Oregon, USA, Ecological Regions and Subregions for Water Quality Management[1]

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ABSTRACT / To aid in producing a protection and management strategy for the freshwater resources of Oregon, USA, we have defined an initial set of ecological regions and subregions of the state that organize the spatial similarities and differences in water quality. We have delineated and mapped these subregions using existing maps of ecological regions, maps of selected environmental characteristics, remote sensing imagery, and descriptive literature. To help in interpreting the resulting map, a unique approach to mapping regions is used. We have described the relative widths of regional boundaries, and we ranked the characteristics used in determining them. Water quality managers in Oregon intend to apply these subregions as an organizational framework for data display and reporting, prioritizing monitoring and pollution control strategies, developing biological criteria for water quality standards, and developing other regional water quality management approaches.

In June 1988, the Oregon (USA) Department of Environmental Quality (DEQ) initiated a State Clean Water Strategy (SCWS) to set priorities among river reaches, lakes, aquifers, and estuaries for management attention. DEQ managers were interested in using ecological regions (ecoregions) as a possible framework for water quality management. Two ecoregion schemes for the conterminous United States were defined by Bailey (1980) and by Omernik (1987). Omernik and Gallant (1986) described in detail the regionalization of Oregon and the Pacific Northwest. Although Oregon DEQ was generally interested in the original Omernik ecoregions as a possible framework for water quality management, the resolution at which these ecoregions were developed was too coarse and the lines were too generalized for their purpose. This issue could not be rectified simply by enlarging the original 1:2,500,000-scale map, because the distortions inherent in mechanical enlargement and the low resolution of the original base maps would have caused poor fidelity to ground truth. A more suitable approach was to refine the original lines using medium-scale (1:250,000) maps. In addition, the ecoregions could be further divided to identify more homogeneous smaller units called subregions. These subregions represent areas more suitable for applying management practices by DEQ. The delineation of subregions was accomplished by working at a larger scale (higher resolution) and in smaller areas.

This article describes the process of creating ecological subregions for Oregon. Further investigation could lead to additional refinements in the work presented here. We provide the background to this work and then describe our methodology, results, and potential applications in subsequent sections.

KEY WORDS: Ecoregions; Ecological regions; Water-quality management

Background

The conceptual and methodological basis for ecological regionalization is discussed in Gallant and others (1989), Bailey and others (1985), Bailey (1983), and Rowe and Sheard (1981). In Bailey and others (1978), ecological regionalization is considered as a process for classifying landscapes using a subdivisional, or top-down, methodology. The process used in the work re-

[1]The research described in this article has been funded by the U.S. Environmental Protection Agency. This document has been prepared at the EPA Environmental Research Laboratory in Corvallis, Oregon, in part through contract number 68-C8-0006 to NSI Technology Services Corporation. It has been subjected to the agency's peer and administrative review and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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ported here (see the Methodology section below) follows this general paradigm, although it is based explicitly upon specific physical and cultural factors, such as soil, vegetation, land use/land cover, and topography, that are considered to most strongly influence regional patterns of water quality. In this sense, the methodology is also synthetic; however, the synthesis is not strictly formal as might occur in a map overlay process using a geographic information system (see Burrough 1986 for a general discussion of methods and issues and Bailey 1988 for a cautionary evaluation). Rather, the contributing factors are weighed qualitatively and synthesized mentally, prior to subdividing into (sub)regions.

The validity and usefulness of regions developed using this synthetic process can be evaluated with site-specific data. Although the Oregon subregions reported here have not been quantitatively evaluated, ecoregions at the coarser level of resolution have been evaluated. Hughes and others (1987) and Whittier and others (1988) evaluated the robustness of Omernik's eight Oregon ecoregions for river basins and small streams, respectively.

Methodology

Source Data

Initially, maps of environmental characteristics, aerial photography, satellite imagery, and descriptive documents were obtained. Multispectral scanner false color composites, at a scale of approximately 1:1,000,000, and various scales of aerial photography were available for consultation through the Environmental Remote Sensing Applications Laboratory at Oregon State University (NASA Ames 1972–1978, USGS EROS 1972–1979). Thematic maps were obtained from the US Geological Survey, Oregon state agencies, the Oregon State University Map Library, and the Atlas of Oregon (Loy and others 1976). The preferred map scale was 1:250,000, although for some environmental characteristics only smaller-scale maps were available.

