WASHINGTON STATE DEPARTMENT OF ECOLOGY

Trophic State Census of Washington State Lakes by Satellite Imagery

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Trophic State Census of Washington State Lakes by Satellite Imagery

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Abstract

The state of Washington is required to periodically report on statewide conditions of lake water quality under both federal and state law. The Washington State Department of Ecology had to discontinue the lake monitoring program due to fiscal constraints, and at present, there is no statewide monitoring of lake water quality. To address these legal requirements, this report investigates the use of satellite imagery to conduct statewide assessments of lake water quality. Ground observations of three trophic state indicators from lakes were compiled from existing data sources. Data from the LandSat® Thematic Mapper Satellite© were compiled from 1991 to 2000. These data were used to conduct various statistical tests to evaluate the relationships between lake trophic state indicators, morphometric measures, and LandSat® image spectral characteristics. A multivariate model was developed for each trophic state indicator. Model performance was evaluated with an independent data set.

The statewide census of trophic state indicators predicted from the empirical models show little change in lake Secchi transparency values between 1991 and 2000. Lake chlorophyll *a* concentrations had increased in observations from 2000 for those lakes with previously existing low productivity conditions. Total phosphorus concentrations in both mesotrophic and eutrophic lakes increased from 1991 to 2000. Results from the predicted census of each trophic state indicator showed only slight differences between most ecoregions. The census of predicted lake trophic states revealed that a small percentage of mesotrophic lakes had become eutrophic over the ten-year period. A relatively large percentage of oligotrophic lakes have become mesotrophic in the Coast Range and Cascades ecoregions. In addition, small mesotrophic lakes and highly convoluted lakes (i.e., high shoreline development index) show an increase in productivity over this same period.

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Background

One of the most often asked questions is: *What is the overall status of water quality in Washington State?* This is the same question that state environmental agencies are required to periodically report on statewide conditions under both federal and state law. Water quality information from lakes is critical for effective environmental planning and management.

The federal Clean Water Act requires the state to report on the extent to which control programs have improved water quality or will improve water quality for the purposes of ". . . the protection and propagation of a balanced population of shellfish, fish, and wildlife and . . . recreational activities in and on the water" (40 CFR 130.8(b)(2) and 40 CFR 130.8(b)(1)). Under Section 305(b), the state is required to biennially report the extent to which all surface waters meet the objectives of the Clean Water Act and attain applicable water quality standards. Under Section 314(a)(1)(F), the state is also required to report on the status and trends of water quality in lakes. Federal guidance directs the state to address these requirements through the use of models or from monitoring information. This report was produced to partially comply with these reporting requirements.

In 2001, Governor Locke signed into law the Watershed Health and Salmon Recovery Monitoring Act. The law required state agencies to develop a Comprehensive Monitoring Strategy (CMS) and Action Plan for monitoring watershed health statewide. The law also requires the Washington State Department of Ecology (Ecology) to implement the recommendations of the CMS (Chapter 90.82 Revised Code of Washington). The CMS and action plan were submitted to the governor and the legislature in 2002 (CMS, 2002). The CMS describes the need to conduct lake monitoring statewide. The CMS Policy Development Group consisted of senior staff from state and federal agencies that prioritized monitoring tasks required in the CMS Action Plan. Implementing statewide monitoring of water quality was one of the highest priorities that were identified by the Policy Development Group. The action plan recommends information collected under the CMS guidelines be evaluated and reported every two years. This report supports the CMS recommendation.

Governmental organizations have monitored the aquatic environment for many years. This includes monitoring of estuaries, coastal waters, streams, rivers, lakes, reservoirs, and wetlands. Most, if not all, of these monitoring efforts have been designed to fulfill specific purposes (e.g., are municipal treatment plants meeting permit limits). More recently, monitoring programs have been asked to address questions at a larger spatial scale. Examples for the types of questions these monitoring programs are asked to address are:

- What is the condition of lakes statewide?
- What is the water quality of lakes in the Puget Sound region?

Establishing study objectives are critical as they determine the monitoring design. It is common for monitoring programs to attempt to incorporate more objectives than are possible to address with limited time and money. A precise statement of the objectives is beneficial for designing a monitoring program that will provide useful information for making effective decisions.

Before a monitoring program is established, a clear description of the aquatic resource target population is defined. The target population is statistical terminology that refers to a subset of aquatic resources. Both the "target population" for which information is wanted and the "elements" that describe the target population must be carefully defined (Särndal et al, 1992). The following are two examples that describe a target population:

- <u>Lakes as a "Discrete" Target Population.</u>
  Assume that a study of lakes is to be conducted and that questions focus on determining the number of lakes that have a particular characteristic, such as its trophic status, a recommended indicator by the U.S. Environmental Protection Agency. The target population might be all lakes in Washington State that are greater than 20 acres and are wholly within the boundaries of the state. The "elements" of the target population are the individual lakes. Note that any lake which is partly in an adjoining state would not be included in the target population. To be rigorous requires that a definition be included for what constitutes a lake. For example, does the definition of a lake include man-made reservoirs? What if the lake is no deeper than 1 meter and over 50% is covered by vegetation? Is this a lake of interest for the study? The definition must be sufficiently rigorous and explicit so that it can be clearly determined if a body of water is part of the target population. Note that in our example the target population is discrete, i.e., there are a finite number of lakes (elements) that comprise the target population. Each indicator measured for a lake results in a single trophic state value for the lake. Consequently, the summary information about the target population focuses on the number or proportion of lakes that have a particular trophic status.

- <u>Lakes as a "Continuous" Target Population.</u>
  Assume that a study of Lake Whatcom, located in northwest Washington, required an estimate of the percent of the lake volume with depleted zones of dissolved oxygen. In this case, the target population is the entire surface area of Lake Whatcom and the elements of the target population are all points within the lake. Conceptually, dissolved oxygen can be measured everywhere on the lake (an infinite number of points). Practically it is impossible to do so; it is routine to sample from a limited number of locations. Relevant elements that would define the target population include: the boundaries of Lake Whatcom, and whether the boundary definition involves a minimum water depth. These considerations are important for a sampling field crew who must visit a proposed sample site and determine if the site is included in the target population.

The target population defines the main aquatic resource of interest. Usually subpopulations of the target population are also of interest. For example, in a study of all lakes in Washington two potential subpopulations, or strata, might be natural lakes and man-made lakes (i.e., reservoirs). The study may be interested in comparing all lakes between 20 to 100 acres versus all lakes greater than 100 acres. The intersection of these two strata will yield information about four lake categories.

Why is the definition of subpopulations important in the planning of monitoring? Subpopulations arise from the questions that monitoring must answer. For example, the need for answers on natural and man-made lakes arises from questions posed at the initiation of the monitoring that the trophic status may differ between man-made and natural lakes. If such a difference exists, then different management strategies may be taken for the two types of lakes. During the initial planning, it is typical for many subpopulations of interest to be identified. In each case a strong rationale can be given as to why the information on the subpopulation is important. A study can only meet the expectations of those requiring the information if clarity is reached on what subpopulations estimates will be provided. Subpopulations contain important characteristics that "explain" natural variation, and are isolated by partitioning.

Särndal et al (1992) define the sampling frame as any material or device used to obtain observational access to the target population. What does the definition imply when studying aquatic resources? The answer depends upon what information, in a usable form, currently exists about the location of the target population and all of its elements. For example, in the study of all lakes in Washington, a list of all the lakes and their location may exist in a computer database. This list could then be used as the sample frame. Sample sites would be selected from the list and since their location is known they could be visited to obtain the desired measurements. This lake sample frame is very simple and easy to use. However, the list only has information on the lake name and its location. If the monitoring design required additional information, such as lake depth, to complete the sample selection, then the frame would be inadequate and an alternative sample frame for lakes would be needed.

Can a complete census be accomplished for aquatic resources? The practical answer is, rarely. A census of lakes in Washington would involve visiting every lake and obtaining water quality and physical measurements outlined in the project plan. The measurements from all lakes would be used to determine summary characteristics about the target population. The next step would be a search for relevant and useful lake information that describes the target population. This may be in the form of spatial data and lake specific data. This information defines the sampling frame (Särndal et al. 1992).

A sample survey is the term used to describe sub-sampling from the target population with the intention of using the information to determine summary characteristics about the population. Whenever sub-sampling occurs, uncertainty about the estimate for lake conditions increases. This is the tradeoff between all lakes versus a subset of lakes. The approach typically used is to randomly sample a subset of waterbodies to infer conditions over the scale of the assessment (e.g., statewide or at a watershed scale). This approach, known as *sample survey monitoring design*, provides a statistically representative view of sampled conditions over a broad spatial scale. This monitoring provides fundamental information on baseline conditions and complements other types of monitoring.

Satellite imagery also has the potential to be a cost-effective means of supplementing monitoring of lakes for trophic state indicators like chlorophyll *a* and transparency (Howman et al., 1989; Stadelmann et al., 2001). Satellite monitoring of water quality has several potential advantages over traditional ground-based monitoring, especially for statewide or regional assessments. Satellite imagery provides simultaneous assessment of all lakes in a given region. Unlike ground-based information, which usually is based on samples from a single location on a lake, satellite monitoring can use nearly the entire lake surface in determining water quality. Although this may not be as important for simple lakes, it may be important for large lakes or irregularly shaped lakes with multiple basins. Data from satellite imagery comes from a single source and thus does not have the potential inconsistencies associated with ground-based data obtained over time by numerous personnel and agencies. In addition, archived satellite images may be used to analyze historical trends in water quality that otherwise would not be possible. Recent advances in computer hardware and software and decreasing costs of images combine to make water quality monitoring by satellite imagery more feasible than ever.

Assessment of lake water quality by satellite imagery requires the development of empirical relationships between satellite observations (generally spectral brightness values in the visible to near-infrared range) and near-simultaneously collected ground measurements of water quality indicators. Optically active substances such as suspended sediment, phytoplankton pigments, and dissolved organic matter all contribute to the spectral response recorded by the satellite. Relationships found between satellite data and variables related to water clarity such as Secchi transparency and suspended solids are generally strong; those for chlorophyll *a* are moderately reliable; and those for nutrients (e.g., total phosphorus concentrations) are poor (Kloiber et al., 2000). These relationships are found to apply to lakes that are limnologically similar within broad geographic regions. Satellite data are related intrinsically to variables directly associated with water clarity (e.g., Secchi transparency), but only indirectly to variables such as total phosphorus. In 1982, the Thematic Mapper Satellite© became available on LandSat® sensors generating measurements along seven spectral Bands (Table 1), finer spatial resolution (30 meters), and higher radiometric sensitivity (Figure 1).

Table 1. Spectral and Spatial Characteristics of the LandSat® Thematic Mapper Satellite© Data.

Image Band	Spectral Region	Band Wavelength (um)	Spatial Resolution
Band 1	Blue	0.45 - 0.52	30 meters
Band 2	Green	0.53 - 0.61	30 meters
Band 3	Red	0.63 - 0.69	30 meters
Band 4	Near Infrared	0.75 - 0.90	30 meters
Band 5	Shortwave Infrared	1.55 - 1.75	30 meters
Band 6	Thermal Infrared	10.40 - 12.50	60 meters
Band 7	Shortwave Infrared	2.09 - 2.35	30 meters
Band 8	Panchromatic	0.52 - 0.90	15 meters

Ecology monitored lakes in Washington State from 1989 through 1999. During that period, Ecology collected data from more than 180 lakes, with assistance from about 250 volunteers. In 2000, Ecology discontinued the lake monitoring program due to fiscal constraints. However, the state is still required to periodically report on statewide conditions of lake water quality under both federal and state law. To address these legal requirements, this report investigates the use of satellite imagery to conduct statewide assessments of lake water quality.

Data Compilation

Ground observations of three trophic state indicators for lakes were compiled from existing data sources. Measurements of lake Secchi transparency, chlorophyll *a*, and total phosphorus were compiled from monitoring programs operated by Snohomish County, King County, and the Washington State Department of Ecology. In addition, several lake projects conducted by consultants were included. These programs use volunteers to collect most of the Secchi transparency measurements, but laboratory analysis and quality assurance were provided for the chlorophyll *a* and total phosphorus measurements. Data were culled to include only those measurements collected within a 2-week period of the LandSat® overpass. These indicator measurements were used to develop relationships with satellite reflectance data.

Data from the LandSat® Thematic Mapper Satellite© were compiled from 1991 to 2000 (Appendices B & C). Scenes were selected that had no cloud cover to minimize interference with reflectance from the lake surfaces. The image data are recorded as pixel brightness levels that are related to the radiance in each of seven wavelength Bands (Table 1). Band 6 (thermal infrared), Band 7 (shortwave infrared), and Band 8 (panchromatic) were not used in the analysis because they were not expected to be related to the reflectance characteristics of the trophic state indicators (Lathrop, 1992). The images were geometrically corrected to ensure proper alignment and scale with registration to the Washington Hydrography Framework GIS coverage (Appendix A).

The Hydrography Framework GIS coverage (Appendix A) served as the sampling frame to provide a census of all natural lakes in Washington State. The target population was defined as natural lakes (e.g., impoundments were not included). Only waterbodies identified in the GIS coverage as a lake (cartographic feature code = 421) were used in the analysis. Geographic coordinates of the lake were defined by the center point identified in the GIS coverage. Other cartographic features of lake size and perimeter length were also compiled from the GIS coverage. The ecoregion (Figure 2) that each lake resides was determined by intersection of the Hydrography Framework GIS coverage with the Ecoregion GIS coverage (Appendix D).

To match the resolution of the images of spectral Bands 1 through 5, a 100-ft circular area surrounding the identified lake center was sampled for image pixel intensity. The median brightness for each spectral Band within the 100-ft radius of each lake center was sampled. For lakes that appeared on overlapping scenes, the brightest pixel intensity was selected as the preferred reflectance characteristic. Image raster data was converted to vector data for use in subsequent analysis with ArcGIS software.

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Analysis Approach

The analysis conducted in this report uses various statistical tests to evaluate the relationships between lake trophic state indicators, morphometric measures, and LandSat® image spectral characteristics. Since statistical tests can sometimes provide misleading information, several statistical tests will be investigated to derive decisions with a weight-of-evidence approach. The following is a list of the statistical tests used and their purpose, in order of their application.

1. *Generation of Descriptive Statistics* - The existing raw data of several variables were reduced to provide various distribution statistics. These statistics were derived to look at ecoregional differences.

2. *Testing for Normality* - The seasonal descriptive statistics were tested for use in parametric tests. Both logarithmic transformed and non-transformed data were tested. The Kolmogrov-Smirnov Goodness of Fit Test was applied. The values of both kurtosis and skewness were assessed to show normality and support the use of parametric statistical tests on the logarithmic transformed in the subsequent analyses of multivariable characterization of each lake.

3. *Box plots* - Box plots are used to visually inspect the characteristics of the statistical distributions of the variables.

4. *Analysis of Variance* - A factorial design one-way analysis of variance was applied to evaluate differences between ecoregions and lake morphometry. These tests were used to guide the stratification of variables into groups for the subsequent analyses.

5. *Cluster Analysis* - Standardized variables were clustered into groups using the hierarchical Ward method applied to evaluate differences between ecoregions. These tests were used to guide the stratification of variables into groups for the subsequent analyses.

6. *Multicollinearity Tests* - The independent variables were assessed for inter-correlation to avoid ill-conditioning during the subsequent multiple regression analysis. Variables found to have significant multicollinearity were culled from use in the subsequent analyses. Variable without significant multicollinearity were used for subsequent analyses.

7. *Single Regression Analysis* - The 3 trophic state indicators (Secchi transparency, chlorophyll *a*, and total phosphorus) used separately as the dependent variable were regressed against each independent variable (area, shoreline development index, image Bands 1-5). The single regression results were used to identify variables that had no significant relationship with trophic state indicator levels from use in the subsequent analyses.

8. *Discriminant Analysis* - A stepwise discriminant analysis was used to identify “prediction”

variables that were based on lake associations from cluster analysis.

9. *Ordination Analysis* - A principal components analysis was conducted to help explore which independent variables show important empirical relationships to trophic state indicators in multidimensional space.

10. *Multiple Regression Analysis* - A stepwise multiple linear regression was conducted with the variables selected as a result of the analyses conducted. The approach culled other variables resulting in a final "predictive" multivariate model for each trophic state indicator.

11. *Model Performance* - Accuracy and bias of the Secchi transparency empirical model was evaluated with several different statistics: root mean square error, median absolute deviation, scaled residuals, the relative error, and the paired comparison test.

12. *Census Distribution Changes* - Histograms, box plots, and ogives were visually inspected from the predicted dependant variables for all lakes statewide.

13. *Census Spatial Distribution* - Statewide maps and analyses of variance were prepared to evaluate effects caused by ecoregional influence.

14. *Census Trophic State Changes* – Frequency distributions of lake trophic state were assessed for influence by ecoregions and lake morphometric measures.

Descriptive Statistics

Data obtained from environmental measurements for 3 trophic state indicators were combined with pixel intensity for Bands 1 – 5 from LandSat® images collected within 2 weeks of the indicators. In addition, census morphometric data on lake area and the shoreline development index (SDI) were generated from characteristics in the Hydrography Framework GIS layer. The SDI relates shoreline length to the circumference of a circle that has the same area as the lake. The SDI of a perfectly round lake would be 1.0, with more convoluted lakes showing index values higher than 1.0 (Cole, 1975). Table 2 presents general statistics on the distribution of trophic state indicator, image, and lake morphometric data.

Table 2. Descriptive Statistics of Trophic State, Image, and Morphometric Lake Data.

Variable	**Sample Size**	**Median**	**Mean**	**Coefficient of Variation**
Secchi Transparency (m)	167	3.5	3.6	47%
Chlorophyll *a* (ug/L)	64	4.4	6.3	98%
Total Phosphorus (ug/L)	93	13.9	17.1	96%
Lake Area (acres)	4577	8.0	42.5	934%
Shoreline Development Index	4577	1.2	1.4	30%
Image Band 1	168	62.0	64.7	34%
Image Band 2	168	37.0	35.3	70%
Image Band 3	168	26.0	25.0	92%
Image Band 4	168	13.0	17.2	106%
Image Band 5	168	11.0	14.1	120%

Since the reduced data were to be used in parametric statistics, the assumption that the distributions were normal was tested for each variable. The data were transformed using a natural logarithmic function and then tested for approximation to normality. Mathematical transformations alter the fundamental nature of the data and may alter the interpretation of the results (Osborne, 2002). The Kolmogrov-Smirnov Goodness of Fit Test was used to assess the distributions of both the un-transformed and transformed data (Zar, 1984). The Kolmogrov-Smirnov Goodness of Fit Test uses the shape, location, and scale of the sample distribution. The test determined that several variables approximated normality (Table 3). The natural logarithmic transformation showed the highest similarity to a normal distribution. The Kolmogrov-Smirnov Goodness of Fit Test has limitations when testing for normality when in the presence of large sample sizes.

Table 3. Descriptive Statistics of Trophic State, Image, and Morphometric Lake Data.

Variable	Untransformed		Log-transformed	
	Maximum Difference	**Probability**	**Maximum Difference**	**Probability**
Secchi Transparency (m)	0.061	0.564	0.080	0.239
Chlorophyll *a* (ug/L)	0.191	0.019	0.069	0.921
Total Phosphorus (ug/L)	0.218	**<0.001**	0.68	0.780
Lake Area (acres)	1.000	0.999	0.063	**<0.001**
Shoreline Development Index	0.173	**<0.001**	0.132	**<0.001**
Image Band 1	0.321	**<0.001**	0.226	**<0.001**
Image Band 2	0.262	**<0.001**	0.228	**<0.001**
Image Band 3	0.303	**<0.001**	0.186	**<0.001**
Image Band 4	0.324	**<0.001**	0.174	**<0.001**
Image Band 5	0.301	**<0.001**	0.176	**<0.001**

-bold items are statistically significant

In addition to using the Kolmogrov-Smirnov Goodness of Fit Test for assessing distributions, the values of kurtosis (level of peakedness) and skewness (level of symmetry) were examined to assess whether data transformation provides a more normal distribution (Table 4). Normal distributions have kurtosis and skewness values of zero. A positive value for skewness indicates a long right tail; a negative value, a long left tail. A positive value for kurtosis indicates that the tails of the distribution are longer than those of a normal distribution; a negative value, shorter tails (i.e., box shaped).

Table 4. Effect of Data Transformation on Kurtosis and Skewness.

Variable	Untransformed		Log-transformed	
	Kurtosis	**Skewness**	**Kurtosis**	**Skewness**
Secchi Transparency (m)	0.25	0.61	0.36	-0.72
Chlorophyll *a* (ug/L)	9.74	2.76	0.32	-0.13
Total Phosphorus (ug/L)	50.2	6.24	2.18	0.40
Lake Area (acres)	1949	39.0	1.14	2.34
Shoreline Development Index	15.7	3.0	2.9	1.55
Image Band 1	46.3	6.2	19.4	3.6
Image Band 2	41.9	5.4	1.3	0.4
Image Band 3	51.3	6.3	2.6	0.7
Image Band 4	21.6	4.3	3.3	1.5
Image Band 5	16.7	3.8	0.8	0.2

Figures 3 through 12 provide a visual comparison for the effect of logarithmic transformation. In most cases, log-transformation improved approximation of normality. All data were log-transformed and used in subsequent parametric analyses.

Stratification of Data for Analysis

Before the development of a "predictive" model, data should be examined for spatial patterns that may improve model performance. For example, improved predictions could be realized by applying different regression models for the different ecoregions of the state. Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources. Regional or other spatial patterns may reflect natural variability of lake trophic state and the resulting color distribution of the satellite imagery. One way to evaluate whether these patterns may exist is by visually comparing distribution statistics with a series of box plots.

Box plots provide a convenient way to visually inspect the characteristics of entire statistical distributions. A series of box plots can be presented for the distribution of one variable as a function of other variables (e.g., ecoregions). This display enables simultaneous presentation of central tendency (medians), sample variability (interquartile range), and the detection of outliers (unusually small or large values for individual cases in a sample). The asterisks indicate that there are one or more data points lying outside the view for the individual data points.

Box plots for each of the variables are presented in Figures 13-22. Distinct differences between ecoregions are observed in the distributions of Secchi transparency data. There was not enough data to evaluate ecoregional differences using chlorophyll *a* and total phosphorus data. No spatial patterns were observed in lake size and shoreline development index distributions. Much of the imaging data showed the same distribution patterns among ecoregions. However, the image data from the Cascade Ecoregion showed distinct differences for all spectral Bands.

A factorial design one-way analysis of variance (ANOVA) is considered a more robust approach to assess the influence of spatial patterns on lake condition. The transformed variables were used in the ANOVA model. The effects of two factors were tested: (1) ecoregions (Omernik and Gallant, 1986), and (2) lake morphological effects (data were stratified based on the lake size and shoreline development index (SDI)). Lake size and SDI were ranked into 3 categories based on quartiles.

Results showed that spectral Band 1 LandSat® imagery distinguished between at least two ecoregions (Table 5). The only significant effect inferred is on spectral Band 1 between ecoregions. To help distinguish which ecoregions are different from the others in spectral Band 1, results from an ANOVA using the Tukey Method for pairwise means comparisons was examined. The Tukey Method is more sensitive in detecting subtle differences than is the Bonferroni method when dealing with larger sample sizes. Results show significant differences are observed in spectral Band 1 between the Northern Rockies ecoregion and both the Cascades ($p = 0.023$) and Columbia Basin ($p=0.041$) ecoregions.

Table 5. Analysis of Variance for Regional, Morphological, or Temporal Effects.

Variable	Effect Probability		
	Ecoregion	Lake Size	SDI
Secchi Transparency	0.135	0.042	0.594
Chlorophyll *a*	0.748	0.116	0.121
Total Phosphorus	0.575	0.553	0.507
Band 1	**0.040**	0.824	0.546
Band 2	0.880	0.256	0.487
Band 3	0.683	0.372	0.473
Band 4	0.379	0.162	0.207
Band 5	0.934	0.115	0.185

bold values indicate significance at $a = 0.05$

Identifying the influence of distinct strata (i.e., ecoregions) could further be accomplished with cluster analysis. A cluster analysis used the median values of the trophic state indicators, the image spectral characteristics, and morphometric characteristics for lakes from each ecoregion. Cluster analysis is used to create groupings of observations on the basis of their similarity from multiple characteristics. Results from the cluster analysis are only used to identify natural groupings (Gaugush, 1986). In this study, the cluster analysis was used to investigate inter-relationships of spatial regions in order to continue with regression model development.

First, the variables must be standardized to remove the influence of the units of measurement from the results of the analysis. These standardized variables are unitless, so any linear change in the units will not affect the results. Since some of the variables likely covary (e.g. spectral Bands 2 and 3), the transformed, standardized variables were clustered using the hierarchical Ward method which resembles the centroid linkage approach but adjusts for covariance. The Euclidean distance measure was used for clustering since the data are continuous. Other clustering approaches were also investigated, but not selected based on the poor separation.

The results show no distinct patterns in the clusters (Figures 23-27). The clustering of the spectral characteristics shows the Columbia Basin closest to the Puget Lowlands and furthest from the Willamette ecoregion. The trophic state indicators and the lake morphometric characteristics all showed different clustering. Based on this analysis, ecoregions do not seem to explain any separate variability in the variable data.

Variable Selection for Regression Analysis

With some understanding of influential spatial factors and relationships with lake characteristics to develop a predictive model can be developed using regression analysis. The first step is to build a multiple linear regression model using all of the transformed variables. The results will test the robustness of the least-squares sets to sources of ill-conditioning. When there are high correlations among independent variables, the estimates of the regression coefficients can become unstable.

Multicollinearity of independent variables is a common problem that diminishes the strength of a multiple linear regression model. A "tolerance" rating reflects the level of multicollinearity in a multiple linear regression model. Very small tolerance values indicate weak regression models. Tolerance is 1 minus the multiple correlation between a predictor and the remaining predictors in the model. The Eigenvalue Condition Indices describe the redundancy of the data set. The Eigenvalue Condition Indices are derived using the square roots of the ratios of the largest eigenvalue to each successive eigenvalue. Multicollinearity is suggested when tolerance values are very small and when eigenvalue condition indices exceed 30.

Results of a multiple linear regression model using all the variables show a notable problem with multicollinearity. Tolerance values for Band 2 and Band 3 are very low (Table 6). The condition indices for half of the eigenvalues are over 30. These results suggest that some of the variables should be removed because they are inflating the standard errors and F statistics through inter-correlation.

Simple linear regressions were examined for the relationships between independent variables. The adjusted coefficient of determination (R^2) and the associated probability from an F ratio in the analysis of variance table were compiled for each of these regressions (Table 7). Relationships showing a significantly high confidence (at 95% and 99%) were identified for possible further use in other regression models. An analysis of the residuals was not conducted since this effort was only used to select independent variables for inclusion in a multiple regression model. Further examination of these correlations using scatter plot matrices and the 75% Gaussian bivariate distribution ellipse (Figures 28-30) revealed useful information.

