Research Report

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An empirical approach to predicting water quality in small streams of southern British Columbia using biogeoclimatic ecosystem classifications

Chad D. Luider[1], Rob Scherer[2], and P. Jefferson Curtis[3]

Abstract

Water quality data from a synoptic survey of low-order streams ($n = 581$) were investigated as a function of the biogeoclimatic zone and moisture subzone groupings of the biogeoclimatic ecological classification (BEC) system. The potential utility of the BEC system as a watershed characterization tool was evaluated. The preliminary results were limited to streams sampled during June 1998 and 1999 over the large spatial scale of southern British Columbia. Significant differences ($p < 0.05$) were observed among biogeoclimatic zones and moisture subzones for specific conductance, turbidity, pH, and dissolved organic carbon (DOC) concentration. Our approach explained between 8 and 37% of the variation in water quality data, which could significantly reduce error in assessing water quality or investigating the effects of watershed activities among watersheds. The data provide a snapshot of water quality and identify areas that are likely to exceed water quality guidelines ($p > 0.50$). High proportions of low-order streams within the southern interior of British Columbia are likely to exceed water quality guidelines for turbidity and DOC content during a comparable sample period. Similarly, streams located in coastal areas of southern British Columbia exhibited pH values that were below the approved guideline of 6.5. Overall, the BEC system accounted for a significant amount of variation in water quality, suggesting that further development of this approach is warranted. The addition of other variables such as a history of land-use activities should be included, and data should be extended temporally to account for different flow regimes.

KEYWORDS: *baseflow, biogeoclimatic ecosystem classification, British Columbia, conductivity, dissolved organic carbon, pH, turbidity, water quality.*

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Introduction

Watershed properties strongly influence water quality in small streams because of hydrologic coupling between terrestrial and aquatic environments (Engstrom *et al.* 2000). Important watershed properties include underlying geology, soil types, and terrestrial vegetation (Stumm and Morgen 1995). These properties influence chemical and biological weathering processes and the exchange of elements from soils that contribute to the chemical constituents of stream water (Strobel *et al.* 2001; Stutter *et al.* 2003; Johnson-Maynard *et al.* 2005). Climate, hydrology, and land-use activities influence these processes and their interactions (Engstrom 1987; Curtis and Schindler 1997; Curtis 1998). For example, high amounts of rainfall, snowmelt, or storm events can markedly influence stream water chemistry. Storm events have been associated with pH depression in some watersheds, and snowmelt events have been associated with influxes of dissolved organic matter (DOM) into headwater streams (Whitfield and Michnowsky 1993; Brooks *et al.* 1999). Because of the high diversity in climate and watershed properties within British Columbia, enormous potential exists for natural variation in water quality. This high background variation makes management of surface waters and their watersheds very challenging.

Variability in climate and watershed properties is reflected in the biogeoclimatic ecosystem classification (BEC) (Pojar *et al.* 1987), which uses climate, soil, and characteristic vegetation types to regionally group British Columbia into biogeoclimatic zones. These zones range from very wet, such as the Coastal Western Hemlock (CWH) zone, to very dry, such as the Interior Douglas-fir (IDF) zone. Differences between zones are mechanistically associated with the occurrence of water quality. For example, weathering by-products are heavily diluted in areas of high precipitation and are quickly leached from the watershed, resulting in low conductivity or pH depression (Valiela and Whitfield 1989; McKean and Nagpal 1991). The BEC system shows promise as an indicator of natural variability for water quality over a large spatial scale, which would be useful as a management tool for surface waters (Mitchell and McDonald 1995; Richards and Kump 1997; Simeonov *et al.* 2003).

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One essential part of managing surface water quality for drinking water, aquatic habitat, or other purposes is assessment, which can be challenging when watershed scale increases or when natural variation in water quality cannot be demarcated from the effects of land-use activities (Valiela and Whitfield 1989; Temnerud and Bishop 2005). The latter scenario is typical in watersheds that exhibit widespread land uses, such as agriculture or forest harvesting activities. Furthermore, within a watershed, headwater streams can exhibit drastically different water quality than downstream locations where water quality assessments are typically conducted for pragmatic reasons, such as accessibility (Temnerud and Bishop 2005). Recent initiatives, such as the "source to tap" plan outlined in an amended version of the *Water Protection Act*[1] and the British Columbia Approved Water Quality Guidelines (B.C. Ministry of Environment 2006), aim to improve the management of freshwater resources within British Columbia. This requires watershed-specific objectives for water quality and for monitoring programs.

