | 1.216 | 0.013 | 1 | 23.9 | 4.3 | 12.3 | 9.3 |
| 02/11/2004 | 00:00 | 0.25 | 1.229 | 0.008 | 0.75 | 14.1 | 4.2 | 9.2 | 5.0 |
| 02/11/2004 | 00:45 | 0.25 | 1.237 | 0.001 | 0.75 | 7.9 | 4.8 | 6.5 | 1.6 |
| 02/11/2004 | 03:30 | 0.5 | 1.241 | -0.002 | 0.75 | 18.2 | 2 | 10.5 | 8.1 |
| 02/11/2004 | 05:45 | 1.75 | 1.231 | -0.007 | 0.75 | 121.1 | 3.2 | 49.0 | 63.2 |
| 02/11/2004 | 09:15 | 1.75 | 1.206 | -0.005 | 0.75 | 19.6 | 1.2 | 11.6 | 9.4 |
| 02/11/2004 | 12:15 | 0.25 | 1.191 | -0.006 | 0.75 | 57.4 | 1.7 | 22.5 | 30.4 |
| 02/11/2004 | 01:45 | 0.5 | 1.242 | 0 | 1.5 | 52.4 | 3.9 | 28.6 | 16.8 |
| 06/11/2004 | 22:45 | 1.5 | 1.157 | 0.004 | 0.75 | 13.5 | 0.9 | 6.5 | 6.4 |
| 07/11/2004 | 03:15 | 1.5 | 1.2 | 0.006 | 0.75 | 18 | 1.9 | 9.1 | 8.2 |
| 07/11/2004 | 12:45 | 0.5 | 1.245 | -0.001 | 0.75 | 26.8 | 2.2 | 12.8 | 12.6 |
| 07/11/2004 | 14:00 | 0.75 | 1.247 | -0.009 | 0.75 | 13.4 | 2.3 | 8.1 | 5.6 |
| 07/11/2004 | 16:45 | 0.5 | 1.237 | -0.005 | 0.75 | 23.2 | 1.8 | 13.9 | 11.0 |
| 07/11/2004 | 19:30 | 1 | 1.232 | -0.006 | 0.75 | 35.6 | 3.5 | 19.4 | 16.1 |
| 07/11/2004 | 23:30 | 3.5 | 1.213 | 0.001 | 0.75 | 19.7 | 0.6 | 8.6 | 9.9 |
| 07/11/2004 | 11:30 | 1 | 1.243 | -0.001 | 1 | 54.3 | 0.9 | 24.0 | 22.2 |
| 07/11/2004 | 15:15 | 0.75 | 1.238 | -0.002 | 1.25 | 21.5 | 3.7 | 9.2 | 7.1 |
| 07/11/2004 | 06:45 | 0.25 | 1.213 | 0.013 | 2.25 | 28.4 | 1.3 | 11.1 | 7.9 |
| 08/11/2004 | 02:45 | 0.5 | 1.203 | -0.001 | 0.75 | 14.3 | 0.5 | 7.0 | 6.9 |
| 08/11/2004 | 04:15 | 0.5 | 1.202 | -0.007 | 1.75 | 41.8 | 0.3 | 11.6 | 14.1 |
| 15/11/2004 | 03:45 | 2 | 1.14 | 0.023 | 0.75 | 25.8 | 0.3 | 12.0 | 12.9 |
| 15/11/2004 | 16:30 | 0.25 | 1.279 | -0.006 | 0.75 | 21.6 | 3.8 | 12.7 | 8.9 |
| 15/11/2004 | 23:30 | 0.75 | 1.232 | -0.004 | 0.75 | 52.3 | 0.4 | 24.2 | 26.2 |
| 15/11/2004 | 05:45 | 1.5 | 1.229 | 0.052 | 1 | 407.2 | 4.2 | 110.8 | 197.7 |
| 15/11/2004 | 19:00 | 1 | 1.258 | -0.007 | 1.5 | 53.1 | 0.9 | 20.6 | 21.2 |
| 15/11/2004 | 11:45 | 0.25 | 1.321 | -0.045 | 4.25 | 178.2 | 4.1 | 38.4 | 46.6 |
| 15/11/2004 | 06:45 | 0.25 | 1.281 | 0.04 | 5 | 244.6 | 3.8 | 58.2 | 77.5 |
