MODELING THE ENVIRONMENTAL PROTECTION AGENCY'S LEVEL IV ECOREGIONS WITHIN THE KLAMATH MOUNTAINS OF SOUTHERN OREGON AND NORTHERN CALIFORNIA:

A Geographic Information Systems Approach

By

Christopher Zanger

A RESEARCH PAPER

Submitted to

THE DEPARTMENT OF GEOSCIENCES

OREGON STATE UNIVERSITY

In partial fulfillment of the
Requirements for the
Degree of

MASTER OF SCIENCE

GEOGRAPHY PROGRAM

December 2004

Directed by
Dr. Dawn J. Wright

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Acknowledgements

There have been a number of people who have helped me throughout my master's work at Oregon State University. First and foremost, I would like to thank my major professor Dawn Wright; without her guidance, patience, and support this project would not have been possible. Dawn continued to support me throughout my time at OSU with an RAship with COMCI, a TA position as the campus GIS assistant (the best TA position on campus), and -- of utmost importance to my research -- Davey Jones' Locker, which was always supplied with top-shelf computers and resources with which to pursue my research and course work. My additional committee members --Alan Woods, Denis White, and Jon Kimerling (the friendliest face in Geosciences) -- have all helped me tremendously throughout this project.

My friends and colleagues at OSU have all played a huge role in my success and enjoyment. Kelli Larson has continually been helpful in putting my research in context and making me laugh. All the Rogues --Chad, Alli, Emily^2, Keldah, Pete Bower, Pete Martin, and Kuuipo-- have been awesome to work around. The staff in Geosciences, particularly Mark Meyers and Joanne VanGeest have assisted me enormously throughout my time at OSU. I also would like to thank Steve Cook for helping me keep life in perspective and cycling motivation. I would also like to extend my thanks to Mike Phoenix, Ann Johnson, and Angela Lee at ESRI for making my summer internship a wonderful experience. Additionally, I would like to mention John Pine, who was a colleague for too brief a time period and is now charting the heavens.

My family and large extended family have continued to support me throughout my education and all have been a valuable contribution to my success – thank you all.

Lastly, I owe the largest debt of thanks to Andrea for her undying patience and never-ending support. Without her as my life partner, none of this would have been possible; and Zoë, too.

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ABSTRACT: Ecoregions are regions of relative homogeneity with respect to specific ecosystem variables (Bailey 1976; Omernik 1995). There has been an increasing awareness that effective management of environmental resources must be undertaken with an ecosystem perspective (Omernik, 1995). Ecoregions serve as a spatial framework for assessing, managing, and monitoring ecosystems that have gained recognition among scientists and resource managers as a more effective boundary for natural resource assessment and management compared to the more arbitrary nature of political boundaries (Bryce et al, 1999). Each region can be viewed as a discrete system that is representative of the interaction between geology, landforms, soils, vegetation, climatic, hydrological, and human variables (Omernik 1995). Ecoregion maps are primarily produced by qualitative analyses for boundary delineations, which are often derived by consensus with indistinct weighting of input variables, and are essentially impossible to replicate by others. This paper presents the process and results of using multiple spatial analysis techniques within a geographic information system (GIS) as a potentially more quantitative and transparent tool for delineating ecoregions. Due to the qualitative nature of prior EPA ecoregion delineations and in an effort to quantify accuracy, this research focused on emulating the existing large-scale ecoregions nested within the Oregon portion of the EPA's Klamath Mountain Ecoregion straddling southern Oregon and northern California. Results indicate that replicating qualitative (EPA) ecoregions with a more quantitative process such as those within a GIS have the potential to be problematic, and accuracy is low (~19%) when compared to the original delineations. Increases in GIS data quantity, accuracy, resolution, and attribute richness will improve quantitative modeling potential. Additionally, quantitative EPA Level IV ecoregion replication that is highly similar to existing ecoregions will require extensive collaboration between researchers and the original manual delineation geographers with particular attention focused on delineation process in areas with broad ecotones.

INTRODUCTION

Ecoregions are regions of relative homogeneity with respect to specific ecosystem variables (Bailey 1976; Omernik 1995). Their boundaries represent a transition area of varying width between areas of unique ecology (McMahon et al. 2001).

There has been an increasing awareness that effective management of environmental resources must be undertaken with an ecosystem perspective (Omernik 1995). Ecoregions serve as a spatial framework for assessing, managing, and monitoring ecosystems and are additionally gaining recognition among scientists and resource managers as a more effective boundary for natural resource assessment and management compared to the more arbitrary nature of political boundaries (Bryce et al. 1999). Each region can be viewed as a discrete system that is similar with respect to geology, landforms, soils, vegetation, climatic, hydrological, and human variables such as land use (Omernik 1995). The hierarchical relevance of these variables is unique for each ecoregion and scale of delineation (Wiken et al. 1996, Omernik 1995).

RESEARCH RATIONALE

Currently, U.S. Environmental Protection Agency (EPA) ecoregion delineation is a manual "weight-of-evidence" approach that involves consideration of multiple variables and delineation of boundaries by qualitative assessments of natural breaks among analysis variables (Omernik 1995). While the advantage of this approach is that it incorporates the expert judgment and local knowledge of dominant landscape factors, the downfall is that this approach is difficult for others to quantify and replicate (McMahon et al. 2001). A GIS is an effective tool for quantitative landscape analysis that is easily replicated by others (e.g., DeMers 2002). Spatial analysis in a GIS has been moderately successfully at classifying ecologically similar areas or ecoregions at varying spatial scales (Host et al. 1996; Lowell 1990). Host et al. (1996) combined multivariate statistical analyses and a GIS to classify "regional landscape ecosystems" for 29,340-km^2

in northwestern Wisconsin. Lowell (1990) classified 2.9-km^2 into Ecological Land Types (ELT) in the southeastern Missouri Ozarks at about 45% accuracy, when compared to manual delineations, using a GIS. Although the scale and methodology in the Host (1996) and Lowell (1990) studies were different, conceptually they had a similar research objective of developing a more standardized and analytical method of classifying ecoregions.

It is important to state up-front that an ecoregion map produced by a GIS is not any more or less accurate than an ecoregion map produced by manual methods; they are each a unique representation of their associated scale, methodology, inputs, and objectives. However, there are some advantages to maps produced using GIS analyses instead of by manual methods. These include transparency in analysis and classification techniques (accurate metadata must be compiled), accurate replication by others, and the relative ease with which additional landscape variables can be introduced and weighted (DeMers 2002). Perhaps the most significant advantage of a GIS in ecoregion-map production is the ability to quantify the intensity or influence that each landscape variable has in relation to the ecoregion classification.

In both the weight-of-evidence and quantitative (GIS) ecoregion delineation processes, ecoregions and their associated boundaries are representative of the scale and purpose for which they were originally developed (McMahon et al. 2001). The EPA delineates ecoregions at four scales -- a small-scale Level I through large-scale Level IV -- all of which are further discussed in the Background section of this paper. The Level I through Level III maps have previously been completed and the Level IV maps are currently proceeding on a state-by-state basis (EPA 2004). Therefore, the political boundaries between states with Level IV delineations and those without also become ecoregion boundaries (Figure 1). This political boundary was especially noticeable to the author, who has thorough local personal knowledge of the Klamath Mountains that run through southern Oregon and deep into northern California. The land ownership in the Klamath Mountains is a patchwork of federal, state, and private (Oregon Department of Forestry 2004). However, the effectiveness of ecoregions as transboundary federal management units is severely limited when ecoregions end at state boundaries (Figure 2). Completing the large-scale delineation for all the states will be necessary if EPA ecoregions are to be effectively used as transboundary management and analyses units.

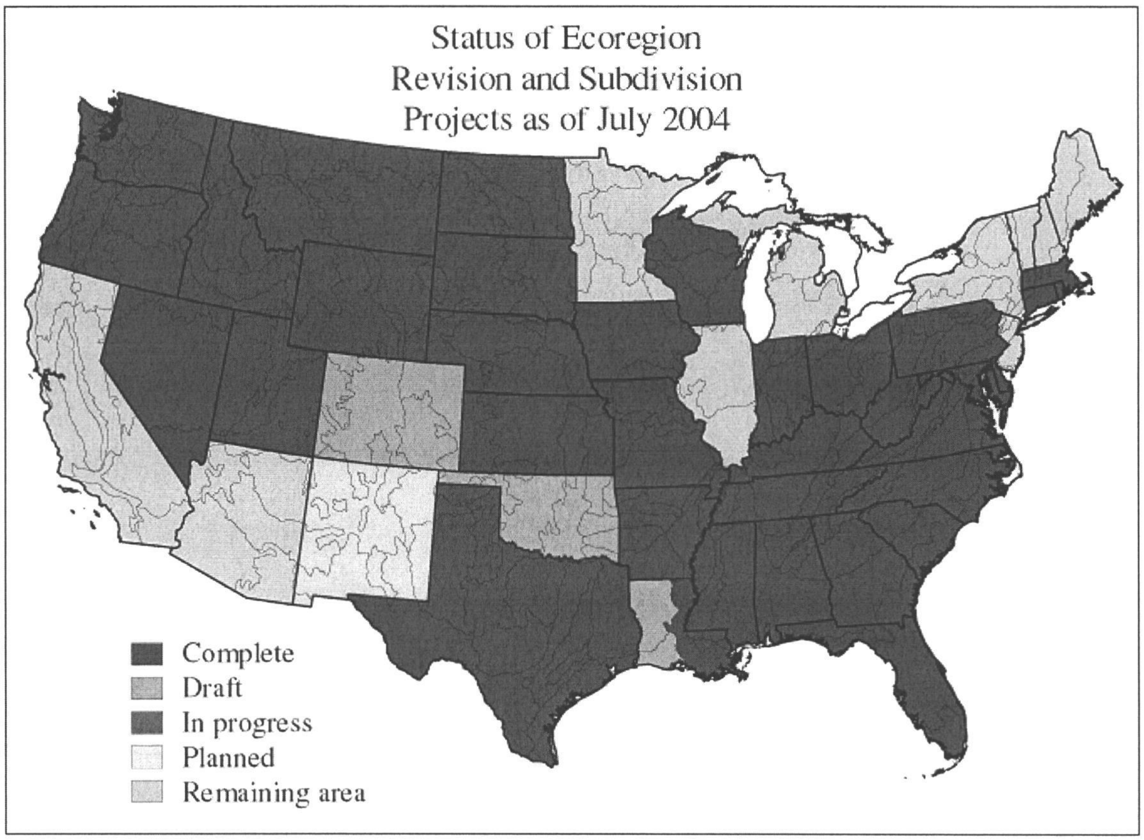


Figure 1 – Current status of EPA Level IV ecoregion delineations (EPA 2004).

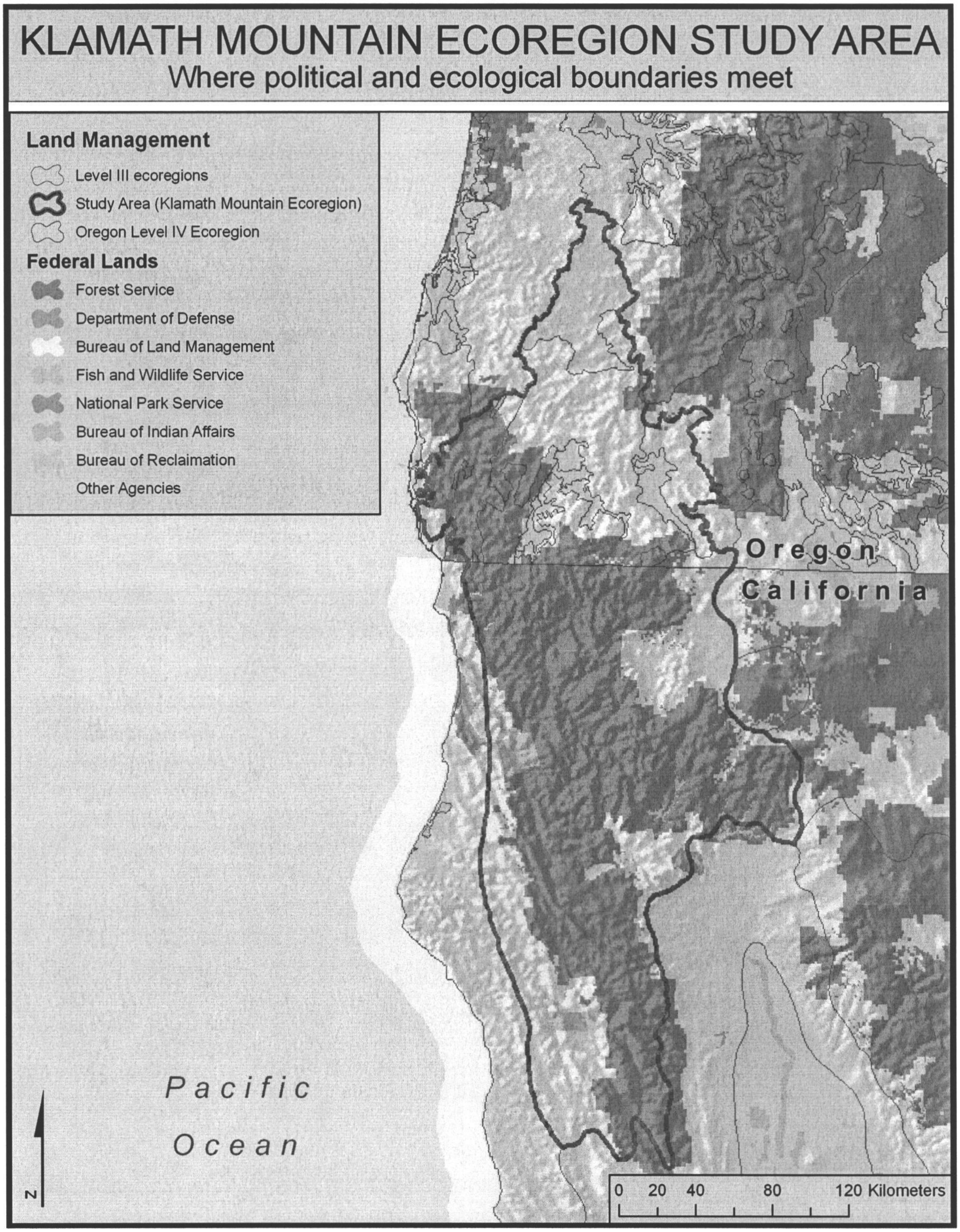


Figure 2– Oregon/California border region. The nested higher resolution ecoregions in Oregon end at the California border.

If and when the EPA decides to map out larger-scale or higher-resolution ecoregions in the remaining states (Figure 1), specifically California, this research may provide a useful starting point for the agency in the delineation process, especially since ecoregions in both Oregon and Nevada have previously been mapped at a larger scale, and share an extensive length of the border with California. Currently California has seven ecoregions that span into surrounding states. If this research is successful at building a descriptive model of delineations within an existing ecoregion and using a prescriptive model to expand those delineations into an unclassified region, a substantial portion of California could be classified at the scale based on the work previously completed in Oregon and Nevada.

