ENVIRONMENTAL PROTECTION DIVISION

WATER STEWARDSHIP DIVISION

MINISTRY OF ENVIRONMENT

Water Quality Assessment and Objectives for the McKelvie Creek Community Watershed

TECHNICAL REPORT

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

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

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Fern Schultz
Director, Science and Information
Water Stewardship Division

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Deborah Epps, Environmental Impact Assessment Biologist
Environmental Protection Division
Ministry of Environment

Burke Phippen, RPBio.
BWP Consulting Inc.
Kamloops, BC

1.0 INTRODUCTION

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

There are over 60 community watersheds within the Vancouver Island Region of the Ministry of Environment. Rather than developing water quality objectives for each of the watersheds on an individual basis, an ecoregion approach has been implemented. The 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, the Vancouver Island Region has been split into 11 terrestrial ecoregions (six on Vancouver Island), based on similar climate, geology, soils, hydrology etc. (Figure 1).

Due to accessibility and holding time of samples only the six ecoregions on Vancouver Island are being considered at this time. Fundamental baseline water quality should be similar in all streams and all lakes throughout each ecoregion. However, the underlying physical, chemical and biological differences between streams and lakes must be recognized. Representative lake and stream watersheds within each ecoregion are selected (initially stream focused) and a three year monitoring program is implemented to collect water quality and quantity data, as well as biological data. Standard base monitoring programs have been established for use in streams and lakes, to maximize data comparability between watersheds and among ecoregions, regardless of location.

Watershed objectives will be developed for each of the representative lake and stream watersheds based on this data, and these objectives will also be applied on an interim basis to the remaining lake and stream watersheds within that ecoregion. Over time, other priority watersheds within each ecoregion will be monitored for one year to verify the validity of the objectives developed for each ecoregion and to determine whether the objectives are being met for individual watersheds.

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

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

This report examines the existing water quality of McKelvie Creek and recommends water quality objectives for this watershed based on potential impacts and water quality parameters of concern. McKelvie Creek, located on the west coast of Vancouver Island, is a second-order stream, 10.2 km in length, draining into the Tahsis River just north of the Village of Tahsis, BC. The portion of the watershed designated as a community watershed is 2,111 ha in area, and includes the upper portion of McKelvie Creek above the Village of Tahsis water intake (Figure 2). The intake is located approximately 1 km upstream from the confluence of McKelvie Creek and the Tahsis River. McKelvie Creek has significant fisheries values, with steelhead present in the creek, and likely a number of other species as well (FISS 2005).

Anthropogenic land uses within the watershed include timber harvesting and recreation which, in addition to natural erosion and wildlife, can potentially affect water quality in McKelvie Creek.

One water quality monitoring location was selected within the McKelvie Creek watershed. Site E230718 is located upstream from the main water intake (Figure 2). Water samples were collected once in early 1998, five times in early 1999, five times in the fall of 2001, on an almost monthly basis from July 2002 to June 2005, and weekly for five consecutive weeks during the summer low flow and fall high flow period from 2002 to 2004. Water samples were then sent to a laboratory for analyses of fecal coliforms, *E. coli*, turbidity, non-filterable residue, temperature, true colour, specific conductivity, pH, nitrate and nitrite, total phosphorus, and metals concentrations. Continuous monitoring data was collected from June 2003 to December 2004. Parameters monitored were turbidity, conductivity, and temperature. The project consisted of five phases: water quality data collection, gathering information on water use, determination of land use activities that may influence water quality, assessment of water quality based on land use influences and establishment of water quality objectives.

Figure 2. McKelvie Creek community watershed.

2.0 WATERSHED PROFILE AND HYDROLOGY

2.1 BASIN PROFILE

The community watershed portion of McKelvie Creek is approximately 2,111 ha in area and ranges in elevation from approximately 120 m at the Village of Tahsis water intake to about 1,600 m in the upper watershed. The creek is approximately 10.2 km long in total, and about 9 km long from the its headwaters near Mount McKelvie to the Village of Tahsis intake. There are no named lakes within the watershed.

The majority of the watershed falls within the Coastal Western Hemlock (submontane very wet maritime, CWHvm1) biogeoclimatic zone, with higher elevations (above about 800 m) falling within the Mountain Hemlock (windward moist montane, MHmm1) biogeoclimatic zone and small areas above 1,200 m composed of Alpine Tundra undifferentiated and parkland (ATunp). McKelvie Creek falls within the Windward Island Mountains (WIM) ecoregion established for Vancouver Island by MOE staff (Figure 1).

2.2 HYDROLOGY

The nearest climate station to the watershed is the Tahsis Village North station (elevation 9.0 m) (Environment Canada Climate Station 1037899). The following averages are based on average monthly values measured between 1994 and 2003. Average daily temperatures ranged from 3.5 °C in December to 17.0 °C in August. Average total annual precipitation between 1994 and 2003 was 4,279 mm, with only 55 mm (water equivalent) (1%) of this falling as snow (Figure 3). A larger portion of the annual total precipitation occurs as snowfall in the higher-elevation terrain of the watershed. Most precipitation (3,182 mm, or 74%) falls between October and March.

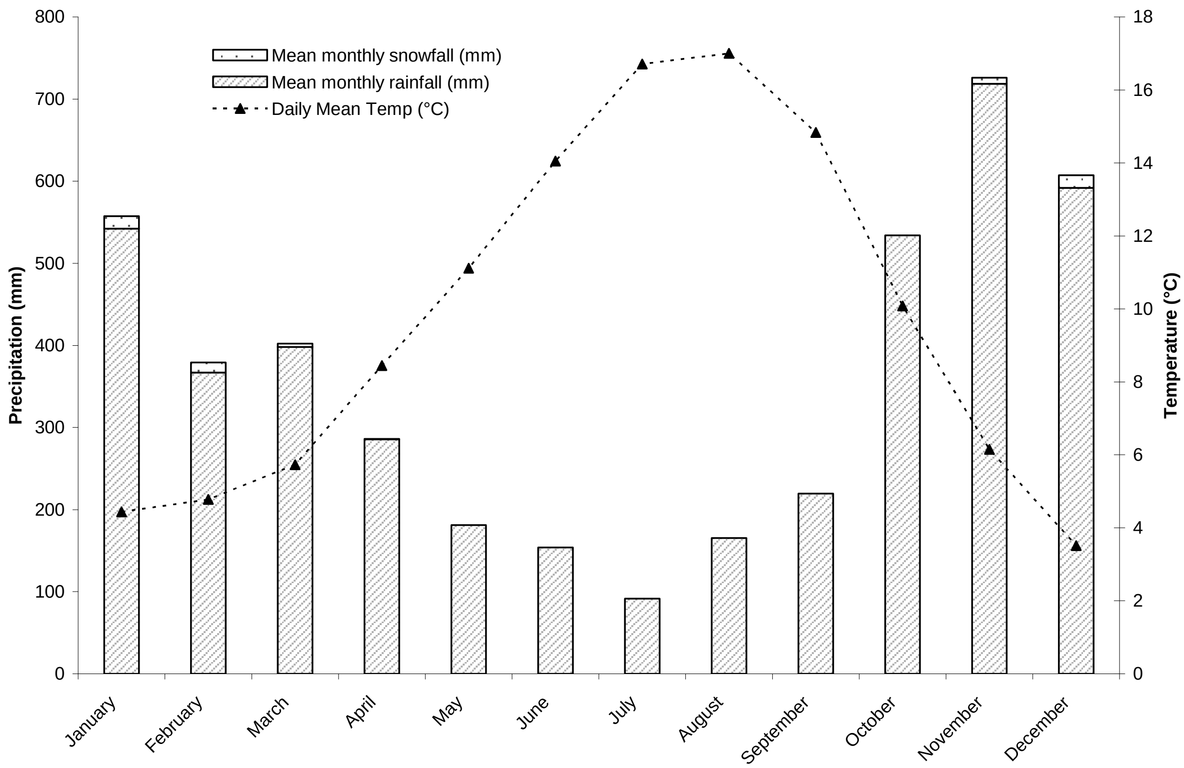

Figure 3. Summary of climate data for Tahsis between 1994 and 2003 (Environment Canada Climate Station 1036206).

