Nutrient Levels in Canadian Coastal Waters
and
Development of Nutrient Standards for Coastal Waters Receiving Agricultural Inputs

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SUMMARY

The National Marine Nutrient Database recently developed by Environment Canada was analyzed to examine regional trends in the extent of nutrient over-enrichment in Canadian nearshore coastal waters, and to provide a reference basis for nutrient levels that may be used to establish initial regional guidelines and/or reference conditions for dealing with coastal systems exhibiting symptoms of nutrient over-enrichment. In addition, a case study using nearshore systems in Prince Edward Island was carried out in an attempt to establish nutrient standards based on a coastal system's susceptibility to nutrient over-enrichment.

The analyses of the National Marine Database consisted of mapping the levels of four parameters typically used to assess nutrient over-enrichment (nitrogen, phosphorus, chlorophyll *a* and dissolved oxygen concentration), and basic statistical analyses to determine the degree of regional differences between these parameters. The results suggest that, although some regions of Canada exhibit evidence of nutrient over-enrichment, especially Prince Edward Island where costal watersheds are characterized by porous soils and high levels of agricultural activity, most Canadian nearshore waters do not appear to be exhibit symptoms of nutrient over-enrichment as a result of anthropogenic activities. In addition, there is some evidence that West coast nearshore waters have higher nutrient concentrations than East coast nearshore waters, but the reasons for this are not readily evident based on information currently available.

The results of the case study carried out for PEI nearshore systems illustrated that, although coastal systems having a high level of agricultural activity within their watershed are more susceptible to nutrient over-enrichment, the response to nutrient over-enrichment depends on physical characteristics of the system that determine its ability to either dilute or export nutrients entering the system. An approach was developed to establish nutrient standards for coastal systems based on their potential susceptibility to nutrient over-enrichment.

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1. Background

Marine eutrophication is a growing concern in many estuaries, inlets and coastal systems on both the east and west coasts of Canada. Agricultural practices are often thought to play a prominent role in nutrient over-enrichment of coastal systems. This is particularly true in some areas of Eastern Canada, such as Prince Edward Island, where nutrient over-enrichment caused by runoff of agricultural fertilizers has resulted in extensive growths of marine algae and the resulting development of anoxic/hypoxic conditions in many coastal systems. Environment Canada's Agricultural Policy Framework (APF) includes the need to develop a suite of non-regulatory standards to specify desired levels of environmental quality required in waters receiving inputs from agricultural areas, and for validating best management practices.

Preliminary work carried out by Environment Canada to address this problem has involved identification of existing datasets on nutrient levels and other parameters relevant to marine eutrophication (Brylinsky et al. 2005), collation of this data into a Microsoft® Access National Marine Nutrient Database, and an initial analysis of the data to determine regional levels and patterns for nearshore Canadian waters (Brylinsky et al. 2006). The initial analysis identified potential errors in the database related primarily to inconsistencies in the conversion factors used during compilation of the various databases. In addition, the original analysis of regional levels and patterns was limited to waters having salinities $\leq$30 psu. It is possible that this criterion may have excluded relevant data from nearshore areas in some regions.

An additional initial study involved examining the relationship between parameters related to nutrient over-enrichment of nearshore waters and the level of agricultural activity within the corresponding watershed for a number of watersheds in Prince Edward Island (Brylinsky et al. 2006). Although preliminary, this analysis showed a general correspondence between agricultural activity and nutrient enrichment.

The major objectives of the project reported on here were to:

1. Evaluate the National Marine Nutrient Database for possible errors and make the necessary corrections. This included comparing the Access database to the original databases from which it was compiled to ensue that the appropriate conversion units were used and correcting any errors identified,

2. Examine the relationship between salinity and the distribution of data within the National Maine Nutrient Database to determine the salinity level most appropriate and representative of marine nearshore waters,

3. Prepare a set of maps illustrating spatial trends in the parameters relevant to marine nutrient over-enrichment contained within the National Marine Nutrient Database,

4. Using the percentile approach developed by the USEPA and recommended by the Canadian Council for Ministers of the Environment for use in Canada, calculate reference/background levels for parameters revenant to nutrient over-enrichment and, based on these results, recommend criteria for these parameters,

5. Develop an index of trophic status for each site for which the required data are available and produce maps showing the regional trends in this index and,

6. Using data available for agricultural activities within Prince Edward Island coastal watersheds, determine the degree to which the levels of nutrient over-enrichment parameters are correlated to agricultural activities, and determine if an approach can be developed to establish nutrient standards for these systems based on their susceptibility to nutrient over-enrichment.

2. Validation of the National Marine Nutrient Database

The National Marine Nutrient Database was compiled from 19 different sources which included various Federal and Provincial agencies as well as numerous consulting firms. By far the largest portion of the data was obtained from the MEDS and BIOCHEM databases developed by the Department of Fisheries and Oceans. The compiled database contains more than 600,000 records on 24 parameters and includes the location and time of collection for each record. The parameters contained in the database fall into four categories: nutrients (various forms of phosphorus, nitrogen and silicate); carbon (organic and inorganic forms); algal biomass (mainly as chlorophyll *a*); dissolved oxygen; and water transparency (as Secchi disk depth).

Based on the results of an initial analysis of this database (Brylinsky et al. 2006), it appeared that some of the data compiled for the parameters most relevant to analyses of marine nutrient over-enrichment and trophic state (nitrate, phosphate, chlorophyll *a* and dissolved oxygen concentration) may have not been standardized to common units of measurement prior to collation into the main database. To validate the main database prior to any further analyses, the data contained within the original databases, as well as the conversion factors used in compiling the final database, were examined to determine if any errors had been made.

The only errors found were for chlorophyll *a* which was reported as mg/L for one database whereas in all other databases it was reported as µg/L. The main database was therefore corrected so that the measurement unit for all of the chlorophyll *a* data is µg/L.

3. Determination of Appropriate Records for Nearshore Waters

Many of the more than 600,000 records contained in the National Marine Nutrient Database are for sites located well offshore. In order to determine which records best represent nearshore marine waters, an analysis of the distribution of data based on various levels of salinity was carried out. The number (Table 3.1 and Figure 3.1) of sites having salinity values ranging from ≤ 30 to ≤35 psu was determined and mapped at 1 psu intervals, and from this a decision was made as to which salinity levels should be included in the analysis. The greatest amount of data on all of the parameters is contained in the ≤30 salinity range and the least is contained in the >34-≤35 range. About 93 % of the data is contained within the ≤33 range.

The final decision was to include all records for data collected at sites within 10 km of the shoreline having salinities >30 and ≤33 psu and all sites having salinities ≤30 psu since these sites are highly likely to contain significant amounts of freshwater inputs. These two criteria was considered to best represent nearshore waters since offshore waters typically have salinities >34 psu. In addition, data on nitrate, phosphate and chlorophyll *a* were limited to surface waters (depths ≤6 m), which is about the depth where there is sufficient light for photosynthesis to occur, and data for dissolved oxygen concentration was limited to bottom waters (depths ≥ 6 m) since surface waters are seldom depleted of dissolved oxygen, especially when the water column is stratified. The resulting database contained a total of 84,718 records on nitrate, phosphate chlorophyll *a* and dissolved oxygen concentration.

Table 3.1 Number of records for each parameter within each salinity category

Salinity	Chlorophyll *a*	Dissolved Oxygen	Nitrate	Phosphate
≤30	5399	9756	8513	10515
>30-≤31	2455	3789	3412	4028
>31-≤32	3883	6245	5824	6001
>32-≤33	4065	1740	4866	5227
>33-≤34	1460	1322	1344	1715
>34-≤35	184	129	234	398

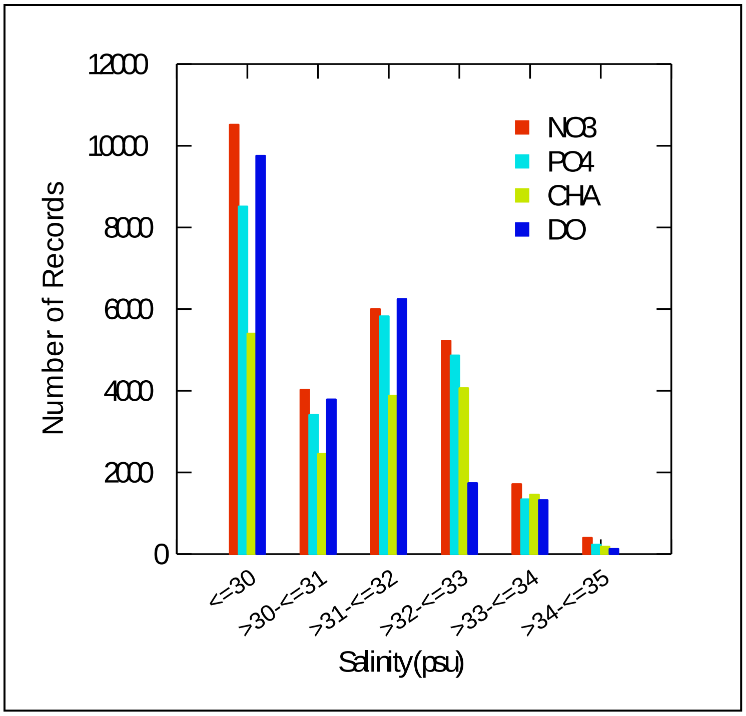

Figure 3.1 Number of each parameter for each salinity level.

4. Mapping of Trophic State Parameters

Maps were generated using the ArcGIS 9 Geographic Information System software. Base maps were obtained from the ESRI Data and Maps Media Kit that accompanies this software package. Data was displayed using NAD 27 coordinates.

Maps were produced on a regional basis in order to produce larger scale maps that allowed for better resolution of the data. The regions selected were East, Northeast, West and Northwest. The geographic coordinates used to define each region are listed in Table 4.1 and the regions depicted in Figure 4.1.

Table 4.1 Coordinates used to define each region.

REGION	Latitude	Longitude
East	≤ 52.00	≥ -77.68
Northeast	> 52.00	≥ -77.68
West	≤ 52.00	< -77.68
Northwest	>52.00	< -77.68

Figure 4.1 Delineation of regions.

The parameters chosen for mapping were those typically used to assess trophic state. These included two causal[1] parameters (nitrate and phosphate concentration) and two response[2] parameters (chlorophyll *a* and dissolved oxygen concentration).

Figure 4.1 illustrates the spatial distribution of data available for analysis. The greatest amount of data available is for the East region and the least amount of data available is for the Northern regions. The spatial distribution of each of the four trophic state parameters is illustrated in Figure 4.2 and follows the same trends. The East is well represented for all four parameters, but the West, with the exception of dissolved oxygen concentration, is poorly represented for most of the parameters. There is only one value of chlorophyll *a* concentration for the West, and relatively little chlorophyll *a* data for the Northwest. Table 5.1 provides more details of the actual numbers of data for each region.

[1]The term 'causal' refers to parameters that are considered to be the main causes of nutrient over-enrichment.

[2]The term 'response' refers to parameters that are considered to be indicative of the degree of nutrient over-enrichment

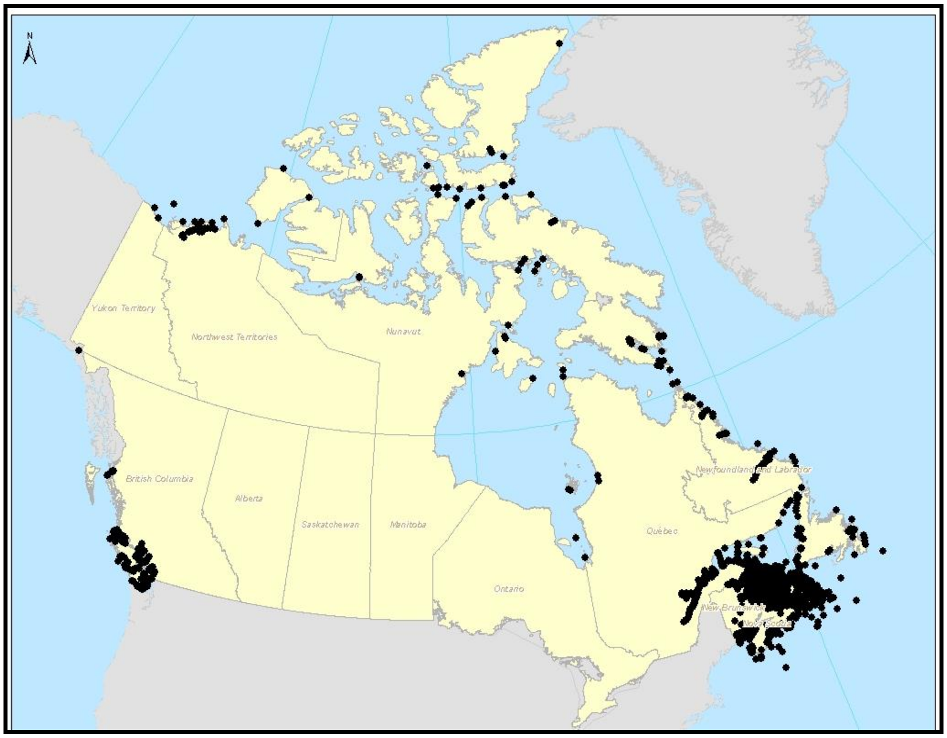

Figure 4.2 Spatial distribution of data available for mapping.

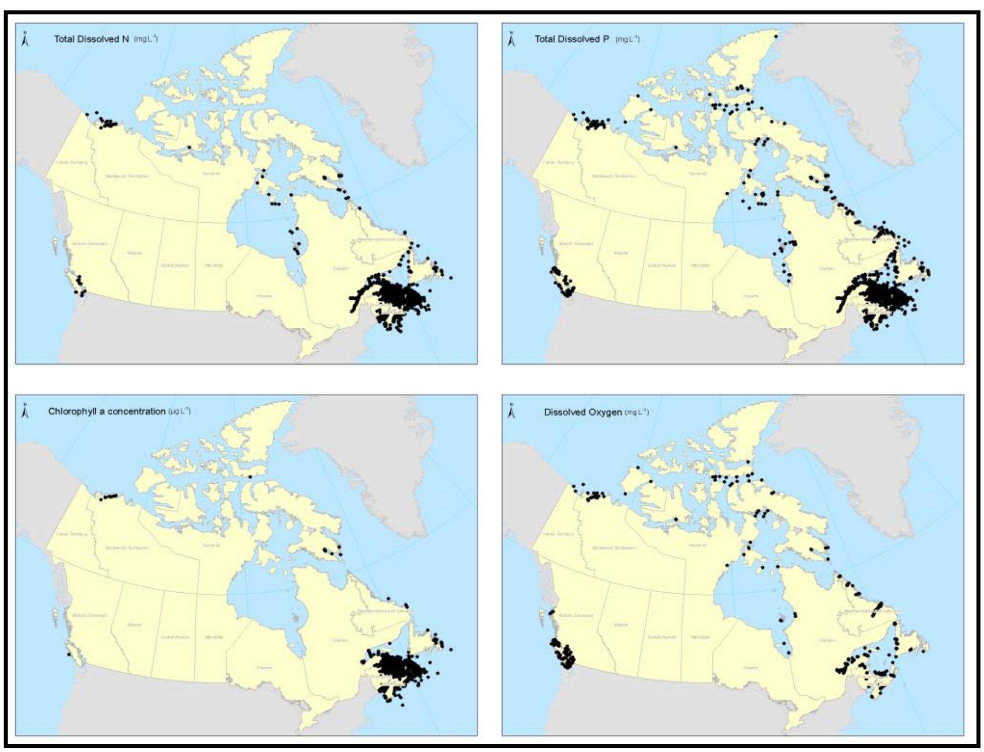

Figure 4.3 Spatial distribution of data for each parameter.

Mapping of the relative level of trophic state parameters was based on the trophic state level criteria proposed by Bricker et al. (1999). These are listed in Table 4.2. These criteria were established on the basis of an extensive survey of US coastal waters and are considered to represent general guidelines for determining the degree of nutrient over-enrichment within a particular coastal system.[1]

Table 4.2 Eutrophication criteria based on guidelines proposed by Bricker et al. (1999).

Degree of Nutrient Over-enrichment	Total Dissolved N ($mg\ L^{-1}$)	Total Dissolved P ($mg\ L^{-1}$)	Chl *a* ($ug\ L^{-1}$)	Dissolved Oxygen (mg/L)
Low	$0 - \leq 0.1$	$0 - \leq 0.01$	$0 - \leq 5$	> 4
Medium	$>0.1 - \leq 1$	$>0.01 - \leq 0.1$	$>5 - \leq 20$	-
High	>1	>0.1	>20	≤ 4

Appendix I contains a series of maps showing the spatial distributions of trophic state levels for each parameter for each region. Figure 4.4 illustrates the percentage of trophic categories falling within each region for each parameter, and Figure 4.5 illustrates the mean value of each parameter for each region in relation to the Bricker et al. (1999) guidelines.

For the East and West regions, the majority of nitrate levels fall within the medium category. For the Northeast and Northwest, most are about equally divided into the low and medium categories. The West and Northwest are the only regions which contain a significant percentage of values within the high category.

For phosphate, the East and Northeast regions contain levels that fall mostly within the medium category and the West region contains mostly high levels. The Northwest region contains about equal numbers within the medium and high categories. Only the Northwest contains a significant percentage of nitrate values within the low category.

Chlorophyll *a* levels are mostly low in all regions (note that there is little chlorophyll *a* data for the West region). Relatively few values fall within the medium and high categories for any region.

[1] The values for dissolved inorganic nitrogen available within the main database are slightly different than those used in the Bricker et al. (1999) guidelines. Total dissolved nitrogen consists primarily of ammonia, nitrite and nitrate nitrogen. The main database, however, contains relatively little data on ammonia and nitrite nitrogen so the analysis was limited to nitrate nitrogen concentrations. This, however, should make little difference since ammonia and nitrite are typically present in significant amounts only under conditions of low dissolved oxygen concentration which was relatively rare within the database.

Dissolved oxygen levels are mainly low for all regions. Note that a low level in this case is indicative of a low level of nutrient enrichment rather than a low level of dissolved oxygen. Like chlorophyll *a*, for all regions very few values fall with the medium and high categories.

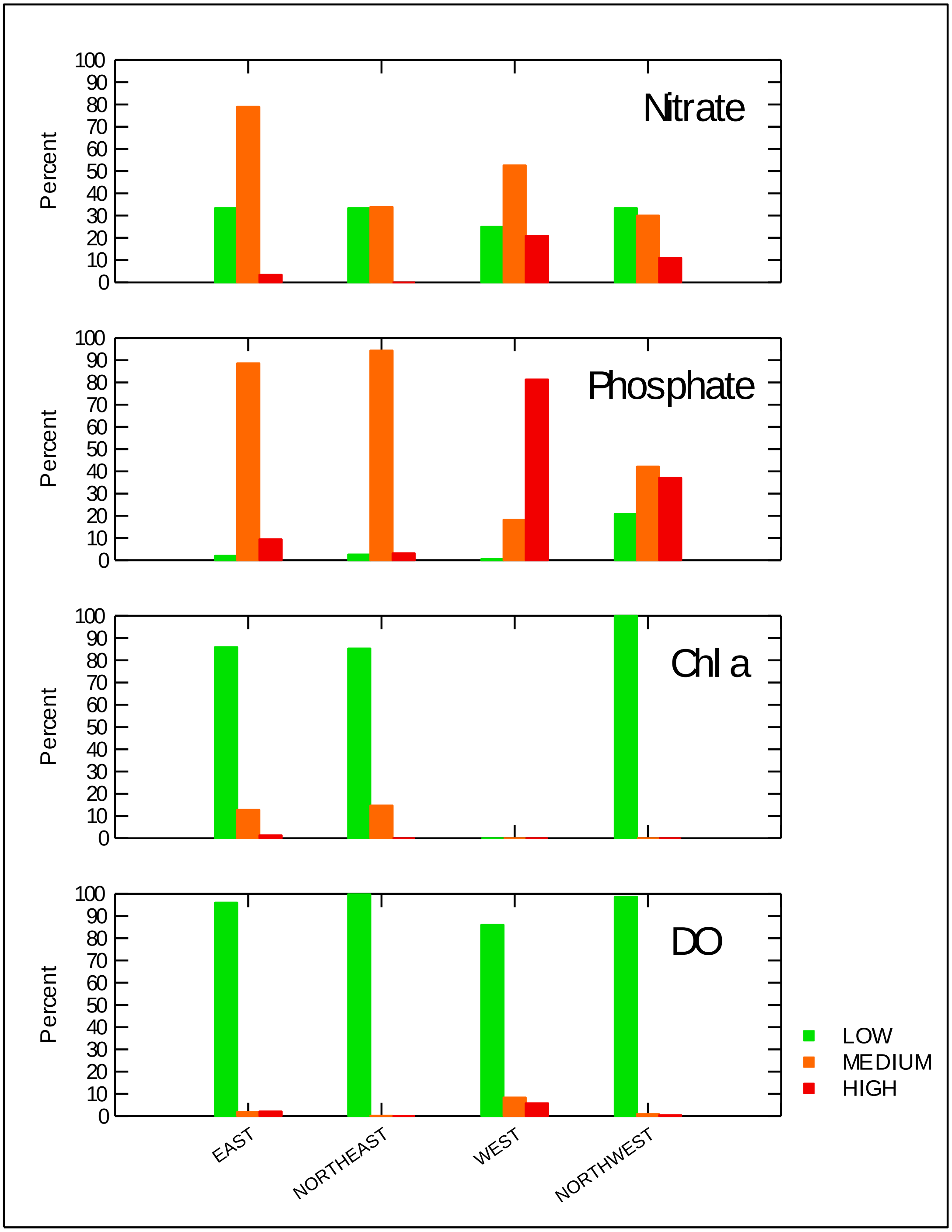

Figure 4.4 Percentage of trophic state levels contained in each category.

