Reference Model Supporting Documentation Template
For CABIN Analytical Tools

MODEL NAME: Peace River 2019

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1. STUDY DESIGN AND SITE SELECTION

This document provides a brief synopsis covering the data collection and analysis and various attributes of the recommended Reference Condition Approach (RCA) model for the Peace River watershed. Full details on the development and testing of the Peace River 2019 model are provided in the Technical Report (Reynoldson 2019).

1.1. Model Purpose

The British Columbia (BC) Ministry of Environment and Climate Change Strategy (ENV) and Environment and Climate Change Canada (ECCC) developed this model as an assessment tool for aquatic ecosystems in the Peace River watershed, BC. The methods followed those of the Canadian Aquatic Biomonitoring Network (CABIN) program to create a bioassessment model for the study area using the principles of the RCA (Bailey et al. 2003) and BEnthic Assessment of SedimenT (BEAST; Reynoldson et al. 1997, Reynoldson et al. 2000).

1.2. Spatial and Temporal Scope

The model was developed using data collected by ENV and ECCC from B.C. portion of the Peace River watershed. The geographic coverage of the model includes the entire B.C. portion of the Peace River watershed, including tributaries that drain to the Williston reservoir ("Williston Basin") as well as to the Peace River downstream of the W.A.C. Bennett Dam ("Peace Basin"). Samples were collected across different habitats in the Peace River watershed, as represented by ecoregions. Almost 50% of the samples were collected from Ecoregion 200 (Central Canadian Rocky Mountains), with ecoregions 145 (Western Alberta Upland) and 138 (Peace Lowland) also being well-represented (22% of samples) (Figure 1).

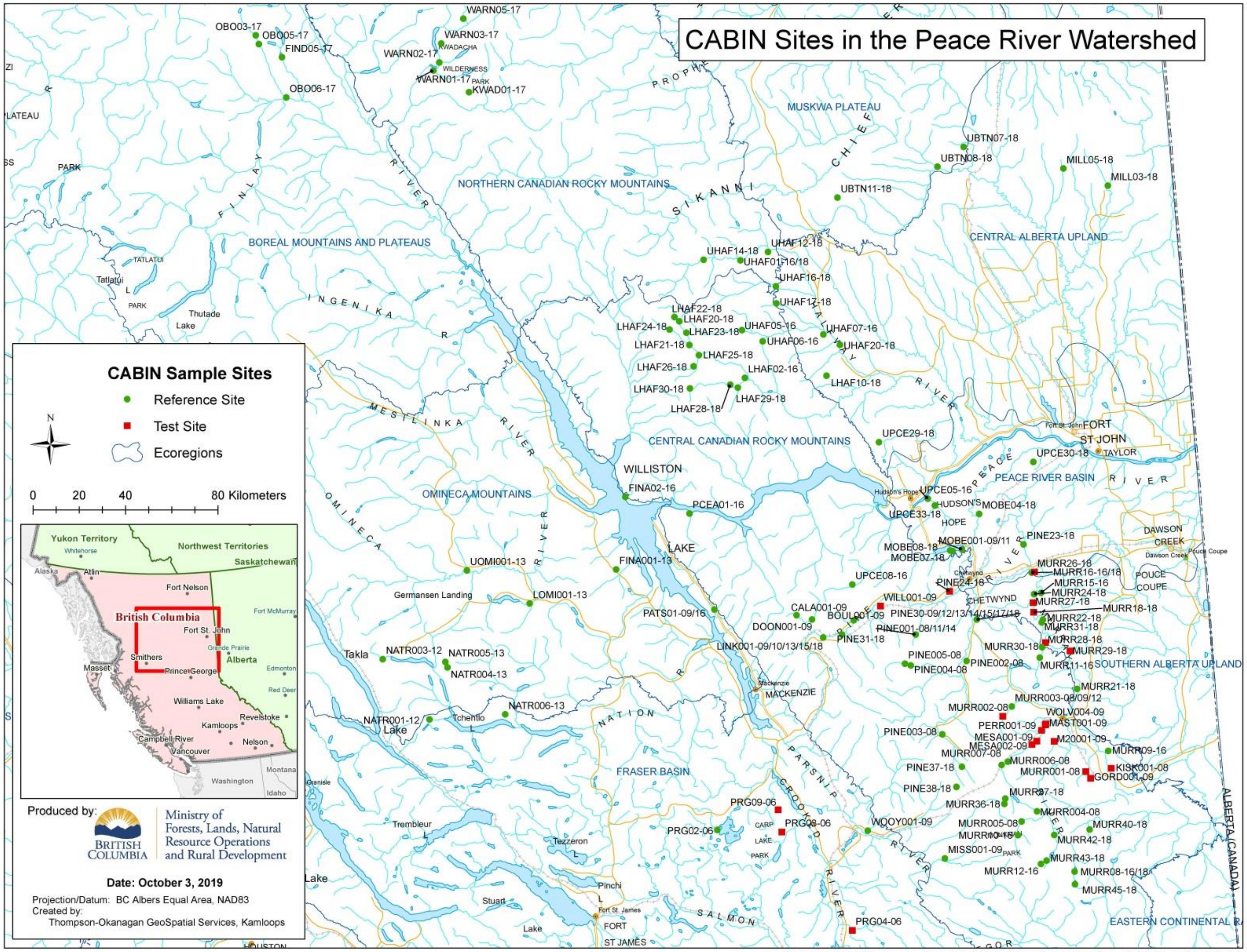

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Figure 1. *Site locations and ecoregions for the Peace River watershed 2019 model.*

All samples were collected at low flow in late August and early September following CABIN field protocols (Environment Canada 2012) between 2006 and 2018. The majority of sampling was conducted in 2018 (47 sites). The other major sampling years were 2016 (17 sites) and 2008, 2009, and 2017 (10 sites each year). The spatial and temporal distribution of sites is summarised in Table 1.

