ICF CONSULTING

MEMORANDUM

To: Dr. Michael Suplee, Montana Department of Environmental Quality

From: Arun Varghese and Joshua Cleland

Date: June 29, 2005

Subject: Seasonally Stratified Water Quality Analysis for Montana Rivers and Streams – Final Report

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1. Introduction

This memorandum presents ICF's analysis of regionally based stratification methodologies for water quality criteria determination in Montana rivers and streams.

The purpose of this analysis is to support the Montana Department of Environmental Quality (MT DEQ) as it develops nutrient and nuisance-algae criteria for flowing waters. This analysis builds upon research and analysis ICF performed for related project phases sponsored by the U.S. Environmental Protection Agency (EPA) and MT DEQ:

- In a July 2004 report (ICF 2004b), we analyzed the relationships between ambient surface water quality and selected environmental and geospatial characteristics of Montana rivers and streams; and
- In a November 2004 (ICF 2004a) report, we analyzed the relationship between the statistical distributions of water quality parameter observations at designated reference locations and in the whole population of observations from water quality monitoring locations in various classes of Montana rivers and streams.

In the current analysis, most elements of the previous two phases of have been reworked with an expanded database and employing seasonal stratification as a further means of partitioning the data. In addition, the current analysis examines whether general purpose, regionally based stratifying methodologies such as Omernik ecoregions provide an adequate basis to establish geographic zones for nutrient criteria determination in the state of Montana. The analysis also examines using stream order and lithology data in combination with Omernik ecoregions to establish nutrient zones.

Section 2 of this memorandum describes the scope and objectives of this analysis. Section 3 identifies the sources of data ICF used for the analysis and explains how we compiled the data into a relational database. Section 4 describes the statistical methods used in the analysis. In Section 5, we present the results and conclusions of the analysis. Section 6 identifies the literature cited in this memorandum. Appendix A documents the methodologies used to group water quality parameters, Appendix B documents the methodologies used to group data by seasons, Appendix C describes the lithologic grouping methodology, and Appendix D provides the detailed results log files of the statistical analysis.

2. Scope and Objectives

EPA's guidance on nutrient and algal criteria development (EPA 2000) recognizes the need for identifying stream groups with comparable biological, ecological, physical, and chemical features, because natural levels of nutrient concentrations in streams are likely to be related to these factors. Spatially defined nutrient zones developed by grouping streams with similar characteristics are therefore an appropriate mechanism of setting nutrient criteria that reflect natural variability.

A stratifying system that tends to minimize variability within nutrient zones and maximize differences between nutrient zones is considered suitable for setting nutrient criteria. Two approaches have previously been proposed in regulatory guidance and literature for delineating such nutrient zones: (1) general purpose regionalizations that depend on subjective expert judgment in identifying regions that are relatively homogenous in terms of a composite set of environmental variables such as geology, ecology, climate and land-use and (2) nutrient-specific regionalizations that depend on empirical analysis and data-mining approaches to identify regions that are relatively homogenous in terms of the concentration of a particular nutrient. While nutrient-specific regionalizations may potentially provide a higher level of homogeneity and statistical precision, general-purpose zones offer advantages in terms of their easy applicability and convenience.

To support the development of general-purpose nutrient zones for Montana, we used statistical metrics to gauge the performance of potential general-purpose environmental stratifying methodologies. Specifically, we evaluated the Omernik ecoregions approach and improvised classifications based on Omernik ecoregions in combination with geological and hydrologic variables. The analyses were applied exclusively to Montana river and stream reaches, and the data were seasonally stratified to improve statistical precision. The analytical methods included tests to verify that the stratifications and sub-stratifications based on these parameters are statistically meaningful. We also computed alternative measures of variation to assess the effectiveness of the stratification methodologies. All analyses were conducted separately for the reference and whole population. Furthermore, the analyses were performed using all observed data, as well as station median data. The analyses based on station median data were expected to be more statistically robust.

Another objective of this project was to perform distributional analyses that would enable MT DEQ to use data from reference sites to develop nutrient and algal criteria within nutrient zones. EPA guidance (EPA 2000) recommends that the 75th percentile of the frequency distribution of water quality measurements at reference stream reaches be used to develop nutrient criteria. In the absence of data for reference stream reaches, EPA guidance recommends choosing from the 5th to 25th percentile of the frequency distribution of the whole population of a class of streams to develop the criteria.[1] Therefore, application of the EPA guidance requires not only the computation of the 75th percentile in reference population, but also comparison of this value with 5th to 25th percentile in the whole population. This analysis computes the 75th percentile of nutrient concentrations in the reference population and matches these to the whole population distribution to assess how the two populations are related for various potential nutrient zone groupings. This is effectively a revision of the analysis conducted in November 2004 (ICF, 2004b) using the updated database developed as part of this phase of the project.

A further objective of this analysis was to compare the distribution of stream order in the whole population data and the reference population data. This analysis was conducted for specific nutrients in Omernik level III ecoregions at both the observation level and the station level. This part of the analysis could potentially lay the groundwork for refined analyses based on bootstrapping or simulation methods that ensure appropriate representation of different stream orders in the determination of nutrient criteria. The analysis also tested for statistically significant differences in nutrient concentrations between seasons in Omernik level III ecoregions.

3. Data Sources and Database Development

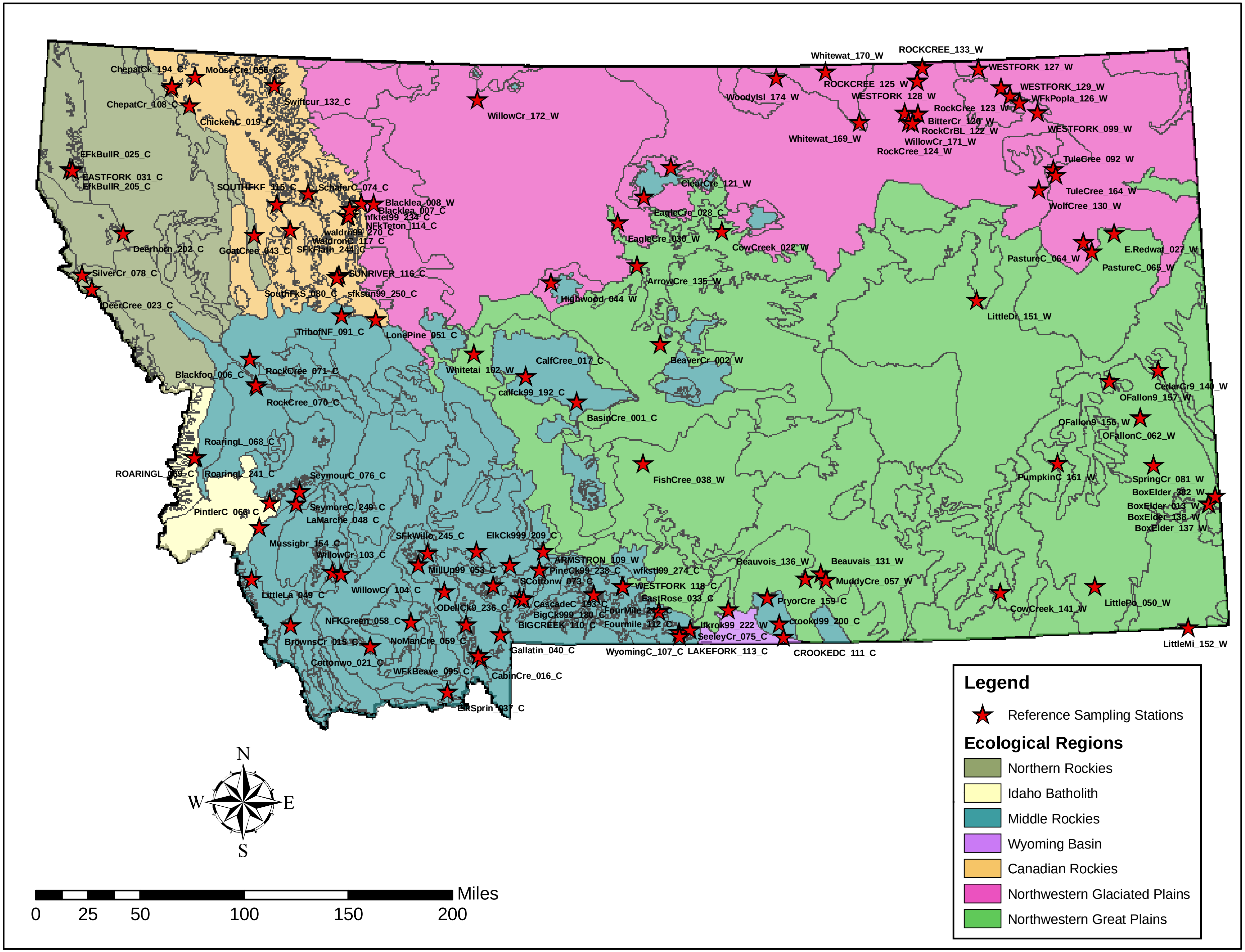
The first step of this analysis was to compile sources of water quality data and selected environmental and geospatial characteristics into a single relational database. Most of the water quality data were available in a database ICF compiled for the previous phases of the analysis (ICF 2004a).[2] ICF deleted reference data from the previously compiled database and then added water quality data from sampling sites in designated reference reaches as well as from a few non-reference reaches. These newly-added data were provided by MT DEQ[3] and reflected more-refined screening techniques for identifying reference reaches, as well as new data sources. Specific details on the reference site screening methodology are provided by MT DEQ (2005).

Figure 3.1 displays the location and identity of the reference stations in the newly-added MT DEQ data.

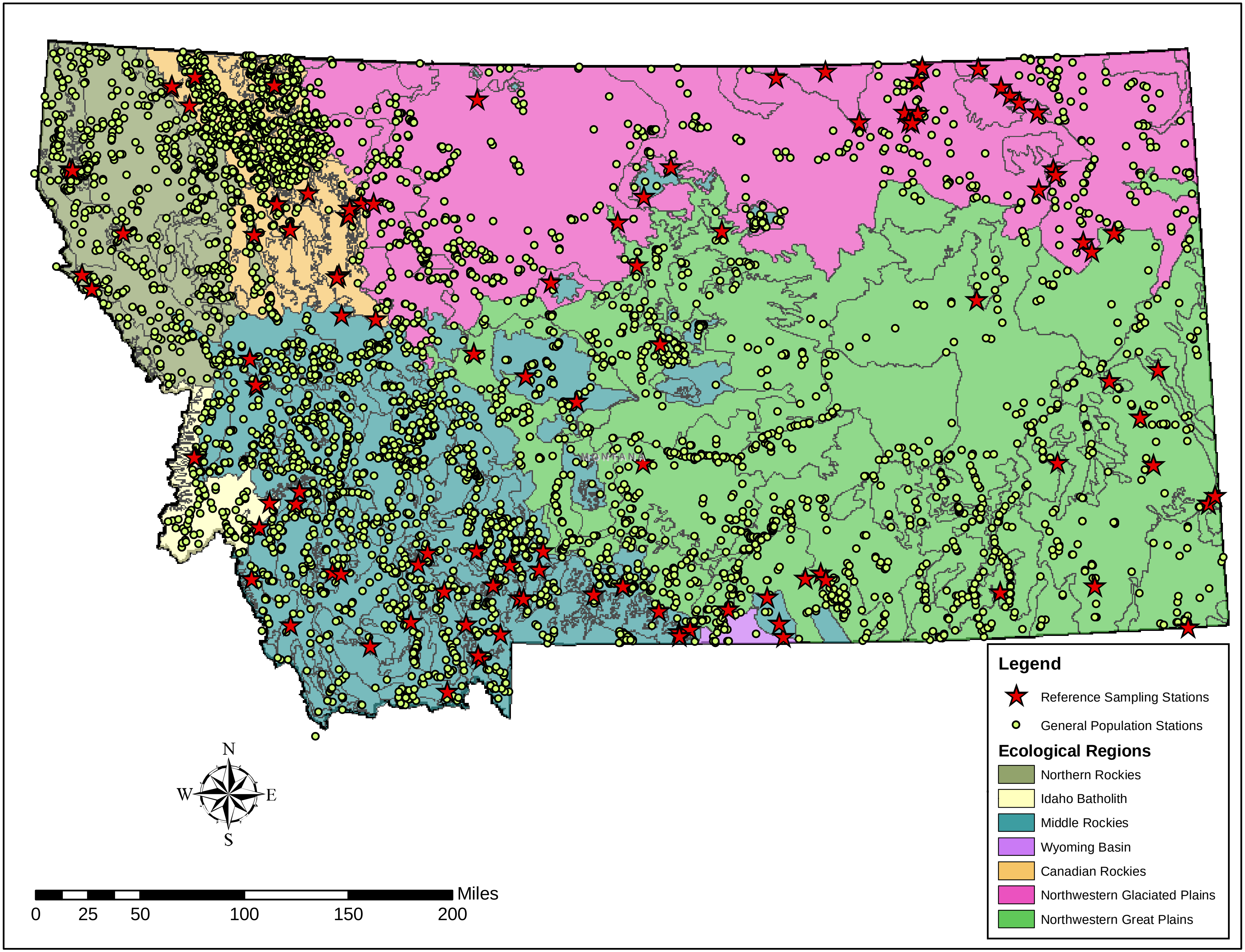
Figure 3.2 displays the location of the general population and reference population stations in the new database.

[1] Hereafter, we refer to data for the reference stream reaches as the "reference population." We refer to data for non-reference stream reaches as the "general population."
[2] See ICF (2004a and 2004b) for details about the sources of data used to create the database.
[3] Email communication with Dr Michael Suplee, MT DEQ, April 18, 2005.

Map 1: Reference Sampling Stations



Map 2: General Population and Reference Sampling Stations



ICF used the following steps to integrate the new and previously compiled data:

- The existing database was updated for Strahler stream order using new data provided by MT DEQ that related Strahler stream order to sampling stations.

- The updated version of the existing database (with reference data deleted) was appended to the new data provided by MT DEQ. A number of queries were designed to check for duplicate observations, which were identified and deleted. New fields were introduced to indicate whether the data related to a reference reach, and to indicate the origin of the data.

- The water quality data, which included latitude and longitude coordinates for each observation, were spatially joined to GIS layers containing information on the stratifying parameters of interest. In particular, using a spatial join, each observation was assigned appropriate values for each stratifying parameter depending on the location of the sampling site. The stratifying parameters thus incorporated into the database include Omernik level III ecoregions, Omernik level IV ecoregions, geologic formation, and elevation. Elevation does not play a role in this analysis but was included in the database for later use by MT DEQ.

- ICF created two stratifying parameters specifically for this analysis:

    - "Grouped level III ecoregions" creates superecoregions, which represent a coarser stratification than level III ecoregions. This stratification divides the state into Mountain and Prairie areas. The Mountain areas comprise the following level III ecoregions: Northern Rockies, Idaho Batholith, Middle Rockies and Canadian Rockies. The Prairie areas comprise the Wyoming Basin, Northwestern Glaciated Plains and Northwestern Great Plains.

    - "Grouped Strahler Stream Order" groups together stream orders 1&2, 3&4, 5&6, and 7&8, respectively, in order to increase sample size in each category without significant loss of hydrologic similarity.

- The previously compiled water quality data, which were obtained from Legacy STORET, were collected by various agencies using various methods. A methodology developed by MT DEQ was used to group related water quality parameters. The objective of the water quality parameter grouping methodology was to group fundamentally equivalent analytic measurements, while avoiding double counts. A detailed explanation of the parameter grouping methodology is provided in Appendix A.

- The water quality data were seasonally defined as Winter, Runoff, or Growing using a methodology developed by MT DEQ. A detailed explanation of the seasonal grouping methodology is provided in Appendix B.

- MT DEQ had previously provided ICF with data on lithologic classifications (e.g., rock types) within Montana (ICF, 2004b). The data were supplied in a GIS shapefile on a CD-ROM and were originally developed by Raines and Johnson (1996). The lithological classification shapefile contained over 80 groupings (i.e., rock types). Following the GIS-based spatial join, ICF combined these into 19 major lithologic categories according to a methodology proposed by MT DEQ, which is described in Appendix C. Lithologic classifications are also referred to as geologic formations in this analysis.

- To eliminate potentially erroneous or highly uncertain data from the assessment, ICF excluded water quality data associated with certain comment codes[4] in the Legacy STORET data. For example, these codes denoted estimated values or values from analyses known to be in error.

- In addition, ICF replaced Legacy STORET data bearing comment codes[5] denoting non-detects with values equal to 50 percent of the reported detection limits.

- ICF also eliminated from use all water quality parameters that had reported values of zero. Most analytical results in the database provided a result value and a detection limit, or an indication that the analyte was below the detection limit. True analytical values of zero are very unlikely (Luce, 2005), and therefore these data (most of which are old) were not used.

The resulting database is referred to hereafter as the "all-observation database."

We then processed the all-observation database to develop a "median database" as an alternative basis for analysis. The median database contains a unique observation for each nutrient, for each station, for each season. This observation is the median observed value for a nutrient, at a particular station, in a particular season. The median database is less likely to be influenced by outliers and is more amenable to parametric statistical analysis. Analyses based on station median data are therefore expected to be more statistically robust. Many of the analyses conducted in this assignment were performed for both the total database and median database. However, many of the results summarized in this report are based on the median database.

The software used in the creation of the combined database included Arcview GIS, Stata (version 7), Microsoft Access and Microsoft Excel.

4. Statistical Methods

This section discusses the statistical methods employed in the following components of the analysis:

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[4] Specifically, ICF eliminated Legacy STORET data bearing comment-codes *H, O, Q, L, Y* and *"*"*; USGS data bearing comment code *E;* and estimated data bearing comment code *J (*with the exception of benthic chlorophyll-A data bearing comment code *J.)*

[5] The specific legacy STORET comment codes included *T, M, W, K, U, ND,"<" and "Non-detect."*

- Mapping percentiles of interest from the reference population to the general population;
- Testing of different stratification methodologies;
- Computing measures of variance for alternative stratification methodologies;
- Examining seasonal differences in nutrient concentrations; and
- Analyzing stream order distributions in the general and reference populations.

For all analyses, ICF performed a series of statistical calculations by means of programs written in Stata (version 7), a statistical analysis software package. ICF ran the Stata program for each water quality parameter for various combinations of stratifying parameters. Coarse-scale stratifications refer to stratifications based on a single stratifying parameter. Fine-scale stratifications refer to stratifications based on two stratifying parameters, one embedded or sub-stratified within the other. The results of the Stata runs are presented in Appendix D, along with a guide to their interpretation.

Most analyses were conducted separately for the general population and the reference population. Certain analyses were conducted exclusively on the all-observation database, other analyses exclusively on the median database, and some analyses were performed on both databases. Most analyses were performed for all seasons as well as for specific seasons.

Sections 4.1 through 4.5 provide further explanation of each component of the statistical analysis. Section 4.6 describes ICF's quality assurance measures for the statistical results.

4.1 Percentile Mapping

Percentile mapping was performed using only the all-observation database. The percentile mapping methodology included four steps:

- Computing summary statistics to describe the reference, non-reference, and whole population characteristics for alternative stratification methodologies;
- Performing tests of equality of populations to assess whether the reference and non-reference populations within each level of each stratification could be considered similar; and
- Matching the reference and whole population distributions within each level of each stratification methodology.

ICF performed the percentile matching only when four or more observations were available at non-reference and reference locations. Results were reported for each specific season and for all seasons combined. Each step in the percentile mapping analysis is described further below.

4.1.1 Summary Statistics for Reference and Whole Population

Summary statistics in the Stata results characterize the reference, non-reference, and whole population statistical distributions for the selected water quality parameter for each value of the stratifying or sub-stratifying parameter. Statistics are reported for the all-observation database and not the median database. Specific summary statistics include the total number of observations, minimum, maximum, mean, standard deviation and skewness for reference observations, non-reference observations, and whole population observations. In addition, the summary statistics include the values of the 10th, 25th, 50th, 75th, and 90th percentiles for reference observations, non-reference observations, and whole population observations.

4.1.2 Tests of Equality of Populations

ICF performed the Kolmogorov Smirnoff Test and the Kruskal Wallis Test to determine whether the reference and non-reference populations could be considered different from each other. Both tests were applied at the 95 percent confidence limit to determine if the null hypothesis of equality of the two populations could be rejected. (The Kolmogorov Smirnoff test assesses the equality of the entire distributions, while the Kruskal Wallis test assesses the equality of the medians of the populations.)

4.1.3 Percentile Matching

The statistical analysis program matched water quality parameter values in the reference and whole population distributions to find the percentiles in the whole population distribution that correspond to the percentiles of interest (i.e., 75th and 90th percentiles) in the reference population. Specific steps in this approach are listed below:

1. Compute the water quality parameter value corresponding to the percentile of interest in the reference population.

2. Generate a cumulative distribution function that calculates a percentile rank for each water quality parameter value in the whole population.

3. Determine the percentile in whole population that corresponds to the water quality parameter value of the percentile of interest in the reference distribution.[6]

4. Generate box-whisker plots of nutrient concentrations at reference and non-reference sites for each level of each stratification and for each season.

The text-format log files produced by the statistical program include the percentile matching results for each reference population percentile of interest.

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[6] ICF used a linear interpolation method in this step. ICF also tested a cubic interpolation method. However, in most cases the cubic interpolation method did not differ from the linear method. In a few cases, the cubic interpolation method resulted in missing values. Therefore, ICF decided to apply the linear interpolation method exclusively for this analysis.

4.2 Testing of Stratification Methodologies

This analysis was performed exclusively on the median database (described in Section 3) for various stratification and sub-stratification methodologies. Results were reported for all seasons and for specific seasons.

The results of the Stata runs included:

- Summary statistics describing the statistical distribution of each water quality parameters for coarse and fine-scale stratifications;
- Parametric and non-parametric statistical tests to assess whether stratifications and sub-stratifications are statistically significant; and
- Box-whisker plots for each coarse-scale stratifying parameter for each nutrient for each season.

4.2.1 Summary Statistics by Stratum

Summary statistics in the Stata results characterize the statistical distributions for the selected water quality parameter for each level of the stratifying or sub-stratifying parameter. All statistics are reported only for the median database. Specific summary statistics include the total number of observations, minimum, maximum, mean, standard deviation and skewness. In addition, the summary statistics include the values of the 10th, 25th, 50th, 75th, and 90th percentiles.