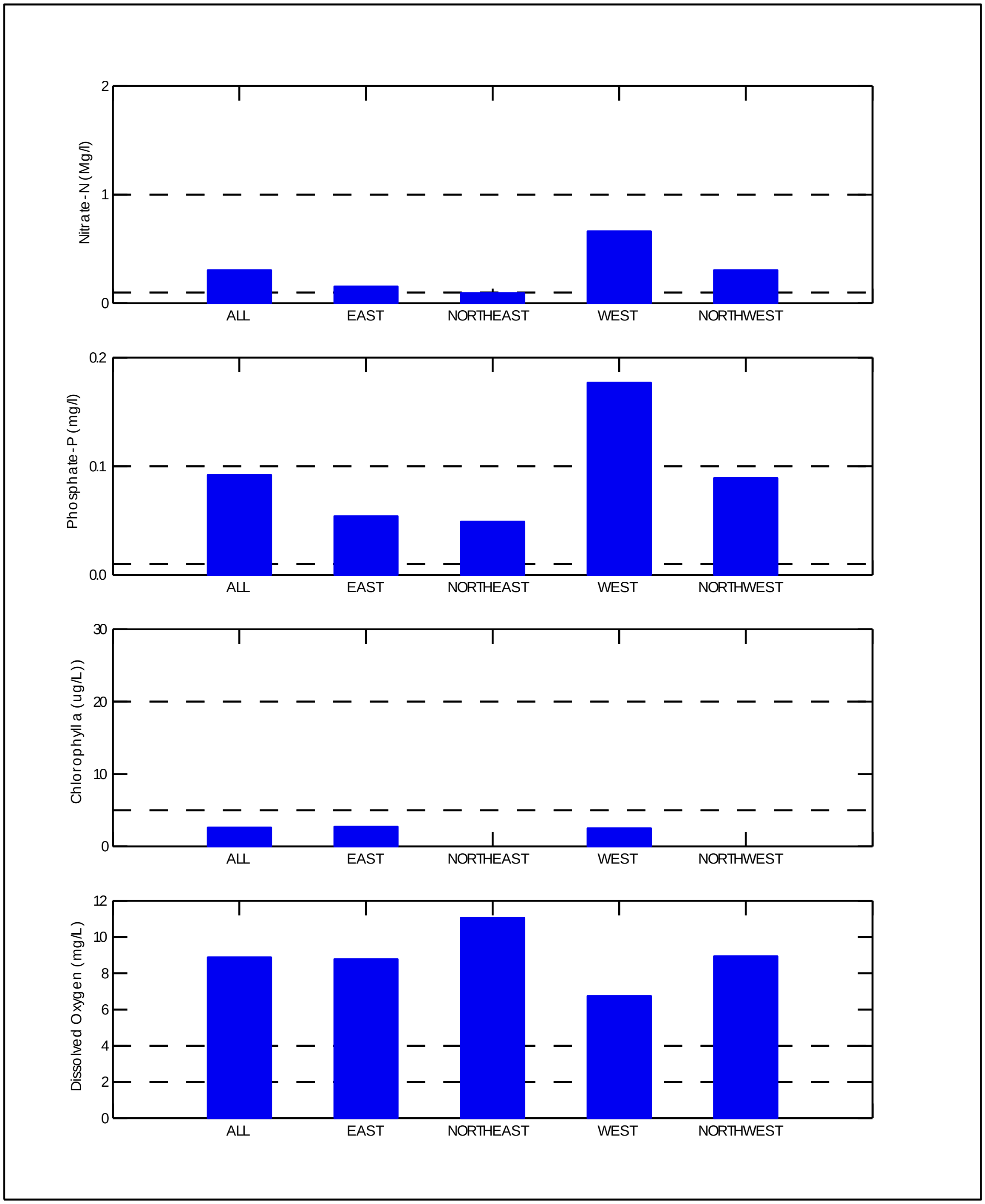

Figure 4.5 Mean values of trophic state parameters for each region (dashed lines represent the divisions between the nutrient criteria categories proposed by Bricker et al. 1999).

Although it is likely that in some regions, notably the nearshore areas of Prince Edward Island, land based nutrient inputs are responsible for the generally high nutrient levels in Canadian nearshore waters, the influence of upwelling deep oceanic water, which is known to occur along both the East and West coasts of Canada, may also play a major role.

The lower mean dissolved oxygen values within the Western regions relative to other regions suggests that nutrient over-enrichment may be a problem in some areas of this region. The data available for the Western region may, however, be somewhat biased. The abundance of dissolved oxygen concentration observations relative to other parameters within the Western regions suggests that this data was collected as part of surveys that were specifically looking for areas of depleted dissolved oxygen levels. Much of this data was supplied by consulting firms and was collected as part of monitoring programs for various types of industries that release effluents into coastal waters. In contrast, most of the data for the Eastern regions was collected by Federal laboratories as part of routine exploratory surveys. As a result, it is difficult to reach any definitive conclusions from the regional analyses carried out using this database without having additional information on the objectives and potential biases of the sampling programs under which the data was collected.

5. Development of Nutrient Standards for Canadian Nearshore Waters

The relatively high levels of the two causal parameters, nitrate and phosphate, together with the relatively low levels of the two response parameters, chlorophyll *a* and dissolved oxygen, present somewhat of a dilemma and suggest that direct application of the Bricker et al. (1999) nutrient criteria may not be appropriate for developing nutrient standards for Canadian nearshore waters. For some reason, relatively high nutrient concentrations do not result in high chlorophyll *a* levels or depressed levels of dissolved oxygen within Canadian waters to the same extent they do in more southern latitudes. This may be at least partially due to the colder waters and shorter growing season in northern latitudes. It would be useful to further evaluate the relationships between nutrient levels and chlorophyll *a* and dissolved oxygen concentrations for each region to see if any significant relationships exist between these parameters. This may require using subsets of the database that are limited to data collected during the growing season.

An approach to developing nutrient standards has been developed by the USEPA (USEPA 2001) and is based on an analysis of the frequency distribution of each of the causal and response parameters relevant to nutrient over-enrichment. This approach has recently been adopted by the Canadian Council for the Ministers of the Environment (2007) to establish nutrient standards for Canadian nearshore waters. In this approach, where the data is known to have come from relatively pristine unimpacted sites, the upper 75^{th} percentile is typically chosen as a reference condition guideline. If the data is from both pristine sites and sites known to be subjected to some anthropogenic impacts, the lower 25^{th} percentile is typically chosen.

Table 5.1 contains a statistical summary for each parameter for each region. Frequency and quantile plots for the same are contained in Appendix II. Also listed are the statistics for waters having salinities ≤30 psu, waters having salinities >30 - ≤33 psu and located within 10 km of the shoreline, and for both datasets combined.

Median nitrate values for the West region are significantly higher, by a factor of about ten, than those for the Northwest and both Eastern sites. Median phosphate values are also higher for the West regions, but only by a factor of about two. The median phosphate values for the Eastern and Northwestern regions are within the same range. The median chlorophyll *a* value for the Northwest is very low compared to the Eastern regions. Within the Eastern Regions the Northeast median is significantly higher that the East region. The median dissolved oxygen values vary little among regions except for the West region where it is considerably lower than the median value for all other regions.

In summary, the West region exhibits the highest median values for nutrients and the lowest median values for dissolved oxygen. As discussed in Section 4, this trend may be related to possible differences in the objectives of the programs for which the data was collected.

In comparing median values for low and high salinity waters, there is little difference between nitrate values for the two Eastern regions, but within the West regions the median value is significantly higher for higher salinity waters. For phosphate, the only significant difference in medians is for the Northwest region where the median for the higher salinity waters is an order of magnitude greater than the median for lower salinity waters. For chlorophyll *a*, within the East region the median value for the lower salinity waters is about three times that of the higher salinity waters which is likely an indication of the influence of freshwater nutrient inputs. There is insufficient chlorophyll *a* data for the Western regions to compare differences related to salinity. For dissolved oxygen, the only significant difference is for the West region where the median for higher salinity waters is lower than the median for the lower salinity waters.

With respect to the feasibility of utilizing the information contained in Table 5.1 as a basis for reference or background levels for parameters related to nutrient over-enrichment of Canadian nearshore waters, this is likely to be appropriate for the Eastern region, but not for the Western region. The higher median values of nutrients for the Western region, together with the low median for dissolved oxygen, strongly suggest that the databases compiled for the Western region are likely to be from numerous sites that are far from pristine.

Table 5.1 Number of records and percentiles for each region and salinity range**.**

Region	Dataset	Nitrate –N (mg/L)				Phosphate-P (mg/L)				Chlorophyll *a* (ug/L)				Dissolved Oxygen (mg/L)			
		Number	25^{th} Percentile	Median	75^{th} Percentile	Number	25^{th} Percentile	Median	75^{th} Percentile	Number	25^{th} Percentile	Median	75^{th} Percentile	Number	25^{th} Percentile	Median	75^{th} Percentile
East	PSU ≤30	7159	0.009	0.038	0.154	4507	0.023	0.040	0.065	5102	1.0	2.5	5.5	728	6.9	8.5	9.4
	PSU >30 - ≤33*	12502	0.010	0.040	0.213	11090	0.028	0.047	0.073	9734	0.4	0.8	1.8	1079	8.1	9.5	10.8
	All East	19661	0.010	0.034	0.161	15597	0.027	0.043	0.071	14836	0.5	1.1	3.0	1807	7.7	9.0	10.3
Northeast	PSU ≤30	241	0.001	0.011	0.087	559	0.022	0.032	0.049	196	0.7	1.1	1.9	212	10.1	10.3	10.6
	PSU >30 - ≤33*	1170	0.007	0.050	0.148	1912	0.032	0.048	0.068	669	1.1	2.1	3.6	317	10.9	11.5	12.3
	All Northeast	1411	0.006	0.038	0.144	2471	0.029	0.045	0.065	865	0.9	1.7	3.3	529	10.3	10.9	11.9
West	PSU ≤30	275	0.155	0.036	0.949	4257	0.106	0.193	0.244	Only one data value available				8243	6.7	7.9	8.5
	PSU >30 - ≤33*	204	0.037	0.211	0.794	982	0.129	0.187	0.227					7797	4.8	5.8	6.6
	All West	479	0.087	0.310	0.880	5239	0.109	0.191	0.241					16040	6.0	7.0	7.9
Northwest	PSU ≤30	838	0.012	0.037	0.174	1192	0.008	0.038	0.101	102	0.3	0.5	0.7	573	8.9	10.3	11.6
	PSU >30 - ≤33*	227	0.167	0.583	1.209	453	0.083	0.140	0.214	No Data				2582	7.5	8.9	10.0
	All Northwest	1065	0.120	0.050	0.384	1645	0.017	0.064	0.148	102	0.3	0.5	0.7	3155	7.7	9.2	10.3

*Limited to sites located within 10 km of the shoreline.

6. Composite Index of Trophic State

In order to develop a better visual representation of the spatial variations in trophic status, an attempt was made to derive a composite index of trophic state based on the Bricker (1999) trophic state parameters listed in Table 4.2. An index of trophic state could be developed for each parameter by assigning a value of 1, 2 or 3 corresponding to a low, medium and high trophic index for each parameter, and then summing the values. Sites having all of the parameters falling into the low category would have an index of 4 while a site being high in all categories would have an index of 12. The summed trophic status for each site in the database could then be mapped according to the following categories: 4 - ≤6, >6 -≤ 10, and >10 ≤12 which would correspond to low, medium and high trophic states. However, this became problematic because the dissolved oxygen data was selected to include only those data collected at depths ≥6 m and chlorophyll *a* concentration is not typically measured in bottom waters which resulted in only 25 records for which all four parameters were measured at the same site and time. As a result, the index was calculated by excluding dissolved oxygen and the summed trophic index was revised as follows: low, 1 - ≤3; medium, >3 - ≤ 6; and high >6 – 9.

Of the 84,902 records contained within the main database, there were 3,246 instances in which all three parameters were measured at the same site and time. However, because no chlorophyll *a* data was available for the West region, this dataset included only data for the East, Northeast and Northwest regions. Most of the data (2,760 records) is for the East region. The Northeast and Northwest regions had 385 and 101 records, respectively.

Figure 6.1 contains scatterplots showing the relationship between each trophic parameter for each region as well as for all regions combined. Although there is an obvious positive relationship between phosphate and nitrate, except for the Northwest region, neither of these nutrients exhibits a clear relationship to chlorophyll *a* levels.

When the composite index was calculated for this dataset, all but four of the values fell within the medium range, largely as a result of the relatively high values of phosphate and low values of chlorophyll *a*. As a result, this approach proved unsuccessful and suggests that the Bricker et al. (1999) nutrient criteria for evaluating trophic status are not applicable for Canadian nearshore waters.

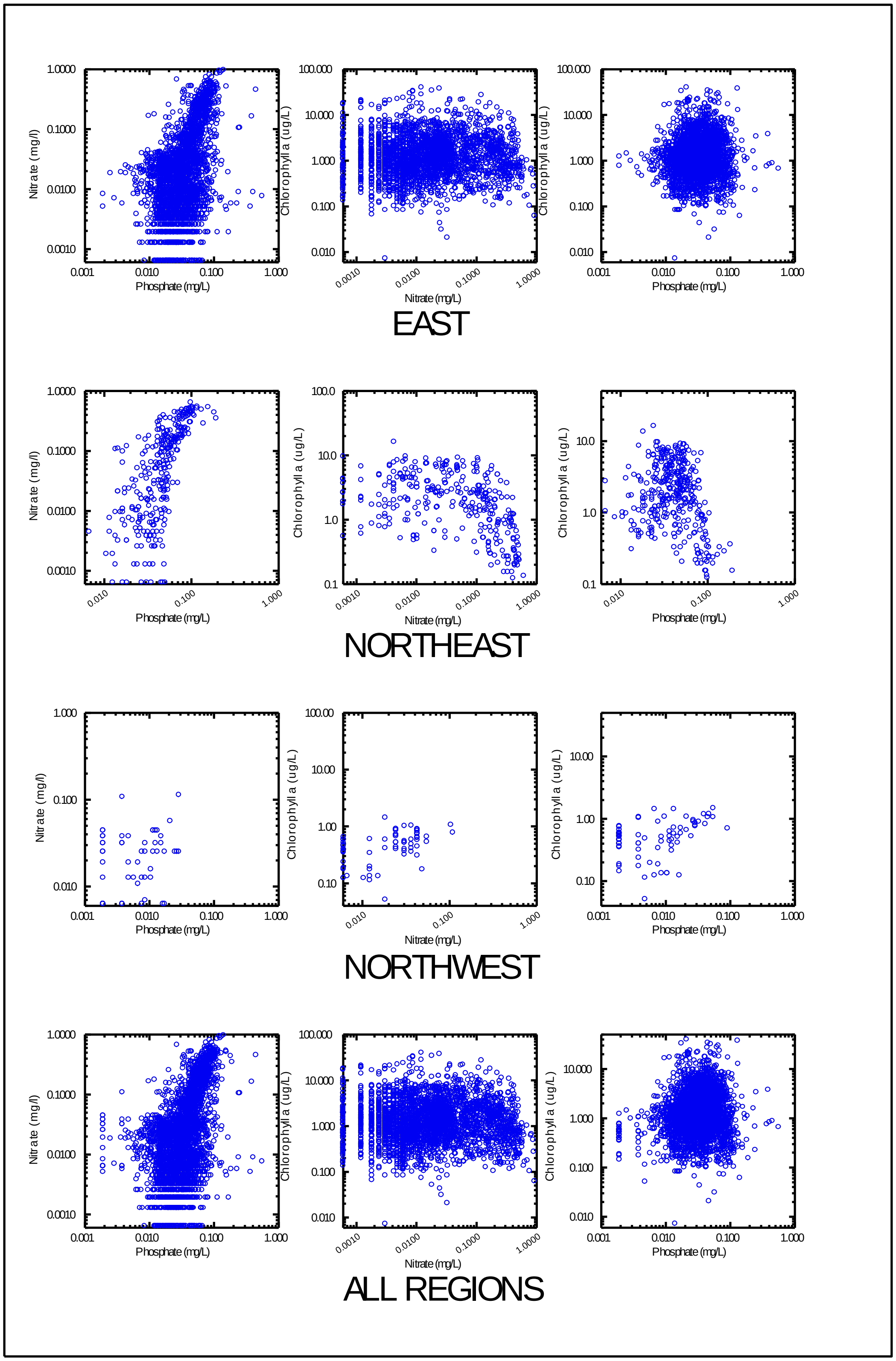

Figure 6.1 Relationships between trophic parameters.

7. Relating Nearshore Nutrient Over-enrichment to Agricultural Practices

A major objective of this study was to determine if nutrient standards could be developed for a coastal system subjected to nutrient enrichment as a result of agricultural activities within its watershed. Data available to test this is available for Prince Edward Island which has been experiencing nearshore nutrient enrichment problems for the last several decades, and has developed an extensive monitoring program and corresponding database for many of its coastal systems. Data on agricultural land use within its major watersheds is also available.

A preliminary analysis of these databases (Brylinsky et al. 2006) showed that there were a number of strong relationships between causal and response parameters, and that the degree of nutrient over-enrichment generally increased in proportion to the percentage of agricultural activity within a watershed. However, because there are no pristine or near pristine coastal systems in PEI, and the existing databases do not provide adequate historical data on the development of nutrient over-enrichment, it was not possible to apply the USEPA or recently developed CCME approach to establishing nutrient standards for these systems. In the following, an alternative approach is carried out involving a detailed analysis of these databases which also takes into account the potential susceptibility of the coastal system to nutrient over-enrichment based on its physical characteristics. The basic approach was to (1) determine the trophic status of each coastal system; (2) develop an index of the susceptibility of each system to nutrient over-enrichment, and (3) based on this information, determine if a relationship exists between agricultural activity, trophic status, and susceptibility that could be used to establish nutrient standards.

7.1 Development of the Database

The database required to apply this approach includes information on the following:

1. Data on each of the four trophic state parameters for each system,
2. Information on the physical factors of each system that influence its susceptibility to nutrient over-enrichment, and
3. Information on the level of agricultural activity within the watershed of each system.

For marine systems, trophic status is typically evaluated using the four primary response and causal parameters associated with nutrient over-enrichment: dissolved inorganic nitrate, dissolved inorganic phosphate, chlorophyll *a* and dissolved oxygen. This information was obtained from databases developed by the PEI Department of Environment, Energy and Forestry.[1]

[1]For this analysis total nitrogen and total phosphorus concentration were used rather than the dissolved inorganic forms because they are the preferred forms measured within PEI and data on the dissolved inorganic forms is very limited.

The degree to which a coastal system is susceptible to nutrient over-enrichment is largely a function of its nutrient input (i.e., loading), its ability to dilute nutrients entering the system, and its ability to flush nutrients out into offshore waters. Nutrient loading depends for the most part on the types of landuse activities that exist within a watershed. Dilution potential is a function of the relative volume of water inputs from the watershed and the volume of the receiving water body. Flushing potential is a function of the relative volume of offshore water entering the receiving water body on each tidal cycle and the volume of the receiving water body. Although there exists little data on nutrient loading, a rough estimate of potential loading can be obtained based on the percentage of agricultural activity within a watershed if it is assumed that most nutrient runoff results from the application of agricultural fertilizers. The morphological parameters required to compute the volumes for estimates of dilution and export potential were obtained from hydrographic and tidal charts.

Drainage basin area and the aerial percentage of agricultural activity for each watershed were obtained from databases developed by the PEI Department of Agriculture, Fisheries and Aquaculture. Appendix III contains this database.