***Table 1**. Distribution of reference sites across ecoregions in the Peace River watershed.*

	Ecoregion (no.)								
	Muskwa Plateau (66)	**Clear Hills Upland (137)**	**Peace Lowland (138)**	**Western Alberta Upland (145)**	**Boreal Mountains and Plateaus (180)**	**Northern Canadian Rocky Mountains (183)**	**Omineca Mountains (199)**	**Central Canadian Rocky Mountains (200)**	**Fraser Basin (203)**
2006	-	-	-	-	-	-	-	-	1
2007	-	-	-	-	-	-	-	-	-
2008	-	-	-	-	-	-	-	10	-
2009	-	-	1	1	-	-	-	7	1
2010	-	-	-	-	-	-	-	-	-
2011	-		1	-	-	-	-	1	-
2012	-	-	-	1	-	-	2	1	-
2013	-	-	-	1	-	-	6	1	-
2014	-	-	-	1	-	-	-	1	-
2015	-	-	-	1	-	-	-	1	-
2016	-	1	2	2	-	1	-	11	-
2017	-	-	-	1	4	5	-		-
2018	2	7	7	6	-	3	-	22	-
Total	**2**	**8**	**11**	**14**	**4**	**9**	**8**	**55**	**2**

1.3. Reference Site Selection

ENV and ECCC used two different GIS-based approaches to select minimally disturbed conditions or areas of low anthropogenic and natural disturbance for locating reference sites for sampling and data collection. Between 2006 and 2015, ENV sampled potential reference sites using the methods described by Norris (2012). The second approach was used by ENV and ECCC for reference sites sampled after 2015, where potential reference locations were identified using the Human Activity Gradient (HAG) approach (Yates and Bailey 2010).

1.4 Data Availability

Using the methods described above, a total of 113 reference sites sampled over the 12 year period, were available with matching biological and habitat data, and thus, were selected for inclusion in the model building procedure. These data are available in 3 different CABIN studies (Table 2) and full details on data collection and QA/QC methods are summarised in Appendix 1.

Table 2. *CABIN studies with data used to develop the Peace River watershed 2019 model.*

CABIN Study Name	# of Reference Sites	Date Sampled
BC MOE-FSP Skeena Region	1	2006
BC-MOE-Omineca/Peace Region	89	2008 - 2018
EC-NEBC Baseline Water Quality	23	2018

2. MODEL DEVELOPMENT

2.1. Biological Data

The 62 invertebrate families found in the Peace River watershed show the typical pattern of taxon occurrence, with a few very abundant families (Table 3), and the remaining families (56 of 62) each having low abundance (i.e., <5% of the total number found). The six abundant families represented more than 75% of the organisms found and all but one (Taeniopterygidae) occurred at more than 80% of the sites (Table 3). A complete list of families found at the 113 reference sites is presented in Appendix 2 of the technical report (Reynoldson, 2019).

Four community metrics are shown that provide an overall description of the biological data, richness (S), abundance (N), evenness, and Simpson's diversity (Table 4). There is a four-fold difference in richness across the 113 reference sites, and a very large range in abundance (i.e., three orders of magnitude) at the reference sites. The two descriptors of diversity (evenness and Simpsons Diversity Index) both have high scores with mean values close to the maximum value of 1.0, suggesting the reference sites are in good condition.

Table 3. *Summary of the abundant and frequently occurring families at 113 reference sites.*

Order	Family	% Occurrence at Reference Sites	% of Total Organisms	Cumulative % Total
Diptera	Chironomidae	97.4	19.8	19.8
Ephemeroptera	Heptageniidae	93.9	18.1	37.9
Ephemeroptera	Baetidae	96.5	14.5	52.4
Plecoptera	Nemouridae	97.4	11.6	64.0
Plecoptera	Taeniopterygidae	64.4	6.8	70.8
Ephemeroptera	Ephemerellidae	88.7	5.7	76.5

Further details on the community composition of the individual reference groups are provided below (Section 2.4).

2.2. Habitat Data

Preliminary examination of the field and GIS-based habitat data identified 109 potential predictor variables that were considered minimally affected by human activity and had sufficient data for consideration in the predictive model. There were six variable categories describing general geographic and topographic attributes, bedrock and surficial geology, land-cover, climate, channel, and substratum attributes (Table 5). The majority of the habitat data (49 variables) were generated using GIS, with historic climate variables as the single largest category (41). There were 19 field variables measured at each sampling site.