We predominantly used maps of land use/land cover, vegetation, soil, and topography. The US Geological Survey's 1:250,000- and 1:100,000-scale land use/land cover maps (USGS 1970a), based on the classification of Anderson and others (1976), helped to differentiate between agriculture, forest, and range. Landsat imagery (NASA Ames 1972–1978) and drainage basin maps of land use (Oregon Water Resources Department 1978–1980) aided in discriminating between irrigated and nonirrigated agriculture. The Anderson second level division of forest land into deciduous and evergreen classes was not an important distinction for subregionalization in Oregon, where conifers are dominant. However, some subregions were partially distinguished by differences in tree species. For example, the mesic environment of the high Cascades, typified by the high-elevation firs and hemlock, contrasts sharply with the xeric ponderosa pine, characteristic of the slopes and foothills of the eastern Cascades. Several types of vegetation maps were helpful in assessing the importance of species differences for subregionalization.

The available intermediate-scale vegetation maps followed different classification schemes. The most useful vegetation map available was a 1936 map of forest types by H. J. Andrews and R. W. Cowlin (map scale 1:253,440) (1936). This map shows forests as they existed in 1936, including an estimation of the maturity of some of the stands. Unfortunately, the forest types for recent (at the time of the mapping) cut-over and burned lands could not be ascertained from the map and the vegetation for the vast areas of nonforested lands was unmapped. Maps of potential natural vegetation or climatic climax are not influenced by transient impacts to the landscape and can sometimes be useful in defining ecoregions. Although Küchler's (1964) map of the potential natural vegetation of the United States was small-scale (1:3,168,000), it had enough detail to be of use to this project. Frenkel and Kolar's (1976) map of natural vegetation (map scale 1:2,000,000), and Franklin and Dyrness's (1988) map (scale 1:3,500,000) and descriptions of zones of vegetation, based on climax vegetation, were also helpful.

Topographic information was available from the US Geological Survey's 1:250,000-scale topographic maps (USGS 1970b). The spacing of contour lines and the texture of the landscape interpreted from the juxtaposition of the contour lines were used to determine the land surface form. Omernik used a national map of land surface form (Hammond 1970) for his ecoregion delineation, but interpreted larger-scale maps of land surface form for Oregon were not available.

We used two soil maps: General Soil Map: State of Oregon (map scale 1:750,000) (USDA SCS and others 1985) and Soils (map scale 1:2,000,000) from the Atlas of Oregon (Simonson and USDA SCS 1976). The General Soil Map was available in digital format, and we were able to plot the lines at our working scale of 1:250,000, for qualitative comparisons with other maps.

Analysis and Mapping

Once the data were gathered, the maps were analyzed separately to identify potential subregions—areas distinctly different from the surrounding area and large enough to warrant being distinguished as separate units. The intended use of the map to be produced helped establish bounds for the definition. We evaluated homogeneity in types of water bodies, potential water quality stressors, and the effects of these stressors to determine the soundness of creating each subregion. Information provided by the potential DEQ users of the map enabled us to estimate the unit size at the lowest management level of interest. In general, each subregion is at least 150 square km, although discontinuous units of a subregion may be smaller.

USGS (1970b) 1:250,000-scale topographic maps served as the base for defining final subregion boundaries, because the quality of these maps was judged to be the best of all the available maps or map series. By quality we mean to include the concepts of the completeness of coverage, the comparability of the map series across the state, the representativeness of the maps' portrayal of surface topography, the accuracy of the topographic information presented, and the precision or resolution of both the horizontal locations (i.e., the map scale) as well as the vertical elevation data. For reference, Omernik's ecoregion lines were transferred to the topographic maps. In addition, a sheet of clear acetate was overlaid on each topographic map and registered to it. Color-coded soil and land use/land cover lines were transferred to this sheet. Since the vegetation information was synthesized from several maps, these lines were not drawn on the acetate. However, the clear acetate sheets could be registered to the Andrews and Cowlin vegetation map (1936). A second acetate sheet also was registered to the topographic map and used to sketch the refined ecoregion lines and potential subregion lines. The process of delineation of ecological regions was iterative. The lines sketched on the acetate were evaluated and redrawn when necessary. By using water-soluble pens on the acetate, we were able to change the lines easily. We solicited feedback from several DEQ staff members who had studied the types and locations of water quality issues. In addition, we examined aerial photos (NASA Ames 1972–1978) of several areas of contention and took field trips to some problematic boundary areas and subregions.

After this evaluation, each boundary segment was assigned two attributes—the relative width of the transition zone and the rank of the importance of the characteristics used to determine the boundary (Figures 1 and 2). Lines were segmented according to natural changes in these attributes. Although natural resource boundaries are commonly defined by a single line, in reality they usually are transition zones of varying widths (Figure 1). While map users may recognize this aspect of boundaries, reinforcement through the explicit portrayal of transition widths is useful. In some areas in Oregon, the change is abrupt, for example along the face of the fault block ridges in southeastern Oregon. More gradual transitions are evident in several places, such as the transition from the western Cascades to the Klamath Mountains. In the quantification of a transition width, we wanted to characterize the distance over which most of the change occurred. We made no attempt to describe an unequal change in the transition width on either side of the center of the boundary line, although there were cases where this would better describe the change. We also attempted to explain the map compilation process by identifying the geographic characteristics used and their importance in delineating the boundaries (Figure 2). By quantifying the transition widths and explaining the map compilation procedure, we hoped to make the map more effective, understandable, and useful.