Turbidity (caused by suspended matter), dissolved organic carbon (DOC; a factor associated with brown-coloured water), pH, and specific conductance are variables used in water quality monitoring programs for assessing water sources (Nagpal *et al.* 2006). They help identify the direct or indirect health risks or aesthetic requirements of a water source for drinking water or other purposes, such as recreation or habitat protection. For example, high turbidity is an indirect health risk because it can limit the effectiveness of water treatment by shielding pathogens from disinfection or by providing substrate for growth. It can also be aesthetically unpleasing (Caux and Moore 1997). High DOC concentrations colour water, which is aesthetically undesirable, and can result in health risks due to trihalomethane production during chlorination (Moore and Caux 1997). Low pH

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[1] Revised Statutes of British Columbia. 1996. Chapter 484. *Water Protection Act.* URL: *http://www.qp.gov.bc.ca/statreg/stat/W/96484_01.htm*

levels can mobilize toxic metals in soils, increase the bioavailability of metals to aquatic biota, and corrode metals in distribution systems (McKean and Nagpal 1991; Munk and Faure 2004; Strobel *et al.* 2005). High levels of conductivity are associated with water hardness or salinity that can foul water systems (especially hot water) and at very high levels have direct health effects from excess salt. Approved water quality guidelines for drinking water sources are as follows for these parameters:

- conductivity: less than 700 μS/cm specific conductance
- turbidity: less than 1 nephelometric turbidity unit (NTU) of induced turbidity when the background is ≤ 5 NTU
- pH: between 6.5 and 8.5 pH units
- total organic carbon (TOC): less than 4 mg-C/L of TOC (with chlorination) (B.C. Ministry of Environment 2006).

The main objective of this research was to evaluate the BEC system as a watershed characterization tool for water quality over the large spatial scale of southern British Columbia. An empirical multivariate statistical analysis was used to identify differences in water quality data between the BEC categories. Although we emphasize the relation between BEC-based watershed variables and the above-mentioned water quality parameters, we recognize that other sources of variation, such as land-use history, will also influence water quality.

We undertook this study with the following hypothesis: water quality in small streams is correlated to watershed properties that are reflected in the BEC system. We report results for turbidity, DOC, pH, and specific conductance. We empirically quantified how much variation in water quality was associated with BEC categories, and predicted the probability of exceeding water quality guidelines within the BEC zones by establishing an expected range (95% confidence interval) of water quality values. For the purpose of this study, the threshold (guideline) for turbidity was arbitrarily set at 1 NTU for drinking water because induced turbidity (i.e., within the scope of water quality monitoring) was not quantified in this research. Similarly, the drinking water threshold for TOC includes dissolved and particulate phases of carbon, and is set at less than 4 mg-C/L. In this study, we measured only DOC, but conservatively maintained the threshold at 4 mg-C/L to assure that guideline exceedance was not falsely identified (e.g., a water source that exceeds the threshold for DOC will also exceed the guideline set for TOC because TOC is equal to or greater than DOC).

Methods

Sample Design

First-order streams ($n = 581$) from six different biogeoclimatic zones and five moisture subzones in central and southern British Columbia (south of 53°59.44'N) were sampled once to provide a synoptic survey, or snapshot, of water quality for a summer flow period during June 1998 and June 1999 (Table 1; sample sites are shown in Figure 1). Discharge conditions were analyzed to determine whether anomalous flows were observed during the sampling period relative to other years. Eight major drainages within British Columbia were analyzed, including the Fraser, Squamish, Cowichan, Nechako, Clearwater, Thompson, Columbia, and Okanagan Rivers, which have periods of discharge records from 1911 to 2003 (Water Survey of Canada). Mean discharge values for June 1998 and June 1999 were typically within 20% of average June values for the entire period of recorded data.