Of the 21 major watersheds in PEI, 17 had sufficient data to be included in the analysis. Those excluded were considered to either have too little or no recent data on the required trophic state parameters, or there were no hydrographic charts available for their coastal systems to enable computation of the morphological characteristics required to calculate dilution and export potentials. The location of each watershed is shown in Figure 7.1

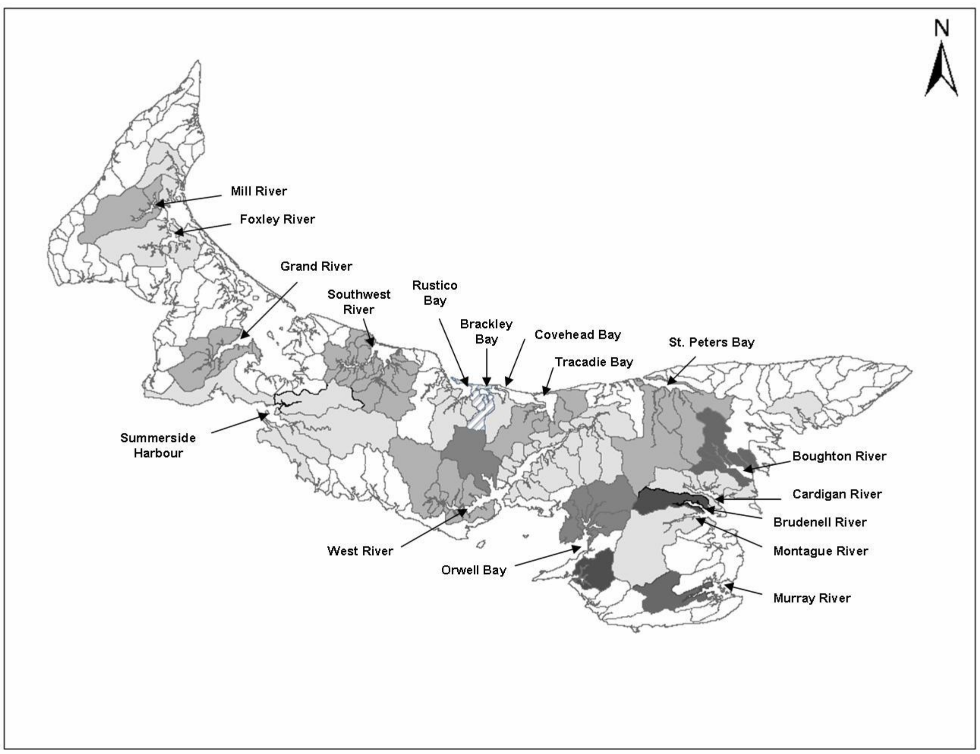

Figure 7.1 Location of watersheds (shaded areas) and offshore sites (arrows) included in the analysis.

7.2 Evaluation of Trophic Status

Table 7.1 lists the mean value of the trophic state parameters for all sampling stations for each watershed. Also listed is the percentage of dissolved oxygen concentration measurements that were ≤4 mg/L, an indication of hypoxic or anoxic condition.

Because the two nutrient parameters are for total rather than dissolved inorganic forms, the Bricker et al. (1999) criteria do not apply and could not be used in evaluating trophic status. Evaluation of the trophic status of each system was therefore based only on the two response parameters, chlorophyll *a* and low dissolved oxygen concentration. Sites in which the percentage of low dissolved values was zero were evaluated using the Bricker (1999) criteria for chlorophyll *a*. Sites which had dissolved oxygen values ≤4 mg/L were rated as high.

Although the PEI trophic parameter database includes data obtained as early as the 1970s, the means and percentages listed in Table 7.1 were limited to data collected after 1998 in order to reduce the chance of error resulting from significant landuse changes over time. The data is also limited to locations within the inner portions of each coastal system since there was little evidence of nutrient over-enrichment ever being a problem within the outer portions.

Table 7.1 Mean value of trophic state parameters for all sampling stations within each watershed.

Watershed	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Dissolved Oxygen (mg/L)	Low Dissolved Oxygen* (%)	Trophic Status
Boughton River	0.29	57.9	5.3	7.9	7.1	High
Brackley	0.32	36.6	12.3	7.2	6.1	High
Brudenell Bay	0.24	56.3	7.8	8.4	0.0	Medium
Cardigan River	0.19	49.5	8.2	7.6	0.0	Medium
Covehead Bay	0.27	31.2	9.4	8.6	3.7	High
Foxley River	0.39	96.0	13.5	6.9	4.2	High
Grand River	0.30	78.8	10.1	6.8	3.2	High
Mill River	0.50	73.9	14.5	6.6	8.3	High
Montague River	0.32	66.9	14.0	7.7	4.2	High
Murray River	0.19	54.7	6.0	7.8	0.0	Medium
Orwell Bay	0.19	68.2	4.9	6.4	2.6	Low
Rustico Bay	0.33	55.3	14.9	7.1	13.0	High
Southwest River	0.57	68.6	16.4	7.3	11.2	High
St Peters River	0.23	42.0	5.1	7.5	0.0	Low
Summerside Harbour	0.37	42.4	10.0	7.8	0.0	Medium
Tracadie Bay	0.19	40.2	5.0	7.8	0.0	Low
West River	0.21	73.1	10.6	7.0	0.0	Medium

*Values ≤4 mg/L

Table 7.2 lists the mean values of each parameter for sites falling into low, moderate and high trophic categories. Although these categories are based on percent low dissolved oxygen and chlorophyll *a* concentration, there is an obvious trend of increasing total nitrogen and total phosphorus concentrations with increasing trophic status. Mean dissolved oxygen concentration, however, varies little with trophic status.

Table 7.2 Mean values of causal and response parameters.

Trophic State	Total Nitrogen (mg/L)	Total Phosphorus (µg/L)	Chlorophyll *a* (µg/L)	Dissolved Oxygen (mg/L)
Low	0.206	50.1	5.1	7.2
Moderate	0.250	55.2	8.5	7.7
High	0.377	62.8	12.3	7.3

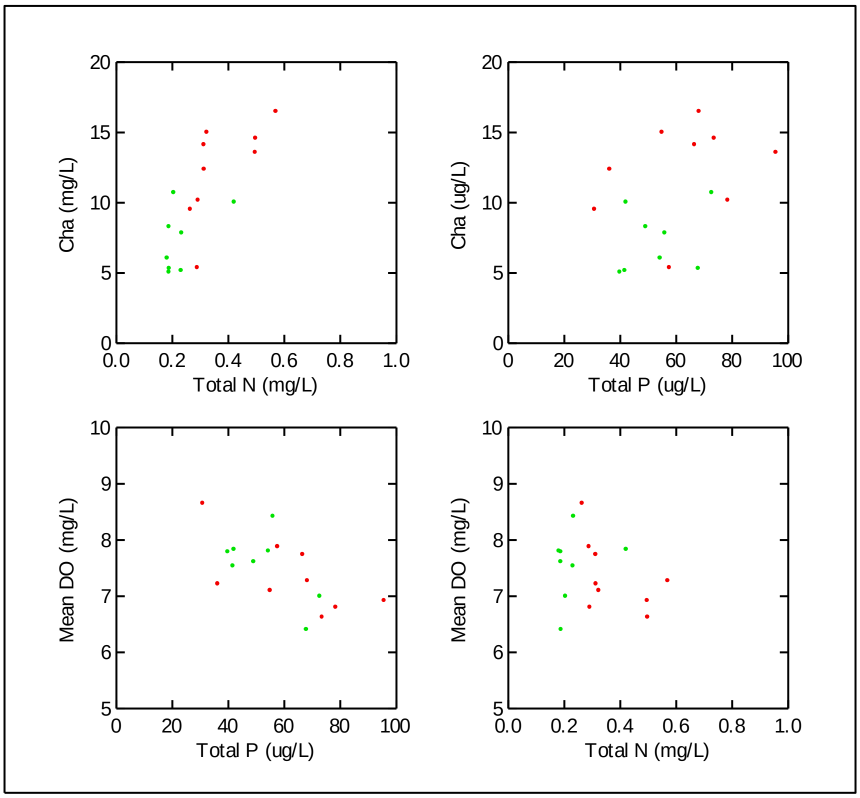

Figure 7.2 Relationships between causal and response parameters (red symbols represent sites that exhibit anoxic/hypoxic conditions).

Figure 7.2 illustrates the relationships between the mean values of causal and response parameters for each watershed. Total nitrogen exhibits a strong positive relationship with chlorophyll *a*, both of which tend to have higher concentrations for sites that exhibit anoxic/hypoxic conditions. Total phosphorus shows a strong negative relationship to mean dissolved oxygen concentration. The relationship between total nitrogen and mean dissolved oxygen concentration is also negative but weaker than that exhibited by total phosphorus.

7.3 Determination of Dilution and Flushing Potential

7.3.1 Dilution Potential

The ability of a coastal system to dilute nutrient inputs depends on the volume of the system. A simple index of dilution potential was calculated as the ratio of freshwater entering the system and the mean volume of the coastal system. The amount of freshwater entering the system was in turn calculated as the product of the drainage basin area and mean annual precipitation. The volume of the coastal system was determined using hypsographic data obtained by digitizing bathymetric charts and using an image analysis program to calculate surfaces areas for depth intervals ranging from one to twenty metres depending on the maximum depth of the system. The volume used was the mean of the high and low water volumes. The formula used to calculate dilution potential is as follows:

$$\text{Dilution Potential} = \frac{\text{DBA x PPT}}{(\text{MLWV} + \text{MHWV})/2}$$

where,

DBA = Drainage Basin Area (m^2)
PPT = Mean Annual Precipitation (m)
MLWV = Mean High Water Volume (m^3)
MHWV = Mean High Water Volume (m^3)

7.3.2 Flushing Potential

There are many ways to calculate flushing times for tidal systems. The method chosen for this study is that proposed by Gregory et al. (1998) which is an estimate of the time in hours it takes for a substance entering a coastal water body to be reduced to approximately one-third of its initial concentration and is calculated as follows:

$$\text{Flushing Time (hrs)} = \frac{-12.42}{\ln((\text{MLWV} / (\text{MLWV} + \text{TPRISM}))}$$

where,

12.42 = Tidal Cycle Time (hrs)
MLWV = Low Water Volume (m^3)
MTPRISM – Tidal Prism (m^3)

The tidal prism is the volume of water entering the system from offshore on each tidal cycle and is calculated as follows:

$$\text{Tidal Prism} = \text{MTR} \times \frac{\text{MHWSA} + \text{MLWSA}}{2}$$

where,

MTR = Mean Tidal Range (m)
MHWSA = Mean High Water Surface Area (m^2)
MLWSA = Mean Low Water Surface Area (m^2)

7.4 Determination of Nutrient Loading Potential

A simple index of potential nutrient loading was calculated as the product of the drainage basin area and the percentage of agricultural activity within the drainage basin.

7.5 Index of Susceptibility to Nutrient Over-enrichment

An index of the susceptibility of each site to nutrient over enrichment was calculated by combining potential nutrient load, dilution potential and flushing time into one index. However, because the magnitude of the various indices differ greatly, it was necessary to scale each to produce a relative index before summing them. The scaling was done by dividing the value of each by its maximum value to produce values ranging between zero and one and was also done for the determining the final overall susceptibility index..

The susceptibility index was calculated as follows using the relative indices:[1]

$$\text{SI} = \frac{\text{Potential Nutrient Load} \times \text{Export Potential}}{\text{Dilution Potential}}$$

The values of the morphological parameters for each watershed are listed in Appendix IV. Table 7.3 lists the relative indices for each site. The higher the susceptibility index, the more sensitive the system is to nutrient over-enrichment.

7.6 Relationship of Susceptibility Index to Trophic Parameters

As a test of the susceptibility index, it was plotted against each of the causal and response parameters (Figure 7.3). Although there is considerable variability, total nitrogen and chlorophyll *a* both show an increase in concentration as susceptibility increases, and

[1] It should be noted that since export potential is actually the flushing ***time***, it appears in the numerator of the equation.

those sites exhibiting anoxic/hypoxic conditions show a very strong positive relationship between the percent of anoxic/hypoxic observations and susceptibility. Total phosphorus and mean dissolved oxygen concentrations, however, show no clear relationship to the index.

Table 7.3 Relative indices for each watershed.

Watershed	Index			
	Dilution Index	Export Index	Nutrient Input Index	Overall Susceptibility Index
Boughton River	0.089	0.523	0.062	0.466
Brackley	0.494	0.514	0.440	0.589
Brudenell Bay	0.253	0.451	0.201	0.460
Cardigan River	0.047	0.682	0.020	0.374
Covehead Bay	0.461	0.508	0.344	0.487
Foxley River	0.350	0.464	0.206	0.350
Grand River	0.121	0.652	0.051	0.357
Mill River	0.512	0.612	0.400	0.614
Montague River	0.913	0.451	0.599	0.380
Murray River	0.189	0.517	0.071	0.251
Orwell Bay	1.000	0.187	1.000	0.241
Rustico Bay	0.146	0.566	0.201	1.000
Southwest River	0.141	0.517	0.197	0.924
St Peters River	0.369	1.000	0.201	0.698
Summerside Harbour	0.674	0.246	0.739	0.347
Tracadie Bay	0.218	0.497	0.146	0.427
West River	0.172	0.357	0.208	0.556

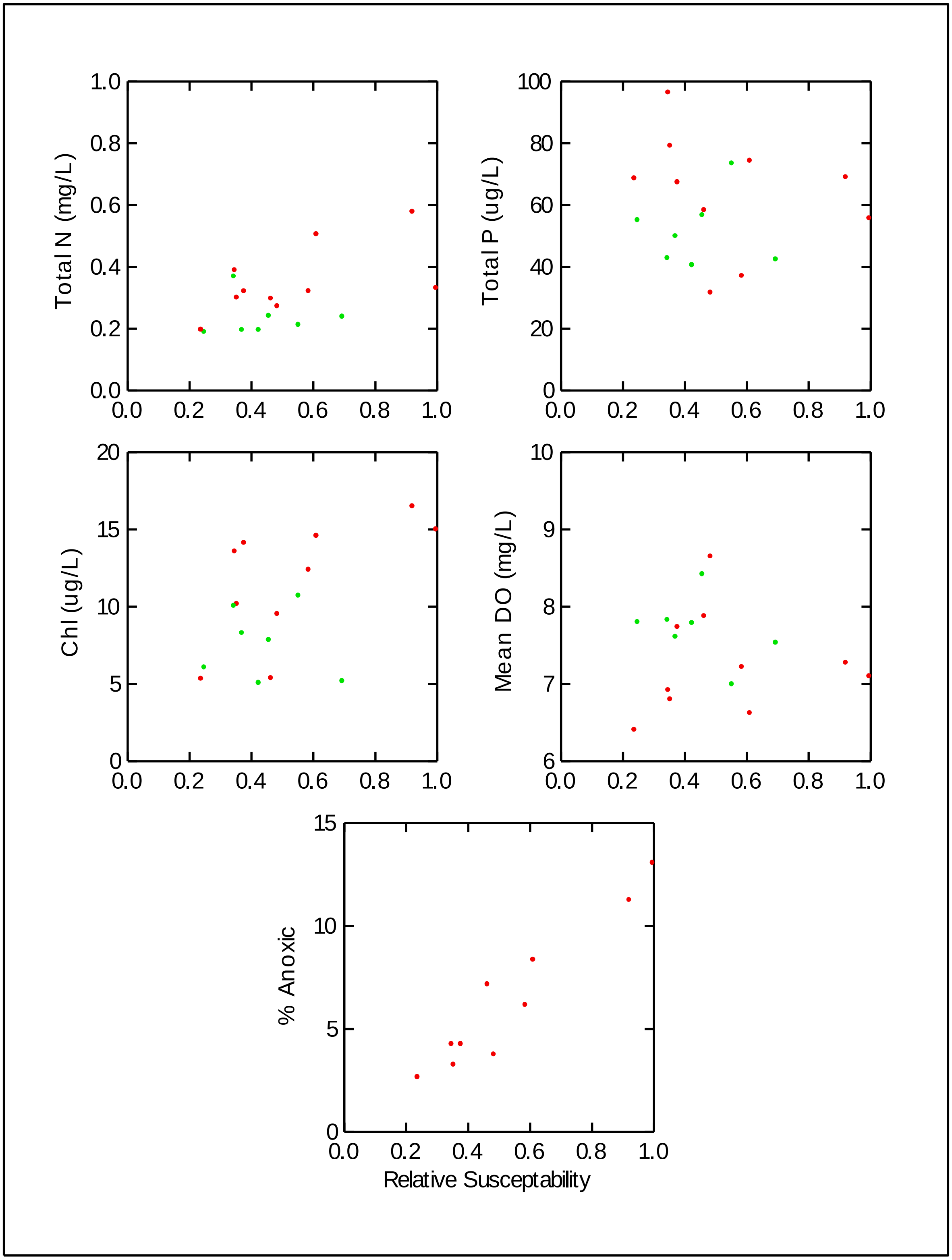

Figure 7.3 Relationship between susceptibility index and trophic parameters (red dots indicate sites that experience anoxic/hypoxic conditions.)

7.7 Using the Indices to Establish Nutrient Criteria

Although the nutrient concentrations for low trophic status listed in Table 7.2 could potentially be used as rough estimates for nutrient standards, it would be much more desirable to refine this by developing standards that take into consideration the physical susceptibility of the system to nutrient over-enrichment which is a function of both nutrient export and nutrient dilution. These two processes determine the extent to which nutrients within the system will result in high concentrations of chlorophyll *a* and, subsequently, the degree to which hypoxic conditions, the most severe consequence of nutrient over-enrichment, will occur. A simple index of physical susceptibility was derived by multiplying the relative dilution and export indices (developed in Section 7.3) and using the reciprocal, scaled to produce values ranging between zero and one. Table 7.4 lists this index for each site and Figure 7.4 shows the relationship of this index to the mean value of the causal and response parameters for each site.

Table 7.4 Relative physical sensitivity of each watershed to nutrient over-enrichment.

Watershed	Relative Physical Susceptibility
Boughton	1.000
Brackley	0.176
Brudenell	0.303
Cardigan	0.620
Covehead	0.187
Foxley	0.225
Grand	0.917
Mill	0.203
Montague	0.084
Murray	0.464
Orwell	0.032
Rustico	0.655
Southwest	0.620
St Peters	0.459
Summerside	0.062
Tracadie	0.387
West	0.352

Although there is some variability, it is clear from Figure 7.4 that those sites exhibiting anoxic/hypoxic conditions (red symbols) generally have higher concentrations of total nitrogen and chlorophyll *a*, and lower concentrations of dissolved oxygen than those sites which do not exhibit anoxic/hypoxic conditions (green symbols). In addition, and more importantly, the results clearly show a decrease in the causal parameter (total nitrogen concentration) and the response parameters (chlorophyll *a* and mean dissolved oxygen concentration) with increasing physical susceptibility for those sites not exhibiting anoxic/hypoxic conditions. In other words, sites having a low susceptibility can have higher concentrations of nitrogen before they begin to exhibit high chlorophyll *a* and low dissolved oxygen concentrations, i.e., symptoms of nutrient over-enrichment.

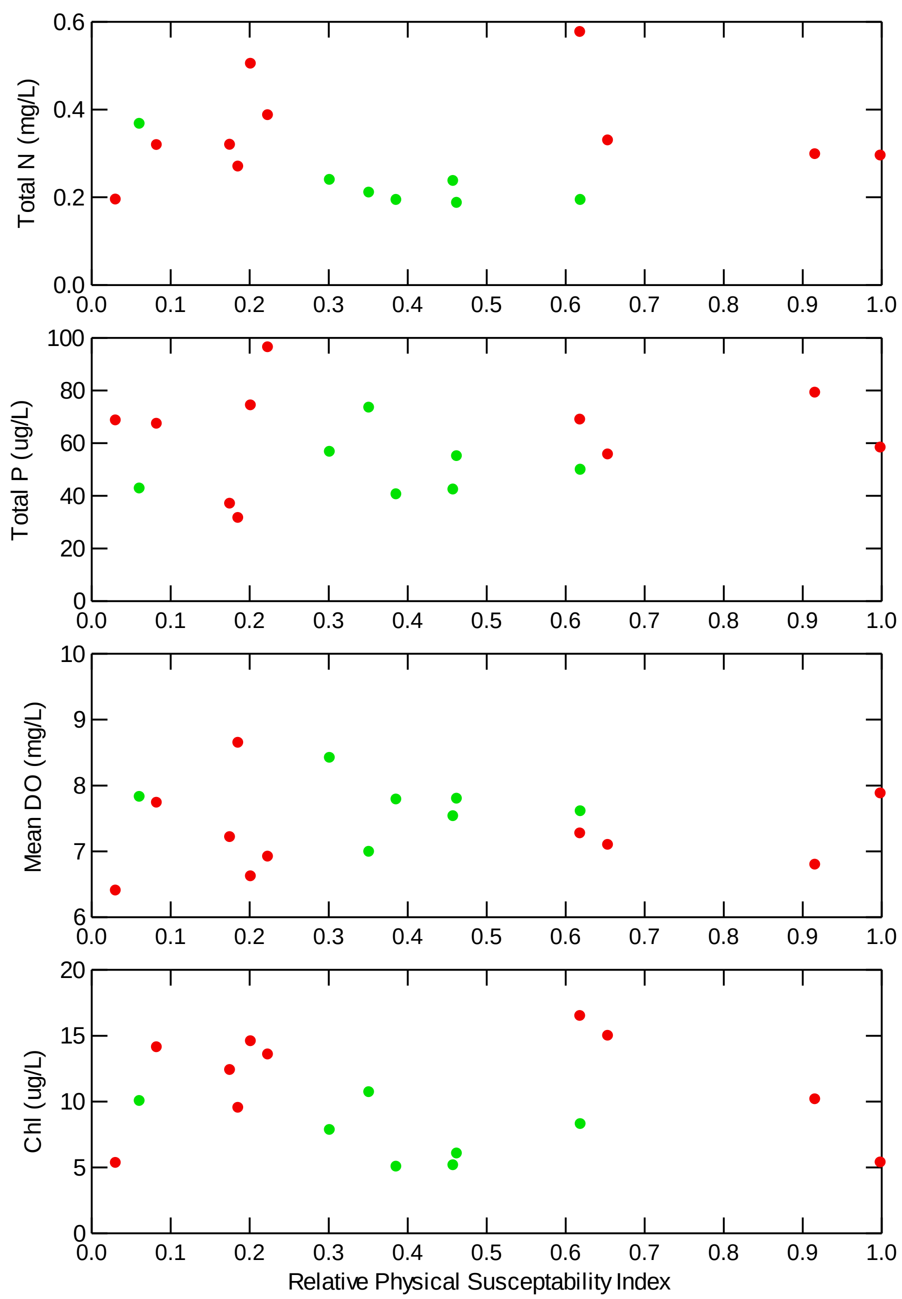

Figure 7.4 Relationship between the relative physical susceptibility index and trophic state parameters for each watershed (red symbols indicate anoxic/hypoxic sites; green symbols indicate sites that are not anoxic/hypoxic).