An important part of the validation and refinement of the subregion map was consultation with experts in ecoregion delineation and water quality management. We systematically reviewed our provisional regionalizations with these experts to verify our decisions and improve the results on both the distinguishing characteristics of the regions and subregions as well as on the definition of the boundaries between regions and subregions.

Results and Discussion

The resulting map of ecoregions and subregions is shown in Figure 1. Twenty-three subregions were developed from the initial eight regions of Omernik (1987). See the Appendix for detailed descriptions of each subregion, including information on soil, land use/land cover, vegetation, and topography.

Coast Range

In western Oregon, the Coast Range contains a number of small, relatively flat coastal lowlands (subregion 2) distinguished from the largely mountainous areas (subregion 1) in the rest of the range.

Willamette and Umpqua Valleys

The Willamette and Umpqua Valley region is divided into the flat, agricultural plains (subregion 3), the surrounding foothills that merge into the Coast Range to the west and the Cascades to the east (subregion 4), and the more xeric hills and valleys of the mid-Umpqua Valley (subregion 5).

Klamath Mountains

The Klamath Mountain region, the Oregon portion of Omernik's (1987) Sierra Nevada ecoregion, is di-

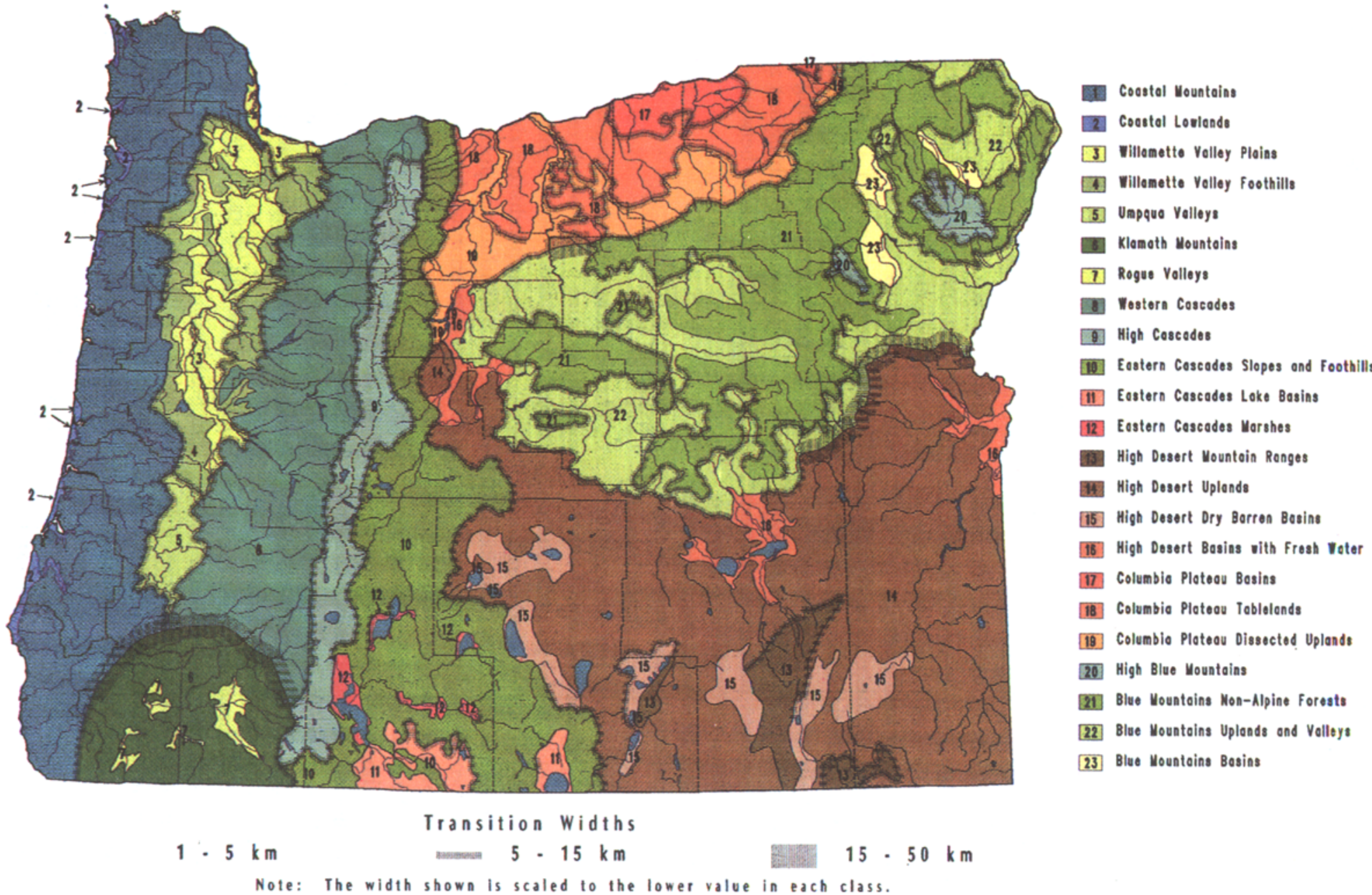

Figure 1. Oregon ecological regions and subregions for water quality management (By Sharon Clarke and Denis White).