4.2.2 Non-Parametric Tests for Differences Between Stratified Populations

A stratification methodology may be considered statistically significant if there are differences in nutrient concentrations between the strata defined by the methodology, i.e., if at least one stratum may be considered to have a higher or lower median or mean concentration than the other strata. In order to test for statistically significant differences between the median nutrient concentrations of different strata within a given stratification methodology, ICF used the non-parametric Kruskal Wallis test. The test was used only on the median database. A 95 percent confidence level was used to identify statistically significant differences.

If the test indicated the existence of statistically significant differences in median concentrations between the strata, a post-hoc non-parametric multiple comparison test was implemented based on procedures described in Siegel and Castellan (1988). These procedures helped determine whether specific strata could be considered different from one another.

4.2.3 Parametric Tests for Differences Between Stratified Populations

In order to test for statistically significant differences between the mean nutrient concentrations of different strata within a given stratification methodology, ICF used analysis of variance (ANOVA) tests.

ANOVA procedures are most accurate when the underlying populations are normally distributed with equal variance in each stratum. To determine if the data could be considered normally distributed for each nutrient for each stratification methodology, ICF performed the Shapiro-Wilk test of normality and assessed normal probability plots. In general, the hypothesis of normality could not be rejected for log-transformed data in the median database. (The all-observation database did not show the same characteristics; the log-transformed data in that database could not usually be considered normally distributed. Therefore, the all-observation database was not used for significance testing procedures.)

The Levene test was performed to determine if the data could be considered homoscedastic (having equal variance in each stratum) for each nutrient for each stratification methodology. In many cases, the hypothesis of homoscedasticity was rejected. However, the absolute value of the ratio of standard deviations across strata was most often less than two.

A consultation with ICF's statistician (Cohen, 2005) concluded that ANOVA results were likely to be robust to these levels of non-normality and heteroscedasticity.

ANOVA was implemented only on the median database. A 95 percent confidence level was used to identify statistically significant differences.

If the test indicated statistically significant differences in mean concentrations between the strata, a post-hoc parametric multiple comparisons of means was performed using the Bonferroni adjustment.

In order to test the statistical validity of sub-stratification, we used a nested ANOVA model with sub-strata nested within the main strata. We then used the Wald test to test the significance of the sub-stratification term in the nested model. The Wald test is a way of testing the significance of particular explanatory variables in a statistical model. The Wald test works by comparing the performance of the unrestricted model with a restricted model in which the variables to be tested have been dropped. If the Wald test is significant for a particular explanatory variable or group of explanatory variables, then we would conclude that the parameters associated with these variables are not zero, and that the variables should be included in the model. If the Wald test is not significant then these explanatory variables can be omitted from the model. Further details on the Wald test may be found in Statacorp (2001).

The R^2 and adjusted R^2 statistics were computed for all ANOVA runs. Ideally, however, these measures should not be used to select between alternative statistically valid stratification methodologies, because adding variables or sub-strata to a model will always improve the R^2 measure. Instead, once a set of statistically significant stratification methods have been determined, the selection of the optimal method may be based on *a priori* ecological, biological, and hydrogeologic considerations and practical ease of applicability. More complex model selection methods, such as those based on the Akaike Information Criterion statistics or the Davidson and MacKinnon J test, were not included in this analysis.

4.3 Computation of Measures of Variance for Alternative Stratification Methods

For the purposes of this project, a suitable stratification methodology is one that can be used to define nutrient zones in Montana between which nutrient concentrations differ from one another, and within which the variability of nutrient concentrations is minimized. Section 4.2 discussed tests to ascertain statistically significant differences between nutrient zones. To assess the performance of alternative stratification methodologies in minimizing variation within nutrient zones, two measures of variance were computed: the mean coefficient of variation and the coefficient of efficiency.

4.3.1 Mean Coefficient of Variation

For each stratification methodology, the mean coefficient of variation (MCV) was computed as follows, based on a definition provided in Robertson et al. (2001):

$$MCV = \sqrt{\frac{\sum (CV^2 \times n)}{N}}$$

$$CV = \frac{StDev}{\overline{X}}$$

where,

CV is the coefficient of variation of each group (or area);
n is the number of observations in each group;
N is the total number of observations in all of the groups;
$StDev$ is the standard deviation of each group; and
$\overline{X}$ is the mean concentration of each group.

One shortcoming of the MCV measure is that it is likely to improve (i.e., show lower absolute values) with increasing stratification. Therefore it would only be appropriate to use the MCV to assess the performance of alternative stratification schemes if the schemes divide the state into roughly equal number of strata.

4.3.2 Coefficient of Efficiency

Legates and McCabe (1999) proposed the coefficient of efficiency as a means of evaluating the goodness-of-fit of hydrologic and hydroclimatic models. This measure is defined as follows:

$$COE = 1 - \frac{\sum_i (O_i - P_i)^2}{\sum_i (O_i - \overline{O})^2}$$

where,

O_i = Value of the ith observation

P_i = Predicted value corresponding to the ith observation (equal to the mean of the observations in the stratum of the ith observation)

$\overline{O}$ = Grand mean of observed values

Thus, the COE in this analysis will equal the ANOVA R^2.

This measure can vary from minus infinity (poor model) to 1.0 (perfect model).

Like the MCV, the COE has the shortcoming of being likely to improve with increasing stratification. Therefore it would only be appropriate to use the COE to assess the performance of alternative stratification schemes if the schemes divide the state into roughly equal number of strata.

Although the MCV and COE will usually be negatively correlated (i.e., high MCV associated with low COE and vice versa), there may be exceptions to this trend. These exceptions may occur because the MCV is weighted by the number of observations in each group and because the COE is more sensitive to departures from the grand mean.

4.4 Examination of Seasonal Differences in Nutrient Concentrations

In order to determine whether nutrient concentrations within nutrient zones differ by season, a limited analysis was performed for nutrient zones based on Omernik level III ecoregions. This analysis included:

- Summary statistics;
- Non-parametric tests for between-season differences; and
- Parametric tests for between-season differences.

4.4.1 Summary Statistics by Season

Summary statistics in the Stata results characterize the statistical distributions for the selected water quality parameter by season for each Omernik level III ecoregion. All statistics are reported for both the all-observation database and the median database. Specific summary statistics include the total number of observations, minimum, maximum, mean, standard deviation and skewness. In addition, the summary statistics include the values of the 10th, 25th, 50th, 75th, and 90th percentiles.

4.4.2 Non-parametric tests for between season differences

In order to test for statistically significant differences between the median nutrient concentrations in different seasons of a given Omernik level III ecoregion, ICF used the non-parametric Kruskal Wallis test. The test was used for both the median database and the all-observation database. A 95 percent confidence level was used to identify statistically significant differences.

If the test indicated statistically significant differences in median concentrations between the seasons, a post-hoc non-parametric multiple comparison test was implemented based on procedures described in Siegel and Castellan (1988). These procedures help determine whether specific seasons may be considered different from one another.

4.4.3 Parametric tests for between season differences

In order to test for differences between the mean nutrient concentrations of different seasons within a given Omernik level III ecoregion, ICF implemented analysis of variance (ANOVA) tests on the log-transformed data. The tests were implemented for both the median database and the all-observation database.

Although ANOVA procedures are most accurate when the underlying populations are normally distributed with equal variance in each stratum, no specific tests were performed to verify that these conditions were met. On the basis of the exploratory data analysis undertaken earlier in the analysis, we assumed that departures from these conditions are not sufficient to bias the accuracy of the results. However, the results of the non-parametric tests are preferred in assessing seasonal trends.

If ANOVA indicated the existence of statistically significant differences in mean concentrations between the seasons, we performed a post-hoc parametric multiple comparisons of means using the Bonferroni adjustment.

4.5 Distribution of Stream Order in the Reference and General Populations

Higher stream orders often are associated with higher levels of nutrient concentrations as a result of increased natural and anthropogenic loadings. Regulators setting nutrient criteria would therefore be interested in knowing the distribution of stream order amongst reference sites in each nutrient zone for the available sample of water quality data. A preponderance of lower-order streams may suggest that a criterion based on the sample could be environmentally conservative. On the other hand, if higher order streams predominate, criteria based on the sample may not be sufficiently environmentally conservative. While the ideal distribution of stream order in the reference sample is an issue best judged by regulators, this analysis attempts to support this process by providing a distributional analysis of stream order in the reference and general populations. Future criteria-setting analyses that use bootstrapping or simulation methods to generate appropriately balanced and representative distributions of reference and general population data may also benefit from this groundwork.

Distributions of stream order were provided for the all-observation database as well as for the median database (which represents individual stations). The analyses are provided by nutrient for each Omernik level III ecoregion for all seasons only.

4.5.1 Histograms of Strahler Stream Order Distribution

Histograms representing the proportion of observations/stations from each stream order were developed for the reference and general populations. A normal distribution curve was superimposed on the histograms. These graphs are developed for each nutrient for each level III ecoregion.

4.5.2 Tabulation of Strahler Stream Order

The Stata runs present a breakdown of the distribution of Strahler stream order in the reference and general population for each nutrient for each level III ecoregion.

4.5.3 Tests for Differences in Stream Order Distribution

The Pearson Chi-square test was performed to test for statistically significant differences in the distribution of stream order between the reference and general population.

The Kruskal Wallis test was also performed. However, this test is less appropriate than the Pearson Chi-square test, because the stream order variable is treated as an ordinal variable instead of as a categorical variable for this test. The results of the Pearson Chi-square test should therefore be preferred.

4.6 Quality Assurance

The quality assurance methodology ICF adopted for this analysis involved replication of randomly selected cases from the *Stata* log files in independent database management and statistical software. Specifically, the data pertinent to the randomly selected cases were independently queried and analyzed with *Statistica*, a competing statistical analysis software application. Because the *Stata* and *Statistica* results were in agreement for all QA cases, we concluded that the quality assurance analysis validated the querying system, the program, and the analysis conducted in *Stata*. For some cases, the QA was conducted in *Stata* but outside of the programming framework, in order to serve as a check on the integrity of the programs.

5. Results and Conclusions

ICF performed the suite of statistical analyses described in Section 4 for ten water quality parameters and several stratification and sub-stratification methodologies. As described in Section 4, some analyses were performed on the all-observation database, some analyses on the median database, and some analyses were performed on both databases. All analyses were seasonally stratified.

Because the suite of statistical analyses produced a very large amount of results, this section presents only the most interesting trends as well as summary tables for each type of analysis. The full results of the statistical analyses were saved in easily readable, self-explanatory, computer-generated text files, referred to as log files, which are included in Appendix D. A guide to locating and reading the log files also is included in Appendix D.

In the tables presented in this section, water quality parameters are represented by a set of abbreviations. A key to these abbreviations is presented below.[7]

5.1 Percentile Mapping

Tables 5.1.1 through 5.1.4 present the 75th and 90th reference percentile equivalents in the whole population for each Omernik level III ecoregion for seven nutrients, benthic chlorophyll *a* and two turbidity parameters for each season and for all seasons combined. The summary statistics in these tables were computed without ammonia, benthic chlorophyll and turbidity. Ammonia was excluded from the summary statistics because it is very often at or below detection level in oxygenated surface waters, and oxygenated surface waters comprise the bulk of the data being analyzed. In general, bacteria rapidly convert ammonia N to its dominant and most oxidized form, NO_3 (ICF, 2004a). We excluded turbidity and benthic chlorophyll data from the summary statistics in the tables because MT DEQ requested that turbidity and benthic chlorophyll be analyzed separately from nutrients.

It is apparent from Tables 5.1.1 through 5.1.4 that seasonal trends are not very pronounced in the percentile mappings. The only exception to this finding is for the Middle Rockies and the Canadian Rockies in which the general population percentiles corresponding to the 75^{th} and 90^{th} percentile in the reference population are lower in the Winter season than for other seasons.

Cross-nutrient trends suggest that the Northwestern Glaciated Plains and the Northwestern Great Plains are fairly homogeneous in their reference and general population distributions for all nutrients for all seasons. For the Northern Rockies, however, the 75^{th} and 90^{th} reference percentiles correspond to fairly low general population percentiles.

[7] BNCHLOR-A = Benthic Chlorophyll-A; NO3+NO2 = Nitrates and Nitrites; SRP = Soluble Reactive Phosphates; TDP=Total Dissolved Phosphorus; TKN = Total Kjeldahl Nitrogen; TOTALN = Total Nitrogen; TOTALP = Total Phosphorus; TURB-JTU = Turbidity (JTUs); TURB-NTU = Turbidity (NTUs)

Table 5.1.1: Cross-Nutrient Percentile Matching Summary for Level III Ecoregions (All Seasons)
Summary Statistics Exclude Ammonia, Benthic Chlorophyll and Turbidity

Water Quality Parameter	Northern Rockies		Middle Rockies		Canadian Rockies		Northwestern Glaciated Plains		Northwestern Great Plains	
	p75	p90	p75	p90	p75	p90	p75	p90	p75	p90
AMMONIA	-	-	17.74	45.54	13.03	13.03	80.67	91.36	39.36	63.35
BNCHLOR-A	-	-	31.24	50.31	54.84	93.55	69.95	88.14	57.26	71.57
NO_3+NO_2	31.52	47.43	37.73	59.41	18.52	26.24	48.8	73.57	75.77	82.18
SRP	15.56	16.76	8.87	23.12	45.46	54.17	63.88	83.38	80.12	85.21
TKN	26.38	49.06	43.71	60.19	52.06	65.84	80.59	90.64	68.33	92.43
TOTAL N	-	-	74.69	78.72	61.67	76.67	66.13	88.32	72.11	88.26
TOTAL P	3.27	3.27	27.4	52.39	25.65	29.83	81.02	89.63	85.13	96.03
TDP	-	-	-	-	-	-	84.44	96.38	95.59	97.85
TURB-JTU	-	-	-	-	-	-	-	-	89.14	98.03
TURB-NTU	-	-	76.14	91.74	55.59	63.55	92.21	96.31	70.1	75.16
Mean	19.18	29.13	38.48	54.77	40.67	50.55	70.81	86.99	79.51	90.33
Std Dev	12.52	22.76	24.18	20.20	18.10	22.08	13.71	7.79	9.84	6.17
CV	0.65	0.78	0.63	0.37	0.44	0.44	0.19	0.09	0.12	0.07

Table 5.1.2: Cross-Nutrient Percentile Matching Summary for Level III Ecoregions (Winter)
Summary Statistics Exclude Ammonia, Benthic Chlorophyll and Turbidity

Water Quality Parameter	Northern Rockies		Middle Rockies		Canadian Rockies		Northwestern Glaciated Plains		Northwestern Great Plains	
	p75	p90	p75	p90	p75	p90	p75	p90	p75	p90
AMMONIA	-	-	16.76	43.27	-	-	82.79	84.5	47.55	60.89
BNCHLOR-A	-	-	-	-	-	-	-	-	-	-
NO_3+NO_2	-	-	27.49	38.27	9.14	15.28	74.53	78.78	72.23	76.66
SRP	-	-	8.56	25.21	15.49	18.31	51.62	77.96	84.84	94.49
TKN	-	-	38.54	53.88	-	-	80.87	88.13	85.67	94.36
TOTAL N	-	-	-	-	-	-	87.74	96.66	81.31	91.31
TOTAL P	-	-	14.7	42.75	5.77	7.05	75.45	84.42	89.6	97.27
TDP	-	-	-	-	-	-	74.06	87.89	97.43	98.26
TURB-JTU	-	-	-	-	-	-	-	-	-	-
TURB-NTU	-	-	72.82	92.44	-	-	92.71	97.17	-	-
Mean	-	-	22.32	40.03	10.13	13.55	74.05	85.64	85.18	92.06
Std Dev	-	-	13.38	11.86	4.94	5.83	12.16	6.93	8.40	7.93
CV	-	-	0.60	0.30	0.49	0.43	0.16	0.08	0.10	0.09

Table 5.1.3: Cross-Nutrient Percentile Matching Summary for Level III Ecoregions (Runoff)
Summary Statistics Exclude Ammonia, Benthic Chlorophyll and Turbidity

Water Quality Parameter	Northern Rockies		Middle Rockies		Canadian Rockies		Northwestern Glaciated Plains		Northwestern Great Plains	
	p75	p90	p75	p90	p75	p90	p75	p90	p75	p90
AMMONIA	-	-	18.94	46.41	-	-	87.07	91.59	15.55	44.93
BNCHLOR-A	-	-	-	-	-	-	-	-	-	-
NO_3+NO_2	29.78	46.87	38.71	63.84	26.91	35.29	69.02	76.47	54.41	77.1
SRP	19.03	21.11	18.61	39.37	58.84	70.44	75.91	87.5	70.45	79.24
TKN	-	-	46.51	61.36	-	-	75.42	90.49	89.38	97.46
TOTAL N	-	-	-	-	-	-	57.37	78.95	90.92	97.13
TOTAL P	5.97	5.97	32.56	54.26	35.28	42.09	80.61	89.58	91.99	97.92
TDP	-	-	-	-	-	-	89.69	97.42	88.82	96.31
TURB-JTU	-	-	-	-	-	-	-	-	86.67	93.49
TURB-NTU	-	-	90.02	98.85	-	-	92.15	95.59	-	-
Mean	18.26	24.65	34.10	54.71	40.34	49.27	74.67	86.74	81.00	90.86
Std Dev	11.92	20.68	11.80	11.00	16.56	18.64	10.90	7.78	15.29	9.87
CV	0.65	0.84	0.35	0.20	0.41	0.38	0.15	0.09	0.19	0.11

Table 5.1.4: Cross-Nutrient Percentile Matching Summary for Level III Ecoregions (Growing)
Summary Statistics Exclude Ammonia, Benthic Chlorophyll and Turbidity

Water Quality Parameter	Northern Rockies		Middle Rockies		Canadian Rockies		Northwestern Glaciated Plains		Northwestern Great Plains	
	p75	p90	p75	p90	p75	p90	p75	p90	p75	p90
AMMONIA	-	-	33.81	48.20	22.55	22.55	76.91	85.24	45.39	75.71
BNCHLOR-A	-	-	29.73	48.33	54.84	93.55	70.87	88.65	55.11	73.81
NO_3+NO_2	26.98	26.98	29.12	58.26	18.66	27.08	32.79	55.72	80.61	88.73
SRP	13.44	14.32	7.57	26.87	43.45	50	61.75	84.25	81.14	81.14
TKN	23.74	43.44	40.65	70.48	60	70.67	86.36	91.16	63.09	74.91
TOTAL N	-	-	76.95	78.91	84.85	90.91	59.33	89.35	78.35	96.88
TOTAL P	3.24	13.02	17.87	44.02	23.51	27.03	77.43	89.27	76.84	92.17
TDP	-	-	-	-	-	-	79.7	92.87	95.75	97.73
TURB-JTU	-	-	-	-	-	-	-	-	-	-
TURB-NTU	-	-	79.09	80.85	-	-	93.17	95.2	-	-
Mean	16.85	24.44	34.43	55.71	46.09	53.14	66.23	83.77	79.30	88.59
Std Dev	10.75	14.15	26.79	20.80	27.23	27.86	19.48	14.04	10.44	9.03
CV	0.64	0.58	0.78	0.37	0.59	0.52	0.29	0.17	0.13	0.10

It is apparent from Tables 5.1.1 through 5.1.4 that the cross-nutrient standard deviation of the matched percentiles around the mean is quite low in ecoregions such as the Northwestern Glaciated Plains and the Northwestern Great Plains. A low standard deviation implies the matched percentiles lie in a narrow band around the mean, and that the mean may be considered a good predictor of the matching percentile. Our analyses suggest that the cross-nutrient standard deviation around the mean in a given ecoregion is generally lower than the cross-ecoregional standard deviation around the mean for a given nutrient. One possible conclusion from these results is that in the absence of reference information for a given nutrient in a given ecoregion, the percentile mapping of a similar nutrient in that ecoregion would be a better predictor of an appropriate criterion than the percentile mapping of the nutrient in another ecoregion.

5.2 Testing of Stratification Methodologies

Coarse-scale Stratifications for the General Population

Tables 5.2.1 through 5.2.4 report the results of the Kruskal Wallis test for between-strata differences in median nutrient concentrations for various coarse-scale stratification methodologies for the general population for a limited selection of nutrient parameters. These tests were performed on the median database only. These tables show that stratification by Omernik level III ecoregions consistently produce strata that differ from one another in terms of their median nutrient concentrations for all nutrients for all seasons. Geologic formation is also a significant coarse-scale stratification methodology. Grouped level III ecoregions and Strahler stream order are less consistently significant as course-scale stratifying methodologies.

Table 5.2.1 : Statistical Significance of Coarse Scale Stratifying Parameters
(General Population, Median Data, All Seasons)

Stratifying Parameter	Nutrient Group					
	TKN	**TOTALN**	**NO3+NO2**	**SRP**	**TOTALP**	**TDP**
Grouped Level III Ecoregions	Y	Y	Y	Y	Y	N
Level III Ecoregions	Y	Y	Y	Y	Y	Y
Geologic Formation	Y	Y	Y	Y	Y	N
Strahler Stream Order	Y	Y	Y	N	Y	Y

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter (KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.2 : Statistical Significance of Coarse Scale Stratifying Parameters
(General Population, Median Data, Winter)

Stratifying Parameter	Nutrient Group					
	TKN	**TOTALN**	**NO3+NO2**	**SRP**	**TOTALP**	**TDP**
Grouped Level III Ecoregions	Y	Y	Y	N	Y	Y
Level III Ecoregions	Y	Y	Y	Y	Y	Y
Geologic Formation	Y	Y	Y	Y	Y	N
Strahler Stream Order	N	Y	N	N	N	Y

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter (KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.3 : Statistical Significance of Coarse Scale Stratifying Parameters
(General Population, Median Data, Runoff)

Stratifying Parameter	Nutrient Group					
	TKN	**TOTALN**	**NO3+NO2**	**SRP**	**TOTALP**	**TDP**
Grouped Level III Ecoregions	Y	Y	Y	N	Y	N
Level III Ecoregions	Y	Y	Y	Y	Y	N
Geologic Formation	Y	Y	Y	Y	Y	N
Strahler Stream Order	Y	N	Y	N	Y	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter
(KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.4 : Statistical Significance of Coarse Scale Stratifying Parameters
(General Population, Median Data, Growing)

Stratifying Parameter	Nutrient Group					
	TKN	**TOTALN**	**NO3+NO2**	**SRP**	**TOTALP**	**TDP**
Grouped Level III Ecoregions	Y	Y	N	N	Y	N
Level III Ecoregions	Y	Y	Y	Y	Y	Y
Geologic Formation	Y	Y	Y	Y	Y	N
Strahler Stream Order	Y	Y	Y	N	Y	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter
(KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Course-Scale Stratifications for the Reference Population

Tables 5.2.5 through 5.2.8 report the results of the Kruskal Wallis test for between-strata differences in median nutrient concentrations for various coarse-scale stratification methodologies for the reference population for a limited selection of nutrient parameters. These tests were performed on the median database only.

