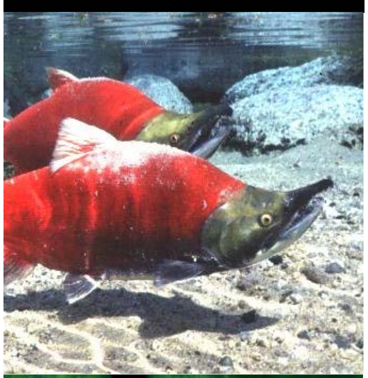

Whistler Valley Water Quality Monitoring Program:

Preliminary Assessment

Prepared for:

Environmental Quality Section
Environmental Protection Division
Lower Mainland Region
BC Ministry of Environment

Prepared by:

Aquatic Informatics Inc.

Reference to this report:

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Acknowledgements

The British Columbia Ministry of Environment (MOE) has provided funding for this study. Special thanks to Rod Shead for data, administrative support, and helpful review comments.

Distribution Notes and Caveats

It must be recognized that certain portions of this report present experimental results based on forward-looking, R&D-oriented work performed by Aquatic Informatics Inc. (AI) on contract to BC MOE; this pertains, in particular but not necessarily exclusively, to the risk-based temperature guidelines discussed in the report.

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Executive Summary

The River of Golden Dreams (ROGD) watershed encompasses approximately 48 square kilometers within the Whistler valley, with a variety of land uses (e.g., residential and commercial development, transportation infrastructure, recreational use, etc.) occurring within the watershed. The watershed resources contribute significantly to the area's economy by attracting visitors interested in fishing, swimming, canoeing and other recreational opportunities. In December 2001, the Resort Municipality of Whistler (RMOW) developed a *Watershed Management Plan* (WMP) for the ROGD. This plan defines a vision "*to protect and restore aquatic and terrestrial ecosystems from the pressures of land use and human activities within the watershed*". In working towards this vision, the WMP calls for increased information on baseline conditions and the detection of areas of concern – these will provide a foundation for effective mitigation.

In 2002, the British Columbia Ministry of Environment (MOE) installed automated water quality monitors on the ROGD and on Crabapple Creek, a tributary to ROGD. These stations monitor stream temperature, conductivity, pH, dissolved oxygen, turbidity, and water level near-continuously. Automated temperature sensors (thermistors) were installed in nearby Whistler Creek. The automated water quality monitoring program is supplemented with grab-sampling for investigation of a wider variety of parameters than can be conducted with automated monitoring alone. The intent of the sampling program is to: i) provide decision makers with data to feedback into the ROGD Watershed Management Plan, and ii) collect data for the development of Water Quality Objectives within the ROGD watershed.

The objective of this report is to summarize and assess data collected to date, and to make recommendations on how monitoring might be improved so that the program meets its objectives. In doing so, we have:

- (i) validated and corrected the automated data, where appropriate;
- (ii) assessed stream temperature and turbidity risks to the aquatic environment, using magnitude-duration based techniques;
- (iii) determined potential impacts on ROGD and Crabapple Creek from road salting;
- (iv) summarized and assessed stream chemistry (e.g., nutrients, metals, bacteria, etc.) for compliance with applicable provincial and federal regulatory guidelines for (in general) the protection of aquatic life.

Overall, the monitoring program to date has been successful. The automated monitoring stations have performed relatively well, providing detailed information on stream processes. The grab sampling has also been effective, though s ampling frequency needs to be increased to 5-times every 30 days, each season. Analysis of the data collected to date suggests generally good water quality in all three rivers.

Stream temperatures are well below those that could cause acute (lethal) risks to rainbow trout and Kokanee (salmonids present). Chronic risks, as measured by potential reduction in growth, have been generally low. Turbidity risks were also relatively low, with the majority of events rated as having minor effect on fish. For assessment of the impacts of road salting, peak chloride concentrations were estimated to be less than 1/3 of provincial and federal guidelines. This suggests that road salting during the winter of 2003/04 had a minimal impact on the ecology of these streams. Bacterial indicators (fecal coliforms and *Escherichia coli*) were elevated in all three streams, particularly in Crabapple Creek; however, levels could not be compared directly to guidelines due to the frequency of sampling. It is likely that levels in Crabapple Creek would have exceeded guidelines. Iron exceeded guidelines occasionally in all three creeks, and copper and zinc exceeded guidelines occasionally in Crabapple Creek. Although these metals are often associated with urbanization, they could also be natural and more sampling is necessary to identify the sources. Sulfate exceeded the alert level for aquatic moss monitoring in Crabapple Creek for six of 16 samples. Site-specific *Water Quality Objectives* for temperature and chloride have been recommended. Additional Water Quality Objectives can be developed once additional years of data have been collected.

1. Introduction

1.1 Project Background

The River of Golden Dreams (ROGD) watershed encompasses approximately 48 square kilometers within the Whistler valley (**Figure 1**), with a variety of land uses (e.g. residential and commercial development, transportation infrastructure, recreational use, etc.) occurring within the watershed. The watershed resources contribute significantly to the area economy by attracting visitors interesting in fishing, swimming, canoeing and other recreational opportunities. In December 2001, the Resort Municipality of Whistler (RMOW) developed a watershed management plan for the ROGD. This plan defines a vision that describes the desired state of the watershed for the future. The vision, "*to protect and restore aquatic and terrestrial ecosystems from the pressures of land use and human activities within the watershed*", has six general goals, each having associated objectives and actions. The first goal of the ROGD Watershed Management Plan states "*water quality and quantity are protected and restored in all streams, lakes and wetlands within the River of Golden Dreams watershed*". As part of this goal, an action item is to increase information on baseline conditions, to detect areas of concern, and to provide a foundation for effective mitigation. This report summarizes recent work conducted under this action item.

The British Columbia Ministry of Environment (MOE) has undertaken several initiatives with the Resort Municipality of Whistler (RMOW) and other stakeholders to protect important environmental values in the Whistler Valley. One of these initiatives includes the installation of automated water quality monitors in 2002 on the ROGD and Crabapple Creek, a tributary to ROGD. Continuous temperature dataloggers (thermistors) were also installed in nearby Whistler Creek. The automated water quality monitoring program is supplemented with grab-sampling for investigation of a wider variety of parameters than can be conducted with automated monitoring alone. The intent of the sampling program is to:

i) Provide decision makers with data to feedback into the ROGD Watershed Management Plan.
ii) Collect data for the development of Water Quality Objectives within the ROGD watershed.

Once sufficient data has been collected (3-5 years), the ministry intends to develop water quality objectives (allowable levels of a particular substance for the protection of a designated water use) within the ROGD watershed.

1.2 Water Quality Objectives

British Columbia *Water Quality Guidelines* and *Water Quality Objectives* (collectively referred to as *Water Quality Criteria*) are both allowable levels of a particular substance for the protection of a designated water use (e.g., drinking water, aquatic life, livestock watering, recreation), but differ in their scope. *Guidelines* are set to protect a designated water use in general, whereas *Objectives* are set to protect a designated water use at a specific location. *Objectives* are a combination of *Water Quality Guidelines* plus the site characteristics that may influence the toxic action of the substance of concern. Unless *Water Quality Objectives* have been established for a specific water body, the *Water Quality*

Guidelines are the default criteria. Water quality criterion values have traditionally been (and generally continue to be) simple maximum or minimum values.

It is recognized that it is not only the magnitude of a particular exposure, but also the duration of the exposure that has environmental relevance. For example, high magnitude, short duration events (usually in response to weather conditions) can have significant impacts on aquatic populations and communities, impacts that may require years for complete recovery. Conversely, lower magnitude but very long-duration events may also strongly harm aquatic ecosystems. Automated water quality monitoring facilitates the development of magnitude-duration water quality objectives, and meeting such objectives (by avoiding event-related peaks) reduces the potential for long-term impacts to aquatic populations and communities.

1.3 Objectives of this Report

MOE contracted Aquatic Informatics Inc. (AI Inc.) to assess the data collected to date from these three creeks. The objective of this report is to summarize the results of MOE's water quality monitoring in the Whistler Valley for 2003 and 2004 and make recommendations (if any) on improving the sampling program. Specific tasks include:

i) Validating and correcting automated data. The automated ROGD and Crabapple water quality data, as well as the Whistler Creek automated temperature data, are in need of corrective measures (e.g., removal of outliers, gap filling, drift correction);
ii) Preliminary assessment of automated data (e.g., risk assessment, trend detection);
iii) Preliminary assessment of grab-sampling data from ROGD, Crabapple Creek, and Whistler Creek;
iv) Recommendation for improvements to the water quality monitoring program to ensure that sampling activities (i.e., timing, frequency, selected parameters, etc.) will provide decision makers will data that facilitates management of water resources in the Whistler Valley.

2. Methods

2.1 Monitoring

MOE worked with RMOW to install multiparameter aquatic monitoring stations in Crabapple Creek and ROGD. Each station consists of a protective steel deployment tube (**Figure 2**) that houses a Hydrolab monitoring sonde. The Hydrolabs monitor pH, specific conductivity (SC), water temperature, stage, turbidity, and dissolved oxygen (DO) near-continuously (15-minute interval sampling). Water temperature is monitored near continously in Whistler Creek using thermistors. Grab samples are also collected for all three watersheds, and are sent to a certified laboratory for analysis for general chemistry, bacteria, and metals.

a) b)

Figure 2. Hydrolab near-continuous aquatic monitoring stations in a) Crabapple Creek and b) River of Golden Dreams.

2.2 Data Validation and Correction

Automated water quality data typically have sections suffering from data errors such as outliers, sensor drift, noise, and gaps. Before data analysis is attempted, data must be validated and corruptions eliminated. This task was completed using the software package **AQUARIUS™**, developed by Aquatic Informatics. Details of the methodology are described in Quilty et al. (2004a,b). In general, the signals were statistically validated using relationships with surrogate signals, and data deemed erroneous was then corrected using these relations. For example, water temperature in ROGD was validated using water temperatures in nearby Crabapple Creek, Millar Creek, and Whistler Creek. Outliers, sensor drift, and noise were removed, and data gaps were then reconstructed using either linear regression or nonlinear artificial neural networks (ANNs).

2.3 Statistical Analysis of Automated Water Quality Data

Water Temperature

In general, risks to salmonids in British Columbia streams from high water temperatures include acute and chronic impacts over the summer warm period. Acute impacts consist of direct mortality from high water temperatures and begin at about 24°C. The highest instantaneous water temperatures measured over the observation period in Whistler and Crabapple Creeks and the River of Golden Dreams were 17.7, 18.4, and 19.7°C, respectively. There is, therefore, no evidence that salmonids incur acute thermal risks in these rivers at present.

Chronic risks consist of sub-lethal temperature impacts which can compromise the viability of salmonid populations. Such chronic impacts are incurred at considerably lower water temperatures than acute risks. For example, suboptimal steelhead/rainbow trout growth rates begin to be incurred at about 14°C, well below the maximum observed temperatures in the systems of concern. The current assessment thus focuses on chronic risk.

The risk assessment procedure applied consists of the magnitude-duration method introduced and explained in detail by Fleming et al. (2004). Readers should refer to that report for a full explanation of the method. In summary, the approach: (i) uses temperature impacts upon growth as a measure of chronic temperature risk; (ii) explicitly incorporates the effects of both magnitude and cumulative duration of high daily mean water temperatures over the summer; (iii) adjusts the result for local watershed conditions, so that a naturally warm system is unlikely to be identified as being thermally polluted, while a naturally cool system remains closely monitored for ecologically harmful thermal changes; and (iv) expresses the net result both graphically and as a risk quotient, closely analogous to that used in toxicological risk assessments. This leads to a simple but robust and rigorous decision rule for watershed managers. *Specifically, a yearly risk quotient, RQ, greater than 1 indicates abnormally high chronic temperature risk, and cause for environmental management concern and potentially corrective action. In contrast, a risk quotient less than or equal to 1 indicates that there is no immediate cause for management concern.*

The results are species-dependent (see Fleming et al., 2004). The Fisheries Information Summary System (FISS) online database indicates that prickly sculpin (*Cottus asper*), Dolly Varden char (*Salvelinus* *malma*), Kokanee salmon (*Oncorhynchus nerka*), rainbow trout (*Oncorhynchus mykiss*), and an unstated species of stickleback are present in ROGD, and Kokanee and rainbow are present in Whistler Creek. The database contains no information for Crabapple Creek, but it is a tributary to ROGD and we assume its fish distribution to be similar. Note that management emphasis lies upon salmonid species; little information appears to be available regarding the temperature requirements of Dolly Varden; and that rainbow is a variant of steelhead. While the temperature tolerance range for rainbow is broader than that for Kokanee, the optimal growth temperature for Kokanee is 15^{o}C (both juveniles and adults) whereas the optimal growth temperature for rainbow is 10-14^{o}C (Ford et al., 1995). We therefore conservatively select rainbow trout as the target species for assessing and managing chronic water temperature risks (as this should also be generally protective of Kokanee). A relationship between daily mean water temperature and rainbow/steelhead specific growth rate, defined specifically for temperatures exceeding the optimum, was presented in Fleming et al. (2004) and is applied here for assessing potential growth losses.

The method also requires selection of a reference value for annual total growth risk (TGR_{ref}). This is a reference value for the loss in yearly total percent growth due specifically to sub-optimally high water temperatures, and is preferably based upon a substantial historical temperature dataset. Temperature data for the three study rivers, however, are too short to directly evaluate TGR_{ref}. This challenge was addressed by regressing observed summer 2004 daily mean water temperature data upon Pemberton Airport summer 2004 daily mean air temperature, and then using the relationship to calculate summertime daily mean water temperatures for 1994 through 2003 on the basis of the longer air temperature record. The process was performed independently for Crabapple Creek, Whistler Creek, and ROGD. Air temperature is generally an effective predictor of water temperature, and the regression relationships found here were of good quality. The resulting 1994 – 2004 summertime water temperature time series reflect year-to-year variability in water temperatures resulting from climatic variability. Using this 11-year observed and synthetic record as a baseline period thus permits selection of a reasonable value for TGR_{ref}. For each creek, the 90th percentile value of the 11 resulting annual total growth risk values was taken to be TGR_{ref} for that system.