The specific objectives of this research are twofold. The first objective is to build a descriptive GIS model of the seven larger-scale EPA Level IV ecoregions nested within the Oregon portion of the smaller scale EPA Level III Klamath Mountain Ecoregion. A detailed description of EPA ecoregions and their level nomenclature are given in the next section. The intent of the GIS model is to reconstruct, as closely as possible, the previously delineated higher-resolution boundaries, where the GIS is used to combine and weight environmental variable data in the descriptive models' delineation process, as well as to quantify both the classification results and the errors. The second objective of this research is to use the descriptive GIS model to prescribe larger-scale ecoregion boundaries to the California portion of the Klamath Mountain Ecoregion.

BACKGROUND

Ecoregions

The concept of ecoregions has been evolving for the past four decades. There are no standard definitions or parameters specifically coupled with the term ecoregion, and the environmental variables used in the delineation process vary depending on the organization or individual compiling the map (Omernik 1995, Wiken 1986). Both Bailey (1976) and Omernik (1986) have compiled ecoregion maps of the U.S., but the process, inputs, criteria and uses differ between the two.

Some of the early forms of ecoregion-like delineations concentrated on vegetation, such as Küchler's (1964) map of Potential Natural Vegetation. Other early ecological classifications were based primarily on climate (Bailey 1976). Later, in the mid-1980's, Omernik (1986) and Wiken (1986) approached the ecological classification process with a more holistic approach that recognized the importance (which varies geographically) of a wide range of physical and biotic variables in delineating regions.

The value of ecological classification is illustrated by the numerous organizations, both governmental and private, that use the ecoregion concept as a system for land classification. Some of these organizations include Environment Canada, Canadian Council on Ecological Areas, U.S. Forest Service, U.S Geological Survey, U.S. Fish and Wildlife Service, The Nature Conservancy, World Wildlife Fund, and the Sierra Club, as well as and the EPA itself. The scale, scope and components of ecoregion classification differ by organization. However, they all use ecoregions as both a system for classifying or organizing, and as a tool for managing or analyzing the landscape.

EPA Ecoregions

Ecoregions are an abstraction of reality that in the natural world occur at a continuum of scales. In an effort to identify the different regions at different scales, the EPA uses a five-tier spatial hierarchy developed by Jim Omernik (1995) to subdivide ecoregions into subregions. This hierarchy of regions and subregions starts at classification Level I (Appendix A) with 15 ecoregions and Level II (Appendix B) with 52 ecoregions, both of which extend spatially across the whole North American continent at a small scale. The Level III (Appendix C) classification represents a national scale for the U.S. with 84 ecoregions in the conterminous U.S., and an additional 20 ecoregions in Alaska. With international cooperation Level IV ecoregions have been expanded to include Canada and Mexico (Commission for Environmental Cooperation 1997). The Level IV (Appendix D) regions are more detailed ecoregions for state-level applications, and the numbers of ecoregions vary with the spatial extent of the map product (Omernik, 1995). A larger landscape-level Level V ecoregion has been proposed and tested for more detailed local applications (Bryce and Clarke, 1996). However, there are currently no plans to pursue the production of maps at a Level V resolution (A. Woods, pers. comm. 2003).

The EPA ecoregions are developed through an iterative process that involves map analysis, collaboration with regional experts, an extensive literature review, and a final integration of all available information. The delineations reflect the spatial coincidence in characteristics of geographical phenomena such as climate, physiography, geology, soil, vegetation, and land use, among others. The weights of the individual environmental characteristics, as well as the regional experts' opinions on an actual ecoregion's delineation, vary with scale and geography (Omernik 1995, A. Woods, pers. comm. 2003). The actual ecoregion boundaries are created by drawing lines directly onto mylar sheets placed over maps of geographic variables (i.e. soils, geology, vegetation, topography, land-use, etc.) at a scale as similar as possible. The mylar sheets are then stacked on top of each other and coincidences between lines are sought out, or the mylar sheets are digitized and printed out. The result is the same: either a mylar sheet or paper product with areas of strong coincidences between the chosen geographic variables identified. The boundary decisions differ with the objective and scale of the particular project. In areas where there is no coincidence between geographic variables, the input from regional experts and published literature are used to decide on boundary placement (Bryce and Clark 1996):

> The [ecoregion] product is not the result of the mechanical overlay of maps; the computerized geographic information system is a tool to aid in the analysis and final graphic display of the regions. It [the GIS] does not have a role in making line decisions except to allow viewing of landscape data at a common scale.

Ultimately at all stages of production a geographer makes a qualitative decision and the ecoregion boundaries are the results of those decisions.

There are metadata created for each map product that describes the input data sets used, the scale and accuracy of boundaries, attribute information, and spatial reference information (EPA 2004). The EPA often additionally publishes a journal article discussing specific ecoregion projects. These publications are a necessary complement to the metadata because these articles are where others can find out what the geographer was actually evaluating when drawing the different delineations in the project. In projects that don't have accompanying publications, the metadata is insufficient at describing to others the process and decisions made in determining specific ecoregion boundaries.

The ecoregion boundaries used in this research were delineated at a scale of 1:7,500,000 for the Level III map of the conterminous U.S. (Omernik, 1987), and at a scale of 1:250,000 for the Oregon Level IV map (Thorson et al). The Level IV ecoregions are nested within the Level III ecoregions (Appendix D).

Study Area

The study area for this research is the EPA Level III Klamath Mountain Ecoregion (Figure 2 and 3), which is one of 84 Level III ecoregions in the conterminous U.S.; it straddles the California/Oregon border and is over 500 km in length and almost 50,000 km^2.

> The Klamath Mountain ecoregion is physically and biologically diverse. Highly dissected, folded mountains, foothills, terraces, and floodplains occur and are underlain by igneous, sedimentary, and some metamorphic rock. The mild, sub-humid climate of the Klamath Mountains is characterized by a lengthy summer drought. It supports a vegetal mix of northern Californian and Pacific Northwest conifers (Omernik 1987).

There are seven discrete Level IV ecoregions that comprise the Oregon portion of the study area (~15,000 km^2). These Level IV ecoregions are the Rogue/Illinois Valleys, the Oak Savanna Foothills, the Umpqua Interior Foothills, the Serpentine Siskiyous, the Inland Siskiyous, the Coastal Siskiyous, and the Klamath River Ridges. This study site is particularly interesting because of the distinct break in Level IV delineations at the California/Oregon state border (Figure 3). At the Level III scale, the whole study area is classified as the single Klamath Mountain ecoregion. The spatial extent of the Klamath Mountain ecoregion was also chosen as the spatial extent for the study area for several reasons: a distinct boundary was needed for the analysis, and the Level III and Level IV ecoregions share that delineation and ecology. Also, when compared to the rest of the country, it is relatively homogenous. Therefore, more subtle landscape processes will influence the ecological variation across the Level IV ecoregions. See Table 1 for a detailed description of each region.

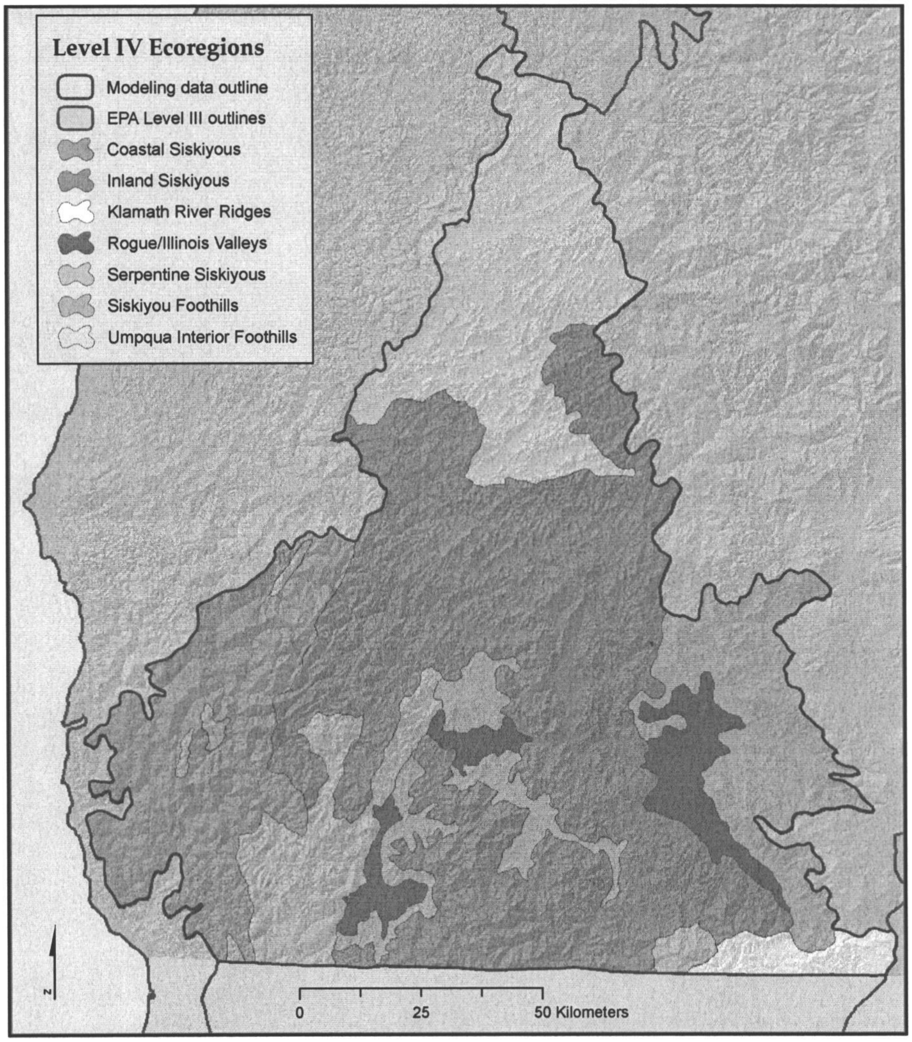


Figure 3 – Level IV ecoregion delineations within study area

Table 1 – EPA Level IV Klamath Mountain ecoregions descriptions

78. KLAMATH MOUNTAINS

Level IV Ecoregions	Area (square miles)	Physiography	Elevation/ Local Relief (feet)	Geology: Surficial and Bedrock	Soils: Order (Great Group)	Soils: Common Soil Series	Soils: Temperature/ Moisture Regimes	Climate: Precipitation Mean annual (inches)	Climate: Frost Free Mean annual (days)	Climate: Mean Temperature January min/max; July min/max (°F)	Potential Natural Vegetation*/ Present Vegetation (*Source: Küchler, 1964)	Land Cover and Land Use
78a. Rogue/Illinois Valleys	285	Terraces and floodplains in mountain valleys	900-2000/ mostly less than 100-200; max 600	Quaternary fluvial terrace and floodplain deposits	Mollisols (Haploxerolls, Argixerolls), Alfisols (Palexeralfs), Inceptisols (Haploxerepts, Endoaquepts)	On floodplains: Newberg, Camas, Evans. On valley terraces: Medford, Foehlin, Central Point. On fans: Ruch, Barron, Clawson	Mesic/ Xeric	20-60	120-180	31/47; 51/89	Mostly Oregon oak woods, scattered Douglas-fir forest and grasslands/ Oregon white oak, madrone, California black oak, ponderosa pine, and grasslands. Common understory plants include California fescue, snowberry, and serviceberry; in riparian areas willow and cottonwood	Woodland, grassland, orchards, cropland, pastureland, and rural residential, residential and commercial development
78b. Oak Savanna Foothills	818	Moderately sloping mountain foothills with medium gradient streams	1400-4000/ 400-2000	Quaternary colluvium and alluvium. In east: Eocene basaltic lava flows. In west: Jurassic sandstone and shale	Mollisols (Haploxerolls, Argixerolls), Inceptisols (Haploxerepts), Vertisols (Haploxererts)	Medco, McMullin, McNull, Bender, Debenger, Carney	Mesic/ Xeric	25-45	110-160	28/45; 50/87	Oregon oak woods and Douglas-fir forest/ Oregon white oak and California black oak woodlands, madrone, and ponderosa pine, grassland savanna. Wetter areas: Douglas-fir and incense cedar. Understory species include oceanspray, poison oak, snowberry, Idaho fescue, California brome, roughstalk bluegrass, and ceanothus.	Woodland, forest, grassland savanna, rangeland, orchards, and some row cropland. Rural residential development and some logging.
78c. Umpqua Interior Foothills	421	Foothills and narrow interior valleys containing fluvial terraces and floodplains	400-2800/ less than 100-1900	Quaternary alluvium and colluvium. Pliocene marine sandstone. Eocene basalt	Mollisols (Haploxerolls, Argixerolls, Argialbolls), Alfisols (Haploxeralfs), Inceptisols (Dystroxerepts)	On terraces: Coburg, Newberg, Roseburg. On foothills: Oakland, Sutherlin, Nonpareil	Mesic/ Xeric	30-50	120-185	34/49; 53/84	Douglas-fir forest and Oregon oak woods/ Oregon white oak, Douglas-fir, ponderosa pine, grand fir, madrone, tanoak, and chinquapin. Understory plants include snowberry, salal, Oregon grape, poison oak, oceanspray, and swordfern	Woodland, forest, pastureland, vineyards, orchards, cropland, and rural residential, commercial, and residential development
78d. Serpentine Siskiyous	440	Highly dissected mountains containing perennial, high gradient streams	1300-4900/ 600-3400	Quaternary colluvium. Jurassic ultramafic and related rocks	Alfisols (Haploxeralfs), Inceptisols (Dystroxerepts)	Pearsoll, Dubakella, Eightlar, Perdin, Gravecreek	Mesic, Frigid/ Xeric	45-120	70-140	32/44; 49/82	Mixed conifer forest and montane chaparral/ Jeffrey pine, tanoak, incense cedar, Douglas-fir, and chaparral composed of manzanita, ceanothus, Idaho fescue, and Lemmon needlegrass. Soils derived from serpentine support unique understory species and sparse woodland vegetation	Sparse woodland. Recreation, logging, and mining. Historical gold, nickel, chrome, copper, and mercury mining.
78e. Inland Siskiyous	2610	Highly dissected mountains with high gradient streams. A few small lakes are found at higher elevations	900-7500/ 1900-2800	Quaternary colluvium. Jurassic granitic rocks, shale, and sandstone	Alfisols (Haploxeralfs), Inceptisols (Haploxerepts, Dystroxerepts), Ultisols (Haploxerults)	Vannoy, Caris, Offenbacher, Josephine, Beekman, Kanid, Siskiyou, Tethrick	Mesic, Frigid/ Xeric	35-70	90-160	29/44; 50/86	Mixed conifer forest/ Douglas-fir, ponderosa pine, Oregon white oak, California black oak, madrone, serviceberry, snowberry, Oregon grape, California fescue, and poison oak	Forest. Logging, recreation, rural residential development, and mining.
78f. Coastal Siskiyous	853	Highly dissected mountains with high gradient streams	600-5600/ 1000-2700	Quaternary colluvium. Cretaceous and Jurassic conglomerate, sandstone, and siltstone	Inceptisols (Dystrudepts, Dystroxerepts), Ultisols (Palehumults, Palexerults)	Frinland, Bravo, Cassiday, Dewline, Barkshanty, Nailkeg, Jayar, Althouse, Skymor, Atring, Kanid, Acker	Mesic, Frigid/ West: Udic; East: Xeric	70-136	160-190	38/36; 50/76	Mostly mixed conifer forest/ Tanoak, Douglas-fir, madrone, bigleaf maple, California laurel, Port Orford cedar, chinkapin, salal, rhododendron, and swordfern; some western hemlock in west on udic soils	Forest. Logging, recreation, rural residential development, and some mining
78g. Klamath River Ridges	121	Highly dissected mountains containing high gradient streams	1800-7300/ 800-3000	Quaternary colluvium. Miocene and Oligocene basaltic and andesitic flows. Jurassic granitic rocks	Mollisols (Argixerolls, Haploxerolls)	Skookum, McMullin, McNull	Mesic/ Xeric	25-35	90-160	24/42; 49/88	Montane chaparral and mixed conifer forest/ Higher altitudes and north-facing slopes: Douglas-fir and white fir. Lower altitudes and south-facing slopes: ponderosa pine, western juniper, and chaparral. Oregon grape, western fescue, snowberry, bluebunch wheatgrass, and ceanothus	Forest, woodland, savanna, and chaparral. Logging, livestock grazing, and recreation.