It is apparent from these tables that none of the coarse-scale stratification methodologies are effective for the Winter and Runoff seasons for the reference data. However, for the Growing season, and for all seasons together, stratification by Omernik level III ecoregions does produce strata that differ from one another in terms of their median nutrient concentrations for nearly all nutrient groupings.

Table 5.2.5 : Statistical Significance of Coarse Scale Stratifying Parameters
(Reference Population, Median Data, All Seasons)

Stratifying Parameter	Nutrient Group					
	TKN	TOTALN	NO3+NO2	SRP	TOTALP	TDP
Grouped Level III Ecoregions	Y	Y	N	N	Y	N
Level III Ecoregions	Y	Y	Y	Y	Y	N
Geologic Formation	Y	Y	N	N	Y	N
Strahler Stream Order	N	Y	N	N	N	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter
(KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.6 : Statistical Significance of Coarse Scale Stratifying Parameters
(Reference Population, Median Data, Winter)

Stratifying Parameter	Nutrient Group					
	TKN	TOTALN	NO3+NO2	SRP	TOTALP	TDP
Grouped Level III Ecoregions	Y	N	N	N	Y	N
Level III Ecoregions	Y	N	N	N	N	N
Geologic Formation	N	N	N	N	N	N
Strahler Stream Order	N	N	N	N	N	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter
(KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.7 : Statistical Significance of Coarse Scale Stratifying Parameters
(Reference Population, Median Data, Runoff)

Stratifying Parameter	Nutrient Group					
	TKN	TOTALN	NO3+NO2	SRP	TOTALP	TDP
Grouped Level III Ecoregions	Y	Y	N	N	Y	N
Level III Ecoregions	Y	N	N	N	Y	N
Geologic Formation	N	N	N	N	N	N
Strahler Stream Order	Y	N	N	N	Y	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter
(KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Table 5.2.8 : Statistical Significance of Coarse Scale Stratifying Parameters
(Reference Population, Median Data, Growing)

Stratifying Parameter	Nutrient Group					
	TKN	**TOTALN**	**NO3+NO2**	**SRP**	**TOTALP**	**TDP**
Grouped Level III Ecoregions	Y	Y	N	Y	Y	N
Level III Ecoregions	Y	Y	Y	Y	Y	N
Geologic Formation	Y	Y	N	Y	Y	N
Strahler Stream Order	N	Y	N	N	N	N

"Y" indicates significant differences in median concentrations between different levels of the stratifying parameter (KW Test, 95% confidence level)
"N" indicates absence of significant differences in median concentrations between different strata
"-" indicates inadequate data

Fine-scale Sub-stratifications for the General Population

Tables 5.2.9 through 5.2.12 report the results of post-ANOVA Wald tests used to verify the statistical significance of various sub-stratification methodologies within coarse-scale strata for the general population for a limited selection of nutrient parameters. These tests were performed on the median database only. These tables indicate that sub-stratification by Omernik level IV ecoregions is consistently an improvement over stratification by Omernik level III ecoregions for all seasons combined and for specific seasons. However, sub-stratifications based on geological formation and Strahler stream order within Omernik level III ecoregions are also significant. To decide between these competing sub-stratification methodologies, ICF recommends choosing the one that *a priori* creates zones most similar in terms of composite physical, ecological and hydrogeological parameters. In this respect, Omernik level IV ecoregions seems to be a superior sub-stratification methodology to geological formation and Strahler stream order, which do not control for ecological effects and which group widely dispersed areas together.

As an additional but secondary basis for deciding between competing stratification methodologies, it is possible to compare the performance of each methodology in terms of total variance explained (as measured by the adjusted R^2) and the mean coefficient of variance. Such a comparison is admissible in this circumstance, because these sub-stratification methodologies divide the state into roughly equal numbers of zones. On the basis of these measures of variance, the sub-stratification based on Omernik level IV ecoregions generally outperforms the others. However, statistical significance and expert judgment are the best basis for deciding on a stratification methodology.

The analysis shows that even finer sub-stratification of Omernik level IV ecoregions by Strahler stream order produces statistically significant results. However, this level of stratification would fragment the state into too many nutrient zones to be practically useful. Also, given the small number of observations, especially reference observations, in each of the resulting nutrient zones, this level of stratification would result in excessively wide confidence intervals around the criteria.

Fine-scale Sub-stratifications for the Reference Population

Tables 5.2.13 through 5.2.16 report the results of post-ANOVA Wald tests used to verify the statistical significance of various sub-stratification methodologies for coarse-scale strata for the reference population for a limited selection of nutrient parameters. These tests were performed on the median database only.

At the all-season level, sub-stratification by Omernik level IV ecoregions is consistently an improvement over stratification by Omernik level III ecoregions. The other sub-stratification methods do not show statistically significant results. However, sample size was limited at this level of stratification for the reference population and the power of these tests is likely to be low.

Table 5.2.9 : Statistical Significance of Fine Scale Stratifying Parameters (General Population, Median Data, All Seasons)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	Y	0.3681	Y	0.6607	Y	0.1176	Y	0.2708
Level III Ecoregions	Strahler Stream Order	Y	0.2116	Y	0.5662	Y	0.0664	Y	0.1786
Level III Ecoregions	Geologic Formation	Y	0.2474	Y	0.58	Y	0.0928	Y	0.1588
Level IV Ecoregions	Strahler Stream Order	Y	0.409	Y	0.7507	Y	0.1569	Y	0.345

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.10: Statistical Significance of Fine Scale Stratifying Parameters (General Population, Median Data, Winter)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	Y	0.4073	Y	0.6716	Y	0.1069	Y	0.2271
Level III Ecoregions	Strahler Stream Order	Y	0.2225	Y	0.5122	Y	0.0455	Y	0.132
Level III Ecoregions	Geologic Formation	Y	0.2188	Y	0.5957	Y	0.0696	Y	0.1118
Level IV Ecoregions	Strahler Stream Order	Y	0.5271	Y	0.7333	N	0.134	Y	0.277

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.11 : Statistical Significance of Fine Scale Stratifying Parameters (General Population, Median Data, Runoff)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	Y	0.4175	Y	0.7652	Y	0.1532	Y	0.2871
Level III Ecoregions	Strahler Stream Order	Y	0.2126	N	0.5993	Y	0.0796	Y	0.195
Level III Ecoregions	Geologic Formation	Y	0.2513	Y	0.7037	Y	0.0824	Y	0.1426
Level IV Ecoregions	Strahler Stream Order	Y	0.48	N	0.8052	Y	0.1902	Y	0.3599

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.12 : Statistical Significance of Fine Scale Stratifying Parameters (General Population, Median Data, Growing)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	Y	0.4277	Y	0.7002	Y	0.1428	Y	0.2991
Level III Ecoregions	Strahler Stream Order	Y	0.2411	Y	0.5715	Y	0.0888	Y	0.2211
Level III Ecoregions	Geologic Formation	Y	0.245	Y	0.6232	Y	0.0904	Y	0.196
Level IV Ecoregions	Strahler Stream Order	Y	0.4791	Y	0.7395	Y	0.2208	Y	0.383

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.13 : Statistical Significance of Fine Scale Stratifying Parameters (Reference Population, Median Data, All Seasons)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	Y	0.6416	Y	0.6855	Y	0.5653	Y	0.5477
Level III Ecoregions	Strahler Stream Order	N	0.5163	Y	0.6746	N	0.2192	N	0.4177
Level III Ecoregions	Geologic Formation	N	0.6128	N	0.6687	N	0.1992	Y	0.5281
Level IV Ecoregions	Strahler Stream Order	N	0.679	N	0.7021	N	0.599	Y	0.6338

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.14 : Statistical Significance of Fine Scale Stratifying Parameters (Reference Population, Median Data, Winter)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	N	0.421	-	-	N	0.5171	Y	0.8828
Level III Ecoregions	Strahler Stream Order	N	0.6487	N	0.6743	N	0.0842	N	0.2366
Level III Ecoregions	Geologic Formation	N	0.5989	N	-0.4625	N	-0.0044	N	0.3818
Level IV Ecoregions	Strahler Stream Order	N	0.5419	-	-	N	0.3561	N	0.8929

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.15 : Statistical Significance of Fine Scale Stratifying Parameters (Reference Population, Median Data, Runoff)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	N	0.7344	N	0.6694	N	0.3725	N	0.6354
Level III Ecoregions	Strahler Stream Order	N	0.6749	N	0.4958	N	0.1763	N	0.6764
Level III Ecoregions	Geologic Formation	Y	0.7608	N	0.5785	N	0.1222	N	0.6177
Level IV Ecoregions	Strahler Stream Order	N	0.8063	N	0.4958	Y	0.8623	N	0.6494

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

Table 5.2.16 : Statistical Significance of Fine Scale Stratifying Parameters (Reference Population, Median Data, Growing)

Stratifying Parameter	Sub-Stratifying Parameter	Nutrient Group							
		TKN		TOTALN		SRP		TOTALP	
		Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2	Significance	Adjusted R2
Level III Ecoregions	Level IV Ecoregions	N	0.6386	N	0.7197	Y	0.613	Y	0.5586
Level III Ecoregions	Strahler Stream Order	N	0.5884	N	0.8079	Y	0.3456	N	0.4449
Level III Ecoregions	Geologic Formation	Y	0.6662	Y	0.8074	N	0.2519	Y	0.5821
Level IV Ecoregions	Strahler Stream Order	N	0.6654	N	0.783	N	0.5934	N	0.6401

"Y" indicates the sub-stratification is significant (post-ANOVA Wald test, 95% confidence level)
"N" indicates the sub-stratification is not significant
"-" indicates inadequate data

5.3 Computation of Measures of Variation for Stratification Methodologies

In order to assess how well the various stratification methodologies perform in explaining nutrient concentration variability, we computed the mean coefficient of variation (MCV) and the coefficient of efficiency (COE).

As described in Section 4, the MCV and the COE should not be used to compare stratification methodologies that create widely differing numbers of strata. This is because both measures are likely to improve as the dataset is increasingly partitioned and as fewer numbers of observations become available in each stratum.

The measures may be used, however, in combination with the tests of significance and theoretical considerations described in Section 5.2, to compare stratifications and sub-stratifications that partition the state into similar numbers of strata. They are also useful in identifying seasons with high variance in nutrient concentrations. All COEs in Tables 5.3.1 through 5.3.16 are reported for log-transformed data.

<u>Course-scale Stratifications for the General Population</u>

Tables 5.3.1 through 5.3.4 report the MCV and COE for selected coarse-scale stratifications in the general population for a selection of nutrient groupings by season. These tables indicate that the stratification methodologies considered are more successful in explaining variance for nitrogen group nutrients than for phosphorus groups. This is consistent with the findings in Robertson, et al. (2001). However, the values of the MCVs computed in this analysis are higher than those reported in that paper.[8] It is also notable that the stratification methodologies have the most explanatory power in the Winter season.

[8] The higher values observed in the general population analysis (compared to Robertson (2001)) may be the result of using a database that was not specifically selected to exclude particular sites or observations except those that did not pass the QC measures used to screen the data. The stratification methodologies used in this analysis are mainly intended to capture factors that contribute to natural nutrient loadings. This is evident in the better performance of the stratification methodologies in the designated reference data. It should also be noted that the data used in the general population analysis spanned over 40 years. Partitioning the data by time periods (e.g. 1990s only) may potentially reduce variability further. The current analysis used data that spanned both wet and dry climatic cycles which necessitated using multiple-decade data. Reducing the data to a given decade could reduce noise, especially if all the data come from a dry cycle, for example, but would be less representative of the complete recent climatic record.

Table 5.3.1 : MCV Summary by Coarse Scale Stratifying Parameter (General Population, Median Data, All Seasons)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	3.95	0.16	2.12	0.52	5.17	0.004	5.46	0.09
Level III Ecoregions	3.82	0.17	1.96	0.53	3.94	0.05	5.23	0.12
Level IV Ecoregions	1.72	0.39	1.57	0.71	2.9	0.15	3.59	0.29
Geologic Formation	2.54	0.14	2.23	0.34	3.86	0.06	5.26	0.08
Strahler Stream Order	2.79	0.04	1.83	0.05	4.5	0.003	5.49	0.03

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.2: MCV Summary by Coarse Scale Stratifying Parameter (General Population, Median Data, Winter)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	1.84	0.12	0.87	0.45	5.3	0.0007	4.09	0.01
Level III Ecoregions	1.85	0.15	0.82	0.47	3.73	0.04	3.44	0.07
Level IV Ecoregions	1.13	0.44	0.61	0.72	2.45	0.15	2.44	0.27
Geologic Formation	1.35	0.17	0.91	0.29	3.98	0.04	3.22	0.04
Strahler Stream Order	1.37	0.01	0.86	0.09	3.99	0.01	3.37	0.01

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.3 : MCV Summary by Coarse Scale Stratifying Parameter (General Population, Median Data, Runoff)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	4.06	0.16	0.92	0.59	4.02	0.0001	5.12	0.07
Level III Ecoregions	3.91	0.18	0.89	0.6	3.52	0.05	4.97	0.1
Level IV Ecoregions	1.47	0.45	0.69	0.81	2.09	0.2	3.05	0.32
Geologic Formation	2.54	0.15	0.93	0.33	3.1	0.05	4.35	0.09
Strahler Stream Order	2.44	0.04	0.87	0.07	3.07	0.004	3.71	0.07

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.4 : MCV Summary by Coarse Scale Stratifying Parameter (General Population, Median Data, Growing)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	1.6	0.17	2.31	0.54	3.8	0.00003	4.66	0.1
Level III Ecoregions	1.57	0.18	2.08	0.56	3.32	0.06	4.37	0.14
Level IV Ecoregions	1.12	0.45	1.44	0.75	1.57	0.19	2.04	0.33
Geologic Formation	1.4	0.12	2.41	0.31	2.44	0.06	4.65	0.1
Strahler Stream Order	1.33	0.05	2.02	0.08	2.6	0.007	4.76	0.03

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Coarse-scale Stratifications for the Reference Population

Tables 5.3.5 through 5.3.8 report the MCV and COE for selected coarse-scale stratifications in the reference population for a selection of nutrient groupings by season. The stratification methodologies show considerably lower variance for these data than for the general population. The tables also indicate that the stratification methodologies considered are more successful in explaining variance for nitrogen group nutrients than for phosphorus groups. As was evident for the general population, the stratification methodologies have the most explanatory power in the Winter season. The Growing season appears to be the most noisy.

Table 5.3.5 : MCV Summary by Coarse Scale Stratifying Parameter (Reference Population, Median Data, All Seasons)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	2.01	0.49	2.18	0.51	0.76	0.07	2.27	0.28
Level III Ecoregions	1.57	0.57	1.5	0.61	1.69	0.19	1.73	0.44
Level IV Ecoregions	0.76	0.79	0.7	0.83	0.9	0.77	1.15	0.7
Geologic Formation	1.14	0.56	1.04	0.57	1.55	0.26	1.75	0.35
Strahler Stream Order	1.36	0.14	1.45	0.31	1.54	0.04	1.84	0.1

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.6 : MCV Summary by Coarse Scale Stratifying Parameter (Reference Population, Median Data, Winter)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	0.53	0.62	0.78	0.06	1.26	0.2	0.9	0.19
Level III Ecoregions	0.54	0.63	0.89	0.06	1.04	0.4	0.78	0.42
Level IV Ecoregions	0.55	0.74	0	1	0.4	0.88	0.25	0.97
Geologic Formation	0.47	0.78	0.56	0.37	1.23	0.19	1.1	0.15
Strahler Stream Order	0.48	0.79	0.67	0.66	0.96	0.6	0.69	0.43

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.7 : MCV Summary by Coarse Scale Stratifying Parameter (Reference Population, Median Data, Runoff)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	0.68	0.59	0.4	0.85	0.97	0.03	1.39	0.6
Level III Ecoregions	0.69	0.6	0.41	0.85	0.93	0.3	1.27	0.69
Level IV Ecoregions	0.49	0.88	0.34	0.87	0.71	0.7	0.93	0.83
Geologic Formation	0.92	0.62	0.49	0.57	0.94	0.05	1.29	0.35
Strahler Stream Order	0.65	0.58	0.93	0.42	0.67	0.32	1.33	0.6

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.8 : MCV Summary by Coarse Scale Stratifying Parameter (Reference Population, Median Data, Growing)

Stratifying Parameter	Nutrient and Measure of Variation							
	TKN		TOTALN		SRP		TOTALP	
	MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	2.09	0.47	2.08	0.56	1.86	0.08	2.26	0.28
Level III Ecoregions	1.54	0.6	1.51	0.68	1.76	0.21	1.68	0.44
Level IV Ecoregions	0.7	0.79	0.63	0.85	0.89	0.81	1.11	0.72
Geologic Formation	1.14	0.53	1.08	0.73	1.64	0.34	1.58	0.45
Strahler Stream Order	1.31	0.1	1.31	0.3	1.37	0.1	1.69	0.08

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Fine-scale Sub-stratifications for the General Population

Tables 5.3.9 through 5.3.12 report the MCV and COE for selected fine-scale stratifications in the general population for a selection of nutrient groupings by season. These tables indicate a considerable improvement in the measures of variance with increasing sub-stratification. However, as explained earlier, this improvement may partly be the result of a fewer number of observations contributing to each stratum.

Table 5.3.9 : MCV Summary by Fine Scale Stratifying Parameter (General Population, Median Data, All Seasons)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	2.52	0.2	1.57	0.57	3.97	0.03	4.07	0.133
Level III Ecoregions	Strahler Stream Order	2.1	0.23	1.28	0.61	2.42	0.09	0.46	0.2
Level IV Ecoregions	Strahler Stream Order	1.08	0.5	0.7	0.84	1.54	0.3	1.73	0.44

MCV=Mean Coefficient of Variation

COE= Coefficient of Efficiency

Table 5.3.10 : MCV Summary by Fine Scale Stratifying Parameter (General Population, Median Data, Winter)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	1.17	0.2	0.69	0.54	3.78	0.03	2.71	0.08
Level III Ecoregions	Strahler Stream Order	1.02	0.26	0.65	0.57	2.08	0.09	1.71	0.17
Level IV Ecoregions	Strahler Stream Order	0.69	0.65	0.47	0.83	1.3	0.34	1.05	0.44

MCV=Mean Coefficient of Variation

COE= Coefficient of Efficiency

Table 5.3.11 : MCV Summary by Fine Scale Stratifying Parameter (General Population, Median Data, Runoff)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	2	0.19	0.87	0.64	2.53	0.02	3.18	0.16
Level III Ecoregions	Strahler Stream Order	1.53	0.25	0.81	0.66	1.87	0.12	2.63	0.23
Level IV Ecoregions	Strahler Stream Order	0.87	0.61	0.5	0.87	1.07	0.38	1.36	0.5

MCV=Mean Coefficient of Variation

COE= Coefficient of Efficiency

Table 5.3.12 : MCV Summary by Fine Scale Stratifying Parameter (General Population, Median Data, Growing)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	1.2	0.23	1.71	0.58	1.99	0.03	3	0.16
Level III Ecoregions	Strahler Stream Order	1.13	0.26	1.36	0.62	1.71	0.12	2.35	0.24
Level IV Ecoregions	Strahler Stream Order	0.77	0.59	0.7	0.85	1.05	0.39	1.23	0.51

MCV=Mean Coefficient of Variation

COE= Coefficient of Efficiency

Fine-scale Sub-stratification for the Reference Population

Tables 5.3.13 through 5.3.16 report the MCV and COE for selected fine-scale stratifications in the reference population for a selection of nutrient groupings by season. These tables indicate an even greater improvement in the measures of variance with increasing sub-stratification for the reference population. However, as explained earlier, these effects may be the result of a fewer number of observations contributing to each stratum.

Table 5.3.13 : MCV Summary by Fine Scale Stratifying Parameter (Reference Population, Median Data, All Seasons)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	1.28	0.55	1.51	0.59	1.21	0.26	1.7	0.36
Level III Ecoregions	Strahler Stream Order	1.07	0.64	1.03	0.78	1.01	0.43	1.34	0.52
Level IV Ecoregions	Strahler Stream Order	0.58	0.88	0.54	0.89	0.51	0.85	0.91	0.82

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.14 : MCV Summary by Fine Scale Stratifying Parameter (Reference Population, Median Data, Winter)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	0.44	0.81	0.38	0.89	0.94	0.62	0.71	0.47
Level III Ecoregions	Strahler Stream Order	0.44	0.81	0.37	0.89	0.89	0.66	0.48	0.7
Level IV Ecoregions	Strahler Stream Order	0.47	0.83	0	1	0.4	0.88	0.18	0.98

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.15 : MCV Summary by Fine Scale Stratifying Parameter (Reference Population, Median Data, Runoff)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Strahler Stream Order	0.52	0.82	0.35	0.89	0.65	0.47	1.08	0.78
Level III Ecoregions	Strahler Stream Order	0.55	0.84	0.33	0.9	0.79	0.61	0.93	0.82
Level IV Ecoregions	Strahler Stream Order	0.31	0.95	0.33	0.9	0.28	0.96	0.75	0.89

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

Table 5.3.16 : MCV Summary by Fine Scale Stratifying Parameter (Reference Population, Median Data, Growing)

Stratifying Parameter	Sub Stratifying Parameter	Nutrient and Measure of Variation							
		TKN		TOTALN		SRP		TOTALP	
		MCV	COE	MCV	COE	MCV	COE	MCV	COE
Grouped Level III Ecoregions	Grouped Strahler Stream Order	1.26	0.56	1.29	0.66	1.04	0.41	1.61	0.73
Level III Ecoregions	Grouped Strahler Stream Order	1.01	0.72	0.9	0.88	0.78	0.56	1.24	0.57
Level IV Ecoregions	Grouped Strahler Stream Order	0.52	0.89	0.52	0.92	0.53	0.85	0.78	0.84

MCV=Mean Coefficient of Variation
COE= Coefficient of Efficiency

5.4 Seasonal Differences in Nutrient Concentrations

To determine whether nutrient concentrations within nutrient zones differ by season, we performed a limited analysis for nutrient zones based on Omernik level III ecoregions. This analysis, which included Kruskal Wallis tests for differences in median nutrient concentration over different seasons, was performed separately for the general population and reference population for both the median database and for the all-observation database.