Independent variables Band 2 and Band 3 showed strong colinearity. As a result, one of the variables was excluded from inclusion in a "predictive" empirical model. The independent variable Band 3 was retained based on a stronger relationship with Secchi transparency found by Kloiber et al. (2000). Tolerance values for Band 3 were raised to the same range as the other independent variables for each dependant variable (Table 8). In addition, the second and third Eigenvalue Condition Indices reduced (Table 9). These results suggest that removing Band 2 data from subsequent regression analysis will prevent inflating the standard errors and F statistics through multicollinearity.

Table 6. Multiple Linear Regression Results Using All Variables.

Dependent Variable	Independent Variable	Tolerance	Probability
Secchi Transparency	Constant	-	0.024
	Band 1	0.199	0.085
	Band 2	0.030	0.046
	Band 3	0.021	0.047
	Band 4	0.148	0.065
	Band 5	0.116	0.515
	Area	0.479	0.002
	SDI	0.593	0.032
Chlorophyll *a*	Constant	-	0.519
	Band 1	0.142	0.810
	Band 2	0.026	0.566
	Band 3	0.025	0.224
	Band 4	0.251	0.679
	Band 5	0.164	0.601
	Area	0.708	0.023
	SDI	0.791	0.045
Total Phosphorus	Constant	-	0.836
	Band 1	0.223	0.288
	Band 2	0.031	0.543
	Band 3	0.026	0.714
	Band 4	0.232	0.307
	Band 5	0.156	0.319
	Area	0.778	0.009
	SDI	0.784	0.465

All correlations based on natural log transformed data

Table 7. Pearson Correlation Matrix Using All Independent Variables.

	Area	**SDI**	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**
Area	1.000	0.311	0.066	0.082	0.082	0.117	0.173
SDI	0.311	1.000	0.051	0.080	0.040	0.136	0.059
Band 1	0.066	0.051	1.000	0.902	0.903	0.612	0.747
Band 2	0.082	0.080	0.902	1.000	**0.985**	0.597	0.754
Band 3	0.082	0.040	0.903	**0.985**	1.000	0.638	0.777
Band 4	0.117	0.136	0.612	0.597	0.638	1.000	0.855
Band 5	0.173	0.059	0.747	0.754	0.777	0.855	1.000

All correlations based on natural log transformed data

Table 8. Multiple Linear Regression Results Excluding the Band 2 Variable.

Dependent Variable	Independent Variable	Tolerance	Probability
Secchi Transparency	Constant	-	0.111
	Band 1	0.204	0.154
	Band 3	0.128	0.697
	Band 4	0.158	0.016
	Band 5	0.116	0.418
	Area	0.479	0.002
	SDI	0.593	0.040
Chlorophyll *a*	Constant	-	0.480
	Band 1	0.148	0.720
	Band 3	0.151	0.090
	Band 4	0.262	0.758
	Band 5	0.165	0.570
	Area	0.709	0.023
	SDI	0.811	0.033
Total Phosphorus	Constant	-	0.939
	Band 1	0.223	0.269
	Band 3	0.172	0.611
	Band 4	0.242	0.241
	Band 5	0.158	0.283
	Area	0.779	0.008
	SDI	0.801	0.407

All correlations based on natural log transformed data

Table 9. Change in Eigenvalue Condition Indices by Excluding the Band 2 Variable.

Dependent Variable	Eigenvalue Number	Eigenvalue Condition Index	
		All Variables	Excluding Band 2
Secchi Transparency	1	1.0	1.0
	2	4.9	4.6
	3	8.9	8.3
	4	27.5	28.6
	5	35.7	36.5
	6	49.1	45.9
	7	123.2	136.2
Chlorophyll *a*	1	1.0	1.0
	2	6.5	6.1
	3	9.6	9.0
	4	25.8	26.5
	5	37.0	38.0
	6	54.8	51.2
	7	191.2	356.8
Total Phosphorus	1	1.0	1.0
	2	6.2	5.9
	3	11.0	10.3
	4	29.6	30.1
	5	42.3	43.4
	6	58.5	54.7
	7	189.8	260.1

Standardization of variables for use in multivariate analysis results in a stronger model. Numerical data that differs by an order of magnitude results in unequal weighting of variables in the model. The clustered, transformed, standardized independent variables were subjected to stepwise discriminant analysis to test for multivariate differences between the trophic state dependent variables. The Trophic State Index (TSI) was used to categorize lakes into 3 trophic states: oligotrophic, mesotrophic, and eutrophic (Carlson, 1977). The TSI values can be calculated from either Secchi disk, chlorophyll *a*, and total phosphorus data. Ranges of TSI values are often grouped into trophic state classifications. The range between 40 and 50 is usually associated with mesotrophy (moderate productivity). TSI values greater than 50 are associated with eutrophy (high productivity). TSI values less than 40 are associated with oligotrophy (low productivity). Discriminant analysis was used to find which independent variables are most useful for identifying membership to trophic state categories.

The effect of specific independent variables on cluster separation can be shown by plotting the canonical variable scores with the confidence ellipse based on the centroid of each group (Figures 31-33). A plot of the canonical variables against each other show the separation between the trophic state clusters caused by the independent variables. Canonical variables are formed in the discriminate analysis as a linear combination on variables that best discriminate among the groups. Additional canonical variates are orthogonal to each other and represent separate, combinations of the variables that distinguish cluster groups that are uncorrelated to each of the other canonical variates.

A forward stepwise discriminate analysis was conducted to examine which independent variables most influence trophic state cluster differences. Trophic state derived from Secchi transparency measurements were most influenced by spectral Band 4, area, and SDI. Trophic state derived from chlorophyll *a* measurements were most influenced by spectral Band 3. Trophic state derived from total phosphorus measurements were most influenced by lake surface area. The eigenvalues show that the canonical expressions derived from these specific variables account for most of the dispersion between trophic state clusters.

The independent variables were also analyzed using ordination techniques. These techniques can help define which factors are important in empirical relationships. In ordination, the stations are arranged in relation to one or more coordinate axes such that their relative position provides maximum information about their similarities. Conceptually, ordination can be visualized as placing stations within a variable hyper-space, where there is a single dimension for each variable. The aim of ordination is to simplify and condense large data sets in the hope that relationships will emerge.

The most commonly used ordination technique is principal components analysis (PCA). PCA is multivariate analytical method that partitions a variable matrix into a set of orthogonal axes or components. Each PCA axis has a corresponding eigenvalue and several eigenvectors that describe each axis. The eigenvalue is the variance accounted for by that axis. Even though PCA can be used to formally test hypotheses of relationships, the method is typically used to identify relationships among more than two variables.

Applying PCA to the independent variables indicate that there are four distinct factors in the multidimensional variable space. The first two principal components explain 61% and 24% of the variance, respectively. The spectral image data appear in the same ordination space while the morphometric data appear in a different portion of the ordination space (Figure 34). Examination of the component loadings shows the nearly same influence of all variables ordination space. One method of further elucidating interpretable factors is through axis rotation to reduce the influence of the large component loadings. Using the most commonly used varimax rotation did not change the effect of spacing the factors appreciably (Figure 35). Therefore, it appears that both factors including all independent variables tested best explain the variable hyper-space.

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Development of Empirical Models

Data for six of the independent variables were used in a stepwise multiple linear regression analysis to predict three trophic state indicators. All variables were transformed using natural logarithmic function in order to satisfy the normality requirement of the statistical analysis. A stepwise multiple linear regression analysis sequentially removes the variables that do not significantly contribute to model performance.

Results for the first stepwise multiple linear regression analysis included information on specific cases (i.e., lakes) that have a strong influence on the estimate of regression coefficients. Leverage is a measure of the influence of an observation on the model fit. Leverage is derived from the number of estimated parameters and the number of cases. Leverage helps identify outliers in the independent variable space. Cases with leverage values over 0.2 were considered outliers and were removed from the subsequent stepwise multiple linear regression analysis.

For Secchi transparency, data from the shoreline development index and spectral Bands 1 and 3 were removed from the model because they did not significantly contribute to the model performance. The final model resulted in a linear combination of lake size and spectral Bands 4 and 5. The final model derived from the data is highly significant ($p< 0.001$) and explains about 14% of the variation in the data: The standard error of the estimate is 1.6 meters. The residuals plot indicates acceptable homoscedasity, which is the equal distribution of residuals about a mean of zero (Figure 36).

$$\ln(\text{Secchi(m)}) = 0.087\ln(\text{Acres}) - 0.463\ln(\text{Band 4}) + 0.165\ln(\text{Band5}) + 1.628$$

For chlorophyll *a*, the final model used a linear combination of variables including lake size, shoreline development index and spectral Band 3. The final model is highly significant ($p = 0.007$) and explains about 14% of the variation in the data: The standard error of the estimate is 2.2 ug/L. The residuals plot indicates acceptable homoscedasity (Figure 37).

$$\ln(\text{Chl. } a\text{(ug/L)}) = 1.273\ln(\text{SDI}) - 0.258\ln(\text{Acres}) + 0.497\ln(\text{Band 3}) + 0.397$$

For total phosphorus, the final model used a linear combination of variables including lake size and spectral Band 1. The final model is significant ($p = 0.050$) and explains about 5% of the variation in the data: The standard error of the estimate is 1.7 ug/L. The residuals plot indicates acceptable homoscedasity (Figure 38).

$$\ln(\text{TP (ug/L)}) = 0.131\ln(\text{Band 1}) - 0.139\ln(\text{Acres}) + 2.566$$

The regression equations to predict trophic state indicators are based on instantaneous measurements collected within 2 weeks of when the satellite images were taken. This approach makes sense for Secchi transparency and chlorophyll *a* that have direct reflective properties. However, total phosphorus concentration is related to these indicators and may not have a direct spectral signature. Most research has found that the summer mean total phosphorus concentrations is a better predictor of Secchi transparency and chlorophyll *a* in lakes (Welch, 1980). Therefore, the summer mean total phosphorus concentration were used instead of the instantaneous measurement.

Summer mean total phosphorus was derived from the lake epilimnetic data collected from June through September as defined by Washington State's Water Quality Standards (Chapter 173-201A-230(2)(a) WAC). Stepwise multiple linear regression analysis was conducted with the six independent variables to predict summer mean total phosphorus. The final model used a linear combination of variables including lake size and spectral Bands 1 and 4. The final model is significant ($p = 0.002$) and explains about 12% of the variation in the data: The standard error of the estimate is 1.6 ug/L. The residuals plot indicates acceptable homoscedasity (Figure 39). Therefore, using the summer mean total phosphorus concentration slightly improved model performance over the instantaneous measurement and was used as the final predictive model.

$$\ln(\text{TP (ug/L)}) = 0.333\ln(\text{Band 4}) - 2.395\ln(\text{Band 1}) - 0.086\ln(\text{Acres}) + 11.866$$

Predictive models should be verified to assess model performance using an independent data set not used in the model development. Secchi transparency data collected by citizen volunteers for the Great American Secchi Dip-In was used to verify the first empirical model developed. The Dip-In is an international effort in which volunteers collect Secchi transparency of lakes throughout the United States and Canada. The Dip-In is sponsored by the North American Lake Management Society and the United States Environmental Protection Agency, and directed by Kent State University. Only five independent Secchi transparency measurements were available from the Dip-In database for use in model verification. No independent data for total phosphorus or chlorophyll *a* was available to test the empirical models developed for these trophic state indicators.

Accuracy of the Secchi transparency empirical model was evaluated with several different statistics: root mean square error, median absolute deviation, scaled residuals, the relative error (Reckhow et al. 1986), and the paired comparison test (Zar, 1984). The root mean square error presents an estimate of the variation in the same units as the measurement (i.e., meters). The relative error presents this variation as a percentage of the measurement mean. The median absolute deviation describes the central tendency of model performance. The median scaled residual provides a relative estimate whether the model is over or under predicting measured conditions. Bias can be inferred by the precision statistics of median scaled residual. The paired comparison test assessed for significant differences between model predictions and actual measurements.

Verification statistics showed poor model performance for predictions of Secchi transparency (Table 10) and the calculated Trophic State Index (Table 11). The root mean square error and the relative error were large. The paired comparison test showed a significant difference between predicted and measured Secchi transparencies. The median scaled residual showed a positive bias predicting greater Secchi transparency than measured. The poor model performance is likely due to the small sample size of the independent data set.

Table 10. Verification Statistics of the Empirical Model for Secchi Transparency.

Statistic	Value
Root Mean Square Error	2.9 meters
Relative Error	138%
Median Scaled Residual	52%
Median Absolute Deviation	1.1 meters
Probability of Paired Comparison	0.020

Table 11. Verification Statistics of the Empirical Model for Trophic State Index.

Statistic	Value
Root Mean Square Error	20 TSI units
Relative Error	38%
Median Scaled Residual	12%
Median Absolute Deviation	6 TSI units
Probability of Paired Comparison	0.057

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Application of Empirical Models

The empirical models developed above were used with the satellite imagery and lake morphometric information to predict the three trophic state indicators for lakes statewide in the years 1991 to 2000. In addition, the mean TSI was derived from each of the indicators statewide. Visual comparison of the distribution between 1991 and 2000 with histograms and box plots show slight differences for two of the indicators (Figures 40-43). Both chlorophyll *a* and the TSI show an increase in statewide lake productivity between 1991 and 2000. No change is observed for Secchi transparency and total phosphorus. Applying a paired comparison test to the statewide predictions showed a high statistically significant difference ($p < 0.001$) between 1991 and 2000 for all 3 indicators and the TSI. This result is likely due to the large sample size of the census (n=4576) increasing the degrees for freedom for the statistical test.

Cumulative distribution frequency plots are another useful approach in comparing changes in statewide lake trophic condition between 1991 and 2000 (Figures 44-47). Also known as ogives, the plots are developed from a table of frequency distributions. An ogive provides a visual analysis for the extent and magnitude of change in statewide lake condition over time. Note that the cumulative frequency for the last observation in the sample is equal to the sample size (n=4576) and that the cumulative relative frequency for the last observation is equal to 100%.

Comparing the lake Secchi transparency ogives show little difference for most values except for lake with transparency values around 3 meters (Figure 44). Lakes with this level of clarity increased about 10% between 1991 and 2000. The ogive for chlorophyll *a* shows increased productivity between 1991 and 2000 for all lakes below a value of 15 ug/L (Figure 45). For low productivity lakes this difference is as much as 20%. The total phosphorus ogive shows that mesotrophic and eutrophic lakes both increased in total phosphorus concentration between 1991 and 2000 by as much as 10% (Figure 46). The overall trophic state increased slightly for only the mesotrophic lakes between 1991 and 2000 (Figure 47).

The observations above that show that only some types of lakes have increased productivity between 1991 and 2000, that may be related to particular characteristics and human activities in each ecoregion. Observation of the statewide spatial distribution of lake trophic states and trophic state indicators visually suggest some similarities among adjacent lakes (Figures 48-51), however, these are weak inferences. An analysis of variance (ANOVA) was conducted to test for a significant difference between ecoregions for each of the natural log-transformed dependant variables. The tests showed that there is a significant difference ($p < 0.001$) between 1991 and 2000 for all 3 indicators and the TSI. Again, this result is likely due to the large sample size of the census (n=4576).

Visual comparison with box plots of the distribution of the dependant variables show only slight differences between ecoregions for each trophic state indicator in 2000 (Figures 52-54). The inter-quartile ranges overlap for each trophic state indicator between ecoregions. However, visual comparison of the TSI boxplots show a big difference between the Willamette Ecoregion (Number 3) and the Cascades Ecoregion (Number 4). As expected, this observation shows that lakes in the Cascade Mountains are much less productive than lakes in the Willamette Valley (Figure 55).

Examination of the frequency of lakes in each of the trophic states is another approach that may indicate the influence of ecoregional characteristics and increase in productivity seen between 1991 and 2000 (Table 12). This partitioning shows that a small percentage of mesotrophic lakes have become eutrophic between 1991 and 2000. The largest change over this period occurs in the Coast Range and Cascades ecoregions. In these areas, a larger percentage of oligotrophic lakes have become mesotrophic. In addition, many lakes in the Columbia Basin appear to have experienced reduced productivity by shifting from formally eutrophic to mesotrophic conditions.

Table 12. Change in Lake Trophic State between 1991 and 2000 by Ecoregion as a Discrete Target Population Census

#	Ecoregion	Number of Lakes	Oligotrophic		Mesotrophic		Eutrophic	
			1991	2000	1991	2000	1991	2000
1	Coast Range	95	26%	5%	57%	80%	17%	15%
2	Puget Lowlands	991	6%	3%	69%	71%	25%	26%
3	Willamette Valley	159	1%	1%	38%	40%	61%	59%
4	Cascades	1380	13%	7%	75%	79%	12%	14%
6	East Cascades and Foothills	34	0%	0%	23%	24%	77%	76%
7	Columbia Basin	1606	1%	2%	10%	20%	89%	78%
8	Northern Rockies	308	5%	5%	71%	75%	24%	20%
9	Blue Mountains	3	0%	0%	100%	100%	0%	0%
-	All Ecoregions Statewide	4576	6%	6%	77%	75%	17%	21%

Lake morphology may be an important partitioning variable that explains the observed increase in productivity between 1991 and 2000 (Table 13). Lakes were divided into 3 categories for size and morphometry using inter-quartiles as cutpoints. Data for lakes were derived from the hydrography framework. The largest change over the period occurs in small mesotrophic lakes where productivity shifted toward to eutrophying conditions. In addition, many large oligotrophic lakes experienced productivity shifts toward mesotrophy. Largely convoluted lakes (i.e., high shoreline development index) showed an increase in eutrophy over this same time period.

Table 13. Change in Lake Trophic State Index between 1991 and 2000 by Morphometry as a Discrete Target Population Census.

Morphometric Measure	Number of Lakes	Oligotrophic		Mesotrophic		Eutrophic	
		1991	2000	1991	2000	1991	2000
Small Size	1144	2%	1%	66%	60%	32%	39%
Medium Size	2288	4%	2%	81%	80%	15%	18%
Large Size	1144	17%	11%	80%	84%	3%	5%
Small SDI (nearly round)	1144	8%	4%	85%	83%	11%	14%
Medium SDI	2288	6%	4%	76%	76%	18%	20%
Large SDI (convoluted)	1144	6%	4%	73%	69%	21%	27%
All Lakes Statewide	4576	6%	4%	77%	75%	17%	21%

Water quality in Washington is often managed within Water Resource Inventory Areas (WRIA). These basin or watershed areas are defined by State Rule (Chapter 173-500 Washington Administrative Code). Comparing the mean TSI of all lakes within a WRIA shows that between 1991 and 2000 most areas increased in trophic state (Table 14). The largest change in lake trophic states occurred along the Strait of Juan de Fuca in northeastern Washington State (Figure 56).

Table 14. Change in Lake Trophic State between 1991 and 2000 by Water Resource Inventory Area as a Discrete Target Population Census.

WRIA#	WRIA Name	Number of Lakes	TSI in 1991	TSI in 2000	Percent Change
1	Nooksack	91	44.9	46.5	3.6%
2	San Juan	51	45.1	47.6	5.5%
3	Lower Skagit-Samish	63	45.1	47.1	4.4%
4	Upper Skagit	206	42.9	45.0	4.9%
5	Stillaguamish	59	46.8	46.0	-1.7%
6	Island	39	45.6	45.8	0.4%
7	Snohomish	530	46.2	46.4	0.4%
8	Cedar-Sammamish	84	46.1	46.6	1.1%
9	Duwamish-Green	55	45.4	45.5	0.2%
10	Puyallup-White	95	45.3	46.2	2.0%
11	Nisqually	77	46.2	47.0	1.7%
12	Chambers-Clover	22	45.5	46.7	2.6%
13	Deschutes	41	45.4	45.7	0.7%
14	Kennedy-Goldsborough	36	43.7	44.7	2.3%
15	Kitsap	116	46.4	46.5	0.2%
16	Skokomish-Dosewallips	43	44.8	45.5	1.6%
17	Quilcene-Snow	39	45.6	46.0	0.9%
18	Elwah-Dungeness	16	40.6	45.0	10.8%

19	Lyre-Hoko	2	30.8	44.6	44.8%
20	Soleduck-Hoh	37	36.3	42.8	17.9%
21	Queets-Quinault	24	44.9	45.1	0.4%
22	Lower Chehalis	36	43.8	47.2	7.8%
23	Upper Chehalis	20	45.9	46.6	1.5%
24	Willapa	22	46.8	46.9	0.2%
25	Grays-Elokoman	3	47.5	47.9	0.8%
26	Cowlitz	86	44.9	46.0	2.4%
27	Lewis	71	48.1	48.6	1.0%
28	Salmon-Washougal	132	50.6	50.1	-1.0%
29	Wind-White Salmon	41	46.5	46.6	0.2%
30	Klickitat	26	46	46.3	0.7%
31	Rock-Glade	22	45.7	47.3	3.5%
32	Walla Walla	26	46.4	47.4	2.2%
33	Lower Snake	7	47.8	48.5	1.5%
34	Palouse	154	46	46.2	0.4%
35	Middle Snake	12	47.7	47.9	0.4%
36	Esquatzel Coulee	90	45.8	46.4	1.3%
37	Lower Yakima	43	46.8	47.9	2.4%
38	Naches	70	46.5	47.0	1.1%
39	Upper Yakima	118	45.8	45.9	0.2%
40	Alkali-Squilchuck	19	46.3	46.8	1.1%
41	Lower Crab	281	45.9	48.0	4.6%
42	Grand Coulee	72	45.6	46.3	1.5%
43	Upper Crab-Wilson	171	45.7	48.8	6.8%
44	Moses Coulee	46	45.3	47.1	4.0%
45	Wenatchee	132	43.7	44.7	2.3%
46	Entiat	10	43.5	45.0	3.4%
47	Chelan	49	42.9	44.9	4.7%
48	Methow	157	44.9	47.8	6.5%
49	Okanogan	365	46.3	45.0	-2.8%
50	Foster	171	47.2	47.4	0.4%
51	Nespelem	9	48.3	45.8	-5.2%
52	Sanpoli	29	46.0	46.5	1.1%
53	Lower Lake Roosevelt	24	46.6	48.5	4.1%
54	Lower Spokane	25	47.7	48.0	0.6%
55	Little Spokane	32	46.4	45.7	-1.5%
56	Hangman	14	46.7	47.8	2.4%
57	Middle Spokane	13	44.7	45.7	2.2%
58	Middle Lake Roosevelt	21	45.1	44.8	-0.7%
59	Colville	79	47.0	46.5	-1.1%
60	Kettle	40	46.9	48.1	2.6%
61	Upper Lake Roosevelt	23	47.0	47.6	1.3%
62	Pend Oreille	89	46.7	47.1	0.9%
All	Statewide	4576	45.8	46.6	1.7%

The primary purpose for the development of this analytical approach for lake assessment was to investigate and report statewide condition of lakes as required by the state under Sections 305(b) and 314(a) of the federal Clean Water Act. Guidance from the U.S. Environmental Protection Agency directs how these reporting requirements can be met (Wayland, 2001). Lake assessments and reporting of conditions are required to be reported based on total area affected not based on total numbers of lakes. The discrete target population census information used in this study does not meet the intent of federal reporting requirements. Areas of each lake within a trophic status were summed to produce census of lakes as a continuous target population. A similar examination of the frequency distribution of trophic states based on the total size of lakes over the period was conducted to observe any influence from ecoregions or lake morphometry (Tables 15 and 16). The use of these numbers should be qualified with a discussion of the poor model performance.

Examination of the frequency occurrence in each lake area category shows oligotrophic lake areas have declined, whereas mesotrophic and eutrophic lake areas have increased over the 9-year period. The largest change is observed in the Columbia Basin ecoregion (Table 15) and in large sized lakes (Table 16).

Table 15. Change in Lake Trophic State between 1991 and 2000 by Ecoregion as a Continuous Target Population Census in Acres.

Ecoregion	**Total Acres**	**Oligotrophic**		**Mesotrophic**		**Eutrophic**	
		1991	**2000**	**1991**	**2000**	**1991**	**2000**
Coast Range	19,109	17,943	17,045	959	1,878	207	186
Puget Lowlands	65,985	47,261	43,758	17,028	20,394	1,694	1,832
Willamette Valley	5,361	2,732	2,769	2,043	2,017	549	575
Cascades	29,732	14,042	11,200	14,499	17,489	1,191	1,043
East Cascades and Foothills	827	0	0	751	758	76	69
Columbia Basin	57,685	23,983	16,442	32,343	38,420	1,359	2,824
Northern Rockies	15,661	8,552	8,651	6,404	6,521	705	489
Blue Mountains	11	0	0	11	11	0	0
All Ecoregions Statewide	194,368	114,550	99,865	74,038	87,486	5,780	7,017

Table 16. Change in of Lake Trophic State between 1991 and 2000 by Morphometry as a Continuous Target Population Census in Acres.

Morphometric Measure	**Total Acres**	**Oligotrophic**		**Mesotrophic**		**Eutrophic**	
		1991	**2000**	**1991**	**2000**	**1991**	**2000**
Small Size	3,228	39	7	2,200	2,037	988	1,184
Medium Size	20,733	836	544	16,901	16,642	2,996	3,547
Large Size	170,408	113,676	99,315	54,937	68,808	1,795	2,285
Small SDI (nearly round)	9,783	1,759	804	7,561	8,450	463	528
Medium SDI	44,817	18,769	15,898	24,096	26,838	1,952	2,081
Large SDI (convoluted)	139,769	94,023	83,163	42,381	52,198	3,365	4,407
All Lakes Statewide	194,368	114,550	99,865	74,038	87,486	5,780	7,017

Findings

- Based on a distribution analysis of independent variables, the best fit for a normal distribution was achieved using a natural logarithm transformation. These log-transformed data were used in all subsequent parametric analyses.

- Based on ANOVA, measured trophic state indicators and most spectral characteristics differentiate ecoregions or lake morphometry equally well.

- Based on cluster analysis, there are no distinct patterns of measured trophic state indicators and spectral characteristics between the ecoregions or lake morphometry.

- Significant multicollinearity was found between the spectral variables representing Band 2 and Band 3. As such, data from the Band 2 independent variable was removed from further empirical model development.

- Based on discriminate analysis, the influence on trophic state cluster differences from each independent variables was assessed: (1) trophic state derived from Secchi transparency measurements were most influenced by spectral Band 4, area, and SDI, (2) trophic state derived from chlorophyll *a* measurements were most influenced by spectral Band 3, and (3) trophic state derived from total phosphorus measurements were most influenced by area.