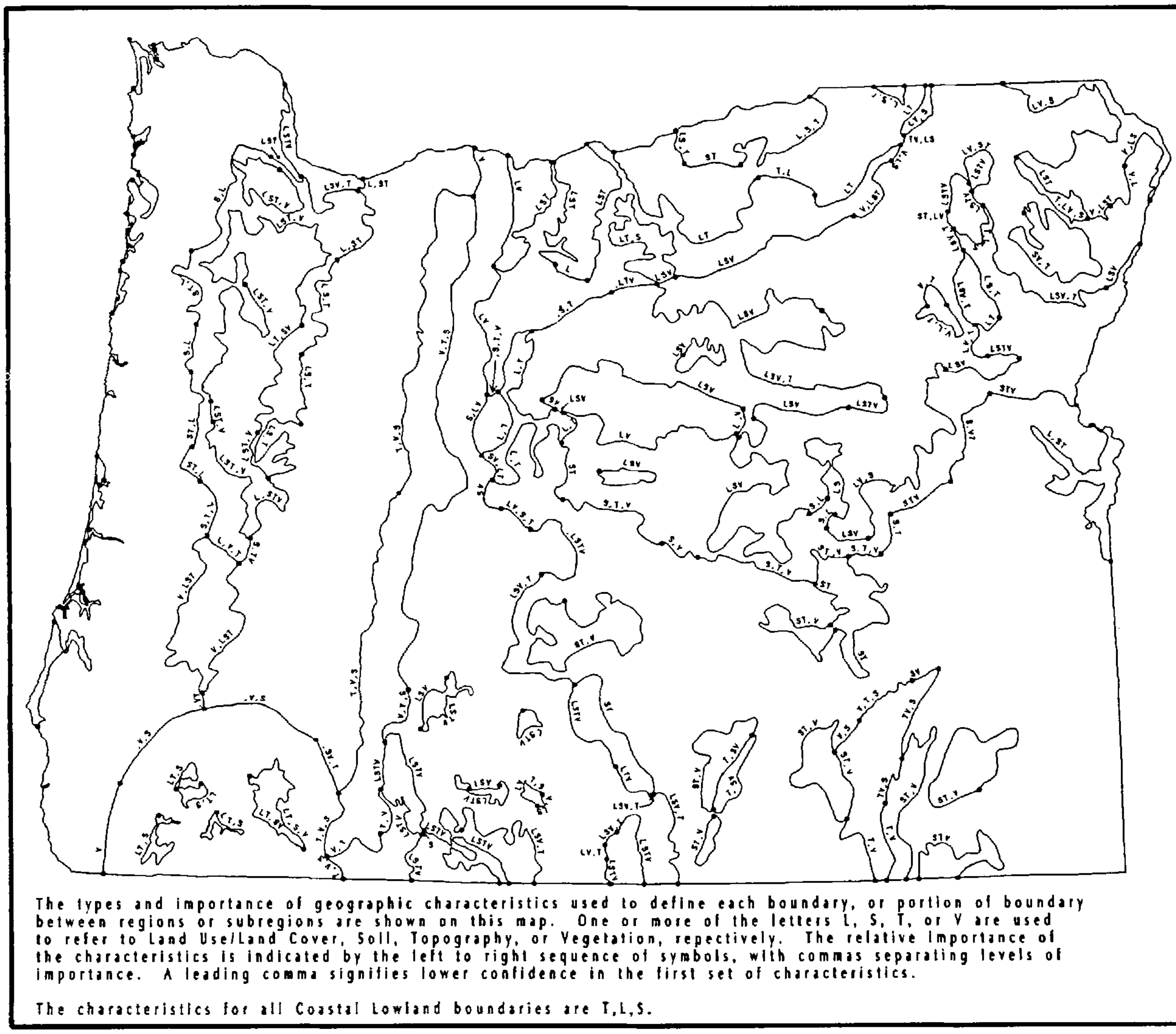

Figure 2. Oregon ecological regions and subregions for water quality management (By Denis White and Sharon Clarke).

vided into the mountains (subregion 6) and the relatively flat, partly agricultural valleys of the Rogue River and its tributaries (subregion 7).