Sample sites for both years were randomly selected from 1:50 000 NTS maps to ensure streams were of low order with no lakes in the upstream catchment that could influence water quality. The only restriction on site selection was road access to the point of sample collection. Low-order streams were defined as first order

TABLE 1. Number of streams sampled (*n*) in each biogeoclimatic zone and moisture subzone grouping (one sample was taken per stream)

Biogeoclimatic zone		Moisture subzone		Sample size (*n*)
IDF	Interior Douglas-fir	x	Very Dry	25
		d	Dry	53
		w	Wet	16
MS	Montane Spruce	d	Dry	55
SBS	Sub-Boreal Spruce	d	Dry	20
		w	Wet	25
ICH	Interior Cedar–Hemlock	d	Dry	14
		m	Moist	73
		w	Wet	58
		v	Very Wet	13
ESSF	Engelmann Spruce–Subalpine Fir	m	Moist	18
		w	Wet	22
CWH	Coastal Western Hemlock	x	Very Dry	62
		d	Dry	49
		m	Moist	18
		v	Very Wet	60
TOTAL				*581*

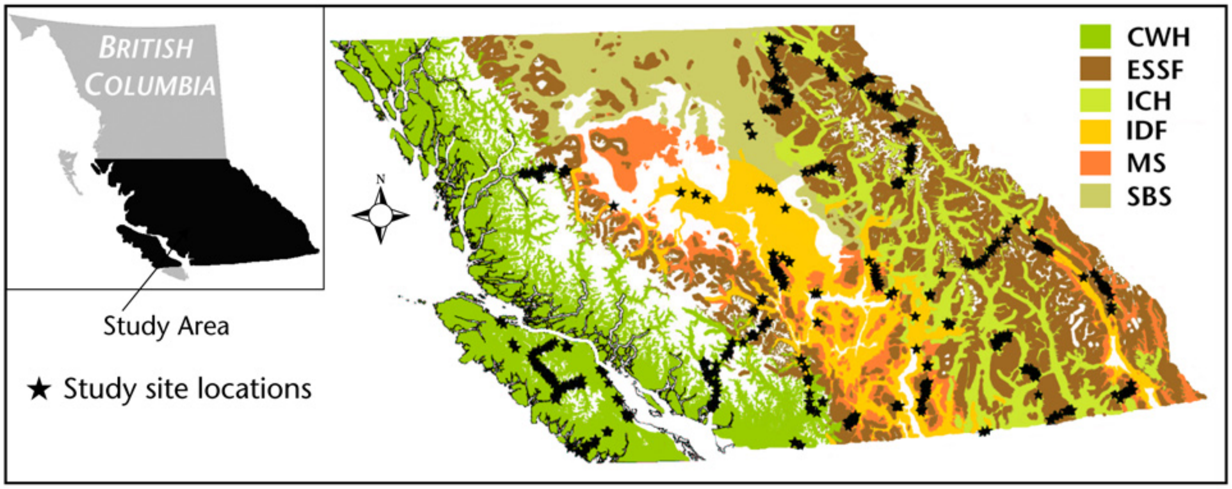

FIGURE 1. Sites sampled for a summer flow period during June 1998 and June 1999.

(e.g., streams with no upstream tributaries) or less (e.g., streams not shown). Systems having lakes or reservoirs were not included because the travel times of water can significantly affect water quality (Curtis and Schindler 1997; Curtis 1998). Each site was assigned a BEC category based on the dominant upstream BEC coverage from the point of sample collection. The assigned category covered on average 84% of the watershed. Biogeoclimatic zones and moisture subzones not listed in Table 1 were not included in the analysis because of insufficient sample size ($n < 12$).

The mean area of selected watersheds was approximately 3.7 km^2. Additional watershed properties, such as land-use intensity and road density, varied among watersheds. Variation in water quality due to these properties was included in the error term of the statistical analysis. Therefore, significant differences in water quality (i.e., $p < 0.05$) between BEC categories are conservative with respect to these additional sources of variation. Furthermore, the results from this research can be applied to other small streams with the assumption that the sample population is representative of the broader population of small streams within the spatial and temporal range of sample collection, including all sources of variation in the error term of the statistical analysis. This assumption was thoroughly evaluated (see "Statistical Analysis" below).