- Based on principal component analysis, the spectral image data and the morphometric data explain 61% and 24% of the variance, respectively.

- Empirical models developed by stepwise multiple linear regression analysis of the independent spectral image and morphometric variables to predict the three trophic state indicators of lake Secchi transparency, chlorophyll *a*, and total phosphorus explained 14%, 14%, and 12% of the variance, respectively.

- Verification of the Secchi transparency empirical model showed poor performance likely a result of the small sample size of the independent data set.

- Ogives of the statewide census of trophic state indicators predicted from the empirical models ogives show little change in lake Secchi transparency values between 1991 and 2000. The ogive for chlorophyll *a* show increased productivity between 1991 and 2000 for all lakes with existing low productivity. The total phosphorus ogive shows that both mesotrophic and eutrophic lakes both increased in total phosphorus concentration between 1991 and 2000.

- Only slight differences are observed in the predicted census of each trophic state indicator between most ecoregions. However, the mean TSI shows that lakes in the Cascade Mountains are much less productive than lakes in the Willamette Valley, as expected.

- The frequency of the census of predicted trophic states show statewide that a small percentage of mesotrophic lakes have become eutrophic between 1991 and 2000. A relatively large percentage of oligotrophic lakes have become mesotrophic in the Coast Range and Cascades ecoregions. In addition, small mesotrophic lakes and highly convoluted lakes (i.e., high shoreline development index) show an increase in productivity over the same time period.

- The mean lake TSI values of Water Resource Inventory Areas show most watersheds increased in trophic status between 1991 and 2000.

- Examination of the frequency of the census of lake areas shows that oligotrophic lake areas have decreased, whereas mesotrophic and eutrophic lake areas increased over the nine year period. The largest change is observed in the Columbia Basin ecoregion and in large-sized lakes.

- While satellite-based assessment will never replace in-lake monitoring, they provide an efficient way to collect regional status and trend information.

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Figures

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Figure 1. Image of Washington State Spectral Band 2 Obtained by the LandSat® Satellite in 2000.

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Figure 2. Ecoregions of Washington State.

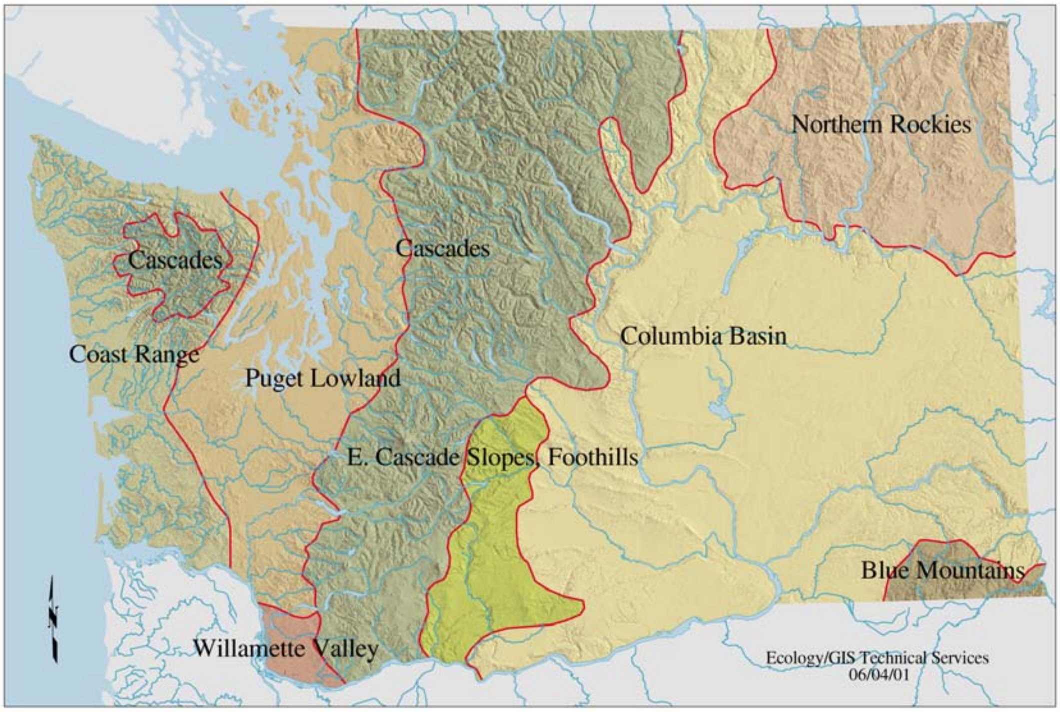

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Figure 3. Effect of Logarithmic Transformation on the Census Distribution of Lake Secchi Transparency Measurements.

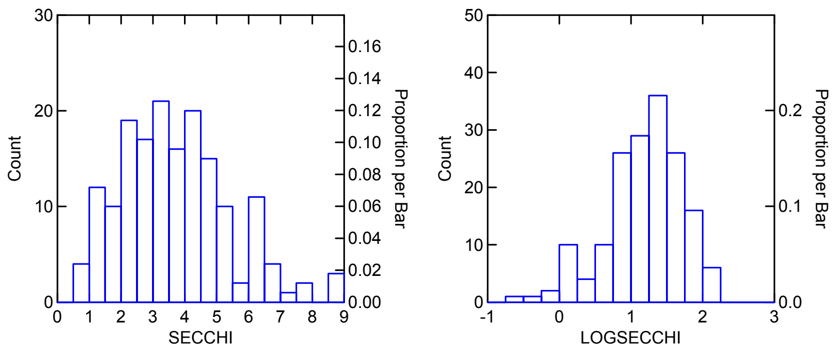

Figure 4. Effect of Logarithmic Transformation on the Census Distribution of Lake Chlorophyll *a* Measurements.

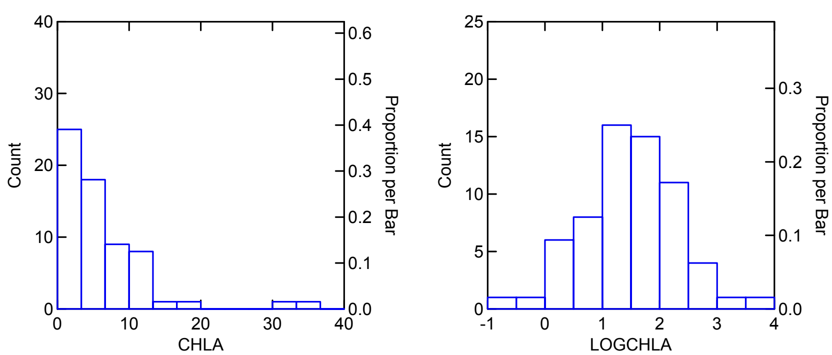

Figure 5. Effect of Logarithmic Transformation on the Census Distribution of Lake Total Phosphorus Measurements.

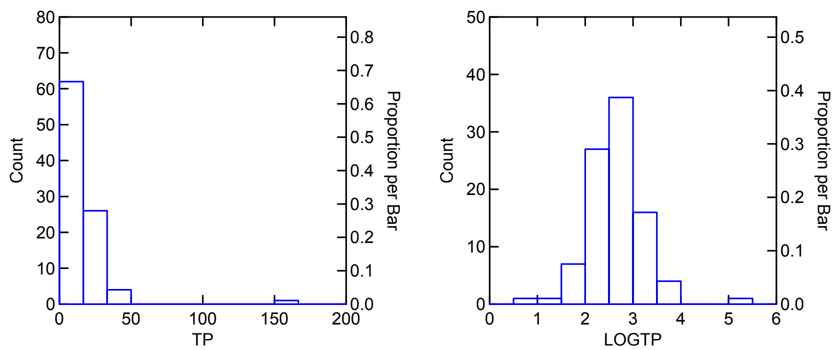

Figure 6. Effect of Logarithmic Transformation on the Census Distribution of Lake Sizes.

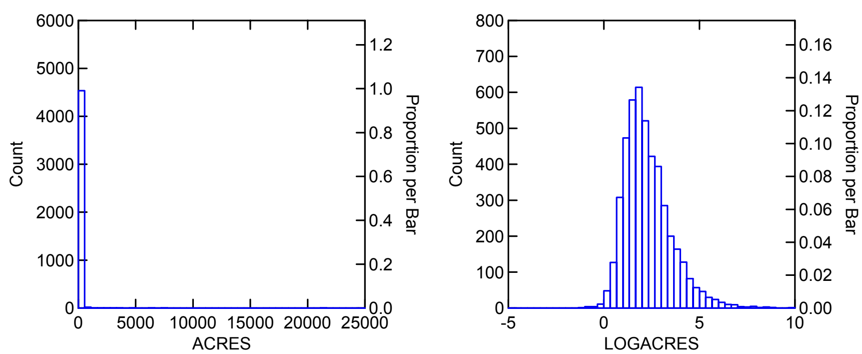

Figure 7. Effect of Logarithmic Transformation on the Census Distribution of Lake Shoreline Development Index Values.

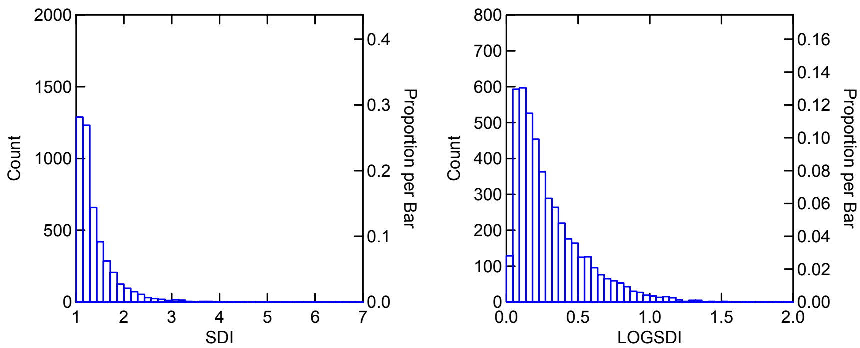

Figure 8. Effect of Logarithmic Transformation on the Census Distribution of Lake Image Band 1 Intensity Values.

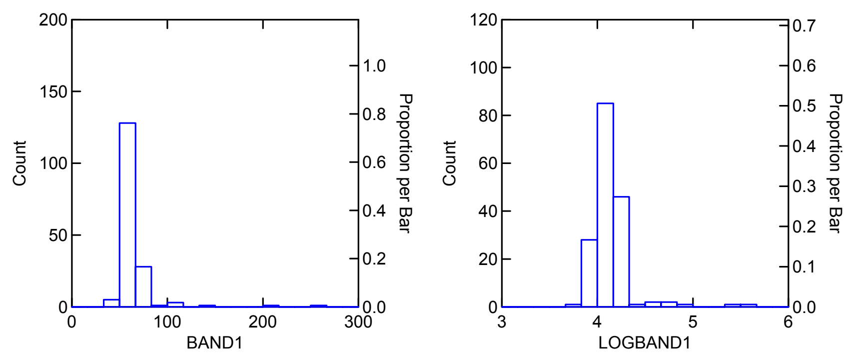

Figure 9. Effect of Logarithmic Transformation on the Census Distribution of Lake Image Band 2 Intensity Values.

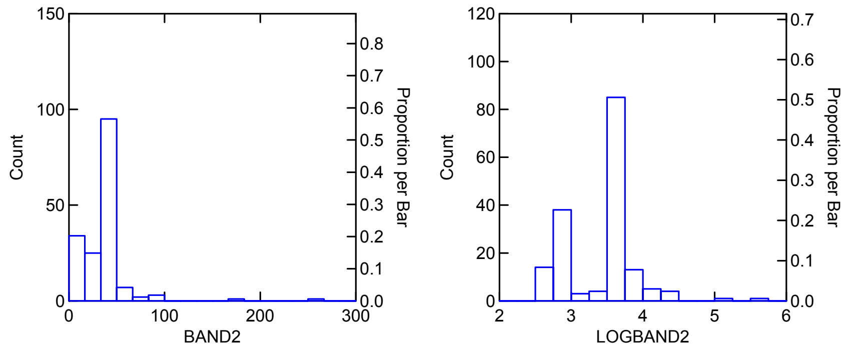

Figure 10. Effect of Logarithmic Transformation on the Census Distribution of Lake Image Band 3 Intensity Values.

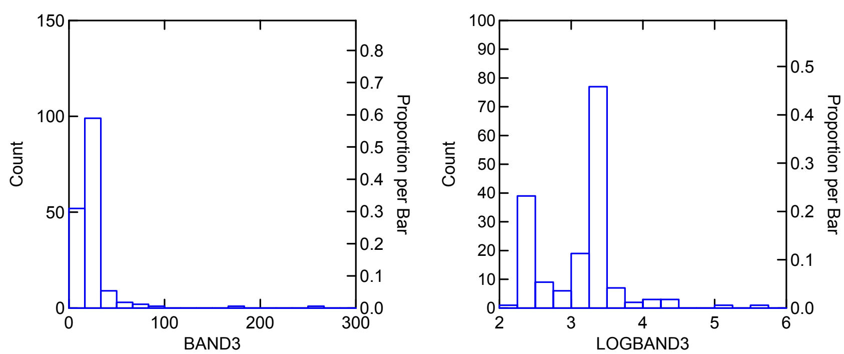

Figure 11. Effect of Logarithmic Transformation on the Census Distribution of Lake Image Band 4 Intensity Values.

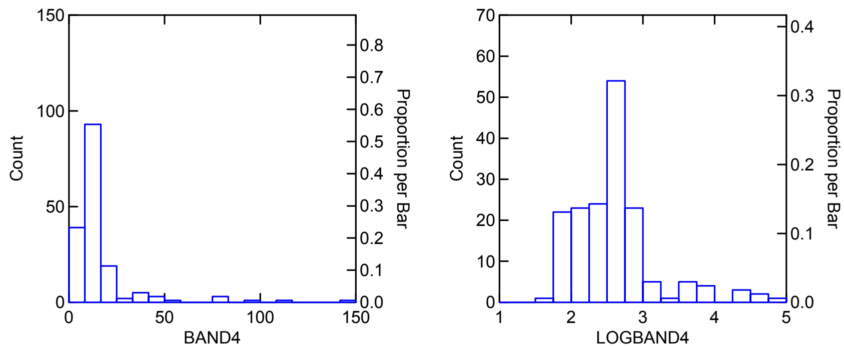

Figure 12. Effect of Logarithmic Transformation on the Census Distribution of Lake Image Band 5 Intensity Values.

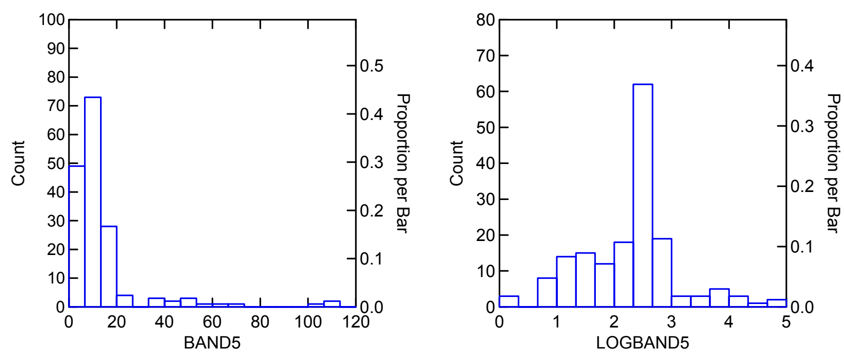

Figure 13. Boxplot of Secchi Transparency Data by Ecoregion.

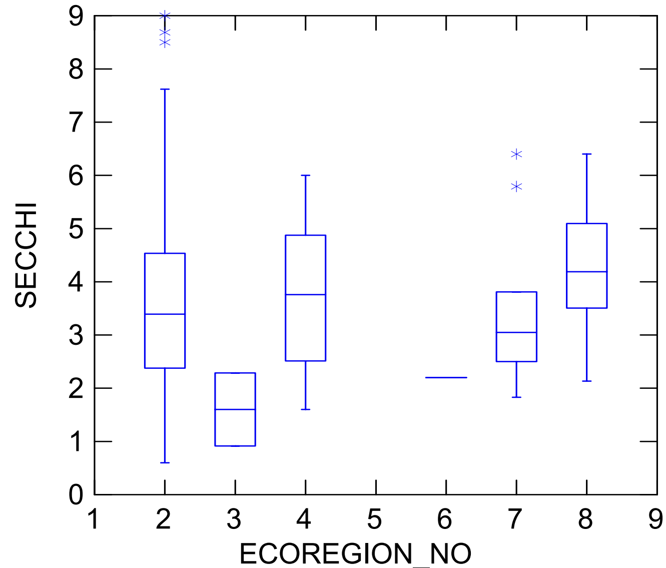

Figure 14. Boxplot of Chlorophyll *a* Data by Ecoregion.

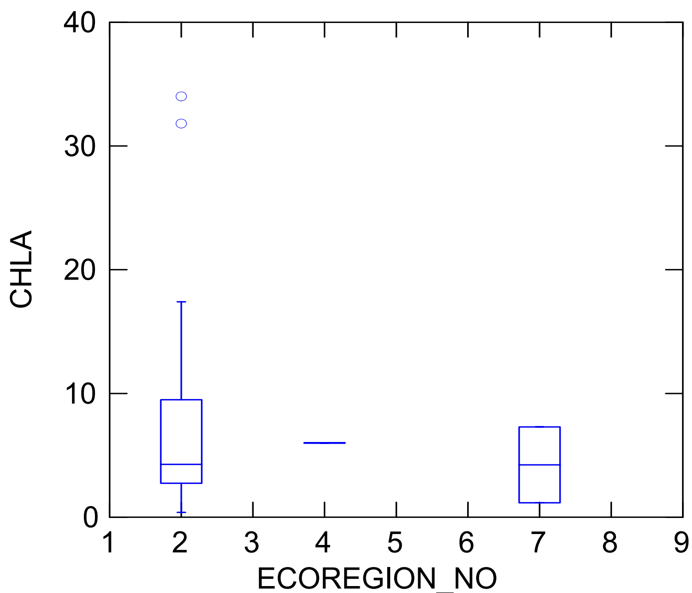

Figure 15. Boxplot of Total Phosphorus Data by Ecoregion.

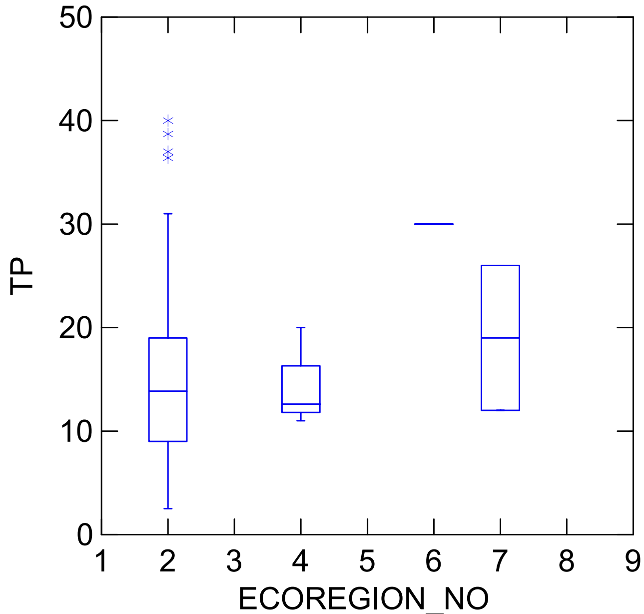

Figure 16. Boxplot of Lake Sizes from Census by Ecoregion.

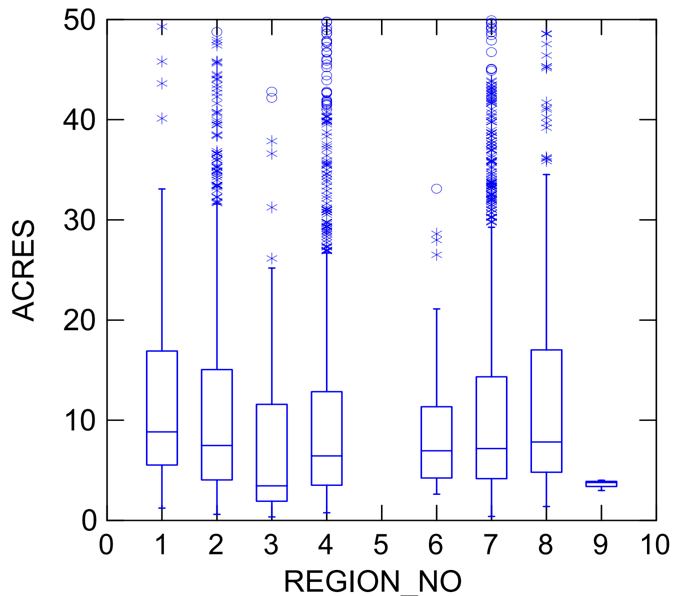

Figure 17. Boxplot of Shoreline Development Index Values from Census by Ecoregion.

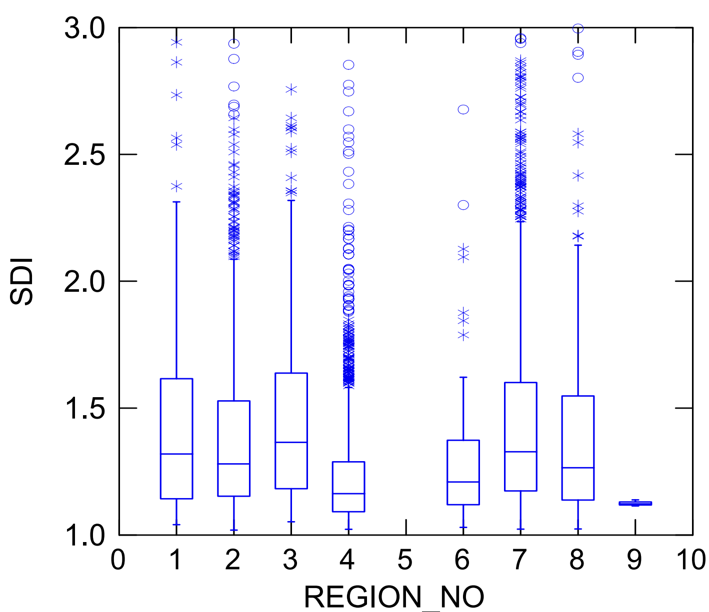

Figure 18. Boxplot of Band 1 Image Data by Ecoregion.

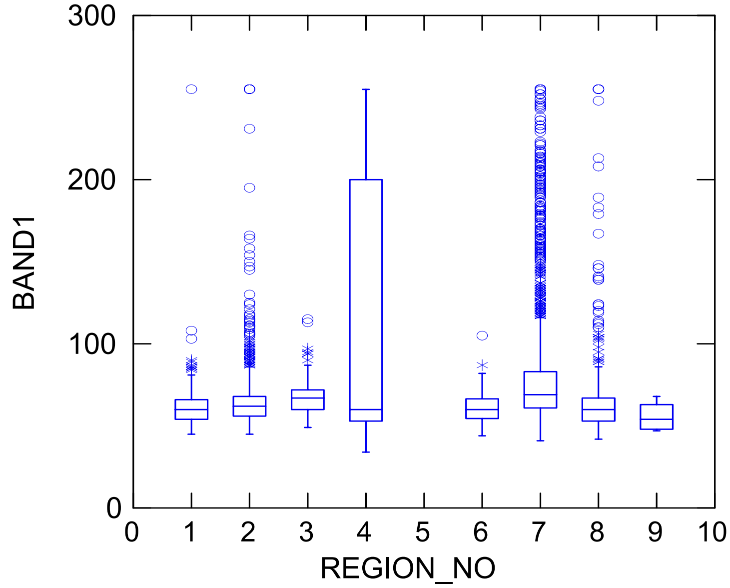

Figure 19. Boxplot of Band 2 Image Data by Ecoregion.

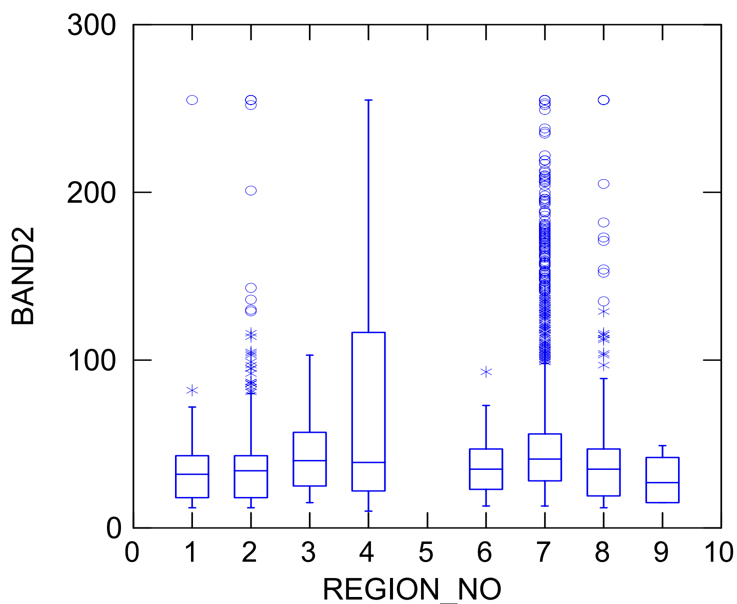

Figure 20. Boxplot of Band 3 Image Data by Ecoregion.

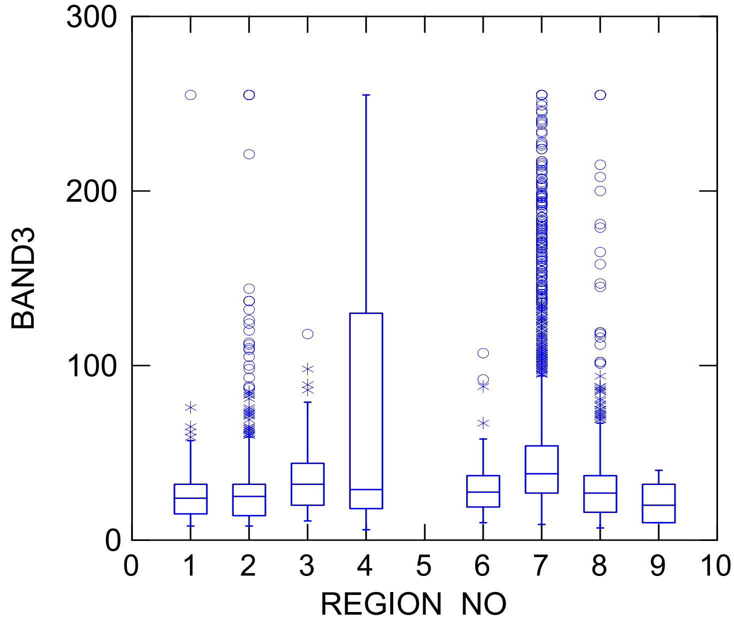

Figure 21. Boxplot of Band 4 Image Data by Ecoregion.