An important caveat is that the effects of anthropogenic watershed modifications which affect the relationship between water temperature and air temperature are propagated back in time using this particular TGR_{ref} selection method. Thus, if the thermal regimes of the study rivers have already been significantly impacted by human activities (e.g., urban development), then those effects are also present in the back-projected water temperature time series, and are reflected in the TGR_{ref} value against which future temperatures are to be assessed for compliance. The practical consequence lies in the implied management goal. Specifically, the goal under this approach is to ensure that watershed thermal regimes are not significantly impacted beyond current conditions, which may or may not already be impacted to some degree. In contrast, if the selected management goal is to ensure that chronic temperature risks to salmonids in these creeks are strictly at natural levels, which could conceivably require remediation, then significant further work will be required to assess whether changes in thermal regime due to watershed modification have already taken place and, if so, what the natural regime is. Note that zero temperature growth risk is not an appropriate water quality objective or remediation target unless that was the natural state of the system.

Turbidity

The severity-of-ill-effect (*SEV*) index of Newcombe (2003), which incorporates the ecological effects of both magnitude and duration of exposure to elevated turbidity levels, was used to quantify optical turbidity risks to clear water fish and to assign an impact ranking. The observation period is short, and (unlike temperature) turbidity is generally difficult to model well from other parameters. As a result, site-specific water quality objectives for either event-wise or cumulative ecological impacts due to elevated turbidity (see Fleming et al., 2004) cannot be set until additional years of data have been collected. Nevertheless, the *SEV* rankings provide a useful measure of turbidity impacts in ROGD and Crabapple Creek. As detailed in Fleming et al. (2004), a turbidity event is defined as any time interval over which turbidity exceeds the drinking water standard of 1 *NTU*; *SEV* values calculated to be less than 0 using the relationship of Newcombe (2003) were set to 0; and the highest-*SEV* sub-event was selected as being representative of conditions during intervals over which multiple turbidity sub-events occur.

Conductivity (to estimate chloride from road-salting)

Near continuous specific conductivity (SC) readings collected by the ROGD and Crabapple Creek stations were used to estimate chloride concentrations [Cl^-], which were sampled intermittently through the grab sampling program. We used the well-recognized relationship between specific conductivity and total dissolved solids (TDS) and, in turn, [Cl^-]. The SC-[Cl^-] relation varies between watersheds due, at a minimum, to varying geologic characteristics, so regression analyses were performed independently for ROGD and Crabapple Creek. Once the relation was established, near-continuous [Cl^-] concentrations were estimated.

Dissolved Oxygen, pH, and Stream Depth

For dissolved oxygen and pH, we statistically characterize the signals and compare to existing guidelines. Stream depth is usually used to estimate discharge (flow) when stage-discharge relations have been established; however, for ROGD and Crabapple Creek, these relations have not yet been established. We therefore use depth as a general indicator of hydrological conditions in the streams (i.e., baseflow, freshet, storm flow, etc.).

2.4 Assessment of Grab-sampling Water Quality Data

Summary statistics (number of samples; minimum, mean, and maximum values; standard deviation) were determined for grab samples from all three creeks for 2003 and 2004. When a concentration was less than the detection limit for the laboratory analytical method used, the value was set to one-half the reported detection limit for the purpose of calculating summary statistics, unless all observations for a given parameter, creek, and year were under the detection limit. These were compared against corresponding water quality guidelines suggested by British Columbia MOE (available online at wlapwww.gov.bc.ca/ wat/wq/wq_guidelines.html#approved) and the Canadian Council of Ministers of the Environment (CCME) (available online at www.ec.gc.ca/ceqg-rcqe/English/Ceqg/Water/default.cfm). Guidelines for protection of freshwater aquatic life were used, with the exception of bacteriological indicators, for which we use the recreational – primary contact guideline. Where possible, instantaneous maxima were generally applied here, due to the temporal point nature of grab sampling. BC guidelines for total copper, lead, manganese, and zinc are currently defined as functions of hardness; the observed total hardness corresponding to the metal sample was used in the calculations.

3. Results and Discussion

3.1 Data Validation and Correction

Validated/corrected near-continuous data are compared to raw data in **Appendix 1**. Overall, the raw temperature, stage, and conductivity data were of relatively good quality. Unprocessed dissolved oxygen (DO) and pH data exhibited more gaps, outliers, and sensor drift, often in association with sensor calibration and maintenance. Raw turbidity readings were noisy, which is typical of data from these types of sensors. All signals were validated and corrected where statistically appropriate. The corrected/validated signals are approved by AI Inc. for further analysis, and were used in all subsequent work summarized in this report. Turbidity time series gaps were not filled because turbidity is difficult to model well from the available input variables.

3.2 Assessment of Automated Water Quality Data

Processed and validated data ("approved") as described in the previous section are provided in **Figures 3** to **7** below, and were used in all assessments described in this section. Given the relatively short data record at this point in the monitoring program, assessment possibilities were somewhat limited, and should be considered preliminary.

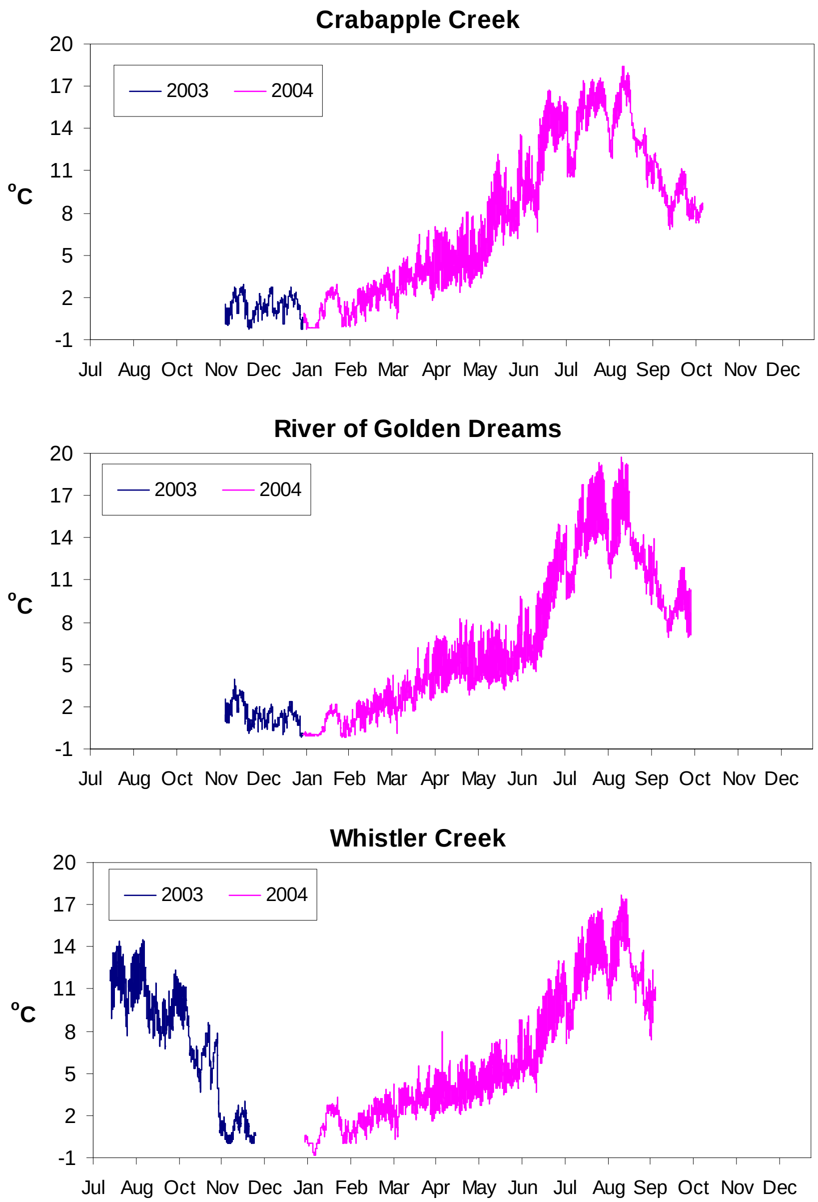


Figure 3. Automated water temperature signals from the three study creeks, 2003-2004.

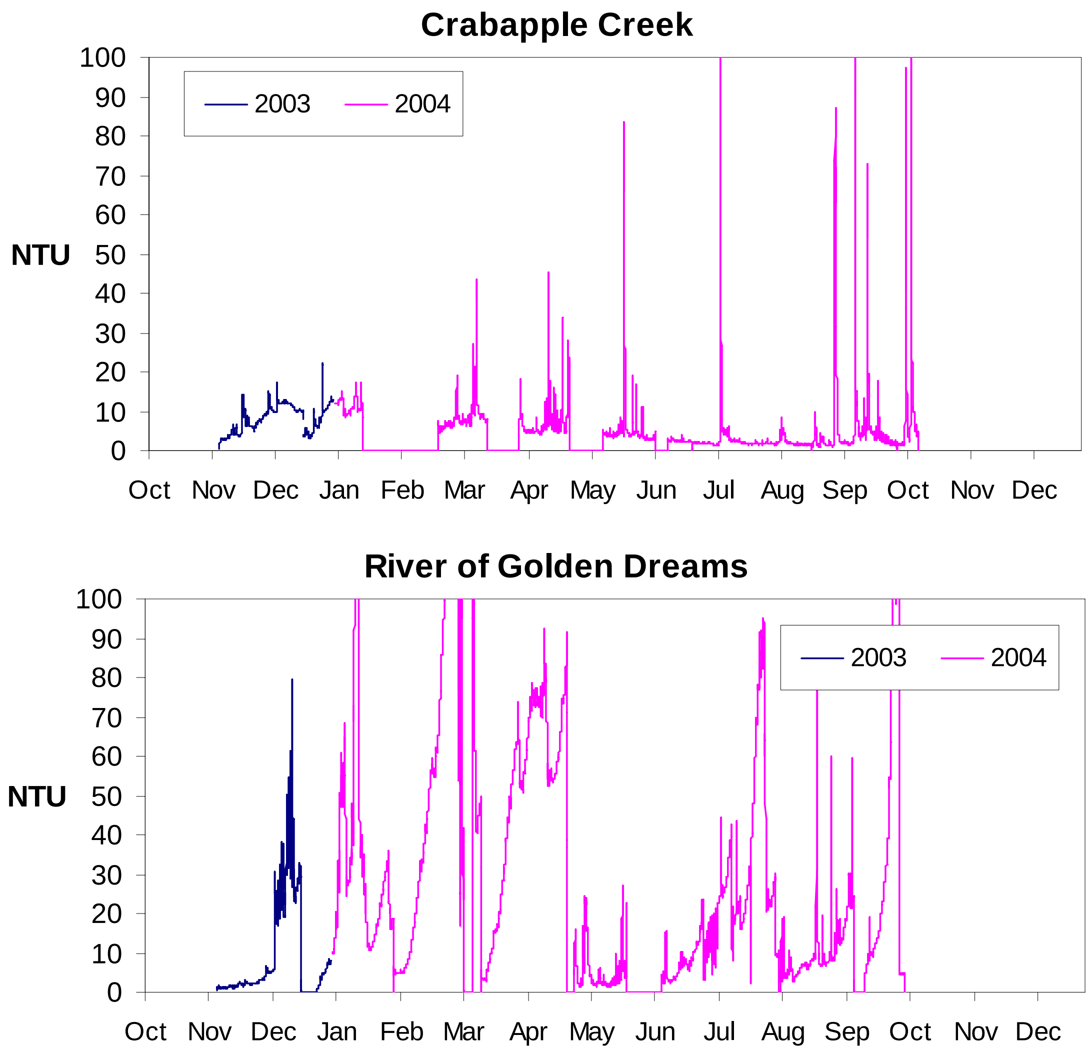


Figure 4. Automated turbidity signals from ROGD and Crabapple Creek, 2003-2004.