Table 4. *Four community metrics for 113 reference sites in the Peace River watershed.*

Statistic	Richness (S)	Abundance (N)	Evenness	Simpson's Diversity
Mean	18	3549	0.7	0.8
Maximum	28	18320	0.9	0.9
Minimum	7	33	0.3	0.3
SD	4.0	3593	0.1	0.1

As noted that climate data is the largest category of habitat data available, and while the nature of these data is such that it provides a good overall indication of climate, the long-term nature of these variables (*i.e.,* long term averages) and that they may be acquired from stations distant from the sample sites in both time and space is problematic. Benthic invertebrates are short lived with life cycles often of one or two years. This means that the climate data used in the models do not provide an indication of what the organisms see, which is more related to weather rather than large spatial patterns in climate. This was identified as an issue in the Technical Report (Reynoldson 2019), which recommended further investigation into the most appropriate climate descriptors for benthic invertebrate RCA models.

Table 5*. Variable categories and variable types considered as model predictors.*

	Variable Category					
	Geographic	**Geology**	**Land-cover**	**Climate**	**Channel**	**Substratum**
Variables	Latitude Longitude Slope Drainage area	Bedrock Surficial	Vegetation	Precipitation Temperature	Hydrology Riparian Zone	Size Category
Number	16	15	20	41	15	7

A complete list of the habitat variables and the variability associated with each variable are provided in Appendix 3 of the Technical Report (Reynoldson, 2019). Further details on the environmental attributes of the reference groups are provided below (Section 2.4).

2.3. Model Building

Using these biological and habitat data, the biological data were classified into groups of sites representing similar community assemblages and then these groups were used to select a set of habitat variables that best matched the biological groups. Presently, the RCA is the standard approach to building models in the CABIN program (Wright et al 1984, Reynoldson et al 1997).

Prior to the actual model building process initial examination of the 113 sites using non-metric multidimensional scaling (nMDS) ordination (PRIMER6), showed that two sites were outliers (WARN05-17 and PINE30-17) (Figure 2). These were sites with very low numbers of organisms and taxa, and were removed from further analysis leaving a data set of 111 sites for model development.

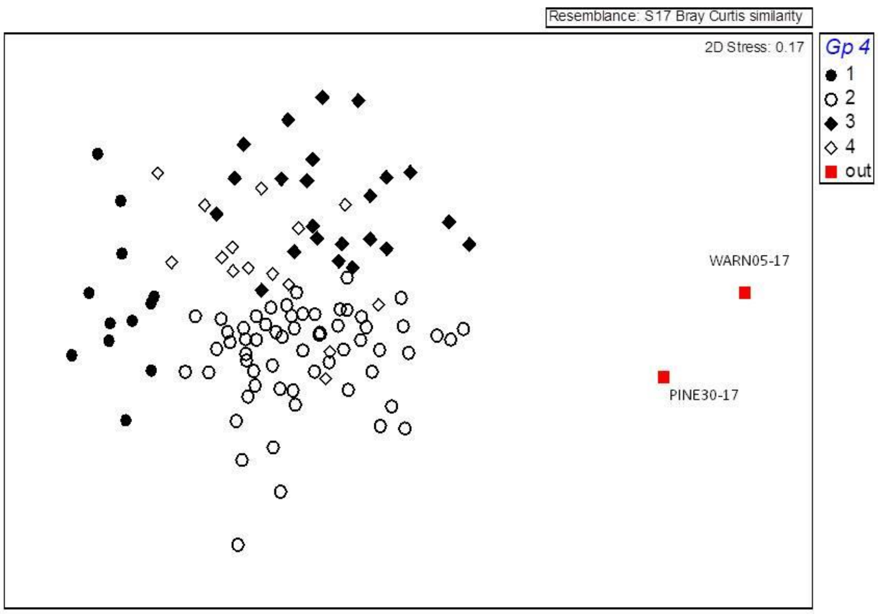

Figure 2. *nMDS ordination of 113 reference sites from the Peace River. Shown are the two outliers and the remaining 111 reference sites with the groups used in the model.*

2.3.1. Classification

Classification of the family level data for these 111 sites was done using two different classification algorithms from PATN and PRIMER software and produced distinct reference groups (Figure 3). The solution selected for model building was derived from these two classifications approaches, which showed more than 97% concordance in the biological groups that were created. Up to five reference groups were considered and tested as possible model solutions.