Tables 5.4.1 through 5.4.4 present the results of these analyses. It is apparent that, for nutrient zones based on Omernik level III ecoregions, there are significant seasonal differences in median nutrient concentrations in the general population for the all-observation database as well as for the median database. For certain nutrient groupings, the trends are not significant, but these results may reflect the low power of the tests for the relatively small sample sizes associated with those nutrients.

The seasonal trends are less significant for the reference population but this may reflect the low power of the tests for the relatively small sample sizes associated with the reference population.

Table 5.4.1 : Significance of Seasonal Stratification in Level III Ecoregions (General Population, All Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	Y	Y	Y	Y	N	Y
Idaho Batholith	Y	Y	N	Y	N	Y
Middle Rockies	Y	Y	Y	Y	N	Y
Wyoming Basin	Y	N	Y	N	N	Y
Canadian Rockies	Y	N	Y	Y	N	Y
Northwestern Glaciated Plains	Y	Y	Y	Y	Y	Y
Northwestern Great Plains	Y	Y	Y	N	Y	Y

"Y" indicates that median concentrations are different between seasons (KW Test, 95% confidence level)
"N" indicates that median concentrations are not different between seasons
"-" indicates insufficient data

Table 5.4.2 : Significance of Seasonal Stratification in Level III Ecoregions (General Population, Median Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	Y	Y	N	N	N	Y
Idaho Batholith	N	Y	N	N	N	Y
Middle Rockies	Y	Y	N	Y	N	Y
Wyoming Basin	N	N	N	N	N	Y
Canadian Rockies	Y	N	N	N	N	N
Northwestern Glaciated Plains	Y	Y	N	Y	N	Y
Northwestern Great Plains	Y	Y	Y	N	Y	Y

"Y" indicates that median concentrations are different between seasons (KW Test, 95% confidence level)
"N" indicates that median concentrations are not different between seasons
"-" indicates insufficient data

Table 5.4.3 : Significance of Seasonal Stratification in Level III Ecoregions (Reference Population, All Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	Y	N	N	N	-	N
Idaho Batholith	N	N	N	-	-	N
Middle Rockies	Y	Y	N	Y	-	Y
Wyoming Basin	-	-	-	-	-	-
Canadian Rockies	Y	N	N	N	-	Y
Northwestern Glaciated Plains	Y	N	N	N	N	Y
Northwestern Great Plains	Y	N	N	N	N	Y

"Y" indicates that median concentrations are different between seasons (KW Test, 95% confidence level)
"N" indicates that median concentrations are not different between seasons
"-" indicates insufficient data

Table 5.4.4: Significance of Seasonal Stratification in Level III Ecoregions (Reference Population, Median Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	Y	N	N	N	-	N
Idaho Batholith	N	N	N		-	N
Middle Rockies	N	N	N	N	-	N
Wyoming Basin	-	-	-		-	N
Canadian Rockies	N	N	N	N	-	N
Northwestern Glaciated Plains	N	N	N	N	N	N
Northwestern Great Plains	N	N	N	N	N	N

"Y" indicates that median concentrations are different between seasons (KW Test, 95% confidence level)
"N" indicates that median concentrations are not different between seasons
"-" indicates insufficient data

5.5 Distribution of Stream Order in the Reference and General Population

In order to assess whether the distributions of stream orders in the reference and general populations were significantly different, we performed a limited analysis for nutrient zones based on Omernik level III ecoregions. The analysis, which included the Pearson Chi-square test, was performed separately at the all-observation level and at the station level for all seasons only.

Tables 5.5.1 and 5.5.2 present the results of these analyses. It is apparent that there are significant differences in stream order distributions between the reference and general population for the all-observation database. The trend is less significant at the station level, in which each station contributes a single observation for each nutrient. The observed difference in trends between the all-observation database and the median database is because certain stations contribute substantially more observations than others. The statistically significant difference in stream order distributions between the reference and general population for the all-observation database implies that standards based on the reference population distributions in the all-observation database may be overly or insufficiently conservative, depending on whether lower order streams are over or under-represented in the reference population compared to the general population. The fact that the differences in stream order distribution between the general and reference population are less pronounced in the median database implies that standards based on the reference population in the median database are less likely to be biased in this regard. However, relatively low sample size in the median database may have resulted in statistical tests with low power in some cases. Ideally, regulators should also ensure that the distribution of stream order in the general population is balanced and appropriately representative of each nutrient zone.

Table 5.5.1: Stream Order Distribution in Level III Ecoregions (General v Ref Population, All Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	Y	Y	Y	Y	-	Y
Idaho Batholith	N	N	-	-	-	N
Middle Rockies	Y	Y	Y	Y	-	Y
Wyoming Basin	-	-	-	-	-	-
Canadian Rockies	Y	Y	Y	Y	-	Y
Northwestern Glaciated Plains	Y	Y	Y	Y	Y	Y
Northwestern Great Plains	Y	Y	Y	Y	Y	Y

"Y" indicates differences between stream order distribution in the reference and general population (Pearson Chi Square, 95%)
"N" indicates stream order distributions are not different between the reference and general population
"-" indicates insufficient data

Table 5.5.2: Stream Order Distribution in Level III Ecoregions (General v Ref Population, Station Data)

Level III Ecoregion	Nutrient Group					
	NO3+NO2	TKN	TOTALN	SRP	TDP	TOTALP
Northern Rockies	N	N	N	N	-	N
Idaho Batholith	N	N	-	-	-	N
Middle Rockies	Y	Y	N	Y	-	N
Wyoming Basin	-	-	-	-	-	-
Canadian Rockies	N	N	N	N	-	N
Northwestern Glaciated Plains	Y	Y	N	Y	N	Y
Northwestern Great Plains	N	N	N	N	N	N

"Y" indicates differences between stream order distribution in the reference and general population (Pearson Chi Square, 95%)
"N" indicates stream order distributions are not different between the reference and general population
"-" indicates insufficient data

5.6 General Conclusions

The preceding analyses suggest the following general conclusions:

- Percentile mapping trends between the reference and general population do not show pronounced seasonal differences (based on the analysis for Omernik level III ecoregions);

- Omernik level IV ecoregions constitute a statistically significant parameter for stratifying the state for most nutrients in most seasons for both the general and reference population;

- Nutrient zones based on Omernik level IV ecoregions may be regarded as the best performing stratifying methodology considered in this analysis, based on tests of statistical significance, measures of variation, and *a priori* theoretical considerations;

- Sub-stratifying Omernik level IV by Strahler stream order results in nutrient zones that show statistically significant trends for the general population. However, this level of stratification partitions the state into too many zones to be practically useful with the current data;

- Most of the stratifying methodologies considered in this analysis perform better for the Nitrogen group than the Phosphorus group for both the general and reference populations;

- The Winter season is generally less noisy than other seasons for the stratifying methodologies considered in this analysis;

- For nutrient zones based on Omernik level III ecoregions, there are significant seasonal differences in nutrient concentrations in the general population;

- For nutrient zones based on Omernik level III ecoregions, there are significant differences in stream order distribution between the general and reference population for most nutrients if all observations are considered. These differences are less significant if only one observation per station is considered.

6. Literature Cited

Cohen, J., 2005, Personal communication between Jonathan Cohen, Statistician, ICF Consulting, and Arun Varghese, Senior Associate, ICF Consulting, June 2, 2005.

EPA, 2000, *Nutrient Criteria Technical Guidance Manual*, U.S. EPA, Office of Water, Document Number EPA-822-B-00-002, July 2000.

ICF, 2004a. “Montana Rivers and Streams Reference-to-Whole-Population Percentile Mapping for Selected Water Quality Parameters – Final Report,” Memorandum to Dr. Michael Suplee, Montana Department of Environmental Quality, from Arun Varghese and Joshua Cleland, ICF Consulting, November 22, 2004.

ICF, 2004b. “Stratification of Algae and Nutrient Data of Montana Rivers and Streams to Assist in the Development of Numeric Standards – Final Report,” Memorandum to Dr. Michael Suplee, Montana Department of Environmental Quality, from Arun Varghese and Joshua Cleland, ICF Consulting, July 13, 2004.

MT DEQ, 2005. “Identification and Assessment of Montana Reference Streams: A Follow-up and Expansion of the 1992 Benchmark Biology Study”, Suplee, M., Sada de Suplee R., Feldman, D., Laidlaw, T.

Legates, D.R. and McCabe, G.J. “Evaluating the Use of “Goodness of Fit” Measures in Hydrologic and Hydroclimatic Model Validation”, Water Resources Research, 1999, 35:233-241

Luce, W., 2005. Personal communication between Wendy Luce, Analytic Chemist, ICF Consulting, and Arun Varghese, Senior Associate, ICF Consulting, May 5, 2005.

Robertson, D.M., Saad, A.S., Wieben, A.M., 2001. “An Alternative Regionalization Scheme for Defining Nutrient Criteria for Rivers and Streams.” U.S. Geological Survey, Middleton, WI. Water-Resources Investigations Report 01–4073. 2001.

Siegel, S., & Castellan, N. J., Jr., 1988. Nonparametric Statistics for the Behavioural Sciences (2nd ed.). McGraw-Hill Publishing, New York.

Statacorp. 2001. *Stata Reference Manual, Stata Press, College Station, Texas.*

APPENDIX A

WATER QUALITY DATA GROUPING METHODOLOGY

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Updated: May 16, 2005

Organization of Nutrient, Benthic Chlorophyll *a* and Turbidity data from NEW, Legacy, and non-STORET Databases

The organizational objective outlined herein was to group analytical measurements together that are fundamentally equivalent, while at the same time avoiding double-counts in cases where an agency may have measured two or more closely related parameters from the same sample. The approach was undertaken in a series of steps as follows:

1. The different analytical measurements (e.g. total nitrate, dissolved nitrate, total phosphorus) were identified in the database, checked against STORET and other records to determine what they actually measured, and then organized into groups. The groups (e.g., total N group, soluble reactive phosphorus group) were composed of similar measurements that fundamentally measured the same thing.

2. For each group, a series of exploratory queries were made in the databases, by agency, to ascertain if the various analytical measurements within the group were derived from the same sample. In cases where this occurred, only one of the analytical measurements was retained for that particular agency. Entire analytical measurements (regardless of agency) were eliminated if a clear definition for the measurement could not be located or if its inclusion resulted in other data-collation problems (these will be detailed below for each group).

This methodological appendix is an update of two earlier versions, Appendix C (Varghese and Cleland 2004a) and Appendix A (Varghese and Cleland 2004b). The present description outlines what data sources were used, which water quality measurements were grouped together for common analysis and how the database was screened to assure quality. In earlier analyses (Varghese and Cleland 2004a and 2004b) only Legacy STORET and a handful of other data were used. In the present work the database was enhanced by adding to it all relevant MT DEQ data from NEW STORET (2000-2004), EMAP-West (2000-2004), the University of Montana (1987-2004) and Utah State University (2001). All of the data used were from rivers and streams only. There were thirty-six nutrient, benthic chlorophyll *a* (Chl *a*) and turbidity measurements found in the above databases for rivers and streams. In total, including the previous Legacy STORET data, the data spanned the time period from the early 1960s to September 2004.

Table 1.0 (below) shows the thirty-five nutrient and turbidity analytical measurements that were identified in the databases. These have been organized into groups. Individual analytical measurements that were completely eliminated from use in the present analysis are shown in the table in gray. The development of each group will be detailed below, with explanations as to why the measurements were grouped together, why certain analytical measurements were eliminated and why some were restricted only to certain agencies. For simplicity, analytical measurements will be referred to by their STORET parameter code numbers (also used by the USGS in their database, the National Water Information System [NWIS]).

With the development of the NEW STORET system in the late 1990's, the use of STORET parameter code numbers was no longer continued as a means to identify analytical measurements. Instead, analytical measurements are identified by information contained in several NEW STORET fields, the key fields being 'Characteristic Name', 'CharUnit', 'Sample Fraction' and 'Analysis Procedure Name'. Because the programming developed in STATA to identify sample types and undertake database analyses for the present project was already based on parameter codes, NEW STORET data were mapped to their appropriate parameter code as found in Legacy STORET (Table 2). The parameter codes were included in the dataset as additional fields accompanying those fields already found in NEW STORET. This process was also undertaken for non-STORET data that needed parameter code associations.

Agencies not found in Legacy or NEW STORET may be included in the queries that will be detailed below. These are EMAP (the U.S. EPA's Western Environmental Monitoring and Assessment Program), MT DNRC (Montana Department of Natural Resources and Conservation), UM (the University of Montana), and USU (Utah State University). Data from these entities were obtained as part of the collation of reference-site and general population data. In addition, a new inclusion for the present analysis was benthic algal Chl *a* data (Table 3). Only a few examples of benthic Chl *a* data were found in the Legacy STORET database, and so the algal data used here were collected exclusively by MT DEQ or the University of Montana. Table 3 shows the STORET parameter code assigned to the four variations of the collection procedure. See Suplee (2004) and MT DEQ (2005) for more detail on the benthic Chl *a* collection procedures.

In a report detailing methods used by the USGS for its stream water-quality monitoring network over the period 1962-1995, Alexander et al. (1996) indicated that the term "total", when applied to measurements of dissolved solutes, is simply a methodological term and refers to a method in which the heavier solids of a sample are allowed to settle out and then the sample water is decanted off the top for analysis. The method was statistically indistinguishable from methods that filtered the sample through a 0.45μm filter (Alexander et al. 1996). A 0.45 μm filter is by convention the separation point between dissolved and suspended forms (APHA 1992). So when dealing with *dissolved* solute measurements in the Legacy STORET dataset, measurements labeled "diss" (dissolved) and those labeled "total" are, for practical purposes, the same. This applies to all the groups that will be discussed.

Table 1.0 Nutrient & turbidity measurements from MT rivers & streams, identified in Legacy & NEW STORET and other data sources. Measurements are organized into functional groups. Gray areas contain measurements that were excluded from use.

AGENCY	STORET PARAM 1*	STORET PARAM 2*	STORET PARAM 3	STORET CODE	Nutrient Reported as:	NOTES (STORET codes & definitions 3/96; US EPA 1979)	What is the parameter basically a measure of:	Functional Groups
VARIOUS	NH3 + NH4	N-TOTAL	MG/L	00610	N	Total ammonia nitrogen, as N	Ammonia	Ammonia group
USGS & COEOMAHA	AMMONIA	TOT-NH4	MG/L	71845	NH4	Total ammonia nitrogen, as NH4	Ammonia	
VARIOUS	NH3 + NH4	N-DISS	MG/L	00608	N	Dissolved ammonia nitrogen, as N	Ammonia	
USGS	AMMONIA	DISS-NH4	MG/L	71846	NH4	Dissolved ammonia nitrogen, as NH4	Ammonia	
VARIOUS	TOT KJEL	N	MG/L	00625	N	TKN (mg/L as N)	Total Kjeldahl N (dissolved and particulate)	TKN group
USGS	ORG-N	N	MG/L	00605	N	Total organic N	Total organic N (~ TKN)	
USGS	ORG-N	DISS-N	MG/L	00607	N	Dissolved organic N	Dissolved organic N	
U.S. EPA and USGS	KJELDL N	DISS	MG/L	00623	N	Dissolved Kjeldahl N	Dissolved Kjeldahl N	
MT DEQ and USGS	KJELDL N	SUSP	MG/L	00624	N	Suspended Kjeldahl N	Suspended Kjeldahl N	
VARIOUS	TOTAL N	N	MG/L	00600	N	Total N (mg/L as N)	Total N	Total N group
N. Park Service & USGS	DISS.	NITROGEN	MG/L N	00602	N	Total N, water, filtered	Non-particulate total N	
USGS	TOTAL N	AS NO3	MG/L	71887	NO3	Total N (mg/L as NO3)	Total N	
VARIOUS	NO2 + NO3	N-TOTAL	MG/L	00630	N	NO2 + NO3, total, as N	Nitrate + Nitrite	Nitrate & nitrite group
VARIOUS	NO2 + NO3	N-DISS	MG/L	00631	N	NO2 + NO3, dissolved, as N	Nitrate + Nitrite	
VARIOUS	NO3-N	DISS	MG/L	00618	N	Dissolved nitrate nitrogen, as N	Nitrate	
VARIOUS	NO3-N	TOTAL	MG/L	00620	N	Total nitrate nitrogen, as N	Nitrate	
U.S. Forest Service & USGS	NITRATE	TOT-NO3	MG/L	71850	NO3	Nitrate nitrogen, total, as NO3	Nitrate	
VARIOUS	NITRATE	DISS-NO3	MG/L	71851	NO3	Dissolved nitrate nitrogen, as NO3	Nitrate	
VARIOUS	NO2-N	DISS	MG/L	00613	N	Dissolved nitrite nitrogen, as N	Nitrite	
USGS	NITRITE	DISS-NO2	MG/L	71856	NO2	Dissolved nitrite nitrogen, as NO2	Nitrite	
VARIOUS	NO2-N	TOTAL	MG/L	00615	N	Total nitrite nitrogen, as N	Nitrite	
VARIOUS	PHOS TOT		MG/L P	00665	P	Total phosphorus	Total Phosphorus	Total P group
USGS & BLM	TOTAL P	AS PO4	MG/L	71886	PO4	Total phosphorus reported as PO4	Total Phosphorus	
VARIOUS	PHOS TOT	HYDRO	MG/L P	00669	P	Phosphorus, total hydrolyzable	TAHP	
COEOMAHA & MT DEQ	PHOS TOT	HYDRO + ORTH	MG/L P	00678	P	Phosphorus, hydrolyzable + ortho, total, autoanalyzer.	TAHP	
VARIOUS	PHOS-DIS	ORTHO	MG/L P	00671	P	Dissolved orthophosphate	SRP, 0.45 um filtered	Soluble reactive phosphate group
VARIOUS	PHOS-T	ORTHO	MG/L P	70507	P	Total orthophosphate	Unfiltered, total reactive phosphate, which is largely orthophosphate	
VARIOUS	ORTHOPO4	PO4	MG/L	00660	PO4	Dissolved orthophosphate as PO4	SRP, 0.45 μm filtered	
VARIOUS	T PO4	PO4	MG/L	00650	PO4	Total orthophosphate	Total reactive phosphate,probably with a more aggressive digestion-may contain organic phosphates	
VARIOUS	PHOS-DIS		MG/L P	00666	P	Dissolved phosphorus	TDP	Total Dissolved P group
VARIOUS	TURB	JKSN	JTU	00070	na	Jackson candle units. Meaningful only above 25	Turbidity	Turbidity group
VARIOUS	TURB	TRBIDMTR	HATCH FTU	00076	na	Hach kit, formazin turbidity units (meaningful below and above 25)	Turbidity	
VARIOUS	TURBIDITY	LAB	NTU	82079	na	Laboratory measured turbidity in NTU's.	Turbidity-formazin used to calibrate, results may be comparable to 00076.	
VARIOUS	TURB	TRANS	%	00074	na	Transmissometer, percent transmission.	Turbidity	
VARIOUS	TURB	HLGE	PPM SIO2	00075	na	Hellige, ppm as silicon dioxide.	Turbidity	

***USGS (Alexander et al. 1996) defines these terms as follows:**

Total: (as applicable to N, P, TKN, N) means all the constituent that was present in a water-suspended sediment sample.

"Total": (as applicable to NO_3, NO_2, NH_3 NH_4 $_{and}$ orthophosphate) means that part of the constituent that was in the dissolved phase of a water + suspended-sediment sample, after the sample water was decanted off (solids where allowed to settle out) and is statistically the same as filtering with a 0.45 um filter.

Dissolved: means that the sample was filtered through a 0.45 um filter. (This is part of Standard Methods [1992] and applies to all 'dissolved' measurements.)

Table 2. Translation of NEW STORET analytical measurements to equivalent Legacy STORET parameter codes. NEW STORET fields shown were those used to undertake the translation.

NEW STORET Field Descriptors					*Legacy STORET Parameter Code*			
Characteristic	Sample Fraction	Analytical Proceedure	Analytical Proceedure Name	Other data descriptors	STORET PARAM CODE	Param 1	Param 2	Param 3
"Nitrogen, ammonia as N"	Total				00610	NH3 +NH4	N-TOTAL	MG/L
"Nitrogen, Kjeldahl"					00625	TOT KJEL	N	MG/L
"Nitrogen, Nitrite (NO2) + Nitrate (NO3) as N"					00630	NO2 + NO3	N-TOTAL	MG/L
"Nitrogen, mixed forms (NH3)+(NH4)+organic+(NO2)+(NO3)"	Total				00600	TOTAL N	N	MG/L
Phosphorus	Total				00665	PHOS-TOT		MG/L P
"Phosphorus as P"	Total				00665	PHOS-TOT		MG/L P
"Phosphorus, hydrolyzable plus orthophosphate as P" *		365.4	Total Phosphorus after Block Digestion	Method 365.4, Total P after Block Digestion.	00678	PHOS TOT	HYDRO + ORTH	MG/L P
"Phosphorus, hydrolyzable plus orthophosphate as P"		365.1	Phosphorus by Colorimetry	Method 365.1, Phosphorus by Colorimetry	70507	PHOS-T	ORTHO	MG/L P
"Phosphorus, hydrolyzable plus orthophosphate as P"	Dissolved			Dissolved fraction	00650	T PO4	PO4	MG/L
"Phosphorus, orthophosphate as P"	Total	365.1	Phosphorus by Colorimetry	Total fraction, Method 365.1, Phosphorus by Colorimetry	70507	PHOS-T	ORTHO	MG/L P
"Phosphorus, orthophosphate as P"	Dissolved			Dissolved fraction	00671	PHOS-DIS	ORTHO	MG/L P
Turbidity					82079	TURBIDITY	LAB	NTU

* This analytical measurement could also have been translated to 00665 (total P), but since the sample fraction was not specified and there existed two other naming conventions that captured total P samples, these were assumed to be the less commonly used 00678 (phosphorus, hydrolyzable + ortho, total, auto analyzer). Affects 252 lines of data from NEW STORET.