Water Survey Canada (WSC) operated a hydrometric station on McKelvie Creek above the Village of Tahsis intake between 1998 and 2004. Minimum, maximum and average daily flows for this period are shown in Figure 4. Peak flows measured between 1998 and 2004 were approximately 33.1 m^3/s, while minimum flows were approximately 0.008 m^3/s.

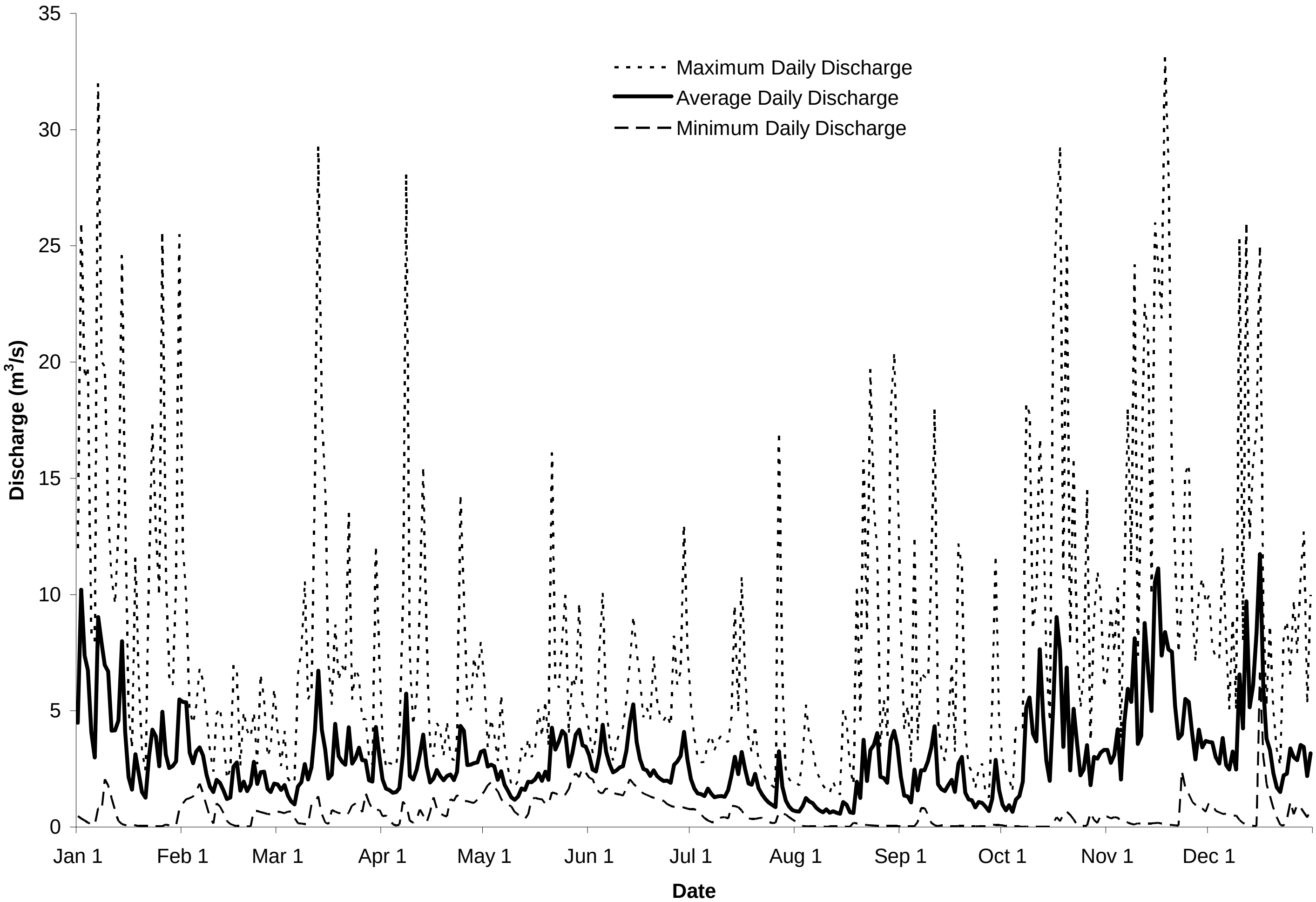

Figure 4. Minimum, maximum and average daily discharge data for McKelvie Creek above intake (Water Survey Canada Station 08HE010) between 1998 and 2004 (Water Survey Canada Hydat Data, 2005).

3.0 WATER USES

3.1 WATER LICENSES

Two water licenses have been issued for McKelvie Creek within the community watershed boundaries. The Village of Tahsis has a licence to withdraw 166 dam^3/year for domestic use. This water is chlorinated prior to consumption.

In addition, a power generating company has a licence to utilize 11,823 dam^3/year from the mainstem, approximately 500 m upstream from the Village of Tahsis intake, for the purposes of generating power. This hydroelectric project is currently in its preliminary stages. Over the next two years a dam will be constructed upstream of the village intake, which will allow the diversion of 60% - 70% of the flow from McKelvie Creek to a generating plant down at the Village center. The plant will operate seasonally to allow for adequate flows during the summer period and meet the community water supply withdrawal requirement.

3.2 FISHERIES

McKelvie Creek has significant fisheries values, and is utilized by steelhead (*Oncorhynchus mykiss*) (FISS, 2005), and likely other species as well.

3.3 RECREATION

The community watershed designation has restricted recreational use in the McKelvie Creek watershed. The local community is very supportive of this restriction and there is little or no access to the watershed. There is no BC Forest Service recreation sites located in the McKelvie Creek watershed.

3.4 WILDLIFE

The McKelvie Creek watershed provides habitat to a variety of species typical of the west coast Vancouver Island, including blacktail deer, black bear, cougar, and numerous other small mammals and birds.

3.5 DESIGNATED WATER USES

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

As discussed in Section 3.1, two water licenses have been issued for the McKelvie Creek community watershed, for waterworks purposes and for power generation. In addition to drinking water, the presence of salmonid species in the creek as well as the normal terrestrial fauna of the area suggests that water should also be protected aquatic life and wildlife.

4.0 INFLUENCES ON WATER QUALITY

The community watershed portion of McKelvie Creek is located primarily on Crown Land managed under Tree Farm Licence (TFL) 19. There are no licensed discharges within the watershed. Recreational use is restricted and there are no sanctioned camping areas within the watershed. Therefore, the primary concerns with regards to potential anthropogenic impacts on water quality in McKelvie Creek are associated with forestry activities.

4.1 LAND OWNERSHIP

The community watershed portion of McKelvie Creek contains no private households located within its boundaries, and so potential sources of contamination associated with households (such as septic fields) will not impact water quality in McKelvie Creek.

4.2 LICENSED WATER WITHDRAWALS

As mentioned in Section 3.1, there are two licensed water withdrawals from the McKelvie Creek community watershed, with an overall maximum volume of 11,989 dam^3/year. Assuming water was withdrawn from McKelvie Creek at a constant rate throughout the year (an unlikely scenario), this would result in an average withdrawal rate of 0.38 m^3/s. Average daily flows between 1998 and 2004 ranged from 0.008 m^3/s to 33.1 m^3/s. However, as the vast majority of the volume withdrawn is non-consumptive (*i.e.* water utilized for power generation is returned to the creek), it is not expected that flows downstream from the intakes will be appreciably affected.

The biggest potential impact to water quality may be during the construction of the proposed hydroelectric dam and associated works. If best management practices are adhered to, this may not be an issue. Once in operation, the new dam may help to settle suspended matter in the water column and help to improve water quality during peak flow events.