The above results provide a basis for establishing nutrient standards relative to the physical susceptibility of each watershed. For example, in the case of total nitrogen and chlorophyll *a* levels, by examining the levels of these parameters in Figure 7.4 for those watersheds that do not exhibit anoxic/hypoxic conditions (green symbols), it appears that for sites having a relative index of physical susceptibility ≤0.5, total nitrogen values should be kept below about 0.3 mg/L and chlorophyll *a* levels should not exceed about 10 µg/L. Unfortunately, for values of the index above 0.5, there was only one site that did not exhibit anoxic/hypoxic conditions so there is insufficient data to establish nutrient standards for this region of the susceptibility index unless one is willing to extrapolate the graph by assuming that the gradual decline in total nitrogen and chlorophyll *a* concentration as susceptibility increases continues for index values above 0.5. If this assumption is made, for sites having index values >0.5, total nitrogen levels should not exceed about 0.1 mg/L and chlorophyll *a* values should not exceed about 2-3 µg/L. These estimates could be further refined as additional sites not experiencing anoxic/hypoxic conditions are included in the analysis.

8. Discussion

Although Canadian nearshore waters appear to have relatively high phosphate concentrations, both the mapping and statistical analyses of the response parameters, chlorophyll *a* and dissolved oxygen, indicate that, with the exception of some areas within the East, most notably Prince Edward Island, as a whole Canadian nearshore waters are relatively unimpacted by nutrient over-enrichment. Results of the analyses also suggest that Western region nearshore waters have higher nutrient concentrations than Eastern region nearshore waters. However, a shortcoming of the analysis is that the data within western Canada are poorly distributed. This makes it difficult to draw any strong conclusions regarding major differences between the regions. Another factor that may confound any conclusions regarding regional differences is the objective of the study during which the data was collected. The abundance of dissolved oxygen observations within the Western region relative to other parameters suggests that this data was collected as part of surveys that were looking specifically for areas of depleted dissolved oxygen levels and, if so, can not be validly compared to data that was collected as part of routine or exploratory surveys. It does, however, indicate that low dissolved oxygen concentrations are an issue in the West region. As a result, it is difficult to reach any definitive conclusions regarding differences between the East and West regions. Data for the East regions, however, is likely to be suitable for establishing nutrient standards for that area.

The case study carried out for PEI produced promising results with respect to the potential for developing nutrient standards for a coastal watershed that are specific to the system's susceptibility to nutrient over-enrichment. It is likely that this approach could be significantly improved if the data used were better suited to the approach than what was available for PEI. For example, with respect to the susceptibility index that included nutrient inputs and dilution and export potential, actual nutrient inputs would be much better that the surrogate used: percent agriculture in the drainage basin. However, because of the resources required to measure annual nutrient inputs, it is unlikely that much of this kind of data will become widely available in the near future. As an alternative to annual nutrient inputs, the approach would probably benefit from better data on land-use within the watershed, especially if nutrient runoff coefficients were know for the various types of land-use. At the least, land-use databases should include the type of agricultural land-use. The production of vegetable crops, for example, uses more fertilizer and results in more runoff than does the production of forage or grain crops, and pastureland is often not fertilized at all.

The forms of nitrogen and phosphorus used in the analyses were also not the most appropriate. The forms most readily available and utilized by primary producers are the dissolved inorganic forms. Total nitrogen often includes particulate forms that have low bioavailability, especially in watersheds that contain significant amounts of coniferous forests. The same is true of total phosphorous, although to a lesser extent.

The types of biological communities present in the system are also likely to have an influence on susceptibility. For example, the presence of filter feeders, such as cultivated mussels which are quite prevalent in PEI, would reduce the system's susceptibility to nutrient over-enrichment by grazing phytoplankton, and the presence of benthic macroalgae, such as sea lettuce, which is also quite prevalent in many PEI systems, would tend to increase susceptibility since they retain nutrients within the system as a result of not being flushed out by tidal action.

In summary, although the approach used for PEI coastal waters was rather elementary, it appears to have much potential for establishing nutrient criteria guidelines based on consideration of a system's susceptibility to nutrient over-enrichment. Further development of this approach based on the suggestions made above should improve this capability.

9. Acknowledgements

I would like to thank Cynthia Crane and Bruce Raymond of the PEI Department of Environment, Energy and Forestry and Bill Glen of the PEI Department of Agriculture, Fisheries and Aquaculture for providing us with the information on land use within PEI watersheds.

10. References

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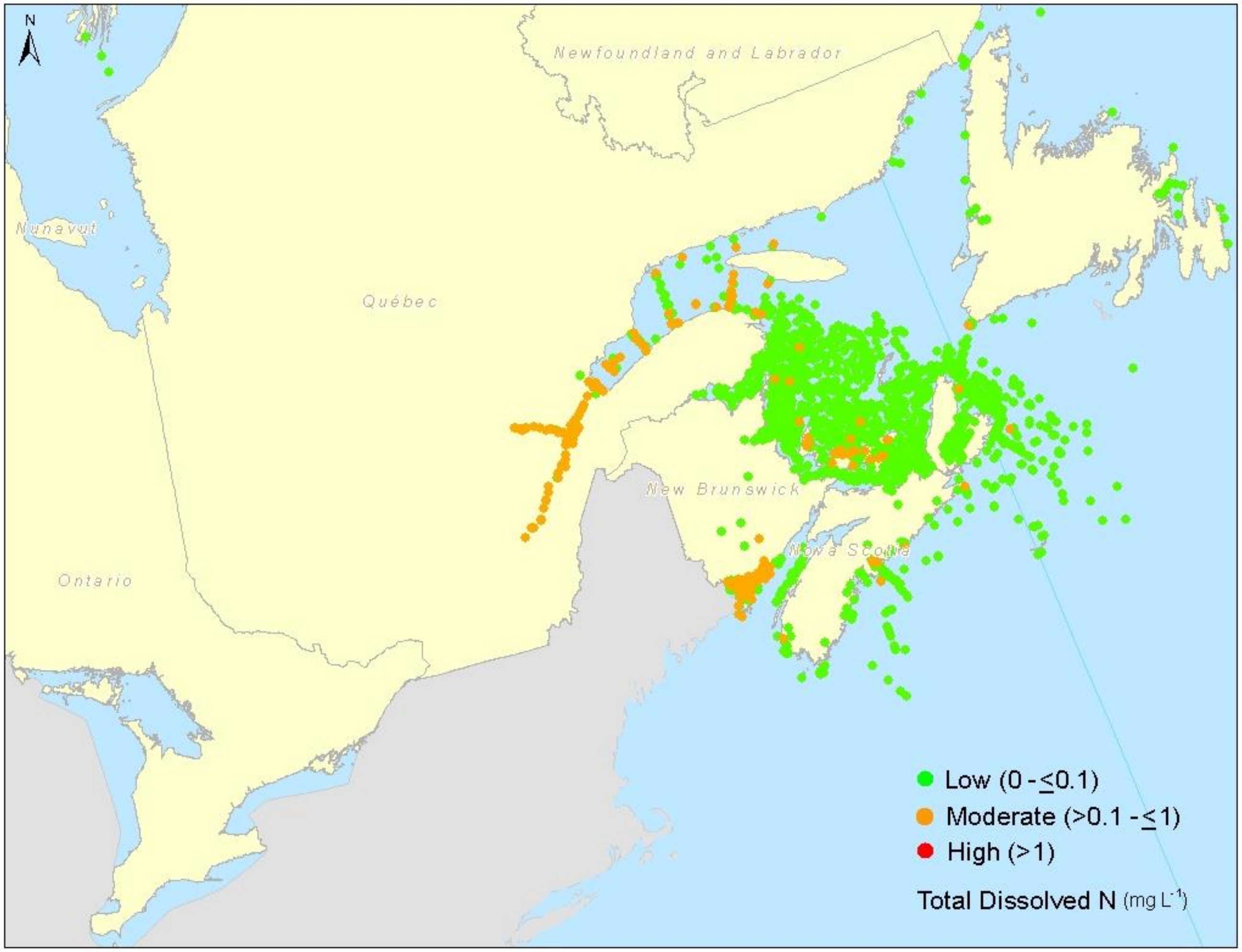
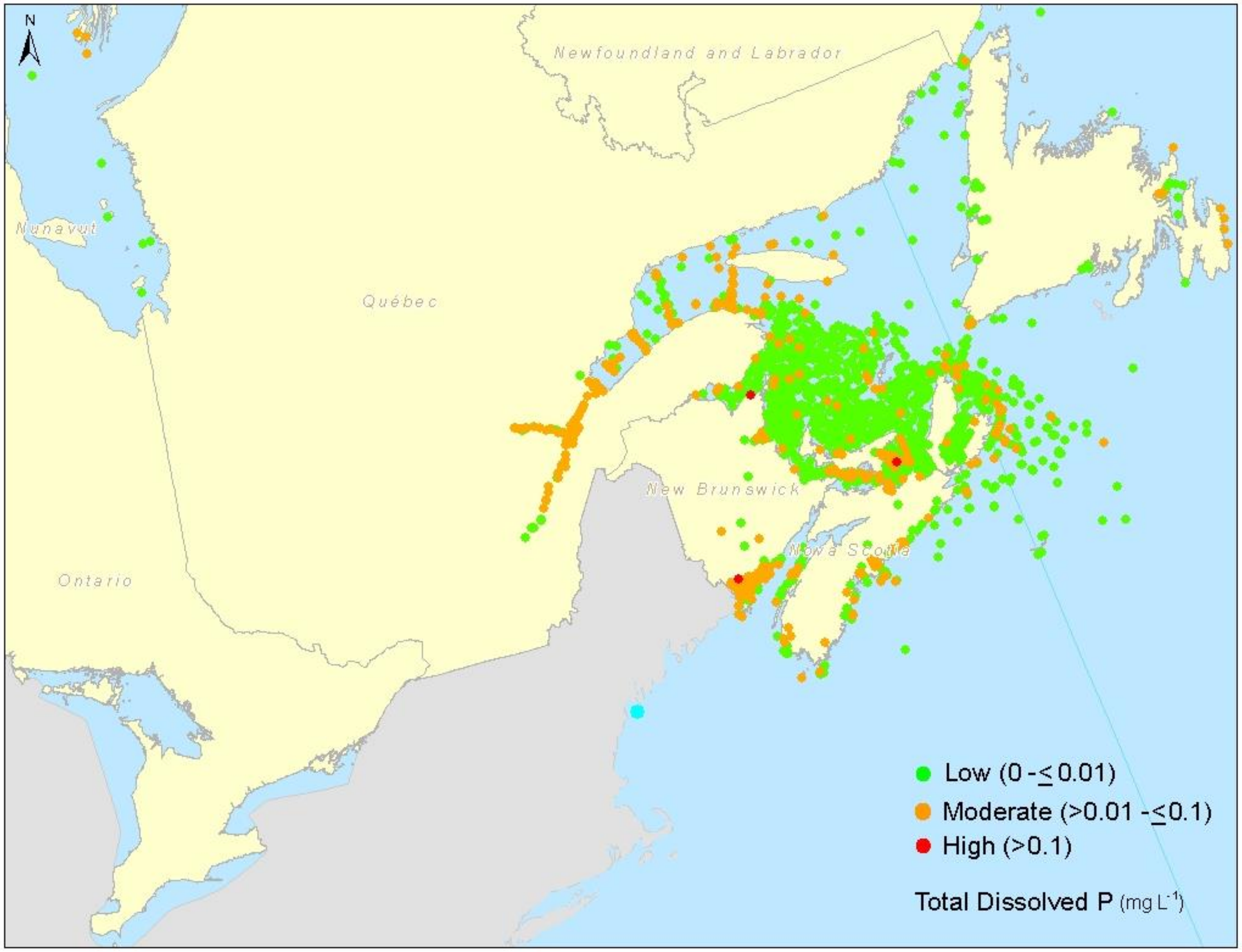
APPENDIX I

Maps Illustrating Levels of Each Nutrient Criteria Parameter for Each Region


N
Newfoundland and Labrador
Nunavut
Québec
New Brunswick
Nova Scotia
Ontario
Low (0 - ≤0.1)
Moderate (>0.1 - ≤1)
High (>1)
Total Dissolved N (mg L⁻¹)

EAST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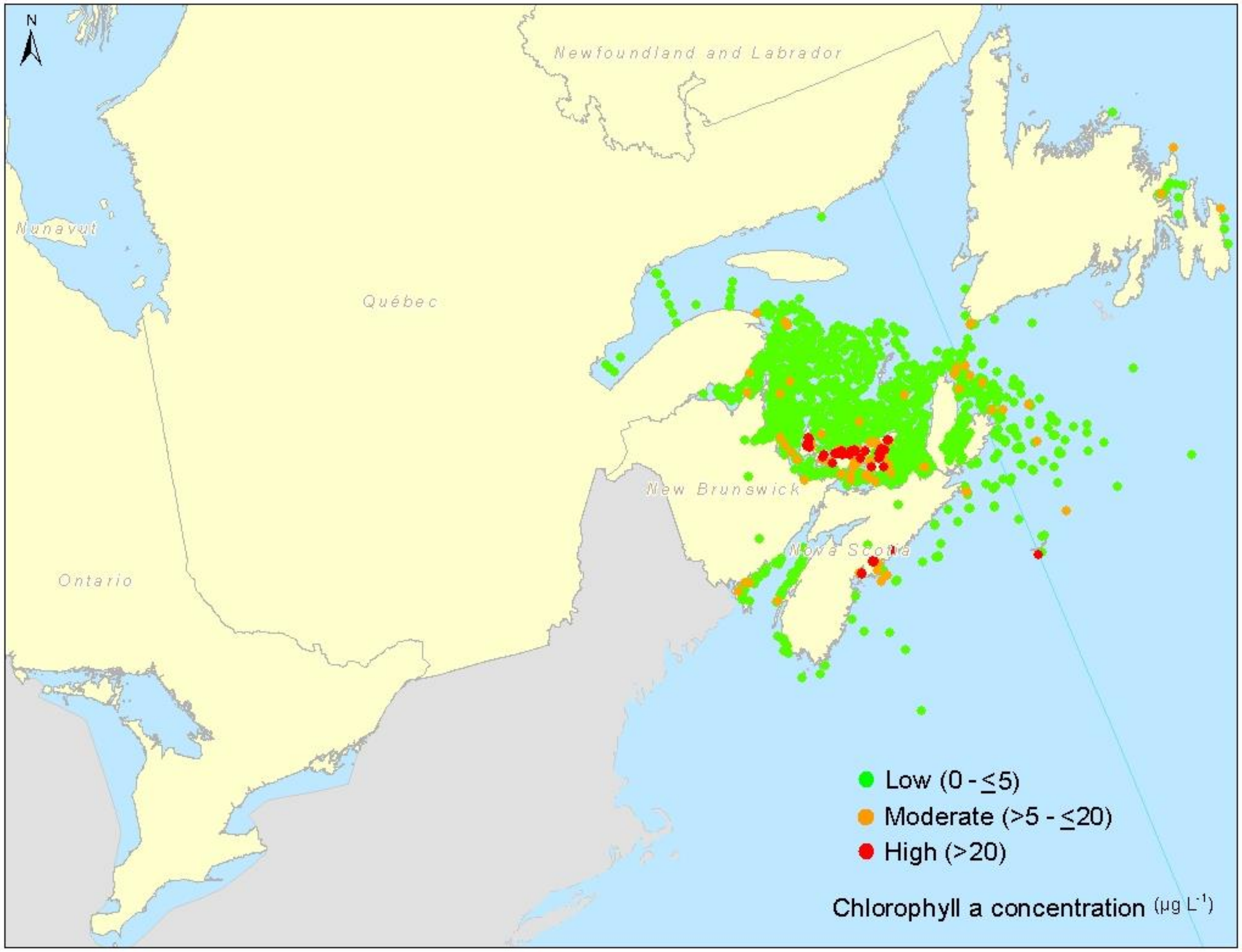
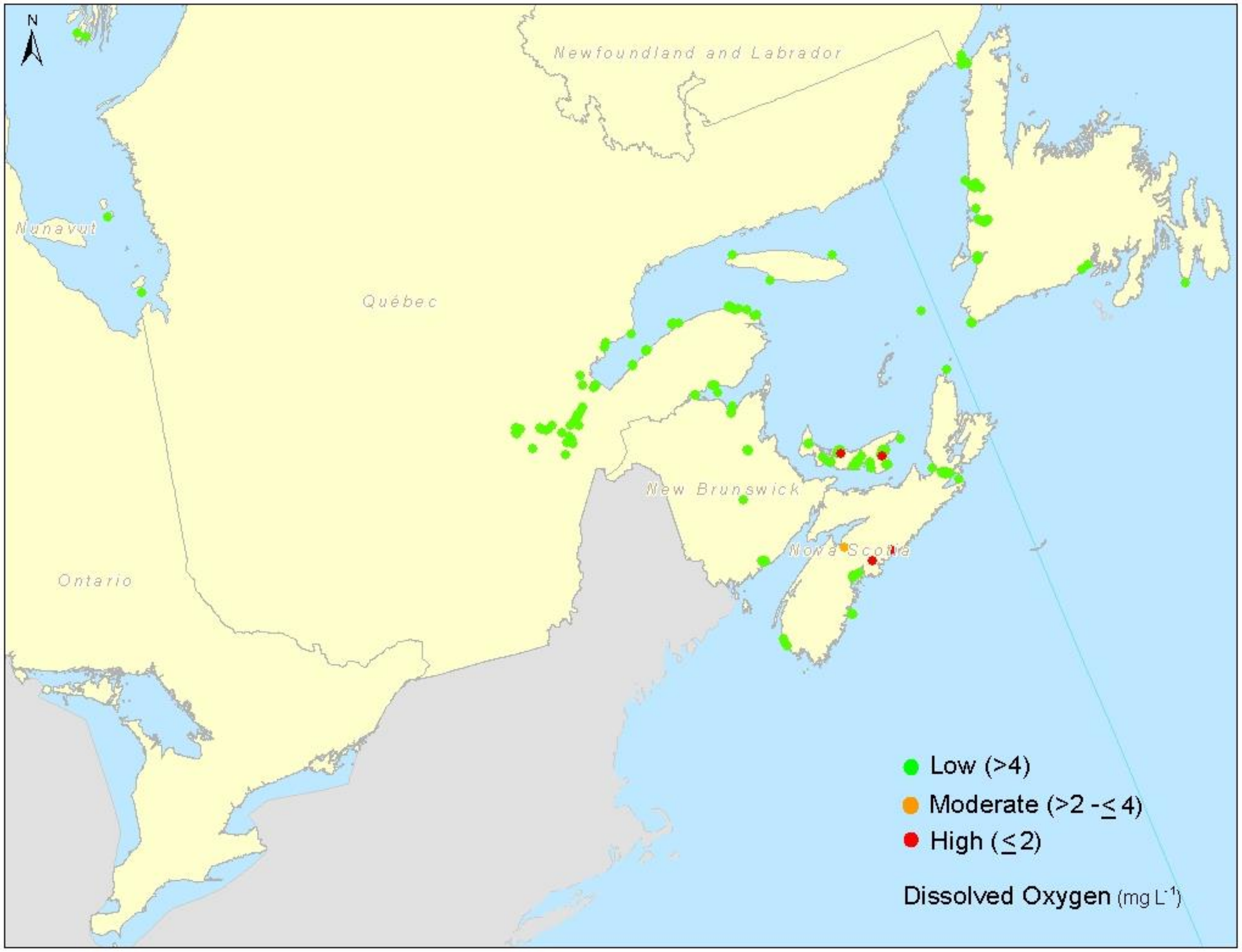
Newfoundland and Labrador
Nunavut
Québec
New Brunswick
Nova Scotia
Ontario
Low (0 - ≤ 0.01)
Moderate (>0.01 - ≤ 0.1)
High (>0.1)
Total Dissolved P (mg L-1)

EAST


N
Newfoundland and Labrador
Nunavut
Québec
New Brunswick
Nova Scotia
Ontario
Low (0 - ≤5)
Moderate (>5 - ≤20)
High (>20)
Chlorophyll a concentration (µg L-1)