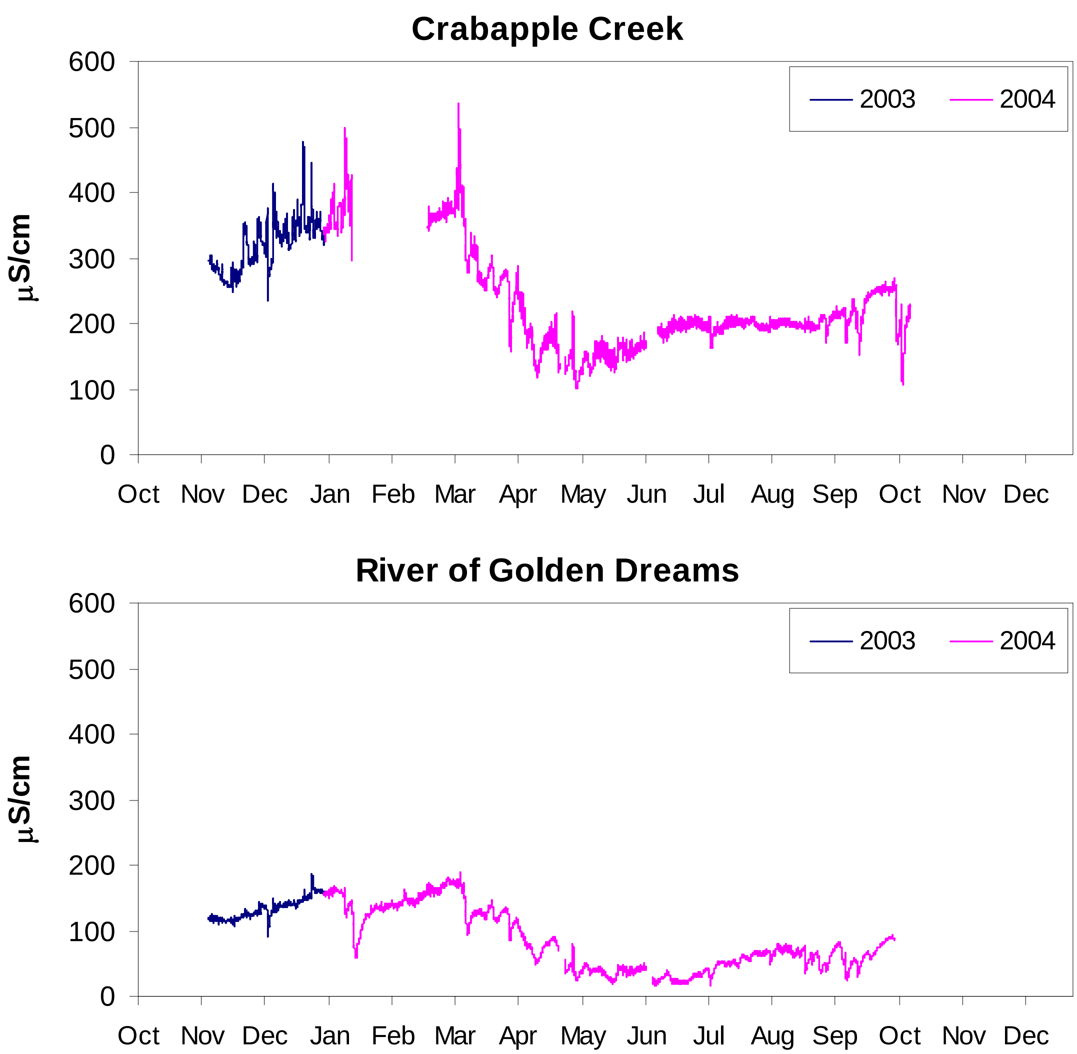


Figure 5. Automated conductivity signals from ROGD and Crabapple Creek, 2003-2004.

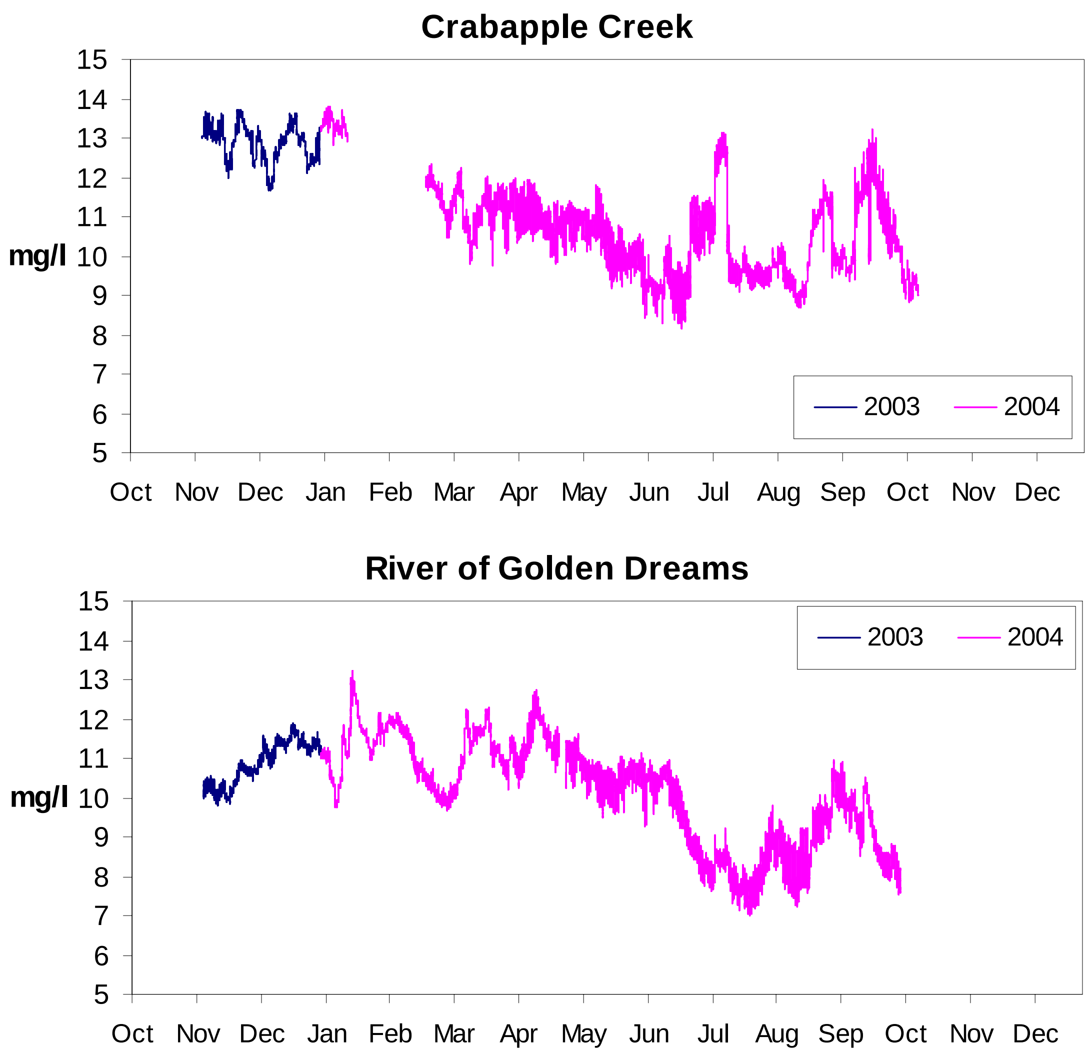


Figure 6. Automated dissolved oxygen signals from ROGD and Crabapple Creek, 2003-2004.

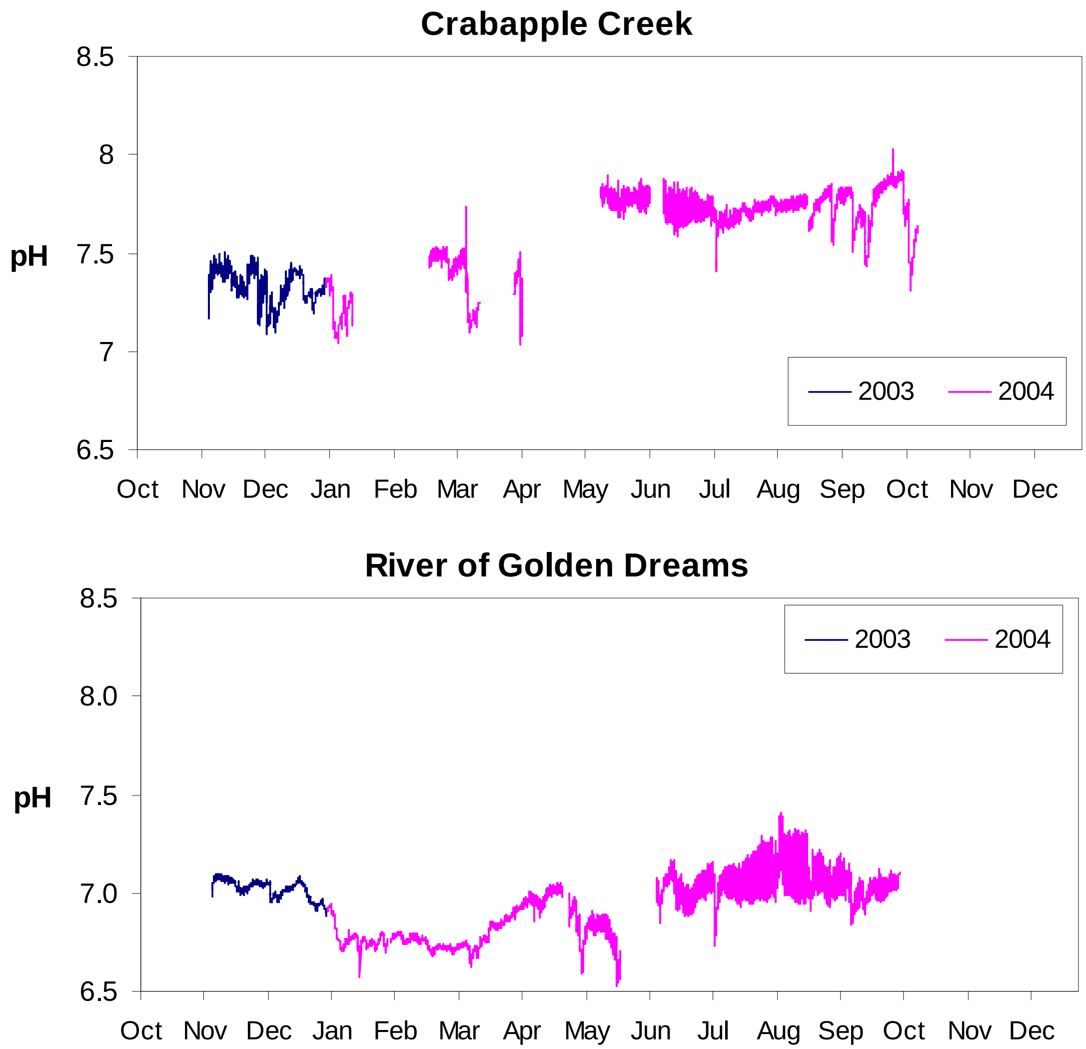


Figure 7. Automated pH signals from ROGD and Crabapple Creek, 2003-2004.

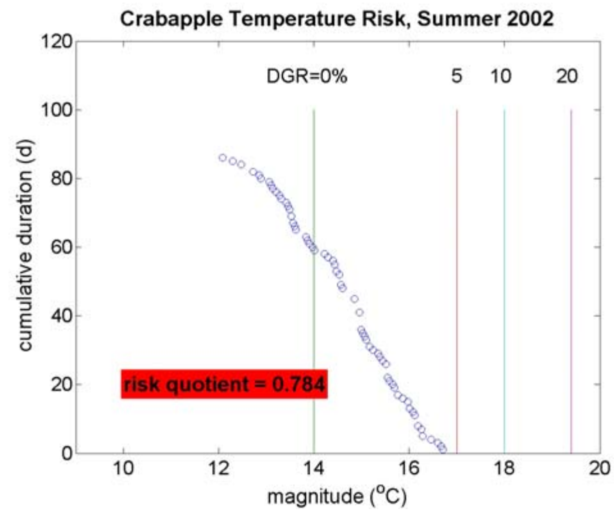
Temperature

Temperature risks were considered for Whistler and Crabapple Creeks and the River of Golden Dreams. In general, risks to salmonids in streams from high water temperatures include acute and chronic impacts over the summer warm period. Acute impacts consist of direct mortality from high water temperatures and begin at about 24°C. The highest instantaneous water temperatures measured over the observation period in Whistler and Crabapple Creeks and the River of Golden Dreams were 17.7 °C, 18.4 °C, and 19.7°C, respectively. There is, therefore, no evidence that salmonids incur acute thermal risks in these rivers at present. However, future temperature data should continue to be assessed for the potential of acute thermal risk, which would indicate a sharp change in watershed thermal regime.

For assessment of chronic risks, *TGR* values were estimated for each year from 1994 – 2004 (**Table 1**). Examples of the assessment plots from 2002 for the three streams are shown in **Figure 8**. The physical interpretation is that, over the past 10 years, the total growth risk to rainbow trout from high summer temperatures has been low. Risk to Kokanee would have been less. Year-to-year *TGR* fluctuations correspond to climatic variability, given reconstruction of pre-2003 data from air temperature records (see above). For example, 1994 and 1998 were strong El Niño years. TGR_{ref} values used to calculate *RQ* were set as the 90th percentile values of annual *TGR*, corresponding to 3.9% (Crabapple Creek), 0.57% (Whistler Creek), and 3.8% (ROGD). The implied management goal is to ensure that watershed thermal regimes are not significantly impacted beyond current conditions; specifically, so that rainbow trout do not suffer a total temperature-induced growth loss (per unit body mass) exceeding the above TGR_{ref} values.

Table 1. Total growth risk values, and associated risk quotients, for rainbow trout in Crabapple Creek, ROGD, and Whistler Creek during 1994 – 2004.