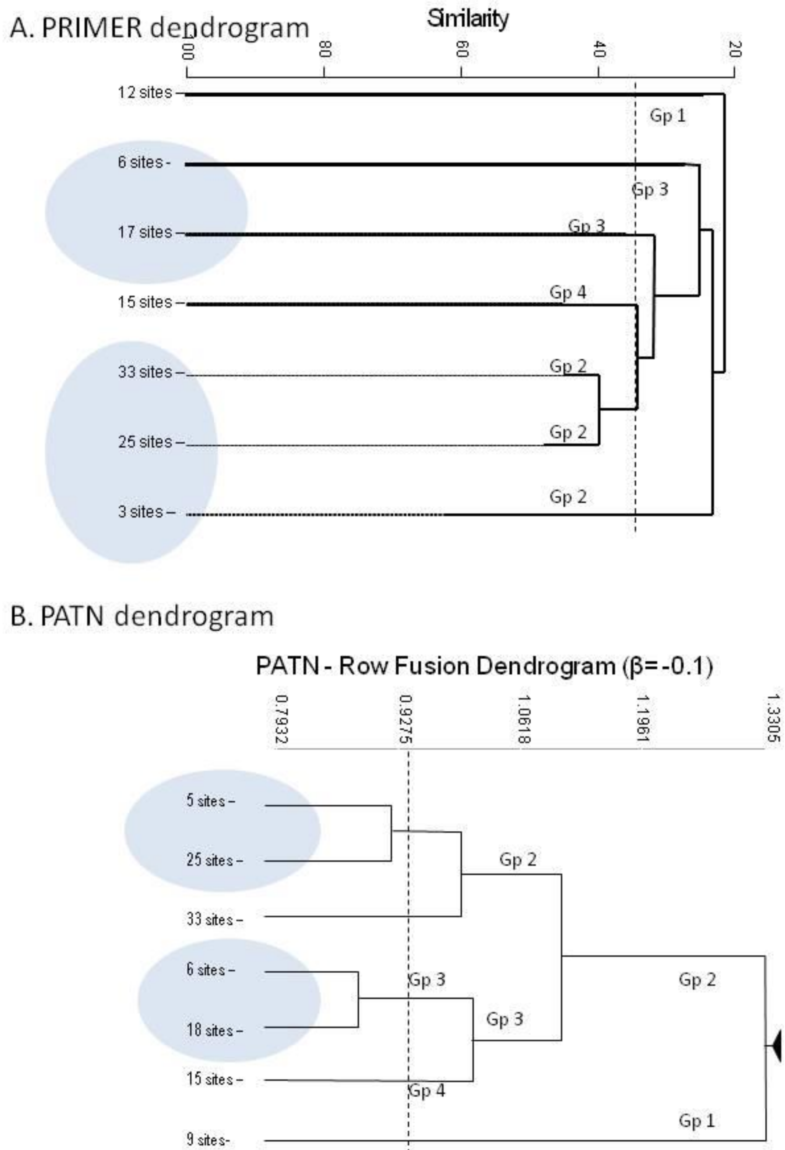

Figure 3. *Comparison of dendrograms created by PRIMER (A) and PATN (B) showing seven groups of sites, from the 111 Peace River watershed reference sites. The shaded ovals indicate the groups that were merged for the four group solution used in the model. The hatched line shows the stopping point for group creation.*

2.3.2.<u>DFA Model</u>

109 habitat variables were available from 111 sites as potential predictors in the model. As described above, these include six categories of variables, many obtained through GIS. Prior to model building, a subset (20% or 23 sites) of sites were randomly extracted from the full data set to be used as validation

sites to test model performance. The remaining 88 sites were used as the training data set for model building.

Several approaches were then used to select the final habitat predictors:

1. Forward and Backward Stepwise DFA and then optimization by variable removal and entry based on individual F scores.
2. Variable selection based on similarity matrix matching using BVSTEP in PRIMER with transformed and normalized habitat data.
3. The correlation of habitat variables with the nMDS biological ordination axes; and
4. The classification of the habitat data (LINKTREE in PRIMER 6) using the grouping structure from the biological data.

Using the above approaches to selection of a final set of predictor variables more than 90 models with two to five reference groups and varying arrays of predictor variables were considered.

2.3.3. Model Performance

The final selection of the model to be recommended for use in the Peace River was based on a number of performance factors. The following characteristics of the >90 models tested were used to select the recommended model.

- **Classification accuracy –** This assesses how well the discriminant model assigns sites to the correct group. There are two common methods of assessing classification accuracy, including resubstitution, where the classification functions are calculated from all the samples, and cross-validation (jack-knifed), where each sample being classified is removed from the data set and then classified with the remaining samples. This produces a less biased estimation of the classification error rate (Lance et al. 2000) and tends to have a higher apparent error rate. In all cases where the classification accuracy is reported, it is based on the more rigorous cross-validation method.

- **The number of variables –** In general, the number of predictor variables should not exceed the size of the smallest group and therefore models with smaller numbers of variables are desirable, as they are more likely to provide accurate future classifications (Eisenbeis 1971).

- ***F*-ratio** – A higher *F* score indicates greater difference between the group means for the predictor variables. Higher *F* scores are preferred.

- **Wilk's lambda (λ)** – This statistic is a measure of the null hypothesis that the groups have identical means on the discriminant equation. A value near zero indicates an accurate model, a value near one indicates a poor model.

- **Group size** – A balanced group size is preferable as solutions with similar size groups provide more consistent assessments. Small groups are problematic as the variance of the group may not be adequately described by the available reference sites and the number of desirable potential predictors is reduced (see above). Conversely, very large group sizes potentially have a lot of variation and reduce the sensitivity of assessment. Somewhat arbitrarily, a minimum group size of 10 sites was suggested by Wright and Reynoldson (2000), but this has never been thoroughly tested, and is likely very data set dependent.

- **Number of groups** – As a general rule, and other model attributes being equal, a model with more groups is desirable as it provides a finer discrimination of the biological variation.

- **Differences among groups** – It is desirable to maximise the biological differences among the groups and minimize the differences within the groups. This will be an important component in determining the power of the reference groups to discriminate divergence from reference condition.

In addition to these internal measures of model performance, the use of validation sites provides a more independent and robust measure of performance.

- **Validation site accuracy** – This calculates the percentage of validation sites that are predicted to the reference groups they were assigned in the initial classification.

- **Validation site precision** – This determines how variable the accuracy is across the individual reference groups.

- **Type 1 and 2 error rates** – Using *simpact* (see Section 2.3.3ii) data and validation sites shows how many validation sites are assessed as different to reference (Type 1 error) and how many *simpact* sites are designated as in reference condition (Type 2 error).