EAST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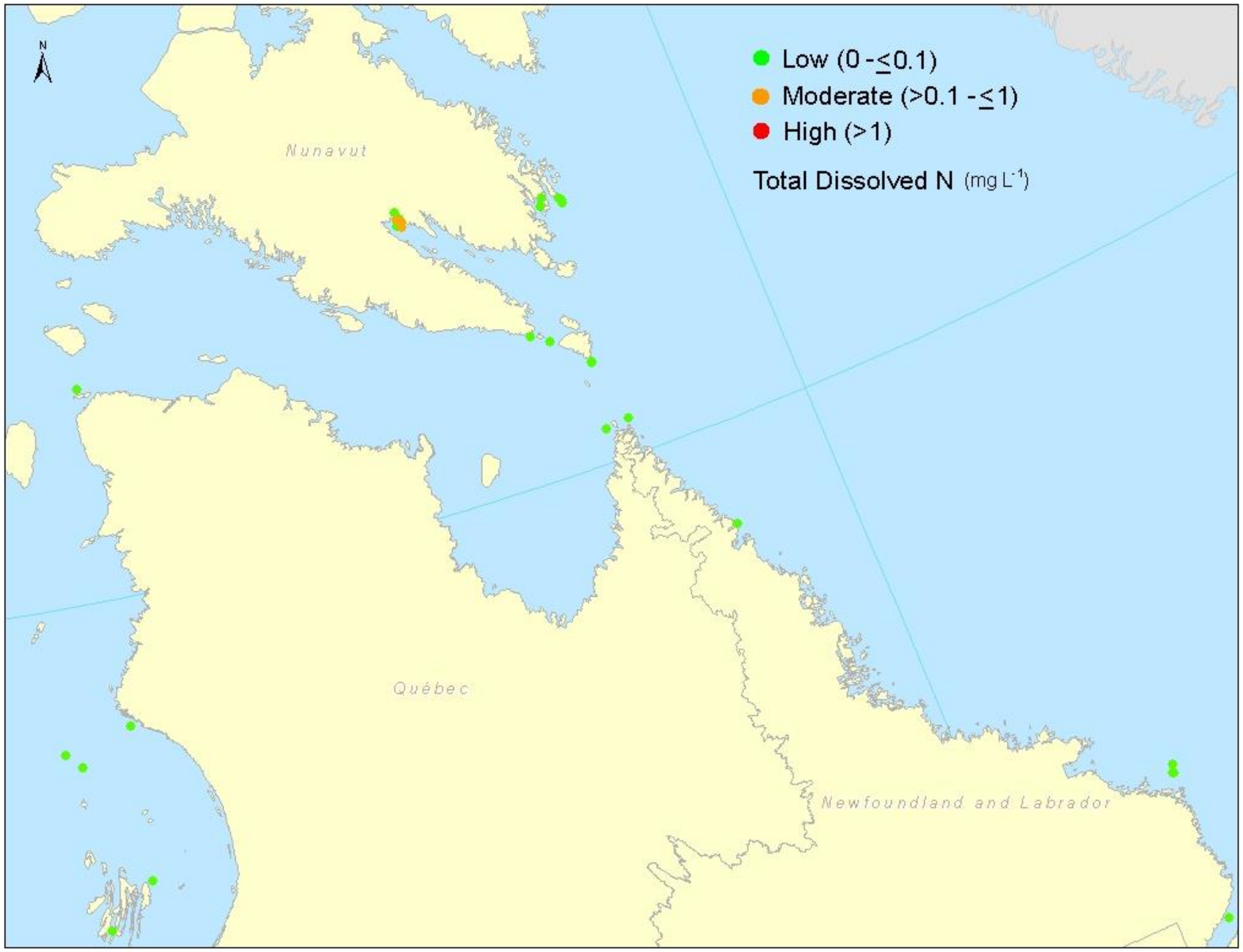
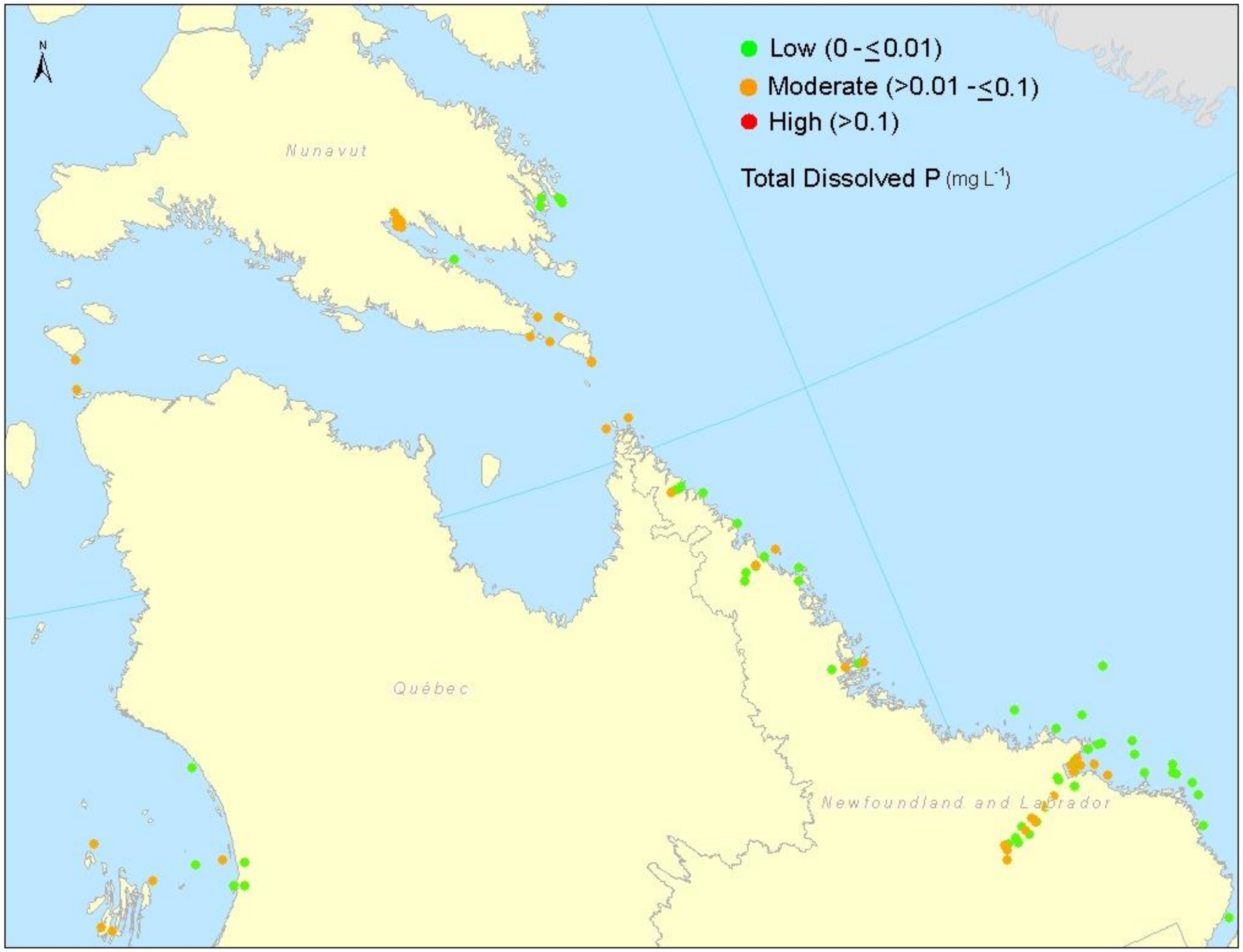
Newfoundland and Labrador
Nunavut
Québec
Ontario
New Brunswick
Nova Scotia
Low (>4)
Moderate (>2 - ≤ 4)
High (≤ 2)
Dissolved Oxygen (mg L-1)

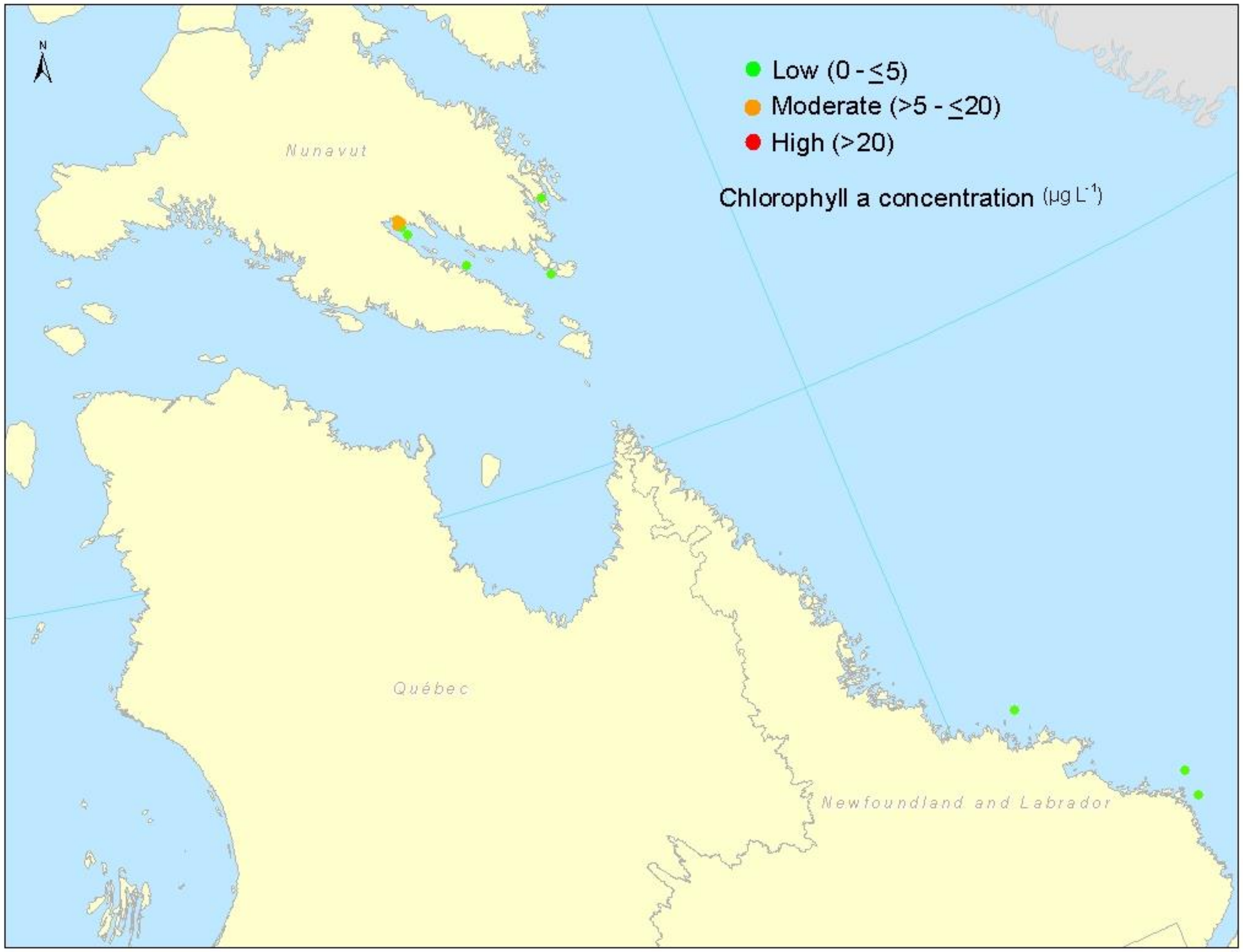
EAST


N
Low (0 -≤0.1)
Moderate (>0.1 -≤1)
High (>1)
Total Dissolved N (mg L-1)
Nunavut
Québec
Newfoundland and Labrador

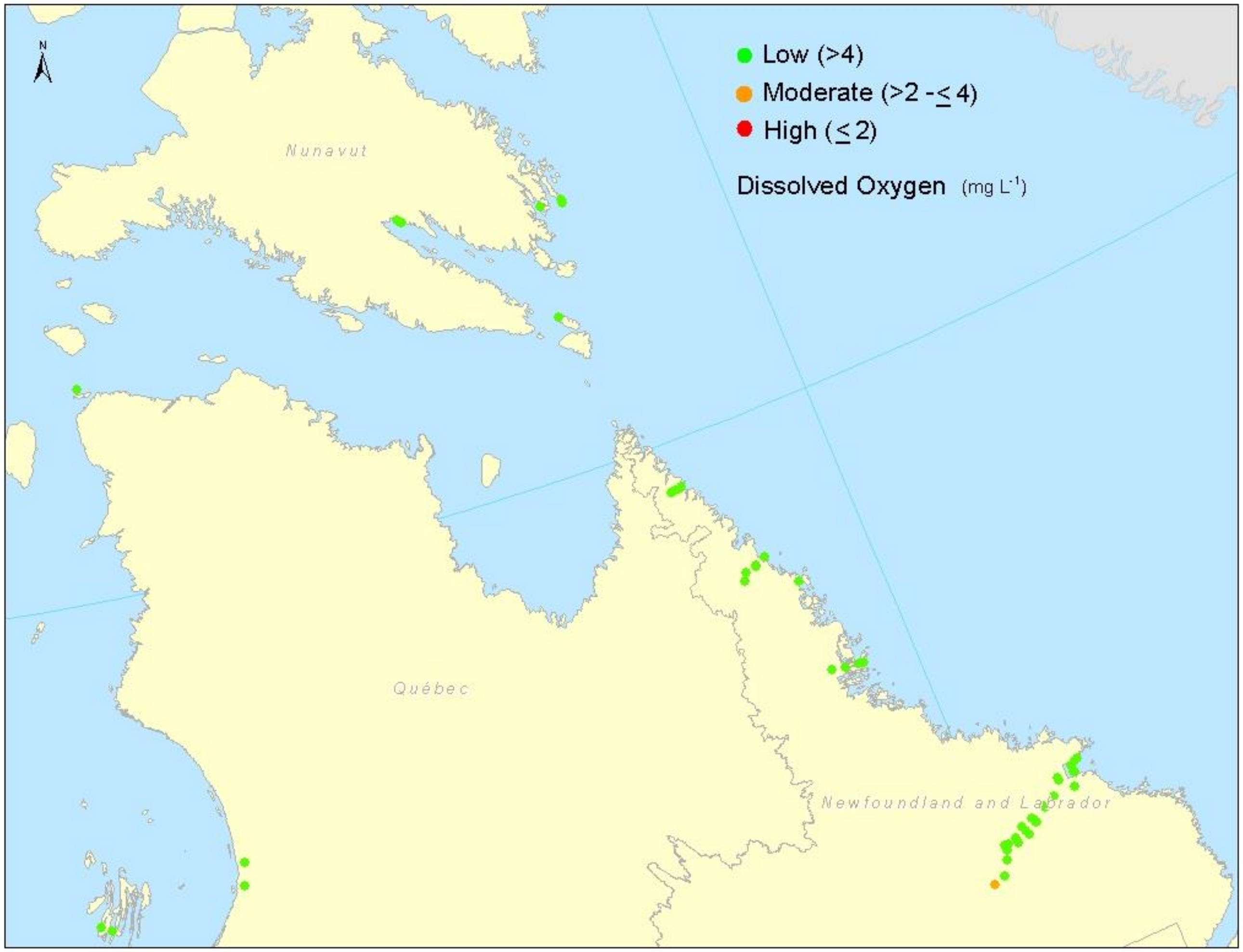
NORTHEAST


Low (0 - ≤ 0.01)
Moderate (>0.01 - ≤ 0.1)
High (>0.1)
Total Dissolved P (mg L⁻¹)
N
Nunavut
Québec
Newfoundland and Labrador

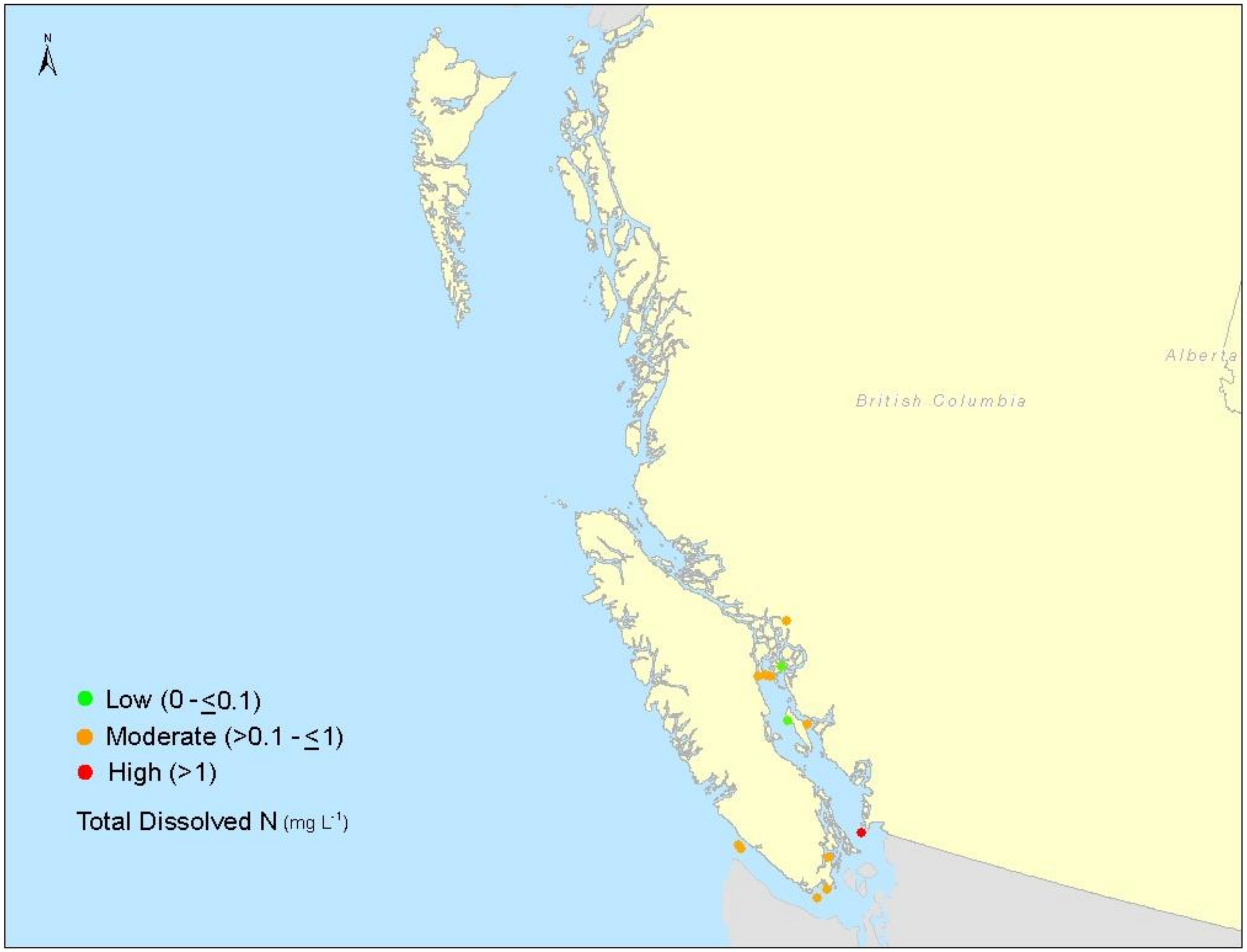
NORTHEAST


Low (0 - ≤5)
Moderate (>5 - ≤20)
High (>20)
Chlorophyll a concentration (μg L⁻¹)
N
Nunavut
Québec
Newfoundland and Labrador

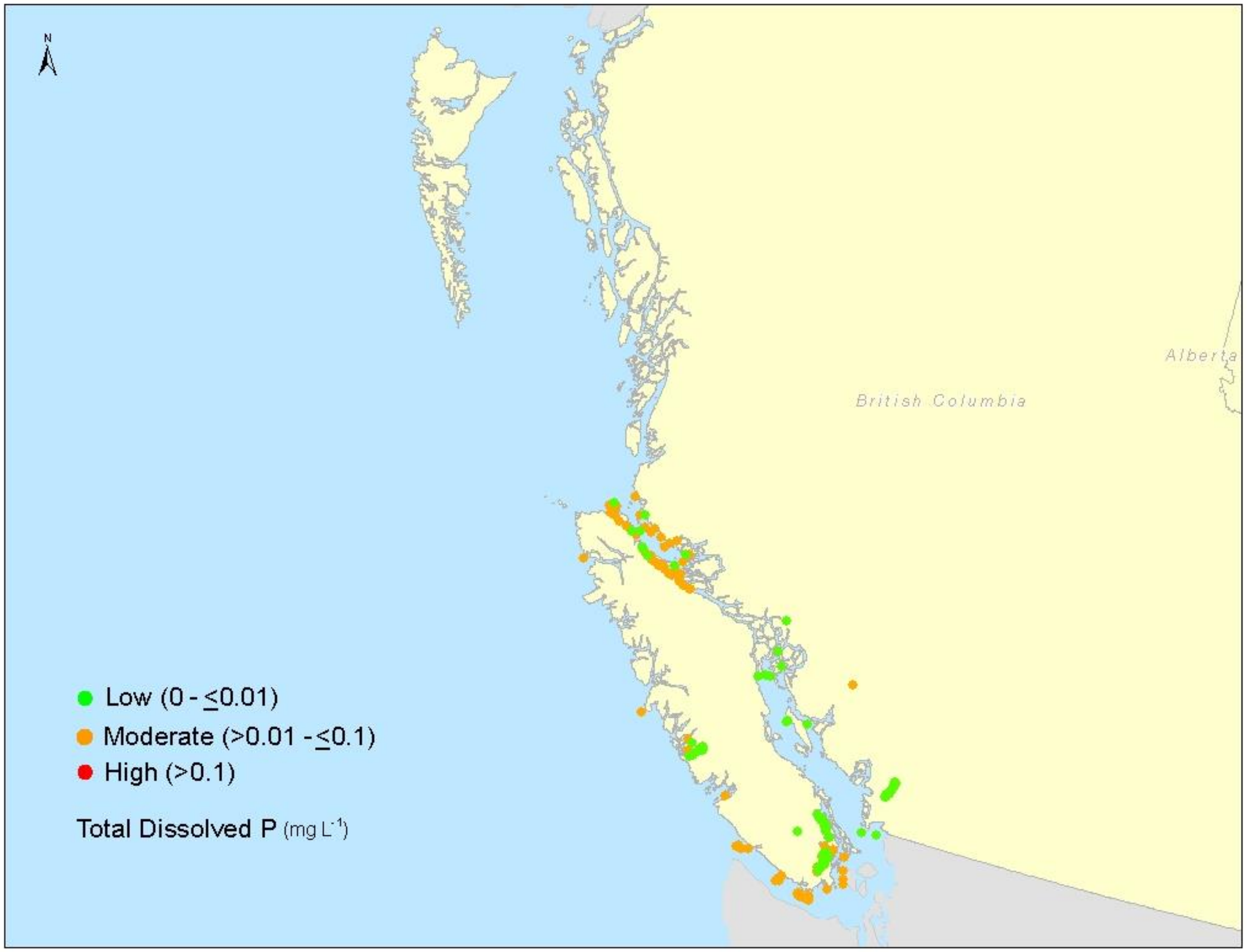
NORTHEAST


N
Nunavut
Québec
Newfoundland and Labrador
Low (>4)
Moderate (>2 - ≤ 4)
High (≤ 2)
Dissolved Oxygen (mg L-1)