Western Cascades

The main part of the Cascade Mountain Range is divided into the high-elevation, lower-relief plateaus with recent volcanic peaks (subregion 9), and the high-relief mountains on the western side of the range (subregion 8).

Eastern Cascades

In central Oregon, the eastern slope of the Cascades is divided into a subregion dominated by ponderosa and lodgepole pine forests (subregion 10), plus two smaller subregions in southcentral Oregon: the lake basins around Klamath Lake and Goose Lake (subregion 11) and the extensive Klamath and Sycan marshlands, plus similar marshlands (subregion 12).

High Desert

The high desert is divided into four subregions. One contains the ranges of Hart Mountain, Steens Mountain, and the Trout Creek Mountains (subregion 13). In the largest subregion, sagebrush and juniper uplands of moderate relief predominate (subregion 14). A third subregion includes the drier basins of Christmas Valley, Summer Lake, Warner Lakes, Catlow Valley, Alvord Desert, and Coyote Lake (subregion 15). Three basins or valleys, where water from surrounding mountains is available, form the fourth subregion (subregion 16). One of the areas surrounds the communities of Bend, Prineville, and Madras; another surrounds Malheur and Harney lakes; and the third is near the communities of Ontario and Vale.

Columbia Plateau

The Columbia Plateau is divided into the dry, flat basins of Umatilla and Walla Walla (subregion 17), the relatively flat-topped tablelands (subregion 18), and the dissected uplands that surround the major drainages of the Columbia River (subregion 19).

Blue Mountains

In the Blue Mountains, the high elevation alpine sections of the Wallowa Mountains and Elkhorn Ridge (subregion 20) are divided from the rest of the forested mountain areas (subregion 21). The flat basins around the communities of Enterprise, Baker, and LaGrande (subregion 23) are distinguished from the rolling, nonforested uplands and valleys in the rest of the region (subregion 22).

While the regions and their subregions reported here were generally agreed upon by our expert advisers, further development of subregions in some of the mountainous regions such as the Coast Range may be appropriate. Incorporation of more detailed information on geology and soil differences and examination of chemical and biological data from water quality monitoring and related research would be an important additional input into such further development.

Applications

The DEQ intends to apply the ecoregions and subregions concept as an organizational framework in four areas: (1) data display and reporting, (2) prioritization of monitoring and pollution control strategies, (3) development of regional water quality management approaches, and (4) development of narrative and numerical biological criteria.

Data Display and Reporting

The ecoregions and subregions concept offers an effective framework for organizing and using the enormous amount of data DEQ has collected. For example, this framework could be used for the biennial water quality status assessment report required by the US EPA [under Section 305(b) of the Clean Water Act]. This report provides a means for Congress and the public to evaluate Oregon's water quality, the progress made in maintaining and restoring its quality, and the problems that remain. Traditionally, the report has been organized by type of waterbody (river, estuary, lake, and groundwater) and major river basin (Oregon has 19 major river basins). This type of organization has resulted in repetitious reporting. For example, it contains separate sections for the north coast, mid-coast, and south coast basins. Together these basins comprise the Coast Range ecoregion and thus are quite similar. The biggest differences within these basins are between the Coastal Lowlands and the Coastal Mountains subregions. A basin reporting system also can lead to disjointed and misleading reporting. Such is the case with the Willamette Basin, which comprises three ecoregions and five subregions. The impacts, issues, and concerns are very different for the agricultural, urbanized Willamette Valley Plains subregion and the forested, remote High Cascades subregion.

The ecoregion and subregion data layers both are available in digital format so that they can be used in the DEQ's geographic information system (GIS), which contains digitized information on water quality and nonpoint-source pollution of Oregon's waters (US EPA 1989). Sources of information for this data base include DEQ data and the US EPA River Reach File, a digital representation of rivers and streams prepared from 1:500,000-scale maps. The data file contains information on the location, type, and severity of water quality problems; the beneficial uses impacted by each problem; the management activity causing the problem; and the categories and subcategories of nonpoint-source pollution associated with the activity causing the problem. Approximately 27,700 mi of Oregon's 90,000 river miles have been assessed using this method. The DEQ has concluded that the ecoregion and subregion framework will serve to improve the organization of these data.

Prioritization of Monitoring and Pollution Control Strategies

Although Oregon contains a large number and variety of waterbodies that are heavily used for recreation and agriculture, compared to other states, the DEQ has a relatively small staff of field scientists and planners. Given the size and diversity of the water resources and of the state itself, only a small percentage of potentially impacted waters can be examined thoroughly. For this reason, the DEQ needs a means for prioritizing field work and analyzing its extensive nonpoint-source data base. The Oregon SCWS was initiated to accomplish this.