A larger, more readable table is located in Appendix F (Thorson et al. 2002).

Data

The data and associated metadata were downloaded from the Oregon Geospatial Data Clearinghouse (OGDC), Oregon Climate Service (OCS), and Virtual Oregon Natural Resources Data Clearinghouse (VO), and thus already in digital form. The original vector data sets included 1:250k vegetation Gap Analysis Program (GAP) coverage, 1:500k US Geological Survey (USGS) geology coverage, and 1:250k State Soil Geographic database (STATSGO) coverage (Figure 4). Additionally a 1:24k USGS Hydrological Unit (HUC) levels 1-6 shapefile and EPA Level III & IV ecoregions coverages' vector data were gathered. Raster data sets included 10 m Digital Elevation Model (DEM) grid and OCS's Parameter-elevation Regressions on Independent Slopes Model (PRISM) 4km Precipitation grid raster data (Figure 5). Tabular data included USGS water quality data and EPA online STOrage and RETrieval (STORET) water quality data. The above data were created by the EPA, USGS, U.S. Department of Agriculture (USDA), and the Oregon Natural Heritage Program (ONHP). ArcGIS 9.0 was used to project or re-project the data into Oregon Lambert projection and clip data to a rectangular spatial extent around the study area. The vector data were imported into an ArcGIS personal geodatabase, and raster data were referenced by an image catalog within the same personal geodatabase.

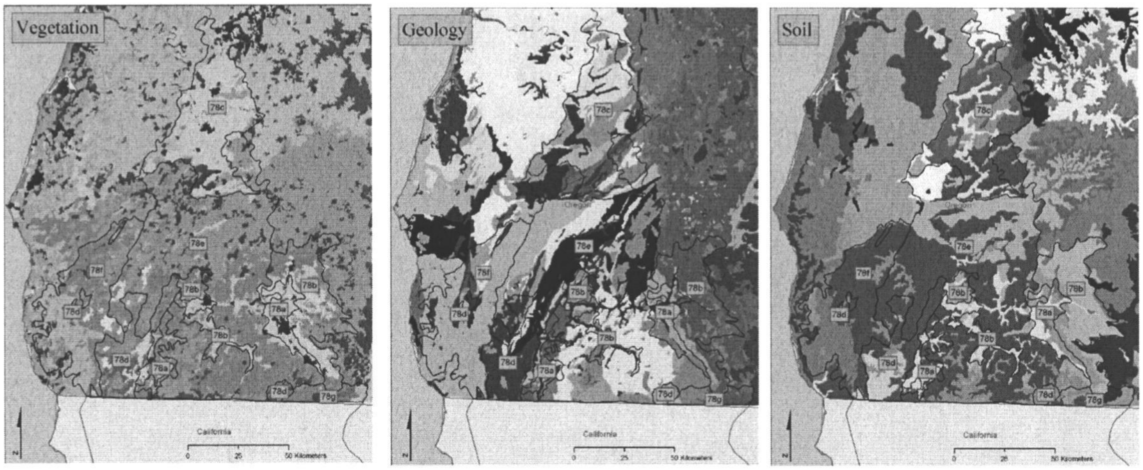


Figure 4 – Vector data: Vegetation, Geology, and Soil.

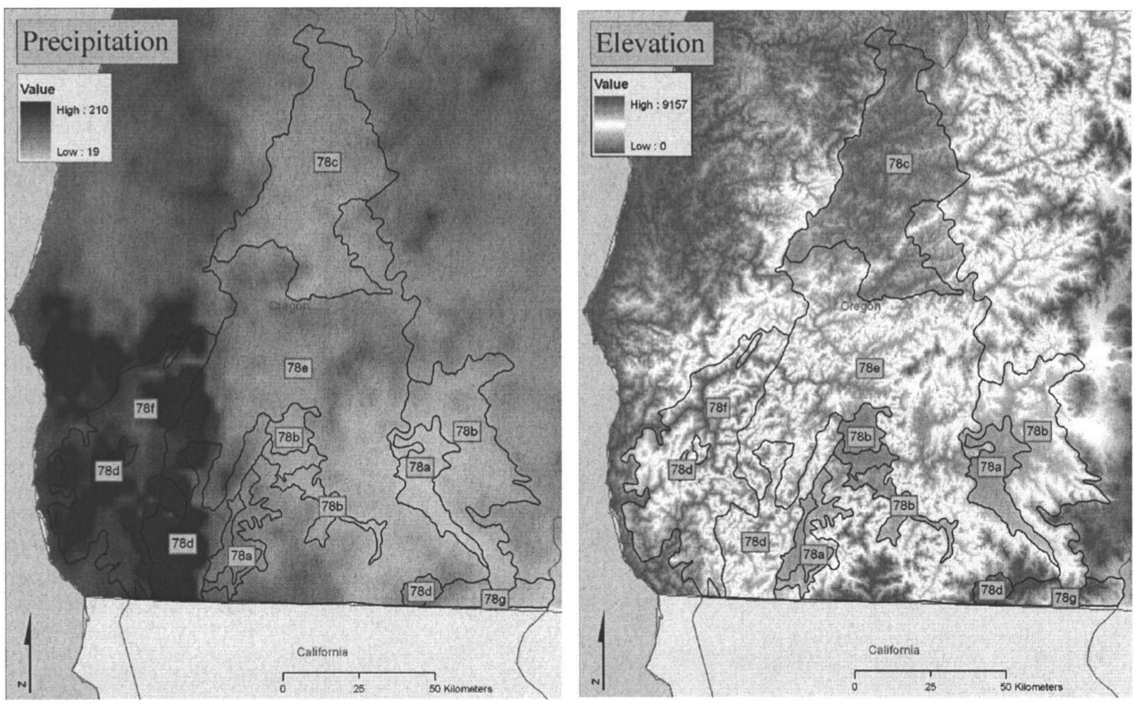


Figure 5 – Raster data: Precipitation and Elevation

The reference data used by the EPA in its Level IV analyses are available in digital format and, whenever possible, the identical data sets were used in this research. When identical data sets were not available, data at the same or larger scales were substituted.

An important note concerning the GIS data used in this research is that the nominal vector data have undergone generalizations and abstractions in order to create polygons representative of homogenous area. Essentially, all physical geography data will have a "fuzzy boundary" that is not accurately represented by the distinct break between polygons (O'Sullivan and Unwin 2003), and the scale and process used to originally delineate these polygons is crucial to their feasibility within additionally analyses (Longley et al. 2001). The vegetation, geology, and soils data (Figure 4) were chosen not only for the location and resolution of the data but also for the attribute accuracy, as was discussed in each data set's associated metadata. Data without FGDC (OGDC 2004) compliant metadata were not used.

The documentation of the processes that EPA used in delineating the Level IV ecoregions for Oregon was limited to personal correspondence with Alan Woods (2003) of the Western Ecology Division of the EPA, Corvallis, OR and metadata from the GIS coverages (EPA 2004). Therefore, the published Oregon Level IV ecoregions poster (Thorson et al. 2002) was used extensively and values in the tables were ancillary in constructing the model and running the analyses.

METHODS

Multiple GIS techniques as well as a feature space classification were explored in attempting to model the existing Level IV ecoregions, with various results and degrees of success, each of which is discussed below. The modeling techniques' results, when available, were visually and quantitatively compared to the EPA Level IV ecoregions independently. All statistical and tabular data analysis were conducted in Microsoft

Excel (XP), and all GIS analysis was conducted using ArcGIS 9.0 (ArcInfo license). A visual flowchart of the successful methodology can be found in Appendix E.

Water Quality Analysis

Surface-water-quality variables can be correlated with ecoregions through which the water primarily flows (Clarke et al. 1991, Hughes and Larsen 1988, Larsen et al. 1986, Lyons 1989, Omernik and Griffith 1991, Griffith et al. 1999). The character of streams reflects the aggregate of the characteristics of the watershed in which they drain (Omernik 1995). It was hypothesized by the author, based on the above research, that collecting various water quality variables from numerous points within the study area would allow specific ecoregions to be correlated with specific combinations of the water quality variables. A numerical raster surface would be interpolated from each sampling location for each water quality variable identified and those surfaces would be the input for the GIS model. Key to the feasibility of this technique would be the distribution and richness of the water quality data sets necessary for relatively accurate interpolation of a surface of the entire study area.

Over the years there were numerous data sets compiled by the USGS and EPA relating to water quality within the study area (EPA STORET). When all the water quality sampling locations are mapped there are a substantial number and relatively even distribution of sampling locations. Unfortunately, there is minimal, if any, consistency with the frequency, location, and variables measured by both USGS and EPA. For example, phosphorous concentration is a variable that is often measured when examining water quality; it may have been frequently sampled in the Rogue Valley farming community, but outside of that specific ecoregion there were other ecoregions that had only one sampling location. There are inconsistencies between the spatial distribution and density of water quality data within the study area (Figure 6). Additionally, the temporal distribution of water quality data collection is limited, and annual fluctuations in surface-water flow also influence water quality concentrations. After clustering the data into broad seasonal groups with the same sampled variables, there are no ecoregions that have sufficient samplings outside of the summer months (Figure 6).

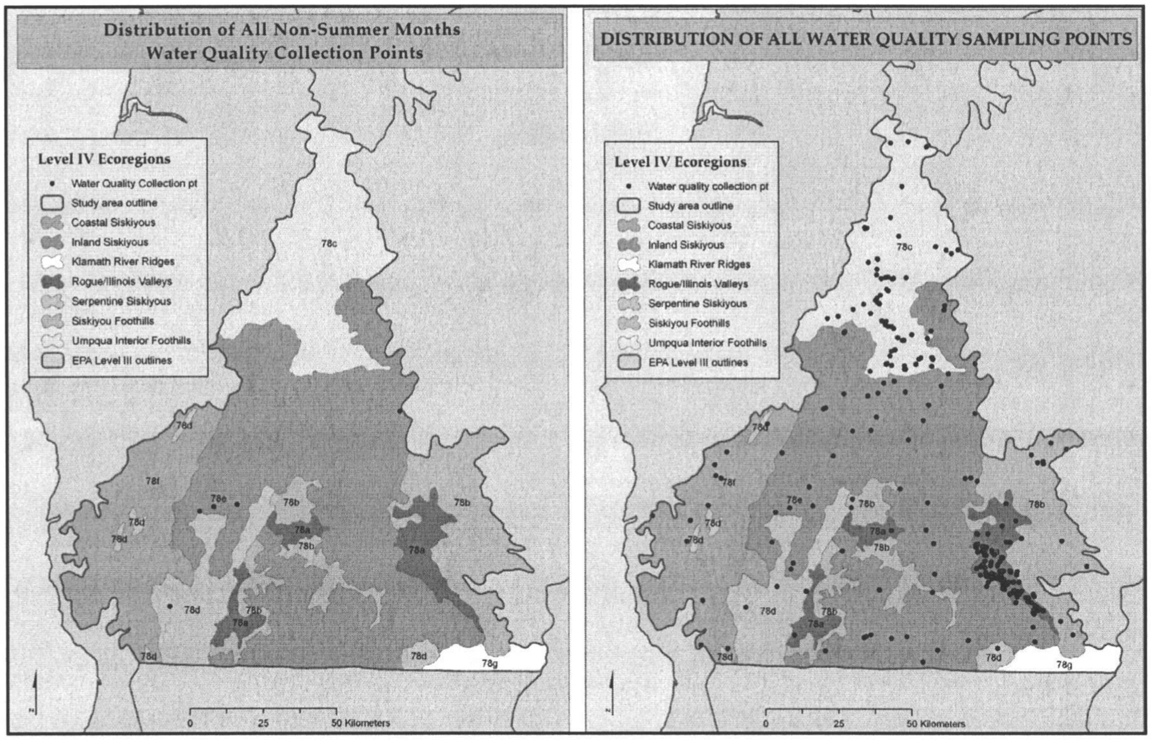


Figure 6 – Distribution of surface-water-variable collection points

The lack of spatial and temporal consistency within the available water quality data is the reason that the water quality analysis technique wasn't further researched for a GIS model of this particular study area; this ultimately led to pursuit of the Calculated Ecoregions Model (discussed later). However, the literature (Bryce and Clark 1996, Clark et al 1991, Hughes and Larsen 1988, Larsen 1996) and sample calculations (the

Rogue/Illinois Valleys have generally different phosphorous concentrations than the Siskiyou Foothills) with a subset of the data within the study area suggests that there are combinations of water quality variables that could be an additional environmental variable used in GIS ecoregion analysis.

Calculated Ecoregions Model

The printed Oregon Level IV ecoregions product (Thorson, et al 2002) included an extremely explicit table (Table 1, Appendix F) describing the environmental variables' ranges and values for each of the seven Level IV ecoregions within the study area. This table was used to construct Model Criteria tables (Tables 3 & 4, Appendix F).

The fields in Table 1 were used as criteria for selecting GIS data sets to use in the analysis. The descriptive variables for each of the Level IV ecoregion were correlated to attributes in the available GIS data sets. The five available GIS data sets that were matches with the fields in Table 1 were elevation (10m DEM), precipitation (PRISM), geology (USGS), soil (STATSGO, USDA), and vegetation (GAP analysis, ONHP). Vector data were converted into raster data using a nearest-neighbor interpolation and the existing grids were resampled using bilinear interpolation. A uniform grid cell size of 300 m was chosen for all analyses for a few reasons. First, a grid size of 300m was large enough that large-scale local variations were smoothed but still small enough to identify unique regions. Also, processing time wasn't exhaustive, and the aggregation of raster cells decreased the potential for individual cell errors since the new cell value was an average of the input cells (ESRI 2004).

Some of the fields within the EPA Level IV Ecoregion Description table (Table 1) were not transposed into the Model Criteria tables (Tables 3 & 4); Table 2 illustrates the fields and the way they match up. The Ecoregion Name and Area fields were not used since they were unique descriptors that couldn't be tested. The Physiography field was not used since it had broad descriptions that were vague when qualified by a GIS. A Topographic Position Index (TPI) was performed on the DEM in an attempt to model physiography; it was rejected due to extreme variation across the study area. The Geology Age field had minimal variation across the study area. Soil order, temperature, and moisture regimes were not used since they were measured on a much smaller scale than the study area and had minimal variation across the study area. The Mean Annual Frost Free Days and Mean Temperature fields were also not used due to the coarse resolution of the available data. The Potential Natural Vegetation field was not used since it was mapped at a very small scale and had minimal variation across the study area. The Land Cover and Land Use field was combined with the Present Vegetation field since the available vegetation GIS dataset had both values within a single field.