	Crabapple Creek		***River of Golden Dreams***		***Whistler Creek***	
Year	***TGR* (%)**	***RQ***	***TGR* (%)**	***RQ***	***TGR* (%)**	***RQ***
1994	3.20	0.831	3.04	0.801	0.506	0.896
1995	2.37	0.616	1.76	0.465	0.266	0.471
1996	2.57	0.667	2.33	0.616	0.326	0.577
1997	2.14	0.556	1.55	0.408	0.204	0.361
1998	3.31	0.860	3.79	1.00	0.601	1.06
1999	1.27	0.329	0.72	0.191	0.083	0.147
2000	1.80	0.466	1.12	0.297	0.085	0.150
2001	2.03	0.527	1.40	0.369	0.141	0.250
2002	3.02	0.784	2.69	0.711	0.396	0.702
2003	3.85	1.00	3.82	1.01	0.505	0.895
2004	4.20	1.09	2.60	0.686	0.565	1.00
90th percentile	3.85	1 by definition	3.79	1 by definition	0.565	1 by definition



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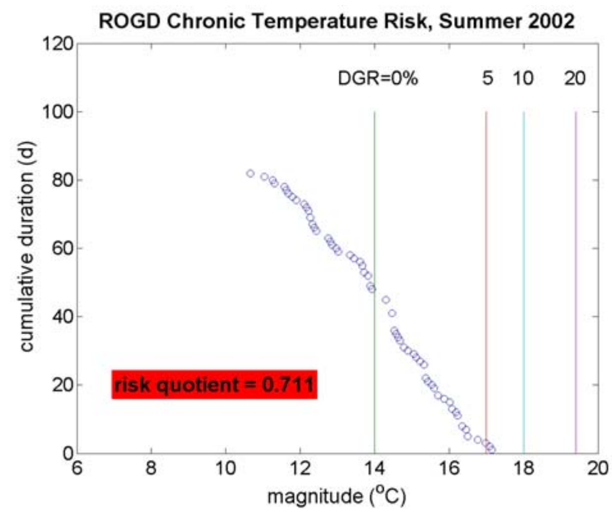

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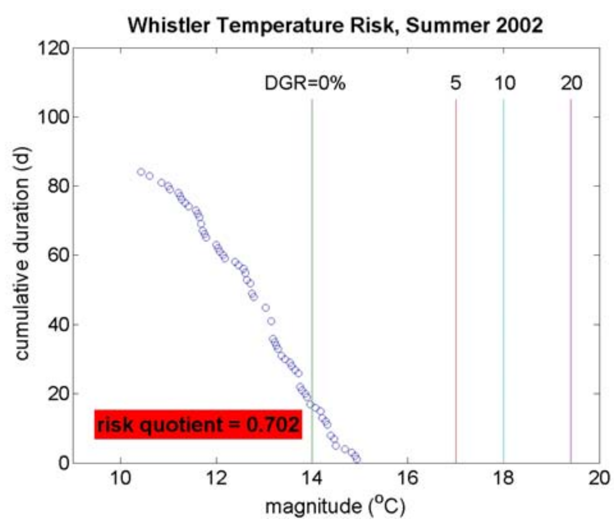


c)

Figure 8. Chronic temperature risk curves, rainbow trout. Blue circles give number of days during the summer (vertical axis) warmer than corresponding temperature (horizontal axis). Points lying to the right of 0% line indicate individual days with mean water temperature sufficiently high to incur daily growth risk, *DGR*, and so contribute to total growth risk (*TGR*). Risk quotient is ratio of 2002 *TGR* to TGR_{ref} .

The foregoing work sets in place a mechanism for assessing the impacts of any future watershed activities upon chronic temperature risks in Crabapple and Whistler Creeks and the River of Golden Dreams. In effect, $RQ = 1$, determined independently for each river using the aforementioned TGR_{ref} values, constitutes the site-specific water quality objective. Any future annual $RQ > 1$ would indicate an increase in chronic salmonid growth risk beyond acceptable levels due to elevated water temperatures. While $RQ > 1$ does not prove the existence of thermal pollution from anthropogenic inputs or watershed modifications – a risk quotient greater than unity was observed over the baseline period due to a climatic anomaly – it effectively flags ecologically salient changes in thermal regime that require closer scrutiny.

Chronic temperature risks require continued monitoring and assessment in these rivers. Crabapple Creeks and ROGD may be particularly important to assess because of their higher maximum instantaneous water temperatures (see above) and higher chronic growth losses, relative to Whistler Creek. Note also that a discussion among stakeholders regarding the most appropriate management goals for watershed thermal regimes and chronic risks, which are important to setting an appropriate TGR_{ref} value, and which might therefore lead to adjustment of the TGR_{ref} values used here, could also be valuable.

Turbidity

Near continuous turbidity data collected by the stations at Crabapple Creek and River of Golden Dreams, and statistically filtered and validated using **AQUARIUS**™, were assessed for ecological risk (severity-of-ill-effect or *SEV*). Results are summarized in **Table 2** (see **Appendix 2** for details). In general, turbidity risks were low in these two creeks. For example, during 2004 in Crabapple Creek, 52 of 69 events were considered to have no effects, while 14 were considered minor, and only 3 to be moderate (none severe). In ROGD, 31 of 62 events were rated as having no effect, 19 rated as minor, and 12 as moderate.

Table 2. Summary of *SEV* ratings for turbidity events in Crabapple Creek and ROGD.

Creek	Period	Events	*SEV* Rating			
			Nil	Minor	Moderate	Severe
Crabapple Creek	2003 (Nov. & Dec.)	10	6	4	0	0
	2004 (Jan. to Oct.)	69	52	14	3	0
River of Golden Dreams	2003 (Nov. & Dec.)	11	1	9	1	0
	2004 (Jan. to Oct.)	62	31	19	12	0

As mentioned above, insufficient data is currently available to quantitatively set historically based reference values which may be used to form magnitude-duration based, site-specific water quality objectives for turbidity. However, if future turbidity data show substantial departures from the overall pattern of ecological impacts in the foregoing tables, this should serve as cause for concern about the state of the watershed.

Chloride (from road salt)

Increased dissolved chloride loads arising from road salting can have substantial ecological impacts, and road salts that contain inorganic chloride salts, with or without ferrocyanide salts, have been legally classified as toxic substances in Canada (Environment Canada, 2001). Federal guidelines for chloride concentrations in continuously or near-continuously monitored surface waters, and provincial chloride concentration guidelines for protection of freshwater aquatic life, are as follows (Nagpal et al., 2003; Environment Canada, 2003):

Federal guidelines:

- Short-term: 1-hr average chloride concentration cannot exceed 860 mg/L more than once every 3 years on average;
- Long-term: 4-day average chloride concentration, when associated with sodium, cannot exceed 230 mg/L more than once every 3 years on average.

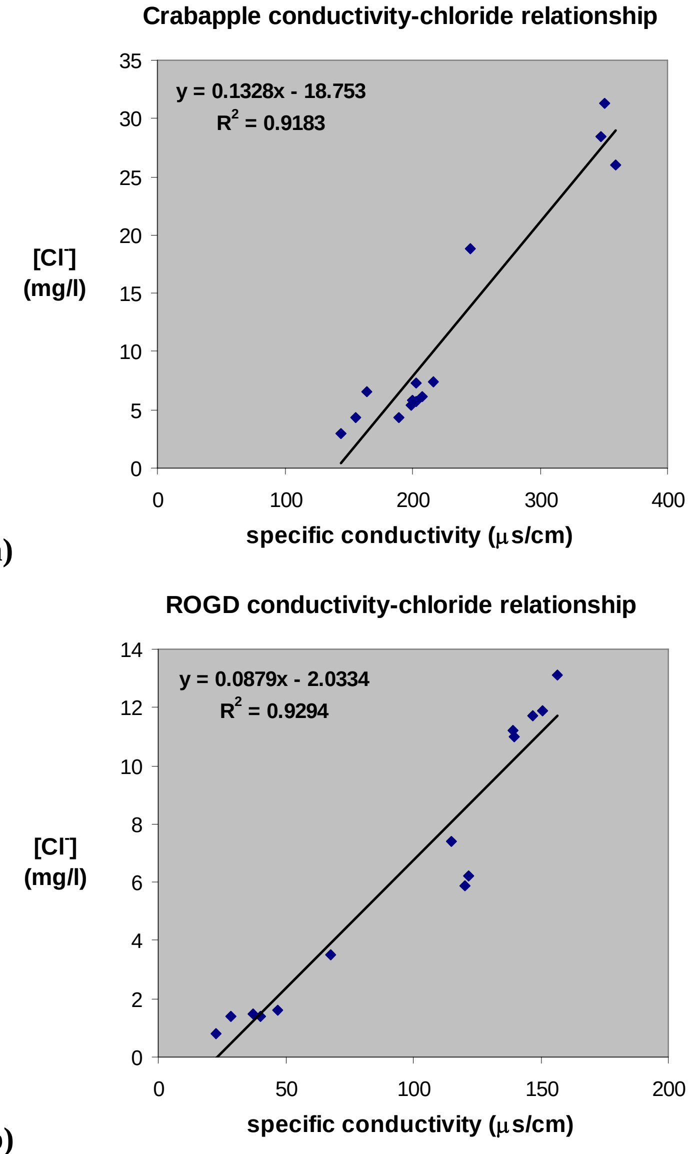
Provincial guidelines:

- Chloride concentration must always be less than 600 mg/L;
- 30-day average chloride concentration must be less than 150 mg/L.

We assessed available data from the River of Golden Dreams and Crabapple Creek for compliance with these guidelines. As discussed earlier, the overall method consisted of developing an empirical relationship between $[Cl^-]$ and specific conductivity, using that relationship to calculate 15-minute $[Cl^-]$ time series, and evaluating those data for compliance. Results of the conductivity-chloride regressions are shown in **Figure 9**. For both rivers, the linear relationship between conductivity and chloride concentration is significant at $P << 0.01$. Nonzero conductivity for zero $[Cl^-]$ may arise from a constant instrument bias, but is also physically reasonable insofar as chloride is not the only ion in solution in a natural water body, and other ions will therefore also contribute to conductivity. To provide a protective assessment, and to ensure that predicted [Cl-] is always nonnegative, we used the estimated upper 95% confidence bounds on the best-fit slope and intercept illustrated in **Figure 9**. The resulting relationships are:

$$[Cl^-] = 0.15766795\ \mathrm{SC} - 12.824042$$ Crabapple Creek

$$[Cl^-] = 0.103733\ \mathrm{SC} - 1.25129$$ ROGD

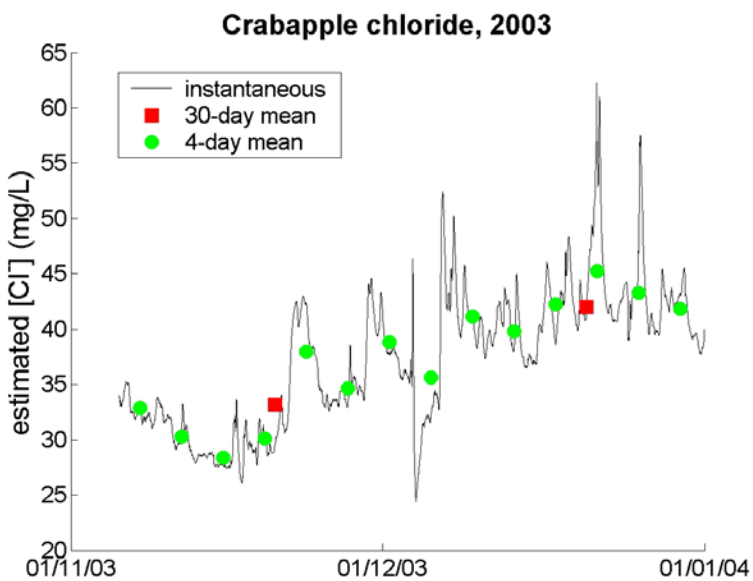


a)

b)

Figure 9. Conductivity-chloride relationships for a) Crabapple Creek, and b) River of Golden Dreams.

Time series of predicted chloride concentrations were generated using the foregoing regressions and specific conductivity data from the automated sampling program. 1-hr, 4-day, and 30-day averages were also calculated for comparison against the federal and provincial guidelines. The results for 2003 and 2004 are shown in **Figures 10** and **11** respectively. The 1-hr mean time series is not shown as it was found to be visually indistinguishable from the 15-minute data. Note that the federal criterion for maximum 1-hr average [Cl^-] is far less restrictive than the provincial criterion for maximum instantaneous [Cl^-] (see above), so little is lost by not incorporating 1-hr average predicted [Cl^-].



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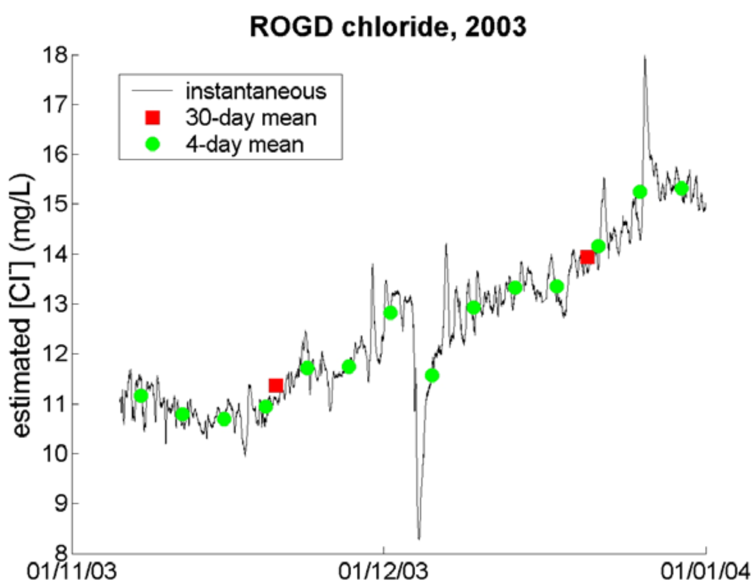
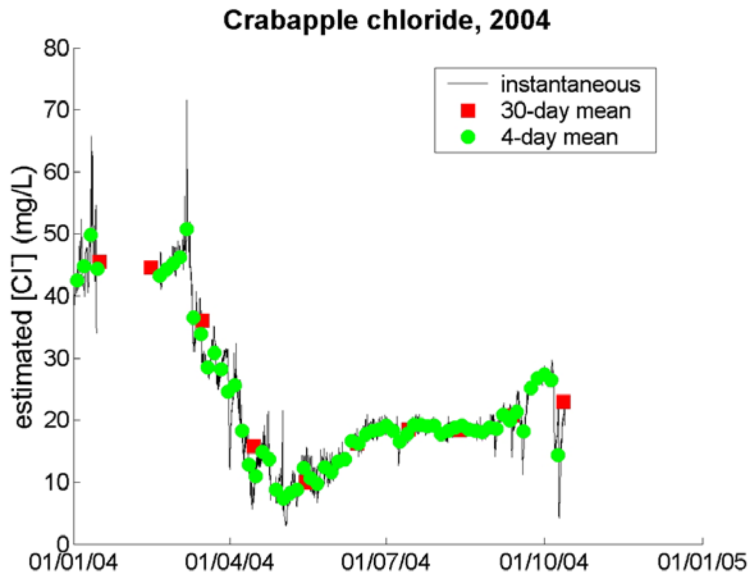


b)

Figure 10. Predicted chloride concentrations during November and December 2003, calculated using specific continuous conductivity data and a statistical model for SC-[Cl^-] relationships, for a) Crabapple Creek and b) River of Golden Dreams. Instantaneous, 30-day mean, and 4-day estimated mean values are provided.