Table 3.0 Benthic chlorophyll *a* measurements from MT rivers & streams.

AGENCY	STORET PARAM 1	STORET PARAM 2	STORET PARAM 3	STORET CODE*	Values Reported as:	NOTES	What is the parameter basically a measure of:
MT-DEQ and UM	CHLRPHYL	A MG/M2	CORRECTD	32223	mg Chl *a* /m^2	Recorded as Rock in "Medium" field of NEW STORET.	Algal chlorophyll *a* from the surface of stream-bottom rocks, collected with a template; values NOT estimated.
MT-DEQ and UM	CHLRPHYL	A MG/M2	CORRECTD	32223	mg Chl *a* /m^2	Recorded as Rock or Other in "Medium" field in NEW STORET.	Algal chlorophyll *a* from the surface of stream-bottom rocks, six-rocks composited; values estimated (J).
MT-DEQ and UM	CHLRPHYL	A MG/M2	CORRECTD	32223	mg Chl *a* /m^2	Recorded as Other in "Medium" field in NEW STORET.	Algal chlorophyll *a* collected using the Hoop Method.
MT-DEQ and UM	CHLRPHYL	A MG/M2	CORRECTD	32223	mg Chl *a* /m^2	Recorded as Sediment in "Medium" field in NEW STORET.	Algal chlorophyll *a* collected using the Core Method.

* Although none of these data are from Legacy STORET, the parameter code and parameter names assigned are the equivelant values as found in Legacy STORET.

A. Ammonia Group

The group was composed of four analytical measurements, all which measure ammonia and/or ammonium; 00610, 00608, 71845 and 71846 (Table 1.0). Only the USGS used 71846 and this parameter was eliminated, as it is similar to 71845 and the USGS frequently reported both 71845 and 71846 from the same sample. The USGS also frequently reported 00610, 00608, and 71845 from a single sample; so only one (00610) was retained to avoid same-sample duplication. All other agencies used 00610, 00608, and 71845, but did not report them from the same sample; so all values from those agencies could be retained. **71845 is reported as NH_4 and, in order that the data be compatible with 00608 and 00610, all sample results for 71845 need to be multiplied by 0.7765 to convert them to 'as N'.**

The database query has two important fields that are required to be correctly queried to produce the Ammonia Group: 'Agency Code' and 'Param Code'. The query for the Ammonia Group should be written as follows:

AGENCY CODE	PARAM CODE
Not "112WRD"	71845
Not "112WRD"	00608
	00610

(Microsoft Access queries described in the remainder of this report will follow the general pattern shown above, and are applicable to the database which combines the 'tblLEGSTORETGRAB(mostly nutrient)' data *and* data from NEW STORET, EMAP and the Universities.)

B. TKN /Organic N Group

The database contained five analytical measurements in this group (00625, 00605, 00607, 00623, and 00624). The USGS reported from individual samples both 00625 (total Kjeldahl N) and 00605 (total organic N), and since 00605 is unique to the USGS it was eliminated. Many other different agencies reported 00625. 00607 (dissolved organic N) is unique to the USGS but is not useful in this effort because it excludes particulate organic N. Similarly, 00623 and 00624 measure either dissolved or suspended TKN, respectively, and therefore they were eliminated. The query was written to capture only 00625 and is shown here:

AGENCY CODE	PARAM CODE
	00625

C. Total N Group

Three TN analytical measurements were located in the database (00600, 00602 and 71887). 71887 is unique to the USGS and is frequently reported along with 00600 from the same samples (71887 is total N reported at NO_3), and was eliminated from use. 00602 only measured total N from the dissolved fraction and therefore is not comparable to 00600. The query for total N is as follows:

AGENCY CODE	PARAM CODE
	00600

D. Nitrate + Nitrite Group

This group contained the largest number of analytical measurement variations and presented the most complicated query challenge. At first, the possibility of summing the individual nitrate value and individual nitrite value (e.g., 71851 and 71856) from the same sample was considered, but this presented a major database effort in order to correctly match stations, dates and times for numerous different agencies. In most natural water exposed to oxygen, nitrite is only present in trace quantities and most dissolved inorganic N is nitrate (Horne and Goldman 1994). A review of this database showed that most nitrite measurements were very low or below the detection limit. Further, analytical measurements that analyzed for both NO_3 + NO_2 simultaneously (both 00630 and 00631 do this) were the largest contributors to the group in terms of sample numbers, and therefore nitrite is included in the bulk of the samples. For simplicity, it was decided to eliminate all nitrite-only measurements (00615, 00613, and 71856) from use (Table 1.0).

Large numbers of USGS samples reported both 71851 (nitrate as NO_3) and 00618 (nitrate dissolved, as N) from the same sample. But there were only 114 non-USGS records for 71851 (for streams & rivers) in the database. Therefore, 71851 was completely eliminated (Table 1.0). The USGS and the U.S. Forest Service were the only agencies to measure 71850 (“total” nitrate as NO3), and sometimes reported both 00618 and 71850 from the same samples; therefore, 71850 (the measurement with fewest values) was eliminated.

The remaining four ‘nitrate’ or ‘nitrate + nitrite’ measurements (00630, 00631, 00618 and 00620) were queried on an agency-by-agency basis to determine which agencies reported more than one of these measurements from a single sample. It resulted that the USGS frequently reported all four, and so their samples are restricted in the query only to 00630 (NO3 + NO2 N-TOTAL). MT DEQ (agency code 21MTHDWQ) did, on very rare occasions, report 00630 and 00620 from the same sample, but in the vast majority of cases reported values were unique and so all four measurements are retained. EPA (agency code 11EPALES) usually reported 00630 paired with 00620, and so 00620 was excluded. EMAP reported both 00618 and 00631, but there were only a few 00631 samples so that parameter was eliminated for EMAP and 00618 was retained. None of the remaining agencies reported more than one of the four measurements from any single sample. 11NPSWRD was excluded because the few sample shown in the database appeared to be end-of-pipe data. The final query is shown below:

Agency Code	Param Code
Not "112WRD" and Not "11NPSWRD" and Not "EMAP"	00631
Not "11NPSWRD"	00630
Not "112WRD" and Not "11NPSWRD"	00618
Not "112WRD" and Not "11EPALES" and Not "11NPSWRD"	00620

E. Total P Group

Comprised of four measurements (00665, 71886, 00669, and 00678). 00669 and 00678 were completely excluded because there was some uncertainty in the comparability of these samples to 00665 and 71886 and together, they represented < 1% of the data of this group. The two remaining measurements (00665 and 71886) were both found to be frequently reported on from a single sample by the USGS, and so the query restricts USGS data to 00665. All other agencies reported one or the other from any given sample. **Values from 71886 are reported as PO_4 and will need to be converted to units of P to combine with 00665, therefore all samples under the 71886 code need to be multiplied by 0.3261.** The query is shown below:

F. Soluble Reactive Phosphate (SRP) Group

This group consists of four analytical measurements (00671, 70507, 00660, and 00650). 00650 was eliminated completely because of uncertainty in the comparability of this analytical measurement to the other three. The USGS frequently reported the remaining three (00671, 70507, 00660) from a single sample, but one of them (00660) was simply a reporting unit change (00660 is reported as PO_4) and of the remaining two, there were six times more records for 00671 than for 70507. Therefore, for the USGS only 00671 is retained. EPA (agency code 1119C050) often reported 70507 and 00671 from a single sample and therefore the query restricts that agency to just 70507. The other agencies did not report more than one measurement from a single sample. The query is shown below:

AGENCY CODE	PARAM CODE
Not “112WRD”	70507
Not “112WRD”	00660
Not “1119C050”	00671

G. Total Dissolved Phosphorus (TDP) Group

Only one analytical measurement was found in the database (00666). No restrictions are placed on any agency for this query, which is shown below:

AGENCY CODE	PARAM CODE
	00666

H. Turbidity Group

Consists of five analytical turbidity measurements (00070, 00076, 82079, 00074, and 00075). 00075 was eliminated as no record of what it actually measures could be found. 00074 was eliminated after a conversation with the USGS revealed that 00074’s units (percent light light transmissivity) could not be directly converted to the other commonly used turbidity unit, JTU or NTU (John Lambing, personal communication). The remaining three measurements (00070, 00076, and 82079) are based on differing measurement methodologies relying on visible light and infrared light respectively. There is no consistent conversion mechanism that can be applied to standardize 00070 and 00076 measurements; the measurements (JTU and FTU) were therefore analyzed separately. Further, 00070 (JTU) values are only meaningful when they are higher than 25 (Hach Chemical Co. 1975). 00076 (FTU) and 82079 (NTU) values are evidently comparable because 82079 values were calibrated using formazin; 00076 values are meaningful down to a value of 1.0 (Hach Chemical Co. 1975; APHA 1992), whereas 82079 values are meaningful down to 0.02 (APHA 1992). No agency reported all three, or pairs, from the same sample. **After the query is run, all values associated with 00070 that are less than 25 should be eliminated, and in any analyses the values from 00070 should be kept separate from those of 00076 and 82079**. The query is shown below:

Agency Code	Param Code
	00070
	00076
	82079

I. Benthic Chlorophyll *a* Group

There is a single analytical measurement for this group (32223), although there are variations in the way benthic Chl *a* have been collected (Table 3; see Suplee 2004 or MT DEQ SOPs for more explanation). All of the samples have been adjusted for phaeophytins (monochromatic method; APHA 1992), and are only measures of algal
Chl *a*. By definition one of the rock methods, wherein 6 stream-bottom rocks are collected and the total attached Chl *a* is extracted (see Notes, table 3.0), is considered an estimate ("J" flag in the Remark_Code field). This is because it is assumed that the Chl *a* was recovered from 50% of the rocks' total surface area, which may or may not be true. The query for these data is shown below. **It should be noted that for this group in the present study, an exception is made to the general exclusion of estimated data ("J" flagged); this exception will apply only to data with STORET parameter code 3223.**

AGENCY CODE	PARAM CODE
	32223

References

Alexander, R. B., Ludtke, A. S., Fitzgerald, K. K., and T. L. Schertz. 1996. Data from selected U.S. geological survey national stream water-quality monitoring networks (WQN) on CD-ROM. United States Geological Survey, Open-File Report 96-337.

American Public Health Association (APHA). 1992. Standards methods for the examination of water and wastewater, 18th edition. American Public Health Association, Washington, D.C.

Hach Chemical Co. 1975. Procedures, chemical lists and glassware for water and wastewater analysis with calibrations for the Bausch and Lomb Spectronic 20, Mini Spec 20 and other popular spectrophotometers. 2nd edition. Hach Chemical Company, Ames, Iowa.

Horne, A. J., and C. R. Goldman. 1994. Limnology, 2nd edition. McGraw-Hill.

Lambing, J. 2004. USGS Water Quality Specialist. Personal communication. Helena, MT, May 10th, 2004.

MT DEQ. 2005. Sample collection and laboratory analysis of chlorophyll-*a*, standard operation procedure. QPBWQM-011, review draft of 5/16/2005. Available from the MT Department of Environmental Quality, 1520 E. 6th Ave, Helena, MT 59620.

STORET. 1996. Printout of STORET parameter numbers and their associated descriptions. Printed from the EPA STORET system on September 11, 1996 (on file at the MT Department of Environmental Quality, Helena, MT).

Suplee, M. 2004. Wadeable streams of Montana's Hi-line region: an analysis of their nature and condition, with an emphasis on factors affecting aquatic plant communities *and* recommendations to prevent nuisance algae conditions. Montana Department of Environmental Quality, May 2004. Available at: http://www.deq.state.mt.us/wqinfo/Standards/Master_Doc_DII.pdf

U.S EPA. 1979. Methods for chemical analysis of water and wastes. United Stated Environmental Protection Agency, publication No. EPA-600/4-79-020. March 1979.

Varghese, A. and J. Cleland. 2004a. Stratification of algae and nutrient data of Montana rivers and streams to assist in the development of numeric standards-final report. Submitted to Dr. Michael Suplee, Montana Department of Environmental Quality, Helena, MT. July 13, 2004.

Varghese, A. and J. Cleland. 2004b. Montana rivers and streams reference-to-whole-population percentile mapping for selected water quality parameters-final report. Submitted to Dr. Michael Suplee, Montana Department of Environmental Quality, Helena, MT. November 19, 2004.

APPENDIX B

SEASONAL GROUPING METHODOLOGY

Prepared by: Dr. Michael Suplee, MT DEQ
June 17, 2005

Techniques used to Determine Seasonal Periods for the Purpose of Segregating Nutrient and Chlorophyll *a* Data by Time of Year

The results of two previous analyses (Varghese and Cleland 2004; Varghese and Cleland 2005) demonstrated that level III and level IV ecoregions (Omernick 1987) are likely to be meaningful tools for the purpose of stratifying nutrient data in Montana. It was hypothesized that the correlation between ecoregions and nutrient concentrations might be further improved by dividing the data into different seasons, as nutrient concentrations in flowing waters often demonstrate distinct seasonal patterns (Lohman and Priscu 1992). For example, phosphorus (P) is frequently associated with total suspended sediment (TSS) and during spring runoff in streams both TSS and total P can be orders-of-magnitude higher than at other times (Horne and Goldman 1994).

Seasonal variation in stream nutrient concentrations are not only influenced by abiotic factors such as runoff patterns, they are also influenced by biological uptake and release by organisms such as aquatic plants. Aquatic plant growth — including algal growth — is influenced by (among other things) light availability and temperature, which are climatically driven. Therefore, the development of seasons to define nutrient concentrations must consider not only hydrologic patterns, but climatic factors such as the onset of cold winter temperatures as well. The following describes techniques that were used to establish distinct seasonal periods, applicable to each of Montana's seven level III ecoregions. The goal of this effort was to define three seasons for each ecoregion: a growing season, which would roughly correspond to the summer months; winter, which would follow the growing season; and runoff, which would terminate the winter period and comprise the yearly high flow period.

1. Selection of best-fit cutoff dates for the runoff period using hydrologic data.

To address the hydrologic component, the United State Geological Survey (USGS) was consulted. The USGS indicated that flow-duration hydrographs for average daily flows could be a useful approach for describing typical, long-term flow conditions on any given stream (C. Parrett, personal communication). The data used in the present work were all extracted from the USGS's online NWIS database.

The flow duration hydrographs were developed using the complete period of record for USGS gauge stations in Montana that typically had a minimum of 10 years of continuous data. For each station, the average of all daily flow records for any given date was calculated. Each day of the year was plotted, and the hydrograph curve thus generated represents the average flow conditions at the station over the course of the year for the time period over which the data were collected (Fig. 1.0).

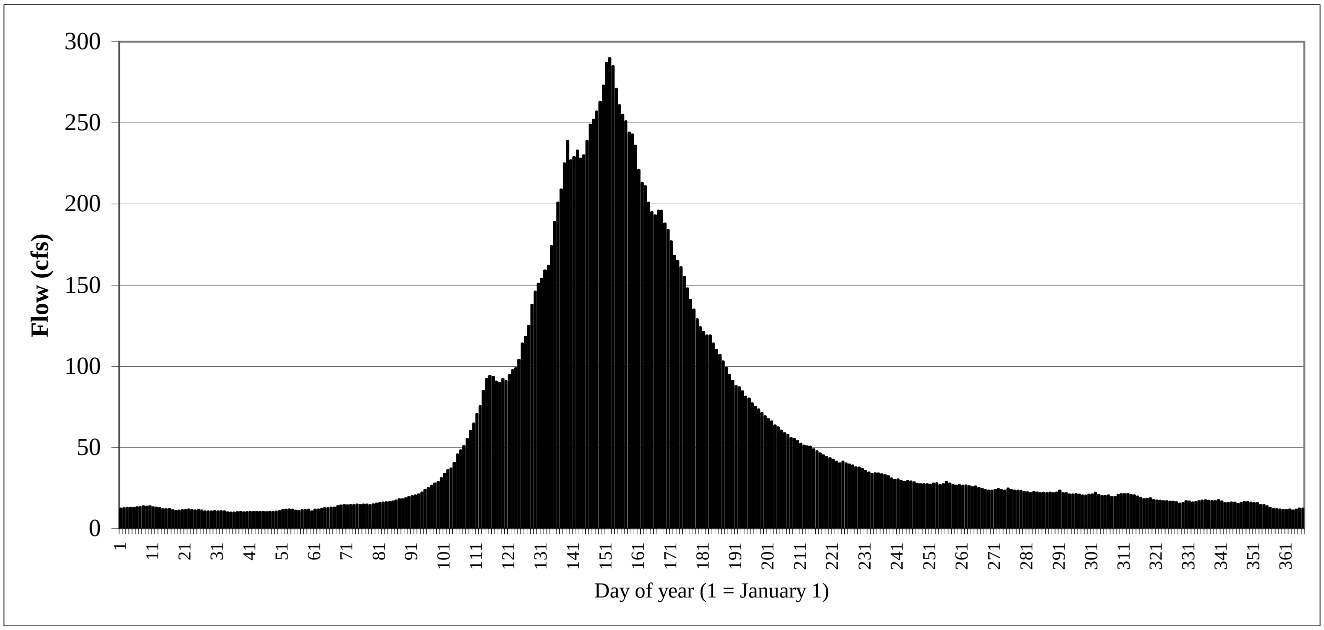


Fig. 1.0. Flow duration hydrograph for daily mean flows at USGS gauge station 12381400, 'South Fork Jocko River near Arlee, MT'. The flow shown for each day was calculated as the average for all records for that day during the period of record (1982-2003).

A number of criteria were established to select the USGS gauge stations used to define flow patterns for each ecoregion. These criteria were:

1. Each gauge station should have at least 10 years of continuous flow records. The stations selected did not need to include sampling up to the present (e.g., a continuous record from 1942-1963 was acceptable).

2. From 10-12 stations should be selected for each ecoregion, equitably spaced across the region in order to best represent the whole.

3. Stations should be on stream segments not having major hydrologic modifications (e.g., dams). (This criteria effectively eliminated gauging stations on Strahler stream orders 7 and 8 [Strahler 1964].)

Using these criteria, a total of sixty-four USGS gauge stations were selected to represent the ecoregions (Fig. 2.0; Table 1.0). Most stations were on stream segments that fell in the stream order range of 3-6 (Strahler 1964). A few stations had less than the ideal number of years of data but were retained anyway, because stations within the ecoregion that met all three criteria were limited. Two ecoregions (16, Idaho Batholith and 18, Wyoming Basin) have very limited geographic extents in Montana and only six and three appropriate gauge stations could be found for each, respectively. Some among the sixty-four stations are probably influenced, by varying degrees, by small irrigation withdrawals and returns, however the affect of this was not considered when developing the hydrographs.

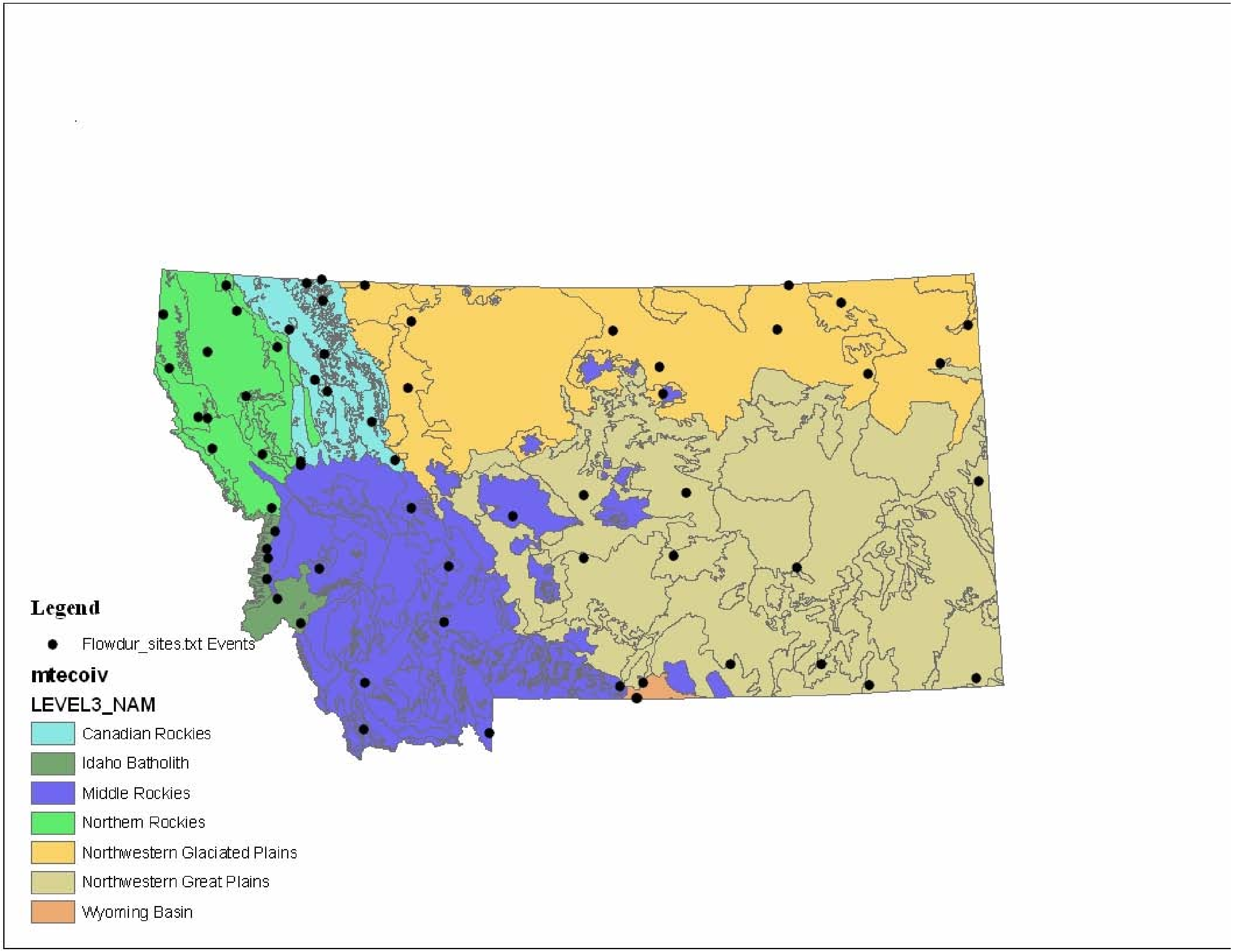


Figure 2.0. Location of USGS gauging stations used to develop ecoregionally-based time periods. The seven Level III ecoregions are shown in color.