Table 2 – Fields transferred from EPA Level IV table to Model Criteria table

EPA Level IV Description Table (Table 1)	Model Criteria Table (Table 3&4)	
Fields Available	**Fields Used**	**Data Type**
Ecoregion Name	N/A	
Area	N/A	
Physiography	N/A	
Elevation	Elevation Range	Interval
Local Relief	Elevation Range	Interval
Geology Age	N/A	
Geology Lithology	Geology	Nominal
Soil Order	N/A	
Soil Common Series	Soil	Nominal
Soil Temperature Regime	N/A	
Soil Moisture Regime	N/A	
Climate - Precipitation	Precipitation	Ratio
Climate - Frost Free Days	N/A	
Climate - Mean Temperature	N/A	
Vegetation - Potential	N/A	
Vegetation - Present	Vegetation	Nominal
Land Cover and Land Use	Vegetation	Nominal

The ratio/interval data values (Precipitation and Elevation) were recorded in a Ratio/Interval Model Criteria table (Table 3) exactly as they were written in Table 1. The nominal variables (Geology, Soil, and Vegetation) values were identified in the EPA Level IV Description table (Table 1). The GIS data sets attribute tables were meticulously searched and compiled for any record that matched the value or description previously identified. The unique ID value for all of the records in the GIS data sets' attribute table that could be associated with a value or description in the original EPA Level IV Description table was recorded in the Nominal Model Criteria table (Table 3). The unique ID value was chosen over the text descriptions to save storage space and computational time after the data sets were converted to raster. A .dbf table was exported from each of the original nominal GIS data sets to be used as a look-up table for the unique ID values later.

Table 3 – Model Criteria Table, Ratio/Interval Data Ranges

Model Criteria Table – Ratio/Interval Data Ranges					
Region	Grid #	Elevation (ft)		Precipitation (in)	
		Min	Max	Min	Max
78-A	1	900	2000	20	60
78-B	2	1400	4000	25	45
78-C	3	400	2800	30	50
78-D	4	1500	4300	45	120
78-E	5	800	7000	35	70
78-F	6	600	5300	70	130
78-G	7	3800	7500	25	35

Table 4 – Model Criteria Table, Nominal Data Values

Model Criteria Table - Nominal Data Values				
Region	Grid #	Geol	Soil	Veg
78-A	1	2, 6, 41, 113, 79	27, 34, 45, 46	5, 7, 51, 52
78-B	2	2, 58, 76, 113, 114	27, 41, 46, 83, 134	7, 23, 26, 28, 52
78-C	3	2, 40, 69, 74, 75, 96, 104	4, 27, 78, 83	6, 7, 8, 28
78-D	4	16, 30, 73, 118	34, 48, 83, 160	28, 52, 60, 62
78-E	5	16, 47, 69, 76, 109	34, 41, 48, 67, 83	6, 7. 28, 51, 52
78-F	6	69, 73, 96, 108	48, 81, 83	8, 28, 52, 55
78-G	7	48, 58, 76	43, 46, 48, 172, 175, 187	6, 13, 45, 52

For example, Table 1 lists the present vegetation for the Coastal Siskiyous (78f) as tanoak, Douglas-fir, madrone, bigleaf maple, California laurel, Port Orford cedar, chinquapin, salal, rhododendron, swordfern and western hemlock. In the Vegetation GIS data set's attribute table, whenever one of the above types of vegetation was identified with any of the records that match the above criteria, unique ID's were recorded in the Nominal Model Criteria table. This process was repeated with the geology, soil and vegetation data sets, as well as for each of the seven ecoregions within the study area.

A separate grid was created for each Level IV ecoregion and given a single value of 1 for the whole region. This was done by a selection query and the "Convert to Raster" command in Spatial Analyst for each of the seven ecoregions. This set of seven grids was saved for use later in the analysis.

To identify the ecoregions using only the nominal variables, a new true/false binary grid was calculated for each ecoregion based on the variables (geology, soil, and vegetation) in the Nominal Model Criteria table (Table 4). A unique grid for each of the seven ecoregions was created where a pixel was either a 1 (true) or 0 (false). A cell was classified as true for each ecoregion if in the calculation a cell in the same spatial location was found to have one of the values identified in the Nominal Model Criteria table for the geology, as well as the soil and vegetation fields. This calculation was performed in ArcInfo GRID using a true/false (.con) argument (Appendix G). The argument query was repeated for each of the seven ecoregions and the resulting seven binary grids were saved as nom_grid 1 through 7.

To identify the ecoregions using the ratio/interval variables, an If-Then-Else query (Appendix G) was used to query the ratio/interval GIS data sets (precipitation and elevation). This query was performed in ArcInfo GRID, and specifically examined the Precipitation and Elevation grids, and again classified the results as true or false based on the ranges identified in the Ratio/Interval Model Criteria table (Table 3). This process created seven new grids with binary results of 1 (true) or 0 (false) for each of the seven ecoregions. The resulting seven grids were saved as ratio_grid 1 through 7.

The nominal ratio/interval grids were combined by ecoregion. The resulting binary grids returned a true cell value, only when there was a true cell value in both the nominal and ratio/interval grids for that ecoregion. This combination was performed, using Raster Calculator in the Spatial Analyst extension of ArcGIS 9.0, by multiplying the nominal and ratio/interval grids together by ecoregion. Another If-Then-Else query (Appendix G) was used to combine the seven individual ecoregion grids into a single grid which had a unique value for each of the seven ecoregions.

The attribute tables for the ratio/interval and nominal query results, as well as the combined grid results, were exported as a .dbf file and combined in one large Excel workbook. In Excel the results were compared to the .dbf table of original Level IV ecoregion cell values and quantities. The comparison results were combined and summarized by ecoregion into number and percent of correctly classified, incorrectly classified, and null classified grid cells.

Two maps were produced from the results in ArcGIS, one illustrating the original EPA Level IV ecoregions and the other illustrating the results of the calculated ecoregion analysis (Figure 7).

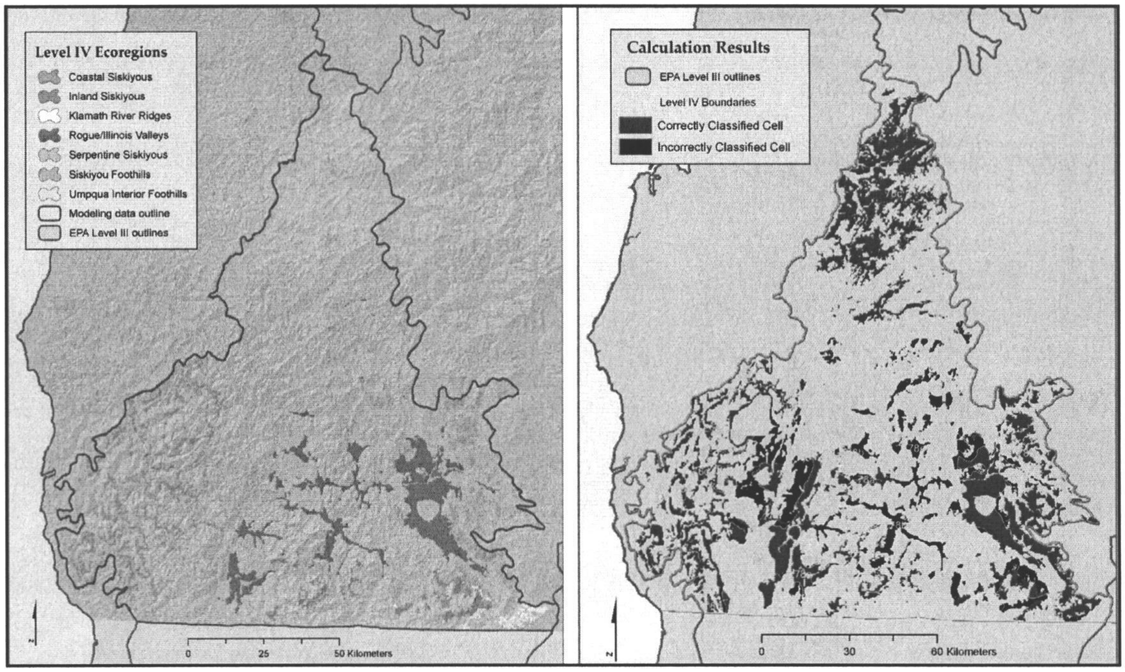


Figure 7 Calculated Level IV results

Functional Operations

Nearly 75% of the calculated ecoregion grid cells within the study area were not classified as one of the seven ecoregions. In an effort to "grow" or expand the calculated ecoregions into larger regions that were more representative of the original Level IV ecoregions, functional operations were used, specifically Inverse Distance Weighting (IDW) interpolation and neighborhood cluster analysis. All functional operations were performed in ArcGIS, using the Spatial Analyst extension.

Inverse Distance Weighting (IDW)

IDW interpolation measures the distance between two points and weights the values between those points based on that distance (e.g., Longley, et al, 2001). Since ecoregions are categorical data, and there can't be gradations in categorical data, the cells that were not identified as an ecoregion (null) in the ecoregion calculation were assigned an ecoregion class, using IDW interpolation.

Every cell with a calculated ecoregion value in the combined ecoregion grid was converted into a point feature class with the calculated ecoregion value assigned to each point's attribute table. An IDW interpolation was performed on the point feature class using a 12-point variable search radius and the same extent and cell size as the other grids used in the study area. The result of the IDW interpolation was a new grid in which every cell was classified as one type of ecoregion, and which was determined by the horizontally closest point's ecoregion attribute (e.g., DeMers 2002). Numerous trials were performed with various sizes and types of search radii and minimal variation in results were noticed.

The attribute table for the IDW functional operation results grid was exported as a .dbf file and added to the previous results Excel workbook. The results were combined and summarized by ecoregion into number and percent of correctly classified, incorrectly classified, and null classified grid cells. A map was produced in ArcMap illustrating the results and accuracy (Figure 8).

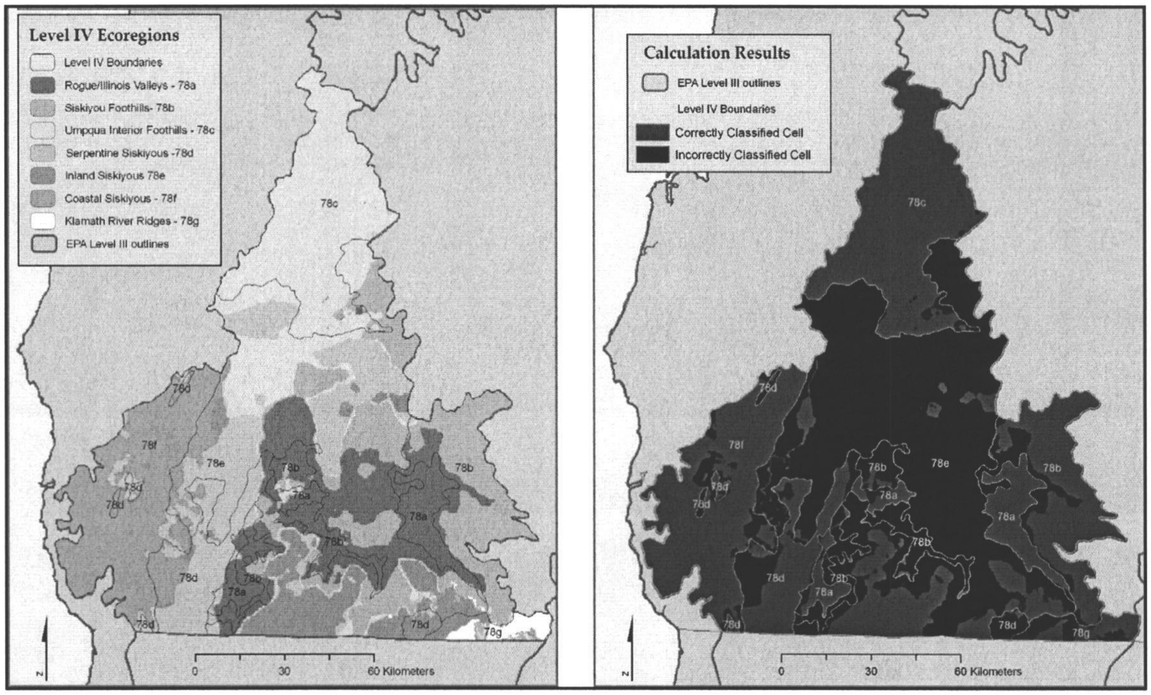


Figure 8– IDW interpolation results

Neighborhood Analysis

Neighborhood functions create output values for each cell based on the value for the location and the values identified in a specified neighborhood (ESRI, 2004). A neighborhood function was used to look at a specific number of cells around each cell in the calculated ecoregions grid, and returned a value based on those surrounding cells, or neighborhood. There were dozens of different neighborhood functions available (DeMers 2002), numerous trials were conducted with many of them, and results visually compare to the original Level IV ecoregions.

The block majority neighborhood function was ultimately used. A block majority function is an aggregate function that partitions the input grid into blocks, finds the majority value (the value that appears most often) for the specified cells (defined by the neighborhood parameters) within the blocks, and sends it to the cell locations in the corresponding blocks on the output grid (ESRI, 2004). A kernel or neighborhood with a size of 15 X 15 cells produces an output grid that is most visually similar to the original Level IV ecoregions.

The attribute table for the Neighborhood functional operation results grid was exported as a .dbf file and added to the previous results Excel workbook. The results were combined and summarized by ecoregion into number and percent, of correctly classified, incorrectly classified, and null classified grid cells. A map was produced in ArcMap illustrating the results and accuracy (Figure 9).

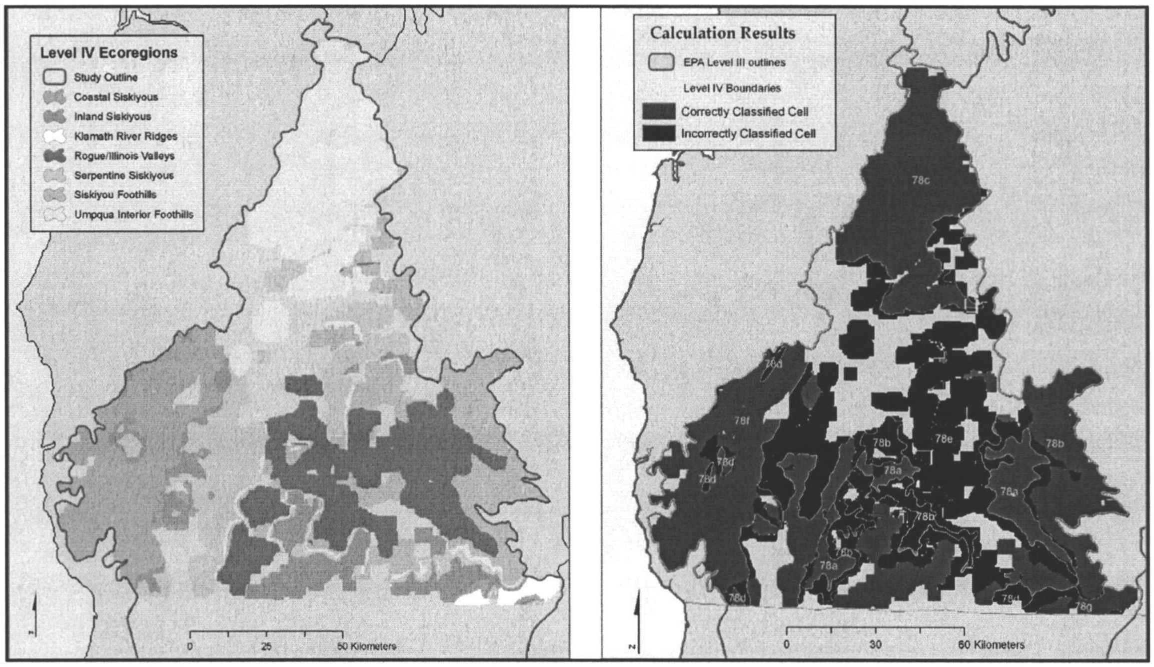


Figure 9– Neighborhood functional analysis results

ISODATA Classifications

The concept of spectral classification is one that is used more often in remote sensing applications. However, the mathematical algorithms can work on other raster data sets (Jenson, 1996). Essentially, a spectral classification combines or clusters spectral signatures stored in multiple images of the same spatial extent into classes. Mathematical algorithms are used to cluster or classify these pixels or cells based on the spectral variation across all the images (Jenson, 1996). The Calculated Ecoregions technique created five grids or raster images, one for each of the environmental variables in both the Nominal and Ratio/Interval Model Criteria tables (Table 2 & 3). Host et al (1996) successfully used an ISODATA clustering algorithm to identify regions of similar climatic trends from climatic, physiographic, and edaphic data. Building on the Host et al. (1996) it was hypothesized by the author that the five raster images from the Calculated Ecoregions technique could be loaded into a classification software package and analyzed as if each image was a unique spectral signature, and thus classified similarly to a traditionally remotely sensed image.