| 16/11/2004 | 02:00 | 0.5 | 1.222 | -0.005 | 0.75 | 16.9 | 2.6 | 9.8 | 7.2 |
| 16/11/2004 | 17:45 | 2.25 | 1.245 | -0.006 | 0.75 | 15.2 | 0.5 | 8.6 | 7.5 |
| 16/11/2004 | 19:15 | 0.5 | 1.233 | -0.005 | 0.75 | 14.5 | 3.6 | 8.8 | 5.5 |
| 17/11/2004 | 16:15 | 0.5 | 1.163 | -0.003 | 0.75 | 22.8 | 0 | 10.4 | 11.5 |
| 17/11/2004 | 00:30 | 3.25 | 1.213 | -0.007 | 1 | 53.5 | 0.3 | 31.9 | 23.1 |

| 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. |
|---|---|---|---|---|---|---|---|---|---|
| 18/11/2004 | 16:45 | 0.5 | 1.247 | -0.004 | 0.75 | 55.1 | 0.8 | 23.5 | 28.2 |
| 18/11/2004 | 18:30 | 1.25 | 1.243 | -0.005 | 0.75 | 28.9 | 2.1 | 12.8 | 14.2 |
| 18/11/2004 | 19:15 | 0.25 | 1.238 | -0.002 | 0.75 | 7.5 | 1.1 | 5.0 | 3.4 |
| 18/11/2004 | 20:15 | 0.5 | 1.234 | -0.001 | 0.75 | 44.6 | 0.6 | 18.8 | 22.9 |
| 18/11/2004 | 15:15 | 1.25 | 1.255 | -0.007 | 1.25 | 293.9 | 0.3 | 75.4 | 123.8 |
| 18/11/2004 | 11:00 | 2.75 | 1.251 | 0.011 | 1.5 | 125.1 | 1.3 | 30.1 | 47.1 |
| 19/11/2004 | 07:30 | 0.25 | 1.194 | -0.001 | 1 | 28.8 | 0.1 | 13.4 | 12.0 |
| 24/11/2004 | 19:30 | 0.5 | 1.177 | 0.002 | 0.75 | 30.7 | 0.6 | 13.7 | 15.4 |
| 24/11/2004 | 22:15 | 0.25 | 1.184 | -0.001 | 0.75 | 65.2 | 3.1 | 28.9 | 32.3 |
| 04/12/2004 | 03:00 | 182.5 | 1.097 | 0.009 | 0.75 | 31.3 | 0.4 | 13.5 | 16.0 |
| 04/12/2004 | 08:30 | 1 | 1.118 | -0.004 | 1 | 51 | 0.2 | 18.6 | 22.6 |
| 09/12/2004 | 03:00 | 4.25 | 1.088 | 0.001 | 1 | 37.6 | 0 | 20.9 | 18.5 |
| 10/12/2004 | 05:45 | 0.75 | 1.219 | 0.192 | 35.75 | 431.4 | 3.1 | 87.1 | 107.6 |
| 11/12/2004 | 17:30 | 0.25 | 1.411 | -0.028 | 1.25 | 39.1 | 4.8 | 18.2 | 14.9 |
| 12/12/2004 | 00:45 | 2.25 | 1.346 | -0.014 | 1 | 9.2 | 3.6 | 7.0 | 2.4 |
| 13/12/2004 | 23:45 | 7.25 | 1.266 | 0.011 | 0.75 | 12.4 | 2.3 | 6.8 | 5.2 |
| 13/12/2004 | 15:15 | 0.25 | 0.859 | 0.328 | 1.5 | 64.4 | 1.3 | 27.9 | 23.7 |
| 14/12/2004 | 14:15 | 0.25 | 1.409 | -0.002 | 1 | 10 | 2.7 | 6.5 | 3.2 |
| 14/12/2004 | 20:15 | 0.5 | 1.376 | -0.012 | 1 | 15.9 | 3.2 | 10.5 | 5.3 |
| 14/12/2004 | 15:30 | 0.5 | 1.399 | -0.001 | 1.25 | 121.4 | 2.2 | 34.8 | 50.5 |