Table 1.0. USGS guaging stations used to define flow patterns for Level III ecoregions.

USGS Station	Station Name	Flow Data Range	Years of Data	Latitude	Longitude	Ecoregion (III)
06180000	West Fork Poplar River near Richland	1935-1949	15	48.80000	-106.01670	42
06168500	Rock Creek at International Boundary	1914-1961	48	48.98889	-106.79170	42
06142400	Clear Creek near Chinook, MT	1984-2002	19	48.57889	-109.39060	42
06154400	Peoples Creek near Hays, MT	1966-2003	38	48.22361	-108.71330	42
06176500	Wolf Creek near Wolf Point, MT	1908-1992	85	48.09639	-105.67810	42
06185110	Big Muddy Creek near mouth near Culbertson, MT	1981-1992	12	48.16444	-104.62920	42
06183800	Cottonwood Creek near Dagmar, Mt	1985-2003	19	48.50972	-104.17310	42
06170200	Willow Creek near Hisdale, MT	1965-1973	9	48.56500	-106.98000	42
06099000	Cut Bank Creek at Cut Bank, MT	1905-2003	99	48.63334	-112.34610	42
06133500	North Fork Milk River AB St. Mary Ca near Browning, MT	1911-2002	92	48.97083	-113.05530	42
06107000	North Fork Muddy Creek near Bynum, MT	1912-1924	13	47.99166	-112.35670	42
06078500	North Fork Sun River near Augusta, MT	1911-1993	83	47.64083	-112.85940	41
05011500	Waterton River near International Boundary	1947-1964	18	48.95555	-113.90000	41
12359000	South Fork Flathead River at SBRS, near Hungry Horse, MT	1948-1967	20	47.92222	-113.52360	41
12361000	Sullivan Creek near Hungry Horse, MT	1948-1976	29	48.02917	-113.70280	41
12357000	Middle Fork Flathead at Essex, MT	1940-1964	25	48.27500	-113.60280	41
12355500	North Fork Flathead near Columbia Falls, MT	1910-2003	94	48.49556	-114.12670	41
05010000	Belly River at International Boundary	1947-1964	18	48.99722	-113.68060	41
12382000	Middle Fork Jocko River near Jocko, MT	1912-1916	5	47.22222	-113.85000	41
05014500	Swiftcurrent Creek at Many Glacier, MT	1912-2002	91	48.79917	-113.65580	41
06072000	Dearborn River AB Falls Creek, near Clemons, MT	1908-1912	5	47.28333	-112.50000	41
12354000	St Regis River near St. Regis, MT	1910-2003	94	47.29694	-115.12170	15
12390700	Prospect Creek at Thompson Falls, MT	1956-2003	48	47.58611	-115.35420	15
12389500	Thompson River near Thompson Falls, MT	1911-2003	93	47.59195	-115.22860	15
12301999	Wolf Creek near Libby, MT	1967-1977	11	48.23361	-115.28390	15
12304500	Yaak River near Troy, MT	1956-2003	48	48.56194	-115.96920	15
12366000	Whitefish River near Kalispell, MT	1928-2003	76	48.32028	-114.27750	15
12301300	Tobacco River near Eureka, MT	1959-2003	45	48.89361	-115.08690	15
12391550	Bull River near Noxon, MT	1973-1982	10	48.04722	-115.83360	15
12374250	Mill Creek above Bassoo Creek, near Niarada, MT	1982-2003	22	47.83028	-114.69580	15
12300500	Fortine Creek near Trego, Mt	1947-1953	7	48.65000	-114.91670	15
12351500	Lolo Creek near Lolo, MT	1911-1915	5	46.75555	-114.21670	15
12388400	Revais Creek below West Fork near Dixon, MT	1983-2003	21	47.26667	-114.40580	15

Table 1.0, continued. USGS guaging stations used to define flow patterns for Level III ecoregions.

USGS Station	Station Name	Flow Data Range	Years of Data	Latitude	Longitude	Ecoregion (III)
06207540	Silver Tip Creek near Belfry, MT	1967-1975	9	45.15889	-108.97530	18
06207500	Clarks Fork Yellowstone River near Belfry, MT	1921-2003	83	45.01028	-109.06470	18
06207510	Big Sand Cl at WY-MONT State line	1973-1981	9	45.00444	-109.05890	18
12343400	East Fork Bitterroot near Conner, MT	1956-2003	48	45.88334	-114.06470	16
06024500	Trail Creek Near Wisdom, MT	1948-1972	25	45.65667	-113.71560	16
12345000	Rock Creek near Darby, MT	1946-1959	14	46.06944	-114.22220	16
12347500	Blodgett Creek near Corvallis, MT	1947-1969	23	46.26944	-114.23610	16
12349500	Fred Burr Creek near Victor, MT	1947-1951	5	46.35556	-114.25280	16
12350500	Kootenai Creek near Stevensville, MT	1949-1963	15	46.53722	-114.15860	16
12381400	South Fork Jocko River near Arlee, MT	1982-2003	22	47.19556	-113.84970	17
12332000	Middle Fork Rock Creek near Philipsburg, MT	1938-2003	66	46.19500	-113.50000	17
06015500	Grasshopper Creek near Dillon, MT	1921-1961	41	45.11111	-112.80000	17
06013500	Big Sheep Creek below Muddy Creek near Dell, MT	1936-1979	44	44.65000	-112.78330	17
06037500	Madison River near West Yellowstone, MT	1913-2001	89	44.65694	-111.06750	17
06209500	Rock Creek near Red Lodge, MT	1932-2003	72	45.12083	-109.29580	17
06035000	Willow Creek near Harrison, MT	1938-2002	65	45.72306	-111.74030	17
06055500	Crow Creek near Radersburg, MT	1901-1990	90	46.26805	-111.69170	17
06071000	Little Prickly Pear Creek near Canyon Creek, MT	1909-1924	16	46.81667	-112.25000	17
06077000	Sheep Creek near White Sulphur Springs, MT	1941-1972	32	46.76805	-110.80920	17
06154410	Little Peoples Creek near Hays, MT	1972-1989	18	47.96611	-108.66000	17
06129500	McDonald Creek at Winnett, MT	1930-1956	27	47.00000	-108.35000	43
06336500	Beaver Creek at Wibaux, MT	1938-1984	47	46.99000	-104.18330	43
06307600	Hanging Woman Creek near Birney, MT	1973-1995	23	45.29917	-106.50780	43
06126470	Halfbreed Creek near Klein, MT	1978-1991	14	46.38722	-108.54140	43
06121000	American Fork near Harlowton, MT	1907-1932	26	46.36666	-109.80000	43
06111000	Ross Fork Creek near Hobson, MT	1946-1962	17	46.98333	-109.80000	43
06294995	Armells Creek near Forsyth, MT	1974-1995	22	46.24972	-106.80610	43
06287500	Soap Creek near St. Xavier, MT	1911-1972	62	45.32722	-107.76940	43
06324500	Powder River at Moorhead, MT	1929-2003	75	45.06778	-105.86940	43
06334000	Little Missouri River near Alzada, MT	1911-1969	59	45.08333	-104.40000	43

Two types of flow duration hydrograph were developed for each station; one based on daily mean flows, and one based on daily median flows. Median flow-duration hydrographs were developed in the present work because studies in New Zealand show that 3 times the median annual flow is a useful flow variable which explains much of the variance in measurements of stream aquatic communities (Clausen and Biggs 1997). This is because scouring occurs at 3 times the median yearly flow, and scouring is a physical stressor that controls many aquatic life populations (Clausen and Biggs 1997).

Specific onset and termination dates for the runoff period were identified on flow-duration hydrographs for both daily mean flows and daily median flows. For the flow-duration hydrographs based on daily means, the points of greatest inflection on the curve were used to define the runoff onset and termination dates (e.g., day 101 and 205 in Fig. 1.0). For the flow-duration hydrographs based on daily medians, the median flow for any given station was first calculated using all records in the dataset, and then this values was multiplied by three. The two dates straddling the runoff period that had flows equal to 3 times the median flow were then noted for that hydrograph.

The best overall results were achieved using the mean-based flow duration hydrographs. New Zealand is a mountainous country, and in the mountainous ecoregions (e.g. 15, Northern Rockies) there was generally good agreement in the dates selected using either the mean- or median-based hydrographs. However, in the plains ecoregions this was not the case. The plains ecoregions (42, 43 and 18) frequently show bimodal runoff periods with an initial rise in flow in March followed by a lull and then, usually in June, a second surge as runoff from distant mountain influences occurs. In a few of the plains hydrographs, thunderstorms appeared to drive much of the high flows and these were often scattered across the entire summer period. In these scenarios, the three-times-the-median-flow approach proved to be unworkable.

2. Selection of best-fit cutoff dates for the start of winter and the start of the growing season, based on biological considerations.

After the hydrologically-based dates for the onset and termination of runoff were compiled, it was immediately obvious that the runoff termination dates suggested by many of the flow-duration hydrographs were frequently extending deeper into the summer than experience has shown there to be discernable scouring effects on aquatic life. As stated earlier, scouring flows from runoff influence aquatic life (Clausen and Biggs 1997) as well as nutrient concentrations (Snelder et al. 2004), but after this affect subsides biological influences on stream nutrient concentrations are likely to become significant (Lohman and Priscu 1992). MT DEQ uses June 21st as the general start date for its biological sampling index period, as experience has shown that runoff effects (i.e., scouring) have usually subsided by that time.

The selection of the start-of-winter date could not be determined using hydrograph characteristics. After runoff, a period of base flow begins which is often fairly uniform well into November or December (Fig. 1.0). However, climatic influences in Montana (mainly reduced temperatures and light intensity) typically cause, by the end of September, a termination in the growth of aquatic plant life. Once the aquatic plant life has begun to senesce uptake of nutrients is reduced and decomposition begins to outweigh production. In general, the MT DEQ uses

September 21st as the termination date for the biological sampling index period, which is supported by work that has been undertaken on macroinvertebrates in Montana streams (Richards 1996).

3. Final selection of best-fit cutoff dates for the winter, run-off and growing season periods.

The final cutoff dates for the three seasons in each ecoregion are shown in Table 2.0. They were derived using a combination of the methods and considerations discussed in 1 and 2 above. For simplicity, all dates were rounded to the nearest mid- or end-of-month date. The start of runoff was calculated as the average onset date of runoff for the set of daily mean flow-duration hydrographs for each ecoregion. The growing season cutoff dates were developed by considering both the hydrograph end-of-runoff dates *and* the biological index period dates. In ecoregions where more than half of the hydrographs still showed sizable flows on June 21st, the start of the growing season was extended to July 16th. By July 16th all of the hydrographs were approaching base flow or were, at least, on the declining leg of the runoff curve. The start of winter was uniformly selected as October 1st, the closest date to the end of the DEQ's indexing period and a date by which most aquatic plant growth should be ended for the year.

Table 2.0. Best-fit cutoff dates, by level III ecoregion, for each of three seasons (winter, runoff and growing season).

Ecoregion Name	Ecoregion Level III Number	Start of Winter	End of Winter	Start of Runoff	End of Runoff	Start of Growing Season	End of Growing Season
Canadian Rockies	41	October 1	April 14	April 15	June 30	July 1	September 30
Northern Rockies	15	October 1	March 31	April 1	June 30	July 1	September 30
Idaho Batholith	16	October 1	April 14	April 15	July 15	July 16	September 30
Middle Rockies	17	October 1	April 14	April 15	July 15	July 16	September 30
Northwestern Glaciated Plains	42	October 1	March 14	March 15	June 15	June 16	September 30
Northwestern Great Plains	43	October 1	February 29	March 1	June 30	July 1	September 30
Wyoming Basin	18	October 1	April 14	April 15	June 30	July 1	September 30

References

Clausen, B., and B. J. F. Biggs. 1997. Relationships between benthic biota and hydrological indices in New Zealand streams. Freshwater Biol. **38**: 327-342.

Horne, A. J., and C. R. Goldman. 1994. Limnology, 2nd edition. McGraw-Hill Inc.

Lohman, K., and J. C. Priscu. 1992. Physiological indicators of nutrient deficiency in *Cladophora* (chlorophyta) in the Clark Fork of the Columbia River, Montana. J. Phycol. **28**: 443-448.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers **77**: 118-125.

Parrett, C. Hydrologist, United State Geological Survey, Helena, MT. Personal communication. February 24, 2005.

Richards, D.C. 1996. The use of aquatic macroinvertebrates as water quality indicators in mountain streams. M.S. thesis, Montana State University, Bozeman, MT, pp 166.

Snelder, T. H., Biggs, B. J. F., and M. A. Weatherhead. 2004. Nutrient concentration criteria and characterization of patterns in trophic state for rivers in heterogeneous landscapes. Journal of the American Water Resources Association **40**: 1-13.

Strahler, A. N. 1964. Quantitative geomorphology of drainage basins and channel networks. *In* Chow, V. T. (ed), Handbook of applied hydrology. McGraw-Hill, New York, pp 439-476.

Varghese, A. and J. Cleland. 2004. Montana rivers and streams reference-to-whole-population percentile mapping for selected water quality parameters-final report. Submitted to Dr. Michael Suplee, Montana Department of Environmental Quality, Helena, MT. November 19, 2004.

Varghese, A. and J. Cleland. 2005. Stratification of nutrient data for Montana rivers and streams-summary of findings. Submitted to Dr. Michael Suplee, Montana Department of Environmental Quality, Helena, MT. February 15, 2005.

APPENDIX C

LITHOGRAPHIC GROUPING METHODOLOGY

Nutrient – Lithology – Geology Layer
June 7, 2004
Jim Stimson (DEQ Source Water Protection Program)

Source of Geologic Information: Gary L. Raines and Bruce R. Johnson, 1996, Digital representation of the Montana state geologic map: a contribution to the Interior Columbia River Basin Ecosystem Management Project, USGS Open File Report 95-691, ArcView Shapefile for Montana.

Source of information on geologic sources of Nitrogen: Holloway, J.M., Dahlgren, R.A., and Casey, W. H., 1998, Contribution of bedrock nitrogen to high nitrate concentrations in stream water, Nature: Vol 395 October 1998, p. 785 – 788.

Reason for lithology groupings: Based on information from the Holloway et al. study forms of nitrate (ammonium) can substitute into the mica crystal structure. In addition, several other sources identify marine shale rocks as containing significant amounts of nitrate. Therefore, sedimentary shale rocks and metamorphic that contain significant volumes of mica minerals, like biotite and muscovite, were two of the lithology categories culled out of the digital version of the 1955 Geologic map of Montana.

How the lithology groupings were made: The digital version of the 1955 Geologic map of Montana comes with an attribute data table that includes multiple fields including eight lithology fields. In transferring the original lithologic descriptions from the 1955 geologic map, the dominant lithology type was placed into the Lith1 field, the next abundant lithology was placed into the Lith2 field, and so on. These lithology fields were used to isolate 17 lithology types. The dominant lithology names taken from the Lith1 and Lith2 fields are included in the lithology shapefile names. A quick review of the attribute table of each shapefile shows which specific lithologies are included in each group. Once a group of lithology types was selected from the original geologic shapefile, the selected records were exported into a new shapefile bearing the name of new lithologic group.

Lithologic Groups: The following lithologic shapefiles have been created:

1) **Igneous Intrusives and extrusives but not volcanics**. Major types of igneous rock. Volcanics excluded.

2) **Igneous volcanics**. Rocks identified specifically as volcanics.

3) **Metamorphic Schist.** Schist is a name applied a metamorphic rock dominated by aligned mica minerals usually biotite and muscovite but there is a host of other mica

minerals. Because the schist rocks contain significant volumes of mica minerals they are thought to be a possible source of geologic nitrate.

4) **Metamorphic Schist and Argillite**. Argillite is a name usually applied a fine-grained rock like a shale or mudstone that is quite hard and breaks into angular “chucks”. Argillites are thought to have been metamorphosed so that the original minerals have been re-crystallized and have grown, and exhibit alignment with the general bedding direction. Because the argillite rocks contain significant volumes of mica minerals they are thought to be a possible source of geologic nitrate.

5) **Sedimentary Sandstones**. Thought to not be a source of geologic nitrate.

6) **Sedimentary Quartzite**. A metamorphosed sandstone composed almost entirely of quartz grains. Thought to not be a source of geologic nitrate.

7) **Sedimentary Gravel, Boulders, and Conglomerates**. Range front gravel deposits and the Flaxville gravels. Flaxville gravels host aquifers that can have elevated nitrate levels related to agricultural practices. Otherwise, thought to not be a source of geologic nitrate.

8) **Sedimentary Limestone and Dolomite**. Thought to not be a source of geologic nitrate.

9) **Sedimentary Argillaceous Limestone**. Limestones with a significant volume of fine grained material (argillite) and could be a source of geologic nitrate.

10) **Sedimentary Shaly Sandstone**. Sandstones with a significant volume of shale and could be a source of geologic nitrate.

11) **Sedimentary Sandy Shale**. Sandstones with a significant volume of shale and could be a source of geologic nitrate.

12) **Sedimentary Shale and Clay**. A grouping of several geologic formations where the Lith1 and Lith2 fields listed shale and clay. Could be a source of geologic nitrate.

13) **Sedimentary Carbonaceous Shale**. Shales with high organic (carbonaceous) content. Could be a source of geologic nitrate.

14) **Sedimentary Siliceous Shale**. Shales with relatively high silica content. Could be a source of geologic nitrate.

15) **Sedimentary Calcareous Shale**. Shales with relatively high carbonate (calcite or dolomite, or other carbonates) content. Could be a source of geologic nitrate.

16) **Sedimentary Argillaceous Shale**. I believe these are shales with relatively high mica content. There could also be shales that are more lithified and hard but I think the term is used to express that the rock has identifiably large mica crystals present. Could be a source of geologic nitrate.

17) **Sedimentary Silt Dominated**. Since there can be a fine line between shales and silts, I pulled out formations that listed silt as the dominant lithology. Usually the term silt is used to describe rocks that are more gritty than shales or clays because the silt rock contains more grains of quartz. If they are associated with shale beds, they could be a source of geologic nitrate.

18) **Sedimentary Silt Shale – Hell Creek Formation.** The Hell Creek is part of the Fort Union Formation and is usually described as containing more shale beds than the Fox Hills member (located below the Hell Creek) and the Tongue River member (located above the Hell Creek. Could be a source of geologic nitrate.

APPENDIX D

LOG FILES OF STATA STATISTICAL ANALYSES

Enclosed with this report is a CD-ROM that contains the detailed output of the statistical analyses conducted for this project. The CD contains several hundred statistical analyses (i.e., Stata log files) for ten water quality parameters evaluated in various combinations of coarse- and fine-scale stratifying parameters, as described in Section 4 of the report. Some analyses were repeated with both databases utilized for this project: the All-Observations database and the Median database. Below, we provide guidance on locating the files on the CD and finding specific statistical results within the log files.

1.1 Contents of Folders

The RUNS folder on the CD-ROM contains six folders. Table D-1 describes the contents of each folder and the databases analyzed.

Table D-1: Folder Contents

Folder Name	Contents	Databases Analyzed
PTILE	Percentile Mapping	All-Observation Database
TESTS	Significance Testing of Stratification Methods	Median Database
MCV	Measures of Variation for Stratification Methods	All-Observation and Median Database
SEASONS	Testing of Seasonal Differences	All-Observation and Median Database
STRAHDIST	Distribution of Strahler Stream Order In General and Reference Population	All-Observation and Median Database
NO7&8	Repeats the analyses of the PTILE, TESTS and MCV folders for the general population after excluding Strahler stream order 7 and 8.	All-Observation and Median Database

Detailed guides to the contents of each folder are provided in Section 2 of this appendix.

1.2 Summary Statistics

Summary statistics of the water quality parameters are found in numerous places in the log files. Table D-2 describes where specific summary statistics may be located.

Table D-2: Location of Summary Statistics

Database	Location of Summary Statistics	Comment
All-Observation	Folder = PTILE. Locate log-file within sub-folder for specific nutrient and stratifying methodology of interest (coarse or fine).	Summary Statistics are presented for each level of various coarse/fine stratification methodologies for each season. General population and reference statistics are presented together.
Median	Folder = TESTS Locate log-file within sub-folder for specific nutrient and stratifying methodology of interest (coarse or fine). Separate log-files are provided for general population and reference population results.	Summary Statistics are presented for each level of various coarse/fine stratification methodologies for each season. General population and reference statistics are NOT presented together but in separate log files.

1.3 Guide to Terminology

The log files contain a number of symbols, or codes, used as short-hand for water quality parameters and stratifying parameters in the database and in the statistical programs. In many cases, the log files provide comments that translate these symbols or codes into plain English equivalents. However, such translation was not always possible, given the complexity of some of the procedures. Therefore, the tables below provide a key to the codes used in this analysis.

Tables D-3, D-4 and D-5 list the codes used for water quality parameters, stratifying parameters, and geologic formations, respectively. Figure D-1 presents the codes used to represent Omernik Levels III and IV ecoregions.