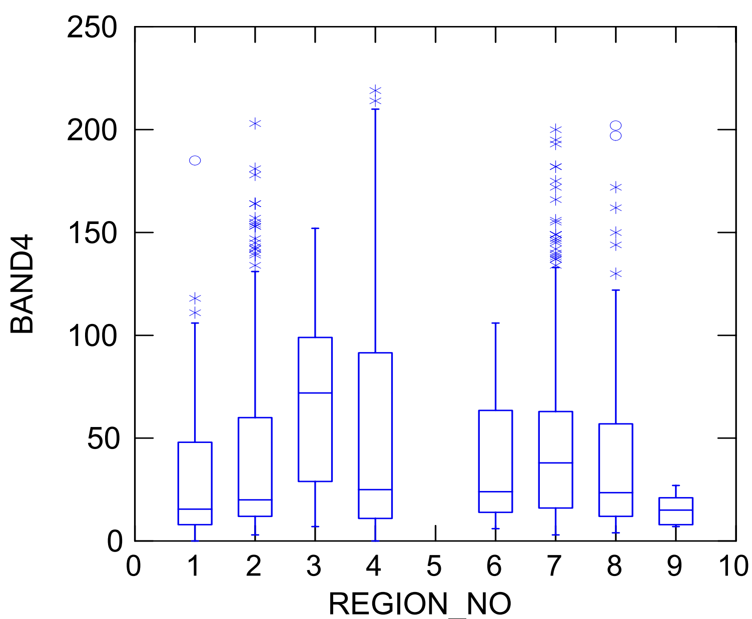

Figure 22. Boxplot of Band 5 Image Data by Ecoregion.

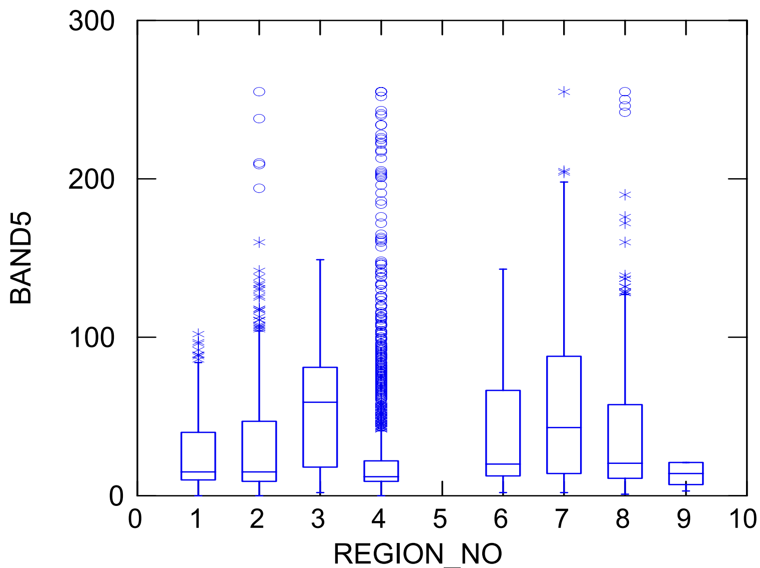

Figure 23. Hierarchical Cluster of Ecoregions using Spectral Characteristics

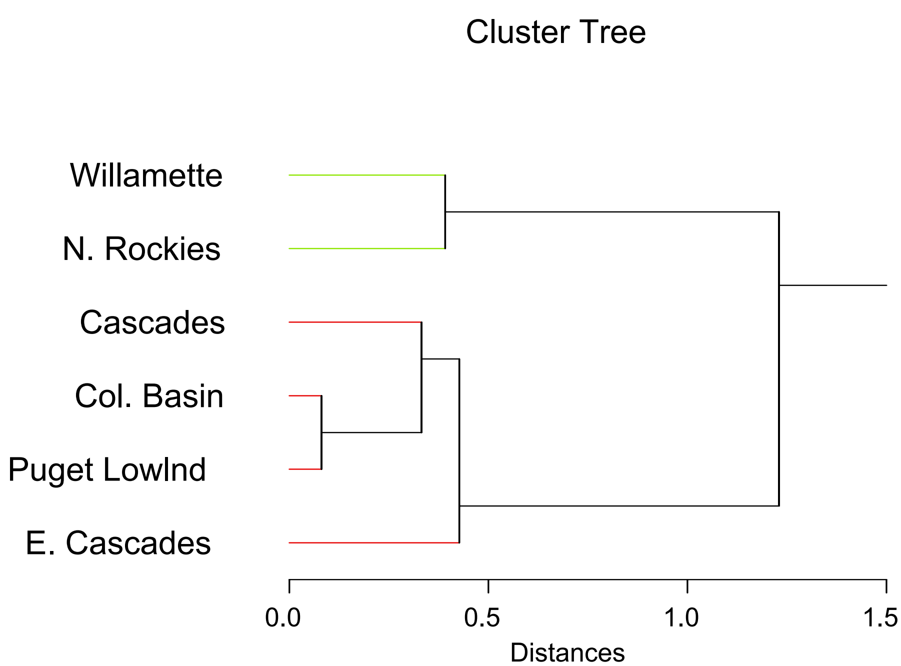

Figure 24. Hierarchical Cluster of Ecoregions using Secchi Transparency Data.

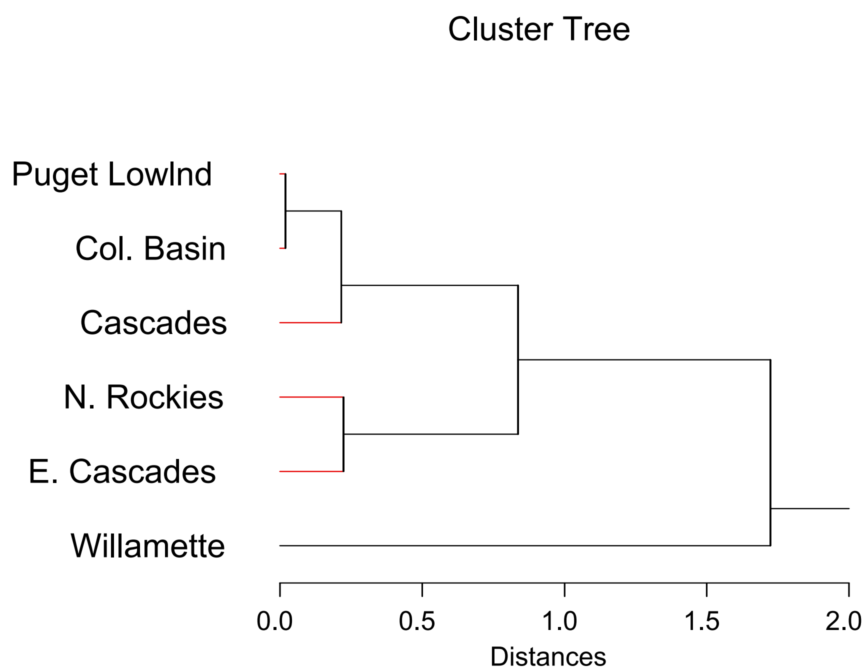

Figure 25. Hierarchical Cluster of Ecoregions using Chlorophyll *a* Data.

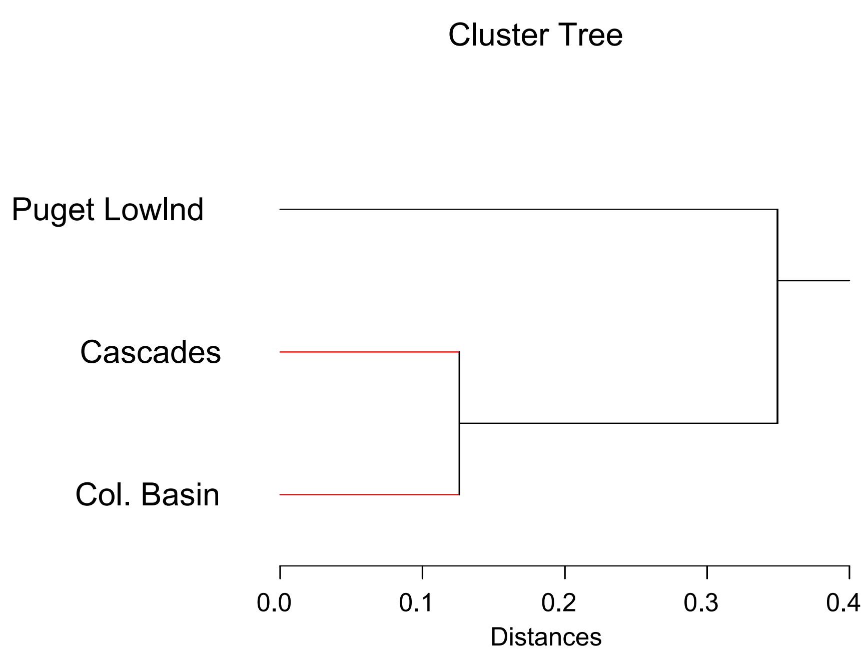

Figure 26. Hierarchical Cluster of Ecoregions using Total Phosphorus Data.

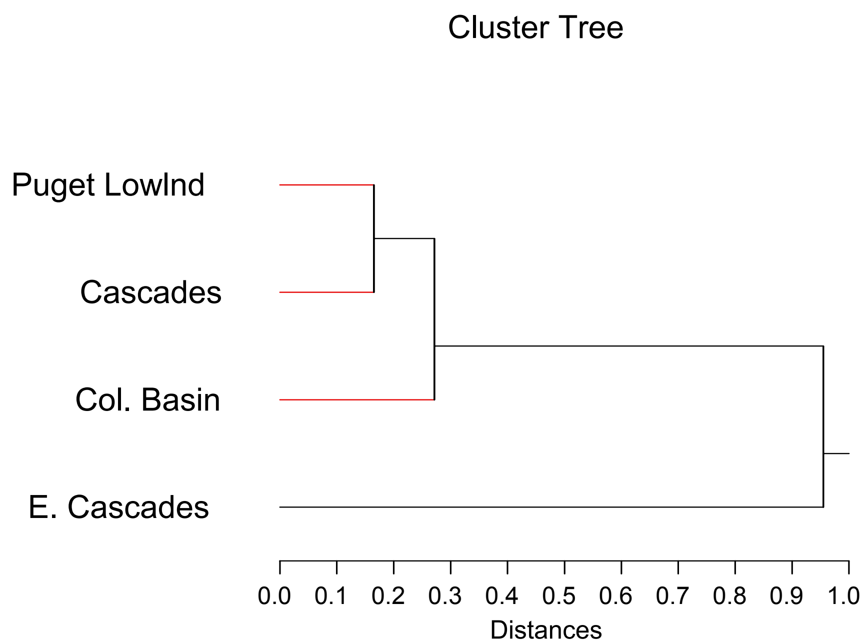

Figure 27. Hierarchical Cluster of Ecoregions using Lake Morphometric Characteristics.

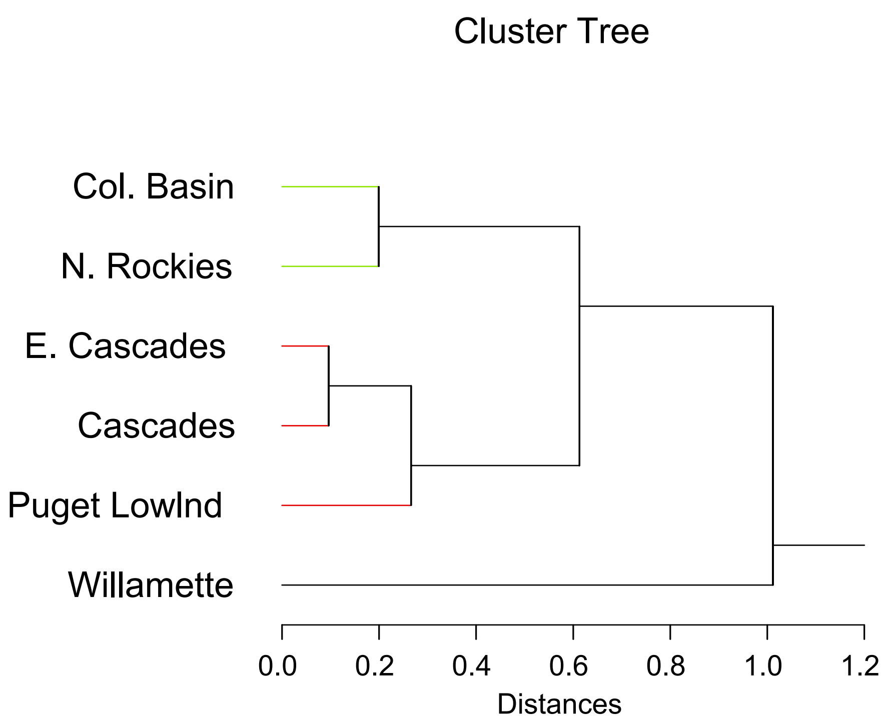

Figure 28. Scatter Plot Matrix of the Lake Data.

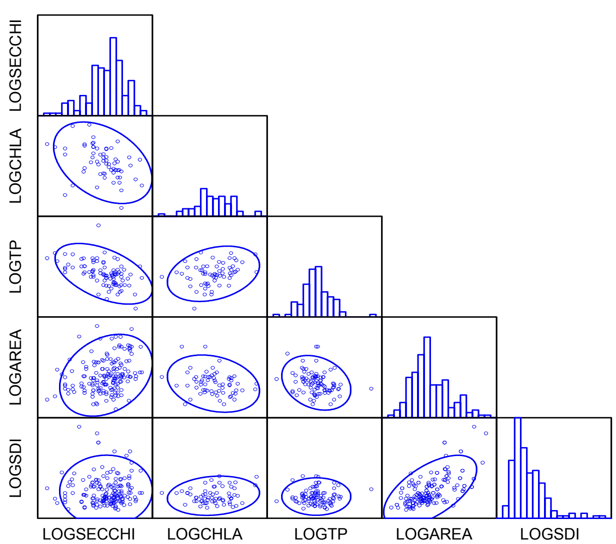

Figure 29. Scatter Plot Matrix of the Image Data.

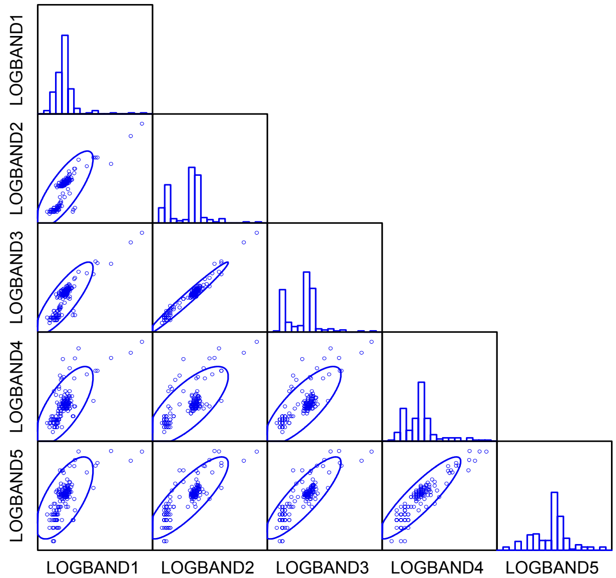

Figure 30. Scatter Plot Matrix of the Image Data and Lake Data.

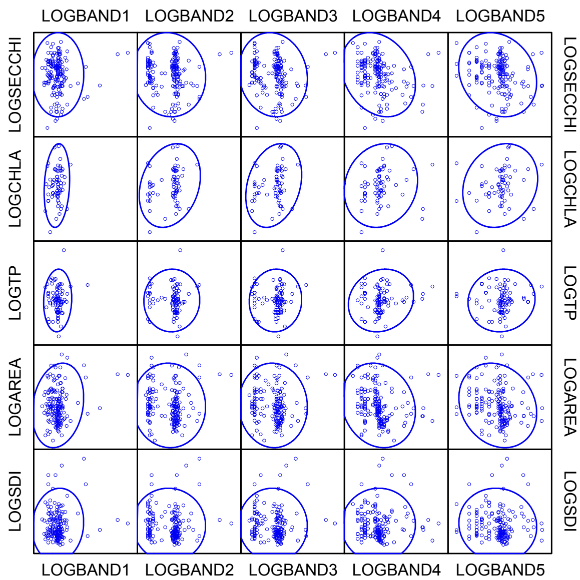

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Figure 31. Canonical Variates of Secchi Transparency Clusters from the Independent Variables.

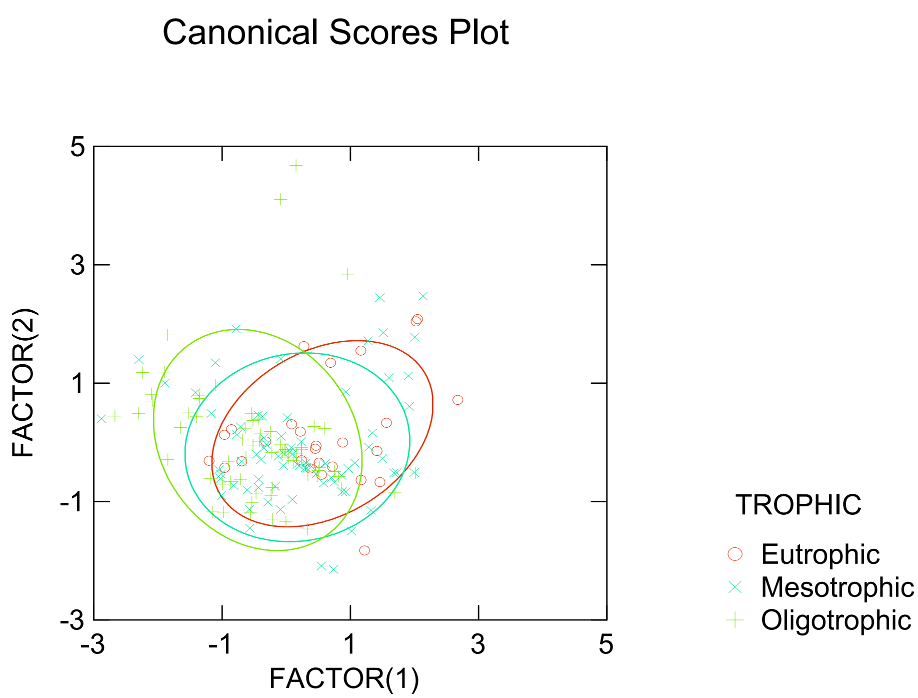

Figure 32. Canonical Variates of Chlorophyll *a* Clusters from the Independent Variables.

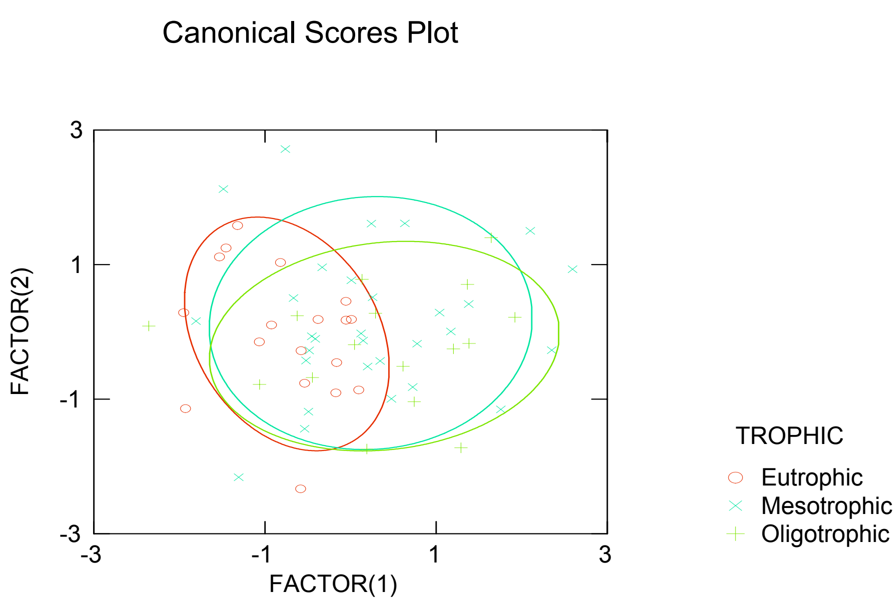

Figure 33. Canonical Variates of Total Phosphorus Clusters from the Independent Variables.

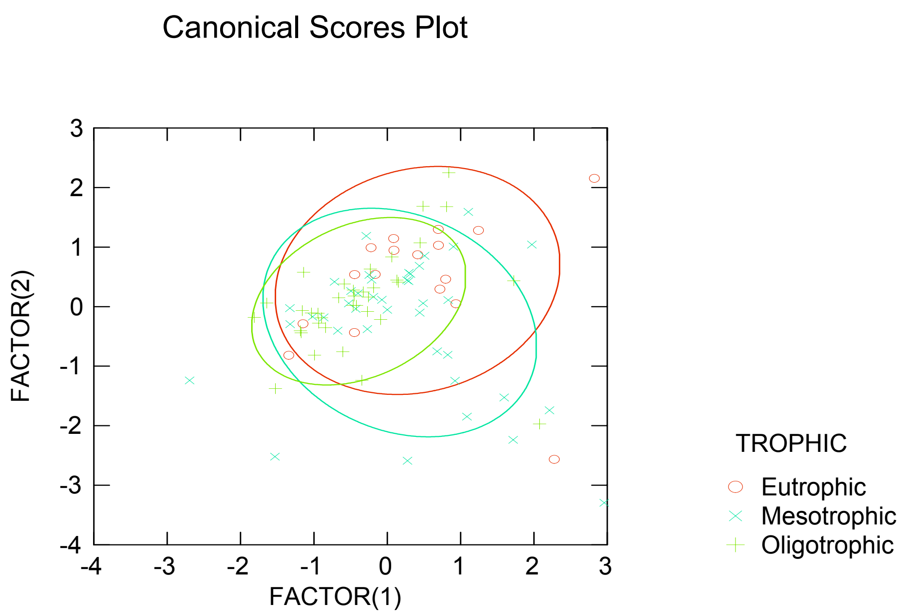

Figure 34. Unrotated Principal Component Factor Loadings.

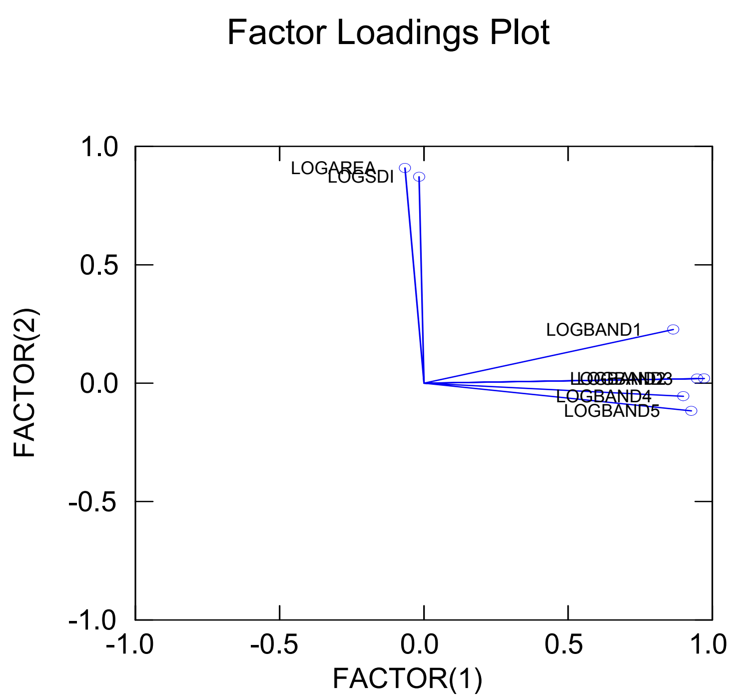

Figure 35. Principal Component Factor Loadings with Varimax Axis Rotation.

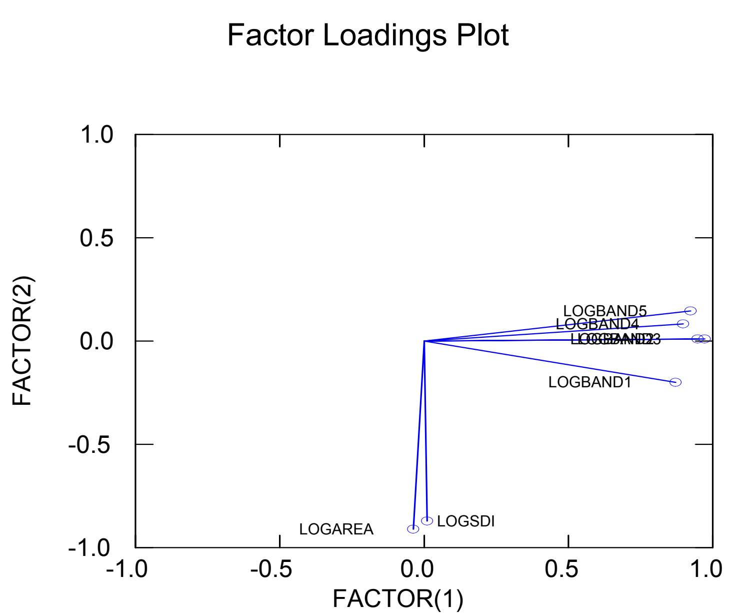

Figure 36. Residual Distribution of Empirical Model for Secchi Transparency.

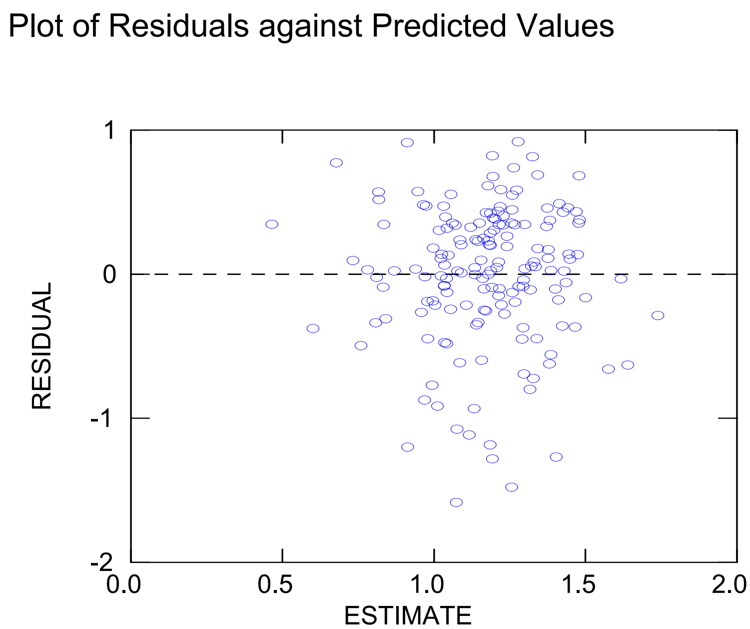

Figure 37. Residual Distribution of Empirical Model for Chlorophyll *a*.