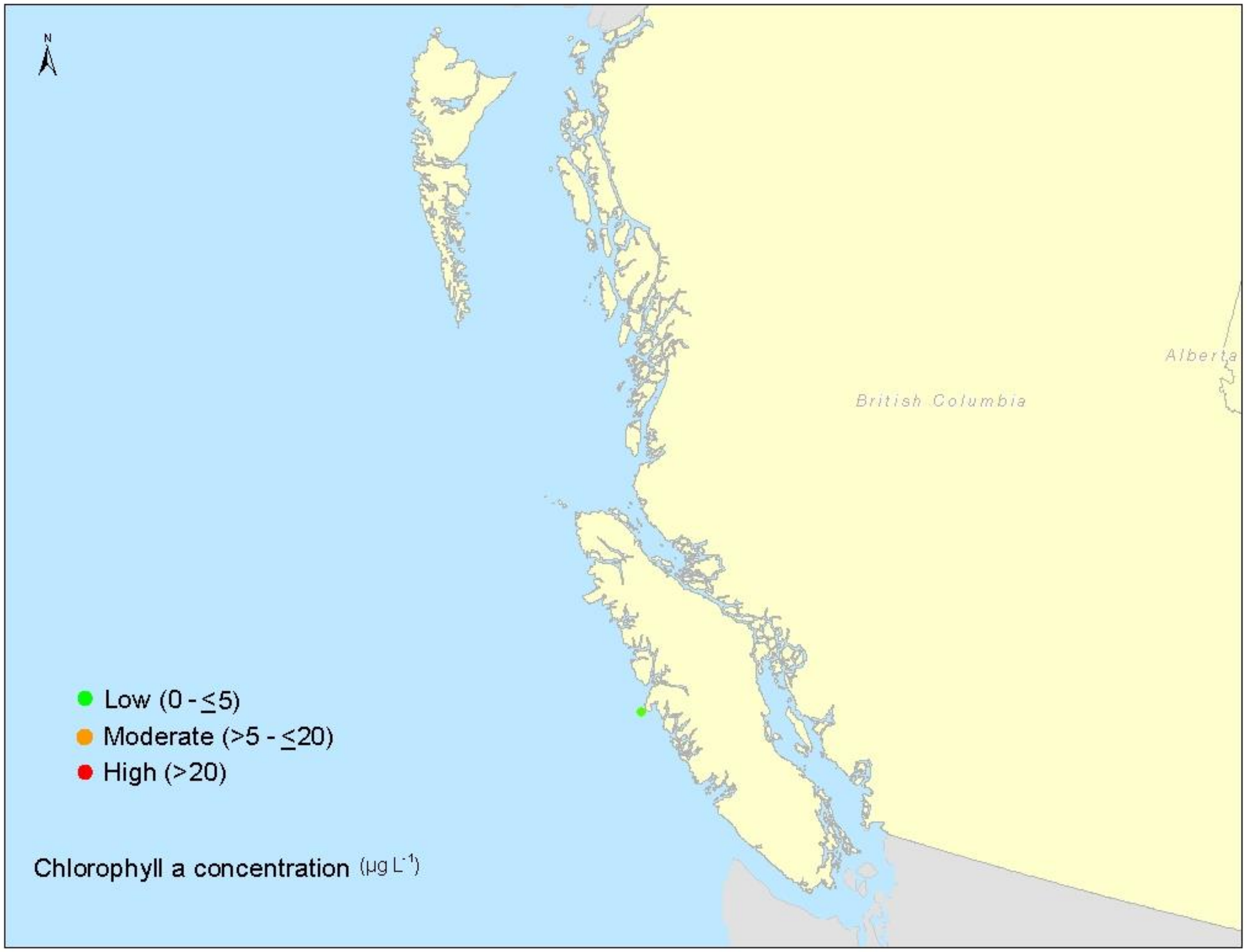
NORTHEAST


N
Alberta
British Columbia
Low (0 - ≤0.1)
Moderate (>0.1 - ≤1)
High (>1)
Total Dissolved N (mg L-1)

WEST


N
British Columbia
Alberta
Low (0 - ≤0.01)
Moderate (>0.01 - ≤0.1)
High (>0.1)
Total Dissolved P (mg L-1)

WEST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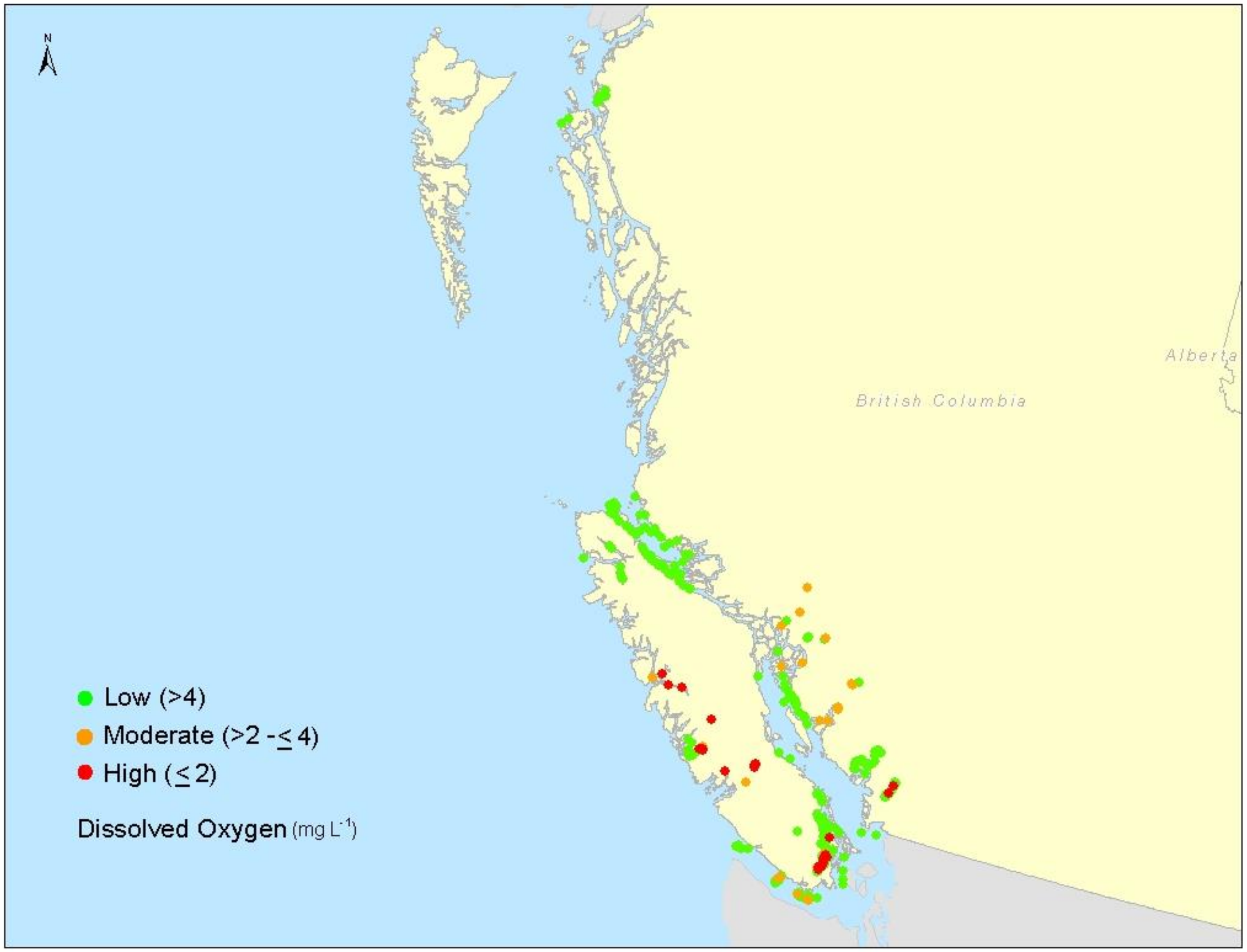
British Columbia
Low (0 - ≤5)
Moderate (>5 - ≤20)
High (>20)
Chlorophyll a concentration (µg L-1)

WEST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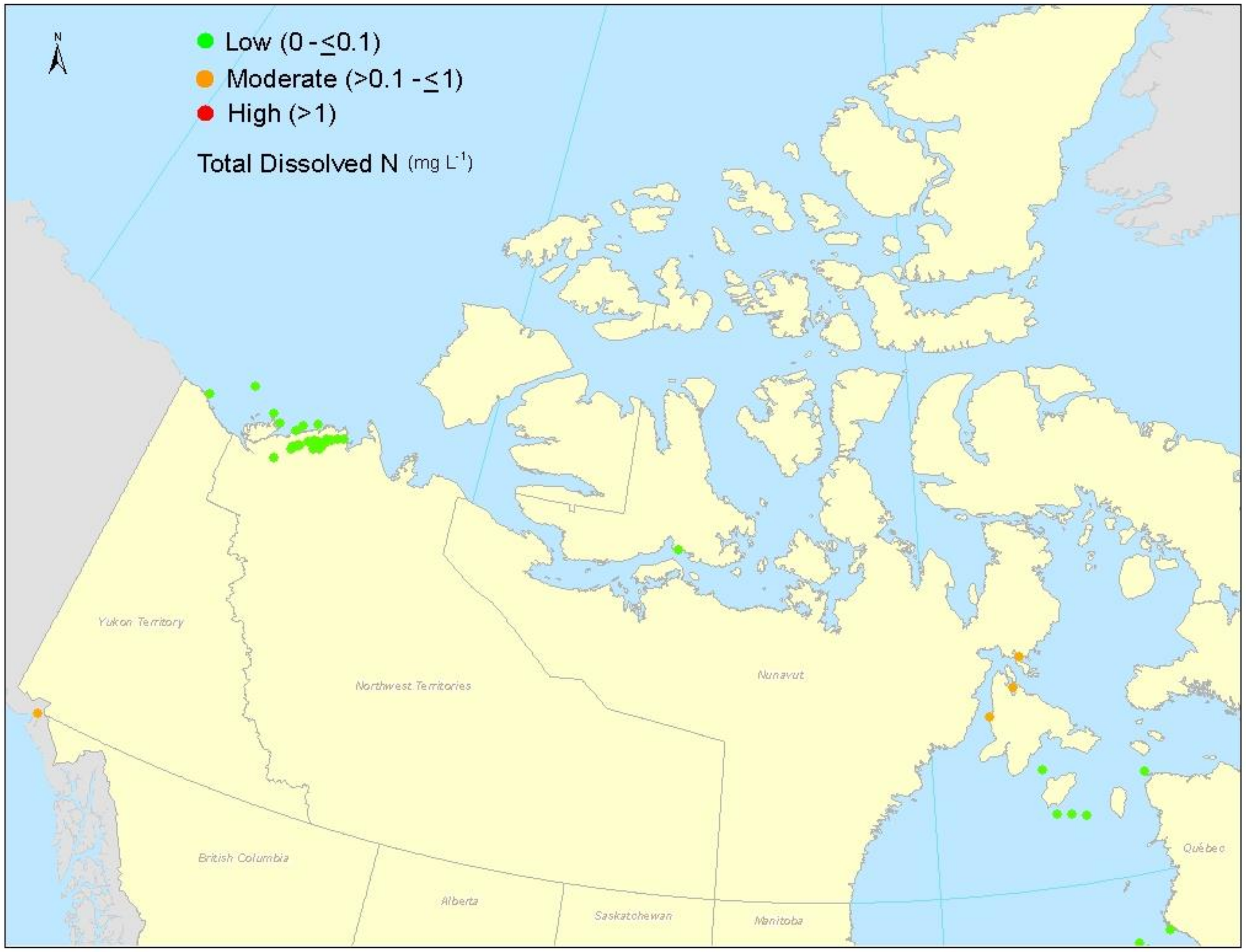
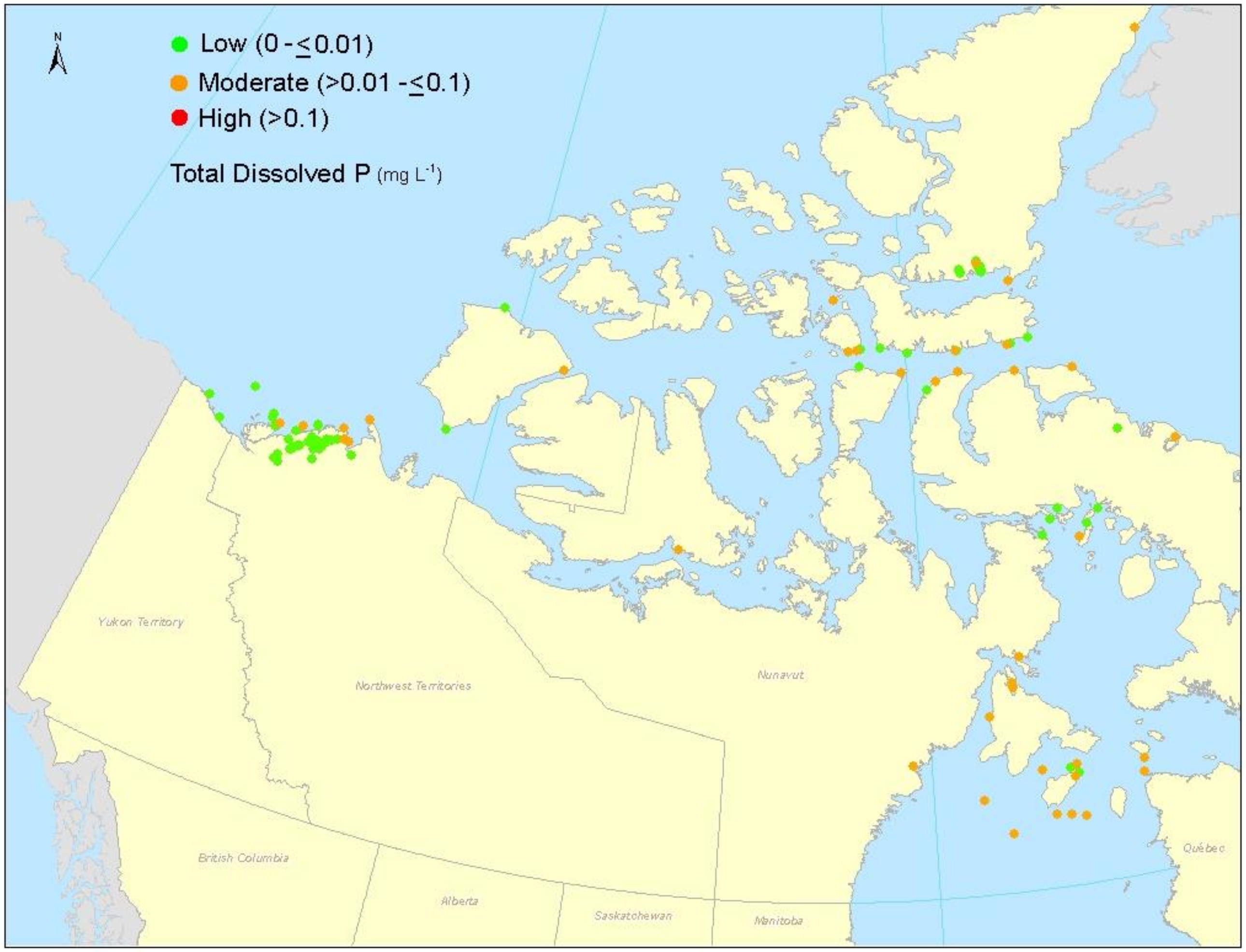
Alberta
British Columbia
Low (>4)
Moderate (>2 - ≤ 4)
High (≤ 2)
Dissolved Oxygen (mg L-1)

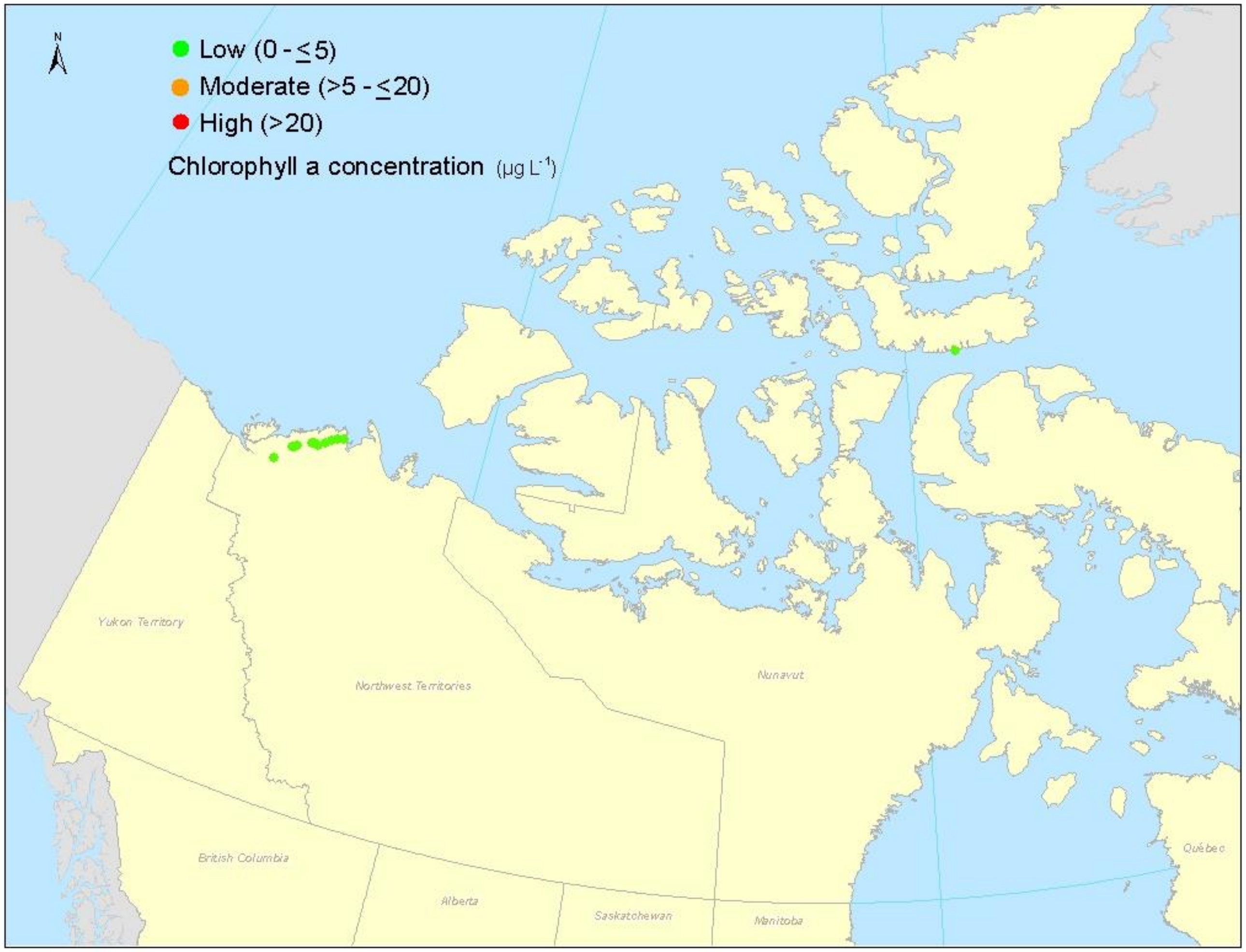
WEST


Low (0 - ≤0.1)
Moderate (>0.1 - ≤1)
High (>1)
Total Dissolved N (mg L-1)
N
Yukon Territory
Northwest Territories
Nunavut
British Columbia
Alberta
Saskatchewan
Manitoba
Québec