| 14/12/2004 | 01:45 | 0.75 | 1.295 | 0.054 | 2 | 54 | 3.2 | 17.8 | 17.7 |
| 14/12/2004 | 04:00 | 0.5 | 1.365 | 0.044 | 10.25 | 99.8 | 5 | 18.0 | 20.2 |
| 15/12/2004 | 19:15 | 10.25 | 1.255 | -0.003 | 0.75 | 125.5 | 0.2 | 45.0 | 69.9 |
| 21/12/2004 | 08:15 | 14.5 | 1.073 | -0.008 | 2.75 | 367.4 | 0.2 | 177.3 | 112.6 |
| 17/01/2005 | 07:15 | 45.75 | 1.034 | 0.278 | 25.75 | 412.7 | 4.1 | 97.2 | 111.7 |
| 18/01/2005 | 09:00 | 0.25 | 1.312 | 0.01 | 2 | 399.4 | 1.8 | 95.0 | 148.5 |
| 18/01/2005 | 11:45 | 0.5 | 1.352 | 0.171 | 44.75 | 419.3 | 2.5 | 104.7 | 117.5 |
| 20/01/2005 | 11:15 | 0.25 | 1.562 | 0.029 | 0.75 | 5.1 | 4.9 | 5.0 | 0.1 |
| 20/01/2005 | 08:30 | 0.25 | 1.523 | 0.039 | 2.75 | 5.9 | 5 | 5.4 | 0.3 |
| 26/01/2005 | 14:15 | 146.5 | 1.016 | 0.114 | 0.75 | 12.1 | 0 | 7.0 | 6.3 |
| 26/01/2005 | 15:30 | 0.25 | 1.109 | -0.462 | 1.25 | 351.8 | 4.8 | 91.2 | 146.8 |
| 26/01/2005 | 16:45 | 0.25 | 0.647 | -0.032 | 2.25 | 402.4 | 1.3 | 145.5 | 163.7 |
| 26/01/2005 | 23:00 | 0.25 | 0.47 | -0.023 | 2.75 | 164.2 | 4.1 | 34.1 | 49.7 |
| 26/01/2005 | 19:00 | 0.25 | 0.615 | -0.145 | 4 | 421.6 | 0.9 | 165.9 | 158.2 |
| 27/01/2005 | 06:15 | 1 | 0.688 | 0.046 | 0.75 | 66.5 | 0.2 | 26.1 | 35.4 |
| 27/01/2005 | 17:30 | 0.25 | 0.717 | 0.041 | 1.5 | 13 | 4.3 | 7.2 | 3.0 |
| 27/01/2005 | 12:00 | 0.25 | 0.755 | 0.14 | 2.25 | 14.7 | 3.7 | 9.5 | 3.7 |
| 27/01/2005 | 14:15 | 0.25 | 0.895 | -0.178 | 3.25 | 27.2 | 4.3 | 12.1 | 8.0 |
| 27/01/2005 | 08:00 | 0.5 | 0.744 | 0.011 | 4 | 129.4 | 3.5 | 31.8 | 30.5 |
| 27/01/2005 | 19:00 | 0.25 | 0.758 | -0.556 | 16 | 180.3 | 4.1 | 37.0 | 30.7 |
| 28/01/2005 | 17:30 | 1.25 | 1.164 | 0.004 | 0.75 | 46.5 | 0.8 | 18.2 | 24.7 |
| 28/01/2005 | 15:00 | 0.25 | 0.372 | 0.794 | 1.5 | 242.3 | 2.6 | 107.4 | 92.5 |
| 28/01/2005 | 11:00 | 0.25 | 0.202 | 0.17 | 4 | 43.6 | 2.1 | 27.6 | 11.8 |
| 30/01/2005 | 18:15 | 0.75 | 1.109 | -0.006 | 1 | 267.3 | 0 | 80.9 | 126.1 |
| 31/01/2005 | 08:30 | 0.75 | 1.049 | 0.069 | 3.5 | 206.8 | 0.8 | 61.2 | 65.9 |
| 01/02/2005 | 19:00 | 0.25 | 1.124 | -0.005 | 0.75 | 42.8 | 0.4 | 23.9 | 21.6 |