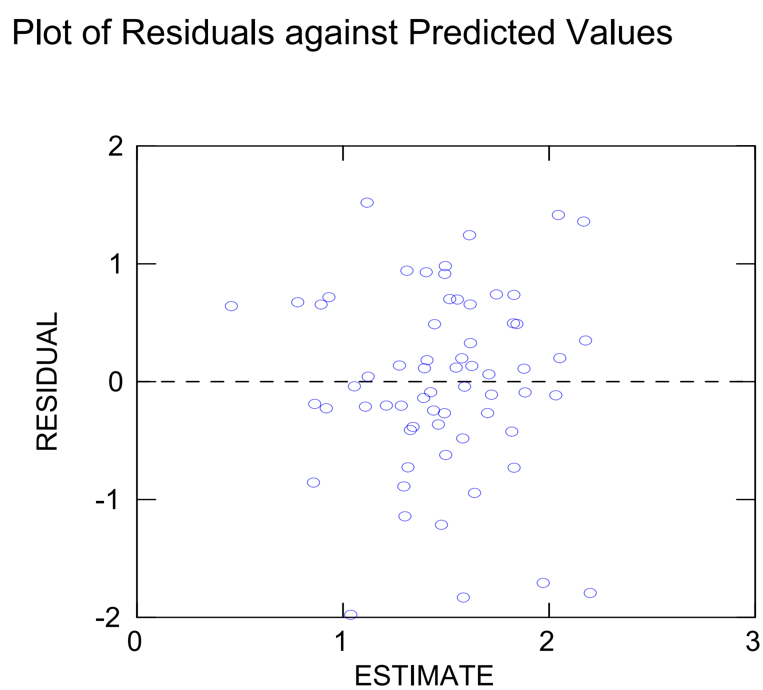

Figure 38. Residual Distribution of Empirical Model for Instantaneous Total Phosphorus.

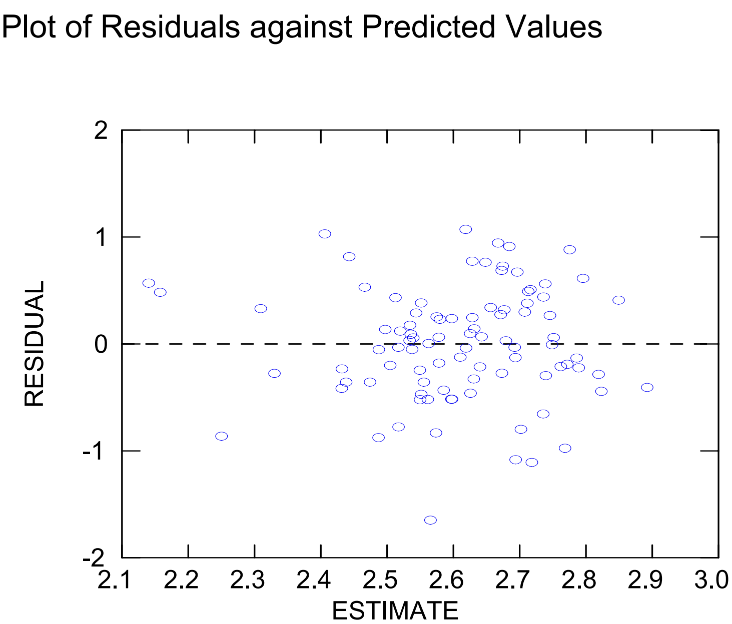

Figure 39. Residual Distribution of Empirical Model for Summer Mean Total Phosphorus.

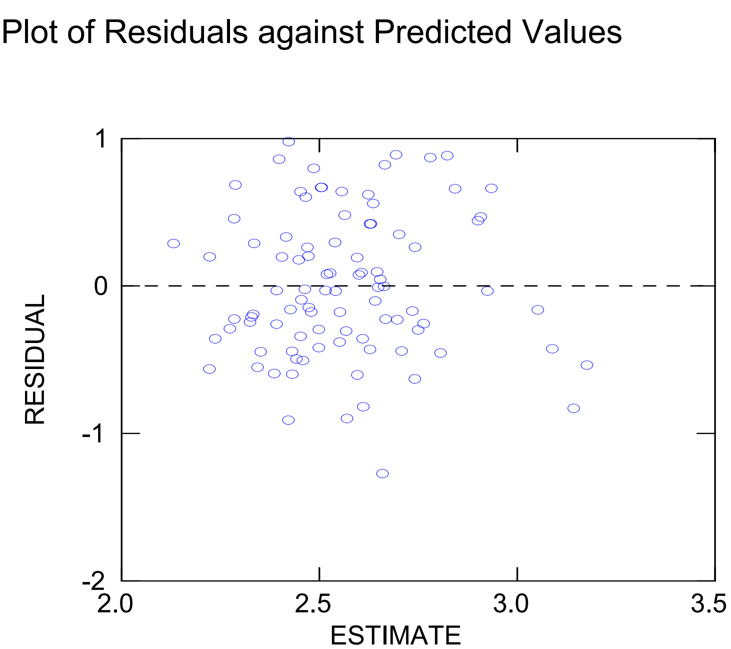

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Figure 40. Comparison of the Statewide Distribution of Lake Secchi Transparency between 1991 and 2000.

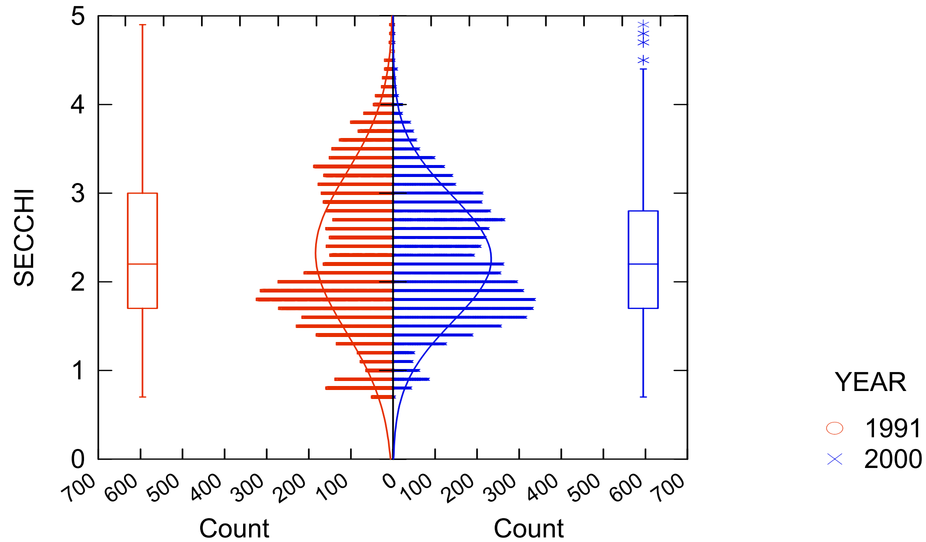


Figure 41. Comparison of the Statewide Distribution of Lake Chlorophyll *a* between 1991 and 2000.

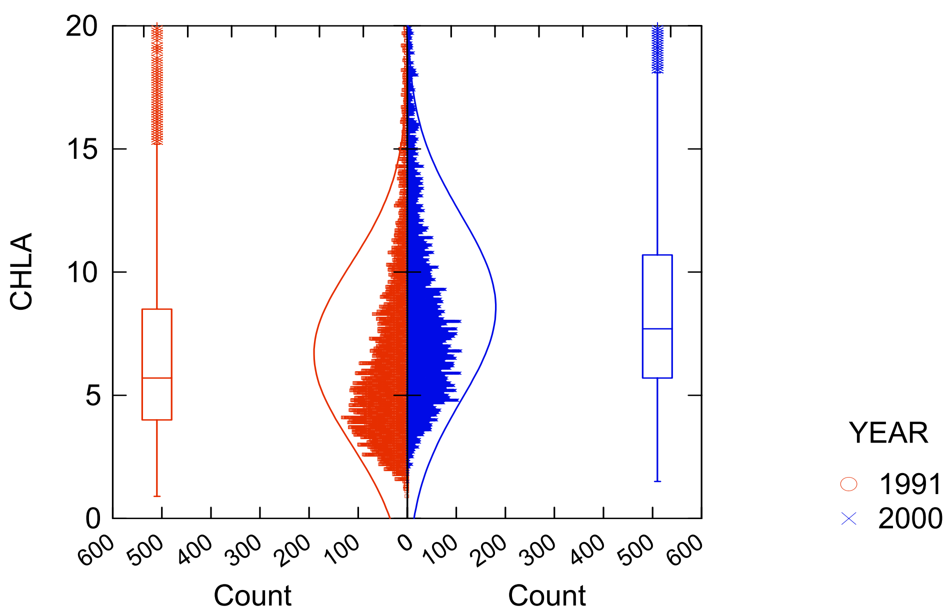


Figure 42. Comparison of the Statewide Distribution of Lake Total Phosphorus between 1991 and 2000.

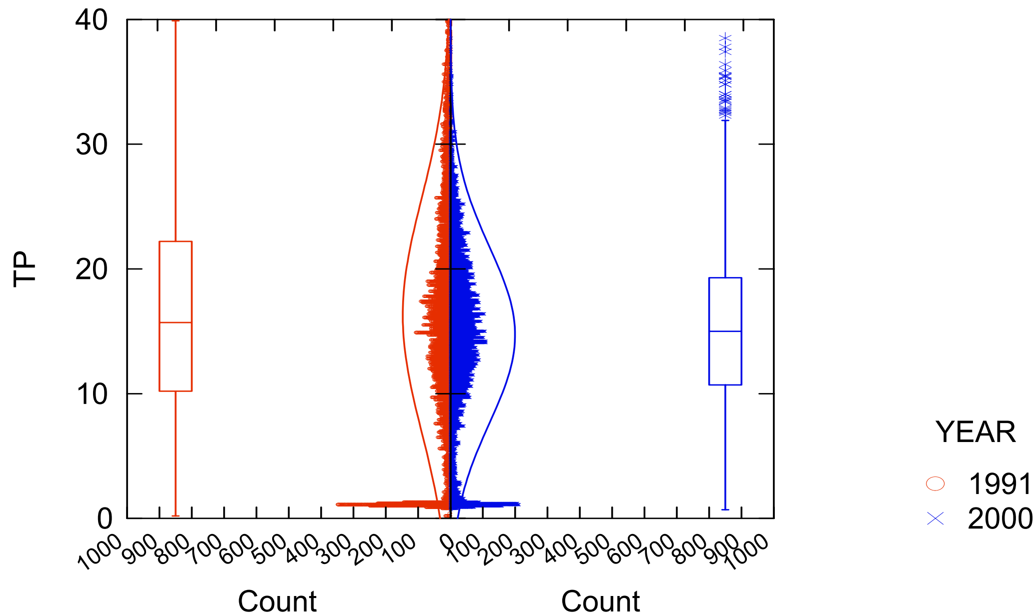


Figure 43. Comparison of the Statewide Distribution of Lake Trophic State Index between 1991 and 2000.

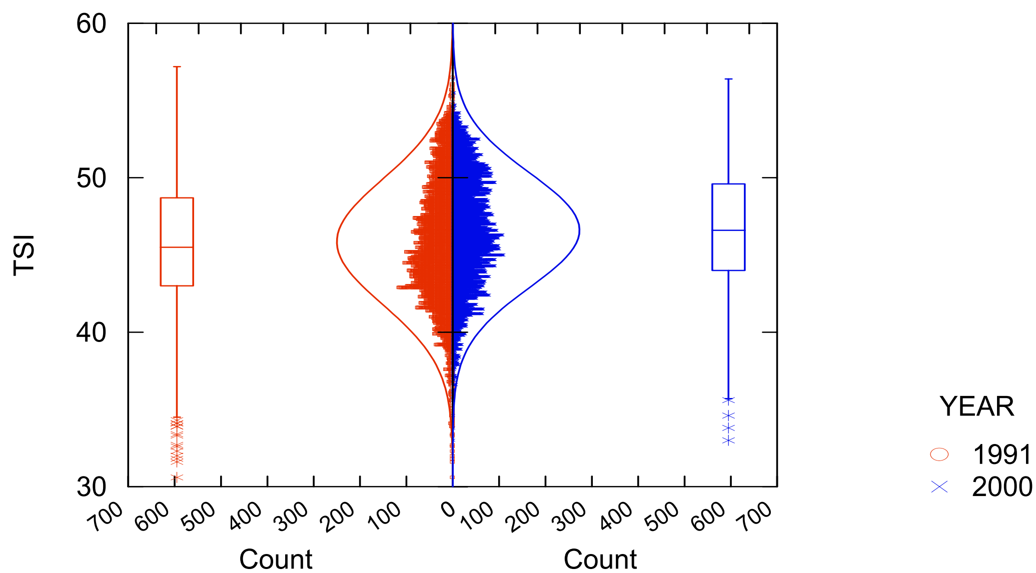


Figure 44. Ogive of Statewide Lake Secchi Transparency between 1991 and 2000.

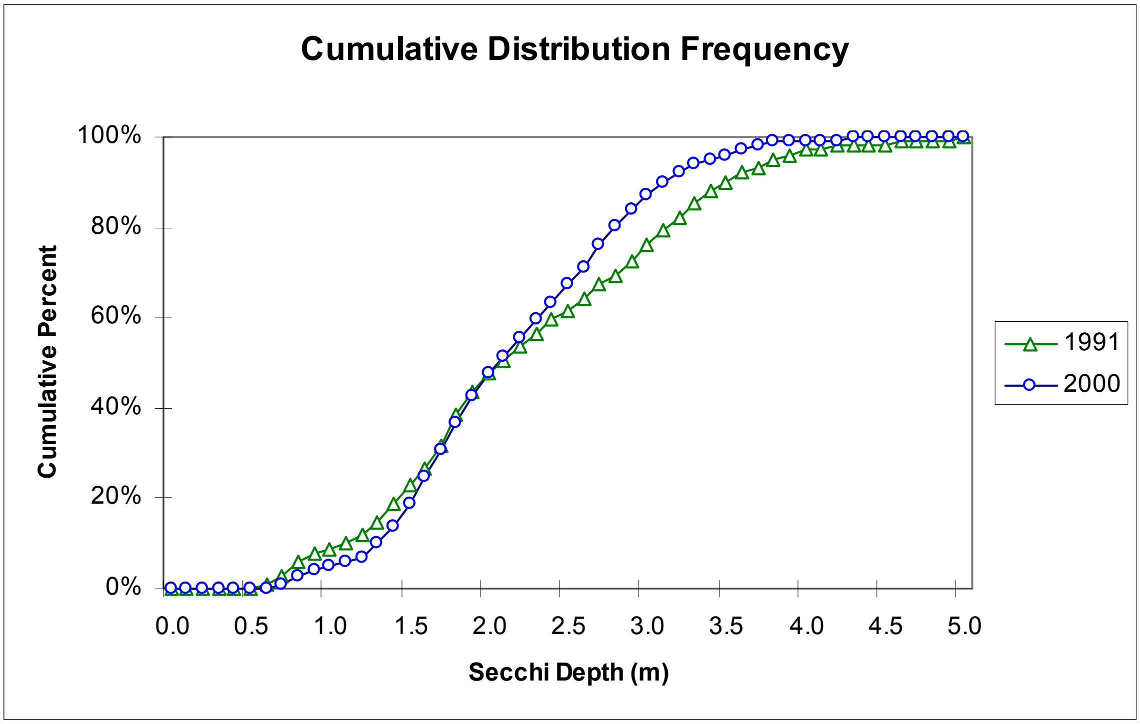


Figure 45. Ogive of Statewide Lake Chlorophyll *a* between 1991 and 2000.

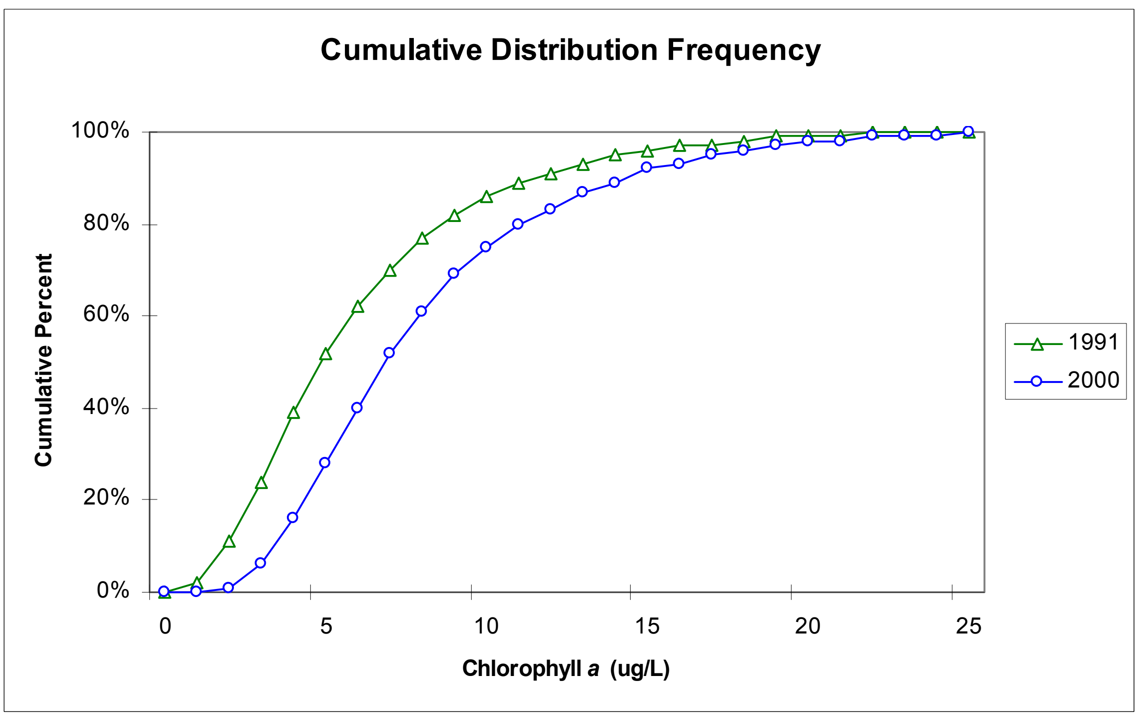


Figure 46. Ogive of Statewide Lake Total Phosphorus between 1991 and 2000.

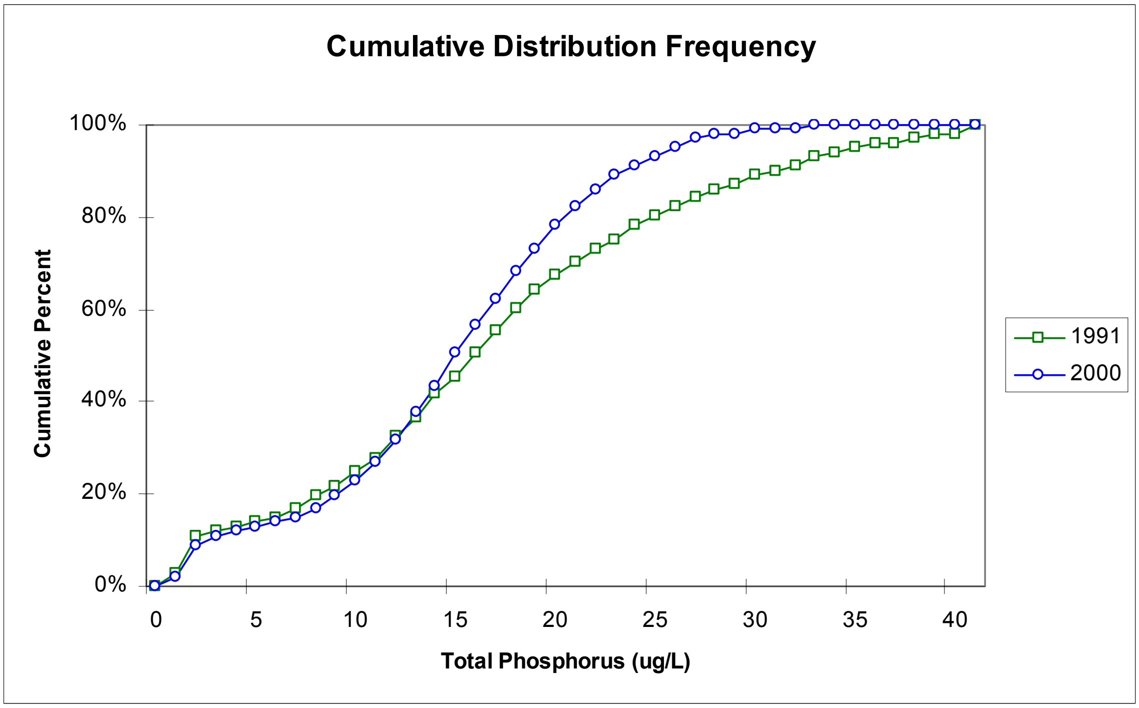


Figure 47. Ogive of Statewide Trophic State Index between 1991 and 2000.

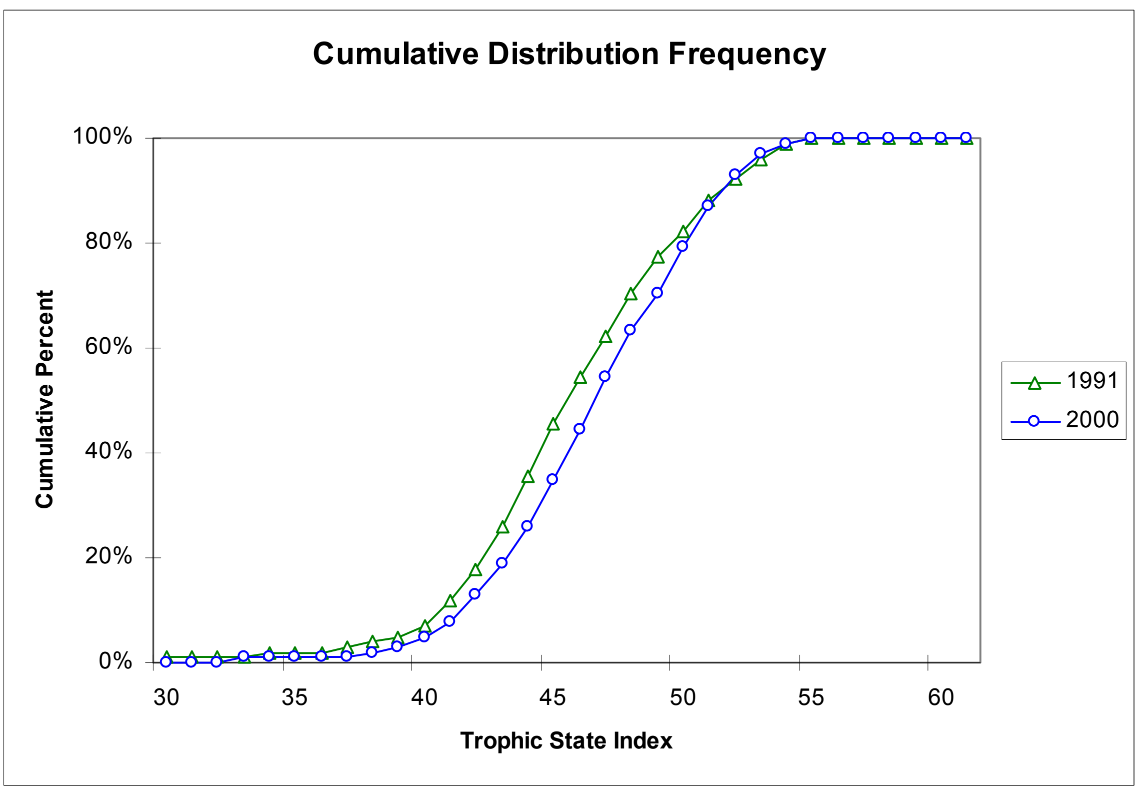


Figure 48. Statewide Spatial Distribution of Lake Secchi Transparency in 2000.

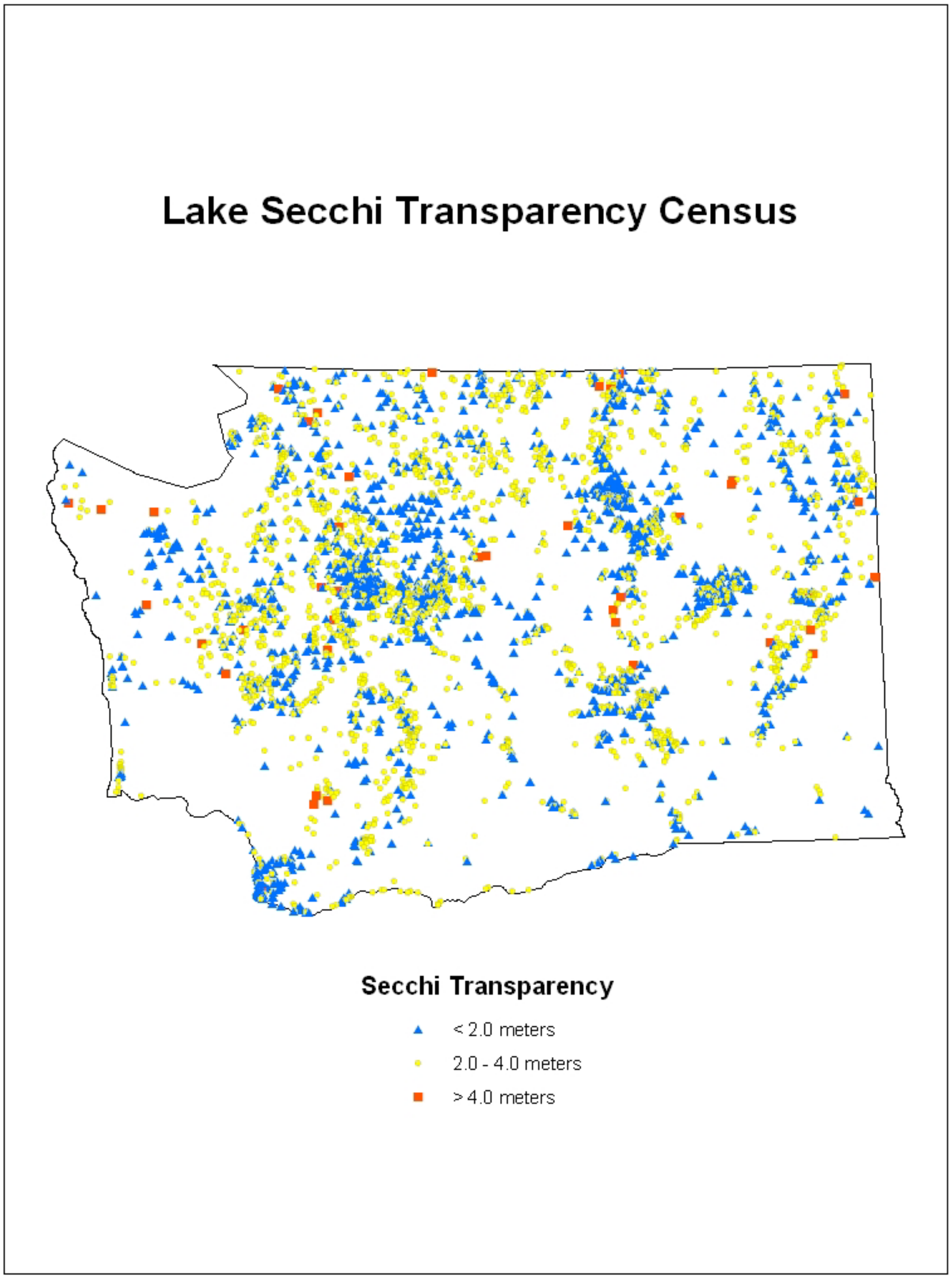


Figure 49. Statewide Spatial Distribution of Lake Chlorophyll *a* in 2000.