To standardize the sample collection process, procedures for stream sampling were taken from the *Ambient Fresh Water and Effluent Sampling Manual* (Resource Inventory Standards Committee 1997). Briefly, each grab sample was collected in a high-density polyethylene bottle. Wherever possible, samples were collected midstream and upstream from any crossings, such as roads. Exceptions to sampling from midstream were minimal because samples were collected during a post-freshet period and in low-order streams, and therefore streams were generally wadable. Samples were transported and stored at approximately 4°C in the dark prior to analyses.

Water Quality Measures

Specific conductance (µS/cm), turbidity (NTU), and pH were measured on unfiltered samples in the laboratory. Specific conductance was measured with an Orion-150 Conductivity Meter calibrated to Orion NaCl standards. Turbidity was measured with a Hach 2100 Turbidimeter. A Beckman combination glass double junction Ag–Ag/Cl pH electrode coupled to an Orion-320 pH Meter with a 25°C automatic temperature compensator was used to measure pH. The electrode was calibrated (pH 4–7) with a stabilization criterion of ±0.1 pH/min and operated at room temperature for standards and samples.

Dissolved organic carbon concentration was measured on subsamples filtered through pre-combusted Whatman GF/C filters using a Shimadzu TOC-5000A Total Organic Carbon Analyzer. Dissolved inorganic carbon was removed by acidifying samples (pH < 2) with select-grade hydrochloric acid (2N HCL) and purging with oxygen for 7 minutes before analysis. The coefficient of variation for instrumental response was consistently less than 2% and the detection limit of the instrument was 0.05 C-mg/L at an injection volume of 750 µL.

Statistical Analysis

Group differences in water quality data between biogeoclimatic zones (factor 1, 6 levels) and moisture subzones (factor 2, 5 levels) were determined by multivariate analysis of variance (MANOVA) using SPSS 10.0.[2] The data set was carefully screened before running the MANOVA to minimize inflation of Type I error and to maximize power. Missing values were deleted case-wise (four values in total), data were log-transformed as necessary to minimize skewness and kurtosis, and the ratio of cases to dependent variables was maintained above a minimum of 2:1 for each grouping cell. The final statistical design contained a minimum of 40 and 73 samples for factor-level groupings of BEC zones and moisture subzones, respectively.

Outliers were identified within the data set, but only extreme cases with high multivariate influence according to Cook's Distance were removed case-wise (four values in total) because low probability scores are expected with a large data set. Finally, the data set was checked for linearity, multi-collinearity, and homogeneity of variance. Levene's and Box's *M* tests for homogeneity of variance failed ($p < 0.05$), indicating possible inflation of Type I error. As a precautionary measure, alpha values were evaluated at $p < 0.01$ to guard against inflation of Type I error at a desired alpha of 0.05.

Data were graphed by mean values for biogeoclimatic zone and moisture subzone groupings showing standard error (Figures 2, 3, 4, and 5). In addition, the probability of guideline exceedance (e.g., $p > 0.10$) was calculated for each BEC grouping by applying *t*-distribution statistics to the data that were cleaned and screened for the MANOVA. More specifically, a *t*-statistic was calculated for each water quality guideline value (e.g., 700 µS/cm for conductivity), and evaluated using the TDIST function in Microsoft Excel to approximate the probability of observing an equal or greater value (e.g., ≥ 700 µS/cm). The results were then mapped for southern British Columbia. The *t*-statistics were evaluated at $p < 0.005$ for a desired alpha of 0.05 (95% confidence interval) to guard against inflation of Type I error due to non-normality and multiple pair-wise comparisons.