After examination of a large number (>90) of model options, a final four group model with six predictor variables (Slope 30-50%, Glac-Sed Blanket %, Precipitation May, Precipitation – total annual, Temperature February minimum, and Channel vegetation shrubs) was selected based on these measures of model performance. The final model is 74% accurate in predicting sites to the correct reference group.

i. *<u>Classification and Cross-Validation</u>*

The recommended four group model performs well across the groups (Table 6). Group 4 is one of the two smaller groups (Figure 4) and has the lowest classification accuracy, but still exceeds 55% correct classifications (Table 6A and B). The model is very robust only requiring six predictor variables. The inclusion of the validation sites reduces the accuracy slightly, with an overall classification accuracy of 72%, compared to 74% based on the training data (Table 7).

Table 6. Values and ranges for predictor variable in each of four reference groups.

	Statistic	Group 1 (12 sites))	Group 2 (61 sites)	Group 3 (23 sites)	Group 4 (15 sites)
Slope 30-50% (%)	Avg	29.3	26.4	10.9	14.8
	Range	26.4-36.3	21.6-29.0	1.7-21.0	6.5-22.0
Glacial Sed. Blanket (%)	Avg	10.9	4.4	22.8	48.9
	Range	0-6.3	0-0	0-23.5	0-99.1
Precip May (mm)	Avg	53	51	44	47
	Range	51-54	49-52	42-46	43-50
Annual Precip(mm)	Avg	654.3	724.0	559.0	596.5
	Range	610-675	671-783	500-618	552-639
Feb. Min Temp(ºC)	Avg	-15.4	-14.6	-15.4	-14.6
	Range	-14.9—16.1	-15.0—13.4	-14- -15.8	-15—14.1
Channel Shrubs (cat)	Avg	0.9	1	1	1
	Range	1-1	1-1	1-1	1-1

Table 7. *Classification matrices for model based on resubstitution and cross-validation.*

A. Resubstitution Matrix - Training Model (88 sites)

Group	**1**	**2**	**3**	**4**	**%correct**
1	7	1	0	1	78
2	4	40	3	3	80
3	0	1	14	3	78
4	3	2	0	6	55
Total	14	44	17	13	76

B. Jackknifed (Cross-validation) Classification Matrix- Training Model (88 sites)

Group	**1**	**2**	**3**	**4**	**%correct**
1	6	2	0	1	67
2	4	40	3	3	80
3	0	1	13	4	72
4	3	2	0	6	55
Total	13	45	16	14	**74**

C. Jackknifed (Cross-validation) Classification Matrix – Full Model (111 sites)

Group	**1**	**2**	**3**	**4**	**%correct**
1	7	3	0	2	58
2	7	48	3	3	79
3	1	1	18	3	78
4	3	2	3	7	47
Total	18	54	24	15	**72**

ii Validation and Simpact Data

As described above, a more robust test of model performance removed 23 sites (approx. 20%) from the data set, which were treated as validation data (Table 8). The model was then constructed using the training data (88 sites) and used to classify the 23 validation sites. The classification accuracy of the validation sites (61%) is somewhat lower than that of the cross validation (74%) (see Table 6B), but this is likely because sample sizes for Groups 1 and 4 (number of validation sites) are small. This may also account for the greater imprecision, which is the variation in accuracy among the groups (Table 7). This data set is a little on the small size for extraction of validation sites, and as more data are acquired to update future models, it is anticipated that the estimates of precision will be more meaningful.