In an unsupervised classification, numerical operations are performed that search for natural groupings of the spectral properties of pixels or cells as examined in multispectral feature space. Once the data are classified, the analyst then attempts *a posteriori* to assign the classes values (Jenson, 1996).

An ISODATA unsupervised classification method was chosen since it is an iterative clustering method that identifies natural clusters or regions within the data. The five raster images were converted into a TIF image format and imported into ENVI (Environment for Visualizing Images, Research Systems, Inc.). The five TIFs were then combined into a layer stack of images. An ISODATA unsupervised classification was performed on the layer stacked images. A minimum and maximum of seven classes, 20 iterations, and a change threshold of 1% were ultimately used. Numerous combinations of iterations and change thresholds were first tested, but the number of classes was always set to seven since that is the number of Level IV ecoregions that were originally classified in the study area.

In an effort to identify the influence the ratio/interval or nominal data had on the ISODATA results, another ISODATA classification was performed, using the same input settings, but using only the elevation raster image as the input dataset.

Both resulting images were exported from ENVI as an ESRI .bil file and mapped in ArcMap with the Level IV ecoregion delineations overlaid (Figure 10). The output images from ENVI are always three-band images, so attribute tables like those for the grids were unavailable for export and summarization in Excel; therefore, a visual comparison was performed and the individual class statistics were exported as text from ENVI and combined separately in Excel.

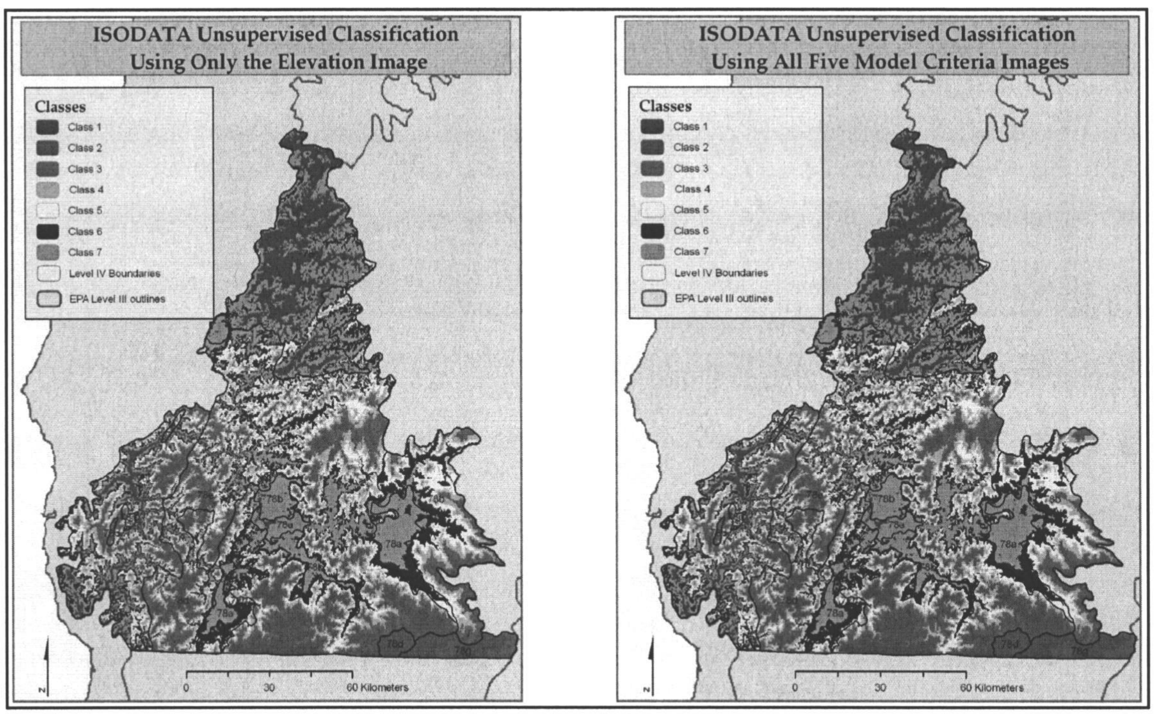


Figure 10– ISODATA Classification results

RESULTS

All the results including analysis calculations are based on data from the Oregon portion of the study area. Within the scope of this research, it is assumed that the EPA's Level IV ecoregions are "correct" and analysis results are compared to their delineations for analysis of accuracy.

The quantitative results were limited to the Calculated Ecoregions Technique, the IDW analysis, and the Neighborhood functional operation. The issues with the Water Quality and Classification analysis, along with the failure to geographically expand the research into California, are further addressed in the Discussion portion of this paper. Table 5 below shows the summary values for each of the Level IV ecoregions: this is what the calculated results and accuracy are based on.

Table 5 – Level IV ecoregions summary values

Level III Regions	Level IV Regions	% of total Study Area	# of EPA Level IV grid cells
78 a	Rogue / Illinois Valleys	5%	7,956
78 b	Oak Savanna Foothills	14%	22,819
78 c	Umpqua Interior Foothills	15%	25,676
78 d	Serpentine Siskiyous	7%	12,147
78 e	Inland Siskiyous	43%	72,628
78 f	Coastal Siskiyous	14%	23,797
78 g	Klamath River Ridges	2%	3,269
Total		100%	168,292

Calculated Ecoregions Model Results

The results of the Calculated Ecoregions model are summarized in Figure 7 and Table 6. The model, when compared to the 168,292 classified cells extracted from the EPA Level IV ecoregions, correctly identified the ecoregions for 19% of the cells and incorrectly identified the ecoregions for only 7% of the cells in the study area. The model failed to classify 74% of the study area into any of the seven original Level IV ecoregions.

Of the seven Level IV ecoregions, the Rogue/Illinois Valleys Ecoregion, which is only 5% of the study area, yielded substantially better results in not only the correct vs. incorrect values, but also in the much lower number of unclassified. Inversely, the Inland Siskiyous Ecoregion, which is 43% of the study area, was correctly classified by only 3% of the cells correctly, and 86% of the cells failed to be classified as any of the ecoregions.

Table 6 – Results of Calculated Ecoregions

Percent land cover of Calculated Level IV Regions								
Grid #	Level IV Region	Correctly Classified grid cells		Incorrectly Classified grid cells		Unclassified grid cells		EPA Level IV grid cells
1	Rogue / Illinois Valleys	4,887	61%	139	2%	2,930	37%	7,956
2	Oak Savanna Foothills	4,594	20%	2,866	13%	15,359	67%	22,819
3	Umpqua Interior Foothills	10,157	40%	38	0%	15,481	60%	25,676
4	Serpentine Siskiyous	3,483	29%	425	3%	8,239	68%	12,147
5	Inland Siskiyous	1,979	3%	7,849	11%	62,800	86%	72,628
6	Coastal Siskiyous	5,462	23%	426	2%	17,909	75%	23,797
7	Klamath River Ridges	762	23%	367	11%	2,507	77%	3,269
Total		31,324	19%	12,110	7%	125,225	74%	168,292

IDW Results

The IDW functional operation successfully classified all of the cells within the study area. Furthermore, the results (Figure 8 & Table 7) indicate that the number of correctly classified cells grew substantially for all of the Level IV ecoregions. This is especially true for the Oak Savanna Foothills and the Coastal Siskiyous: each of these ecoregions more than doubled in the number of correctly classified cells. Again the Inland Siskiyous stood out as the negative anomaly, since this ecoregion was incorrectly classified 84% of the time; this was further substantiated by the relatively large portion of the study area that the Inland Siskiyous Ecoregion represents.

Table 7 – Results of IDW functional operation

Percent land cover of IDW interpolation of Calculated Level IV Regions								
Grid #	Level IV Region	Correctly Classified grid cells		Incorrectly Classified grid cells		Unclassified grid cells		EPA Level IV grid cells
1	Rogue / Illinois Valleys	7,319	92%	637	8%	-	0%	7,956
2	Oak Savanna Foothills	12,894	57%	9,925	43%	-	0%	22,819
3	Umpqua Interior Foothills	24,714	96%	962	4%	-	0%	25,676
4	Serpentine Siskiyous	7,936	65%	4,211	35%	-	0%	12,147
5	Inland Siskiyous	11,662	16%	60,966	84%	-	0%	72,628
6	Coastal Siskiyous	21,203	89%	2,594	11%	-	0%	23,797
7	Klamath River Ridges	1,801	55%	1,468	45%	-	0%	3,269
Total		87,529	52%	80,763	48%	-	0%	168,292

Neighborhood Analysis

The results (Figure 9 & Table 8) of the Neighborhood functional operation indicate that this operation was only slightly less effective at correctly classifying cells than the IDW functional operation -- 49% to 52%. However, the Neighborhood function was substantially better at avoiding the misclassification of cells. Again, similar to the Calculated Ecoregion analysis, there were a number of cells that were not classified as any type of ecoregion, and again the largest portion of these unclassified cells was in the Inland Siskiyous Ecoregion.

Table 8 – Results of Neighborhood functional operation

Percent land cover using Neighborhood Analysis of calculated Level IV Regions								
Grid #	Level IV Region	Correctly Classified grid cells		Incorrectly Classified grid cells		Null Classified grid cells		EPA Level IV grid cells
1	Rogue / Illinois Valleys	7,371	93%	565	7%	20	0%	7,956
2	Oak Savanna Foothills	12,272	54%	9,307	41%	1,240	5%	22,819
3	Umpqua Interior Foothills	23,163	90%	338	1%	2,175	8%	25,676
4	Serpentine Siskiyous	7,012	58%	2,295	19%	2,840	23%	12,147
5	Inland Siskiyous	10,138	14%	40,998	56%	21,492	30%	72,628
6	Coastal Siskiyous	20,455	86%	1,729	7%	1,613	7%	23,797
7	Klamath River Ridges	1,909	58%	969	30%	391	12%	3,269
Total		82,320	49%	56,201	33%	29,771	18%	168,292

Combined Calculation and Function Operation Results

The results in Tables 6, 7 and 8 the results were combined and averaged by ecoregion (Table 9). Table 9 was compiled to identify broad trends in the data, especially with respect to individual ecoregions, and since there were only seven ecoregions, the significance of any statistical analysis is extremely limited. The notable results are that cells in the Inland Siskiyous Ecoregion are incorrectly classified an average of 50% of the time, while the cells in the Rogue/Illinois Valleys are correct an average of 82% of the time.

Table 9 – Averaged Summary of all 3 quantitative analyses

Averaged summary of all 3 quantitative analyses					
% of total Study Area	Level III Regions	Level IV Region	Correctly Classified grid cells	Incorrectly Classified grid cells	Unclassified grid cells
5%	78 a	Rogue / Illinois Valleys	82%	6%	12%
14%	78 b	Oak Savanna Foothills	43%	32%	24%
15%	78 c	Umpqua Interior Foothills	75%	2%	23%
7%	78 d	Serpentine Siskiyous	51%	19%	30%
43%	78 e	Inland Siskiyous	11%	50%	39%
14%	78 f	Coastal Siskiyous	66%	7%	27%
2%	78g	Klamath River Ridges	46%	29%	30%
Total			40%	30%	31%

ISODATA Classification Results

The results (Figure 10 & Table 10) of the ISODATA Classification technique are limited in their quantitative comparison to the results of the previous analyses, since they don't have any corresponding ecoregion criteria or geography. The ISODATA results suggest upon visual comparison with the Level IV ecoregion that there are some similarities between two of the classes, the Rogue/Illinois Valleys and the Umpqua Interior Foothills. It is difficult to distinguish any other correlation between classes and Level IV ecoregions. The ISODATA Classification results further suggest that the controlling variable was the elevation image. As Table 10 illustrates below, there are identical numbers of grid cells for each class. Analysis was completed using a diverse arrangement and number of input raster images as well as ISODATA analysis settings. The results were the same any time the elevation raster data set was used.

Table 10 – ISODATA Classification Summary

ISODATA Classification Summary				
Class	Classified using 5 input images		Classified using only the elevation raster	
	# of classified grid cells	% of total area	# of classified grid cells	% of total area
1	17,515	10%	17,515	10%
2	32,080	19%	32,080	19%
3	29,514	18%	29,514	18%
4	26,135	16%	26,135	16%
5	23,654	14%	23,654	14%
6	25,189	15%	25,189	15%
7	14,205	8%	14,205	8%
Total	168,292	100%	168,292	100%

DISCUSSION

The ability to develop ecoregion classification criteria based on specific data standards, key quantitative variables, and specific processes can remove much of the subjectivity involved in the development of ecoregion classification (Host et al. 1996). Furthermore, post-classification analysis of ecoregions, even those based on quantitative variables, is substantially limited by the inability to know, specifically, what the original geographers were evaluating when making the delineations.

The objectives of this research were met with variable success that is likely due to a number of factors. First, the EPA descriptions of the Oregon Level IV ecoregions (Thorson et al. 2002) are broad generalizations made by the authors and were never intended to be used as input parameters for a GIS model (A. Woods pers. comm., 2003). Second, the construction of the model parameters from the EPA ecoregion descriptions was a qualitative process, as was the reclassification of the variables from the EPA's descriptions to the Model Criteria table. Unfortunately, this was unavoidable due to the subtle variations between the categorical GIS data and the EPA descriptions. Additionally, the potential for error propagation is further increased when building a GIS model based on subjective input. This is especially relevant in this research, since the input values for both the interpolation (IDW) and Neighborhood analysis are the output or results of the Calculated Ecoregions.