4.3 FOREST HARVESTING AND FOREST ROADS

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

The McKelvie Creek watershed consists of Crown Land located within TFL 19, managed by Pacific Forest Products. No watershed assessment procedure (WAP) has been conducted for the watershed, and no logging has occurred to date in the upper watershed (Carmanah, 1997). Road access to the upper watershed is limited. Harvesting activities will likely occur in the near future, but a WAP should be conducted prior to road-building or harvesting activities to ensure that significant impacts to water quality do not occur.

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 the community supports restricted access to and recreational use of the McKelvie Creek watershed, the impacts of recreational activities are likely to be minimal due to the lack of roads and camping areas within the watershed.

4.5 WILDLIFE

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

As discussed in Section 3.4, McKelvie Creek contains significant old-growth wildlife habitat, and provides a home for a wide variety of warm-blooded species including blacktail deer, black bear, wolf, cougar, red squirrels, eagles, hawks, owls, grouse and numerous other species of small birds. Therefore, a risk of fecal contamination from natural wildlife populations within the watershed does exist.

4.6 MINING AND PERMITTED DISCHARGES

Mining activities can impact water quality by increasing metal concentrations water and depending on the location, may contribute to acidification of the water. Generally, mining activities are also associated with road construction and land-clearing which can change water movement patterns and result in increased turbidity levels.

There are no active or inactive mines located within the watershed boundaries, and no mineral prospects shown in MINFILE (MINFILE, 2005). As such, there is a low likelihood of mining activities occurring within the watershed in the foreseeable future.

Discharges from commercial operations can affect water quality and timing of flow, however, there are no licensed discharges within the McKelvie Creek watershed.

5.0 DESCRIPTION OF WATER QUALITY MONITORING DATA

This report provides an assessment of water quality data collected from 1998 to 2005 in the McKelvie Creek watershed. Key drinking water characteristics, such as fecal coliforms, turbidity, true colour, pH, and specific conductivity, are considered to protect raw drinking water supplies. Drinking water is the most sensitive water use in McKelvie Creek for these characteristics. In addition, based on current knowledge of potential anthropogenic impacts to the sub-watersheds (generally associated with forestry), and the lack of permitted waste discharges, these are the water quality parameters most likely to change should impacts occur. Nutrient (nitrate, nitrite and phosphorus) concentrations are also considered as these parameters may be influenced by forestry-related activities.

One water quality monitoring site was selected within the McKelvie Creek watershed: EMS Site #E230718, McKelvie Creek at the main water intake (Figure 2).

Water samples were collected once in early 1998, on a weekly basis for five consecutive weeks in early 1999, on a weekly basis for five consecutive weeks during the summer low flow and fall high flow periods from 2001 to 2004, and usually on a monthly basis for the remainder of the year between 2002 and 2005. Samples were collected according to Resource Inventory Standards Committee (RISC) standards (RISC, 1994). Data are summarized in Appendix I.

An automated water quality/quantity monitoring station was also installed at the water quality monitoring site and programmed to log water temperature, turbidity, specific conductivity and water levels at 15-minute intervals. The station operated from June 2003 to the present. For the purposes of this report, only data up to December 2004 will be reviewed.

6.0 WATER QUALITY ASSESSMENT AND OBJECTIVES

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

6.1 COLIFORM BACTERIA

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

Water from McKelvie Creek is chlorinated prior to consumption. The drinking water guideline for raw waters receiving disinfection only is that the 90th percentile of at least five weekly samples collected in a 30-day period should not exceed 10 CFU/100 mL (B.C. Ministry of Environment, 2006). To represent the worst case scenario, bacteriological samples were only collected during summer low flow (August/September) and fall flush (October/November) periods.

Fecal coliform concentrations were measured 38 times in McKelvie Creek, with values ranging from below detectable limits (<1 CFU/100 mL) to a maximum of 380 CFU/100 mL. Samples were collected with sufficient frequency (a minimum of five weekly samples within 30 days) on seven occasions, and the 90th percentile for these groups of samples ranged from 1.6 CFU/100 mL to 233.6 CFU/100 mL. The average for all seven 90th percentiles is approximately 60 CFU/100 mL; only one sampling period exceeds this value, likely due to one high result (380 CFU/100 mL) measured on September 8, 2004.

E. coli concentrations ranged from below detectable limits (< 1 CFU/100 mL) to 330 CFU/100 mL, for 35 samples collected between October 10, 2001 and October 26, 2004. In the six instances when the requisite sampling frequency was met (at least five weekly samples in 30 days), 90th percentiles ranged from 8.8 CFU/100 mL to 201.6 CFU/100 mL. Similar to the fecal coliform results, the average 90th percentile value for all six sample periods was 57 CFU/100 mL; only one sampling period exceeds this value, again, due to one high result measured on September 8, 2004.

The drinking water guideline for raw water receiving disinfection only (10 CFU/100mL) was exceeded in six of the seven instances for fecal coliforms and in five of six instances for *E. coli*. Occasionally, individual water samples have quite high concentrations of bacteriological indicators. As there is no road access to the upper watershed and no cattle grazing permitted within the watershed, it is likely that the source of these coliforms is the endemic wildlife.

In consideration of the above information and given the lack of anthropogenic influences in the watershed, the values collected during this three year sampling program are reflective of natural or background concentrations. ***Therefore, it is recommended that the 90th percentile of a minimum of 5 weekly samples collected within a 30-day period must not exceed 60 CFU/100 mL for fecal coliforms and/or* E. coli.** While this proposed objective is higher than the provincial guideline it does represent the natural variability within the watershed with respect to bacteriological values. This 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 Village of Tahsis.

6.2 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 (B.C. Ministry of Environment, 2006). Corrosion of metal plumbing may occur at both low and high pH outside of this range, while scaling or encrustation of metal pipes may occur at high pH. The effectiveness of chlorine as a disinfectant is also reduced outside of this range.

pH in the McKelvie Creek watershed ranged from 6.5 to 8.0 pH units with a mean of 7.2 pH units for 39 samples collected. All pH values were well within the drinking water guideline, suggesting that pH is not presently a concern within the McKelvie Creek watershed. Therefore, no objective is proposed for pH in McKelvie Creek.

6.3 TEMPERATURE

Temperature is considered in drinking water for aesthetic reasons. The aesthetic guideline is 15°C – temperatures above this level are considered to be too warm to be aesthetically pleasing (B.C. Ministry of Environment, 2006). For the protection of aquatic life, the allowable change in temperature is +/-1°C from naturally occurring levels. For salmonids and other cold water species, there are a number of guidelines set depending on the species and life stage of the fish. For steelhead, present in McKelvie Creek, the optimum temperature ranges are: 9 – 13°C for incubation; 15 – 19°C for rearing; and 9 – 16.5°C for spawning (B. C. Ministry of Environment, 2001).

Water temperatures in McKelvie Creek varied seasonally, with maximum temperatures occurring in the late summer. Water temperatures measured by the automated station ranged from 1.47°C in the winter months to a maximum of 12.25°C in August 2004 (Figure 5).