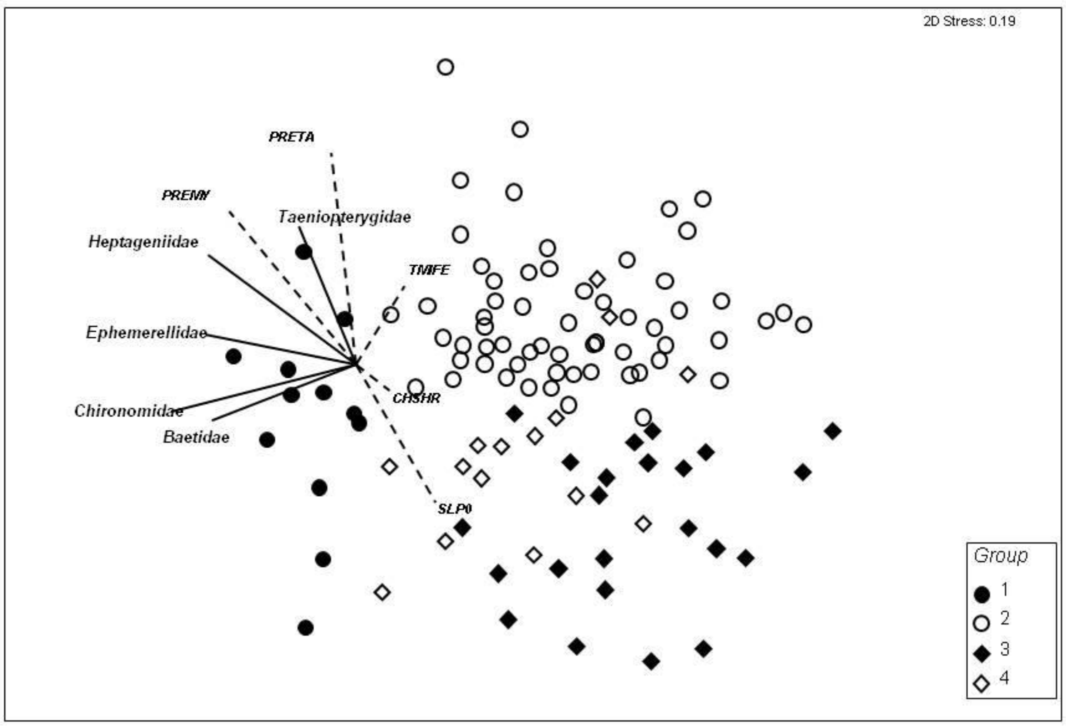

Figure 4. *nMDS ordination of 111 reference sites used to build the DFA model illustrating four community assemblages, and the vectors for the taxa contributing most to the ordination (solid lines) and the predictor variables (dashed lines).*

In addition, the validation data were used to examine Type 1 and Type 2 error rates using simulated impacts (*simpacts*). As there is no a priori way of knowing if a test site is out of reference condition, *simpacts* were used to generate new samples from reference sites that are known to be disturbed and by a known amount. For each of the 23 validation sites, three levels of intensity of disturbance were created for two types of disturbance, enrichment and sedimentation. In both cases, the number of individuals in each taxon was adjusted by a factor representing the three levels of intensity of the disturbance (Reynoldson, 2019) for each of the validation samples. The tolerance values used for the Peace River model included the Hilsenhoff Family Biotic Index (FBI) (Hilsenhoff, 1988) as used by Bailey *et al*. (2014), where taxa are classed as sensitive (FBI 1 to 4), insensitive (FBI 5 or 6) or tolerant (FBI 7 to 10). For the sediment *simpact*, an equivalent value was calculated using the tolerance values for sedimentation derived by Pappas *et al*. (2017) for the NEBC CABIN model, which also included similar response categories, where changes were introduced according to the stress level being simulated. The actual effects of the simulated disturbance are summarized in Table 9, which, for example, shows at the mild level the sediment *simpact* to be more severe.

Table 8. *Comparison of model (88 sites) and number of validation sites correctly classified, based on cross validation.*

	Training data Model (Table 6B)	***Validation sites correctly classified***
Gp 1	*67%*	*2 of 3 (67%)*
Gp 2	*80%*	*6 of 11 (54%)*
Gp 3	*72%*	*5 of 5 (100%)*
Gp 4	*55%*	*1 of 4 (25%)*
Accuracy	*74%*	*14 of 23 (61%)*
Precision (100-CV%)	*84.7%*	*49.4%*

Table 9*. Average change (%) from reference in abundance (N) and richness (S) for simpacted disturbances representing nutrient enrichment and sedimentation for 23 validation sites*

	Variable	**Mild**	**Moderate**	**Severe**
Enrichment *simpact*	Δ N	-52.6%	-78.3%	-79.7%
	Δ S	-15.9%	-33.6%	-58.6%
Sediment *simpact*	Δ N	-47.8%	-57.3%	-94.2%
	Δ S	-53.2%	-52.0%	-64.1%

The results from all the analysis quantifying Type 1 and 2 error rates are summarised in Table 10 for the two types of *simpact*. The Type 1 error rate was low and generally less than one would expect by chance (i.e., 10% at p=0.90). The Type 2 error rates gradually decreased with increasing levels of disturbance as indicated by the average change in abundance (ΔN) and richness (ΔS) in the three levels of disturbance (Table 10).

***Table 10**. Type 1 and 2 error rates (%), for simpacted (S= sediment, E=enrichment) sites for 23 validation sites at P=0.90.*

	Type 1 error	***Type 2 error***	
		Sediment	***Enrichment***
No *simpact*	8.7%	-	-
Mild	-	60.9%	78.3%
Moderate	-	52.2%	17.4%
Severe	-	0.0%	17.4%

2.4. Biological and Environmental Attributes of the Reference Groups

The biological and habitat characteristics of the four groups for both the predictor variables and those best correlated with the biological data are summarized in Table 11.

Five families (Chironomidae, Nemouridae, Baetidae, Hetageniidae and Simulidae) characterize the different groups. However, the relative and actual abundance varies considerably (Table 4) as does the contribution of the family to characterizing the group.

- Group 1 has the highest richness and overall abundance and is characterized by large numbers of Chironomidae (Diptera) and two families of Ephemeroptera, the Heptageniidae and Baetidae. This group contains the highest altitude sites (average = 1005 fasl), with smaller drainage areas and lower annual temperatures and has the second highest annual precipitation. These sites have the highest proportion of low slope in the catchment, and lowest amount of glacial sediment blanket.
- Group 2 has the highest overall species diversity and is dominated by Heptageniidae (Ephemeroptera) and Nemouridae (Plecoptera). These sites are also located at higher altitude, with the highest precipitation and largest particle size. They also have a high proportion of low slope in the catchment.
- Group 3 sites have the lowest total abundance and are dominated by Chironomidae (Diptera), Nemouridae (Plecoptera) and Simuliidae (Diptera). These are sites with the lowest altitude and largest drainage area, lowest annual precipitation and highest annual temperature.
- Group 4 sites have the lowest taxa richness and diversity, and are dominated by Baetidae (Ephemeroptera). These sites have the lowest total stream length in the catchment, higher stream order, and bankfull width.