The Calculated Ecoregions are the locations that explicitly match the descriptions of the Level IV ecoregions. This may also be thought of as the core or essence of the original Level IV ecoregions. The broad, unclassified areas between the Calculated Ecoregions may then be thought of as ecotones or transition zones between ecoregions. This is highly likely with respect to the Rogue/Illinois Valley and Oak Savanna Foothills ecoregions, as well as the Serpentine Siskiyous and Coastal Siskiyous ecoregions. However, the extensive number of unclassified cells in the Inland Siskiyous Ecoregion is suspect; a mistake may have been made in the calculations (thoroughly checked and none identified), the original descriptions may have been off or incomplete, data could have been erroneous, or the highly dissected, broad expanse (43% of the study area) of this ecoregion may have served as a catch-all for features that didn't quite fit into one of the other six Level IV ecoregions. These ecoregion cores with broad ecotones also further illustrate the problem that geographers face during the manual ecoregion delineation process. In the GIS modeling environment these broad ecotones represent what many researchers (e.g., Longley et al. 2001 and references therein) would call "fuzzy sets," or areas where an objects degree of membership to a class can be partial.

However, since one of the goals of ecoregions is that they be effective management units, which involves the political arena, a hard or distinct boundary is necessary.

Pursuant to the objective of classifying the whole study area into ecoregions and quantifying the variation between the modeled and existing EPA Level IV ecoregions, functional operations were used to "grow" or expand the Calculated Ecoregion throughout the study area. The functional operations of IDW Interpolation and Neighborhood analysis were used to increase the number of classified cells. Both operations successfully increased the number of classified cells; an increase in misclassified cells was also associated with this increase in classified cells.

The considerable increase in misclassified cells in the interpolation analysis can be expected when interpolating a large spatial area with limited quantity and spatial distribution of inputs, especially when the interpolation algorithm is required to classify all the cells in the study area. Similarly, the noticeable advantage to the Neighborhood operation is that the process of classifying cells does not mandate that all the cells are classified, thus decreasing the number of misclassified cells; there are still a substantial number of unclassified cells, too. As the number of unclassified cells decreases, the number of incorrectly classified cells increases in a noticeable trend, not just in the above results, but also in extensive experimentation with different functional operations and operation criteria.

The results of the ISODATA unsupervised classification indicate that this technique should probably be limited to data sets of ratio or interval data that have a more continuous surface of numerical values. The numbers used to represent the categorical data in this research were arbitrarily chosen by the computer and had no significance to the variable they were actually representative of. This is likely why the ISODATA Classification didn't classify the single elevation raster any differently from the combined layer stack of five rasters, which had nominal data values that were essentially random and dispersed, and unrelated in feature space. For example, in the nominal soil data set, two coincident soil classes may have had similar characteristics, and if their nominal ID values were divergent, they would never be clustered together by the algorithm. In the original EPA delineations process, the geographer is able to deduce the relationships between the nominal classes for each dataset and modify the delineations accordingly. Additionally, the EPA actively solicits and uses the opinions of regional experts with substantial, field-based ecological experience (A. Woods, pers. comm. 2003, Omernik 1995). This type of integrated knowledge and general sense of the land is difficult, if not impossible to gather and quantify into data sets, thus it is impractical for this research, regardless of how relevant it may have been in the original Level IV delineation process it may have been.

The types of data used in this research were Nominal, Interval and Ratio. Overlay analysis of dissimilar data types has the ability to identify some unique patterns in both data sets (Longley et al. 2001). However, in this research the combination of data types may have actually limited the analysis potential. Nominal data are not conducive to weighted overlays since the data are not representative of a continuous surface of some variable (Chrisman 2002). Therefore, that ability to truly weight all the variables in this research is limited. Unfortunately there is no real way to reclassify Nominal data, unless another variable is chosen. For instance, vegetation density or biomass may be better vegetation variables to use, as they are true ratio/interval data, and thus can be weighted and overlaid with the rest of the data accordingly. The ratio/interval data (precipitation and elevation) in this research are two variables frequently mentioned in the literature as a key component in quantitative ecoregion classification (Host et al. 1996, Lowell 1990, Stocks and Wise 2000). However, these data were essentially used as query parameters as they were combined with the Nominal data.

The specific data sets used in this research were the same, or derived from the same original source data (other than expert knowledge), as that which the EPA used in its original Oregon Level IV delineations (Thorson et al. 2002). Therefore, it should theoretically be feasible to model the process. However, there are some significant sources of error within a GIS model that warrant mentioning. First, a GIS model is only as accurate as the data used in the model (e.g., DeMers 2002). Some of the potential sources of error in the data used in this research are collection errors, polygon generalizations, classification errors, and statistical interpolation errors, just to name a few. Second, error propagation within a GIS model is very real (e.g., Longley et al. 2001). If one of the original polygons or raster cells in a data set has an unknown error, any analyses performed on that data are only accurate outside of the erroneous area, and, unfortunately, a user doesn't know where the errors are located, only the overall accuracy of the data, and then only if it's stated in the metadata. Therefore, any data that use or are built from data with errors will also have errors in those same records or fields. Furthermore, when the nominal data were resampled, using a nearest neighbor operation, errors in the input data set could have been enlarged if they were the value nearest to the center of the output grid.

The nature of manual ecoregion delineation will always have inconsistencies with results from a GIS model: again, neither is more right or wrong. The GIS model is attempting to automate a dynamic process, and even with perfect data there are likely places in the manual delineation process where the geographer is making a decision that can't be converted into a "rule" outside of that unique instance. So even with exhaustive notes on what the geographer was evaluating during the delineation of every ecoregion, there will always be generalization and confounding variables introduced by both the GIS model and manual delineation process.

The GIS model in this research is further constrained because it attempted to replicate, or reverse-engineer, the manual ecoregion delineations' performed by the EPA using similar variables in a completely different analytical process. The EPA ecoregions are conceptually dynamic by design, and the weights given to biotic and abiotic variables vary from region to region (Omernik, 1995). So, even if a model is able to accurately emulate an ecoregion in one region, it will fail in another region. Similarly, if two geographers manually delineate ecoregions in the same geographic area, they will undoubtedly delineate some of the ecoregion differently.

The above example represents one of the more significant advantages that a GIS model (despite the peril mentioned above) can offer ecoregion delineation: the ability to quantify the intensity or influence that each landscape variable has in relation to the ecoregion classification in a transparent and repeatable product.

CONCLUSION AND FUTURE RESEARCH

The value of ecoregion classification is expressed in the large number of organizations that use ecological classifications. The qualitative process that the EPA employs in its manual ecoregion delineations is highly effective, within the current scope of its users. The development of a quantitative GIS model in relation to delineating ecoregions will only increase ecoregion adoption by others, especially if there is a definitive and transparent process or framework identified in the model. Additionally the transition zones (ecotones) between ecoregions will be further understood and expressed. Ultimately, all ecoregions are an abstraction of reality, and none are inherently more correct than another, except within its unique delineation parameters.

Based on the results obtained, the second objective of this research -- expanding the model into the California portion of the study area -- remains an area of future investigation. As it stands now, the accuracy of the proposed GIS model is probably insufficient to give meaningful results for the California portion of the study area.

Increasing model accuracy is something that needs to be further researched. There are numerous quantitative analyses that could be further applied to these existing data sets in an effort to increase the ability to accurately emulate the Level IV ecoregions. Multi-variant regression, regression tree analysis, cellular automata, and discriminate function analysis are some of the more quantitative analyses mentioned in relation to ecological classification in the literature (Host 1996, Lowell 1990, Stocks and Wise 2000). Data are akin to additional research in analyses or modeling techniques.

The potential is high for further research into the format, resolution, accuracy, and quantity of data used in ecoregion classification, especially ratio/interval data; as was previously mentioned in the Discussion section, data representative of a continuous variable across the landscape would be highly valuable in the modeling process. The water quality analysis mentioned in the Methods section of the paper is one example of how an increase in data could help.

A collaborative ecoregion delineation project bringing together researchers with diverse interests -- some with experience with traditional or manual ecological classifications and others with GIS modeling or quantitative landscape analyses -- would definitely increase the understanding and compatibility of both techniques in the future. Specifically, the above collaboration would be valuable in developing a table of Ecoregion Assessment Factors with associated weights and compliance values. Constructing a table like this is an effective and accepted way to build a GIS model (Berry 1995, DeMers 2002), and has the added benefit of being easily used and modified by other users.

Further analysis of the Calculated Ecoregions results with a focus on quantifying and cartographically representing transition zones between ecoregions also would be relevant research, both for the cartographic and ecoregion communities. Incorporating fuzzy approaches to class assignments in these transition zones or areas of varying certainty could also be quantified in a GIS with an error or sensitivity analysis (Longley et al. 2001).

Whatever ecoregion delineation approach is undertaken; there will always be locations where delineation line placement is correct and incorrect with respect to different criteria. In these situations, the approach of weighting the opinions of regional experts developed by Omernik (1987) is especially valid, since often the regional experts are the ones who will be ultimately using the ecoregions as management units. The real challenge lies in incorporating the experts' views into data that can then be used in a GIS model.

REFERENCES

Bryce, S. A. and S. E. Clarke. 1996. Landscape-level ecological regions: linking state-level ecoregion frameworks with stream habitat classifications. *Environmental Management* 20(3):297-311

Bailey, R.G. 1976. Ecoregions of the United States. Unnumbered report. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Region. 1 map (1:7,500,000)

Berry, J.K. 1995. *Spatial Reasoning for Effective GIS*, GIS World Books, Fort Collins, CO.

CEC. 1997. Commission For Environmental Cooperation. Ecological Regions of North America, *Toward a Common Perspective*. 393, rue St-Jacques Ouest, bureau20, Montréal (Québec) Canada H2Y1N9. http://www.cec.org

Chrisman, Nicholas. 2002. *Exploring Geographic Information Systems*, 2nd ed. New York: John Wiley & Sons, Inc.

Clarke, Sharon E., Denis White, Andrew L. Schaedel. 1991, Oregon, USA, Ecological Regions and Subregions for Water Quality Management. *Environmental Management*. 15: 847-856.

DeMers, Michael N. 2002. *GIS Modeling in Raster*. New York: John Wiley & Sons, Inc.

EPA 2004. Web portal for ecoregion maps, data, and publications. http://www.epa.gov/wed/pages/ecoregions/links.htm [11/04]

EPA STORET, 2004. Web portal for monitoring and assessing water quality data, http://www.epa.gov/storet/ [11/04]

ESRI 2004. ArcGIS 9.0 (ArcInfo license) Desktop Help. Environmental Systems Research Institute. Redland, California.

Griffith, G.E., J.M. Omernik, A.J. Woods. 1999. Ecoregions, watersheds, basins, and HUCs: How state and federal agencies frame water quality. *Journal of Soil and Water Conservation*. 54(4):665-678.

Host, George E., Thomas R. Crow, David J. Mladenoff, Philip L. Polzer, Mark A. White. 1996. A Quantitative Approach to Developing Regional Ecosystem Classifications. *Ecological Applications*, 6(2):608-618.

Hughes, Robert M., David P. Larsen. 1988, Ecoregions: an approach to surface water protection. *Journal WPCF.* 60:486-493.

Jensen, John R. 1996. *Introductory Digital Image Processing: a remote sensing perspective*, 2nd ed. Upper Saddle River, NJ: Prentice Hall.

Küchler, A.W. 1964. The Potential Natural Vegetation of the Conterminous United States. American Geographic Society Special Publication. No. 36. 154.

Larsen, D.P., J.M. Omernik, R.M. Hughes, C.M. Rohm, T.R.Whittier, A.J. Kinney, A.L. Gallant, and D.R.Dudley. 1986. The Correspondence between spatial patterns if fish assemblages in Ohio streams and aquatic ecoregions. *Environmental Management.* 10:815-828.

Longley, Paul A., Michael F. Goodchild, David J. Maguire, David W. Rhind. 2001. *Geographic Information System and Science.* Chichester: John Wiley & Sons, Inc.

Lowell, Kim E. 1990. Differences Between Ecological Land Type Maps Produced Using GIS or Manual Cartographic Methods. *Photogrammetric Engineering and Remote Sensing*. 56(2): 169-173.

Lyons, John. 1989. Correspondence between the Distribution of Fish Assemblages in Wisconsin Streams and Omernik's Ecoregions. *American Midland Naturalist.* 122: 163-182.

McMahon, Gerard, Steven M. Gregonis, Sharon W. Waltman, James M. Omernik, Thor D. Thorson, Jerry A. Freeouf, Andrew H. Rorick, James E. Keys. 2001. Developing a Spatial Framework of Common Ecological Regions for the Conterminous United States. *Environmental Management.* 28(3): 293-316.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Map (scale 1:7,500,000). *Annals of the Association of American Geographers.* 77(1):118-125.

Omernik, J.M. 1995. Ecoregions: A Spatial Framework for Environmental Management. In: *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making.* W. Davis and T.P. Simon (eds.). Lewis Publishing, Boca Raton, FL. pp.49-62.

Omernik, James M., Glenn E. Griffith. 1991. Ecological regions versus hydrologic units: Frameworks for Managing Water Quality. *Journal of Soil and Water Conservation.* 46:334-340.

Oregon Climate Service (OCS), Web portal for climate data, http://www.ocs.orst.edu/prism/ [11/04]

Oregon Department of Forestry. Web portal for GIS data. http://www.odf.state.or.us/divisions/administrative_services/services/gis/gishome.html [11/04]

Oregon Geospatial Data Clearinghouse, http://www.gis.state.or.us/index.html [11/04]

Stocks, Christopher E., Steve Wise. 2000. The Role of GIS in Environmental Modeling. *Geographical and Environmental Modeling*. 4:219-235.

O'Sullivan, David and David J. Unwin. 2003. *Geographic Information Analysis*. Hoboken, New Jersey; John Wiley & Sons Inc.

Thorson, T.D., S.A. Bryce, D.A. Lammers, A.J. Woods, J.M. Omernik, J. Kagan, D.E. Pater, and J.A. Comstock. 2002. *Ecoregions of Oregon. (2 sided color poster with map, descriptive text, summary tables, and photographs)*. U.S. Geological Survey, Reston, VA. Scale 1:1,350,000.