Water temperatures remained consistently well below the aesthetic guideline of 15°C over the course of the monitoring program. However, it is possible that activities such as forest harvesting (especially along the stream bank, where cover is reduced) or the micro-hydro project could cause increases in water temperature to the point where this guideline is occasionally exceeded. ***For this reason, a water quality objective is proposed for temperature in McKelvie Creek. It is recommended that maximum instantaneous water temperatures should not exceed 15°C during the summer months, and the maximum hourly temperature change should not exceed +/- 1°C.***

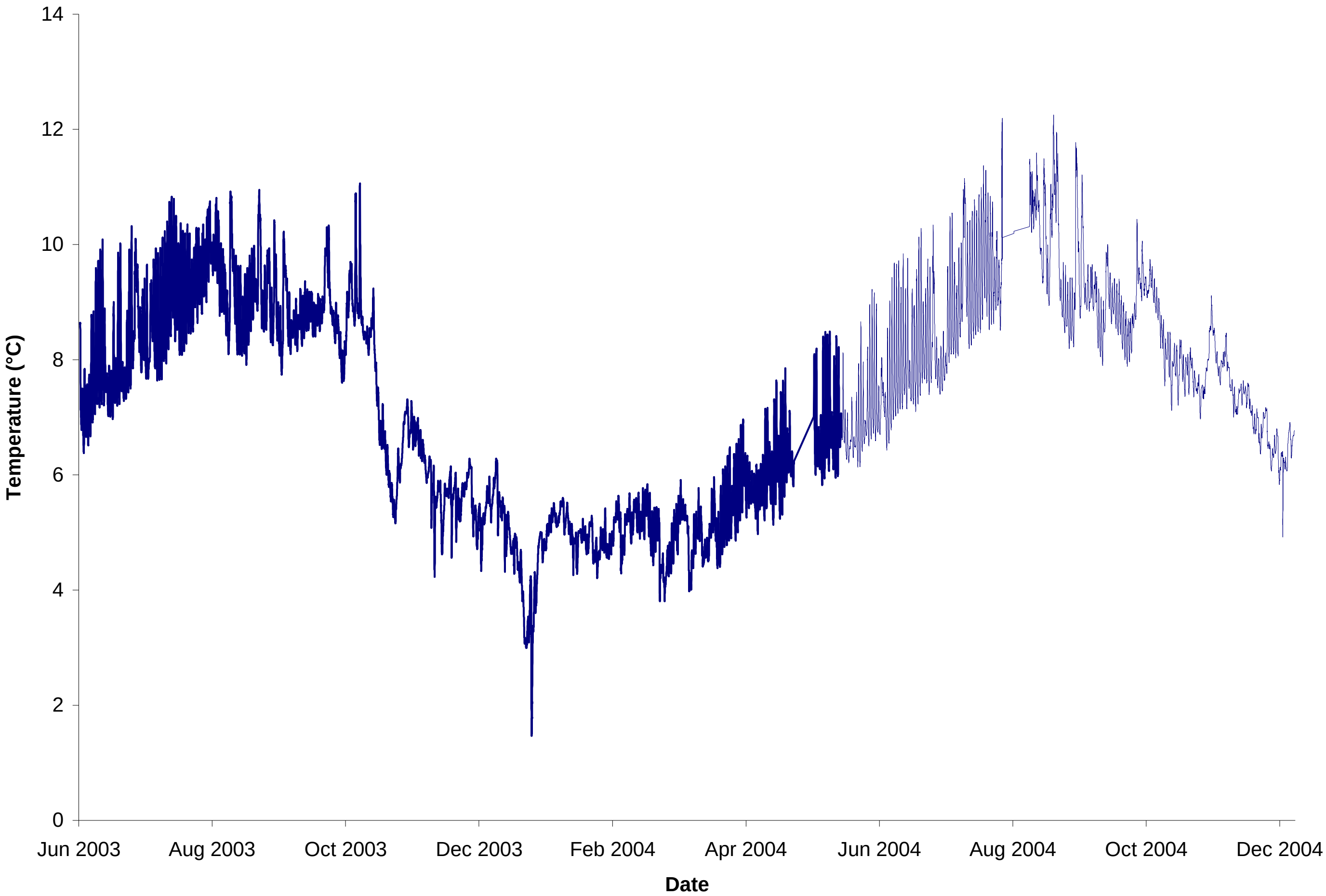

Figure 5. Automated water temperature data collected from McKelvie Creek at the Village of Tahsis intake between June 2003 and December 2004.

6.4 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 objective is a maximum of 15 true colour units (TCU) (B.C. Ministry of Environment, 2006). Colour is also an indicator of the amount of organic matter in water. When organic matter is chlorinated it produces disinfection by-products such as trihalomethanes (THMs).

Colour in McKelvie Creek ranged from 3 TCU to 14 TCU, with an average of 7.75 TCU for 12 samples collected. At this time none of the samples had colour values exceeding the aesthetic guideline of 15 TCU. ***However with the impending construction of the micro-hydro project and the fact that potential forest harvesting activities are likely to occur within the watershed, a water quality objective for colour is proposed. It is recommended that maximum colour values should not exceed 15 TCU.***

Elevated total organic carbon (TOC) levels (above 4.0 mg/L) can result in higher levels of THMs in finished drinking water if chlorination is used to disinfect the water (B.C. Ministry of Environment, 2006). As Tahsis uses chlorine to disinfect their drinking water, TOC concentrations should be monitored. Concentrations of TOC ranged from < 0.5 mg/L to 3.3 mg/L for 15 samples collected during the study. ***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.***

6.5 CONDUCTIVITY

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

In McKelvie Creek, specific conductivity values in the discrete samples ranged from 13 µS/cm to 139 µS/cm, with an average of 30 µS/cm. At the automated station, values ranged from 10 µS/cm to 38 µS/cm, with an average of 28 µS/cm. Values were correlated with flows, with the highest conductivity occurring during summer low flows (when dilution was lowest) and conductivity values dropping during the winter (when dilution from rainfall was highest) (Figure 6). All values were well below the drinking water guideline of 700 µs/cm, and therefore no objective is proposed for specific conductivity.

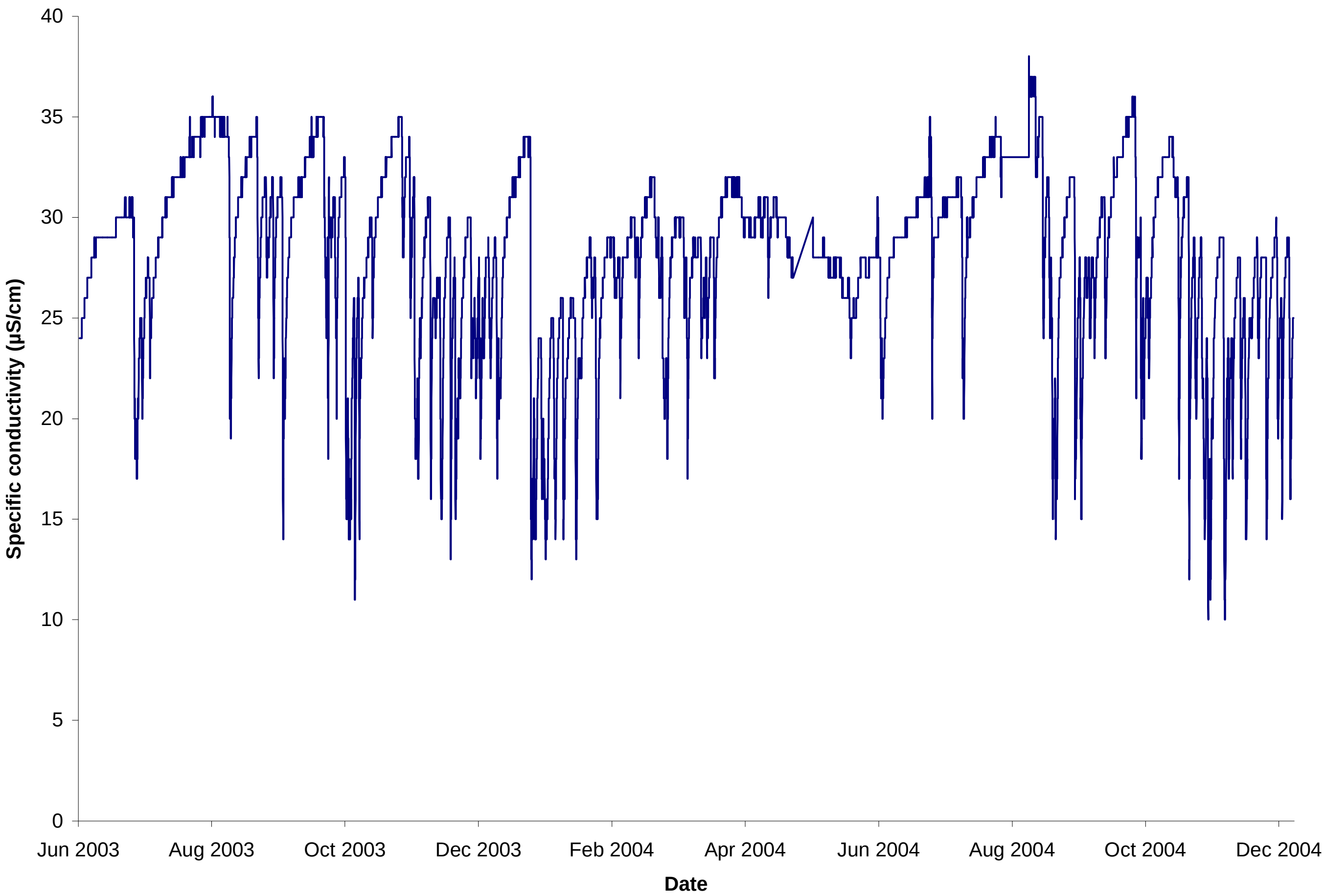

Figure 6. Specific conductivity measured in McKelvie Creek near the Village of Tahsis intake between June 2003 and December 2004.