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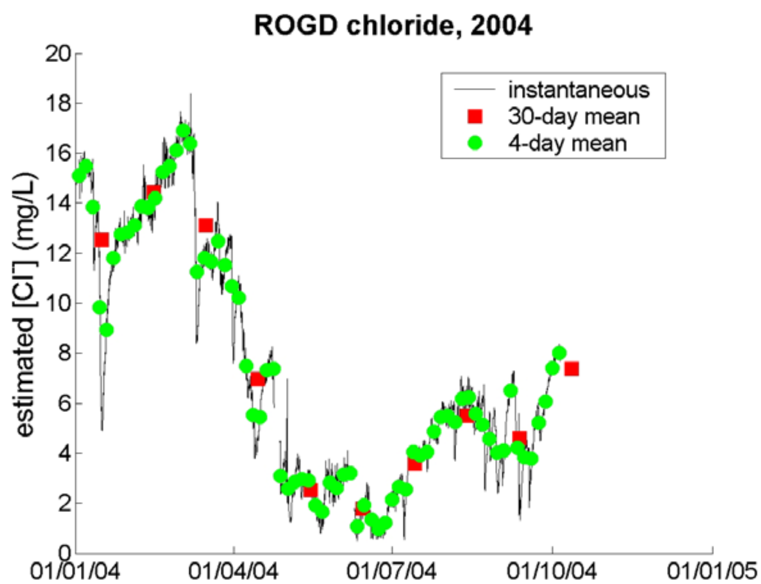

b)

Figure 11. Predicted chloride concentrations during January to October 2004, calculated using continuous specific conductivity data and a statistical model for SC-[Cl^-] relationships, for a) Crabapple Creek and b) River of Golden Dreams. Instantaneous, 30-day mean, and 4-day estimated mean values are provided.

Predicted chloride concentrations were well below (at most 1/3) provincial and federal guidelines, at all sampling intervals. However, it should be emphasized that only a single winter of data was available, and the predicted [Cl^-] time series clearly show increases during the winter months, which seem likely to arise (at least in part) from road salting. Ongoing monitoring and assessment is therefore required, with an emphasis upon maintaining fully continuous measurements; winter data gaps (e.g., Crabapple Creek in early 2004) are particularly undesirable. It is also important to maintain the grab sample program, and to refine the site-specific, empirical SC-[Cl^-] relationships as more data thus become available.

Present regulatory guidelines do not explicitly incorporate the impacts of both magnitude and duration of exposure. Given that estimated chloride concentrations in Crabapple Creek appear to remain elevated for the entire duration of the winter, it may therefore be appropriate to assess the ecological effects of both magnitude and duration of chloride exposures. The LC50 data published by Environment Canada (2001) would facilitate such an analysis. Such an explicit toxicological risk assessment might also help to set site-specific, risk-based water quality objectives for chloride.

Dissolved Oxygen

The BC MOE water quality guidelines for dissolved oxygen are minima of 9 mg/L (instantaneous) and 11 mg/L (30-day mean) for buried embryo and alevin life stages. Dissolved oxygen concentrations dropped below these levels in both Crabapple Creek and the River of Golden Dreams in summer 2004, due in a large part to the relatively warm temperatures that year and the consequent drop in the saturation concentration of oxygen in water. However, the timing of the low oxygen levels is such that a more liberal oxygen criterion likely applies. BC MOE guidelines stipulate an instantaneous minimum of no less than 5 mg/L and a 30-day mean of 8 mg/L for all life stages other than buried embryo and alevin. Given the life cycles of resident fish in these rivers, this criterion seems more appropriate. It does not appear to be violated during 2004. However, continued monitoring and analysis is necessary.

pH

The Canadian Council of Ministers of the Environment (CCME) water quality guideline for pH is 6.5 to 9.0. All observations lie within this range.

Stream Depth

Stream depth, although indicative of hydrological conditions, is more useful when converted to discharge (flow). Unfortunately, a stage-discharge relation has not been established for either ROGD or Crabapple Creek, and therefore depth cannot be converted to flow at this time. River flow can be dramatically affected by land use changes and is of prime ecological and engineering importance. It would be prudent to monitor and evaluate the hydrologic characteristics and dynamics of these rivers.

3.3 Grab Samples

A certified laboratory analyzed each grab sample for 86 water quality parameters. A summary of results for regulated parameters (i.e., having either provincial or federal guidelines) is provided in **Appendix 3**. Guidelines for protection of freshwater aquatic life were used, with the exception of bacteriological indicators, for which we use the recreational – primary contact guideline.

Suspended solids, turbidity, and pH

Grab sample pH, total suspended solids (TSS), turbidity, and chloride levels appear to be generally well within their regulatory limits. However, based on the near-continuous pH and turbidity data, it is clear that the grab sample program missed transient events. Consequently, the turbidity risk assessment based upon continuous monitoring data should provide a more appropriate evaluation of suspended sediment effects in the study rivers. Similarly, it is likely that some high chloride events may be missed by the grab sample program, and the assessment based upon continuous specific conductivity monitoring is likely more appropriate. Nevertheless, it is important to continue obtaining turbidity and chloride grab samples in order to field check the near-continuous data and, in particular, to progressively increase the quality of the SC-[Cl^-] regression relationship used for evaluating road salting impacts.

Sulfate

Less than a full year of sulfate data are currently available, as this parameter was not monitored in any of the creeks during 2003. Observed levels are generally low and well within regulatory limits, with the exception of Crabapple Creek in early 2004. Six of the 16 samples showed sulfate concentrations greater than 50 mg/L, which is stipulated by BC MOE as an alert level to trigger monitoring of aquatic moss populations on an occasional basis. All exceedances occurred over the period January – March 2004, but values remained comparatively high during the remainder of the year relative to the other three creeks. The highest observed value was 93.8 mg/L in February 2004, just short of the 100 mg/L limit specified by MOE as the maximum permissible value for protection of freshwater aquatic life. It is possible that the low-frequency grab sample program did not sample the highest sulfate concentrations present in Crabapple Creek in 2004. All the creeks showed a similar seasonal cycle in sulfate concentration, peaking at the end of the winter baseflow period, which may be typical of this water quality parameter (Singleton, 2000). The origin of these elevated sulfate concentrations are unclear, and could conceivably arise from the natural geologic characteristics of the catchment. Further study of sulfate levels in these watersheds, and particularly in Crabapple Creek, is required.

Nitrogen

Observed values of the various nitrogen metrics (ammonia N, nitrate N – dissolved, nitrite N) are all well within the regulatory criteria. However, it is possible that higher nitrogen levels went unobserved due to the relatively low frequency of the grab sample program. For example, comparatively short-lived nitrogen exceedances in these creeks could conceivably occur due to rainfall-driven releases from septic fields or leaking tanks.

Metals

Assessment of the metals concentration data is more ambiguous due to variable guidelines, and method detection limits that were in several cases greater than the guidelines. However, exceedances clearly occurred for copper, iron, and zinc. Where exceedances occurred, there was no obvious seasonal pattern, although there appears to be a weak tendency for higher values during the late fall to early spring baseflow period. Crabapple Creek metals exceedances in 2003-2004 were for copper (9 of 28 samples by CCME guideline, 2 of 28 samples by MOE guideline), iron (10 of 28 samples by CCME guideline, no MOE guideline exists), and zinc (8 of 28 samples by CCME guideline, 5 of 28 samples by MOE guideline). River of Golden Dreams metals exceedances in 2003-2004 were for iron (17 of 30 samples by CCME guideline, no MOE guideline exists). Whistler Creek exceedances in 2003-2004 were also for iron (2 of 28 samples by CCME guideline, no MOE guideline exists). Note that observed iron, copper, and zinc values were occasionally sufficiently high to unambiguously determine that exceedances occur, but the precise number of exceedances is less clear due to detection limit issues for zinc and copper, in combination with hardness-dependent (i.e., variable) guidelines. Note also that detection limit problems were particularly severe for lead here, which had detection limits consistently higher than the guidelines.

Given the available data, it is not possible to clearly determine whether all, none, or some of the catchments have total lead concentrations exceeding guidelines. However, if lead exceedances do occur, they are probably relatively moderate. Further work is required to compare the observed values to watershed-specific geologic characteristics and potential anthropogenic metals sources. More sensitive laboratory techniques are also key for assessing a broader range of metals for compliance with provincial and federal water quality guidelines.

Bacterial indicators

Escherichia coli and fecal coliforms levels were often elevated, ranging from below detection to 330 col/100 mL and 380 col/100mL respectively. The grab sampling frequency was insufficient to evaluate *E. coli* and fecal coliforms observations against guidelines - at least 5 samples must be taken in a 30-day period. The MOE bacteriological guidelines for primary-contact recreation in freshwater are a geometric mean fecal coliforms level of 200/100 mL, and a geometric mean *Escherichia coli* level of 77/100 mL. Examination of the raw grab sample data suggests that the values of bacteriological indicators can change quickly, and higher temporal resolution is required for adequate environmental monitoring. This is particularly (but not exclusively) true during late summer and in Crabapple Creek, where high values have been observed, likely in violation of the regulatory limit.

4. Conclusions

- <u>Validation and Correction of Near-continuous Data</u> - Overall, the raw temperature, stage, and conductivity data were of relatively good quality. Unprocessed dissolved oxygen (DO) and pH data exhibited more gaps, outliers, and sensor drift, often in association with sensor calibration and maintenance. Raw turbidity readings were noisy, which is typical of data from these types of sensors. All signals were validated and corrected using **AQUARIUS™**, a software package designed specifically for the task. The corrected/validated signals are approved by AI Inc. for further analysis, and were used in all subsequent work summarized in this report.

- <u>Risks from Summer Stream Temperatures</u> - Over the past 10 years, estimated total growth risk to rainbow trout and Kokanee from high summer temperatures has been low in River of Golden Dreams, Crabapple Creek, and Whistler Creek. Reference Total Growth Risks (TGR_{ref}) were based on the warmest years, and corresponded to 3.9% (Crabapple Creek), 0.57% (Whistler Creek), and 3.8% (ROGD). These TGR_{ref} values were used to define a Risk Quotient, $RQ = 1$. This work sets in place a mechanism for assessing the impacts of any future watershed activities upon chronic temperature risks in Crabapple and Whistler Creeks and the River of Golden Dreams. In effect, $RQ = 1$, determined independently for each river, constitutes the site-specific water quality objective. Any future annual $RQ > 1$ would indicate an increase in chronic salmonid growth risk beyond acceptable levels due to elevated water temperatures.

- <u>Risks from Turbidity</u> - Near-continuous turbidity data collected by the stations at Crabapple Creek and ROGD were assessed for ecological risk (severity-of-ill-effect or *SEV*). In general, turbidity risks were low in both creeks, with the majority of events having Nil or Minor SEV ratings.

- Impacts from Road Salting – Near-continuous chloride concentrations in ROGD and Crabapple Creek were modeled from the relationship between near-continuous specific conductivity and intermittent grab samples for chloride. Peak chloride concentrations were estimated to be less than 1/3 of provincial and federal guidelines. This suggests that road salting during the winter of 2003/04 did not have a significant impact on the ecology of these streams.

- Bacterial Indicators – Fecal coliforms and *E. coli* were elevated in all three streams, particularly in Crabapple Creek. However, bacterial levels could not be compared to guidelines due to the frequency of sampling. It is likely that levels in Crabapple Creek have exceeded regulatory guidelines for recreation – primary contact.

- Metals and Sulfate – Iron exceeded guidelines in all three streams; copper and zinc also exceeded guidelines in Crabapple Creek. Although these metals are often associated with urbanization, they could also be natural. More sampling is necessary to discern the sources. Detection limits were such that not all metals could be compared against guidelines. Sulfate exceeded the guideline in Crabapple Creek. The source is unclear.

5. Recommendations

Sampling Program:

(i) Continue all present monitoring activities;
(ii) Try to prevent downtime in the automated water quality sampling systems;
(iii) Collect 5 grab samples in 30-days, every season for bacteriological indicators, and monthly for other parameters;
(iv) Request low detection limits for metals (particularly lead) analyses;

Future Analysis:

(v) Improve the site-specific regressions between automated specific conductivity measurements and grab sample-determined chloride concentrations as more data become available.
(vi) Develop an exposure-based (i.e., magnitude-duration based) risk assessment for the effects of chloride upon salmonids in ROGD and Crabapple Creek. These results could be used to develop site-specific water quality objectives for chloride;
(vii) Continue to evaluate turbidity risk using magnitude-duration based assessment. Develop site specific objectives for turbidity when enough data has been collected to set historically based reference values;

(viii) Determine source of elevated sulfate and metals concentrations by investigating catchment geologic characteristics and potential watershed contamination sources;

(ix) Develop stage-discharge relationships, and comprehensive empirical hydrologic characterizations, for ROGD and Crabapple Creek;

Water Quality Objectives:

(x) The following site-specific *Water Quality Objectives* are recommended for River of Golden Dreams, Crabapple Creek, and Whistler Creek, and are based on the data collected and analyses performed to date. For all other parameters, apply general BC MOE and CCME guidelines until further work, as detailed above, yields site-specific objectives.

Parameter	**Interim water quality objective and data source**
Temperature, ACUTE RISK	If instantaneous temperatures from automated monitoring program are observed to exceed 24°C, perform magnitude-duration based assessment for acute thermal risk (all creeks).
Temperature, CHRONIC RISK	*RQ* must be ≤ 1, as found using site-specific TGR_{ref} values determined in this report and continuous temperature data from automated monitoring program (all creeks).
Chloride	Instantaneous Chloride concentration < 600 mg/L; 30-day average chloride concentration < 150 mg/L. Chloride concentrations are calculated from continuous specific conductivity data via regression relationships (ROGD, Crabapple).