The first step in the preparation of a strategic management plan was to evaluate waterbodies based on the nonpoint-source assessment. Water quality data were combined with point-source and water supply data and information on resource values (fishery, habitat, and recreation) contained in the Northwest Power Planning Council's Pacific Northwest Rivers Study (Oregon Department of Energy 1987). A waterbody score was developed according to three sets of criteria: (1) health (drinking water, shellfish), (2) recreation, and (3) aquatic life (water quality and habitat). Rating tables and maps then could be generated based on state, ecoregion, subregion, river basin, subbasin, county, waterbody, or water quality program element (nonpoint-source, toxics, or lakes). Theoretically, ecoregions and subregions provide the most effective means of determining relative priority for monitoring and pollution control activities and for assessing common trends in point- and nonpoint-source impacts. For example, one can assume that results from assessing a small number of sites can be extrapolated with considerable confidence to sites elsewhere in the same ecoregion or subregion.

Developing Regional Management Approaches

Oregon DEQ views the concept of ecoregions and subregions as extremely useful for fitting management approaches to regionally different stressors and types of water bodies. For example, the DEQ is currently initiating efforts to assess statewide lake quality and develop regional management approaches. Ecoregions and subregions will be used to develop management strategies based on the strong regional differences in lake water quality. For example, lakes contained in the High Cascades subregion are typically low in algal and weed productivity (ranging from ultraoligotrophic to mesotrophic conditions) and have short growing seasons (0.5–3 months). Programs that stress prevention of nutrient enrichment and acidification are important in this subregion. Lakes in the Coast Range Coastal Lowlands subregion are higher in productivity (ranging from oligotrophic to eutrophic conditions), with long growing seasons (4–6 months). Programs that address mitigation of existing problems of macrophyte and algal growth are more important in this subregion.

Development of Numeric Biocriteria in Oregon Water Quality Standards

Recently, Oregon DEQ (1990) has proposed developing biological criteria based partly on conditions at reference sites. The agency is recommending the following process for developing and implementing biological criteria: (1) develop standard biological assessment protocols for all types of Oregon waterbodies, (2) conduct surveys of resident biological assemblages at minimally impaired reference sites in ecoregions or specific basins, (3) establish numerical biological criteria based on the results of the reference site surveys, and (4) adopt numerical criteria as standards for biological assemblages and evaluate impairment at other sites based on these standards. Our subregions map offers a framework for stratifying the tremendous biological variability of Oregon surface waters and for providing relevant and environmentally appropriate expectations for water quality in a cost-effective manner.

Conclusions

We believe the ecoregions and subregions map is preferable to the river basin framework for water quality management because it spatially organizes water resources by the natural phenomena that contribute most to water quality rather than by river basins across which quality can vary considerably. Although potential applications are numerous and preliminary examinations of the map show good correlation with water quality data, the best test of the map's validity will be in its usefulness for interpreting natural and anthropogenic differences in water quality, its usefulness for prioritizing management activities, its value for assessing and reporting monitoring results, and its effectiveness in protecting aquatic life. We believe that the added information provided by quantifying the boundary transition widths and identifying and prioritizing the boundary characteristics will increase the map's value as an analytical and management tool.

Appendix

Ecoregion and Subregion Descriptions

The defining characteristics of land use/land cover, vegetation, soil, and topography for each subregion are listed below. Vegetation terminology is taken from Frenkel and Kolar (1976) and soil terminology from USDA SCS and others (1985).

Coast Range

1. Mountains

Land use/cover:	Mostly forest
Vegetation:	Western hemlock zone and Sitka-spruce zone
Soil:	Mostly udic mesic with some udic frigid and cryic.
Topography:	Rugged hills to mountains

2. Coastal Lowlands

Land use/cover:	Mixture of agriculture, forest, and urban
Vegetation:	Sitka-spruce zone
Soil:	Predominantly udic isomesic
Topography:	Relatively flat, coastal plain

Willamette Valley

3. Plains

Land use/cover: Mostly agriculture with some forest and urban
Vegetation: Forest–prairie zones
Soil: Xeric mesic
Topography: Relatively flat valley

4. Foothills
Land use/cover: Mostly forest with some agriculture
Vegetation: Western hemlock zone and some forest–prairie zones
Soil: Xeric mesic
Topography: Hills

5. Umpqua Valleys
Land use/cover: Mosaic of agriculture and forest
Vegetation: Forest–shrub zones
Soil: Xeric mesic
Topography: Hills and valleys interspersed

Klamath Mountains

6. Mountains
Land use/cover: Forest
Vegetation: Mixed needleleaf–broadleaf forest zones
Soil: Mostly xeric mesic with some frigid
Topography: High mountains

7. Rogue Valleys
Land use/cover: Mostly agriculture with some urban
Vegetation: Forest–shrub zones
Soil: Predominantly xeric mesic
Topography: Relatively flat valleys