6.6 TURBIDITY

Turbidity is a measure of the clarity or cloudiness of water, and is measured by the amount of light scattered by the particles in the water as nephelometric turbidity units (NTU). Elevated turbidity levels can decrease the efficiency of disinfection, allowing pathogens to enter the water system. As well, there are aesthetic concerns with cloudy water, and particulate matter can clog water filters and leave a film on plumbing fixtures. The guideline for drinking water that does not receive treatment to remove turbidity is an induced turbidity over background of 1 NTU. An aesthetic guideline allowing a maximum of 5.0 NTU exists, but this is primarily related to turbidity sources within the distribution system (after disinfection has occurred) (B.C. Ministry of Environment, 2006). In general, it is considered that turbidity values greater than 2.0 NTU will compromise disinfection efficiency (VIHA pers. comm., 2006).

At the intake site, turbidity values ranged from 0.05 NTU to 4.31 NTU, with an average of 0.3 NTU for the 39 samples collected between 1998 and 2005. Only the maximum value (4.31 NTU), measured on April 8, 2003, exceeded the 1 NTU guideline, with the next highest turbidity value being 0.8 NTU.

Turbidity values were also measured by the automated water quality monitoring station situated at the Village of Tahsis intake dam. Here, a McVan analyte SDI-12 turbidity sensor was installed within the stream flow and polled every 15 minutes by a FWS-12 datalogger. A summary of turbidity data collected between June, 2003 and December, 2004 is given in Table 1. The distribution of data shows that almost 91% of values were below the drinking water guideline of 1 NTU, and 99% of values were below the drinking water guideline of 5 NTU. Therefore, only about 0.8% of the time, or about 102 of the 12,715 hours when turbidity was measured over the course of the study, were turbidity values higher than the drinking water guideline of 5 NTU.

Table 1. Summary of automated turbidity data measured at McKelvie Creek at Village of Tahsis intake station between June 2003 and December 2004.

	Number	Percentage	Cumulative %
Number Turbidity <=1 NTU	46254	90.9%	90.9%
Number Turbidity >1, <=5 NTU	4186	8.2%	99.2%
Number Turbidity >5, <=10	238	0.5%	99.6%
Number Turbidity >10, <=50	155	0.3%	99.9%
Number Turbidity >50	27	0.1%	100.0%
Totals:	**50860**	**100**	

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 McKelvie Creek tended to be of relatively short duration and occurred primarily during the fall and winter (Figure 7).

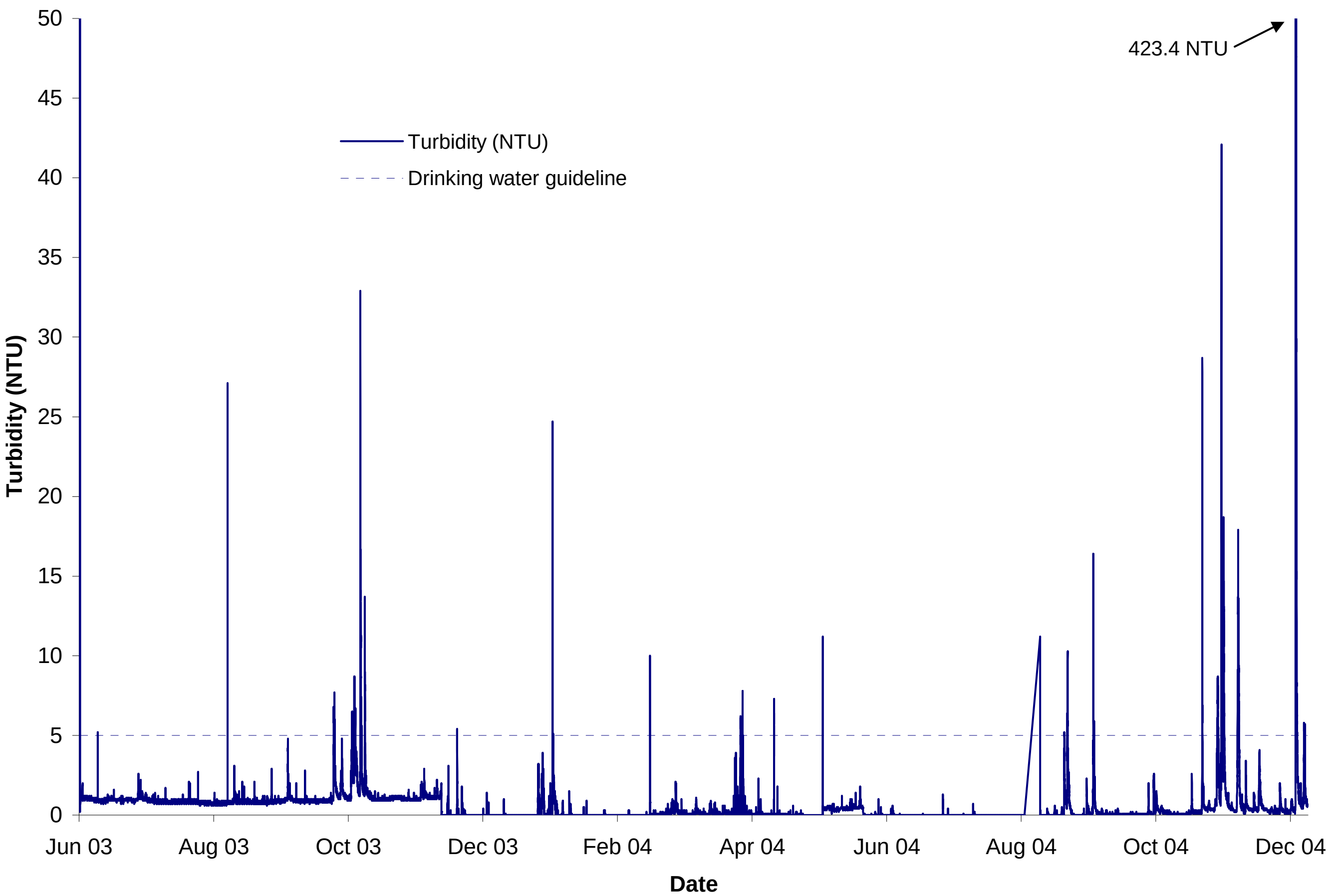

Figure 7. Turbidity levels in McKelvie Creek between June 2003 and December 2004 as measured on 15-minute intervals by the automated water quality monitoring station near the Village of Tahsis intake**.**

Table 2 shows a summary of the intensity and duration of turbidity events occurring at the automated station between 2003 and 2004. A turbidity event, for the sake of this summary, is defined as a number of consecutive turbidity values measured at 15-minute intervals exceeding the 5 NTU threshold. The recovery time is the length of time that has passed since the previous turbidity event (*i.e.*, since the turbidity last exceeded 5 NTU). For the sake of brevity and ease of reading, Table 2 includes only the longest-duration events (*i.e.*, events over 5 hours in length) – the remainder of the summary is included as Appendix II, arranged in chronological order.