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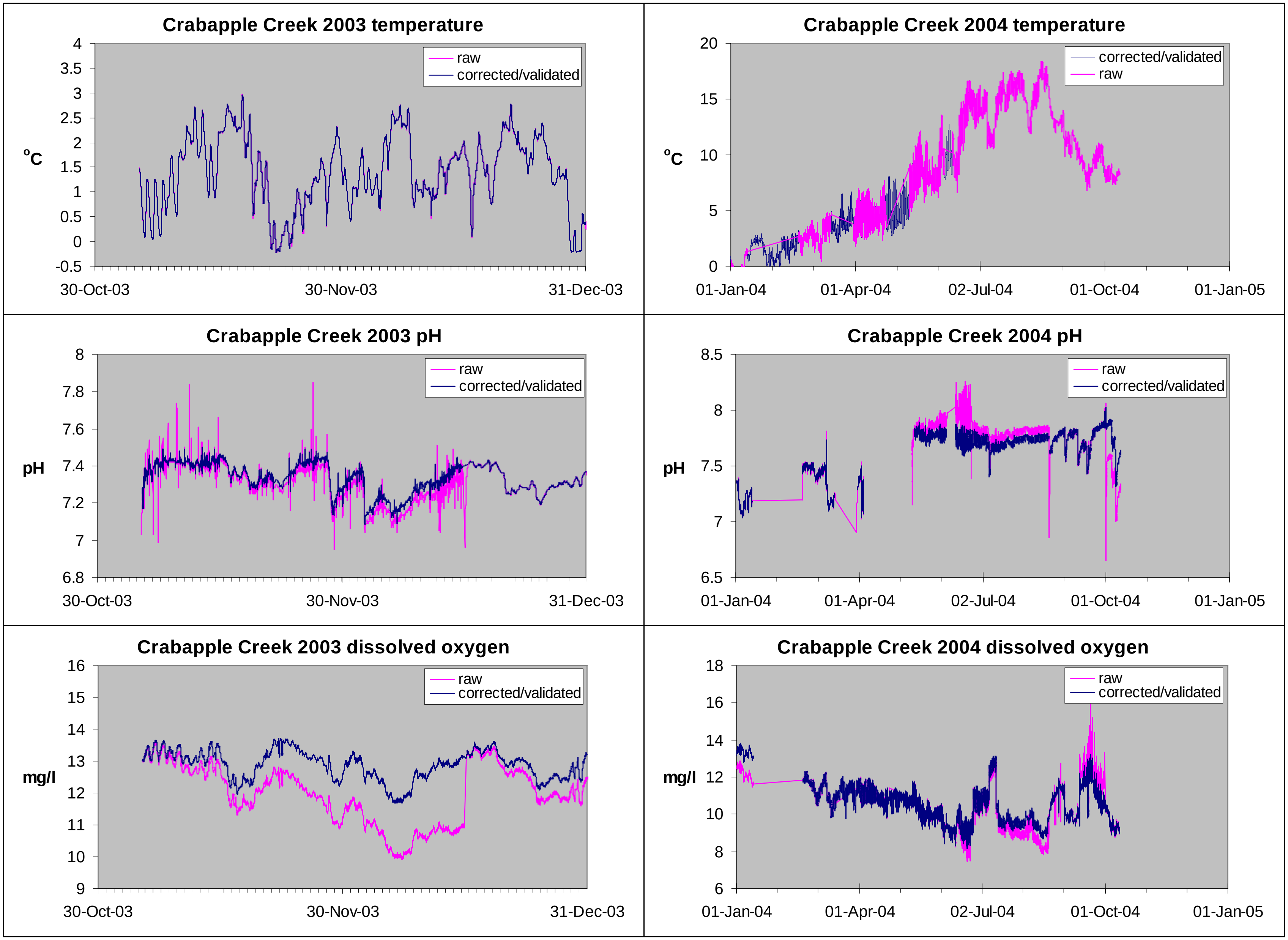
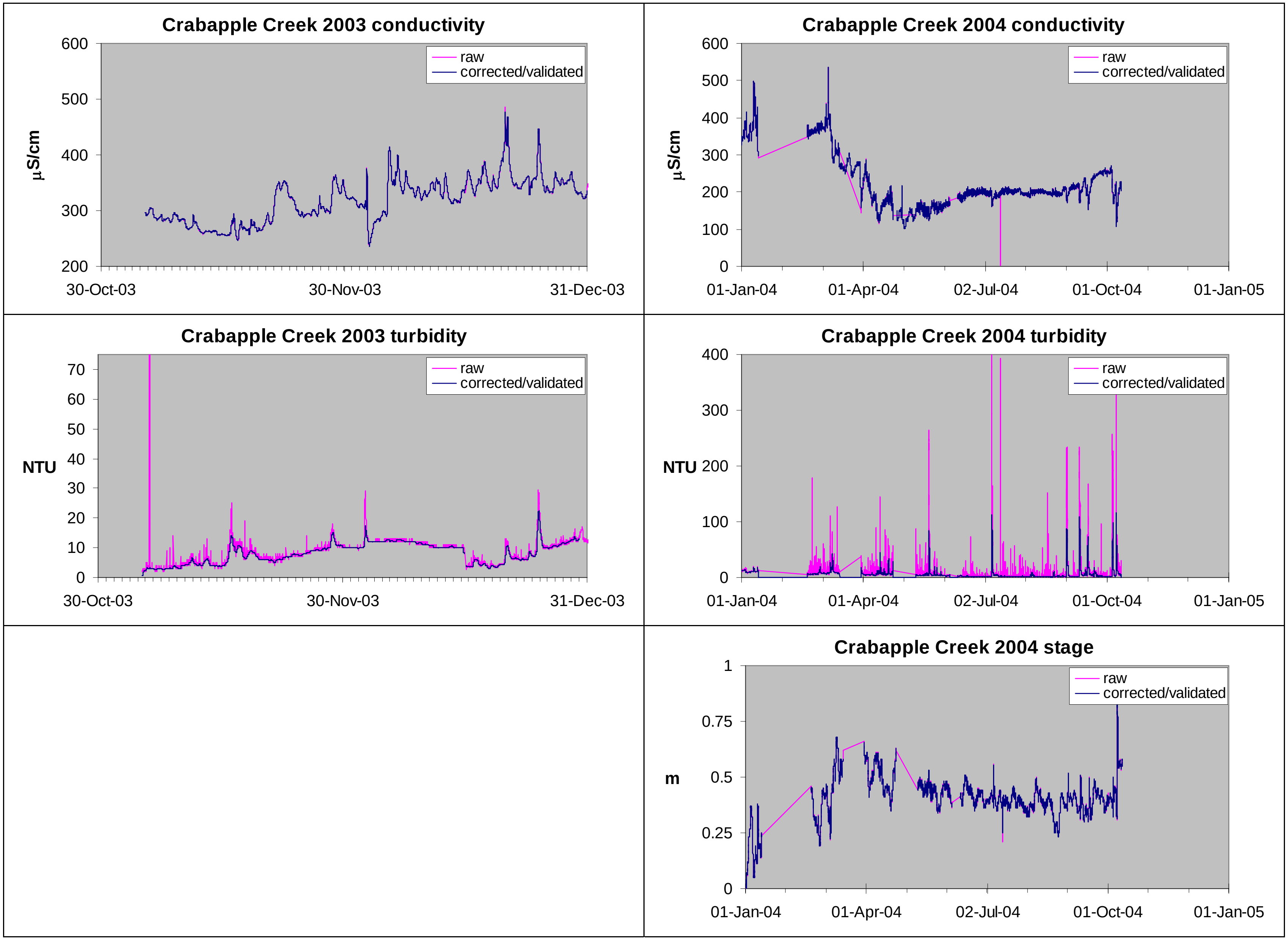
Appendix 1. Data Validation and Correction Summary