Results

Data for specific conductance, turbidity, pH, and DOC concentration were log-transformed to normalize distributions of data points within the overall data set and among mean values for biogeoclimatic zone and moisture subzone factor-level groupings. Data transformation significantly improved normality by more than a factor of two in most cases, as compared to skewness and kurtosis values. Skewness values for transformed data ranged from 1.6 for turbidity data to –0.5 for DOC data (SE = 0.1). Kurtosis values ranged from 3.6 for turbidity data to –0.6 for pH data (SE = 0.2). Most values were significantly different from zero ($p < 0.05$), indicating some remaining deviation from normality.

Specific conductance was more than a factor of two less than the water quality guideline of 700 µS/cm during summer flow conditions in all biogeoclimatic zones and moisture subzones (Figure 2; Table 2). Overall, these values corresponded to a low probability ($p < 0.01$) of exceeding the water quality guideline throughout southern British Columbia for all of the BEC zones and moisture subzones investigated. The overall mean for conductivity was 71.0 µS/cm, as compared to a median

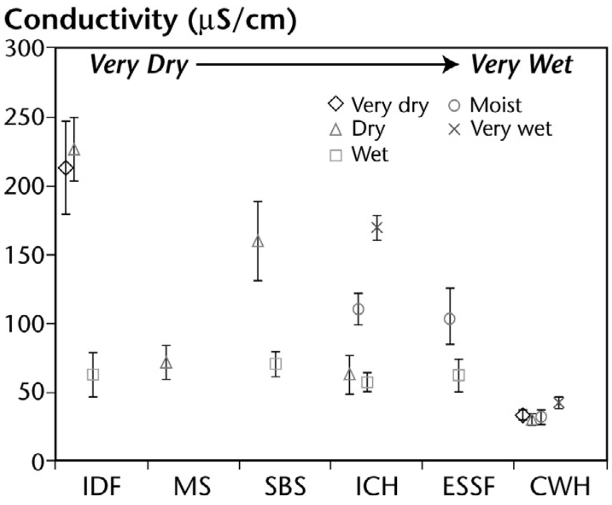

FIGURE 2. Mean specific conductance (±1 SE) of water samples for the BEC system's biogeoclimatic zones and moisture subzones.

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[2] SPSS Syntax as follows: GLM Method = SSType(III), Intercept = Included, Design = BEC-Zone Moisture-Subzone BEC-Zone*Moisture-Subzone, Post-Hoc = BEC-Zone Moisture-Subzone with Bonferroni

TABLE 2. Probability of observing a stream within a given BEC system zone and subzone that will exceed water quality guidelines during summer baseflow conditions as defined in this research. Blank values indicate $p < 0.01$.

Biogeoclimatic zone and moisture subzone		DOC	pH	Conductivity	Turbidity
IDF	x	0.76	—	—	0.94
IDF	d	—	—	—	0.74
IDF	w	—	0.02	—	0.01
MS	d	0.2	—	—	0.2
SBS	d	—	—	—	0.02
SBS	w	0.01	0.15	—	—
ICH	d	—	—	—	—
ICH	m	—	—	—	—
ICH	w	—	—	—	0.09
ICH	v	—	—	—	—
ESSF	m	—	—	—	0.03
ESSF	w	—	—	—	—
CWH	x	—	1	—	—
CWH	d	—	0.62	—	0.35
CWH	m	—	0.43	—	—
CWH	v	—	0.71	—	—

value of 69.0 μS/cm. The upper and lower asymptotic confidence limits (95%) were calculated as 80.6 and 62.6 μS/cm, respectively. Multivariate test statistics of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root were all less than 0.001. Biogeoclimatic zone explained 17% of the overall variability in specific conductance (between-subject effect $F = 7.95$, $p < 0.001$). Mean values and standard deviations were generally larger in drier biogeoclimatic zones, such as IDF, than wetter biogeoclimatic zones, such as CWH ($p < 0.05$), with mean values ranging from approximately 200 μS/cm to less than 50 μS/cm, respectively (Figure 2).