USGS Water-Quality Data for the Nation web portal, http://waterdata.usgs.gov/nwis/qw [11/04]

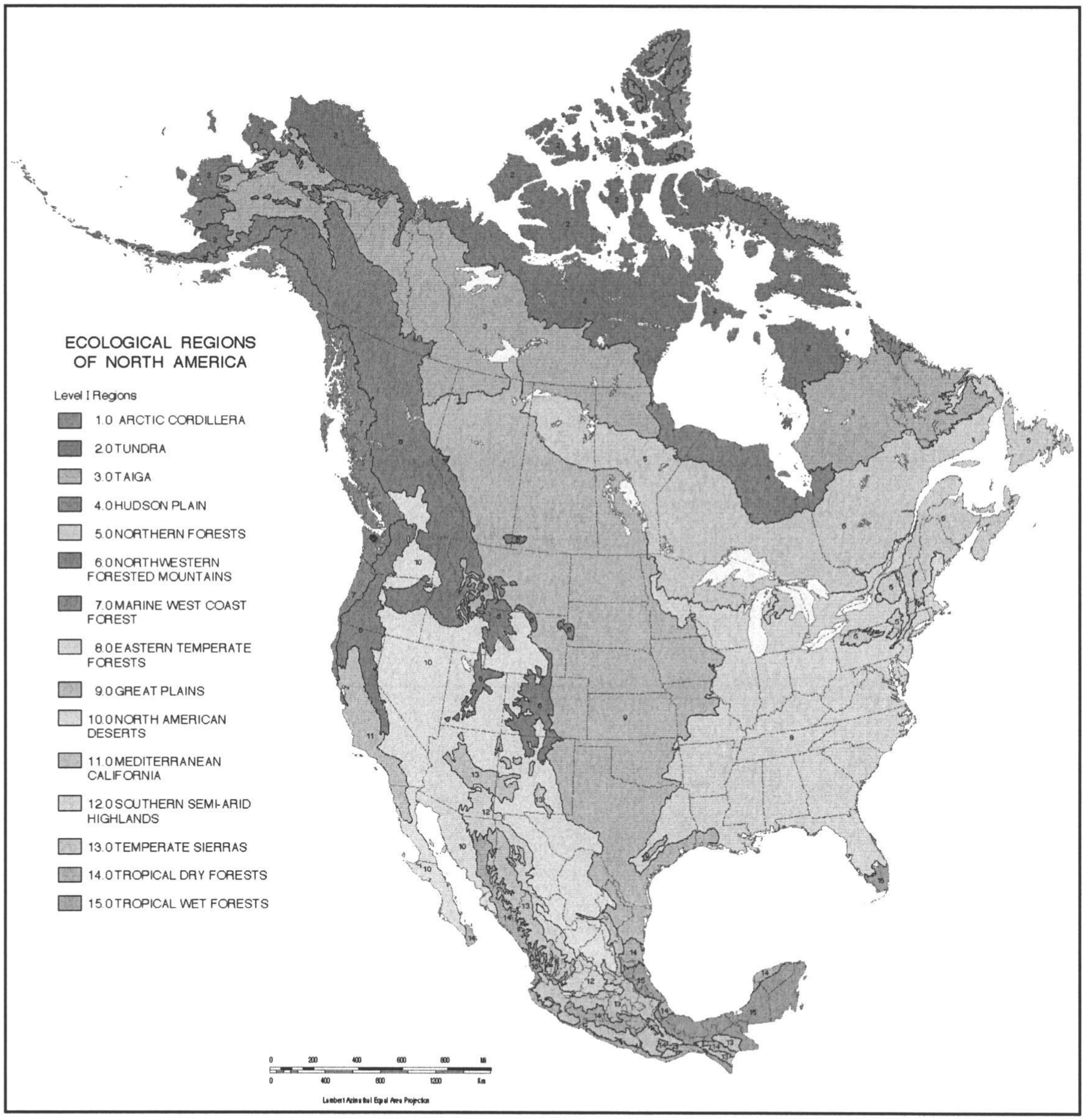
Virtual Oregon Natural Resources Data Clearinghouse web portal, http://digitalcollections.library.oregonstate.edu/virtualoregoncatalog/explorer.jsp [11/04]

Wiken, Ed.B., David Gauthier, Ian B. Marshall, Ken Lawton and Harry Hirvonen. 1996. A perspective on Canada's Ecosystems: An overview of the Terrestrial and Marine Ecozones. Occasional paper N. 14, *Canadian Council on Ecological Areas*, Ottawa, Ont. 95 pp.

Wiken, E.B. 1986. Terrestrial Ecozones of Canada. *Ecological Land Classification, Series* No. 19. Environment Canada. Hull, Quebec. 26pp. + map.

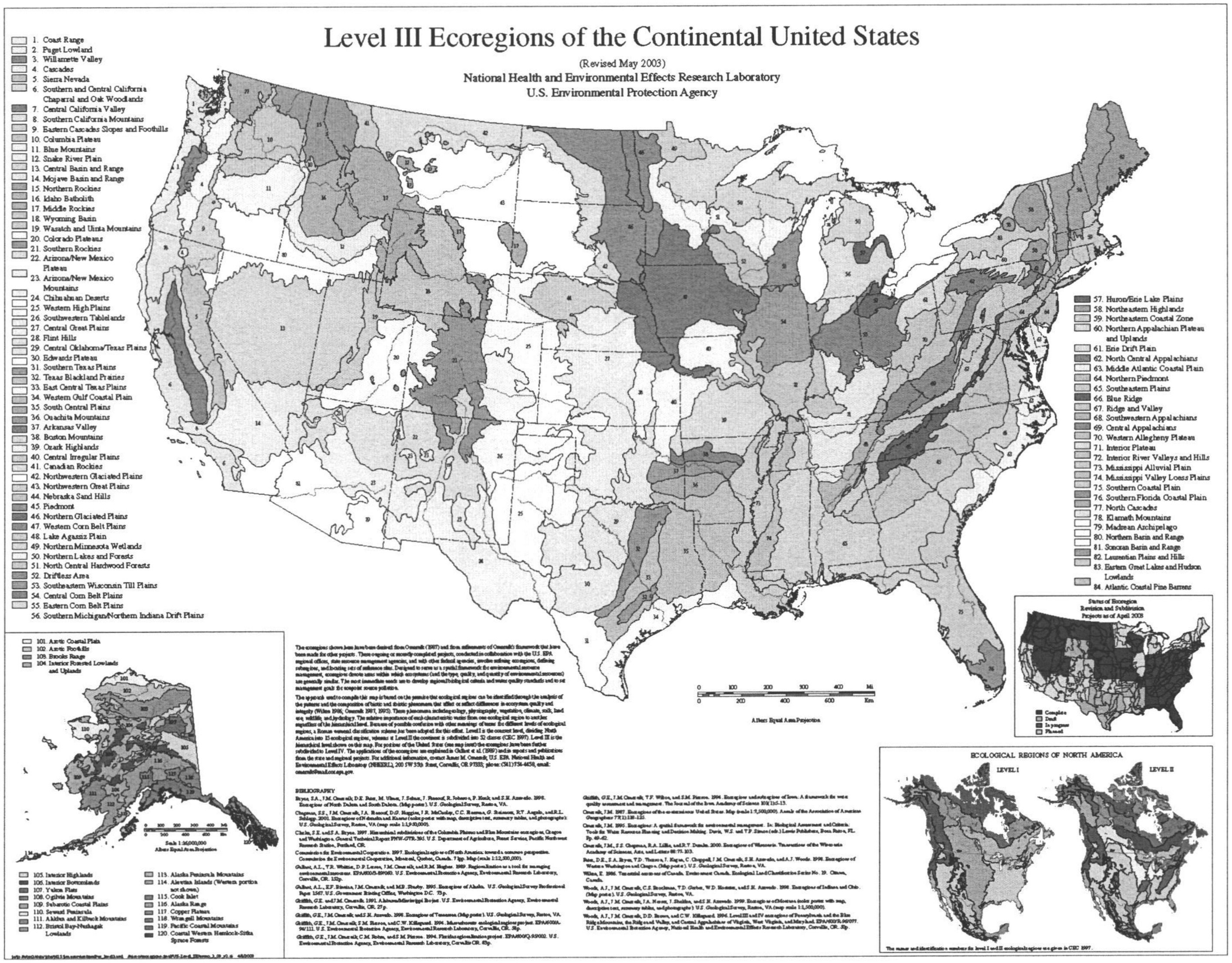
APPENDICES

Appendix A – EPA Ecoregion Map, Level I (EPA, 2004)

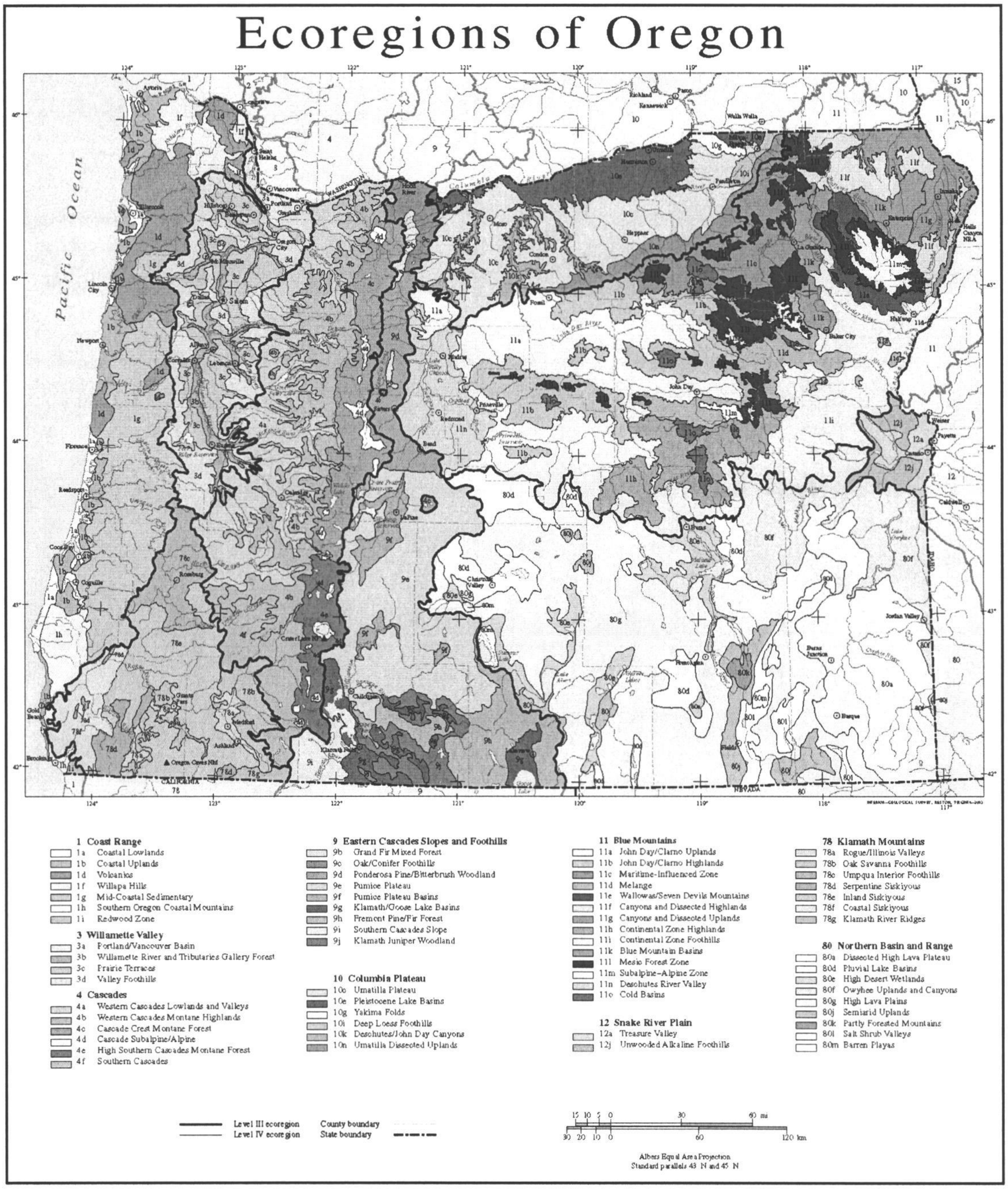


Appendix B – EPA Ecoregion Map, Level II (EPA, 2004)

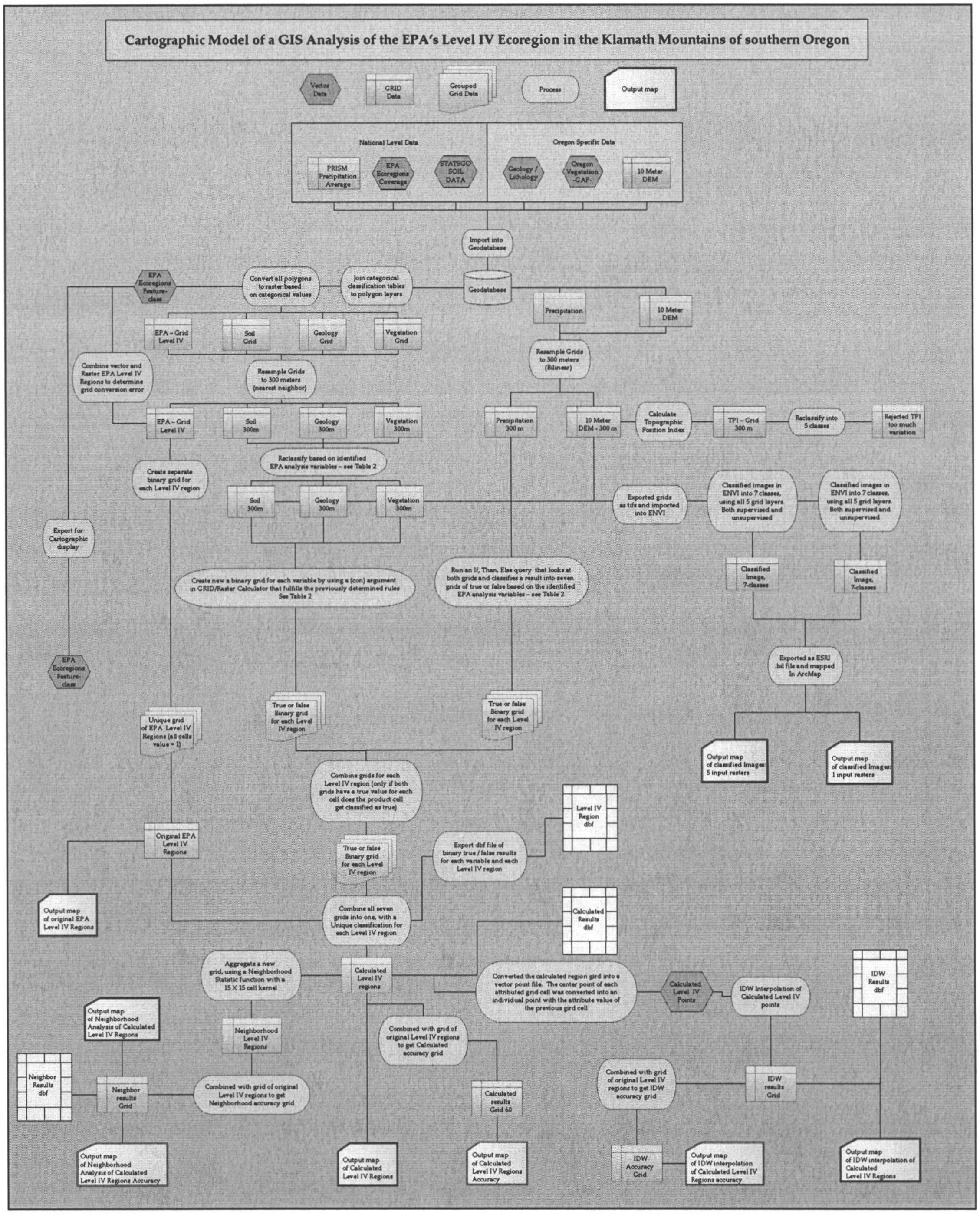
Appendix C – EPA Ecoregion Map, Level III – Conterminous United States (EPA, 2004)



Appendix D – EPA Ecoregion Map, Level IV – Oregon (EPA, 2004)