Table D-3: Water Quality Parameter Codes

Code	Water Quality Parameter
AMMONIA	Ammonia (mg/l)
BNCHLOR-A	Benthic Chlorophyll-*a* (mg/m^2)
NO3+NO2	Nitrate and Nitrite group (mg/l)
SRP	Soluble Reactive Phosphate (mg/l)
TDP	Total Dissolved Phosphorus (mg/l)
TKN	Total Kjeldahl Nitrogen (mg/l)
TOTALN	Total Nitrogen (mg/l)
TOTALP	Total Phosphorus (mg/l)
TURB-NTU	Turbidity (NTU)
TURB-JTU	Turbidity (JTU)

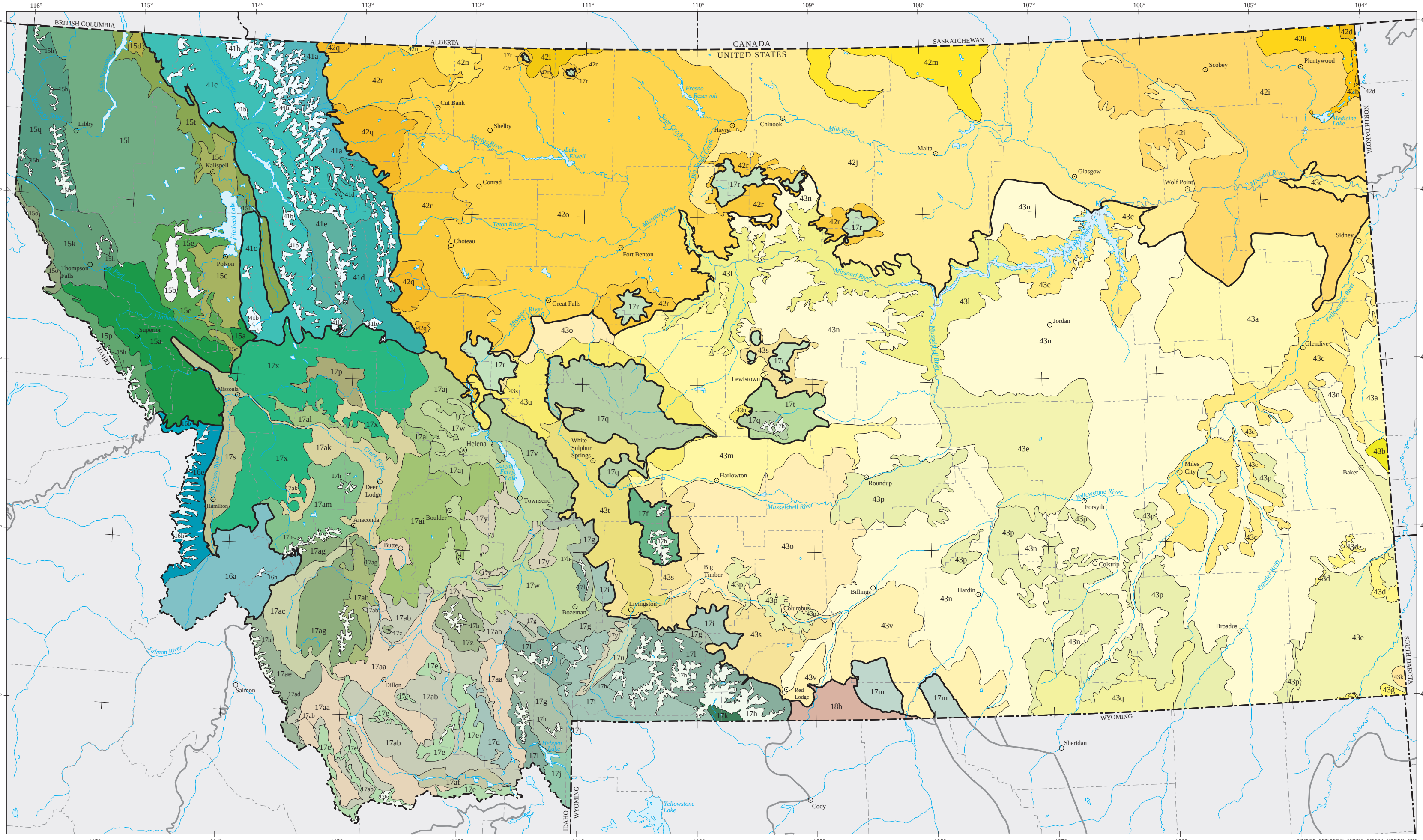
Table D-4: Stratifying Parameter Codes

Code	Stratifying Parameter
eco3	Omernik level III ecoregions
eco4	Omernik level IV ecoregions
sfname	Geologic formation
geco	Grouped level III ecoregions (Mountain or Prairie)
strahgroup	Grouped Strahler Stream Order (1&2, 3&4, 5&6 and 7&8)

Table D-5: Geologic Formation Codes

Code	Geologic Formation
1	Metamorphic Argillite
2	Argillaceous Shale
3	Argillaceous Limestone
4	Calcareous Shale
5	Carbonaceous Shale
6	Gravel, Boulders, Conglomerate
7	Hell Creek Silty Shale
8	Chert
9	Igneous but not Volcanic
10	Limestone and Dolomite
11	Quartzite
12	Sedimentary Sandstone
13	Sandy Shale
14	Metamorphic Schist
15	Shale and Clay
16	Shaly Sandstone
17	Siliceous Shale
18	Sedimentary Silt Dominated
19	Cretaceous and Tertiary Volcanics

Ecoregions of Montana



15 Northern Rockies
- 15a Grave Creek Range-Nine Mile Divide
- 15b Camas Valley
- 15c Flathead Valley
- 15d Tobacco Plains
- 15e Flathead Hills and Mountains
- 15h High Northern Rockies
- 15i Clearwater Mountains and Breaks
- 15k Clark Fork Valley and Mountains
- 15l Salish Mountains
- 15o Coeur d' Alene Metasedimentary Zone
- 15p St. Joe Schist-Gneiss Zone
- 15q Purcell-Cabinet-North Bitterroot Mountains
- 15t Stillwater-Swan Wooded Valley

16 Idaho Batholith
- 16a Eastern Batholith
- 16b Lochsa Uplands
- 16e Glaciated Bitterroot Mountains and Canyons
- 16h High Idaho Batholith

17 Middle Rockies
- 17d Eastern Gravelly Mountains
- 17e Barren Mountains
- 17f Crazy Mountains
- 17g Absaroka-Gallatin-Madison-Bridger Sedimentary Mountains
- 17h High Elevation Rockland Alpine Zone
- 17i Absaroka-Gallatin Volcanic Mountains
- 17j West Yellowstone Plateau
- 17k Lady of the Lake
- 17l Gneissic-Schistose Forested Mountains
- 17m Big Horn-Pryor Mountains
- 17p Foothill Potholes
- 17q Big Snowy-Little Belt Carbonate Mountains
- 17r Scattered Eastern Igneous-Core Mountains
- 17s Bitterroot-Frenchtown Valley
- 17t Limy Foothill Savanna
- 17u Paradise Valley
- 17v Big Belt Forested Highlands
- 17w Townsend Basin
- 17x Rattlesnake-Blackfoot-South Swan-Northern Garnet-Sapphire Mountains
- 17y Townsend-Horseshoe-London Sedimentary Hills
- 17z Tobacco Root Mountains
- 17aa Dry Intermontane Sagebrush Valleys
- 17ab Dry Gneissic-Schistose-Volcanic Hills
- 17ac Big Hole
- 17ae Forested Beaverhead Mountains
- 17af Centennial Basin
- 17ag Pioneer-Anaconda Ranges
- 17ah Eastern Pioneer Sedimentary Mountains
- 17ai Elkhorn Mountains-Boulder Batholith
- 17aj Eastern Divide Mountains
- 17ak Deer Lodge-Philipsburg-Avon Grassy Intermontane Hills and Valleys
- 17al Southern Garnet Sedimentary-Volcanic Mountains
- 17am Flint Creek-Anaconda Mountains

18 Wyoming Basin
- 18b Northern semiarid Intermontaine Basin

41 Canadian Rockies
- 41a Northern Front
- 41b Crestal Alpine-Subalpine Zone
- 41c Western Canadian Rockies
- 41d Southern Carbonate Front
- 41e Flathead Thrust Faulted Carbonate-Rich Mountains

42 Northwestern Glaciated Plains
- 42b Collapsed Glacial Outwash
- 42d Northern Missouri Coteau
- 42i Glaciated Dark Brown Prairie
- 42j Glaciated Northern Grasslands
- 42k Coteau Lakes Upland
- 42l Sweetgrass Uplands
- 42m Cherry Patch Moraines
- 42n Milk River Pothole Upland
- 42o North Central Brown Glaciated Plains
- 42q Rocky Mountain Front Foothill Potholes
- 42r Foothill Grassland

43 Northwestern Great Plains
- 43a Missouri Plateau
- 43b Little Missouri Badlands
- 43c River Breaks
- 43d Forested Buttes
- 43e Sagebrush Steppe
- 43g Semiarid Pierre Shale Plains
- 43k Dense Clay Prairie
- 43l Missouri Breaks Woodland-Scrubland
- 43m Judith Basin Grassland
- 43n Central Grassland
- 43o Unglaciated Montana High Plains
- 43p Ponderosa Pine Forest-Savanna Hills
- 43q Mesic Tongue River Dissected Plains
- 43s Non-calcareous foothill grassland
- 43t Shield-Smith Valleys
- 43u Limy Foothill Grassland
- 43v Pryor-Big Horn Foothills

- Level III ecoregion
- Level IV ecoregion
- County boundary
- State boundary
- International boundary

15 10 5 0 30 60 mi
30 20 10 0 60 120 km

Albers equal area projection
Standard parallels 46° N and 48° N

EPA
USDA Natural Resources Conservation Service
Forest Service — U.S. Department of Agriculture
USGS science for a changing world

2. Detailed Guide to Folders

2.1 PTILE

The PTILE folder contains two separate sub-folders for coarse and fine-scale stratifications. Each of these contains ten sub-folders, one for each water quality parameter. Within the water quality parameter subfolder, are further subfolders for each stratification methodology.

For example, to access the percentile mapping results for TKN by Geologic Formation, follow the path:

Ptile/Coarse/TKN/SFNAME and open the log file TKN.log

To access the percentile mapping results for SRP by Omernik level III ecoregions by Geologic Formation, follow the path:

Ptile/Fine/SRP/ECO3/SFNAME and open the log file SRP.log.

The coarse-scale log files have the following general structure:

> For each level of the coarse-scale stratifying variable, each season is considered in turn. For each season, the log file contains summary statistics, tests of comparison for the reference and general population, and the results of the percentile mapping. After all seasons have been considered, the analysis moves to the next level of the stratifying variable.

The fine-scale log files have the same structure, except that the analysis is performed for each level of the fine-scale parameter within each level of the coarse-scale parameter.

Our previous report (ICF 2004b) provided an annotated guide to the percentile mapping log files, which are nearly identical to those in this analysis and may be consulted for further details on interpreting the log files.

The analyses are supported by a series of graphics, which display adjacent box-whisker plots for logtransformed data for the non-reference and reference populations. An example graph is displayed below. (In the graphs, “Y” refers to the reference population and “N” to the non-reference population.)

Figure D-2: Example of Box-Whisker Plots in Coarse-Scale PTILE Analysis

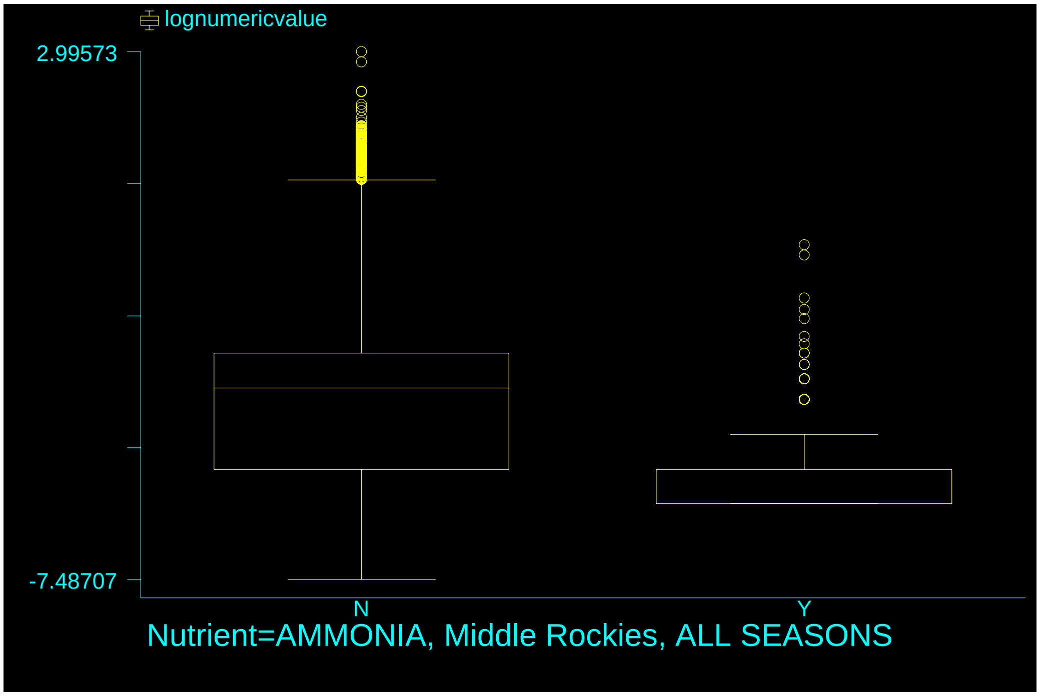
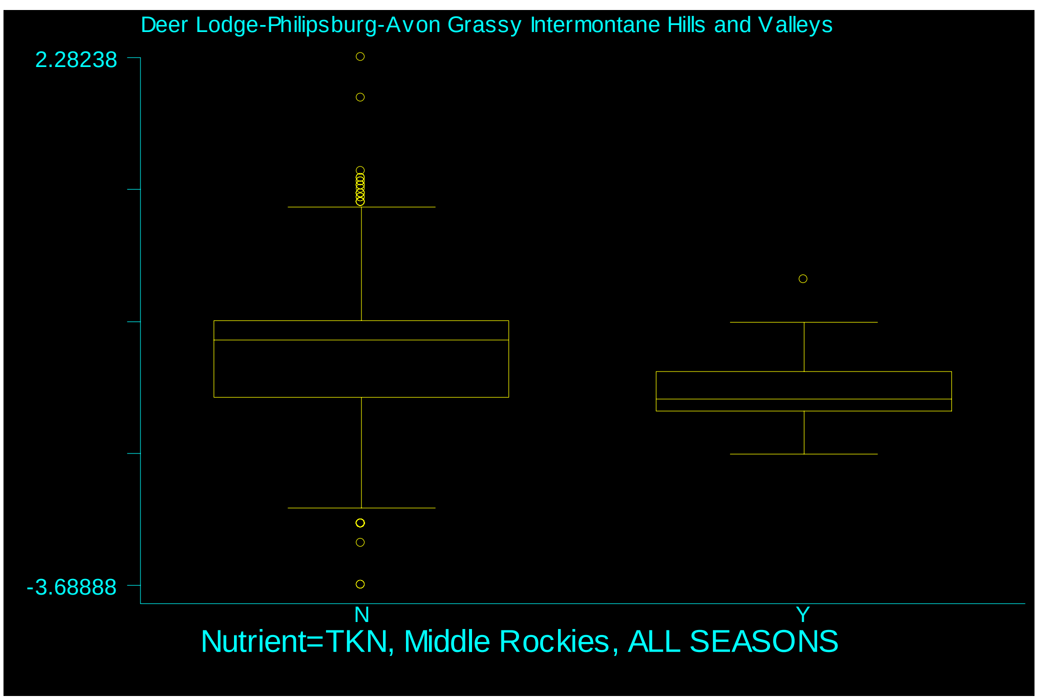


Figure D-3: Example of Box-Whisker Plots in Fine-Scale PTILE Analysis



2.2 TESTS

The TESTS folder contains two separate sub-folders for coarse and fine-scale stratifications. Each of the sub-folders contains a sub-folder for General Population results (GP) and a sub-folder for Reference Population results (REF). Each of these contains ten sub-folders, one for each water quality parameter. Within the water quality parameter subfolders, are further subfolders for each stratification methodology.

For example, to access the significance testing results for TKN by Geologic Formation in the General Population, follow the path:

Tests/Coarse/GP/TKN/SFNAME and open the log file *TKNsfnameGP.log*

To access the percentile mapping results for SRP by Omernik level III ecoregions by Geologic Formation in the Reference Population, follow the path:

Tests/Fine/REF/SRP/ECO3/SFNAME and open the log file *SRPeco3sfnameREF.log*.

The coarse-scale log files have the following general structure:

A separate analysis is performed for each season. First, summary statistics are reported for each level of the stratifying parameter for the nutrient, for the specific season.

An example output of summary statistics is presented below:

```
SUMMARY STATISTICS for Nutrient = TKN by Level 3 Ecoregion for Season = ALL SEASONS

Summary for variables: num
     by categories of: eco3

eco3 |         N       min       max      mean        sd  skewness
-----+------------------------------------------------------------
  15 |    342.00      0.03     23.70      0.42      1.50     13.09
  16 |     39.00      0.05      2.00      0.39      0.45      1.63
  17 |    764.00      0.03     69.30      0.48      2.55     25.75
  18 |     10.00      0.17      2.89      0.73      0.81      2.11
  41 |     43.00      0.05      1.00      0.22      0.23      1.53
  42 |    259.00      0.05     13.00      1.02      1.35      4.93
  43 |    645.00      0.03     51.40      0.87      2.23     18.50
-----+------------------------------------------------------------
Total|   2102.00      0.03     69.30      0.65      2.13     23.40
------------------------------------------------------------------

Summary for variables: num
     by categories of: eco3

eco3 |         N       p10       p25       p50       p75       p90
-----+------------------------------------------------------------
  15 |    342.00      0.05      0.10      0.20      0.50      0.65
  16 |     39.00      0.05      0.05      0.13      0.50      1.10
  17 |    764.00      0.05      0.10      0.25      0.50      0.80
  18 |     10.00      0.18      0.22      0.51      0.74      2.00
  41 |     43.00      0.05      0.05      0.11      0.30      0.60
  42 |    259.00      0.20      0.34      0.70      1.16      1.90
  43 |    645.00      0.14      0.28      0.52      1.00      1.60
-----+------------------------------------------------------------
Total|   2102.00      0.05      0.15      0.35      0.70      1.26
------------------------------------------------------------------
```

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

The Kruskal Wallis (KW) Test for equality of median nutrient concentrations across each stratum is then performed. An example output of the KW test is presented below:

```
KRUSKAL-WALLIS TEST for Nutrient = TKN by Level 3 Ecoregion for Season = ALL SEASONS


Test: Equality of populations (Kruskal-Wallis test)

     eco3          _Obs   _RankSum
       15           342  269425.00
       16            39   32788.50
       17           764  657985.00
       18            10   12734.00
       41            43   26377.00
       42           259  370142.00
       43           645  840801.50

chi-squared =   379.591 with 6 d.f.
probability =     0.0001

chi-squared with ties =   380.900 with 6 d.f.
probability =     0.0001

 ______________________________________________________

Can Reject the Hypothesis that the group medians are equal
 ______________________________________________________
```

Note that the statistical results are interpreted by an explanatory comment.

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

The KW test is followed by a non-parametric multiple comparison of means. An annotated abbreviated example output of the non-parametric multiple comparisons of means is presented below. (Note: the yellow-highlighted comments have been added here to facilitate interpretation and are not part of the log files.)

```
NON-PARAMETRIC MULTIPLE COMPARISON OF MEDIANS


One-way analysis of variance by ranks (Kruskal-Wallis Test)

neco3    Obs   RankSum  RankMean
--------------------------------
  1      342 269425.00    787.79
  2       39  32788.50    840.73
  3      764 657985.00    861.24
  4       10  12734.00   1273.40
  5       43  26377.00    613.42
  6      259 370142.00   1429.12
  7      645 840801.50   1303.57

Chi-squared (uncorrected for ties) =   379.591 with    6 d.f. (p = 0.00010)
Chi-squared (corrected for ties)   =   380.900 with    6 d.f. (p = 0.00010)

Multiple comparisons between groups
-----------------------------------
(Adjusted p-value for significance is 0.001190)
```

```
Ho: num(neco3==1) = num(neco3==2)
    RankMeans difference =     52.94  Critical value =    311.65
    Prob = 0.302903 (NS)
```

THE NULL HYPOTHESIS IS THAT THE MEDIAN VALUE FOR NECO3=1 IS EQUAL TO THE MEDIAN VALUE FOR NECO3=2. NECO3 IS THE CODENAME FOR ECO3. A RELATIONSHIP KEY AT THE END OF THE ANALYSIS WILL ASSOCIATE THE NUMERIC VALUES WITH SPECIFIC LEVELS OF THE STRATIFYING PARAMETER. THE OPERATIVE TERM TO INTERPRETING THE RESULTS HERE IS THE “NS” IN PARENTHESIS, WHICH STANDS FOR “NOT SIGNIFICANT”. THIS IMPLIES THAT THE DIFFERENCE BETWEEN THE MEDIANS OF THE TWO GROUPS COMPARED IS NOT SIGNIFICANT.

```
Ho: num(neco3==2) = num(neco3==7)
    RankMeans difference =    462.84  Critical value =    304.06
    Prob = 0.000002 (S)
```

THE NULL HYPOTHESIS IS THAT THE MEDIAN VALUE FOR NECO3=2 IS EQUAL TO THE MEDIAN VALUE FOR NECO3=7. BECAUSE THE TERM IN PARENTHESIS IS “S”, THIS IMPLIES THAT THE DIFFERENCE BETWEEN THE MEDIANS OF THE TWO GROUPS COMPARED IS INDEED SIGNIFICANT.

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

Here is the relationship key for the stratifying variable:

RELATIONSHIP KEY FOR MULTIPLE COMPARISON TESTS

group(eco 3)	eco3 15	16	17	18	41	42	43
1	342						
2		39					
3			764				
4				10			
5					43		
6						259	
7							645

According to this key, the numeric group 1 refers to the level III ecoregion with the codename 15, which is the Northern Rockies (see figure D-1).