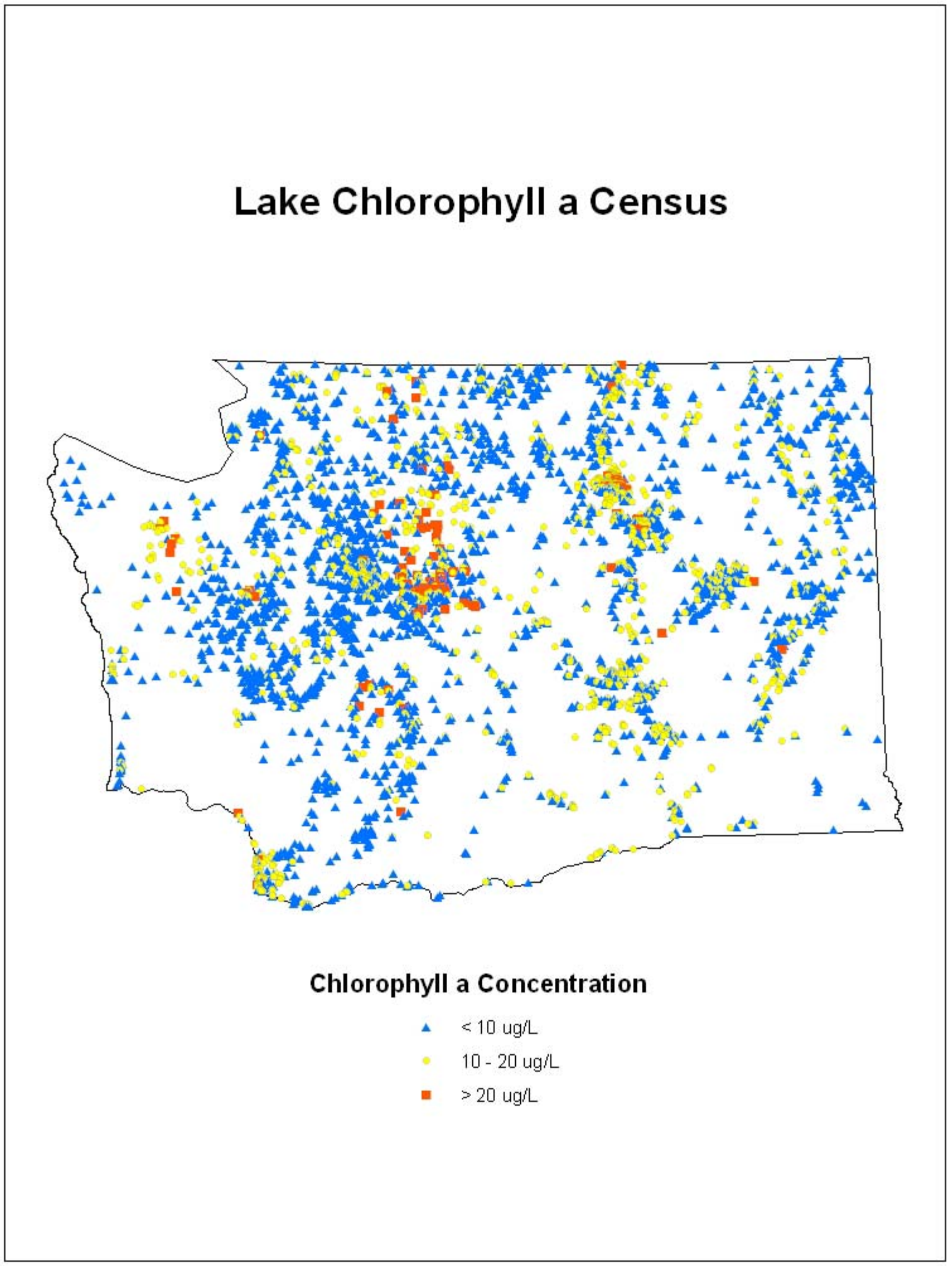


Figure 50. Statewide Spatial Distribution of Lake Total Phosphorus in 2000.

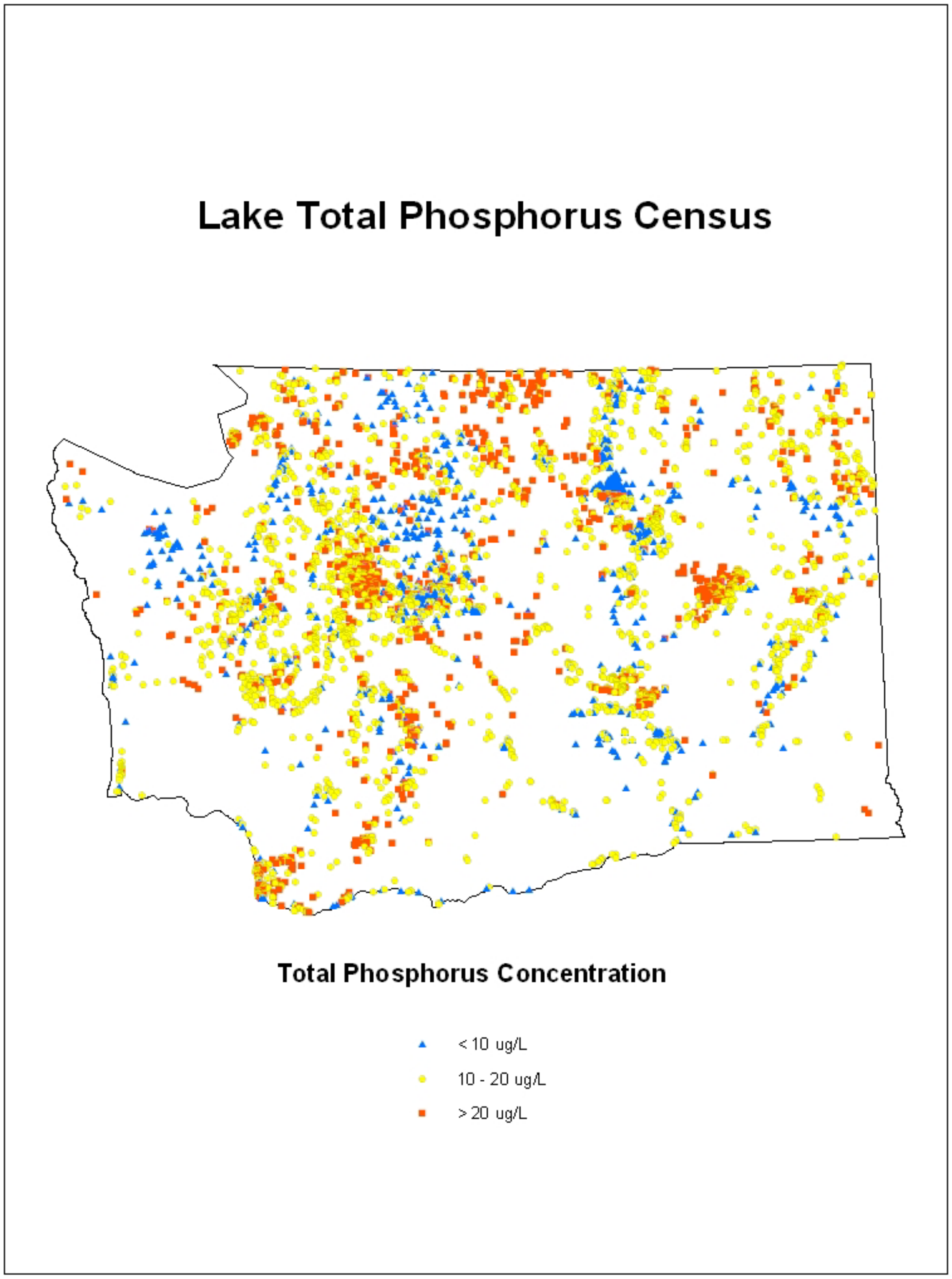


Figure 51. Statewide Spatial Distribution of Lake Trophic State in 2000.

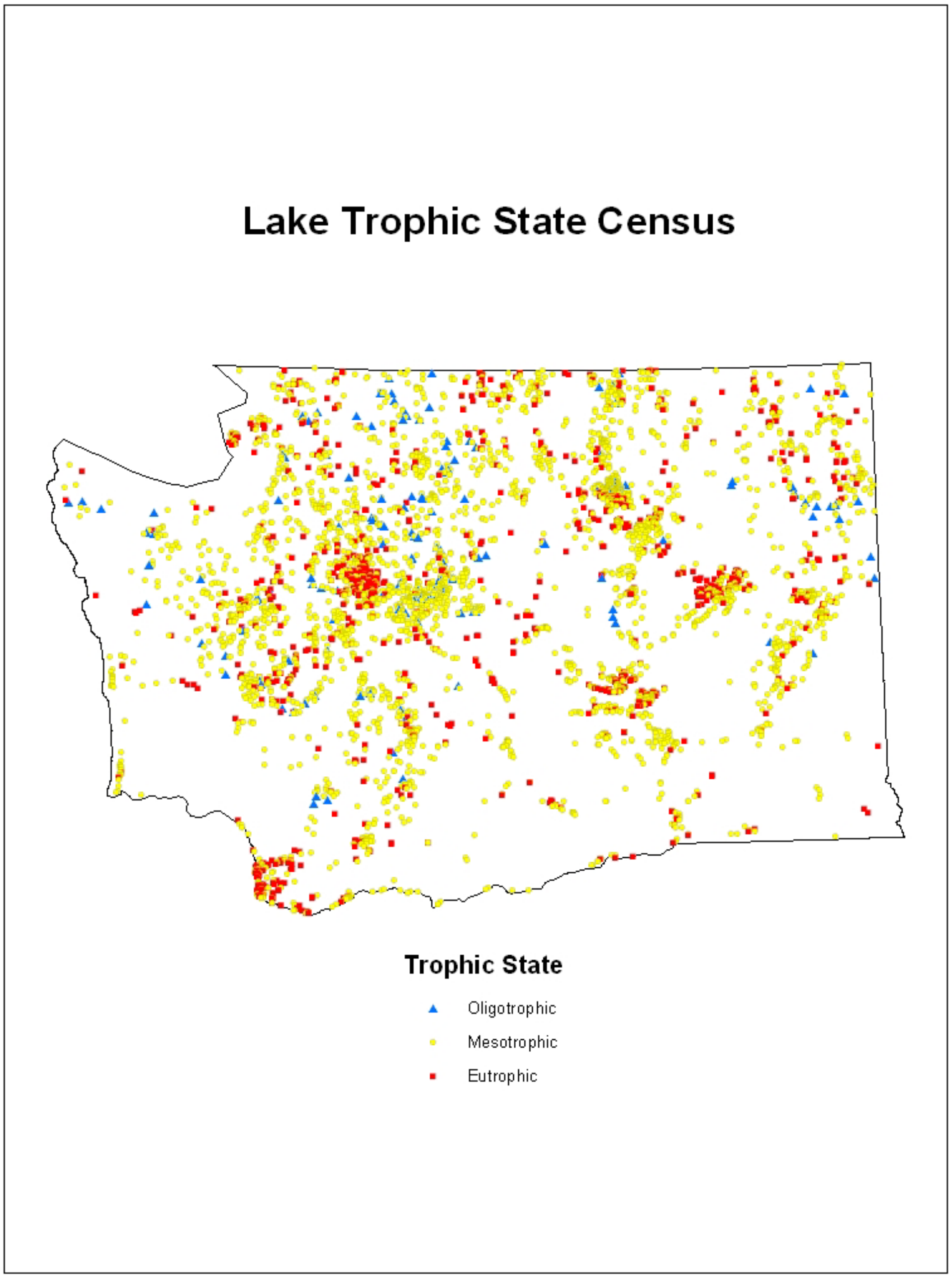


Figure 52. Comparison of the Statewide Distribution of Lake Secchi Transparency between Ecoregions.

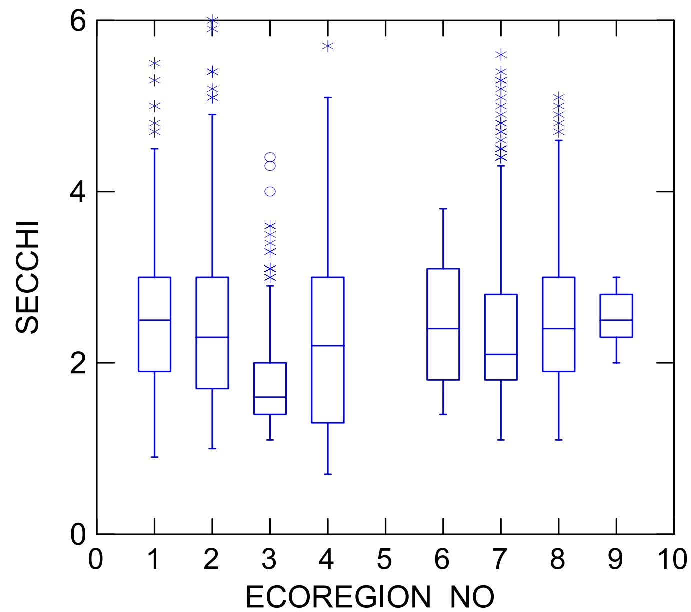


Figure 53. Comparison of the Statewide Distribution of Lake Chlorophyll *a* between Ecoregions

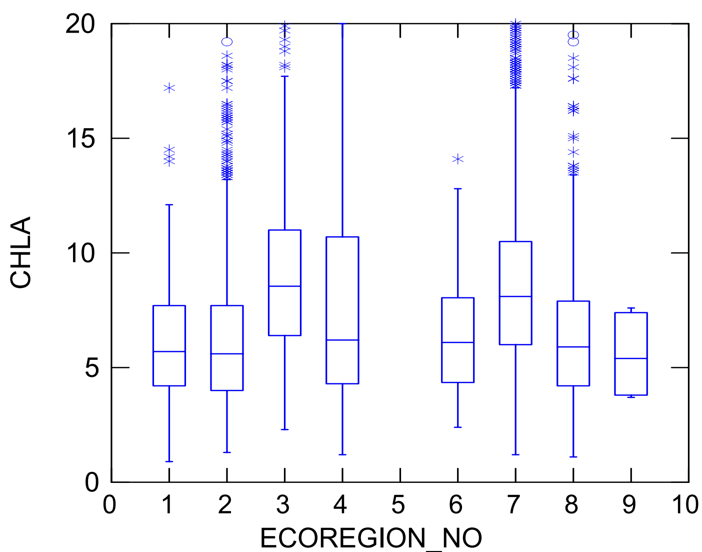


Figure 54. Comparison of the Statewide Distribution of Lake Total Phosphorus between Ecoregions.

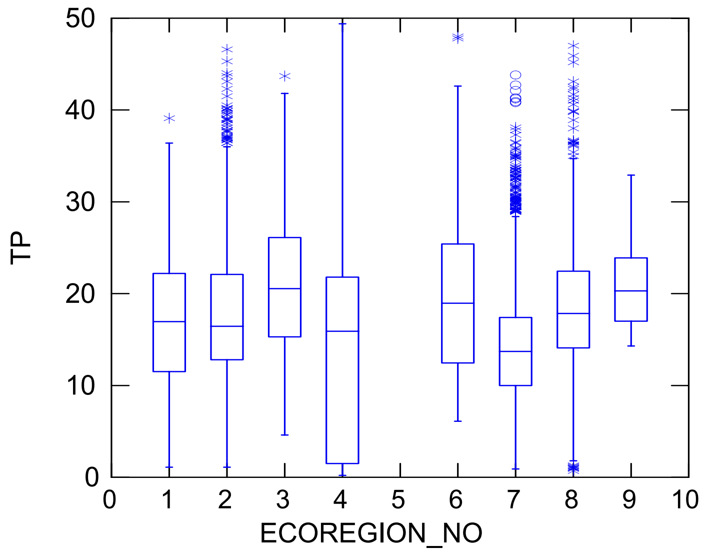


Figure 55. Comparison of the Statewide Distribution of Lake Trophic State Index between Ecoregions.

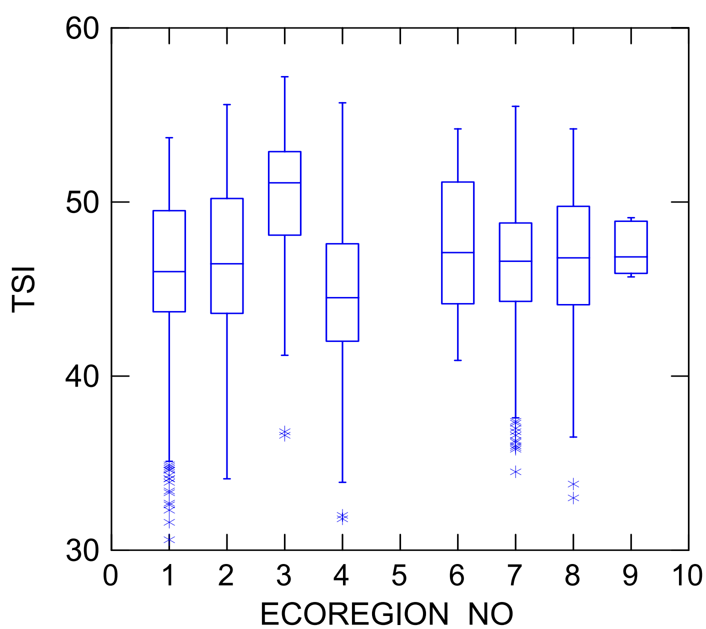
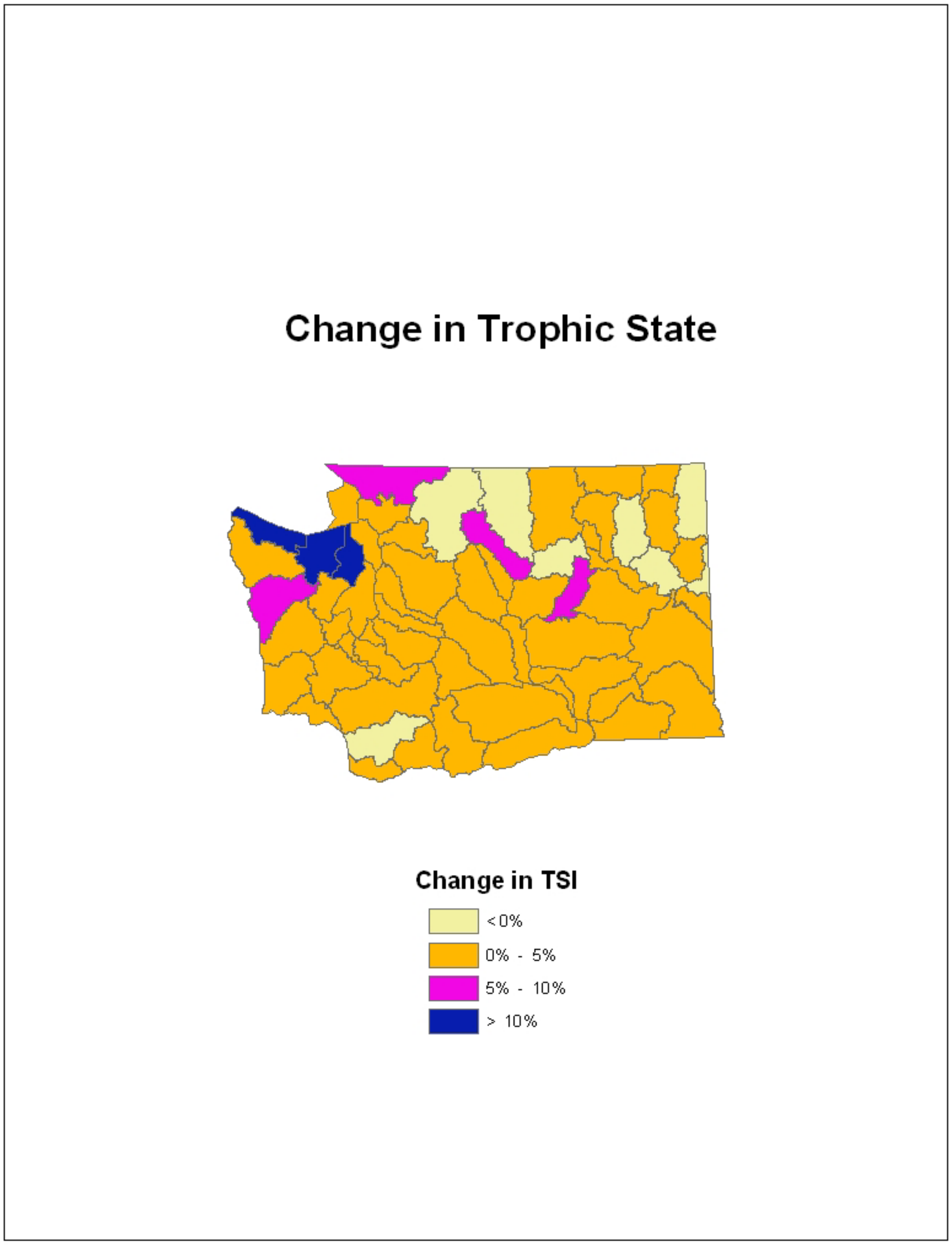


Figure 56. Changes in Trophic State between 1991 and 2000 by Water Resource Inventory Area



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Appendices

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A. Washington Hydrography Framework Metadata

What does this data set describe?

Title: Washington Hydrology Framework 100k Water Bodies
Abstract:
The hydrology (HYDRO) data layer represents a dynamic segmentation coverage that holds data on waterbodies within Washington State.
Supplemental_Information:
(1) Washington State is divided into two State Plane Zones, north and south. For this data set, north zone data coordinates have been converted to south zone coordinates. (2) Time period of content was derived from an estimated range of publication dates from USGS 1:100,000 scale quadrangles encompassing the state of Washington (from which base data were originally compiled). Specific publication dates should be referenced from individual quadrangles. (3) Initial digital data set was acquired from the Washington Department of Fish and Wildlife. Data shifted to dynamic segmentation under funding from the Bonneville Power Administration. (BPA) and is generally referred to as PNW Hydrography Data or PNW data.
(4) Ecology's data update phase was completed on 06/1998. The focus of this effort was on waterbody attribute cleanup and enhancement, waterbody indexing and unique ID generation, and watercourse routing and ID generation for canals and ditches.

1. **How should this data set be cited?**

   Pacific State Marine Fisheries Commission and Washington State Department of Fish and Wildlife, 19970901, Washington Hydrology Framework 100k Water Bodies, Olympia, Washington.

   Online Links:

   - \\Ecyhqnas01\admin\state\hydrofw\wtrbdy

2. **What geographic area does the data set cover?**

   West_Bounding_Coordinate: -124.901372
   East_Bounding_Coordinate: -116.140240
   North_Bounding_Coordinate: 49.050890
   South_Bounding_Coordinate: 45.478446

3. **What does it look like?**

   wb100k.gif (GIF)
   Simple image

4. **Does the data set describe conditions during a particular time period?**

   Beginning_Date: 1953
   Ending_Date: 1997
   Currentness_Reference:
   REQUIRED: The basis on which the time period of content information is determined.

5. **What is the general form of this data set?**

   Geospatial_Data_Presentation_Form: vector digital data

6. **How does the data set represent geographic features?**

   a. **How are geographic features stored in the data set?**

   This is a Vector data set. It contains the following vector data types (SDTS terminology):

   - Complete chain (9244)
   - Label point (7808)

- GT-polygon composed of chains (7808)
- Point (24288)
- Composite object (7026)
- Composite object (7808)

b. **What coordinate system is used to represent geographic features?**

Grid_Coordinate_System_Name: State Plane Coordinate System 1927
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 4602
Lambert_Conformal_Conic:
Standard_Parallel: 45.833333
Standard_Parallel: 47.333333
Longitude_of_Central_Meridian: -120.500000
Latitude_of_Projection_Origin: 45.333333
False_Easting: 2000000.000000
False_Northing: 0.000000

Planar coordinates are encoded using coordinate pair
Abscissae (x-coordinates) are specified to the nearest 0.000980
Ordinates (y-coordinates) are specified to the nearest 0.000980
Planar coordinates are specified in survey feet

The horizontal datum used is North American Datum of 1927.
The ellipsoid used is Clarke 1866.
The semi-major axis of the ellipsoid used is 6378206.400000.
The flattening of the ellipsoid used is 1/294.978698.

7. **How does the data set describe geographic features?**

`wtrbdy.aat`
Arc Attribute Table 1:100,000-scale Hydrography layer for Washington State.
`FID`
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

`Shape`
Feature geometry. (Source: ESRI)

Coordinates defining the features.

`FNODE#`
Internal node number for the beginning of an arc (from-node). (Source: ESRI)

Whole numbers that are automatically generated.

`TNODE#`
Internal node number for the end of an arc (to-node). (Source: ESRI)

Whole numbers that are automatically generated.

`LPOLY#`
Internal node number for the left polygon. (Source: ESRI)

Whole numbers that are automatically generated.

`RPOLY#`
Internal node number for the right polygon. (Source: ESRI)

Whole numbers that are automatically generated.

`LENGTH`
Length of feature in internal units. (Source: ESRI)

Positive real numbers that are automatically generated.

WTRBDY#
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

WTRBDY-ID
User-defined feature number. (Source: ESRI)
WTRBDY_NR
Unique latitude/longitude feature identifier
WS_LLID_NR
Waterbody latitude/longitude identification number
WS_END_AD
Waterbody end address
WS_BEGIN_AD
Waterbody begin address
WS_CART_FTR_CD
Waterbody cartographic code
WS_TYPE_CD
Waterbody type code
wtrbdy.pat
Polygon Attribute Table 1:100,000-scale Hydrography layer for Washington State.
FID
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

Shape
Feature geometry. (Source: ESRI)

Coordinates defining the features.