Table 11. *Biological and selected environmental characteristics (average values; range 25-75%le) for the Reference Groups (for 111 sites) for the recommended model with four reference groups.*

	Statistic	**Group 1 (12 sites))**	**Group 2 (61 sites)**	**Group 3 (23 sites)**	**Group 4 (15 sites)**
Biological attributes					
Richness	Avg	19	18.1	17.4	15.4
	Range	17-20	16-20	13-21	12-18
N	Avg	12101	2765	1658	3263
	Range	9899-15003	1392-3767	971-2227	1806-4244
Simpsons Div.	Avg	0.69	0.80	0.73	0.69
	Range	0.64-0.77	0.77-0.90	0.6-0.9	0.6-0.8
Chironomidae	Avg	3850*	277*	395*	493*
	Range	2970-4845	84-389	171-493	228-678
Heptageniidae	Avg	1771*	757*	68	228
	Range	660-2205	284-940	3-94	71-344
Baetidae	Avg	1620*	230	119	1463*
	Range	458-3240	92-315	21-185	798-1750
Nemouridae	Avg	1410	285*	333*	300*
	Range	256-1156	103-343	78-432	96-494
Simuliidae	Avg	717	13*	174*	131
	Range	24-325	0-11	36-220	3-46
Environmental attributes					
Latitude	Avg	56.401	55.695	56.123	55.932
	Range	56.2-56.9	54.9-56.1	55.5-56.8	55.6-56.4
Longitude	Avg	-122.967	-122.480	-121.865	-122.263
	Range	-123.1—122.8	-123.5-121.5	-121.7—121.2	-123.1-121.3
Altitude (FASL)	Avg	1004.9	965.8	658.4	803.5-
	Range	974-1064	799-1083	563-765	701-944
Drainage area (km^2)	Avg	53.6	52.5	82.0	61.2
	Range	19.8-45.3	15.8-65.4	26.9-85.8	18.7-86.8
Stream length (km)	Avg	137.5	134.4	196.3	125.7
	Range	45-130	47-163	29-221	42-130
Annual temp (°C)	Avg	-0.3	-0.1	1.11	0.93
	Range	-0.9-+0.5	-0.6- +0.6	0.2-2.0	-0.1-1.8
Stream order	Avg	3.2	3.0	3.0	3.33
	Range	3-4	3-4	3 -3	3 – 4
Bankfull width (m)	Avg	8.1	10.9	10.4	11.2
	Range	5.8-10.6	6.5-14.4	4.9-14.4	6.5-14.8
Particle size (DM50)	Avg	7.8	9.0	6.5	7.1
	Range	7.0-8.4	5.8-10.0	4.9-8.1	5.7-8.7

2.5 Data Gaps and Model Application

This model generally performs well, particularly given the relatively small numbers of sites available for validation. Two groups (i.e., Group 1 and Group 4) are on the small side and further sampling should focus on sites from these types of habitat.

3. FINAL MODEL

Data from 111 reference sites were used to create an RCA predictive model for the Peace River watershed. While four different classification options were considered using between two and five groups of reference sites, the final model contains four reference groups. The model was developed using 88 reference sites, with 23 sites removed to be used as a validation set to test model accuracy and precision. Type 1 and 2 errors were determined by modifying the validation sites (*simpacting*) to represent two types of disturbance, including nutrient enrichment and general sediment disturbance.

Initial investigation used nine levels of *simpact* on four representative sites. From this initial analysis, three levels of disturbance were selected to assess the power of the models to detect divergence from reference. The reference condition model for the Peace River watershed shows: distinct reference groups that the available habitat data can classify with relatively high levels of accuracy. The number of variables required to conduct those classifications is comparatively low compared to some other models available in CABIN.

Based on these analyses, a model with four reference groups using six predictor variables (Slope 30-50%, Glac-Sed Blanket%, Precipitation May, Precipitation – total annual, Temperature February minimum, and Channel vegetation shrubs) was chosen (Table 6). This model accurately predicts 74% of sites to the correct reference group.

The model was used to assess 16 test sites and identified six in reference condition, four as mildly divergent and three as highly divergent. While the recommended classification uses four reference groups, the five group solution would have been preferred as it performed a little better with test and *simpacted* data. However, the currently available habitat data were unable to discriminate the groups sufficiently using the five group solution.

Future Model Recommendations

- One of the issues with habitat data are the constraints placed upon available data that has the potential to be modified by human activity. One area that could be investigated to expand on available data would be the use of more relevant climate-based data. Currently, the data being used tend to be long-term averages. While this gives a good indication of the general climate, it is not likely to relate to the much shorter life cycles of the invertebrates with life cycles of one or two years. Some investigation of more biologically relevant climate data would be appropriate for future model development.
- The group sizes used are somewhat unbalanced with two small groups of 12 (Gp 1) and 15 sites (Gp 4) and a very large group of 61 sites (Gp 2). Any further sampling should be focused on sites with the characteristics of Group 1 (Ecoregions 137, 183, 199) and Group 4 (Ecoregions 137, 138, 145, 199).
- There should be some discussion of more appropriate and biologically relevant measures of climate.
- Future sampling in the Peace River watershed focus on areas and sites typical of those occurring in reference Groups 1 and 4. These groups are the smallest in the model, and Group 1 had high Type 2 error rates with the simulated data, which could be associated with the small group size.