Table 2. Summary of turbidity events exceeding 5 hours in duration reported by the automated turbidity meter near Village of Tahsis intake between 2003 and 2004.

Start Date	Start Time	Recovery Time (hours)	Duration of event (hours)	Maximum turbidity (NTU)	Minimum turbidity (NTU)	Average turbidity (NTU)	Standard Deviation
29/10/2004	16:15	1155.5	4.75	28.7	4.5	12.1	7.3
07/11/2004	06:30	34	7.75	42.1	4.3	17.1	12.2
05/11/2004	12:30	2.5	8.25	8.7	4.9	6.8	1.0
08/11/2004	04:15	13	10.75	18.7	3.1	10.1	3.5
20/10/2003	08:00	50	12	32.9	4.1	12.9	6.9
10/12/2004	08:00	602.75	17.5	423.4	2.2	80.4	106.1
14/11/2004	11:30	140.75	18	17.9	4.1	10.1	3.3

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. Table 3 shows a comparison of 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. In all instances, turbidity values measured by the two methods were within 1 NTU of each other, an acceptable level. However, all of the samples were collected when turbidity was very low (< 1 NTU), and are therefore not indicative of the occasional turbidity events that occur in this watershed. Future monitoring should focus on collecting water samples following significant rain events, in order to try and capture these occasional elevated turbidity levels. 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 3. Comparison of turbidity values reported by laboratory analyses and automated turbidity probe.

Date	Laboratory Result (NTU)	Automated Sensor Result (NTU)	Difference (Laboratory - Automated) (NTU)
02/09/2003 9:00	0.22	0.8	0.58
14/10/2003 9:00	0.33	1.2	0.87
04/11/2003 9:00	<0.1	1	0.9
02/12/2003 9:00	0.22	0	-0.22
12/01/2004 9:00	0.5	0	-0.5
17/02/2004 9:00	0.38	0	-0.38
23/03/2004 8:30	0.14	0.1	-0.04
21/04/2004 9:00	<0.1	0	-0.1
18/05/2004 9:00	0.14	0.4	0.26
15/06/2004 9:00	<0.1	0	-0.1
13/07/2004 9:00	<0.1	0	-0.1
08/09/2004 9:00	0.8	0.5	-0.3
04/10/2004 9:00	0.6	0	-0.6

During the monitoring period there has been little or no activity in the watershed suggesting that the data collected actually reflects background levels. The turbidity levels during this period have been maintained at a constant level (below 1.0 NTU for 90% of the data) with only minor fluctuations during rain storm events. Therefore it is recommended that total turbidity measured at the intake should not exceed a maximum of 5.0 NTU at any time and the mean of five weekly samples in a 30-day period should not exceed 2.0 NTU. It should be noted that turbidity values above 2.0 NTU are considered likely to affect disinfection in a chlorine-only system. An alternative to the average objective of 2.0 NTU would be to treat the raw water prior to chlorination to remove some of the turbidity and increase chlorine efficiency.

6.7 TOTAL SUSPENDED SOLIDS

Total suspended solids (TSS, also referred to as non-filterable residue or NFR) include all of the undissolved particulate matter in a sample. This value 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 at this time, however for the protection of aquatic life the maximum concentration allowed is 25 mg/L in 24 hours when background is less than or equal to 25 mg/L with a mean guideline of 5 mg/L in 30 days (B.C. Ministry of Environment, 2006).

Concentrations of total suspended solids were generally below detectable limits (48 of 55 measurements). The maximum value measured was 12 mg/L which occurred on November 12, 2002 after a winter rain event. As there are no upstream monitoring sites within the watershed, it is not possible to determine if concentrations are increasing in a downstream direction. However, 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. ***During the monitoring period there has been little or no activity in the watershed, and as such the total suspended solids have been maintained at a constant level with elevated fluctuations only occurring during rain storm events. This suggests that the data collected actually reflects background levels. It is recommended that total suspended solids measured at the intake should not exceed 25.0 mg/L at any time and the mean of five samples in 30-days should not exceed 5.0 mg/L.***

6.8 NUTRIENTS (NITRATE, NITRITE AND PHOSPHORUS)

The concentrations of nitrogen (including nitrate and nitrite) and phosphorus are important parameters, since they tend to be the limiting nutrients in biological systems. Productivity is therefore directly proportional to the availability of these parameters. Nitrogen is usually the limiting nutrient in terrestrial systems, while phosphorus tends to be the limiting factor in freshwater aquatic systems. In watersheds where drinking water is a priority, it is desirable that nutrient levels remain low to avoid algal blooms and foul tasting water. Similarly, to protect aquatic life, nutrient levels should not be too high or the resulting plant and algal growth can deplete oxygen levels when it dies and begins to decompose, as well as during periods of low productivity when plants consume oxygen (*i.e.*, at night and during the winter under ice cover). The guideline for the maximum concentration for nitrate in drinking water is 10 mg/L (as N) and the guideline for nitrite is a maximum of 1 mg/L (as N). When both nitrate and nitrite are present, their combined concentration must not exceed 10 mg/L as N. For the protection of aquatic life the maximum concentration of nitrate is 13 mg/L and the maximum concentration of nitrite is 0.06 mg/L (CCME, 2002). There are no proposed 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 0.009 mg/L as N to a maximum of 0.127 mg/L as N for 28 samples, while dissolved nitrite concentrations ranged from below detectable limits (<0.002 mg/L as N) to a maximum of 0.005 mg/L as N. All values for both nitrate and nitrite species were well below the existing aquatic life guidelines.

Total phosphorus concentrations ranged from below detectable limits (< 0.002 mg/L) to a maximum of 0.005 mg/L for 26 values; phosphorus concentrations in McKelvie Creek are not likely to be a concern.

As concentrations of both nitrogen and phosphorus are low in McKelvie Creek, no objective is proposed for these parameters.

6.9 METALS

Total metals concentrations were measured on 27 occasions in McKelvie Creek. The concentrations of most metals were below detectable limits, and well below guidelines for drinking water and aquatic life. The one exception to this was for aluminum - the concentration of dissolved aluminum exceeded the aquatic life guideline of 0.1 mg/L on one occasion, with a maximum value of 0.125 mg/L. The elevated concentration of dissolved aluminum in McKelvie Creek is almost certainly a result of the natural geography of the area rather than any anthropogenic activities, and therefore the biota in the creek are likely acclimated to these levels. As well, because the exceedence occurred during the fall flush period while turbidity and total suspended solids were high, it is likely that if these objectives are met, the guideline for aluminum will also be met. For this reason, no objective is proposed for dissolved aluminum.

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

7.0 MONITORING RECOMMENDATIONS

In order to capture the periods where water quality concerns are most likely to occur (*i.e.*, freshet and summer low-flow) we recommend that a minimum of five weekly samples be collected within a 30-day period between August and September, as well as between November and February. Samples collected during the winter months should coincide with rain events whenever possible. In this way, the two critical periods (minimum dilution and maximum turbidity), will be monitored. Samples should be analyzed for general water chemistry (including TSS, turbidity, colour, and DOC/TOC) as well as bacteriology (including fecal coliforms and *E. coli*). One of the samples collected during both the high-flow and low-flow period should also be analyzed for total and dissolved metals concentrations. The proposed monitoring program is summarized in Section 8.0.

7.1 BIOLOGICAL MONITORING

Objectives development has traditionally focused on physical, chemical and bacteriological parameters. Biological data has been underutilized due to the highly specialized interpretation required and the difficulty in applying the data quantitatively. Not withstanding this problem, with few exceptions, the most sensitive use of our water bodies is aquatic life. Therefore biological objectives need to be incorporated into the overall objectives development program.

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

8.0 SUMMARY OF PROPOSED WATER QUALITY OBJECTIVES AND MONITORING SCHEDULE

Table 4. Summary of proposed water quality objectives for the McKelvie Creek community watershed.