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µS/cm
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500
400
300
200
30-Oct-03
30-Nov-03
31-Dec-03
raw
corrected/validated
Crabapple Creek 2004 conductivity
µS/cm
600
500
400
300
200
100
0
01-Jan-04
01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05
raw
corrected/validated
Crabapple Creek 2003 turbidity
NTU
70
60
50
40
30
20
10
0
30-Oct-03
30-Nov-03
31-Dec-03
raw
corrected/validated
Crabapple Creek 2004 turbidity
NTU
400
300
200
100
0
01-Jan-04
01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05
raw
corrected/validated
Crabapple Creek 2004 stage
m
1
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0
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01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05
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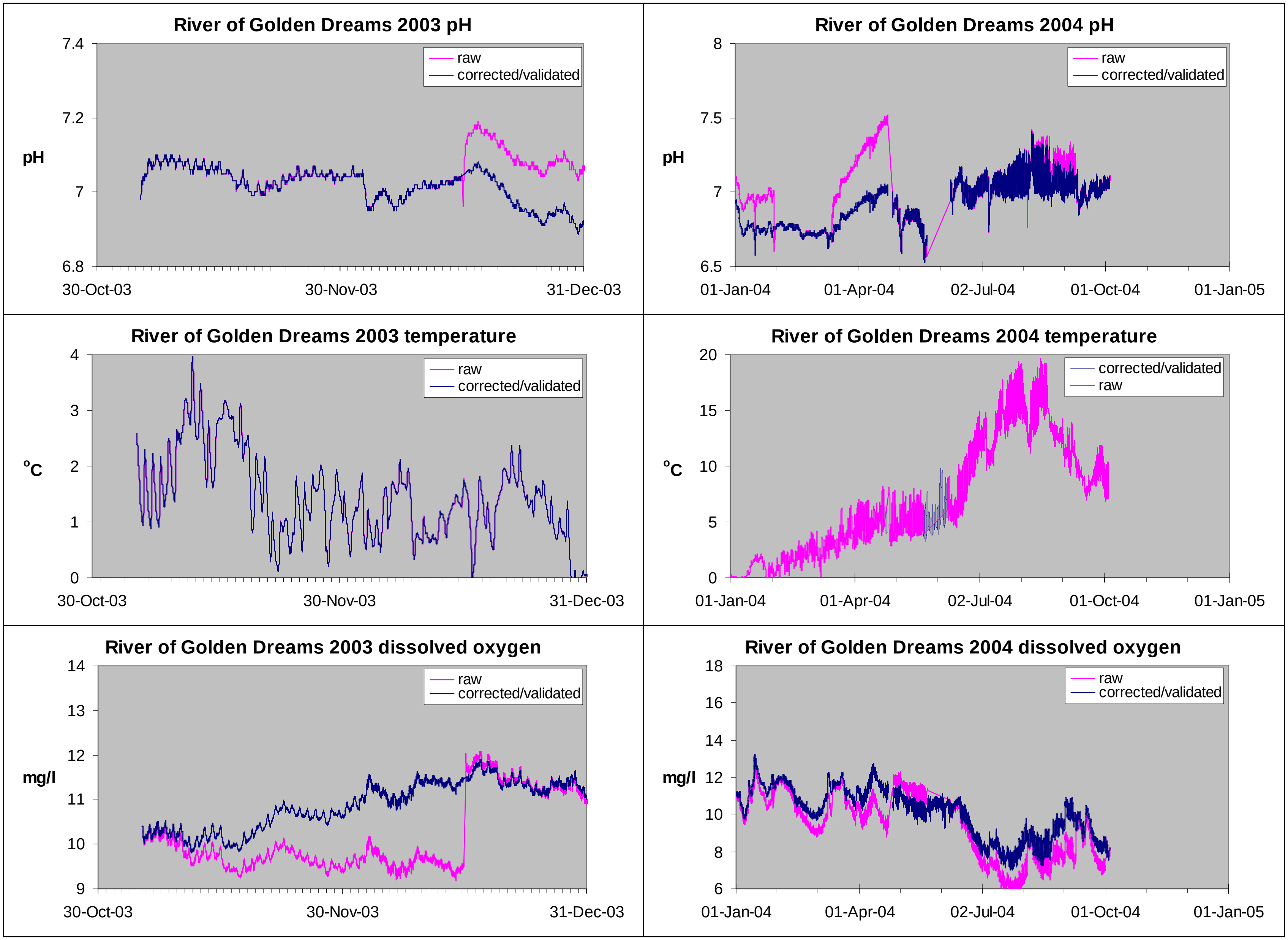
corrected/validated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corrected/validated
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pH
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7.5
7
6.5
01-Jan-04
01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05
raw
corrected/validated
River of Golden Dreams 2003 temperature
°C
4
3
2
1
0
30-Oct-03
30-Nov-03
31-Dec-03
raw
corrected/validated
River of Golden Dreams 2004 temperature
°C
20
15
10
5
0
01-Jan-04
01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05
corrected/validated
raw
River of Golden Dreams 2003 dissolved oxygen
mg/l
14
13
12
11
10
9
30-Oct-03
30-Nov-03
31-Dec-03
raw
corrected/validated
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mg/l
18
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8
6
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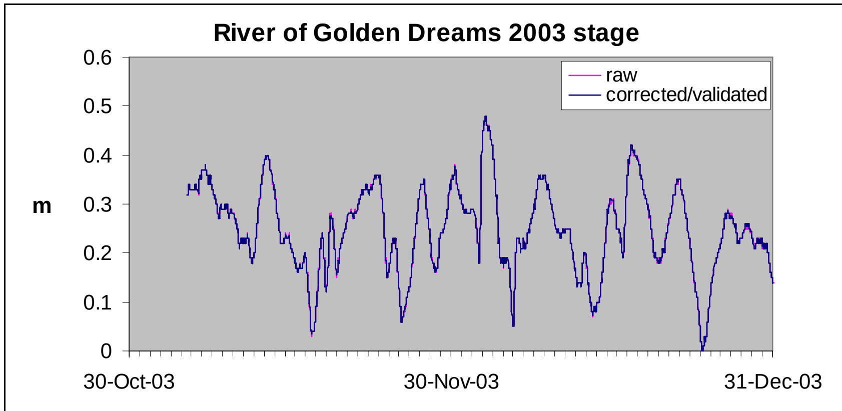
corrected/validated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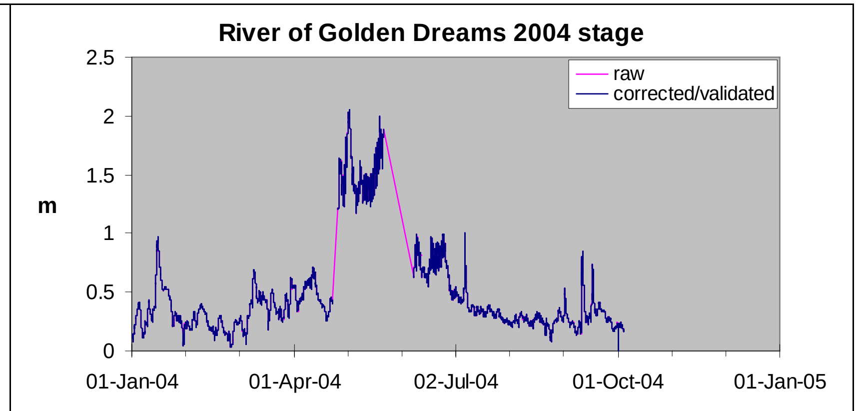
corrected/validated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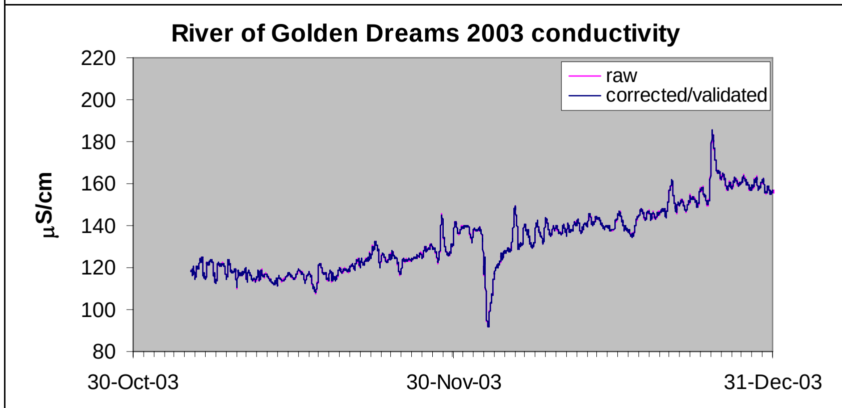
01-Jan-05
raw
corrected/validated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180
160
140
120
100
80
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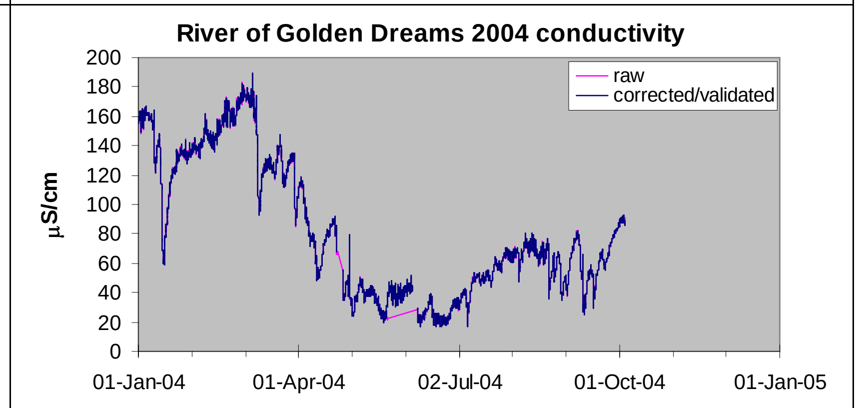
30-Nov-03
31-Dec-03
raw
corrected/validated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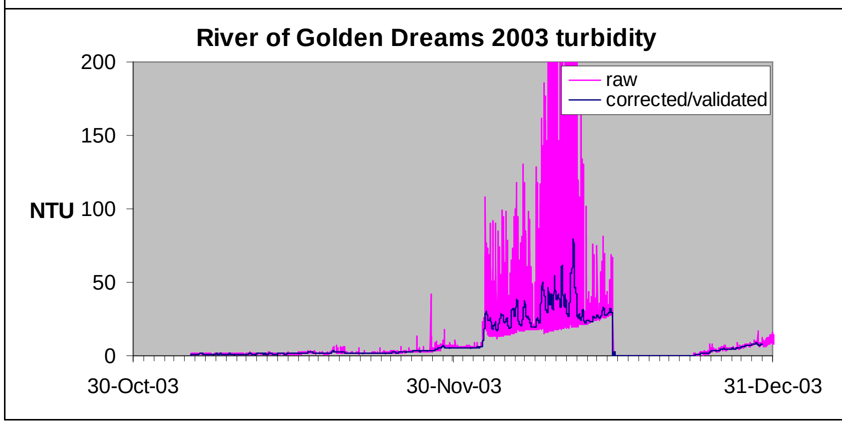
corrected/validated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NTU
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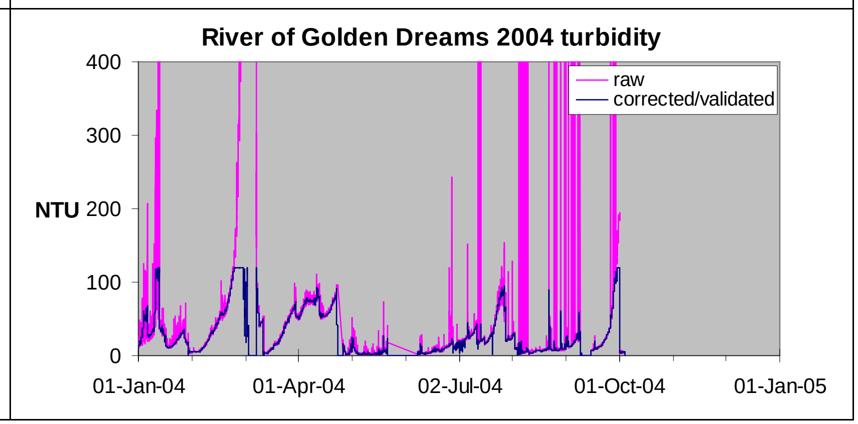
raw
corrected/validated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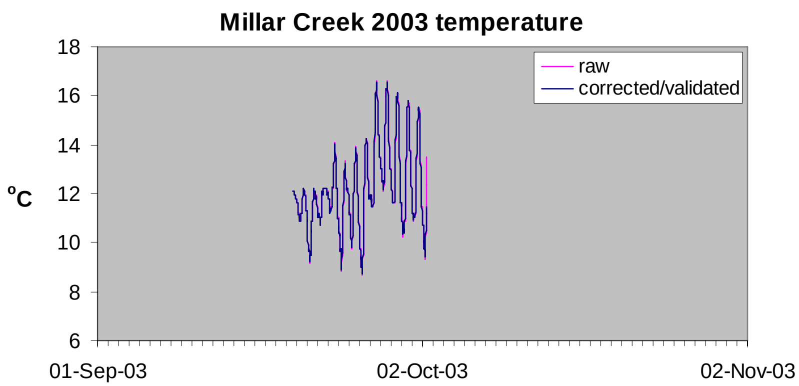
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°C
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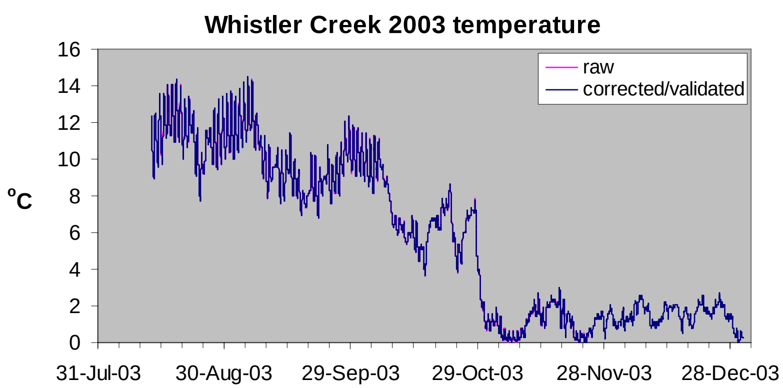
02-Nov-03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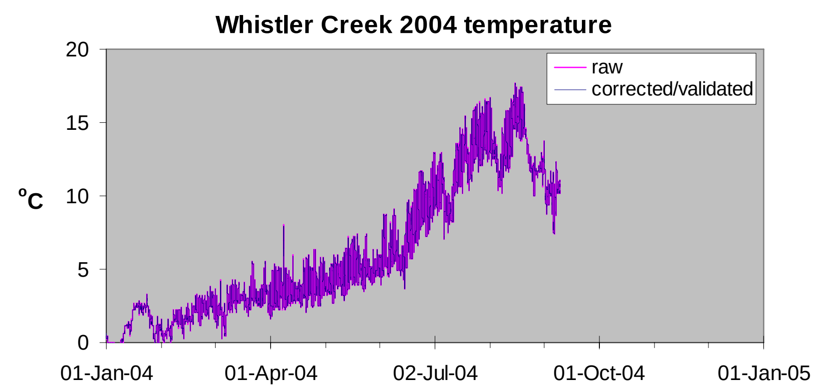
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10
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0
°C
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corrected/validated
01-Jan-04
01-Apr-04
02-Jul-04
01-Oct-04
01-Jan-05

Appendix 2. Summary of Turbidity Event Ratings

Crabapple Turbidity Events and Ecological Impacts, 2003

NTU	Duration (hr)	*SEV*	Rating	*NTU*	Duration (hr)	*SEV*	Rating
3	21	0	Nil	7	4	0	Nil
3	7	0	Nil	11	18	0.6	Minor
5	11	0	Nil	11	195	2.8	Minor
5	16	0	Nil	5	14	0	Nil
5	143	0.9	Minor	9	116	1.9	Minor

Crabapple Turbidity Events and Ecological Impacts, 2004

NTU	Duration (hr)	*SEV*	Rating	*NTU*	Duration (hr)	*SEV*	Rating
10	86	1.9	Minor	4	10	0	Nil
10	5	0	Nil	4	13	0	Nil
10	10	0	Nil	4	3	0	Nil
10	80	1.8	Minor	4	65	0	Nil
10	44	1.3	Minor	67	3	2.7	Minor
7	3	0	Nil	4	9	0	Nil
7	3	0	Nil	13	5	0	Nil
7	8	0	Nil	10	6	0	Nil
7	11	0	Nil	4	3	0	Nil
7	8	0	Nil	4	7	0	Nil
7	9	0	Nil	7	7	0	Nil
7	63	0.8	Minor	4	3	0	Nil
7	21	0	Nil	4	2	0	Nil
7	38	0.4	Nil	4	0.002	0	Nil
7	4	0	Nil	88	4	3.5	Moderate
7	23	0	Nil	4	14	0	Nil
16	10	0.9	Minor	4	5	0	Nil
28	7	1.8	Minor	4	37	0	Nil
13	11	0.5	Minor	7	6	0	Nil
7	7	0	Nil	1	141	0	Nil
7	10	0	Nil	61	11	3.7	Moderate
10	8	0	Nil	85	4	3.5	Minor
34	3	1.2	Minor	4	12	0	Nil
13	4	0	Nil	10	9	0	Nil
7	11	0	Nil	55	6	3.0	Minor
13	3	0	Nil	4	7	0	Nil
7	9	0	Nil	4	6	0	Nil
7	2	0	Nil	7	28	0.1	Nil
28	6	1.6	Minor	4	5	0	Nil
7	0.7	0	Nil	4	3	0	Nil
10	4	0	Nil	4	0.05	0	Nil
25	6	1.3	Minor	82	3	3.2	Minor
4	17	0	Nil	94	5	3.9	Moderate
4	9	0	Nil	4	1	0	Nil
4	13	0	Nil				

River of Golden Dreams Turbidity Events and Ecological Impacts, 2003

NTU	Duration (hr)	*SEV*	Rating	*NTU*	Duration (hr)	*SEV*	Rating
22	14	1.9	Minor	25	93	3.9	Moderate
19	7	0.9	Minor	25	6	1.3	Minor
22	21	2.2	Minor	28	8	1.9	Minor
25	17	2.3	Minor	31	3	1.0	Minor
25	17	2.3	Minor	4	84	0	Nil
25	3	0.6	Minor				

River of Golden Dreams Turbidity Events and Ecological Impacts, 2004

NTU	Duration (hr)	*SEV*	Rating	*NTU*	Duration (hr)	*SEV*	Rating
16	11	0.93	Minor	4	0.4	0	Nil
100	55	6.2	Moderate	4	2	0	Nil
25	77	3.7	Moderate	4	9	0	Nil
31	17	2.7	Minor	10	118	2.2	Minor
118	138	7.4	Moderate	7	85	1.1	Minor
94	17	5.0	Moderate	13	22	1.2	Minor
40	100	4.9	Moderate	22	163	4.1	Moderate
10	0.8	0	Nil	16	199	3.6	Moderate
16	2	0	Nil	76	75	5.9	Moderate
31	3	1.1	Minor	16	2	0	Nil
43	13	3.2	Minor	4	4	0	Nil
49	5	2.6	Minor	16	1	0	Nil
52	104	5.5	Moderate	7	2	0	Nil
52	11	3.4	Minor	4	3	0	Nil
67	218	6.7	Moderate	4	66	0	Nil
55	4	2.7	Minor	7	1	0	Nil
55	6	2.9	Minor	7	3	0	Nil
55	6	3.0	Minor	7	18	0	Nil
55	155	6.0	Moderate	70	3	2.8	Minor
7	22	0	Mil	7	3	0	Nil
22	13	1.7	Minor	7	0.7	0	Nil
4	12	0	Nil	7	40	0.4	Nil
4	8	0	Nil	46	2	1.4	Minor
4	5	0	Nil	10	13	0.2	Nil
4	0.4	0	Nil	13	23	1.2	Minor
7	5	0	Nil	13	4	0	Nil
4	9	0	Nil	16	0.2	0	Nil
4	11	0	Nil	22	33	2.6	Minor
19	4	0.5	Nil	49	3	2.2	Minor
4	6	0	Nil	10	27	0.8	Minor
10	11	0	Nil	97	67	6.4	Moderate

Appendix 3. Grab Sampling Summaries

Note: An asterisk (*) indicates a variable MOE guideline; in this case, the lowest (most protective) guideline for instantaneous measurements is given here. An *italicized* criterion indicates a more complex guideline, subsequently discussed further in the body of the report. Only those parameters for which a federal or provincial guideline exists are listed, with the exception of total hardness due to its role in calculating some BC MOE metals guidelines, denoted *variable* below.