Appendix E – Cartographic Model of Methodology



Appendix F – Nominal Data Look-up Tables

Geology	
VALUE	**LITHOLOGY**
86	Alkalic intrusive rocks, Brush Lake, campt
2	Alluvial deposits
112	Amphibolite of Briggs Creek
81	Andesite
39	Basalt and andesite intrusions
34	Basalt and basaltic andesite
54	Basaltic and andesitic ejecta
52	Basaltic and andesitic rocks
36	Basaltic andesite and basalt
110	Basaltic volcanic and sedimentary rocks of
115	Chetco complex of Hotz(1971)
79	Clastic sedimentary rocks
108	Colebrooke Schist
8	Columbia River Basalt Group and related fl
119	Condrey Mountain Schist
69	Dothan Formation, sedimentary rocks
106	Dothan Formation, volcanic rocks
3	Dune sand
41	Fanglomerate
100	Fisher and Eugene Formations and correlati
102	Fisher and Eugene formations basaltic rock
43	Flows and clastic rocks, undifferentiated
116	Gabbro and ultramafic rocks associated wit
37	Glacial deposits
89	Glaciofluvial deposits
30	Granite and diorite
76	Granitic rocks
44	Hypabyssal intrusive rocks
49	Intrusive basalt and andesite
25	Intrusive rocks
11	Lacustrine and fluvial sedimentary rocks
7	Landslide and debris-flow deposits
29	Mafic intrusions
35	Mafic vent complexes
57	Marine Eugene Formation, where mapped sepa
96	Marine sandstone and siltstone
104	Marine sandstone, siltstone, and mudstone
4	Marine sedimentary rocks
75	Marine siltstone, sandstone, and conglomer
109	May Creek Schist

GEOLOGY_LITHOLOGY...Continued

VALUE	LITHOLOGY
105	Mazama ash flow deposits
117	Melange
118	Melange of Dutchmans Peak
74	Myrtle Group
113	Nonmarine sedimentary rocks
72	Otter Point Formation and related rocks
68	Rhyolite and dacite
70	Ridge-capping basalt and basaltic andesite
18	Saddle Mountain Basalt, Columbia River Bas
16	Sedimentary rocks
26	Sedimentary rocks, partly metamorphosed
114	Shale, mudstone, and sandstone
40	Siletz River Volcanics and related rocks
55	Silicic ash-flow tuff
59	Silicic vent complexes
77	Silicic vent rocks
6	Terrace, pediment, and lag gravels
27	Tillamook Volcanics
31	Tuffaceous sedimentary rocks and tuff
60	Tuffaceous sedimentary rocks, tuff, pumici
14	Tuffaceous siltstone and sandstone
56	Tyee Formation
73	Ultramafic and related rocks of ophiolite
58	Undifferentiated basaltic lava flows
48	Undifferentiated sedimentary and volcanicl
71	Undifferentiated tuff
61	Undifferentiated tuffaceous sedimentary ro
47	Volcanic rocks
1	water body
12	Yamhill Formation and related rock
67	Youngest basalt and basaltic andesite

Soils

VALUE	COMP_NAME
67	ACKER
45	AGATE
25	BATEMAN
83	BEEKMAN
4	BELLPINE
172	BIGELOW

Soils... Continued

163	BIGRIVER
175	CHAIX
14	CHEHALIS
8	CONCORD
90	CRATER LAKE
32	CULTUS
7	DIXONVILLE
35	FREEZENER
47	HUKILL
48	JAYAR
160	JAYEL
13	KEEL
187	KINDIG
138	KIRK
2	KIRKENDALL
15	KLICKITAT
46	LASSEN
17	LASTANCE
82	MEDA
134	MEDCO
1	MURNEN
171	NEUNS
78	OAKLAND
155	OATMAN
11	OLYIC
34	PEARSOLL
31	PEAVINE
177	PINEHURST
169	POKEGEMA
81	RINEARSON
27	RUCH
84	SERPENTANO
89	STEIGER
41	TALLOWBOX
186	TANGLE
43	TATOUCHE
29	TELEMON
73	TEMPLETON
71	WALDPORT
3	WAPATO
159	WEDDERBURN

Vegetation Name	
VALUE	**DESCRIPTION**
7	Agriculture
35	Alpine Fell-Snowfields
37	Coastal Dunes
54	Coastal Strand
28	Douglas Fir Dominant-Mixed Conifer Forest
31	Douglas Fir/White Oak Forest
50	Douglas Fir-Mixed Deciduous Forest
55	Douglas Fir-Port Orford Cedar Forest
8	Douglas Fir-W. Hemlock-W. Red Cedar Forest
52	Douglas Fir-White Fir/Tanoak-Madrone Mixed For
6	Grass-shrub-sapling or Regenerating young fore
60	Jeffery Pine Forest and Woodland
30	Lava Flow
45	Manzanita Dominant Shrubland
3	Mixed Conifer/Mixed Deciduous Forest
17	Modified Grassland
36	Mountain Hemlock Montane Forest
27	NWI Estuarine Emergent
21	NWI Palustrine Emergent
2	NWI Palustrine Shrubland
18	Open Water
26	Oregon White Oak Forest
25	Palustrine Forest
13	Ponderosa Pine Forest and Woodland
23	Ponderosa Pine/White Oak Forest and Woodland
47	Ponderosa-Lodgepole Pine on Pumice
10	Red Alder Forest
62	Serpentine Conifer Woodland
58	Shasta Red Fir-Mountain Hemlock Forest
59	Siskiyou Mtns Serpentine Shrubland
51	Siskiyou Mtns. Mixed Deciduous Forest
4	Sitka Spruce-W. Hemlock Maritime Forest
63	South Coast Mixed Deciduous Forest
16	Subalpine Fir-Lodgepole Pine Montane Conifer
33	Subalpine Grassland
34	Subalpine Parkland
24	True Fir-Hemlock Montane Forest
5	Urban

Appendix G – Model Criteria Table and Klamath Mountains Descriptions

Model Criteria Table

Region	Grid #	Elevation (ft) Min	Elevation (ft) Max	Precipitation (in) Min	Precipitation (in) Max	Geol values	Soil values	Veg values
78-A	1	900	2000	20	60	2, 6, 41, 113, 79	27, 34, 45, 46	5, 7, 51, 52
78-B	2	1400	4000	25	45	2, 58, 76, 113, 114	27, 41, 46, 83, 134	7, 23, 26, 28, 52
78-C	3	400	2800	30	50	2, 40, 69, 74, 75, 96, 104	4, 27, 78, 83	6, 7, 8, 28
78-D	4	1500	4300	45	120	16, 30, 73, 118	34, 48, 83, 160	28, 52, 60, 62
78-E	5	800	7000	35	70	16, 47, 69, 76, 109	34, 41, 48, 67, 83	6, 7. 28, 51, 52
78-F	6	600	5300	70	130	69, 73, 96, 108	48, 81, 83	8, 28, 52, 55
78-G	7	3800	7500	25	35	48, 58, 76	43, 46, 48, 172, 175, 187	6, 13, 45, 52

EPA Level IV Klamath Mountains ecoregion descriptions (EPA, 2004)

78. KLAMATH MOUNTAINS

Level IV Ecoregions	Area (square miles)	Physiography	Elevation/ Local Relief (feet)	Geology: Surficial and Bedrock	Soils: Order (Great Group)	Soils: Common Soil Series	Soils: Temperature/ Moisture Regimes	Climate: Precipitation Mean annual (inches)	Climate: Frost Free Mean annual (days)	Climate: Mean Temperature January min/max; July min/max (°F)	Potential Natural Vegetation*/ Present Vegetation (*Source: Kuchler, 1964)	Land Cover and Land Use
78a. Rogue/Illinois Valleys	285	Terraces and floodplains in mountain valleys.	900-2000/ mostly less than 100-200; max 600	Quaternary fluvial terrace and floodplain deposits.	Mollisols (Haploxerolls, Argixerolls), Alfisols (Palexeralfs), Inceptisols (Haploxerepts, Endoaquepts)	On floodplains: Newberg, Camas, Evans. On valley terraces: Medford, Foehlin, Central Point. On fans: Kuch, Barron, Clawson.	Mesic/ Xeric	20-60	120-180	31/47; 51/89	Mostly Oregon oak woods, scattered Douglas-fir forest and grasslands/ Oregon white oak, madrone, California black oak, ponderosa pine, and grasslands. Common understory plants include California fescue, snowberry, and serviceberry. In riparian areas willow and cottonwood.	Woodland, grassland, orchards, cropland, pastureland, and rural residential, residential, and commercial development.
78b. Oak Savanna Foothills	818	Moderately sloping mountain foothills with medium gradient streams.	1400-4000/ 400-2000	Quaternary colluvium and alluvium. In east: Eocene basaltic lava flows. In west: Jurassic sandstone and shale.	Mollisols (Haploxerolls, Argixerolls), Inceptisols (Haploxerepts), Vertisols (Haploxererts)	Medco, McMullin, McNull, Brader, Debenger, Carney	Mesic/ Xeric	25-45	110-160	28/45; 50/87	Oregon oak woods and Douglas-fir forest/ Oregon white oak and California black oak woodlands, madrone, and ponderosa pine, grassland savanna. Wetter areas: Douglas-fir and incense cedar. Understory species include oceanspray, poison oak, snowberry, Idaho fescue, California brome, roughstalk bluegrass, and ceanothus.	Woodland, forest, grassland-savanna, rangeland, orchards, and some row cropland. Rural residential development and some logging.
78c. Umpqua Interior Foothills	921	Foothills and narrow interior valleys containing fluvial terraces and floodplains.	400-2800/ less than 100-1900	Quaternary alluvium and colluvium. Pliocene marine sandstone. Eocene basalt.	Mollisols (Haploxerolls, Argixerolls, Argiaquolls), Alfisols (Haploxeralfs), Inceptisols (Dystroxerepts)	On terraces: Conser, Newberg, Roseburg. On foothills: Oakland, Sutherlin, Nonpareil.	Mesic/ Xeric	30-50	120-180	34/49; 53/84	Douglas-fir forest and Oregon oak woods/ Oregon white oak, Douglas-fir, ponderosa pine, grand fir, madrone, tanoak, and chinkapin. Understory plants include snowberry, salal, Oregon grape, poison oak, oceanspray, and swordfern.	Woodland, forest, pastureland, vineyards, orchards, cropland, and rural residential, commercial, and residential development.
78d. Serpentine Siskiyous	440	Highly dissected mountains containing perennial, high gradient streams.	1500-4300/ 600-2400	Quaternary colluvium. Jurassic ultramafic and related rocks.	Alfisols (Haploxeralfs), Inceptisols (Dystroxerepts)	Pearsoll, Dubakella, Eightlar, Perdin, Cravecreek	Mesic, Frigid/ Xeric	45-120	70-140	32/44; 49/82	Mixed conifer forest and montane chaparral/ Jeffrey pine, tanoak, incense cedar, Douglas-fir, and chaparral composed of manzanita, ceanothus, Idaho fescue, and Lemmon needlegrass. Soils derived from serpentine support unique understory species and sparse woodland vegetation.	Sparse woodland. Recreation, logging, and mining. Historical gold, nickel, chrome, copper, and mercury mining.
78e. Inland Siskiyous	2610	Highly dissected mountains with high gradient streams. A few small lakes are found at higher elevations.	800-7000/ 1000-2800	Quaternary colluvium. Jurassic granitic rocks, shale, and sandstone.	Alfisols (Haploxeralfs), Inceptisols (Haploxerepts, Dystroxerepts), Ultisols (Haploxerults)	Vannoy, Caris, Offenbacher, Josephine, Beekman, Kanid, Siskiyou, Tetlarick	Mesic, Frigid/ Xeric	35-70	90-160	29/44; 50/86	Mixed conifer forest/ Douglas-fir, ponderosa pine, Oregon white oak, California black oak, madrone, serviceberry, snowberry, Oregon grape, California fescue, and poison oak.	Forest. Logging, recreation, rural residential development, and mining.
78f. Coastal Siskiyous	853	Highly dissected mountains with high gradient streams.	600-5300/ 1000-2700	Quaternary colluvium. Cretaceous and Jurassic conglomerate, sandstone, and siltstone.	Inceptisols (Dystrudepts, Dystroxerepts), Ultisols (Palehumults, Palexerults)	Fritsland, Bravo, Cassiday, Deadline, Barkshanty, Nailkeg, Jayar, Althouse, Skymor, Atring, Kanid, Acker	Mesic, Frigid/ West: Udic; East: Xeric	70-130	100-190	38/50; 50/76	Mostly mixed conifer forest/ Tanoak, Douglas-fir, madrone, bigleaf maple, California laurel, Port Orford cedar, chinkapin, salal, rhododendron, and swordfern; some western hemlock in west on udic soils.	Forest. Logging, recreation, rural residential development, and some mining.
78g. Klamath River Ridges	121	Highly dissected mountains containing high gradient streams.	3800-7500/ 800-3000	Quaternary colluvium. Miocene and Oligocene basaltic and andesitic flows. Jurassic granitic rocks.	Mollisols (Argixerolls, Haploxerolls)	Skookum, McMullin, McNull	Mesic/ Xeric	25-35	90-160	24/42; 49/88	Montane chaparral and mixed conifer forest/ Higher altitudes and north-facing slopes: Douglas-fir and white fir. Lower altitudes and south-facing slopes: ponderosa pine, western juniper, and chaparral. Oregon grape, western fescue, snowberry, bluebunch wheatgrass, and ceanothus.	Forest, woodland, savanna, and chaparral. Logging, livestock grazing, and recreation.

Appendix H – ArcInfo GRID Commands

Nominal Data

Binary, true/false query of nominal data by ecoregion sample syntax:

```
output_grid=con(veg_grid=5,7,51,52,con(soil_grid=27,34,45,46,con(ge
ol_grid=2,6,41,113,79)))
```

The above query was repeated for each of the seven ecoregions. Each query was changed so that the output_grid name was nom_grid 1 through 7 as well as the numerical values following veg_grid, soil_grid, and geol_grid based on the associated numerical values for each variable by ecoregion in the Model Criteria Table.

Ratio/Interval Data

Binary, true/false query of ratio/interval data by ecoregion syntax is:

```
If (elev >= 900 and elev <= 2000 and prcp>= 20 and prcp<= 60)
ratio_grida = 1
Else if (elev >= 1400 and elev <= 4000 and prcp>= 25 and prcp<= 45)
ratio_gridb = 1
Else if (elev >= 400 and elev <= 2800 and prcp>= 30 and prcp<= 50)
ratio_gridc = 1
Else if (elev >= 1500 and elev <= 4300 and prcp>= 45 and prcp<= 120)
ratio_gridd = 1
Else if (elev >= 800 and elev <= 7000 and prcp>= 35 and prcp<= 70)
ratio_gride = 1
Else if (elev >= 600 and elev <= 5300 and prcp>= 70 and prcp<= 130)
ratio_gridf = 1
Else if (elev >= 3800 and elev <= 7500 and prcp>= 25 and prcp<=
35ratio_gridg = 1
Endif
```

The above command query created a new grid for each ecoregion with a value of 1 where ever the conditions were true and a value of 0 where ever the conditions were false.

Creating a common grid of Calculated Ecoregions

Combining the seven individual grids of calculated ecoregions into a single grid with a unique value for each ecoregion used the syntax below:

```
if (eco_a == 1) eco_reg_grid = 1 else if (eco_b == 1) eco_reg_grid = 2
else if (eco_c == 1) eco_reg_grid = 3 else if (eco_d == 1) eco_reg_grid
= 4 else if (eco_e == 1) eco_reg_grid = 5 else if (eco_f == 1)
eco_reg_grid = 6 else if (eco_g == 1) eco_reg_grid = 7
endif
```

The above command combined the separate grid calculation results by ecoregion (eco_a, eco_b, eco_c, eco_d, eco_f, and eco_g) into one grid, eco_reg_grid, with a value of 1 for region a, 2 for region B, and so on.