AREA
Area of feature in internal units squared. (Source: ESRI)

Positive real numbers that are automatically generated.

PERIMETER
Perimeter of feature in internal units. (Source: ESRI)

Positive real numbers that are automatically generated.

WTRBDY#
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

WTRBDY-ID
User-defined feature number. (Source: ESRI)
WB_LLID_NR
Waterbody longitude/latitude identifier number (Source: The identifier is based on position of the polygon label point.)

Value	Definition

`WB_HYDR_FTR_CD`

Waterbody hydrographic feature code (Source: Used to describe the hydrographic feature type that the waterbody polygon represents)

Value	Definition
DC	Ditches, canals, flumes
ES	Bays, estuaries, and oceans
GL	Glaciers or permanent snowfields
IM	Impoundments
IS	Islands
IW	Impounded wet areas
LA	Lakes and ponds
PP	Pipelines and water conveyance structures
SC	Side channels
SP	Springs and seeps
ST	Streams and rivers
UN	Unknown or unclassified

`WB_CART_FTR_CD`

Waterbody cartographic feature code (Source: Code used to describe the cartographic feature type that the waterbody polygon represents.)

Value	Definition
100	Alkali flat
101	Reservoir
103	Glacier or permanent snowfield
105	Inundation
106	Fish hatchery or farm
107	Industrial water impoundment
109	Sewage disposal pond or filtration bed
110	Tailings pond
111	Marsh, wetland, swamp, bog
114	Cranberry bog
115	Flats (tidal, mud, sand, gravel)
116	Bay, estuary, gulf, ocean or sea
117	Shoal

300	Spring or seep
400	Rapids
401	Falls
402	Gravel pit or quarry filled with water
406	Dam or weir
407	Canal lock or sluice gate
408	Spillway
410	Exposed rock
412	Stream or river
414	Ditch or canal
415	Aqueduct
417	Penstock
418	Siphon
419	Channel in water area
420	Wash or ephemeral drain
421	Lake or pond
422	Reef
423	Sand or gravel in open water
425	Fish ladder
466	Pier, jetty, breakwater, dock, wharf or causeway
901	Impoundment
902	Island
999	Unknown or unclassified

WB_GNIS_NM
Waterbody GNIS name (Source: The name of the waterbody as contained within the Geographic Names Information System (GNIS) which is maintained by the USGS.)

WB_GNIS_NR
Waterbody GNIS (Geographic Names Information System) number (Source: The unique identifier number assigned to each feature name represented within the GNIS database. This number is used to insert and/or update waterbody names stored in the framework hydrography database. Not all features contained within the coverage will have GNIS number)

Value	Definition
110	Single line water course
120	Center line of water course through waterbody
200	Marine mainland shoreline
300	Marine island shoreline
400	Waterbody shoreline
410	Freshwater island shoreline
999	Unclassified

WB_PERIOD_CD
Waterbody periodicity code (Source: Classification of a waterbodies in terms of the seasonal behavior of the feature over time or in terms of its surface flow.)

Value	Definition
dry	Dry land. Indicates an island.
eph	Ephemeral. Waterbodies that exist only as a result of storm precipitation.
int	Intermittent or seasonal. Waterbodies that are dry during certain times of the year.
per	Perennial. Waterbodies that essentially exist year round.
unk	Unknown or Unclassified. Used when condition information is unknown or unclassified.

wtrbdy.ratws
Waterbody route attribute table
FID
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

Shape
Feature geometry. (Source: ESRI)

Coordinates defining the features.

WS#
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

WS-ID
User-defined feature number. (Source: ESRI)
WS_LLID_NR
Latitude/longitude number

WS_DATUM_CD
Datum code

Value	Definition
ehw	Extreme high water
elw	Extreme low water
fw	Freshwater
mhhw	Mean higher water
mhw	Mean high water
mllw	Mean lower low water
mlw	Mean low water
na	Does not constitute a shoreline. Not datum associated

WS_DFLT_SHORE_CD
Water feature shore code
wtrbdy.patwb
Waterbody region attribute table
FID
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

Shape
Feature geometry. (Source: ESRI)

Coordinates defining the features.

AREA
Area of feature in internal units squared. (Source: ESRI)

Positive real numbers that are automatically generated.

PERIMETER
Perimeter of feature in internal units. (Source: ESRI)

Positive real numbers that are automatically generated.

WB#
Internal feature number. (Source: ESRI)

Sequential unique whole numbers that are automatically generated.

WB-ID
User-defined feature number. (Source: ESRI)
WB_LLID_NR
Waterbody longitude/latitude identifier number (Source: The identifier is based on position of the polygon label point.)

WB_HYDR_FTR_CD
Waterbody hydrographic feature code (Source: The code used to describe the hydrographic feature type that the waterbody polygon represents.)

Value	Definition
DC	Ditches, canals, flumes
ES	Bays, estuaries, and oceans
GL	Glaciers or permanent snowfields
IM	Impoundments
IS	Islands
IW	Impounded wet areas
LA	Lakes and ponds
PP	Pipelines and water conveyance structures
SC	Side channels to rivers or stream
SP	Springs and seeps
ST	Streams and rivers
UN	Unknown or unclassified

WB_CART_FTR_CD
Waterbody cartographic feature code (Source: The code used to describe the cartographic feature type that the waterbody polygon represents.)

Value	Definition
100	Alkali flat
101	Reservoir
103	Glacier or permanent snowfield
105	Inundation
106	Fish hatchery or farm
107	Industrial water impoundment
109	Sewage disposal pond or filtration bed
110	Tailing pond
111	Marsh, wetland, swamp, bog
114	Cranberry bog
115	Flats (tidal, mud, sand, gravel)
116	Bay, estuary, gulf, ocean or sea
117	Shoal

300	Spring or seep
400	Rapids
401	Falls
402	Gravel pit or quarry filled with water
406	Dam or weir
407	Canal lock or sluice gate
408	Spillway
410	Exposed rock
412	Stream or river
414	Ditch or canal
415	Aqueduct
417	Penstock
418	Siphon
419	Channel in water area
420	Wash or ephemeral drain
421	Lake or pond
422	Reef
423	Sand or gravel in open water
425	Fish ladder
466	Pier, jetty, breakwater, dock, wharf or causeway
901	Impoundment
902	Island
999	Unknown or unclassified

`WB_GNIS_NM`
Waterbody GNIS name (Source: The name of the waterbody as contained within the Geographic Names Information System (GNIS) which is maintained by the USGS.)
`WB_GNIS_NR`
Waterbody GNIS (Geographic Names Information System) number (Source: GNIS database)
Entity_and_Attribute_Overview:
This layer defines waterbody entities. A set of attributes identify and describe these features. Descriptive identifiers include a set of unique waterbody numbers, waterbody IDs, upper and lower address values, and an associated river reach number. Other information included in these attributes are a stream source code for waterbody entities, a waterbody name if applicable, and topological information about each polygon.

Entity_and_Attribute_Detail_Citation:
Complete documentation can be found in the Washington 100K Framework Data Dictionary available through Ecology. Information is available on-line at Ecology's GIS Home page. Hardcopy documentaion can be obtained by contacting the metadata contact person mentioned at the close of this documentation.

Who produced the data set?

1. **Who are the originators of the data set?** (may include formal authors, digital compilers, and editors)

    - Pacific State Marine Fisheries Commission and Washington State Department of Fish and Wildlife

2. **Who also contributed to the data set?**

    USGS, Washington Department of Fish and Wildlife, Pacific States Marine Fisheries Commission

3. **To whom should users address questions about the data?**

    Washington State Department of Ecology
    c/o Dan Saul
    Senior GIS Analyst
    PO Box 47600
    Olympia, Washington 98504-7600
    United States of America

    (360) 407-6419 (voice)
    (360) 407-6493 (FAX)
    dsau461@ecy.wa.gov

    Hours_of_Service: 8:00am - 5:00pm (Pacific)

Why was the data set created?

For statewide planning and analysis applications and general mapping reference. Provides the framework by which to hang a variety of water related information such as fish habitat, water quality, and water quantity.

How was the data set created?

1. **From what previous works were the data drawn?**

    (source 1 of 1)
    Pacific States Marine Fisheries Commission, 19970901, Stream Net River Reach:, Olympia, Washington.

2. **How were the data generated, processed, and modified?**

    Date: 1987 (process 1 of 3)
    This Digital Line Graph was digitized from the USGS source quadrangle, by either the National Mapping Division, one of their cooperators, or one of their contractors. The digital data were produced by on of the following methods. -scanning a stable-based copy of the graphic materials. The scanning process captured the digital data at a scanning resolution of at least 0.001 inches; the resulting raster data were vectorized and then attributed on an interactive editing station. - scanning the paper map. The scanning process captured the digital data at a scanning resolution of at least 0.001 inches; the resulting raster data were vectorized and then attributed on an interactive editing station. -scanning a stable-based copy of the graphic materials. The resulting raster data were then manually digitized and attributed on an interactive editing station. The resolution of the digital data is at least 0.001 inches. -scanning the paper map. The resulting raster data were then manually digitized and attributed on an interactive editing station. The resolution of the digital data is at least 0.001 inches. -manually digitizing from a stable-based copy of the graphic material using a digitizing table to capture the digital data at a resolution of at least 0.001 inches; attribution was performed either as the data were digitized, or on an interactive edit station after the digitizing was

completed. -manually digitizing from the paper map using a digitizing table to capture the digital data at a resolution of at least 0.001 inches; attribution was performed either as the data were digitized, or on an interactive edit station after the digitizing was completed. The determination of the DLG production method was based on various criteria, including feature density, feature symbology, and availability of production systems. Four control points corresponding to the four corners of the quadrangle were used for registration during data collection. AN eight parameter projective transformation was performed on the coordinates used in the data collection and editing systems to register the digital data to the internal coordinates used in PROSYS, and a four parameter linear transformation was performed from the PROSYS internal coordinates to Universal Transverse Mercator (UTM) grid coordinates. The DLG data were checked for position by one of the following processes: -comparing plots of the digital data to the graphic source. - comparing the digital data to the digital raster scan. DLG data classification was checked by at least one of the following processes. - comparing plots of the digital data to the graphic source. - comparing the digital data to the digital raster scan.

Person who carried out this activity:

Washington State Department of Ecology
c/o Dan Saul
Senior GIS Analyst
PO Box 47600
Olympia, Washington 98504-7600
United States of America

360-407-6419 (voice)
360-407-6493 (FAX)
dsau461@ecy.wa.gov

Hours_of_Service: 0800 - 1600
Contact_Instructions:
In addition to the address there are ESIC offices throughout the country. A full list of these offices is at : URL <http://www-nmd.usgs.gov/esic/esic_index.html>
Date: 1901 (process 2 of 3)
The PNW River Reach Files were constructed using ARC/INFO versions 4.0 and 5.0. A unique conflation algorithm was developed by the USGS that transferred the reach identifiers from the RF2 to the new 1:100,000-scale hydrography. The 1:100,000-scale hydrography were constructed from scanned 1:24,000 and 1:63,000-scale separates and then edited. Most, but not all hydrographic features found on these two larger scale products will be found in the PNW Reach Files. Waterbody features such as lakes, reservoirs, defined wetlands, double-banked streams, and others were moved to a separate 'banks' coverage.

Generalized procedures for constructing 100K scale Banks coverages: 1. Read 100K hydrography DLG's for each map into GIS. 2. Edgematch north and west edges of each map to adjacent 100K quads. 3. CLIP each 100K quad with adjusted Hydrologic Unit boundary. 4. APPEND clipped quad pieces together. 5. Correct internal node errors using automated snapping. 6. Remove non-attributed pseudo nodes. 7. Copy polygons to Waterbody coverage. 8. Edit out double-banked streams, shorelines,and braided areas and put into Waterbodies coverage. 1. Read 100K hydrography DLG's for each map into GIS. 2. Edgematch north and west edges of each map to adjacent 100K quads. 3. CLIP each 100K quad with adjusted Hydrologic Unit boundary. 4. APPEND clipped quad pieces together. 5. Correct internal node errors using automated snapping. 6. Remove non-attributed pseudo nodes. 7. Copy polygons to Waterbody coverage. 8. Edit out double-banked streams, shorelines,and braided areas and put into Waterbodies coverage.

Person who carried out this activity:

Matt Freed
Pacific States Marine Fisheries Commission
Project Lead
Date: 1998 (process 3 of 3)
The Washington Hydrography Framework 100k Water Body coverage were constructed from the Streamnet banks coverages. Enhancements made were the editing of polygon attributes for waterbody type

code and geographic feature name, creation of a unique identifier based on the latitude/longitude of the waterbody centroid, and the construction of routes and indexing on the shorelines of certain waterbody types.

The framework processing procedures were:

1. verifying the DLG waterbody type codes for each polygon 2. assigning the GNIS feature name to waterbody polygons 3. assigning a unique Lat/Long identifier to each waterbody polygon (including islands) 4. building routes on the shorelines for waterbodies of types 101, 115, 116, and 421. 5. calculate indexes on the routed waterbody shorelines in a clockwise direction from the southernmost point on the shoreline 6. calculate an index for the main marine shoreline starting at Point Roberts and continuing southward to the Columbia River.

Person who carried out this activity:

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Senior GIS Analyst
PO Box 47600, 300 Desmond Drive
Olympia, Washington 98504-7600
United States of America

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(360) 407-6493 (FAX)
dsau461@ecy.wa.gov

Hours_of_Service: 8:00am-4:30pm PDT

How reliable are the data; what problems remain in the data set?

1. **How well have the observations been checked?**

   Data attributes values are created and updated within the context of rigorous editing routines. Values are checked for validity within a group of specific ranges or within specific sets of codes. Attribute accuracy of data within the initial phase was tested by manually comparing digital products to the source maps.

2. **How accurate are the geographic locations?**

   Accuracy of this dataset is based upon the use of USGS source quadrangles which are compiled to meet National Map Accuracy Standards. NMAS horizontal accuracy requires that at least 90 percent of points tested are within 0.02 inches of the true position (on the map). The digital data are estimated to contain a horizontal positional error of less than or equal to 0.003 inches standard error in the two component directions relative to the source quadrangle. Comparison to the graphic source is used as control to assess digital positional accuracy. Cartographic offsets may be present on the graphic source, due to scale and legibility constraints.

3. **How accurate are the heights or depths?**

   The vertical positioinal accuracy is based upon the use of USGS source quadrangles which are compiled to meet NMAS. NMAS vertical accuracy requires that at least 90 percent of well defined points tested be within one half contour interval of the correct value. Comparison to the graphic source is used as control to assess digital positional accuracy. The file has undergone digital revision. Accuracy of the digital data meets the class 1 positional accuracy specifications in the draft United States National Cartographic Standards for Spatial Accuracy.

4. **Where are the gaps in the data? What is missing?**

   Spatial completeness: Statewide coverage. Data Attribute Completeness: Complete.

5. **How consistent are the relationships among the observations, including topology?**

   Specified spatial processing tolerances are used to snap arc over-shoots to proximal nodes. Remaining anomalous objects falling outside of specified tolerances are flagged by the software and manually corrected for logical consistency.

How can someone get a copy of the data set?

Are there legal restrictions on access or use of the data?
Access_Constraints: none
Use_Constraints: none

1. **Who distributes the data set?** (Distributor 1 of 1)

   Washington State Department of Ecology
   c/o Richard Kim
   Spatial Database Administrator
   P.O. Box 47600
   Olympia, Washington 98504-7600
   United States of America

   (360) 407-6121 (voice)
   (360) 407-6493 (FAX)
   rkim461@ecy.wa.gov

   Hours_of_Service: 8:00am - 5:00pm

2. **What's the catalog number I need to order this data set?**

   `Downloadable Data`

3. **What legal disclaimers am I supposed to read?**

   The Washington State Department of Ecology provides these geographic data "as is." Ecology makes no guarantee or warranty concerning the accuracy of information contained in the geographic data. Ecology further makes no warranties, either expressed or implied as to any other matter whatsoever, including, without limitation, the condition of the product, or its fitness for any particular purpose. The burden for determining fitness for use lies entirely with the user. Although these data have been processed successfully on Ecology computers, no warranty, expressed or implied, is made by Ecology regarding the use of these data on any other system, nor does the fact of distribution constitute or imply any such warranty. In no event shall Ecology have any liability whatsoever for payment of any consequential, incidental, indirect, special, or tort damages of any kind, including, but not limited to, any loss of profits arising out of use of or reliance on the geographical data or arising out of the delivery, installation, operation, or support by Ecology.

4. **How can I download or order the data?**

   - **Availability in digital form:**

     Data format: ARCE (version 8.0.2) ArcInfo export format (E00) Size: 11.633

     Network links:

   - **Cost to order the data:** $75/hour, one hour minimum.

- **Special instructions:**

  Digital data order form is available at <http://www.ecy.wa.gov/services/gis/data/digital.doc>
- **How long will it take to get the data?**

  One week
- **Availability in non-digital form:**

  Custom map
- **Cost to order the data:** $75 per hour, one hour minimum
- **Special instructions:**

  Contact Richard Kim, Washington State Department of Ecology
- **How long will it take to get the data?**

  Variable
- **Availability in digital form:**

  Data format: Size: 11.633
- **Cost to order the data:**

5. **Is there some other way to get the data?**

   Available in other formats, such as CD-ROM and 8mm tape by request. Please contact: Information Resources and Support Section, GIS Unit, Washington State Department of Ecology.

Who wrote the metadata?

Dates:

Last modified: 14-Nov-2002

Metadata author:

Washington State Department of Ecology
c/o Richard Kim
Spatial Database Administrator
P.O. Box 47600
Olympia, Washington 98504-7600
United States of America

(360) 407-6121 (voice)
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rkim461@ecy.wa.gov

Hours_of_Service: 8:00am - 5:00pm

Metadata standard:

FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

Metadata extensions used:

- <http://www.ecy.wa.gov/services/gis/data/hydro/wahyfw_100k.htm>
- <http://www.esri.com/metadata/esriprof80.html>

B. LandSat® Satellite Imagery Metadata for 1991

Identification_Information:
Citation:
Citation_Information:
Originator: Cassidy, K. M.
Publication_Date: 19970101
Title:
Washington Gap Project 1991 Land Cover for Washington State
Edition: Version 5
Publication_Information:
Publication_Place: Seattle, WA
Publisher:
Washington Cooperative Fish and Wildlife Research Unit, University of Washington
Online_Linkage: <ftp://ftp.dfw.wa.gov/pub/gapdata/lcv5>
Larger_Work_Citation:
Citation_Information:
Originator: Cassidy, K. M.
Publication_Date: 19970101
Title:
Land cover of Washington State: Description and management
Series_Information:
Series_Name:
Gap Analysis of Washington State - Final Report
Issue_Identification: Volume 1
Publication_Information:
Publication_Place: Seattle, WA
Publisher:
Washington Cooperative Fish and Wildlife Research Unit, University of Washington
Other_Citation_Details:
This volume is the first volume of the 5-volume set (with one supplement), titled "Gap Analysis of Washington State - Final Report".
Description:
Abstract:
Polygon land cover and land use data for Washington State derived from 1991 TM data, with a nominal minimum mapping unit of 100 hectares.
Purpose:
To map the land cover of Washington State, to aid in identification of conservation priorities, and to serve as a basis for modeling terrestrial vertebrate distributions.
Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 19910522
Ending_Date: 19910803
Currentness_Reference: TM scene dates
Status:
Progress: Complete
Maintenance_and_Update_Frequency:
Version 5 has had one update, to version 6. The changes between the two versions are fairly minor: a bit more detail was added in Adams County and in Asotin County. Version 6 and associated data dictionary information may be downloaded from <ftp://ftp.dfw.wa.gov/pub/gapdata/lcv6>
Spatial_Domain:

Description_of_Geographic_Extent: Washington State
Bounding_Coordinates:
West_Bounding_Coordinate: -125
East_Bounding_Coordinate: -116.875
North_Bounding_Coordinate: 49
South_Bounding_Coordinate: 45.5
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: Land cover
Theme_Keyword: Ecozone
Theme_Keyword: Ecoregion
Place:
Place_Keyword_Thesaurus: None
Place_Keyword: Pacific Northwest
Place_Keyword: Washington
Stratum:
Stratum_Keyword_Thesaurus: None
Stratum_Keyword: none
Temporal:
Temporal_Keyword_Thesaurus: None
Temporal_Keyword: none
Taxonomy:
Keywords/Taxon:
Taxonomic_Keywords: Vegetation
Access_Constraints: None
Use_Constraints: None. User should be aware of scale limitations, however.
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly M. Cassidy
Contact_Organization:
Washington Cooperative Fish and Wildlife Research Unit
Contact_Position:
Washington State Gap Analysis Project Leader
Contact_Address:
Address_Type: Mailing and Physical Address
Address:
Washington Cooperative Fish and Wildlife Research Unit
Address: MS 357980
Address: University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195
Country: USA
Contact_Voice_Telephone: 206-543-6475
Hours_of_Service:
8:00 a.m. to 4:00 p.m. Monday Through Friday
Contact_Instructions:
Kelly Cassidy will not be at the Coop Unit after 1998, but they will be able to provide a contact location
Browse_Graphic:
Browse_Graphic_File_Name: <ftp://ftp.dfw.wa.gov/pub/gapdata/lcv5/browse.jpg>
Browse_Graphic_File_Description: Gap vegetation, NW Washington
Browse_Graphic_File_Type: JPEG
Native_Data_Set_Environment:
Arc/Info 7.0

Data_Quality_Information:

Attribute_Accuracy:

Attribute_Accuracy_Report:

No accuracy assessment was performed on land use polygons. We collected non-random ground data, but the ground data were all used to assist in labeling; none were set aside for accuracy assessment. Since we knew in advance that we were unlikely to afford an accuracy assessment, we avoided labeling beyond the level at which we felt reasonably confident. Thus, we delineated vegetation zones, for example, but did not specify cover to dominant species, which is difficult to reliably determine with TM imagery. Actual accuracy will depend on the amount of ground data for an area, the familiarity of the labeler with the area, the simplicity or complexity of the cover, cover fragmentation, and scene date.

Quantitative_Attribute_Accuracy_Assessment:

Attribute_Accuracy_Value: Unknown

Attribute_Accuracy_Explanation:

No accuracy assessment was done on land cover/land use attributes

Logical_Consistency_Report:

Polygons were checked to verify that there was one and only one label for each polygon using the Arc facility LABELERRORS. All polygons have a unique polygon ID. The cover was not cleaned of all dangling arcs. Arcs may also be split at places other than intersections.

Completeness_Report:

Land cover for the entire state was completed, but some areas of the state are better delineated than others because of ease of cover identification, ruggedness of terrain, fragmentation of cover, and familiarity of the labeler with the area. The nominal minimum mapping units were 100 hectares for non-wetland cover and 40 hectares for wetlands. In practice, some smaller areas were delineated. In particular, all offshore islands large enough to be seen on TM imagery (at least approximately 50 meters wide) were delineated because of their importance to nesting shore birds. Conversely, some polygons are much larger than 100 hectares because of very uniform cover types (e.g., large agricultural fields in the Columbia Basin) or because of lack of time (e.g., many areas of the Cascades with a complex mix of forest and small cuts need further delineation). Although the size of some important cover types and stands were below the minimum mapping units, we initially adhered to them. As mapping progressed, we tended toward a smaller mapping unit more closely matched to the landscape and stand size. For example, much US Forest Service land is a patchwork of 5- to 30-hectare cuts among old forest; a 100-hectare mapping unit gives a poor representation of this landscape. The effort to map these features, was not uniform because of time constraints, but fragmented forest landscapes are delineated below the 100-hectare mapping unit in some parts of the state. Another common problem was adequate representation of highly fragmented developed areas, where boundaries between development levels were unclear. Often, major roads were used as convenient boundaries, but urban areas, especially the Spokane area, needed more work.

Positional_Accuracy:

Horizontal_Positional_Accuracy:

Horizontal_Positional_Accuracy_Report:

The positional accuracy of the TM scenes (root mean square error) on which the map is based is 1 to 2 pixels (25 to 50 meters). Polygon delineation was performed with the TM scenes as a backdrop, but often done with a large area displayed, so the delineator could see patterns over a large area. The positional accuracy of polygon boundaries for cover types with an abrupt border is generally approximately 4 or 5 pixels (100 to 125 meters). For cover types with fuzzy boundaries, such as in highly fragmented urban landscapes or in forests where cover type changes gradually, positional accuracy is somewhat indeterminate. Underlying TM scenes were georectified and terrain corrected by EOSAT.

Vertical_Positional_Accuracy:

Vertical_Positional_Accuracy_Report: See horizontal

Positional_Accuracy:

Lineage:

Methodology:

Methodology_Type:

On-screen delineation with TM scenes as a backdrop

Methodology_Identifier:

Methodology_Keyword_Thesaurus: None
Methodology_Description:
Polygons were delineated at a nominal minimum mapping unit of 100 hectare using spectrally clustered TM imagery as a backdrop.
Methodology_Citation:
Source_Information:
Source_Citation:
Citation_Information:
Originator: TM scenes from LandSat® 5
Publication_Date: 1991
Title: 1991 TM scenes for Washington State
Other_Citation_Details:
16 full or partial TM scenes. All but one were from 1991. See Cassidy 1997 for a list of scenes and dates.
Larger_Work_Citation:
Citation_Information:
Originator: Cassidy, K. M.
Publication_Date: 19970101
Title:
Land cover of Washington State: Description and management
Series_Information:
Series_Name:
Gap Analysis of Washington State - Final Report
Issue_Identification: Volume 1
Publication_Information:
Publication_Place: Seattle, WA
Publisher:
Washington Cooperative Fish and Wildlife Research Unit, University of Washington
Other_Citation_Details:
This volume is the first volume of the 5-volume set (with one supplement), titled "Gap Analysis of Washington State - Final Report".
Type_of_Source_Media: Digital raster files
Source_Time_Period_of_Content:
Time_Period_Information:
Range_of_Dates/Times:
Beginning_Date: 19910522
Ending_Date: 19910803
Source_Currentness_Reference: Ground Condition
Source_Citation_Abbreviation: None
Source_Contribution: Primary basis of land cover map
Process_Step:
Process_Description:
Satellite data were spectrally clustered and colored, with colors indicating pixels of similar spectral reflectance. Individual spectral classes were not matched with specific land cover types, but spectrally clustered data were used as a backdrop for manual land cover polygon delineation and interpretation.
Process_Date: 1992 to 1996
Process_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Kelly M. Cassidy
Contact_Organization:
Washington Cooperative Fish and Wildlife Research Unit
Contact_Position:
Washington State Gap Analysis Project Leader
Contact_Address:
Address_Type: Mailing and Physical Address
Address:
Washington Cooperative Fish and Wildlife Research Unit

Address: MS 357980
Address: University of Washington
City: Seattle
State_or_Province: WA
Postal_Code: 98195
Country: USA
Contact_Voice_Telephone: 206-543-6475
Hours_of_Service:
8:00 a.m. to 4:00 p.m. Monday Through Friday
Contact_Instructions:
Kelly Cassidy will not be at the Coop Unit after 1998, but they will be able to provide a contact location

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method:
Vector

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name:
State Plane Coordinate System 1927
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 4602
Lambert_Conformal_Conic:
Standard_Parallel: 45.833333
Longitude_of_Central_Meridian: -120.5
Latitude_of_Projection_Origin: 45.333333
False_Easting: 609601.2192
False_Northing: 0
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: coordinate pair
Coordinate_Representation:
Abscissa_Resolution: 82.02
Ordinate_Resolution: 82.02
Planar_Distance_Units: feet
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1927
Ellipsoid_Name: Clarke 1866
Semi-major_Axis: 6378206.4
Denominator_of_Flattening_Ratio:
294.98

Entity_and_Attribute_Information:
Overview_Description:
Entity_and_Attribute_Overview:
Each polygon was labeled with several attributes: ecoregion; vegetation zone; primary, secondary, and tertiary land cover; the respective occupancy classes of the primary, secondary, and tertiary cover in each polygon; labeling date; the source of the information for the label if the label was based on information other than the appearance of the polygon from the satellite data; the person doing the labeling; and comments. An ecoregion was defined as a contiguous geographic area of similar climate and geologic history (e.g., the Blue Mountains or Northwest Cascades region). A vegetation zone was defined as an area in which moisture, temperature, elevation, and other environmental parameters combine to create conditions that favor similar vegetation communities (e.g., the Ponderosa Pine or Alpine/Parkland zone).