Variable	Objective Value
Fecal Coliform Bacteria	≤60 CFU/100 mL (90th percentile based on a minimum of five weekly samples collected over a 30-day period)
Escherichia coli	≤60 CFU/100 mL (90th percentile based on a minimum 5 weekly samples collected over a 30-day period)
Turbidity	2 NTU average (based on a minimum 5 weekly samples collected over a 30-day period) 5 NTU maximum
Temperature	≤15°C (long-term) with hourly rate of change not exceeding 1°C
True Colour	15 TCU maximum
Total Organic Carbon	4.0 mg/L maximum
Total Suspended Solids	25 mg/L maximum in a 24-hour period 5 mg/L average (based on a minimum of five weekly samples collected over a 30-day period)

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

Table 5. Proposed schedule for future water quality monitoring in McKelvie Creek.

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

LITERATURE CITED

Brettar, I. and M.G. Höfle. 1992. Influence of ecosystematic factors on survival of *Escherichia coli* after large-scale release into lake water mesocosms. Applied and Environmental Microbiology 58(7): 2201 – 2210.

B.C. Ministry of Environment. 2001. Approved Water Quality Guidelines for Temperature. Water Quality Branch, Environmental Protection Division, British Columbia Ministry of Environment. Victoria, B.C.

B.C. Ministry of Environment. 2006. British Columbia Approved Water Quality Guidelines – 2006 Edition. Water Quality Branch, Environmental Protection Division, British Columbia Ministry of Environment. Victoria, B.C. Available online at: http://www.env.gov.bc.ca/wat/wq/BCguidelines/approv_wq_guide/approved.html

CCME (Canadian Council of Ministers of the Environment). 2002. Canadian Water Quality Guidelines for the Protection of Aquatic Life – Nitrate Ion. In: Canadian environmental quality guidelines. 1999. Canadian Council of Ministers of the Environment. Winnipeg.

Carmanah Research Ltd. 1997. Detailed proposal for a water quality program for community watersheds, Vancouver Island Region. Ministry of Environment, Lands and Parks, Nanaimo, BC.

Demarchi, D.A. 1996. An Introduction to the Ecoregions of British Columbia. Ministry of Environment, Lands and Parks, Victoria. B.C. Available online at: http://www.env.gov.bc.ca/ecology/ecoregions/intro.html

Drinking Water Protection Act – Drinking Water Protection Regulation. 2005. Available online at: http://www.qp.gov.bc.ca/statreg/reg/D/200_2003.htm

Fisheries Information Summary System (FISS) Database. 2006. Ministry of Environment and Department of Fisheries and Oceans. Available online at: http://www.bcfisheries.gov.bc.ca/fishinv/fiss.html

Health Canada. 2006. Guidelines for Canadian Drinking Water Quality – Summary Table. Available online at: http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/doc_sup-appui/sum_guide-res_recom/index_e.html

Howell, J.M., M.S. Coyne and P.L. Cornelius. 1996. Effect of sediment particle size and temperature on fecal bacteria morality rates and the fecal coliform/fecal streptococci ratio. J. Environ. Qual. 25: 1216 – 1220.

Jawson, M.D., L.F. Elliott, K.E. Saxton, and D.H. Fortier. 1982. The effect of cattle grazing on indicator bacteria in runoff from a Pacific Northwest watershed. J. Environ. Qual. 11: 621 - 627.

Lloyd, D., *et al.* 1990. A guide to site identification and interpretation for the Kamloops Forest Region Part 1 and Part 2. B.C. Min. For., Victoria, B.C. Land Management Handbook 23.

MINFILE 2005. Ministry of Energy and Mines Mineral Inventory. Available online at: http://www.em.gov.bc.ca/mining/geolsurv/minfile/

RISC (Resource Inventory Standards Committee). 1994. Ambient Freshwater and Effluent Sampling Manual. Available online at: http://ilmbwww.gov.bc.ca/risc/pubs/aquatic/ambient/index.htm

Stephenson, G.R. and R.C. Rychert. 1982. Bottom sediment: a reservoir of *Escherichia coli* in rangeland streams. J. Range Manage. 35: 119-123.

Tiedemann, A.R., D.A. Higgins, T.M. Quigley, H.R. Sanderson and D.B. Marx. 1987. Responses of fecal coliform in streamwater to four grazing strategies. J. Range Manage. 40(4): 322 – 329.

VIHA (Vancouver Island Health Authority). 2006. Gary Anderson – personal communication. Landuse – Water Consultant, North Vancouver Island Health Service Delivery Area.

Water Survey Canada. 2005. Environment Canada Hydat Online Database. Available online at: http://www.wsc.ec.gc.ca/hydat/H2O/

APPENDIX I. SUMMARY OF WATER QUALITY DATA

Table 6. Summary of general water chemistry at Site E230718, McKelvie Creek at Intake.

Variable	Minimum	Maximum	Average	Std Dev	No. of samples
Fecal coliforms (CFU/100mL)	< 1	380	21.0	62.6	38
E. coli (CFU/100mL)	< 1	330	18.6	56.1	35
Enterococci (CFU/100mL)	< 1	< 1	< 1	0	6
Streptococci (CFU/100mL)	< 1	4	2	1.7	3
Carbon Diss. Inorganic (mg/L)	1.1	2.7	2.0	0.6	7
Carbon Dissolved Organic (mg/L)	0.5	4.2	1.1	0.8	34
Carbon Total Dissolved (mg/L)	2.6	3.3	3.0	0.2	7
Carbon Total Inorganic (mg/L)	1.1	2.7	2.0	0.7	7
Carbon Total Organic (mg/L)	0.5	3.3	1.3	0.7	15
Color True (TCU)	3	14	7.8	3.8	12
C--T (mg/L)	2.7	3.4	3.1	0.2	7
Hardness Total (D) (mg/L)	5.7	12.2	9.3	2.5	13
Hardness Total (T) (mg/L)	6.1	12.1	9.4	2.3	7
Mg-D (mg/L)	0.4	0.7	0.6	0.1	7
Mg-T (mg/L)	0.4	0.7	0.6	0.1	7
Nitrate (NO3) Dissolved (mg/L)	0.009	0.127	0.047	0.023	28
Nitrate + Nitrite Diss. (mg/L)	< 0.002	0.127	0.046	0.023	32
Nitrogen - Nitrite Diss. (mg/L)	< 0.002	0.005	0.002	0.001	32
Ortho-Phosphate Dissolved (mg/L)	< 0.001	0.005	0.002	0.001	27
pH (pH units)	6.5	8	7.2	0.3	39
Phosphorus Tot. Dissolved (mg/L)	< 0.002	0.005	0.002	0.001	26
P--T (mg/L)	< 0.002	0.007	0.003	0.001	33
Residue Non-filterable (mg/L)	< 1	12	1.9	2.2	55
Specific Conductance (μS/cm)	13	129	30.3	18.6	33
Turbidity(NTU)	0.05	4.31	0.33	0.67	39
UV Absorbance 250nm (AU/cm)	< 0.01	0.28	0.05	0.08	15
UV Absorbance 254nm (AU/cm)	< 0.01	0.28	0.05	0.08	15
UV Absorbance 310nm (AU/cm)	< 0.01	0.24	0.04	0.06	15
UV Absorbance 340nm (AU/cm)	< 0.01	0.22	0.03	0.05	15
UV Absorbance 360nm (AU/cm)	< 0.01	0.22	0.03	0.05	15
UV Absorbance 365nm (AU/cm)	< 0.01	0.22	0.03	0.05	15
Ag-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Ag-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
Al-D (mg/L)	0.0047	0.125	0.0283	0.0311	27
Al-T (mg/L)	0.0055	0.258	0.0385	0.0556	27
As-D (mg/L)	< 0.0001	0.0002	0.0001	0.0000	28
As-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
Ba-D (mg/L)	< 0.0001	0.0113	0.0005	0.0021	28
Ba-T (mg/L)	< 0.0001	0.0112	0.0005	0.0021	28
B--D (mg/L)	< 0.01	0.012	0.010	0.001	7
Be-D (mg/L)	0.0001	0.0005	0.0001	0	28
Be-T (mg/L)	0.0001	0.0005	0.0001	0	28
Bi-D (mg/L)	0.0001	0.0005	0.0001	0	28