Cascades

8. Western Cascades
Land use/cover: Mostly forest
Vegetation: Western hemlock zone
Soil: Mixture of udic mesic, frigid, and cryic
Topography: Highly dissected, steep east–west ridges

9. High Cascades
Land use/cover: Mostly forest
Vegetation: Pacific silver fir zone
Soil: Mostly udic cryic with some frigid
Topography: High elevation, gentler slopes punctuated with steep volcanic peaks

Eastern Cascades Slopes and Foothills

10. Slopes and Foothills
Land use/cover: Mostly forest
Vegetation: Ponderosa pine zone
Soil: Mostly xeric cryic, some frigid
Topography: Varied; tablelands with moderate to high relief, plains with low mountains, open low mountains, high mountains

11. Lake Basins
Land use/cover: Agriculture, some shrub and brush range, and some forest
Vegetation: Desert–shrub zones
Soil: Xeric mesic
Topography: Relatively flat basins

12. Marshes
Land use/cover: Mixture of agriculture and range (herbaceous; shrub and brush)
Vegetation: Big sagebrush zone and ponderosa pine zone
Soil: Aquic frigid and cryic
Topography: Flat basins

High Desert

13. Mountain Ranges
Land use/cover: Mostly range with some forest
Vegetation: Western juniper zone
Soil: Mostly xeric cryic; some aridic/xeric frigid
Topography: Relatively steep, medium to high mountains

14. Uplands
Land use/cover: Range
Vegetation: Mostly big sagebrush zone, patches of desert shrub zones
Soil: Mostly aridic/xeric frigid; some aridic/xeric mesic
Topography: Plateaus with moderate relief

15. Dry Barren Basins
Land use/cover: Barren land, some irrigated agriculture and range
Vegetation: Desert–shrub zones and some big sagebrush zone
Soil: Mostly aridic/xeric mesic and frigid; some aquic frigid and cryic
Topography: Relatively flat basins

16. Basins with Fresh Water
Land use/cover: Irrigated agriculture
Vegetation: Western juniper zone, big sagebrush zone, and desert–shrub zones
Soil: Aridic/xeric mesic; aquic frigid and cryic
Topography: Relatively flat basins

Columbia Plateau

17. Basins
Land use/cover: Irrigated agriculture

Vegetation: Steppe zones and big sagebrush zone
Soil: Aridic/xeric mesic
Topography: Slight to moderate irregular plains

18. Tablelands
Land use/cover: Dryland agriculture
Vegetation: Mostly steppe zones, patch of big sagebrush zone
Soil: Xeric/aridic mesic
Topography: Tablelands with moderate to high relief

19. Dissected Uplands
Land use/cover: Herbaceous; shrub and brush range
Vegetation: Steppe zones
Soil: Xeric/aridic mesic
Topography: Uplands and steeply incised valleys

Blue Mountains

20. Alpine and Subalpine zones
Land use/cover: Mostly forest, some tundra
Vegetation: Mostly Pacific silver fir zones
Soil: Udic cryic
Topography: Mountains

21. Nonalpine Forested Mountains
Land use/cover: Mostly forest
Vegetation: Partly ponderosa pine zone, partly grand fir zone
Soil: Mixture of udic cryic and xeric frigid
Topography: Rugged hills and mountains

22. Uplands and Valleys
Land use/cover: Herbaceous; shrub and brush range
Vegetation: Mostly big sagebrush zone and western juniper zone with some steppe zones
Soil: Xeric/aridic mesic and frigid
Topography: Moderately to very steep uplands and valleys

23. Basins
Land use/cover: Agriculture
Vegetation: Mixture of big sagebrush zone and steppe zones
Soil: Xeric/aridic mesic and xeric frigid
Topography: Relatively flat basins

Acknowledgments

We would like to acknowledge the helpful advice and guidance of James Omernik and Robert Hughes in the identification and delineation of the Oregon ecoregions. Jeff Irish and Sandi Azevedo provided excellent technical assistance in the digitization and preparation of our maps. John Jackson and others at DEQ helped sharpen our understanding of water quality issues in Oregon. Doug Terra of DEQ and John Charrard of the Oregon Department of Energy provided assistance in obtaining data bases for our project. Bob Frenkel, George King, Thom Whittier, Susan Christie, and Lisa Ellingson have provided helpful reviews. This research was supported by Christina Groome of the US EPA Office of Policy, Planning, and Evaluation through contract 68-C8-0006 with NSI Technology Services Corporation and by PNW Grant 90-481.

Literature Cited

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. US Geological Survey Professional Paper 964.

Andrews, H. J., and R. W. Cowlin. 1936. Forest type map: State of Oregon. Map scale 1:253,440. Pacific Northwest Forest Experiment Station. USDA Forest Service, Portland, Oregon.