Crabapple Creek, 2003.

	unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	12	8.0	7.4	7.7	0.24
TSS	mg/L	4	25*	-	12	6	2	2.5	1.2
Total Hardness	mg/L	calc	-	-	12	134	18.8	79.7	35.2
Turbidity	NTU	0.10	8*	-	12	3.5	0.5	1.4	0.8
Chloride, Dissolved	mg/L	0.5	600*	-	12	12.1	0.70	4.6	3.2
Total Organic Carbon	mg/L	0.5	*±20%median*	-	12	3.0	0.8	1.8	0.7
Ammonia N	mg/L	0.005	0.681*	-	12	0.36	0.0025	0.039	0.10
Nitrate N Dissolved	mg/L	calc	-	13	12	0.43	0.01	0.10	0.12
Nitrite N	mg/L	0.002	0.06*	0.06	12	0.008	0.001	0.003	0.002
Sulfate	mg/L	0.5	50*	-	0	-	-	-	-
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	0	-	-	-	-
Arsenic, Total	mg/L	0.05	0.005	0.005	12	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	12	<MDL	<MDL	<MDL	<MDL
Cadmium, Total	mg/L	0.002	-	0.000017	12	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	12	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	12	0.008	0.0025	0.0035	0.0019
Iron, Total	mg/L	0.005	-	0.3	12	1.93	0.13	0.40	0.49
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	12	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	12	0.313	0.018	0.091	0.090
Molybdenum, Total	mg/L	0.005	2	0.073	12	<MDL	<MDL	<MDL	<MDL
Nickel, Total	mg/L	0.008	-	0.025-0.15	12	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	12	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	12	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	12	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	variable	0.030	12	0.062	0.0025	0.014	0.018
E. coli	col/100mL	1	*geometric mean = 77*	-	11	330	0.5	35.5	97.8
Fecal Coliforms	col/100Ml	1	*geometric mean = 200*	-	11	380	0.5	49.8	112

Crabapple Creek, 2004.

	Unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	16	8.1	6.8	7.8	0.3
TSS	mg/L	4	25*	-	16	10.0	2.0	3.3	2.3
Total Hardness	mg/L	calc	-	-	16	148	67.6	106	26.4
Turbidity	NTU	0.10	8*	-	16	14.5	0.7	3.2	3.5
Chloride, Dissolved	mg/L	0.5	600*	-	16	31.3	3.0	13.1	10.4
Total Organic Carbon	mg/L	0.5	*±20%median*	-	15	2.6	0.7	1.8	0.5
Ammonia N	mg/L	0.005	0.681*	-	16	0.18	0.0025	0.054	0.060
Nitrate N Dissolved	mg/L	calc	-	13	16	0.25	0.02	0.10	0.08
Nitrite N	mg/L	0.002	0.06*	0.06	16	0.01	0.002	0.004	0.002
Sulfate	mg/L	0.5	50*	-	16	94	24	49	24
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	7	0.07	0.02	0.04	0.02
Arsenic, Total	mg/L	0.05	0.005	0.005	16	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	16	0.008	0.004	0.0043	0.001
Cadmium, Total	mg/L	0.002	-	0.000017	16	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	16	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	16	0.024	0.0025	0.0070	0.0066
Iron, Total	mg/L	0.005	-	0.3	16	0.87	0.16	0.34	0.20
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	16	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	16	0.33	0.029	0.14	0.11
Molybdenum, Total	mg/L	0.005	2	0.073	16	<MDL	<MDL	<MDL	<MDL
Nickel, Total	mg/L	0.008	-	0.025-0.15	16	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	16	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	16	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	16	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	*variable*	0.030	16	0.075	0.0025	0.028	0.026
E. coli	col/100mL	1	*geometric mean = 77*	-	13	110	0.5	22.6	35.2
Fecal Coliforms	col/100mL	1	*geometric mean = 200*	-	13	120	1.0	24.5	37.7

River of Golden Dreams, 2003.

	unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	14	4.6	6.8	7.3	0.2
TSS	mg/L	4	25*	-	14	<MDL	<MDL	<MDL	<MDL
Total Hardness	mg/L	calc	-	-	14	50.3	10.5	32.8	13.5
Turbidity	NTU	0.10	8*	-	14	3	0.5	1.3	0.7
Chloride, Dissolved	mg/L	0.5	600*	-	14	8.1	0.6	3.3	2.4
Total Organic Carbon	mg/L	0.5	*±20%median*	-	14	2.5	0.25	1.4	0.71
Ammonia N	mg/L	0.005	0.681*	-	14	0.063	0.0025	0.016	0.017
Nitrate N Dissolved	mg/L	calc	-	13	14	0.08	0.01	0.03	0.02
Nitrite N	mg/L	0.002	0.06*	0.06	14	0.006	0.001	0.002	0.002
Sulfate	mg/L	0.5	50*	-	0	-	-	-	-
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	0	-	-	-	-
Arsenic, Total	mg/L	0.05	0.005	0.005	14	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	14	<MDL	<MDL	<MDL	<MDL
Cadmium, Total	mg/L	0.002	-	0.000017	14	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	14	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	14	<MDL	<MDL	<MDL	<MDL
Iron, Total	mg/L	0.005	-	0.3	14	3.8	0.06	0.65	0.96
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	14	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	14	0.27	0.005	0.056	0.066
Molybdenum, Total	mg/L	0.005	2	0.073	14	<MDL	<MDL	<MDL	<MDL
Nickel, Total	mg/L	0.008	-	0.025-0.15	14	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	14	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	14	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	14	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	*variable*	0.030	14	0.027	0.0025	0.0060	0.0068
E. coli	col/100mL	1	*geometric mean = 77*	-	12	59	0.5	14.8	19.1
Fecal Coliforms	col/100mL	1	*geometric mean = 200*	-	12	67	0.5	25.6	27.6

River of Golden Dreams, 2004.

	unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	16	7.6	7.0	7.4	0.2
TSS	mg/L	4	25*	-	16	21.0	2.0	3.2	4.8
Total Hardness	mg/L	calc	-	-	16	58.3	10.8	32.4	16.9
Turbidity	NTU	0.10	8*	-	16	4.1	0.7	1.7	1.0
Chloride, Dissolved	mg/L	0.5	600*	-	16	13.1	0.7	5.2	4.9
Total Organic Carbon	mg/L	0.5	*±20%median*	-	16	3.2	0.25	1.4	0.71
Ammonia N	mg/L	0.005	0.681*	-	16	0.067	0.0025	0.023	0.023
Nitrate N Dissolved	mg/L	calc	-	13	16	0.08	0.005	0.032	0.021
Nitrite N	mg/L	0.002	0.06*	0.06	16	0.006	0.001	0.003	0.002
Sulfate	mg/L	0.5	50*	-	15	25.1	3.4	13.6	8.2
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	7	0.04	0.01	0.02	0.01
Arsenic, Total	mg/L	0.05	0.005	0.005	16	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	16	<MDL	<MDL	<MDL	<MDL
Cadmium, Total	mg/L	0.002	-	0.000017	16	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	16	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	16	<MDL	<MDL	<MDL	<MDL
Iron, Total	mg/L	0.005	-	0.3	16	1.25	0.082	0.37	0.29
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	16	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	16	1.23	0.22	0.63	0.37
Molybdenum, Total	mg/L	0.005	2	0.073	16	0.005	0.0025	0.0027	0.0006
Nickel, Total	mg/L	0.008	-	0.025-0.15	16	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	16	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	16	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	16	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	*variable*	0.030	16	0.010	0.0025	0.0046	0.0030
E. coli	col/100mL	1	*geometric mean = 77*	-	13	36	0.5	5.8	9.6
Fecal Coliforms	col/100mL	1	*geometric mean = 200*	-	13	50	0.5	8.7	12.9

Whistler Creek, 2003.

	unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	12	7.7	7.0	7.5	0.2
TSS	mg/L	4	25*	-	12	37	2	6.3	10.3
Total Hardness	mg/L	calc	-	-	12	40.3	16.6	30.3	7.3
Turbidity	NTU	0.10	8*	-	12	5.3	0.2	1.1	1.4
Chloride, Dissolved	mg/L	0.5	600*	-	12	5.0	0.5	2.1	1.4
Total Organic Carbon	mg/L	0.5	*±20%median*	-	12	2.4	0.25	1.1	0.82
Ammonia N	mg/L	0.005	0.681*	-	12	0.009	0.0025	0.0035	0.0023
Nitrate N Dissolved	mg/L	calc	-	13	12	0.080	0.010	0.049	0.021
Nitrite N	mg/L	0.002	0.06*	0.06	12	0.004	0.001	0.002	0.001
Sulfate	mg/L	0.5	50*	-	0	-	-	-	-
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	0	-	-	-	-
Arsenic, Total	mg/L	0.05	0.005	0.005	12	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	12	<MDL	<MDL	<MDL	<MDL
Cadmium, Total	mg/L	0.002	-	0.000017	12	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	12	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	12	<MDL	<MDL	<MDL	<MDL
Iron, Total	mg/L	0.005	-	0.3	12	0.43	0.05	0.16	0.10
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	12	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	12	0.061	0.008	0.030	0.017
Molybdenum, Total	mg/L	0.005	2	0.073	12	<MDL	<MDL	<MDL	<MDL
Nickel, Total	mg/L	0.008	-	0.025-0.15	12	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	12	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	12	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	12	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	*variable*	0.030	12	<MDL	<MDL	<MDL	<MDL
E. coli	col/100mL	1	*geometric mean = 77*	-	12	28	0.5	5.6	8.2
Fecal Coliforms	col/100mL	1	*geometric mean = 200*	-	12	37	0.5	14.1	13.7

Whistler Creek, 2004.

	unit	MDL	MOE	CCME	No.	Max	Min	Mean	SD
pH	pH units	0.1	6.5-9.0	-	16	7.7	7.0	7.5	0.2
TSS	mg/L	4	25*	-	16	<MDL	<MDL	<MDL	<MDL
Total Hardness	mg/L	calc	-	-	16	58.0	19.8	36.5	12.1
Turbidity	NTU	0.10	8*	-	16	4.0	0.3	1.2	0.9
Chloride, Dissolved	mg/L	0.5	600*	-	16	41.4	0.5	9.9	12.9
Total Organic Carbon	mg/L	0.5	*±20%median*	-	16	2.0	0.25	1.1	0.68
Ammonia N	mg/L	0.005	0.681*	-	16	0.029	0.0025	0.0077	0.0076
Nitrate N Dissolved	mg/L	calc	-	13	16	0.11	0.03	0.06	0.03
Nitrite N	mg/L	0.002	0.06*	0.06	16	0.006	0.001	0.004	0.002
Sulfate	mg/L	0.5	50*	-	15	15.8	5.5	11.1	3.4
Aluminum, Dissolved	mg/L	0.02	0.1	0.005-0.1	7	0.030	0.010	0.016	0.010
Arsenic, Total	mg/L	0.05	0.005	0.005	16	<MDL	<MDL	<MDL	<MDL
Boron, Total	mg/L	0.008	1.2	-	16	<MDL	<MDL	<MDL	<MDL
Cadmium, Total	mg/L	0.002	-	0.000017	16	<MDL	<MDL	<MDL	<MDL
Cobalt, Total	mg/L	0.005	0.11	-	16	<MDL	<MDL	<MDL	<MDL
Copper, Total	mg/L	0.005	*variable*	0.002-0.004	16	<MDL	<MDL	<MDL	<MDL
Iron, Total	mg/L	0.005	-	0.3	16	0.356	0.054	0.155	0.082
Lead, Total	mg/L	0.03	*variable*	0.001-0.007	16	<MDL	<MDL	<MDL	<MDL
Manganese, Total	mg/L	0.001	*variable*	-	16	0.086	0.007	0.033	0.026
Molybdenum, Total	mg/L	0.005	2	0.073	16	<MDL	<MDL	<MDL	<MDL
Nickel, Total	mg/L	0.008	-	0.025-0.15	16	<MDL	<MDL	<MDL	<MDL
Selenium, Total	mg/L	0.03	Mean = 0.02	0.001	16	<MDL	<MDL	<MDL	<MDL
Silver, Total	mg/L	0.01	0.003	0.0001	16	<MDL	<MDL	<MDL	<MDL
Thallium, Total	mg/L	0.03	-	0.0008	16	<MDL	<MDL	<MDL	<MDL
Zinc, Total	mg/L	0.005	*variable*	0.030	16	0.0090	0.0025	0.0037	0.0022
E. coli	col/100mL	1	*geometric mean = 77*	-	13	23	0.5	3.0	6.4
Fecal Coliforms	col/100mL	1	*geometric mean = 200*	-	13	29	0.5	4.9	8.2