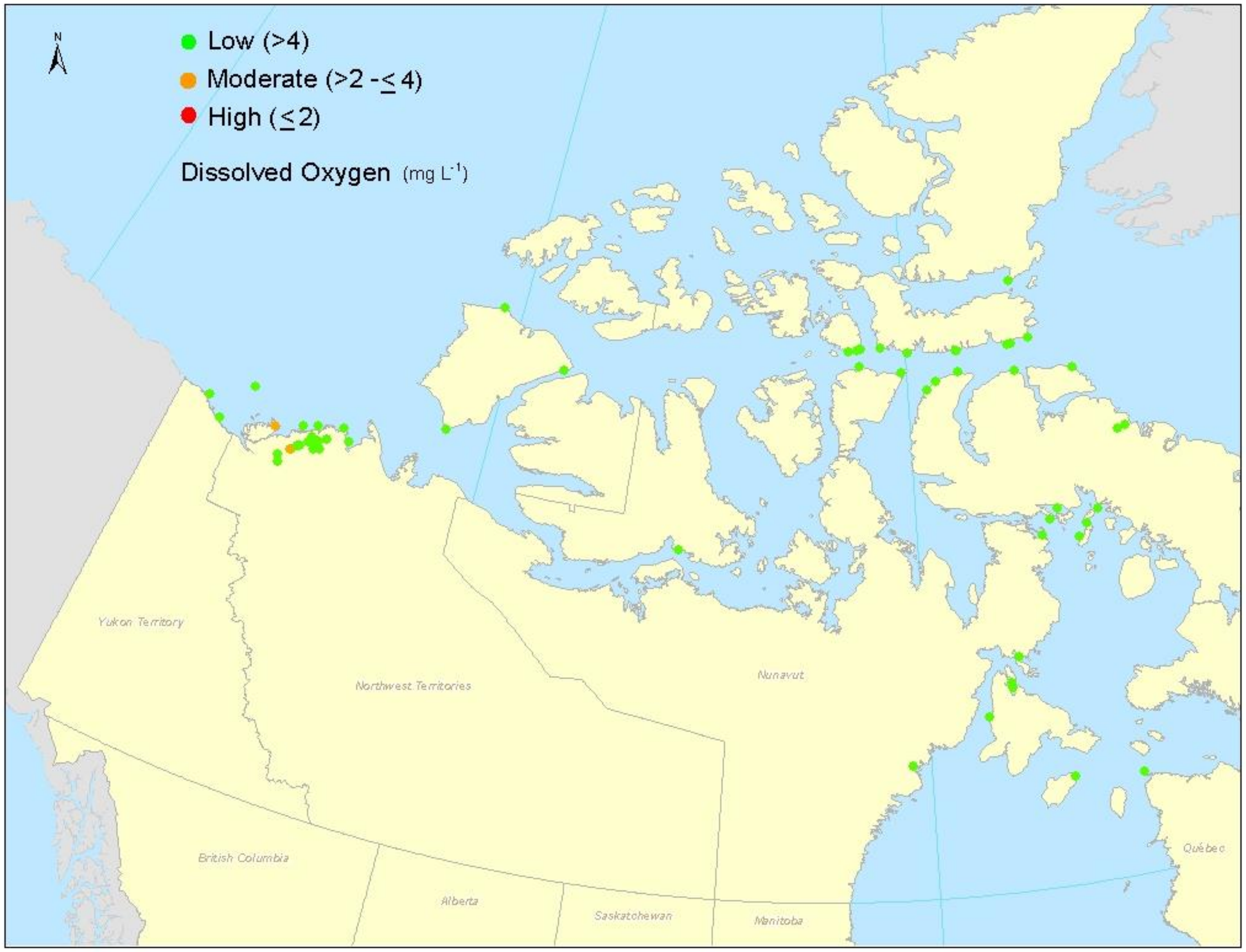
NORTHWEST


Low (0 - ≤0.01)
Moderate (>0.01 - ≤0.1)
High (>0.1)
Total Dissolved P (mg L-1)
Yukon Territory
Northwest Territories
Nunavut
British Columbia
Alberta
Saskatchewan
Manitoba
Québec

NORTHWEST


N
Low (0 - ≤5)
Moderate (>5 - ≤20)
High (>20)
Chlorophyll a concentration (μg L-1)
Yukon Territory
Northwest Territories
Nunavut
British Columbia
Alberta
Saskatchewan
Manitoba
Québec

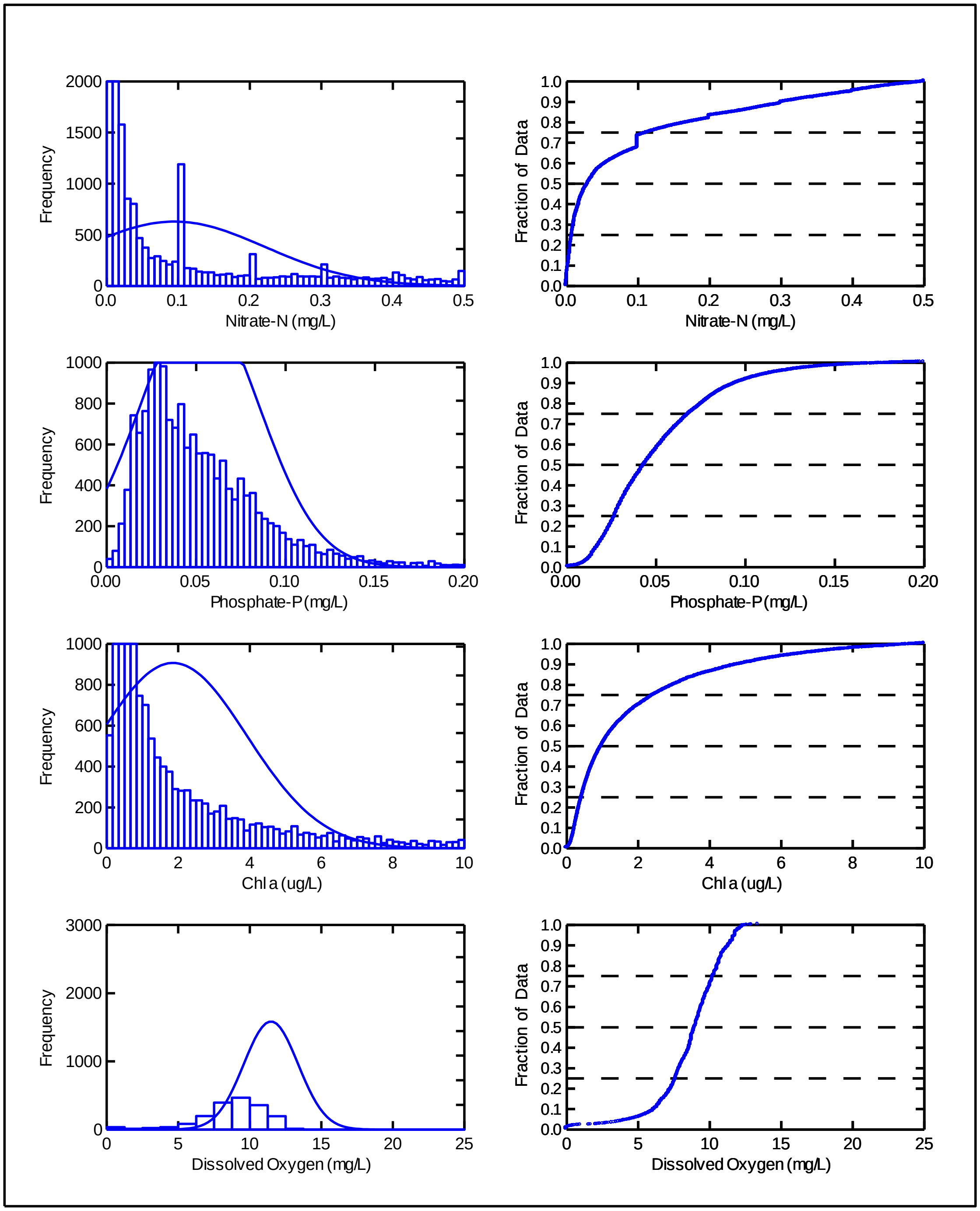
NORTHWEST


Low (>4)
Moderate (>2 - ≤ 4)
High (≤ 2)
Dissolved Oxygen (mg L-1)
Yukon Territory
Northwest Territories
Nunavut
British Columbia
Alberta
Saskatchewan
Manitoba
Québec

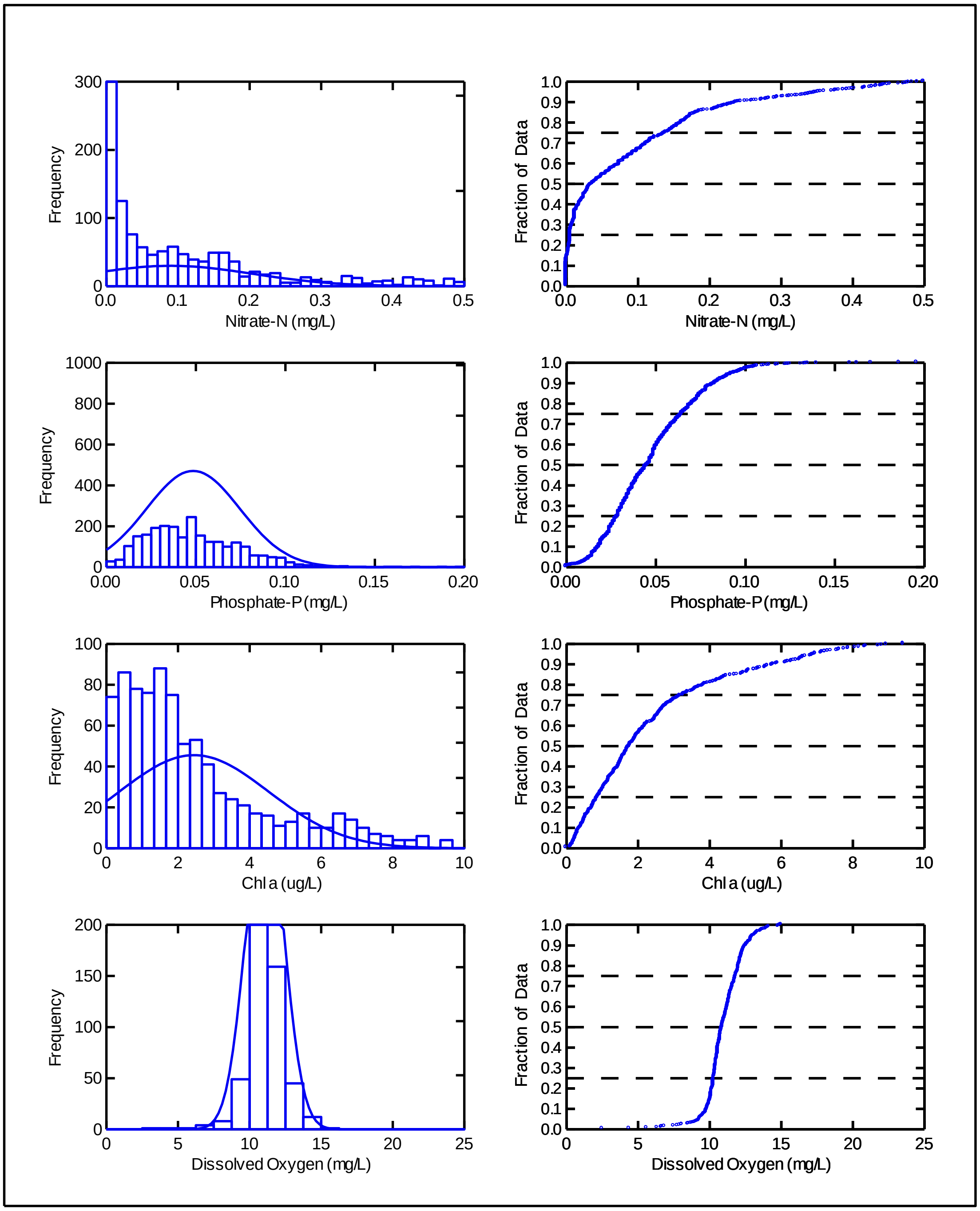
NORTHWEST

APPENDIX II
Probability Plots

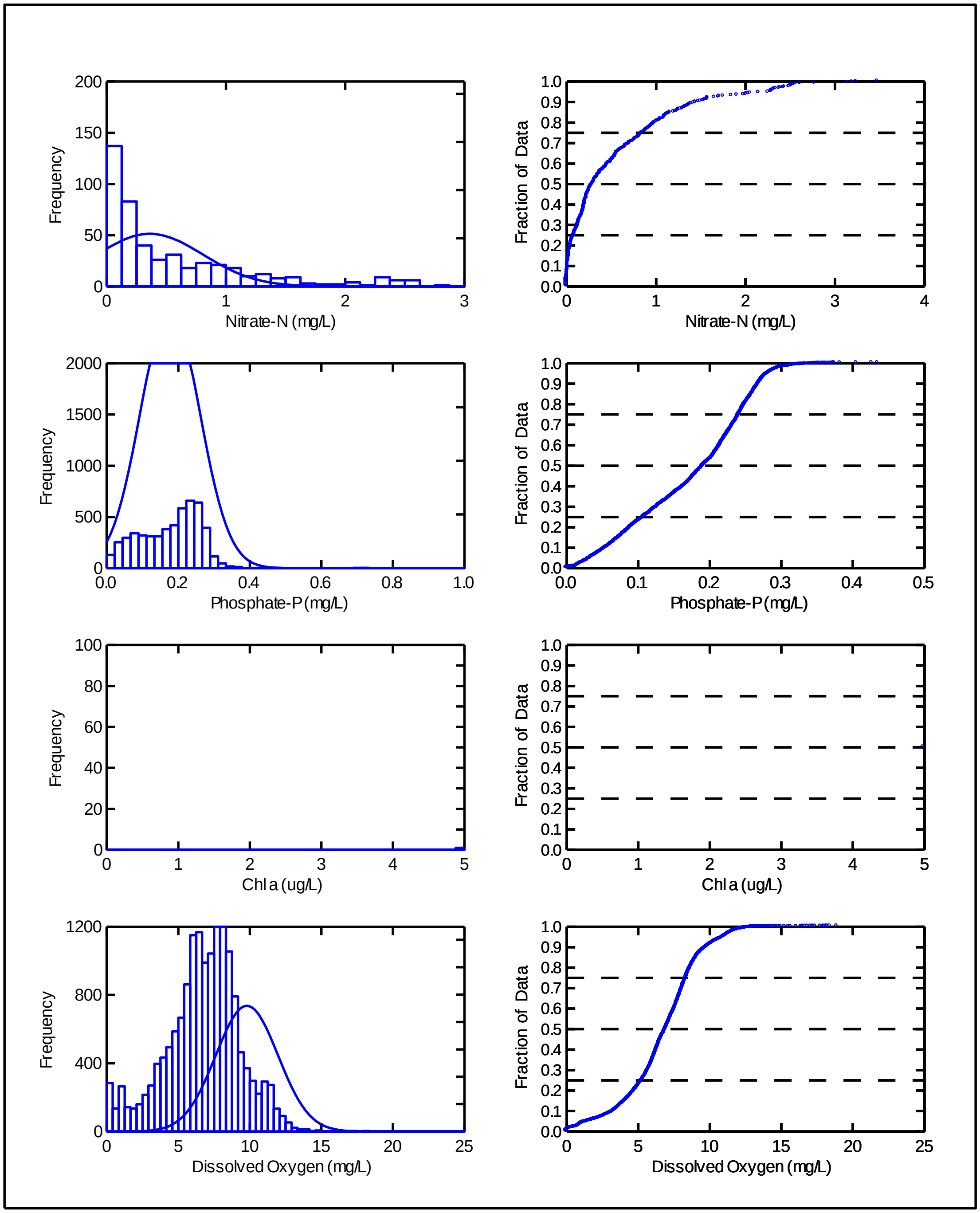
EAST


Frequency
Nitrate-N (mg/L)
Fraction of Data
Nitrate-N (mg/L)
Frequency
Phosphate-P (mg/L)
Fraction of Data
Phosphate-P (mg/L)
Frequency
Chl a (ug/L)
Fraction of Data
Chl a (ug/L)
Frequency
Dissolved Oxygen (mg/L)
Fraction of Data
Dissolved Oxygen (mg/L)

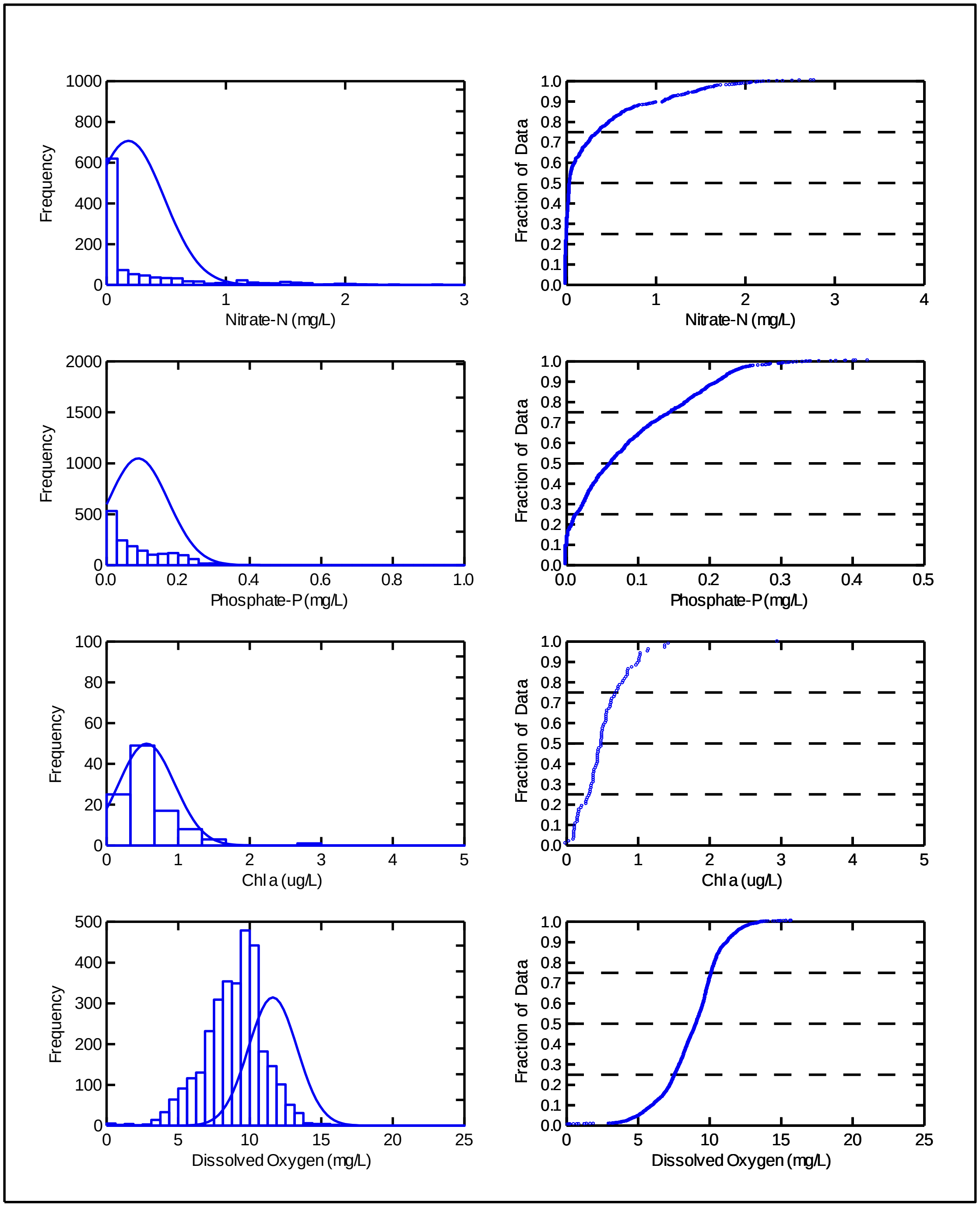
NORTHEAST


Frequency
Nitrate-N (mg/L)
Fraction of Data
Nitrate-N (mg/L)
Frequency
Phosphate-P (mg/L)
Fraction of Data
Phosphate-P (mg/L)
Frequency
Chl a (ug/L)
Fraction of Data
Chl a (ug/L)
Frequency
Dissolved Oxygen (mg/L)
Fraction of Data
Dissolved Oxygen (mg/L)

WEST


Frequency
Nitrate-N (mg/L)
Fraction of Data
Nitrate-N (mg/L)
Frequency
Phosphate-P (mg/L)
Fraction of Data
Phosphate-P (mg/L)
Frequency
Chl a (ug/L)
Fraction of Data
Chl a (ug/L)
Frequency
Dissolved Oxygen (mg/L)
Fraction of Data
Dissolved Oxygen (mg/L)