Turbidity values exceeded the water quality guideline of 1 NTU during summer flow conditions primarily in biogeoclimatic zones of IDF and CWH (Figure 3; Table 2). Overall, these values corresponded to a high probability of exceeding the water quality guideline ($p > 0.50$) throughout southern interior regions of British Columbia, such as IDF zones of the Okanagan region. The overall mean for turbidity was 0.52 NTU, as compared to a median value of 0.40 NTU. The upper and lower asymptotic confidence limits (95%) were calculated as 0.64 and 0.48 NTU, respectively. From the multivariate analysis, biogeoclimatic zone explained 8% of the variability in turbidity among sites (between-subject effect $F = 3.4$, $p < 0.001$). Mean values and standard deviations were generally larger in drier biogeoclimatic zones, such as IDF, than wetter biogeoclimatic zones, such as CWH ($p < 0.05$), with mean values ranging from approximately 1.5 NTU to less than 0.9 NTU, respectively (Figure 3).

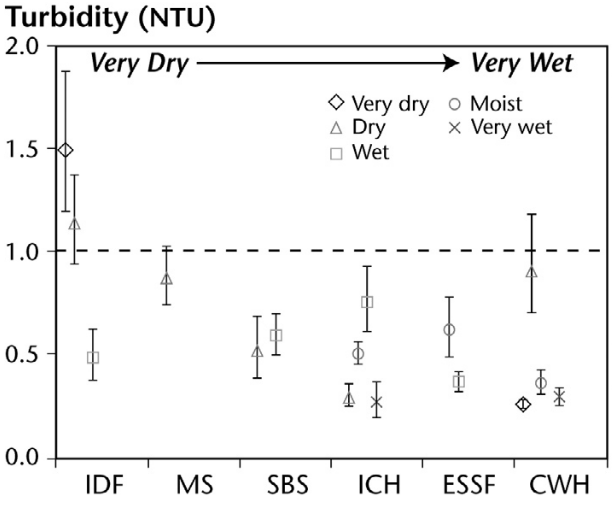

FIGURE 3. Mean turbidity (±1 SE) of water samples for the BEC system's biogeoclimatic zones and moisture subzones. Approved drinking water guideline shown as a dashed line.

Values for pH generally exceeded the guideline level (pH 6.5–8.5) for biogeoclimatic zones and moisture subzones of CWH (Figure 4; Table 2). Overall, these values corresponded to a high probability ($p > 0.50$) of exceeding the water quality guideline throughout southern coastal regions of British Columbia, particularly in zones of CWH. The overall mean pH was 6.9, as compared to a median value of 7.0. The upper and lower asymptotic confidence limits (95%) were calculated as 7.0 and 6.8, respectively. From the multivariate analysis, biogeoclimatic zone explained 37% of the variation in pH among streams (between-subject effect $F = 21.8$, $p < 0.001$). Mean values for pH were higher for the drier biogeoclimatic zones, such as IDF, than wetter zones, such as CWH ($p < 0.05$), with mean values ranging from more than 7.5 to less than 6.5, respectively.

Dissolved organic carbon concentrations exceeded water quality guidelines (4 mg-C/L) for total organic carbon in some biogeoclimatic subzones of IDF and MS (Figure 5; Table 2). Overall, these values corresponded to a high probability ($p > 0.50$) of exceeding the water quality guidelines in IDF biogeoclimatic zones throughout southern interior regions of British Columbia. The overall mean for DOC was 1.6 mg-C/L, as compared to a median value of 1.5 mg-C/L. The upper and lower asymptotic confidence limits (95%) were calculated as 1.6 and 1.2 mg-C/L, respectively. From the multivariate analysis, biogeoclimatic zone explained 25% of the variation in DOC concentration (between-subject effect $F = 12.5$, $p < 0.001$). Mean values and confidence intervals were generally larger in drier biogeoclimatic zones, such as IDF, than wetter biogeoclimatic zones, such as ICH, ESSF, and CWH ($p < 0.05$), with mean values ranging from approximately 4.6 mg-C/L to 0.4 mg-C/L, respectively.