| 01/02/2005 | 20:00 | 0.5 | 1.12 | -0.006 | 0.75 | 57.5 | 1.2 | 24.1 | 29.6 |
| 01/02/2005 | 21:45 | 0.75 | 1.121 | -0.003 | 0.75 | 20.6 | 1.5 | 9.9 | 9.8 |

| 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. |
|---|---|---|---|---|---|---|---|---|---|
| 01/02/2005 | 23:00 | 0.75 | 1.123 | -0.004 | 0.75 | 72.3 | 0.7 | 28.0 | 38.7 |
| 01/02/2005 | 17:00 | 0.5 | 1.127 | -0.003 | 2 | 112.4 | 0.6 | 49.3 | 38.3 |
| 01/02/2005 | 14:30 | 0.25 | 1.118 | 0.011 | 2.25 | 167.2 | 1.5 | 51.8 | 49.6 |
| 02/02/2005 | 03:00 | 0.5 | 1.112 | 0.003 | 0.75 | 42.2 | 0.3 | 17.1 | 22.1 |
| 02/02/2005 | 04:00 | 0.5 | 1.115 | -0.008 | 0.75 | 38.8 | 0.5 | 17.2 | 19.6 |
| 02/02/2005 | 05:30 | 0.25 | 1.111 | -0.004 | 0.75 | 10 | 4.8 | 7.5 | 2.6 |
| 02/02/2005 | 06:15 | 0.25 | 1.107 | -0.004 | 0.75 | 185.4 | 4.6 | 66.3 | 103.2 |
| 02/02/2005 | 08:30 | 0.25 | 1.106 | 0.004 | 0.75 | 17.3 | 0.7 | 9.4 | 8.3 |
| 02/02/2005 | 09:15 | 0.25 | 1.11 | -0.007 | 0.75 | 8.9 | 0.4 | 5.5 | 4.5 |
| 02/02/2005 | 17:15 | 0.25 | 1.097 | 0.002 | 0.75 | 26.4 | 2.2 | 12.5 | 12.5 |
| 02/02/2005 | 07:30 | 0.75 | 1.106 | 0 | 1 | 17.8 | 0 | 9.8 | 7.5 |
| 02/02/2005 | 11:30 | 0.75 | 1.111 | -0.01 | 1 | 23.5 | 0 | 12.3 | 11.2 |
| 02/02/2005 | 15:45 | 1 | 1.099 | -0.006 | 1 | 24.3 | 0.1 | 13.9 | 11.5 |
| 02/02/2005 | 18:15 | 0.5 | 1.103 | -0.006 | 1 | 111.4 | 0 | 53.0 | 49.8 |
| 02/02/2005 | 22:00 | 1.5 | 1.094 | -0.004 | 1.25 | 40.3 | 1.1 | 21.3 | 16.2 |
| 02/02/2005 | 13:00 | 0.25 | 1.095 | 0.003 | 2 | 191.3 | 2.3 | 67.7 | 65.6 |
| 03/02/2005 | 04:00 | 0.5 | 1.093 | -0.007 | 0.75 | 17.4 | 0 | 7.8 | 8.8 |
| 03/02/2005 | 06:00 | 1.5 | 1.091 | -0.008 | 0.75 | 9.1 | 0.5 | 5.6 | 4.5 |
| 03/02/2005 | 02:15 | 0.25 | 1.097 | -0.014 | 1 | 40.7 | 0.4 | 18.8 | 17.0 |
| 03/02/2005 | 09:15 | 0.25 | 1.097 | -0.014 | 1 | 132.6 | 0.5 | 45.7 | 60.6 |
| 03/02/2005 | 09:15 | 0.25 | 1.097 | -0.014 | 1 | 132.6 | 0.5 | 45.7 | 60.6 |
| 03/02/2005 | 07:15 | 0.75 | 1.101 | -0.01 | 1.25 | 32.6 | 0 | 11.3 | 12.6 |
| 03/02/2005 | 07:15 | 0.75 | 1.101 | -0.01 | 1.25 | 32.6 | 0 | 11.3 | 12.6 |