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

The log file then presents the results of a one-way analysis of variance to test the statistical significance of the stratifying parameter. An example output of the ANOVA procedure is presented below:

ANOVA for Nutrient = TKN by Level 3 Ecoregion for Season = ALL SEASONS

```
                        Number of obs =    2102     R-squared     =  0.1707
                        Root MSE      = 1.04184     Adj R-squared =  0.1683
```

Source	Partial SS	df	MS	F	Prob > F
Model	468.139391	6	78.0232318	71.88	0.0000
neco3	468.139391	6	78.0232318	71.88	0.0000
Residual	2273.99068	2095	1.08543708		
Total	2742.13007	2101	1.30515472		

THE P-VALUE HIGHLIGHTED IN GREEN REPORTS THE STATISTICAL SIGNIFICANCE OF THE MODEL. IF THE VALUE IS BELOW 0.05, THE STRATIFYING METHODOLOGY MAY BE CONSIDERED STATISTICALLY SIGNIFICANT AT THE 95% CONFIDENCE LEVEL.

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

The analysis then performs a multiple comparison of means in the various strata using the Bonferroni adjustment. An example output is provided below:

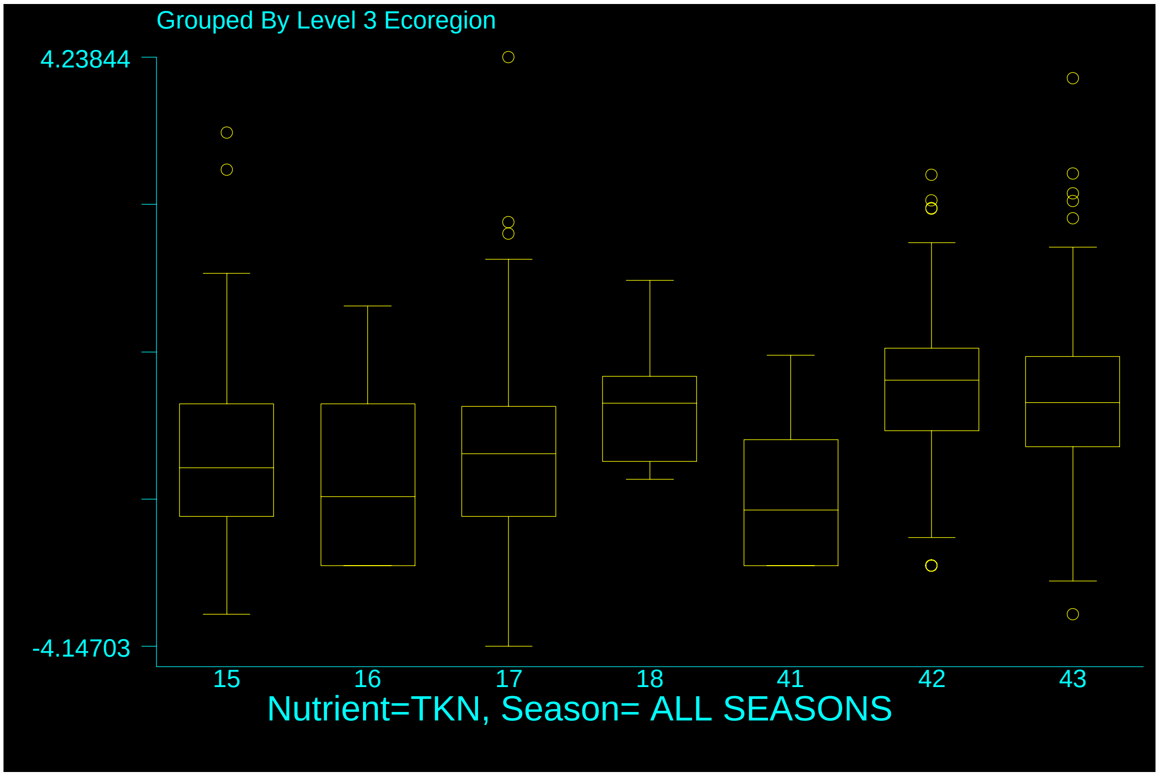
```
ANOVA MULTIPLE COMPARISON OF LOG MEANS WITH BONFERRONI ADJUSTMENT

                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      468.139391      6   78.0232318     71.88     0.0000
 Within groups      2273.99068   2095   1.08543708
------------------------------------------------------------------------
    Total           2742.13007   2101   1.30515472

Bartlett's test for equal variances:  chi2(6) =   8.6057  Prob>chi2 = 0.197
```

```
                     Comparison of lognum by group(eco3)
                                (Bonferroni)
Row Mean-|
Col Mean |          1          2          3          4          5          6
---------+------------------------------------------------------------------
       2 |   -.020504
         |      1.000
         |
       3 |      .1296    .150104
         |      1.000      1.000
         |
       4 |    .943418    .963922    .813818
         |      0.101      0.191      0.298
         |
       5 |   -.386293   -.365788   -.515893   -1.32971
         |      0.463      1.000      0.034      0.006
         |
       6 |     1.1506     1.1711      1.021    .207178    1.53689
         |      0.000      0.000      0.000      1.000      0.000
         |
       7 |    .937479    .957983    .807879   -.005939    1.32377   -.213117
         |      0.000      0.000      0.000      1.000      0.000      0.115
```

THE P-VALUE HIGHLIGHTED IN GREEN REPORTS THE PROBABILITY THAT THE MEAN OF NUMERIC GROUP 6 = THE MEAN OF NUMERIC GROUP 1. IF THIS VALUE IS BELOW 0.05, THE GROUP MEANS MAY BE CONSIDERED DIFFERENT FROM ONE ANOTHER AT THE 95% CONFIDENCE LEVEL. (IN THIS CASE, THE MEANS OF THE TWO GROUPS MAY THEREFORE BE CONSIDERED DIFFERENT). THE VALUE DIRECTLY ABOVE IT SHOWS THE DIFFERENCE BETWEEN THE ROW MEAN AND THE COLUMN MEAN, THAT IS, THE DIFFERENCE BETWEEN THE MEAN OF NUMERIC GROUP 6 AND NUMERIC GROUP 1 (THE DIFFERENCE BETWEEN GROUP MEANS = 1.1506 IN THIS CASE). THE RELATIONSHIP KEY PRESENTED EARLIER MAY BE USED TO RELATE THE NUMERIC GROUP TO SPECIFIC VALUES OF THE STRATIFYING PARAMETER.

The analyses are supported by a series of graphics, which display adjacent box whisker plots for each level of the stratifying parameter. An example graph is provided in Figure D-4.

Figure D-4: Example of Box-Whisker Plots in Coarse-Scale TESTS Analysis



XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

The fine-scale analyses for the significance of sub-stratifying methodologies have a different structure than the coarse-scale.

These analyses first report exploratory one-way ANOVA on the coarse-scale parameter, one-way ANOVA on the fine-scale parameter, two-way factorial ANOVA with interaction on the coarse and fine-scale parameters together, and the KW test for substratification of the coarse scale parameter by the fine-scale parameter. (Annotated output for these exploratory tests are not provided here; however, the same principles may be used to interpret them as described in other parts of this analysis).

To assess the significance of sub-stratification methodologies, the analysis uses a model that embeds the sub-stratification term within the coarse-scale stratification term, and then performs a post-ANOVA Wald test to test the significance of the sub-stratification term. An annotated example of this output is provided below:

```
TEST OF SIGNIFICANCE OF SUBSTRATIFYING Level 3 Ecoregion BY Level 4 Ecoregion


                           Number of obs =    1592     R-squared     =  0.1766
                           Root MSE      = 1.21312     Adj R-squared =  0.1398

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  480.559891    68   7.06705722       4.80     0.0000
```

```
           |
      cell |  480.559891    68  7.06705722       4.80     0.0000
           |
  Residual |  2241.34719  1523  1.47166591
-----------+----------------------------------------------------
     Total |  2721.90708  1591  1.71081526

             Number of obs =    1592     R-squared     =  0.1766
             Root MSE      = 1.21312     Adj R-squared =  0.1398

    Source |  Partial SS    df       MS           F     Prob > F
-----------+----------------------------------------------------
     Model |  480.559891    68  7.06705722       4.80     0.0000
           |
     neco3 |  43.4458137     6  7.24096894       4.92     0.0001
      cell |  400.773277    62  6.46408511       4.39     0.0000
           |
  Residual |  2241.34719  1523  1.47166591
-----------+----------------------------------------------------
     Total |  2721.90708  1591  1.71081526

    Source |  Partial SS    df       MS           F     Prob > F
-----------+----------------------------------------------------
      cell |  400.773277    62  6.46408511       4.39     0.0000
  Residual |  2241.34719  1523  1.47166591
```

The term *cell* is the variable that represents sub-strata within the coarse-scale parameter (in this case the coarse scale parameter is neco3, which represents eco3). If the p-value of *cell* in the Wald test (highlighted in green) is below 0.05, the substratification may be considered meaningful at the 95% confidence level. (In the example provided, the sub-stratification of eco3 by eco4 results in a statistically significant model.)

The analysis thereafter reports summary statistics for each level of the coarse-scale parameter. After performing all these procedures on one season, the analysis moves to the next season.

2.3 MCV

The MCV folder contains two separate sub-folders for coarse and fine-scale stratifications. Each of the sub-folders contains a sub-folder for General Population results (GP) and a sub-folder for Reference Population results (REF). Each of these contains two sub-folders, one for the analysis based on the All-Observation database (ALLDATA) and the other for the analysis based on the Median database (MEDDATA).
Within these sub-folders is a single log file which contains results for all ten water quality parameter for each stratification methodology.

For example, to access the MCV results for TKN by Eco4 in the General Population using the All-Observation database, follow the path:

MCV/Coarse/GP/ALLDATA and open the log file *MCVCoarseGPAllData.log*

To access the MCV results for SRP by Eco4 by Strahler Stream Order in the Reference Population using the Median database, follow the path:

MCV/Fine/REF/MEDDATA and open the log file *MCVFineREFMedData.log*

The coarse scale log files report the MCV, COE and total observations for each nutrient, for a number of stratification methodologies, for each season. The log files are self-explanatory. A sample output is provided below.

```
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

MCV ANALYSIS FOR GENERAL POPULATION, ALL DATA

NUTRIENT = TOTALN BY Level 3 Ecoregion BY SEASON

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX


*************************************************************************************************

NUTRIENT = TOTALN, SEASON = ALL SEASONS, by Level 3 Ecoregion

MCV = 1.472456999216334

COE (Log Transformed) = .4315597138630014

TOTAL OBSERVATIONS = 4830

*************************************************************************************************


*************************************************************************************************

NUTRIENT = TOTALN, SEASON = WINTER,  by Level 3 Ecoregion

MCV = 1.086934706932231

COE (Log Transformed) = .3559982722827028

TOTAL OBSERVATIONS = 1779

*************************************************************************************************


*************************************************************************************************

NUTRIENT = TOTALN, SEASON = RUNOFF, by Level 3 Ecoregion

MCV = 1.144742222687749

COE (Log Transformed) = .5330003741207156

TOTAL OBSERVATIONS = 1716

*************************************************************************************************


*************************************************************************************************

NUTRIENT = TOTALN, SEASON = GROWING, by Level 3 Ecoregion

MCV = 2.010365373877689
```

```
COE (Log Transformed) = .423718064817054

TOTAL OBSERVATIONS = 1335

***************************************************************************************************
```

The introductory comment enclosed between two triple lines of “X”s indicates which nutrient and stratification methodology are being analysed and also specifies which population (general or reference) and database (All-Observations or Median) are analyzed. The MCV and COE results are thereafter reported for each season, enclosed between lines of “*”s. Specific results may be located by using the appropriate word searches within a text editor or by scrolling through the log file. The analyses were processed in the following order:

mtmcvc TOTALN eco3
mtmcvc TOTALN eco4
mtmcvc TOTALN geco
mtmcvc TOTALN sfname
mtmcvc TOTALN strahler
mtmcvc TOTALN strahgroup

mtmcvc TKN eco3
mtmcvc TKN eco4
mtmcvc TKN geco
mtmcvc TKN sfname
mtmcvc TKN strahler
mtmcvc TKN strahgroup

mtmcvc NO3+NO2 eco3
mtmcvc NO3+NO2 eco4
mtmcvc NO3+NO2 geco
mtmcvc NO3+NO2 sfname
mtmcvc NO3+NO2 strahler
mtmcvc NO3+NO2 strahgroup

mtmcvc TOTALP eco3
mtmcvc TOTALP eco4
mtmcvc TOTALP geco
mtmcvc TOTALP sfname
mtmcvc TOTALP strahler
mtmcvc TOTALP strahgroup

mtmcvc SRP eco3
mtmcvc SRP eco4
mtmcvc SRP geco
mtmcvc SRP sfname
mtmcvc SRP strahler
mtmcvc SRP strahgroup

mtmcvc TDP eco3
mtmcvc TDP eco4
mtmcvc TDP geco
mtmcvc TDP sfname
mtmcvc TDP strahler
mtmcvc TDP strahgroup

mtmcvc AMMONIA eco3
mtmcvc AMMONIA eco4
mtmcvc AMMONIA geco
mtmcvc AMMONIA sfname
mtmcvc AMMONIA strahler
mtmcvc AMMONIA strahgroup

mtmcvc BNCHLOR-A eco3
mtmcvc BNCHLOR-A eco4
mtmcvc BNCHLOR-A geco
mtmcvc BNCHLOR-A sfname
mtmcvc BNCHLOR-A strahler
mtmcvc BNCHLOR-A strahgroup

mtmcvc TURB-JTU eco3
mtmcvc TURB-JTU eco4
mtmcvc TURB-JTU geco
mtmcvc TURB-JTU sfname
mtmcvc TURB-JTU strahler
mtmcvc TURB-JTU strahgroup

mtmcvc TURB-NTU eco3
mtmcvc TURB-NTU eco4
mtmcvc TURB-NTU geco
mtmcvc TURB-NTU sfname
mtmcvc TURB-NTU strahler
mtmcvc TURB-NTU strahgroup

The fine-scale analysis follows the same format as the coarse-scale log files. The fine-scale analyses were processed in the following order:

mtmcvf TOTALN eco3 strahler
mtmcvf TOTALN eco3 strahgroup
mtmcvf TOTALN eco3 sfname
mtmcvf TOTALN eco4 strahler
mtmcvf TOTALN eco4 strahgroup
mtmcvf TOTALN eco4 sfname
mtmcvf TOTALN geco strahler
mtmcvf TOTALN geco strahgroup
mtmcvf TOTALN geco sfname

mtmcvf TKN eco3 strahler
mtmcvf TKN eco3 strahgroup
mtmcvf TKN eco3 sfname
mtmcvf TKN eco4 strahler
mtmcvf TKN eco4 strahgroup
mtmcvf TKN eco4 sfname
mtmcvf TKN geco strahler
mtmcvf TKN geco strahgroup
mtmcvf TKN geco sfname

mtmcvf NO3+NO2 eco3 strahler
mtmcvf NO3+NO2 eco3 strahgroup
mtmcvf NO3+NO2 eco3 sfname

mtmcvf NO3+NO2 eco4 strahler
mtmcvf NO3+NO2 eco4 strahgroup
mtmcvf NO3+NO2 eco4 sfname
mtmcvf NO3+NO2 geco strahler
mtmcvf NO3+NO2 geco strahgroup
mtmcvf NO3+NO2 geco sfname

mtmcvf TOTALP eco3 strahler
mtmcvf TOTALP eco3 strahgroup
mtmcvf TOTALP eco3 sfname
mtmcvf TOTALP eco4 strahler
mtmcvf TOTALP eco4 strahgroup
mtmcvf TOTALP eco4 sfname
mtmcvf TOTALP geco strahler
mtmcvf TOTALP geco strahgroup
mtmcvf TOTALP geco sfname

mtmcvf SRP eco3 strahler
mtmcvf SRP eco3 strahgroup
mtmcvf SRP eco3 sfname
mtmcvf SRP eco4 strahler
mtmcvf SRP eco4 strahgroup
mtmcvf SRP eco4 sfname
mtmcvf SRP geco strahler
mtmcvf SRP geco strahgroup
mtmcvf SRP geco sfname

mtmcvf TDP eco3 strahler
mtmcvf TDP eco3 strahgroup
mtmcvf TDP eco3 sfname
mtmcvf TDP eco4 strahler
mtmcvf TDP eco4 strahgroup
mtmcvf TDP eco4 sfname
mtmcvf TDP geco strahler
mtmcvf TDP geco strahgroup
mtmcvf TDP geco sfname

mtmcvf AMMONIA eco3 strahler
mtmcvf AMMONIA eco3 strahgroup
mtmcvf AMMONIA eco3 sfname
mtmcvf AMMONIA eco4 strahler
mtmcvf AMMONIA eco4 strahgroup
mtmcvf AMMONIA eco4 sfname
mtmcvf AMMONIA geco strahler
mtmcvf AMMONIA geco strahgroup
mtmcvf AMMONIA geco sfname

mtmcvf TURB-JTU eco3 strahler
mtmcvf TURB-JTU eco3 strahgroup
mtmcvf TURB-JTU eco3 sfname
mtmcvf TURB-JTU eco4 strahler
mtmcvf TURB-JTU eco4 strahgroup
mtmcvf TURB-JTU eco4 sfname
mtmcvf TURB-JTU geco strahler
mtmcvf TURB-JTU geco strahgroup
mtmcvf TURB-JTU geco sfname

mtmcvf TURB-NTU eco3 strahler
mtmcvf TURB-NTU eco3 strahgroup
mtmcvf TURB-NTU eco3 sfname
mtmcvf TURB-NTU eco4 strahler
mtmcvf TURB-NTU eco4 strahgroup
mtmcvf TURB-NTU eco4 sfname
mtmcvf TURB-NTU geco strahler
mtmcvf TURB-NTU geco strahgroup
mtmcvf TURB-NTU geco sfname

mtmcvf BNCHLOR-A eco3 strahler
mtmcvf BNCHLOR-A eco3 strahgroup
mtmcvf BNCHLOR-A eco3 sfname
mtmcvf BNCHLOR-A eco4 strahler
mtmcvf BNCHLOR-A eco4 strahgroup
mtmcvf BNCHLOR-A eco4 sfname
mtmcvf BNCHLOR-A geco strahler
mtmcvf BNCHLOR-A geco strahgroup
mtmcvf BNCHLOR-A geco sfname

2.4 SEASONS

The SEASONS folder contains two separate sub-folders for coarse and fine-scale stratifications. Each of the sub-folders contains a sub-folder for General Population results (GP) and a sub-folder for Reference Population results (REF). Each of these contains two sub-folders, one for the analysis based on the All-Observation database (ALLDATA) and the other for the analysis based on the Median database (MEDDATA).
Within these sub-folders are sub-folders for the ten water quality parameters, each containing a subfolder named ECO3, which contains a log file with the results of tests for differences in seasonal concentrations in each level III ecoregion.

For example, to access the seasonal testing results for ECO3 for TKN in the General Population using the All-Observation database, follow the path:

SEASONS\GP\ALLDATA\TKN\ECO3 and open the log file *TKNeco3GPAll.log*

In the log files, each level III ecoregion is considered one at a time. Summary statistics are first presented for each season. The Kruskal Wallis test is then performed to test for significant differences between the median nutrient concentrations across the different seasons. A non-parametric multiple comparison test is then performed to determine which specific seasons may be considered different from each other. ANOVA and multiple comparisons of seasonal means based on the Bonferroni adjustment are thereafter presented. The interpretation of these tests has been described in Section 2.2 of this appendix and is not repeated here. The analysis then proceeds to the next level III ecoregion.

(Note: The ALLDATA analyses present results only for specific seasons (Winter, Runoff, Growing) whereas the MEDDATA report result for specific seasons as well as for all seasons. This difference in formats is due to differences in the structures of the two databases.)

2.5 STRAHDIST

The STRAHDIST folder contains two sub-folders, one for station-level analysis (STATION) and the other for observation-level analysis (OBS).

Each of the subfolders has ten subfolders for each of the water quality parameters. Within them is a further subfolder called ECO3, representing the analysis for level III ecoregions. (The analysis is only presented for level III ecoregions for all seasons.)

For example, to access the Strahler stream order distributional analysis for TKN at the station level for level III ecoregions, follow the path:

STRAHDIST\STATION\TKN\ECO3 and open the log file: *TKNeco3stationstrahdist.log*

In the log files, each level III ecoregion is considered one at a time. A tabulation of stream order in the general and reference population in the ecoregion is first presented. The Pearson chi-square test is then presented to assess whether the distribution of stream order in the general and reference populations may be considered equal in that ecoregion.

An example of this test is provided below:

PEARSON CHI SQUARE TEST for Nutrient=TKN, Level 3 Ecoregion = Middle Rockies for REF and NON-REF
ST
> ATIONS

STRAHLER	REF N	Y	Total
1	99	0	99
	15.97	0.00	15.40
2	163	10	173
	26.29	43.48	26.91
3	160	8	168
	25.81	34.78	26.13
4	79	1	80
	12.74	4.35	12.44
5	65	0	65
	10.48	0.00	10.11
6	25	4	29
	4.03	17.39	4.51
7	26	0	26
	4.19	0.00	4.04
8	3	0	3
	0.48	0.00	0.47
Total	620	23	643
	100.00	100.00	100.00

Pearson chi2(7) = 20.3102 Pr = 0.005

REJECT THE HYPOTHESIS THAT STRAHLER DISTRIBUTION IS EQUAL IN REF AND NON-REF STATIONS

The distribution of Strahler stream order may be considered to be different in the general and reference population with 95% statistical confidence if the highlighted p-value is less than 0.05. However, the output translates the result of this test into a direct statement of whether the distributions are different.

The analysis also performs the Kruskal Wallis test, and presents histograms of the stream order distribution in the general and reference population with a superimposed normal distribution curve for each level III ecoregion. An example of the graphical output is presented in Figure D-5. The histogram marked “N” refers to the non-reference population and “Y” refers to the reference population.

Figure D-5: Example of Histograms in STRAHDIST Analysis