Bailey, R. G. 1980. Description of the ecoregions of the United States. Map scale 1:7,500,000. USDA Forest Service Miscellaneous Publications 1391, Washington, DC, 77 pp.

Bailey, R. G. 1983. Delineation of ecosystem regions. *Environmental Management* 7(4):365–373.

Bailey, R. G. 1988. Problems with using overlay mapping for planning and their implications for geographic information systems. *Environmental Management* 12(1):11–17.

Bailey, R. G., R. D. Pfister, and J. A. Henderson. 1978. Nature of land and resource classification—a review. *Journal of Forestry* 76(10):650–655.

Bailey, R. G., S. C. Zoltai, and E. B. Wiken. 1985. Ecological regionalization in Canada and the United States. *Geoforum* 16(3):265–275.

Burrough, P. A. 1986. Principles of geographical information systems for land resources assessment. Clarendon Press, Oxford, UK, 193 pp.

Franklin, J. F., and C. T. Dyrness. 1988. Natural vegetation of Oregon and Washington. Oregon State University Press, Corvallis, Oregon, 452 pp.

Frenkel, R., and S. Kolar. 1976. Natural vegetation. Map scale 1:2,000,000. Pages 143–145 *in* Atlas of Oregon. W. G. Loy, S. Allan, C. P. Patton, and R. D. Plank (eds.), University of Oregon, Eugene, Oregon.

Gallant, A. L., T. R. Whittier, D. P. Larsen, J. M. Omernik, and R. M. Hughes. 1989. Regionalization as a tool for managing environmental resources. EPA/600/3-89/060. US Environmental Protection Agency, Environmental Research Laboratory, Corvallis, Oregon, 152 pp.

Hammond, E. H. 1970. Classes of land-surface form. Map scale 1:7,500,000. Pages 62–63 *in* The National Atlas of the United States of America. US Geological Survey, Washington, DC.

Hughes, R. M., E. Rexstad, and C. E. Bond. 1987. The relationship of aquatic ecoregions, river basins, and physiographic provinces to the ichthyogeographic regions of Oregon. *Copeia* 1987(2):423–432.

Küchler, A. W. 1964. Potential natural vegetation of the conterminous United States. Map scale 1:3,168,000. Special Publication No. 36. American Geographical Society, New York, New York.

Loy, W. G., S. Allan, C. P. Patton, and R. D. Plank. 1976. Atlas of Oregon. University of Oregon, Eugene, Oregon, 216 pp.

NASA Ames Research Center. 1972–1978. U-2 aerial photography 9 × 9-inch color infrared positive transparencies for Oregon. Photo scales approximately 1:60,000 and 1:120,000. Airborne Missions and Applications Division, Moffet Field, California.

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

Omernik, J. M., and A. L. Gallant. 1986. Ecoregions of the Pacific Northwest. Map scale 1:2,500,000. EPA/600/3-86/033. US Environmental Protection Agency, Corvallis, Oregon, 39 pp.

Oregon Department of Energy. 1987. Oregon final summary report for the Pacific Northwest River Study, 89 pp.

Oregon DEQ. 1990. Water quality standards issue paper 13. 17 May 1990. Oregon DEQ, Portland, Oregon, 9 pp.

Oregon Water Resources Department. 1978–1980. Land use inventory by major drainage basins. Map scales from 1:180,000 to 1:370,000. Oregon Statewide Land Use Inventory Series, Salem, Oregon.

Rowe, J. S., and J. W. Sheard. 1981. Ecological land classification: A survey approach. *Environmental Management* 5(5):451–464.

Simonson, G. H., and USDA SCS. 1976. Soils. Map scale 1:2,000,000. Pages 124–125 *in* Atlas of Orgeon. W. G. Loy, S. Allan, C. P. Patton, and R. D. Plank (eds.), University of Oregon, Eugene, Oregon.

US EPA. 1989. Oregon's clean water strategy: A pilot project. *In* CEM Message EPA-013. 26 May 1989.

USDA SCS, Oregon Agricultural Experiment Station, US BLM, and US Forest Service. 1985. General soil map: State of Oregon. Map scale approximately 1:750,000.

USGS. 1970a. Land use and land cover (quadrangles for Oregon). Land use series. Map scales 1:250,000 and 1:100,000. National Mapping Division.

USGS. 1970b. Topography with vegetation overprint and culture (quadrangles for Oregon). Medium scale topographic series. Map scale 1:250,000. National Mapping Division.

USGS EROS Data Center. 1972–1979. 9 × 9 color infrared positive transparencies for Oregon Landsat scenes. Photo scales approximately 1:1,000,000. Sioux Falls, South Dakota.

Whittier, T. R., R. M. Hughes, and D. P. Larsen. 1988. Correspondence between ecoregions and spatial patterns in stream ecosystems in Oregon. *Canadian Journal of Fisheries and Aquatic Sciences* 45(7):1264–1278.