NORTHWEST


Frequency
Nitrate-N (mg/L)
Fraction of Data
Nitrate-N (mg/L)
Frequency
Phosphate-P (mg/L)
Fraction of Data
Phosphate-P (mg/L)
Frequency
Chl a (ug/L)
Fraction of Data
Chl a (ug/L)
Frequency
Dissolved Oxygen (mg/L)
Fraction of Data
Dissolved Oxygen (mg/L)

Appendix III
Watershed Land Use and Areas

Appendix III - Watershed Land Use and Areas

Main Watershed	Sub-Watershed	Agriculture	Commercial	Forest	Industrial	Institutional	No evident use	Recreation	Residential	Transportation	Urban	Wetlands	Total hectares	% Agriculture
Boughton River	BLACKETTS CREEK27	180.84	0.00	757.99	1.23	0.80	15.46	0.00	13.71	15.87	0.00	127.13	1113.03	**16.2**
	BOUGHTON RIVER29	1887.77	3.34	2426.91	14.28	1.91	119.81	4.38	48.11	108.82	12.06	490.16	5117.55	**36.9**
	GRAYSTONE CREEK101	304.04	0.35	418.19	0.00	0.33	18.61	0.00	4.45	11.14	0.00	41.90	799.01	**38.1**
	MORRISON POND165	70.35	0.00	499.55	0.00	0.00	12.32	0.00	10.45	11.32	0.00	32.51	636.50	**11.1**
	NARROWS CREEK169	292.38	0.52	1272.53	0.14	3.20	9.89	0.00	12.94	23.11	0.00	115.07	1729.78	**16.9**
	POPLAR POINT191	263.71	0.00	556.53	0.00	0.00	22.45	1.19	26.17	28.25	0.00	54.62	952.92	**27.7**
Brackley Bay	BLACK RIVER25	1277.19	5.91	609.93	0.57	0.44	33.46	15.66	57.76	37.42	0.00	47.32	2085.66	**61.2**
	McCALLUM CREEK154	448.82	28.68	485.07	11.27	0.69	49.66	24.10	108.63	41.70	0.00	362.93	1561.55	**28.7**
	BRUDENELL RIVER36	2329.22	33.19	2316.78	62.60	1.69	140.63	213.74	120.95	140.43	6.70	160.28	5526.21	**42.1**
Cardigan Bay	BYRNES CREEK37	160.76	0.00	596.35	5.58	0.00	10.52	0.00	6.67	9.18	0.00	18.73	807.79	**19.9**
	CARDIGAN RIVER45	1158.71	10.99	2655.44	34.10	1.71	98.31	6.31	112.36	161.79	24.04	192.03	4455.79	**26.0**
	LAUNCHING129	328.41	0.00	963.80	1.40	0.00	50.82	0.00	37.22	36.47	0.00	129.28	1547.40	**21.2**
	MITCHELL RIVER162	65.52	0.00	1071.28	0.00	0.00	12.42	0.00	10.70	27.28	0.00	74.75	1261.95	**5.2**
	SEAL RIVER (CARDIGAN)215	496.91	0.00	1350.06	0.76	0.47	44.04	0.00	27.56	49.71	0.00	125.42	2094.93	**23.7**
Cascumpec Bay	FOXLEY RIVER83	383.10	0.00	2636.81	148.46	2.13	72.09	1.96	32.98	55.99	0.00	906.02	4239.54	**9.0**
	TROUT RIVER (ROXBURY)244	4274.93	2.94	4877.42	51.23	11.62	359.51	9.57	113.38	199.95	77.62	729.69	10707.86	**39.9**
Colville Bay	SOURIS RIVER224	2037.12	2.27	2488.61	25.66	14.47	195.01	2.24	122.99	145.53	86.02	189.62	5309.54	**38.4**
Covehead Bay	BELLS CREEK15	2194.63	13.41	1437.00	18.94	5.43	119.17	79.90	174.04	71.91	79.27	130.04	4323.74	**50.8**
	BLACK RIVER25	1277.19	5.91	609.93	0.57	0.44	33.46	15.66	57.76	37.42	0.00	47.32	2085.66	**61.2**
	McCALLUM CREEK154	448.82	28.68	485.07	11.27	0.69	49.66	24.10	108.63	41.70	0.00	362.93	1561.55	**28.7**
Grand River	GRAND RIVER99	1162.41	1.82	3175.55	32.44	5.91	173.30	6.69	78.20	116.08	37.36	356.23	5145.99	**22.6**
	LITTLE TROUT RIVER137	635.24	3.71	1258.67	25.60	0.00	46.78	0.66	27.73	51.85	0.00	78.83	2129.07	**29.8**
	NEBRASKA CREEK171	1155.26	0.89	868.35	5.05	0.00	77.58	0.00	39.98	49.22	0.00	205.45	2401.78	**48.1**

	ROCHFORD POND203	228.49	0.79	73.42	0.00	0.27	35.00	0.00	6.05	9.14	0.00	83.96	437.12	**52.3**
	SHIPYARD CREEK221	1480.70	6.05	692.73	5.85	0.00	108.49	1.40	29.19	72.31	0.00	61.52	2458.24	**60.2**
Hillsborough River	APPLETREE CREEK5	203.48	0.00	49.06	0.00	0.00	1.62	0.00	11.88	5.51	0.00	10.40	281.95	**72.2**
Hillsborough River	BLACK BROOK21	197.86	0.23	298.10	0.97	0.00	13.25	0.00	12.48	22.15	0.00	42.78	587.82	**33.7**
	CHEESE FACTORY CREEK51	781.52	1.39	521.63	6.22	5.50	35.71	3.00	26.58	26.77	0.00	99.98	1508.30	**51.8**
	CLARKS BROOK55	1510.59	0.00	2396.72	13.28	0.00	54.56	0.00	40.56	107.17	0.00	507.19	4630.07	**32.6**
	FULLERTONS CREEK86	1698.70	1.55	639.13	16.62	4.21	183.55	2.35	206.67	85.70	22.08	185.09	3045.65	**55.8**
	GLENFINNAN RIVER92	1051.87	0.00	1686.43	9.73	5.94	63.21	2.35	42.68	52.36	0.00	412.80	3327.37	**31.6**
	HILLSBOROUGH RIVER110	1663.47	3.20	2923.01	6.48	8.09	131.97	0.85	45.86	118.71	6.88	401.44	5309.96	**31.3**
	HORNES CREEK1114	842.63	1.18	209.09	3.65	1.65	19.09	23.39	57.28	26.84	0.00	17.76	1202.56	**70.1**
	HORNES CREEK2115	772.91	5.59	156.91	8.20	0.00	29.58	0.00	38.33	31.16	15.57	33.63	1091.88	**70.8**
	JOHNSTONS RIVER124	1999.81	0.00	1211.21	9.39	1.13	100.91	0.01	80.98	58.71	0.00	465.48	3927.63	**50.9**
	MILLERS CREEK159	781.13	0.37	710.93	11.77	0.83	38.83	0.00	33.88	45.04	0.00	169.98	1792.76	**43.6**
	PISQUID RIVER187	1573.99	0.61	2524.09	10.16	0.00	80.75	0.00	47.09	120.18	10.87	386.83	4754.57	**33.1**
	RIVERSIDE202	47.27	0.24	19.97	3.56	43.33	7.83	75.84	0.75	39.37	536.89	13.97	789.02	**6.0**
	ROSEBANK207	115.66	11.00	64.21	23.98	13.61	115.62	82.03	25.81	31.04	311.61	10.33	804.90	**14.4**
	SCOTCHFORT212	381.72	0.58	308.62	2.58	0.00	20.91	1.25	25.21	30.94	3.76	121.64	897.21	**42.5**
	SCOTTS CREEK213	390.64	2.34	98.57	15.15	1.04	20.93	0.63	32.95	9.80	0.00	17.86	589.91	**66.2**
	WRIGHTS CREEK260	398.40	0.00	56.28	9.16	13.67	97.57	4.80	43.57	74.10	211.08	39.23	947.86	**42.0**
Kildare River	DOCK RIVER70	909.65	1.86	493.85	6.97	5.10	58.07	10.51	42.66	63.87	157.31	79.05	1828.90	**49.7**
	HUNTLEY RIVER119	1655.84	1.10	906.81	39.21	1.91	60.09	0.72	68.88	86.43	16.42	48.02	2885.43	**57.4**
	KILDAIRE RIVER127	1657.21	1.13	922.02	7.64	0.05	33.05	0.00	62.87	63.89	0.00	140.90	2888.76	**57.4**
Mill River	HILLS RIVER109	995.75	0.00	239.74	11.11	8.24	16.10	1.34	67.30	31.65	0.00	24.22	1395.45	**71.4**
	MILL RIVER158	4665.38	11.08	5274.46	45.66	23.75	237.05	145.64	204.01	226.13	0.00	414.59	11247.75	**41.5**
Montague River	LOWER MONTAGUE141	26.97	3.59	213.76	0.00	0.00	4.50	0.00	19.34	9.20	8.90	7.93	294.19	**9.2**
	MONTAGUE-VALLEYFIELD163	6925.02	17.69	10749.89	275.12	19.76	295.82	6.44	360.84	412.43	229.75	373.01	19665.77	**35.2**
Murray River	MURRAY RIVER166	1424.07	6.56	4768.09	55.69	3.66	94.47	29.08	103.42	160.32	83.82	361.63	7090.81	**20.1**
New London Bay	BAYVIEW11	550.85	3.91	445.54	3.80	0.96	31.70	23.57	23.28	17.19	0.00	14.49	1115.29	**49.4**
	CAMPBELLS POND40	725.80	0.00	176.73	0.00	0.00	23.28	0.01	20.57	15.49	0.00	54.14	1016.02	**71.4**
	DURANT CREEK72	516.91	0.00	115.16	0.54	0.00	8.78	0.00	13.46	10.48	0.00	11.05	676.38	**76.4**
	FOUNDS RIVER81	974.96	9.17	204.54	3.30	0.00	34.16	2.39	71.99	33.33	0.00	21.92	1355.76	**71.9**
	FRENCH RIVER85	421.97	0.00	113.66	0.75	0.00	23.46	53.36	44.69	21.90	0.00	6.90	686.69	**61.4**

	GRAHAMS CREEK97	218.99	10.23	146.59	0.00	1.18	46.20	40.81	17.83	7.66	0.00	101.45	590.94	**37.1**
	GRANVILLE CREEK100	1374.89	0.00	1050.07	1.05	1.09	58.92	0.00	47.48	36.76	0.00	30.17	2600.43	**52.9**
	HARDING CREEK105	662.61	0.00	118.53	7.73	0.00	26.01	31.24	38.32	18.59	0.00	16.70	919.73	**72.0**
	HOPE RIVER113	992.69	0.00	804.15	10.57	3.38	50.24	0.00	40.19	51.08	0.00	9.81	1962.11	**50.6**
	LONG RIVER140	534.35	0.00	155.92	1.69	0.00	4.57	0.00	27.65	20.13	0.00	5.60	749.91	**71.3**
	MACINTYRES CREEK145	531.52	0.00	64.26	2.69	0.90	18.05	0.00	42.40	17.11	7.97	8.92	693.82	**76.6**
	MACKIES POND147	314.30	0.83	92.28	2.62	0.25	5.20	0.00	30.39	6.90	0.00	18.31	471.08	**66.7**
	PAYNTERS CREEK183	741.78	5.76	176.39	2.03	2.04	8.33	0.00	20.27	23.78	0.00	13.96	994.34	**74.6**
	SOUTHWEST RIVER227	1785.15	18.81	371.48	0.84	1.33	39.81	3.13	77.53	52.35	0.00	65.52	2415.95	**73.9**
	SUTHERLAND CREEK239	275.14	0.00	74.67	0.39	0.00	16.15	0.00	10.31	6.14	0.00	6.39	389.19	**70.7**
	TROUT RIVER (MILLVALE)243	2251.05	4.72	2608.40	15.89	0.91	127.61	8.96	138.20	132.16	4.68	36.99	5329.57	**42.2**
	TUPLIN CREEK247	561.83	0.00	62.15	6.18	7.50	19.62	0.00	36.91	13.04	13.27	29.50	750.00	**74.9**
North River	NORTH RIVER176	5855.84	114.84	1518.79	72.95	54.97	372.78	10.48	322.49	333.26	909.09	332.27	9897.76	**59.2**
	EARNSCLIFFE73	1874.32	0.52	450.32	7.64	1.15	124.22	0.00	52.36	55.52	0.00	143.95	2710.00	**69.2**
	ORWELL COVE178	259.05	0.00	31.50	0.04	0.00	46.72	0.00	11.70	6.82	0.00	52.56	408.39	**63.4**
Orwell Bay	ORWELL RIVER179	1616.64	0.00	1023.44	5.17	0.84	99.98	0.69	46.64	73.70	0.00	85.34	2952.44	**54.8**
	SEAL RIVER (VERNON)216	1451.54	1.10	581.27	8.05	1.23	85.44	0.00	32.79	48.18	0.00	129.97	2339.57	**62.0**
	VERNON RIVER248	2938.86	2.28	2987.77	7.58	6.78	175.07	66.94	97.21	170.02	0.00	462.49	6915.00	**42.5**
Pinette River	PINETTE RIVER185	1672.70	3.66	3413.34	19.05	6.14	55.44	15.12	116.83	90.94	0.00	62.08	5455.30	**30.7**
	CHAPEL CREEK49	790.46	1.14	165.91	0.64	4.55	57.86	0.00	48.00	21.14	0.00	26.22	1115.92	**70.8**
	CYMBRIA65	156.51	6.20	66.12	1.69	0.00	8.53	52.75	64.06	7.57	0.00	9.67	373.10	**41.9**
	HORNES CREEK1114		842.63	1.18	209.09	3.65	1.65	19.09	23.39	57.28	26.84	0.00	17.76	**0.0**
Rustico	HORNES CREEK2115		772.91	5.59	156.91	8.20	0.00	29.58	0.00	38.33	31.16	15.57	33.63	**0.0**
	LUKES CREEK143	159.39	1.63	16.67	0.00	1.33	19.12	0.00	24.07	8.22	0.00	11.40	241.83	**65.9**
	OYSTER BED BRIDGE181	42.55	0.00	8.20	0.00	0.00	7.59	7.09	10.37	5.17	1.48	3.43	85.88	**49.5**
	WHEATLEY RIVER255	4236.86	2.36	1149.74	6.53	2.48	105.08	0.00	140.51	99.87	0.00	55.61	5799.04	**73.1**
	MARIE RIVER153	1249.48	0.00	1312.99	4.55	0.27	34.66	0.00	19.55	64.57	0.00	243.53	2929.60	**42.7**
	MIDGELL RIVER156	1263.07	0.00	4243.62	3.41	1.82	64.19	0.00	32.02	87.30	0.00	682.19	6377.62	**19.8**
St. Peters Bay	MORELL RIVER164	4811.71	4.48	9864.01	53.49	4.15	490.87	66.89	197.81	343.70	36.25	1182.53	17055.89	**28.2**
	ST. PETERS HARBOUR231	74.57	0.00	30.11	0.00	0.00	16.38	0.00	30.25	6.01	0.00	67.06	224.38	**33.2**
	ST. PETERS RIVER233	1547.78	4.27	2085.10	18.16	7.12	248.39	21.76	72.18	130.27	22.59	280.51	4438.13	**34.9**
Summerside	BRADSHAW RIVER30	3245.89	5.16	783.31	13.14	6.18	94.22	6.02	95.03	172.10	35.97	146.57	4603.59	**70.5**

Harbour	DUNK RIVER71	11066.15	31.81	4081.74	43.00	10.06	247.68	1.07	303.37	406.92	52.48	323.53	16567.81	**66.8**
	SCHURMANS POINT211	95.89	0.04	13.94	0.00	0.00	0.00	0.00	30.27	3.16	0.00	0.00	143.30	**66.9**
	SEVEN MILE BAY218	2196.28	4.42	1058.21	47.51	2.44	163.01	3.28	208.73	116.33	140.95	253.45	4194.61	**52.4**
	SUNBURY COVE237	1907.20	128.55	4724.06	88.04	27.35	378.67	93.26	162.72	235.57	405.78	884.73	9035.93	**21.1**
	WILMOT RIVER258	6473.58	28.35	943.34	32.02	5.77	126.09	2.53	171.65	189.99	143.52	222.16	8339.00	**77.6**
Tracadie Bay	BLACK RIVER (DONALDSTON)26	472.42	0.00	356.86	2.74	0.00	23.81	0.00	21.52	15.11	0.00	75.28	967.74	**48.8**
	DEROCHE POND68	627.70	0.23	1471.51	1.60	0.00	41.00	0.00	11.42	40.13	0.00	648.72	2842.31	**22.1**
	KELLYS POINT126	25.73	0.00	36.29	0.00	0.00	7.36	0.00	18.90	4.01	0.00	0.00	92.29	**27.9**
	PIPERS CREEK186	607.89	1.39	1210.96	4.54	5.06	36.28	2.02	67.84	41.96	0.00	150.36	2128.30	**28.6**
	WINTER RIVER259	2882.63	7.73	2903.42	79.81	4.93	228.85	5.56	297.88	305.30	7.90	230.95	6954.96	**41.4**
West River	CHURCHILL54	387.12	1.20	349.14	9.84	1.22	41.84	20.38	21.65	21.75	0.00	28.83	882.97	**43.8**
	CLYDE RIVER56	2892.07	3.18	740.80	27.06	7.65	124.23	49.59	160.90	78.49	0.00	83.49	4167.46	**69.4**
	FAIRVIEW76	1109.90	1.60	404.03	4.65	0.97	80.43	53.90	117.76	45.77	0.00	51.64	1870.65	**59.3**
	HYDE CREEK120	1296.15	0.75	295.52	1.14	11.56	57.38	22.54	85.57	44.48	160.35	50.72	2026.16	**64.0**
	LONG CREEK139	580.13	2.53	159.30	0.75	0.98	15.69	0.00	36.83	16.00	0.00	41.95	854.16	**67.9**
	MACFAYDENS CREEK144	123.75	0.00	250.49	0.59	0.00	19.10	0.00	3.90	3.64	0.00	8.77	410.24	**30.2**
	MACLAUGHLINS CREEK149	222.57	0.00	199.88	1.11	0.00	8.37	0.00	9.12	5.86	0.00	2.50	449.41	**49.5**
	MACLEODS CREEK151	128.43	0.00	14.66	0.07	0.00	6.68	0.00	17.49	5.34	0.00	1.85	174.52	**73.6**
	MCPHEE CREEK155	108.69	3.70	105.22	9.66	0.37	15.61	3.23	37.49	10.20	0.00	3.87	298.04	**36.5**
	WEST RIVER253	4693.20	12.16	5803.53	16.21	6.81	290.27	68.06	170.77	241.69	0.00	110.17	11412.87	**41.1**

Appendix IV

Morphological Parameters, Dilution Potential, Flushing Time and Susceptibility Index for each site.

Watershed	High Water Surface Area (10^6 m^2)	Low Water Surface Area (10^6 m^2)	High Water Volume (10^6 m^3)	Low Water Volume (10^6 m^3)	Mean Tidal Range (m)	Tidal Prism (m^3)	Mean Low Water Depth (m)	Mean High Water Depth (m)	Dilution Potential	Flushing Time (hrs)	Susceptibility Index
Boughton River	9.5	7.2	36.3	22.9	1.6	13.5	3.2	3.8	1.18	26.8	0.466
Brackley	2.3	1.6	4.7	2.9	0.9	1.8	1.8	2.1	6.56	26.4	0.589
Brudenell Bay	4.1	3.2	14.1	8.3	1.6	5.9	2.6	3.4	3.33	23.1	0.460
Cardigan River	8.0	5.8	37.3	26.1	1.6	11.2	4.5	4.7	0.63	35.0	0.374
Covehead Bay	4.1	2.7	8.2	5.1	0.9	3.1	1.9	2.0	6.12	26.1	0.487
Foxley River	14.4	9.2	27.5	16.3	0.9	11.2	1.8	1.9	4.62	23.8	0.350
Grand River	9.5	6.9	18.6	17.9	1.0	8.0	2.6	2.7	2.05	33.5	0.357
Mill River	5.2	4.1	24.5	9.1	0.9	4.4	2.2	2.6	4.26	31.4	0.614
Montague River	4.1	3.2	14.1	8.3	1.6	5.9	2.6	3.4	12.01	23.1	0.380
Murray River	6.3	5.0	23.6	14.8	1.6	8.8	2.9	3.7	2.51	26.5	0.251
Orwell Bay	5.4	1.8	26.0	3.4	2.5	8.9	1.9	2.3	6.08	9.6	0.241
Rustico Bay	11.1	7.6	24.6	16.0	0.9	8.6	2.1	2.2	1.96	29.0	1.000
Southwest River	5.7	4.0	9.9	6.7	0.9	4.0	1.7	1.9	2.00	26.5	0.924
St Peters River	14.4	11.8	48.2	37.9	0.8	10.4	3.2	3.4	5.08	51.3	0.698
Summerside Harbour	20.3	9.4	49.9	17.8	2.0	29.7	1.9	2.3	8.02	12.6	0.347
Tracadie Bay	18.6	13.3	37.9	23.3	0.9	14.6	1.7	2.0	2.88	25.5	0.427
West River	16.2	7.1	33.6	19.8	2.5	19.2	2.8	2.4	2.49	18.3	0.556