- In order to provide more balance between Type 1 and Type 2 errors, some consideration be given to changing the ellipse used to define departure from reference from 90% to a lower value (e.g. 75-80%). This would provide balance between protection to the environment and detection of effects of development.

4. LITERATURE

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APPENDIX 1: DATA COLLECTION, ANALYSIS AND QUALITY ASSURANCE

A. Field Collection

CABIN Study Name	**EC-NEBC Baseline WQ Monitoring**	**BCMOE-Omineca/Peace Region**	**BC MOE-FSP Skeena Region**
Agencies	Environment and Climate Change Canada	BC Ministry of Environment and Climate Change Strategy	BC Ministry of Environment and Climate Change Strategy
Date range	2018	2008 – 2018	2006
Sampling season	Late August/Early Sept	Late August/Early Sept	Late August/Early Sept
# reference samples	23	89	1
Certified samplers (Y or N)	Y	Y	Y
Certified team leader (Y or N)	Y	Y	Y
400 um kicknet (Y or N)	Y	Y	Y
Preservative	Formalin	Ethanol/Formalin	Formalin

B. Macroinvertebrate Identification

CABIN Study Name	**EC-NEBC Baseline WQ Monitoring**	**BCMOE-Omineca/Peace Region**	**BC MOE-FSP Skeena Region**
Taxonomist	Cordillera Consulting	Fraser Environmental/Cordillera Consulting	Fraser Environmental
Marchant Box used (Y or N)	Y	Y	Y
Subsample count	300	300	300
10% of reference samples sent to National Lab for QA	Y	Y	N
Reference Collection maintained	Y	N	N

C. GIS Analyses

GIS analyses were done by Chris Steeves, GeoSpatial Services, Thompson Okanagan Region, B.C. Ministry of Forests, Lands, Natural Resource Operations and Rural Development.
Watersheds were delineated using ArcGIS 10 ArcHdyro 2.0 (ESRI 2010). Delineations were based on 20 m resolution digital elevation models (DEM) and a 1:50,000 scale hydrological network. The DEM was subjected to pre-processing which "burned in" the stream network into the DEM and filled sinks to improve flow modeling. The corrected DEM was used to calculate flow direction and flow accumulation to carry out the terrain procession steps to model catchment areas (AcrHydro 2010). The delineated catchments were described using the GIS layers in the table below collected from publicly available sources

Description	**Scale/ Resolution**	**Source**
Basin Morphometry	20 m	Area (km^2) and perimeter (km) were calculated from delineated catchments, as described above
Hydrology	1:50,000	www.geobase.ca – National Hydro Network Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010) (Variables: stream order based on 1:50,000, stream length in m)
Bedrock	1:100,000	BC Ministry of Energy and Mines – BC Digital Geology Maps 2005 - http://www.empr.gov.bc.ca/Mining/Geoscience/PublicationsCatalogue/DigitalGeologyMaps/Pages/default.aspx Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010) (Variables: Intrusive, Volcanic, Metamorphic, Sedimentary, Ultramafic, Alluvium as % of upstream watershed area).
Geology	1:5,000,000	Geoscape Canada - A Map of Canada's Earth Materials - Surficial and bedrock geology. http://geogratis.gc.ca/api/en/nrcan-rncan/ess-sst/9636bf0e-aba3-59c3-9736-1ac66bab4ac0.html?pk_campaign=recentItem Using the ArcGIS 10.1 intersect function, all vector layers were intersected with the delineated upstream basins to derive attributes within each catchment.
Climate	7.5 km	Natural Resources Canada (contact: Dan McKenney – dan.mckenney@nrcan-rncan.gc.ca) Summarized using rasterized grids describing temperatures normal from 1971-2001 giving long term monthly and annual averages of temperature and precipitations. Grids were used to generate average, minimum and maximum values for each catchment using Geospatial Modelling Environment v. 0.6.0.0 (Beyer 2012). Where catchments were completely contained within one grid cell, catchments were assigned the value of that cell (Variables: Min & max temp for each month, precip for each month, annual precip, annual min, max and mean temp).
Topography	20 m	www.geobase.ca – Digital Elevation Data Described using 20 m DEM and the Geospatial Modeling Environment v. 0.6.0.0 (Beyer 2012) to describe the maximum and minimum elevation in each catchment. Percent slope was generated from the DEM using the slope function in ArcGIS (ESRI 2010) and classified into one of four groups based on the slope value for each grid cell (i.e. 60%) (Variables: Areas of each class within each catchment; Elevation min, max, mean; and Slope min, max, mean).
Land Use	1:2,000,000	www.geobase.ca – Land Cover Intersected with catchment boundaries using intersect function in ArcGIS (ESRI 2010) (Variables: all national landcover variables as % of upstream watershed area).

D. Laboratory Analyses

NOT APPLICABLE: Parameters analyzed in water samples collected by each agency differed and were not used in the development of this model.

E. Statistical Analyses

Statistical Programs used:

- Excel - data manipulation and storage
- PATN V.3.12 - classification and ordination of test sites for assessment
- PRIMER 6 - classification, nMDS ordination, ANOSIM, SIMPER: for habitat variables BEST (BVSTEP) for matching invertebrate and habitat resemblance matrices and LINKTREE for classifying habitat data
- SYSTAT 11 - discriminant analysis and plotting BEAST assessments with probability ellipses

The Peace model full technical report and proposed model was reviewed and approved by the CABIN Science Team August 1, 2019