Primary, secondary, and tertiary cover types were recorded since the polygons were delineated with a 100 hectare minimum mapping unit for terrestrial cover types, and 40 hectares for wetlands; therefore, the land cover within a given polygon could be heterogeneous. The primary land cover was the actual land cover that occupied the greatest proportion of the area in a polygon (e.g., closed-canopy conifer forest or non-irrigated row-crop agriculture). Secondary and tertiary land covers, if needed, were the actual land covers that occupied the second and third greatest proportion of area in the polygon. Primary, secondary, and tertiary covers were each assigned one of six occupancy classes indicating the proportion of the polygon occupied by each.
Entity_and_Attribute_Detail_Citation:
A complete data dictionary (Microsoft Wordpad format) may be downloaded from
<ftp://ftp.dfw.wa.gov/pub/gapdata/lcv5>

Distribution_Information:
Distributor:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization:
Washington Department of Fish and Wildlife
Contact_Position:
Technical Services Manager - Wildlife Management Program
Contact_Address:
Address_Type: Mailing Address
Address: 600 Capitol Way North
City: Olympia
State_or_Province: Washington
Postal_Code: 98501
Country: USA
Contact_Voice_Telephone: 360-902-2515
Hours_of_Service:
8:00 a.m. to 4:00 p.m. Monday Through Friday
Resource_Description: Gap Landcover Version 5
Distribution_Liability:
Although these data have been processed successfully on a computer system at the Washington Department of Fish and Wildlife, no warranty expressed or implied is made regarding the accuracy or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data. It is strongly recommended that these data are directly acquired from a Washington Department of Fish and Wildlife server, and not indirectly through other sources which may have changed the data in some way. It is also strongly recommended that careful attention be paid to the contents of the metadata file associated with these data. The Washington Department of Fish and Wildlife shall not be held liable for improper or incorrect use of the data described and/or contained herein.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARCE
Format_Version_Number: Version 7.1
File_Decompression_Technique: gzip
Transfer_Size: 9.8
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name: <ftp://ftp.dfw.wa.gov/pub/gapdata/lcv5>
Network_Address:
Network_Resource_Name: <http://www.wa.gov/wdfw/wlm/gap/landcov.htm>
Fees: None
Custom_Order_Process: None

Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Ree Brannon
Contact_Organization: National GAP Analysis Program
Contact_Position: Senior GIS Analyst
Contact_Address:
Address_Type: mailing and physical address
Address: 530 S. Asbury St., Suite 1
City: Moscow
State_or_Province: ID
Postal_Code: 83843
Country: USA
Contact_Voice_Telephone: 208-885-3720
Contact_Facsimile_Telephone: 208-885-3618
Contact_Electronic_Mail_Address: abrannon@uidaho.edu
Hours_of_Service: 8:00 a.m. to 4:00 p.m. Monday Through Friday
Distribution_Liability:
Although these data have been processed successfully on a computer system at the U.S. Geological Survey, no warranty expressed or implied is made regarding the accuracy or utility of the data on any other system or for general or scientific purposes, nor shall the act of distribution constitute any such warranty. This disclaimer applies both to individual use of the data and aggregate use with other data. It is strongly recommended that these data are directly acquired from a U.S. Geological Survey server, and not indirectly through other sources which may have changed the data in some way. It is also strongly recommended that careful attention be paid to the contents of the metadata file associated with these data. The U.S. Geological Survey shall not be held liable for improper or incorrect use of the data described and/or contained herein.
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Format_Name: ARC/INFO
Digital_Transfer_Option:
Online_Option:
Computer_Contact_Information:
Network_Address:
Network_Resource_Name: http:/www.gap.uidaho.edu/gap
Offline_Option:
Offline_Media: CD-ROM
Recording_Format: ISO
Fees:
none

Metadata_Reference_Information:
Metadata_Date: 19981104
Metadata_Review_Date: 19981104
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization:
Washington Department of Fish and Wildlife
Contact_Position:
Technical Services Manager - Wildlife Management Program
Contact_Address:
Address_Type: Mailing Address

Address: 600 Capitol Way North
City: Olympia
State_or_Province: Washington
Postal_Code: 98501
Country: USA
Contact_Voice_Telephone: 360-902-2515
Hours_of_Service:
8:00 a.m. to 4:00 p.m. Monday Through Friday
Metadata_Standard_Name:
NBS Content Standards for National Biological Information Infrastructure Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Access_Constraints: None
Metadata_Use_Constraints: None
Metadata_Security_Information:
Metadata_Security_Classification_System: None
Metadata_Security_Classification: Unclassified
Metadata_Security_Handling_Description:
None

The LandSat® Thematic Mapper Satellite© (TM) scenes obtained from the Washington Gap Land Cover study include:

Scene Path/Row	Scene Date	Washington Gap Scene Filename	View Washington Gap Scene
43/26	8/3/91	priest.img	Priest Lake
43/27	7/2/91	spokane.img	Spokane
43/28	7/2/91	bulemts.img	Blue Mountains
44/26	5/22/91	republic.img	Republic
44/27	5/22/91	moses.img	Moses Lake
44/28	5/22/91	tricity.img	Tricity
45/26	9/18/91 and 5/31/92	okanogan.img	Okanogan
45/27	8/1/91	wenatchee.img	Wenatchee
45/28	8/1/91	yakima.img	Yakima
46/26	7/7/91	n_cascades.img	North Cascades
46/27	7/7/91	puget.img	Puget
46/28	7/7/91	sthelens.img	St. Helens
47/26 (quarter scene)	7/30/91	sanjuan.img	San Juans
47/27	7/30/91	olympics.img	Olympics
47/28 (quarter scene)	7/30/91	astoria.img	Astoria
48/26-27 (movable scene)	7/5/91	flattery.img	Cape Flattery

Background

Each of the 7 Bands of each scene were originally in BIL files that were converted to ArcInfo grid format using the ArcInfo IMAGEGRID command or ArcView Spatial Analyst 1.1.

The LandSat® BIL files were obtained from Kelly Cassidy and were the original scenes from 1991 that were used for the WA GAP land cover analyses. The ArcInfo header files for the BIL images were re-constructed from the original header information in the files obtained from Kelly Cassidy.

The BIL files were originally in UTM, Zone 10 or 11, NAD27, meters, and they were converted to grids using either IMAGEGRID with the bil2img.aml or by using ArcView Spatial Analyst 1.1 instead. The processing of the grids was continued using either the bil2img.aml with ArcInfo to re-project the grids, or by using the grid2img.aml for grids that were created from the BIL files using Spatial Analyst. These AMLs re-projected the grids from UTM, zone 10 or 11, NAD27, meters to stateplane, WA south zone, feet, NAD27.

The utm10-sp27.prj file contains the input and output parameters for the projection of the grids for each Band for scenes that were originally in UTM zone 10 projection:

```
input
projection utm
units meters
zone 10
datum NAD27
parameters
output
projection stateplane
units feet
zone 5626
datum NAD27
parameters
end
```

The utm11-sp27.prj file contains the input and output parameters for the projection of the grids for each Band for scenes that were originally in UTM zone 11 projection:

```
input
projection utm
units meters
zone 11
datum NAD27
parameters
output
projection stateplane
units feet
zone 5626
datum NAD27
parameters
end
```

The reprojected grids were then stacked and then converted to IMAGINE format using the grid2img.aml or bil2img.aml with ArcInfo. The resulting IMAGINE file contains all seven Bands of the image in the stateplane, Washington South Zone, feet, NAD27 Projection.

Since the IMAGINE file format contains the georeferencing information, the name of the .igw created by the ArcInfo gridimage command was changed by appending _null to the original name. The purpose of appending _null to the file name was to allow ArcView to ignore the .igw file if it was placed in the same directory as the .img file.

Reference for the source of the scenes

Cassidy, Kelly M. 1997. Land Cover of Washington State,
Description and Management. Washington State Gap Analysis Final Report.
Volume I. Washington Cooperative Fish and Wildlife Research Unit. University of Washington. Seattle, Washington.

National GAP Analysis Program Homepage

Credits

Data Steward: Greg Pelletier, Department of Ecology, Environmental Assessments Program, (360) 407-6485

Data Processing: Samantha Leskie, Department of Ecology, Environmental Assessments Program
Bob Huxford, Department of Natural Resources, (360) 902-1552

C. LandSat® Satellite Imagery Metadata for 2000

WARSC LS7 Metadata Template v1.0

Ver 1.0 - 4/16/02

Identification_Information:

Citation:

Citation_Information:

Originator: Washington State Remote Sensing Consortium (WARSC) - Olympia, WA

Publication_Date: 20020131

Geospatial_Data_Presentation_Form: remote-sensing image

Online_Linkage: n/a

Description:

Abstract: This geometrically terrain-corrected LandSat-7® image data set is made available through the Washington State Remote Sensing Consortium (WARSC). The data provided includes Bands 1, 2, 3, 4, 5, 6, 7, 8 and 9. See Process Description for additional details.

Purpose: This specific dataset is one of seventeen scenes purchased and terrain corrected to create a statewide coverage of LandSat-7® imagery from the year 2000 inventory.

Supplemental_Information: The LandSat® program provides a continuing stream of remote sensing data for monitoring and managing the Earth's resources. The launch of the LandSat-7® satellite on April 15, 1999, marks the addition of the latest satellite to the LandSat® satellite series. LandSats® 1, 2, and 3 carried the multispectral scanner (MSS) sensor and experimental return beam vidicon cameras. The LandSat-4® satellite carried the MSS and Thematic Mapper Satellite© (TM) sensors as does the still currently flying LandSat-5® satellite. The sixth satellite in the LandSat® series was unsuccessfully launched and did not achieve orbit. The LandSat-7® satellite carries the enhanced Thematic Mapper Satellite© plus (ETM+) sensor. The launch of the LandSat-7® satellite is part of an ongoing mission to provide quality remote sensing data in support of research and applications activities.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 20000616

Time_of_Day: 18:28:33

Currentness_Reference: ground condition

Status:

Progress: Complete

Maintenance_and_Update_Frequency: None Planned

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -118.27

East_Bounding_Coordinate: -115.29

North_Bounding_Coordinate: 49.86

South_Bounding_Coordinate: 47.86

Keywords:

Theme:

Theme_Keyword: LandSat-7®

Theme_Keyword: Remote Sensing WARSC DRAFT DOCUMENT

Theme_Keyword: TM

Theme_Keyword: Raster

Theme_Keyword: ETM+

Place_Keyword: Canada

Place_Keyword: Idaho

05/06/02

Theme_Keyword: Satellite Images

Theme_Keyword: Imagery

Theme_Keyword: Infrared Imagery

Theme_Keyword: Thematic Mapper+ Satellite©

Theme_Keyword: Radiance

Theme_Keyword: Visible Imagery

Theme_Keyword: Reflectance

Theme_Keyword: Thermal

Theme_Keyword: Panchromatic

Place:

Place_Keyword: USA

Place_Keyword: WA

Place_Keyword: Washington State

Place_Keyword: Montana

Place_Keyword: Stevens County

Place_Keyword: Pend Oreille County

Place_Keyword: Metaline

Place_Keyword: Sullivan Lake

Place_Keyword: Salmo Priest Wilderness

Place_Keyword: Selkirk Mountains

Place_Keyword: Kalispel Indian Reservation

Place_Keyword: Kaniksu National Forest

Place_Keyword: Colville National Forest

Access_Constraints: No redistribution outside the Washington State Remote Sensing Consortium without Consortium written permission.

Point_of_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Jeff Holm

Contact_Organization: Washington State Department of Information Services

Contact_Position:

Washington State Geographic Information Council Coordinator

Contact_Address:

Address_Type: mailing and physical address

Address: 1110 SE Jefferson Street

Address: P.O. Box 42445

City: Olympia

State_or_Province: WA

Postal_Code: 98504-2445

Country: USA

Contact_Voice_Telephone: (360) 902.3447

Data_Set_Credit:

Washington State Remote Sensing Consortium and EROS Data Center

Security_Information:

Security_Classification: Unclassified

Browse_Graphic:

Browse_Graphic_File_Name:

http://www.wa.gov/gic/tm7/acq01_images/4326_061600.jpg

Data_Quality_Information:

Attribute Accuracy:

Attribute Accuracy Report: Nominal ground sample distances or pixel sizes include 30 meters each for the six visible, near-infrared, and shortwave infrared Bands, 60 meters for the thermal infrared Band, and 15 meters for the panchromatic Band.

Logical Consistency Report: LandSat-7® data are collected from a nominal altitude of 705 kilometers in a near-polar, near-circular, Sun-synchronous orbit at an inclination of 98.2 degrees, imaging the same 183-km swath of the Earth's surface every 16 days.

Completeness Report: The orbital pattern equates to a 233-orbit cycle with a swath sidelap that varies from approximately 7 percent at the Equator to nearly 84 percent at 81 degrees north or south latitude. The LandSat® scenes are mapped to a global notation system called the Worldwide Reference System (WRS), annotating the nominal scene center of LandSat® imagery using Path and Row designators.

Positional Accuracy:

Horizontal Positional Accuracy:

Horizontal Positional Accuracy Report:

Number of EROS Geometric QA: Control Points 14; RMS Along Track 7.05; RMS Across Track 8.80; RMS Combined 11.30 - See summary report (often referred to as EROS Work Order Report) in Documentation Directory on CD - See WARSC QA/QC report in CD Documentation Directory

Lineage:

Source_Information:

Source_Citation:

Citation_Information:

Originator: USGS/EROS Data Center in Sioux Falls, SD

Publication_Date: 20000616

Publication_Time: 18:28:33

Title: EROS Data Center LandSat-7® Imagery 7043026000016850

Source_Scale_Denominator: Resolution 30 m

Type_of_Source_Media: CD-ROM

Source_Information:

Source_Citation:

Citation_Information:

Originator: Washington State Department of Natural Resources - Olympia, WA

Publication_Date: 20010206

Title: Washington State 30 meter DEM (resampled from USGS 10m DEM)

Source_Scale_Denominator: Resolution 30 m

Process_Step:

Process_Description: This geometrically terrain corrected data product was created using EROS Data Center's National LandSat® Archives Program L1T processing. Terrain correction utilized WA State Department of Natural Resources 30 meter DEM (resampled from USGS 10 meter DEM). Metadata about these 10 meter DEMs can be accessed through http://edcwww.cr.usgs.gov/webglis/index.html.

Resampling method was cubic convolution. EROS delivered data in NDF/BSQ format, WARSC reformatted for delivery in GEOTIFF. For details regarding the general NLAPS process please see http://edcwww.cr.usgs.gov/glis/hyper/guide/nlaps.html.

For specifics about this data product please see summary of processing history report (also referred to as Work Order Report) or full Processing History Report in Documentation Directory on CD 4 OF 5 WARSC DRAFT DOCUMENT 05/06/02

Process_Date: 20011012

Process_Time: 11:55:12

Process_Contact:

Contact_Information:

Contact_Person_Primary:
Contact_Person: EROS Data Center Customer Service
Contact_Organization: EROS Data Center
Contact_Position:
Contact_Voice_Telephone: 605-594-6151
Contact_Electronic_Mail_Address: custserv@usgs.gov
Cloud_Cover: <= 10
Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Raster
Raster_Object_Information:
Raster_Object_Type: Pixel
Row_Count: 7051
Column_Count: 7419
Vertical_Count: 9
Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: State Plane Coordinate System 1983
State_Plane_Coordinate_System:
SPCS_Zone_Identifier: 4602
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: row and column
Coordinate_Representation:
Abscissa_Resolution: 30
Ordinate_Resolution: 30
Planar_Distance_Units: meters
Geodetic_Model:
Horizontal_Datum_Name: North American Datum of 1983
Ellipsoid_Name: NAD83
Distribution_Information:
Distributor:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Jeff Holm
Contact_Organization: Washington State Department of Information Services
Contact_Position:

Washington State Geographic Information Council

Coordinator

Contact_Address:

Address_Type: mailing and physical address

Address: 1110 SE Jefferson Street

Address: P.O. Box 42445 05/06/02 WARSC DRAFT DOCUMENT 5 OF 5

City: Olympia

State_or_Province: WA

Postal_Code: 98504-2445

Country: USA

Contact_Voice_Telephone: 360.902.3447

Distribution_Liability: Although these data have been processed successfully on a computer system at the USGS, no warranty expressed or implied is made by the USGS or WARSC regarding the use of the data on any other system, nor does the act of distribution constitute any such warranty. The WARSC will warrant the delivery of this product in source computer-readable format and will offer replacement CD when the physical medium is delivered in damaged condition.

Requests for adjustment of credit must be made within 30 days from the date of this shipment from the order site.

Standard_Order_Process:

Digital_Form:

Digital_Transfer_Information:

Transfer_Size: 260 (approx. in megabytes)

Metadata_Reference_Information:

Metadata_Date: 20020111

Metadata_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization:

Washington State Remote Sensing Consortium

Contact_Person: Jeff Holm

Contact_Position:

Contact_Address:

Contact_Voice_Telephone: 360.902.3447

Metadata_Standard_Name:

FGDC Content Standards for Digital Geospatial

Metadata

Metadata_Standard_Version: FGDC-STD-001-1998

Metadata_Time_Convention: local time

LandSat-7® Websites

NASA LandSat-7® Gateway: http://landsat.gsfc.nasa.gov

USGS LandSat® Program Website: http://landsat7.usgs.gov/index.php

LandSat-7®, Science Data Users Handbook:
http://ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_toc.html

LandSat-7® Tutorial: http://rst.gsfc.nasa.gov/Front/tofc.html

This page is purposely left blank for duplex printing.

D. Ecoregion Coverage Metadata

FGDC Metadata for ORWA_ECO

Identification_Information:
  Citation:
    Originator: S Thiele, D Pater (MERSC) T Thorson (NRSC) J. Kagan(ONHP) C. Chappell(WSDNR)
    Publication_Date: unpublished
    Publication_Time:
    Title: Level III and IV Ecoregions of Oregon and Washington
    Edition: 1
    Geospatial_Data_Presentation_Form: map
    Series_Information:
      Series_Name:
      Issue_Identification:
    Publication_Information:
      Publication_Place:
      Publisher:
    Other_Citation_Details:
    Online_Linkage:
    Larger_Work_Citation:
    Scale_Denominator: 250,000

Description:

Abstract:
Ecoregions denote areas of general similarity in ecosystems and in the type quality, and quantity of environmental resources. This map depicts revisions and subdivisions of ecoregions, that was compiled at a relatively small scale (Omernik 1987). Compilation of this map, performed at the larger 1:250,000 scale, was part of a collaborative project between the United States Environmental Protection Agency, National Health and Environmental Effects Research Laboratory (NHEERL)- Corvallis, OR., the U.S. Forest Service, Natural Resources Conservation Service, Washington State Department of Natural Resources & the Oregon Natural Heritage Program. The ecoregions and subregion are designed to serve as a spatial framework for environmental resource management. The most immediate needs by the states are for developing reg biological criteria and water quality standards, and for setting management goals for nonpoint-source pollution. Explanation of the methods used to describe the ecoregions are given in Omernik (1995), Griffith et al. (1994), and Gallan et al. (1989). This map is a draft product of one of a few regional interagency collaborative projects aimed at obtaining consensus between the EPA, the NRCS, and the USFS regarding alignments of ecological regions.

Purpose:
Assist managers of aquatic and terrestrial resources in understanding the regional patterns of the realistically attainable quality of these resources.
Supplemental_Information:
Procedures_Used:
1) All ecoregion and subregion delineations are digitized from the U.S.G.S. 1:250,000 base maps. Prior to digitizing, each base map must be initialized to orient the map and relate it in geographic coordinates to the surface of the earth. When the registration tics are entered at the start of digitizing, a transformation error of <0.003 must be achieved in order to insure a high level of registration accuracy. The person responsible for digital data entry completes a data sheet describing coverage name, date of entry, and whether a topology for the coverage is established.
2) After each 1:250,000 base map has been digitized, a topology for each coverage is established. This function creates unique identities for each polygon.
3) Next, each base map is tested for polygon errors through an internal editing function. Errors are corrected for unlabeled polygons, unclosed polygons, or polygons with more than one label. Topology is reestablished for each coverage and tested again until no error are indicated.
4) The digital coverage is then plotted at the same scale as the original base map. This coverage is overlaid on a light table with the original, and visually inspected for replication of original lines with digitized lines. Two individuals independently inspect the coverage for accuracy.

Revisions:
Revision 1. 9/95. This coverage was appended from completed Level IV coverages in Oregon and Washington [Coast Range (completed 9/92), Blue Mountains and Columbia Plateau (7/95), Puget lowlands, Willamette Valley, Cascades, East Cascade Slope, North Cascades and Klamath Mountains ecoregions (6/95) 2. 6/96 update coverage. Delete 'hatched' areas. Consolidate all volcanics. Updated lines per Sandy and David's requests.

Reviews_Applied_to_Data:
Data was reviewed by David Pater, MERSC, 9/95.
Data was reviewed by David Pater and Sandy Bryce, Dynamac, 6/96.
Entity_and_Attribute_Overview:
ORWA_ECO.PAT
ECO - ecoregion ID code
1 Coast Range
1a Coastal lowlands
1b Coastal uplands
1c Low Olympics
1d Volcanics
1e Outwash
1f Willapa Hills
1g Mid-Coastal Sedimentary
1h Southern Oregon Coastal Mountains
1i Redwood Zone
2 Puget Lowland
2a Fraser Lowland
2b Eastern Puget Riverine Lowlands

2c San Juan Islands
2d Olympic Rainshadow
2e Eastern Puget Uplands
2f Central Puget Lowland
2g Southern Puget Prairies
2h Cowlitz/Chehalis Foothills
2i Cowlitz/Newaukum Prairie Floodplains
3 Willamette Valley
3a Portland/Vancouver Basin
3b Willamette River and Tributaries Gallery Forest
3c Prairie Terraces
3d Valley Foothills
4 Cascades
4a Western Cascades Lowlands and Valleys
4b Western Cascades Montane Highlands
4c Cascade Crest Montane Forest
4d Cascade Subalpine/Alpine
4e High South Cascades Montane Forest
4f Umpqua Cascades
4g Southern Cascades
9 Eastern Cascades Slopes and Foothills
9a Yakima Plateau & Slopes
9b Grand Fir Mixed Forest
9c Oak/Conifer East Cascade Columbia Foothills
9d Ponderosa Pine/Bitterbrush Woodland
9e Pumice Plateau Forest
9f Cold Wet Pumice Plateau Basins
9g Klamath/Goose Lake Warm Wet Basins
9h Fremont Pine/Fir Forest
9i Southern Cascade Slope
9j Klamath Juniper/Ponderosa Pine Woodland
10 Columbia Plateau
10a Channeled Scablands
10b Scabland Loess Islands
10c Umatilla Plateau
10d Okanogan Drift Hills
10e Pleistocene Lake Basin
10f Canyons and Dissected Uplands
10g Yakima Folds
10h Palouse Hills
10i Deep Loess Foothills
10j Nez Perce Prairie
10k Deschutes/John Day Canyons
11 Blue Mountains
11a John Day/Clarno Uplands

11b John Day/ Clarno Highlands
11c Maritime-Influenced Zone
11d Melange
11e Wallowas/Seven Devils Mountains
11f Canyons and Dissected Highlands
11g Snake and Salmon River Canyons
11h Continental Zone Highlands
11i Continental Zone Foothills
11j Batholith contact Zone
11k Blue Mountain Basins
11l Mesic Forest Zone
11m Subalpine Zone
12 Snake River Basin/High Desert
15 Northern Rockies
77 North Cascades
77a N. Cascades Lowland Forests
77b N. Cascades Highland Forests
77c N. Cascades Subalpine/Alpine
77d Pasayten/Sawtooth Highlands
77e Okanogan Pine/Fir Hills
77f Chelan Tephra Hills
77g Wenatchee/Chelan Highlands
77h Chiwaukum Hills and Lowlands
77i High Olympics
78 Klamath Mountains
78a Rogue/Illinois Valleys
78b Siskiyou Foothills
78c Umpqua Interior Foothills
78d Serpentine Siskiyous
78e Inland Siskiyous
78f Coastal Siskiyous
78g Klamath River Ridges

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Notes:
Level IV ecoregion lines were delineated by Sandy Thiele and David Pater on the paper 1:250,000 maps using a relatively thick marking pen (Sharpielike). Digitizing was done directly off of paper. Coast Range was digitized by Sue Pierson, Ogden, 1992. Columbia Plateau was digitized by F. Faure, 1994, second revision digitized by S. Azevedo, 1995. Blue Mtns. were digitized by S. Azevedo, 1995. Puget lowlands, Willamette Valley, Cascades, East Cascade Slope, North Cascades and Klamath Mountains ecoregions were digitzed by S. Azevedo, 1995.

The EPA's ecoregion ftp site may be reached passively from an internet browser by going to the following address, clicking on the appropriate state directory, and downloading the desired ecoregion file below:

ftp://ftp.epa.gov/wed/ecoregions