Variable	Minimum	Maximum	Average	Std Dev	No. of samples
Bi-T (mg/L)	0.0001	0.0005	0.0001	0	28
B--T (mg/L)	< 0.01	0.03	0.01	0.01	7
Ca-D (mg/L)	1.6	3.7	2.8	0.8	7
Ca-T (mg/L)	1.7	3.7	2.8	0.8	7
Cd-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Cd-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
Co-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Co-T (mg/L)	< 0.0001	0.0002	0.0001	0	28
Cr-D (mg/L)	< 0.0002	0.0005	0.0002	0.0001	28
Cr-T (mg/L)	0.0001	0.0009	0.0003	0.0002	28
Cu-D (mg/L)	0.0001	0.0011	0.0005	0.0003	28
Cu-T (mg/L)	< 0.0001	0.0023	0.0005	0.0005	28
Fe-D (mg/L)	< 0.005	0.021	0.012	0.008	6
Fe-T (mg/L)	< 0.006	0.051	0.023	0.019	6
K--D (mg/L)	< 0.1	0.3	0.1	0.1	6
K--T (mg/L)	< 0.1	0.2	0.1	0.1	6
Li-D (mg/L)	< 0.0001	0.001	0.0002	0.0002	27
Li-T (mg/L)	< 0.0001	0.0008	0.0002	0.0002	27
Mn-D (mg/L)	< 0.0001	0.001	0.0003	0.0003	28
Mn-T (mg/L)	< 0.0001	0.0087	0.0007	0.0016	28
Mo-D (mg/L)	< 0.0001	0.0014	0.0001	0.0002	28
Mo-T (mg/L)	< 0.0001	0.0015	0.0002	0.0003	28
Na-D (mg/L)	< 0.1	0.9	0.6	0.3	6
Na-T (mg/L)	0.8	0.9	0.8	0.0	6
Ni-D (mg/L)	< 0.0001	0.0005	0.0001	0.0001	28
Ni-T (mg/L)	< 0.0001	0.0003	0.0001	0	28
Pb-D (mg/L)	< 0.0001	0.0003	0.0001	0	28
Pb-T (mg/L)	< 0.0001	0.0005	0.0001	0.0001	28
Sb-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Sb-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
S--D (mg/L)	0.16	0.4	0.30	0.10	6
Se-D (mg/L)	< 0.0002	0.0003	0.0002	0	27
Se-T (mg/L)	< 0.0002	0.0004	0.0002	0	27
Si-D (mg/L)	0.81	1.84	1.32	0.39	7
Si-T (mg/L)	1.26	3.97	1.77	0.98	7
Sn-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Sn-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
Sr-D (mg/L)	0.0035	0.0897	0.0091	0.0143	34
Sr-T (mg/L)	0.0037	0.0928	0.0093	0.0149	34
S--T (mg/L)	0.16	0.36	0.28	0.07	6
Tl-D (mg/L)	< 0.0001	0.0001	0.0001	0	28
Tl-T (mg/L)	< 0.0001	0.0001	0.0001	0	28
V--D (mg/L)	0.0003	0.0013	0.0005	0.0002	28
V--T (mg/L)	0.0002	0.0016	0.0006	0.0002	28
Zn-D (mg/L)	< 0.0001	0.0031	0.0007	0.0007	28
Zn-T (mg/L)	< 0.0001	0.0053	0.0005	0.0010	28

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

Start Date	Start Time	Recovery Time (hrs)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
17/06/2003	11:00	1	0.5	67.5	0.9	34.2	47.1
25/06/2003	07:30	161.25	0.5	5.2	1	3.1	3.0
22/08/2003	04:15	1388.25	0.5	27.1	0.8	14.0	18.6
08/10/2003	16:00	2	0.5	5.1	3.7	4.4	1.0
08/10/2003	20:45	4.5	0.5	7.7	3.8	5.8	2.8
08/10/2003	22:15	1.25	0.5	6	3.9	5.0	1.5
08/10/2003	11:45	1134.25	2.5	6.8	5	5.7	0.6
16/10/2003	14:00	183.5	0.5	5.2	4	4.6	0.8
16/10/2003	20:15	0.75	0.5	5.5	4.5	5.0	0.7
16/10/2003	17:30	0.5	0.75	5.7	5	5.4	0.4
16/10/2003	19:00	1	0.75	6.5	4.7	5.7	0.9
16/10/2003	15:30	1.25	1.75	6.5	4.3	5.6	0.8
17/10/2003	14:30	18	0.5	5.1	3.2	4.2	1.3
17/10/2003	18:45	1.5	0.5	8.7	3.2	6.0	3.9
17/10/2003	19:15	0.25	0.5	5.4	3.9	4.7	1.1
17/10/2003	19:45	0.25	1	5.9	5	5.6	0.4
17/10/2003	15:30	0.75	2	8.7	4.7	6.6	1.6
18/10/2003	04:30	8	1.75	6.7	4.5	5.6	0.7
20/10/2003	23:30	3.75	0.5	5.6	2.9	4.3	1.9
20/10/2003	08:00	50	12	32.9	4.1	12.9	6.9
22/10/2003	08:30	32.75	3.5	13.7	3.1	8.1	2.7
02/12/2003	14:15	983.25	0.5	5.4	3.4	4.4	1.4
14/01/2004	01:15	1018.75	0.5	24.7	0.9	12.8	16.8
14/01/2004	08:45	7.25	0.5	5.1	1.7	3.4	2.4
26/02/2004	12:45	1035.75	0.5	10	0.2	5.1	6.9
06/04/2004	21:30	968	1.25	6.2	4.4	5.5	0.7
07/04/2004	18:15	19.75	0.5	7.8	1	4.4	4.8
21/04/2004	20:15	337.75	0.5	5.6	-0.1	2.8	4.0
21/04/2004	20:45	0.25	1.5	7.3	3.7	5.8	1.2
13/05/2004	12:30	304.5	0.5	11.2	-0.6	5.3	8.3
11/08/2004	11:30	2157.75	0.5	11.2	-0.5	5.4	8.3
29/08/2004	06:30	258	0.5	5.2	3.7	4.5	1.1
30/08/2004	14:00	31.25	0.5	6.4	1.6	4.0	3.4
30/08/2004	16:45	2.5	2.75	10.3	4.2	7.1	2.1
11/09/2004	12:30	6.25	0.5	5.9	1.6	3.8	3.0
11/09/2004	04:00	272.75	2.5	16.4	4.2	9.9	4.8
29/10/2004	16:15	1155.5	4.75	28.7	4.5	12.1	7.3
05/11/2004	09:45	157	0.5	6.1	2.1	4.1	2.8
05/11/2004	12:30	2.5	8.25	8.7	4.9	6.8	1.0
07/11/2004	14:15	0.25	0.5	5.6	5	5.3	0.4
07/11/2004	15:00	0.5	0.5	5.6	4.9	5.3	0.5
07/11/2004	06:30	34	7.75	42.1	4.3	17.1	12.2
08/11/2004	04:15	13	10.75	18.7	3.1	10.1	3.5
14/11/2004	11:30	140.75	18	17.9	4.1	10.1	3.3
10/12/2004	08:00	602.75	17.5	423.4	2.2	80.4	106.1

Start Date	Start Time	Recovery Time (hrs)	Duration of event (h)	Max turb (NTU)	Min turb (NTU)	Avg. turb (NTU)	St.Dev.
11/12/2004	01:30	0.25	0.5	5.2	5	5.1	0.1
14/12/2004	05:00	0.75	0.5	5.2	4.7	5.0	0.4
14/12/2004	12:30	7.25	0.5	5.7	2.3	4.0	2.4
14/12/2004	02:45	73	1.75	5.8	4.8	5.4	0.3