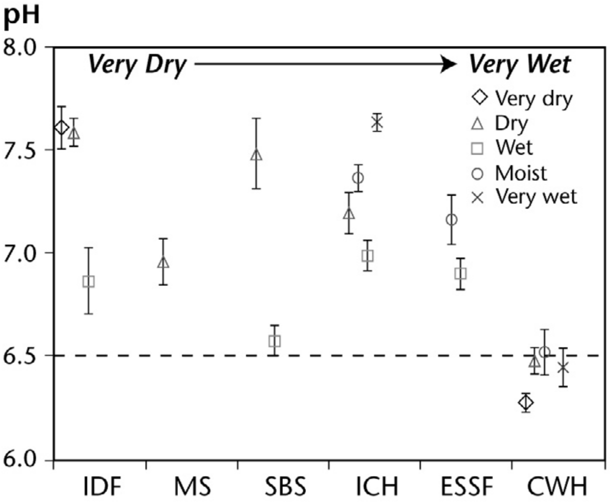

FIGURE 4. Mean pH (±1 SE) of water samples for the BEC system's biogeoclimatic zones and moisture subzones. Approved drinking water guideline shown as a dashed line.

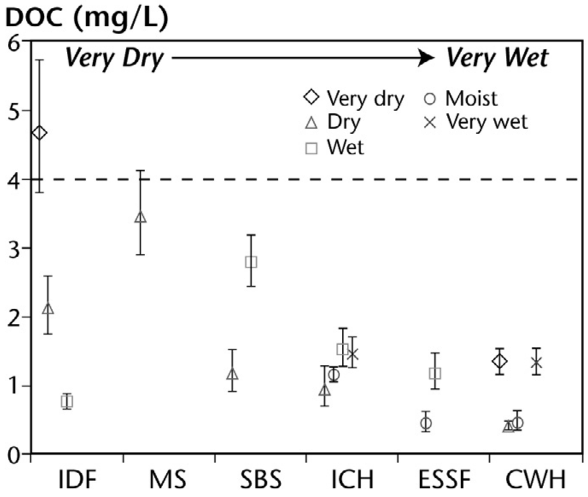

FIGURE 5. Mean DOC concentration (±1 SE) of water samples for the BEC system's biogeoclimatic zones and moisture subzones. Approved drinking water guideline shown as a dashed line.

Discussion

Stream water quality in southern British Columbia varied significantly among biogeoclimatic zones and moisture subzones for headwater streams during the month of June. Our results are consistent with the hypothesis that first-order stream water quality is correlated to watershed properties reflected by the BEC system, and are conservative to the effect that additional watershed variables, such as land-use activities, may have on water quality. Overall, high proportions of first-order stream water sources within British Columbia complied with provincial water quality guidelines for specific conductance, turbidity, pH, and DOC concentrations during our sampling period. Comparisons were weakened by skewness towards lower values, but small differences in mean and median values indicate that central tendency is generally described.

The variance in water quality explained by the BEC system is consistent with the associated differences in climate and watershed properties. For example, coastal regions of British Columbia exhibit high mean annual precipitation that will likely dilute the concentration of weathered materials in small streams relative to drier southern interior regions. Further differences may include rates of evapotranspiration, the proportion of precipitation that falls as snow, and soil water storage capacity. Differences in climate are consistent with comparatively low pH, conductivity, turbidity, and DOC concentrations for zones of CWH. Similar mechanisms relating to climate and watershed properties may explain differences in water quality for moisture subzones within the IDF biogeoclimatic zone. In general, these comparisons demonstrate the potential utility of this modelling approach in evaluating water quality within British Columbia.

Our findings suggest that the BEC system could be used either as a covariate measure for comparisons among watersheds or as a predictive model for water quality within watersheds. As a covariate measure, the BEC system reduces error associated with water quality assessments by establishing a more accurate baseline for water quality data via explained variance (i.e., variance due to differences in watershed properties according to the BEC system). This is particularly important in the biogeoclimatically diverse southern British Columbia interior where neighbouring streams can have very different water quality, independent of watershed activities. For example, a first-order stream draining an IDF-dominated watershed would likely have a much higher DOC content relative to a neighboring ESSF-dominated watershed. This overall approach will help to elucidate the effects of watershed management practices on water quality among different types of watersheds by accounting for background variation associated with BEC designations.

As a predictive model, the BEC system will help to predict and assess (by comparison to predicted norms) the current status of water quality in headwater streams during a summer flow period, thereby helping to better manage surface waters in southern British Columbia for drinking water or other uses. Two important management implications are associated with the use of the BEC system in a predictive model for water quality.

First, our approach enables potential water sources and their need for water source assessment to be prioritized according to expectations of water quality from biogeoclimatic zones (and potentially other watershed properties). For example, catchments in the IDF biogeoclimatic zone will generally exhibit more variable water quality than catchments dominated by different biogeoclimatic zones, such as ESSF or CWH (Figures 3 and 5). Furthermore, the IDF-dominated catchments have a high proportion of stream waters that exceed the approved guidelines for turbidity and DOC concentrations during the month of June, particularly in dry and very dry moisture subzones. Thus, for at least part of the year, water from first-order streams in the IDF biogeoclimatic zone will likely require treatment for drinking water or other specific management alternatives, depending on water use.

As a predictive model, the BEC system will help to predict and assess the current status of water quality in headwater streams during a summer flow period.

Second, our approach provides the ability to test for group membership of stream water samples by comparing measured water quality values to the water quality data presented in this research. The data provide a snapshot of stream water quality for first-order streams resulting from natural variation combined with variation due to contemporary and historic land-use activities for a summer flow period (June). Thus, a small stream (first order or less) can be tested and results analyzed against seasonal norms for the appropriate biogeoclimatic zone group, thereby determining the probability of occurrence for the measured water quality values. Streams exhibiting water quality with a low probability of occurrence (e.g., $p < 0.001$) for that BEC zone at that time of year may indicate highly suspect watershed activities or management practices, which would otherwise be undetectable because of high variability in water quality among biogeoclimatic zones. This approach helps to more accurately identify streams of suspect water quality that may require a more thorough level of investigation than would normally be appropriate for drinking water assessment. Changes in practices can be evaluated by comparing future water quality measures against these data to infer enhancements or degradations in water quality.

Our results assign a significant amount of variation in water quality to biogeoclimatic zone and moisture subzone properties of watersheds. This conservatively identifies the BEC system as a useful characterization tool for the approximation of water quality from watershed properties in small streams over a large spatial scale within southern British Columbia. We plan to extend our analysis to include additional natural and management-related variables such as more specific watershed characteristics, past and present land-use activities within watersheds, and more specific meteorological, geological, and hydrological data. The addition of these variables will likely increase the amount of variation explained by the model, which will elevate its utility as a management tool. Moreover, this approach should be extended temporally. The effects of land-use activities vary throughout the year, and high flows during freshet conditions are associated generally with greater water quality problems (Webber and Pommen 1996). Thus, a parallel study of water quality is needed to address watershed controls on water quality during freshet flows.

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Test Your Knowledge . . .

An empirical approach to predicting water quality in small streams of southern British Columbia using biogeoclimatic ecosystem classifications

How well can you recall some of the main messages in the preceding Research Report?
Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. One challenge to investigating the effects of land-use activities on stream water quality among different watersheds within British Columbia is:
   - A) Accounting for natural variation in water quality due to different watershed properties
   - B) Finding watersheds that exhibit substantial effects of land-use activities
   - C) Assessing what land-use activities are occurring in a given watershed

2. Overall, a ____ proportion of first-order streams within British Columbia comply with provincial water quality guidelines for specific conductance, turbidity, and pH during a summer flow period.
   - A) Low
   - B) High

3. The Biogeoclimatic Ecosystem Classification (BEC) system shows promise as a characterization tool for water quality in small streams because:
   - A) The BEC system is used extensively within British Columbia and is applicable over a large spatial scale
   - B) Measures of water quality were found to vary significantly ($p < 0.05$) among groups of watersheds that were representative of six different biogeoclimatic zones and five moisture subzones of the BEC system
   - C) Both A and B

4. In what area of British Columbia might managers of community watersheds be concerned about turbidity during a summer flow period?
   - A) In all areas of British Columbia
   - B) In areas within British Columbia that exhibit forest harvesting activity
   - C) In areas within British Columbia that exhibit extensive biogeoclimatic zones of Interior Douglas-fir (IDF)

Answers

1. A 2. B 3. C 4. C