UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

FILE

OFFICE OF
THE ADMINISTRATOR

January 22, 1991

EPA-SAB-EPEC-91-003

The Honorable William Reilly
Administrator
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, D.C. 20460

Dear Mr. Reilly:

The Ecoregions Subcommittee of the Science Advisory Board (SAB) has completed its review of the Ecoregions Concept that was developed by scientists from the Environmental Research Laboratory at Corvallis, Oregon. Ecoregions are geographic areas that have similar variations in selected environmental characteristics. These environmental characteristics (e.g., chemical hardness of water and precipitation) are important determinants of the types of biota that can exist in an ecoregion and the quality that the environmental resource can attain. Several states have already used the Ecoregion Concept to delineate areas for water quality management and pollution control. In addition, several Federal resource agencies are considering using the Ecoregion Concept to manage land and forest resources and other EPA programs are considering regulatory uses.

The Subcommittee met on April 16-18, 1990, to review and evaluate the Ecoregion Concept and hear the experiences of three states (Arkansas, Ohio, and Minnesota), the Nature Conservancy, and Environment Canada. The Subcommittee was asked to address the following charge:

a. Can the Ecoregion Concept produce defensible and reproducible classifications for any size areas?
b. Is the biogeographic and ecological science embodied in the ecoregion concept developed well enough for states to use this concept in their water standards program?
c. What are some current and/or future applications?
d. What research is needed?

The Subcommittee believes that the Ecoregion concept is a defensible classification technique for large areas (covering one or more states) that is superior to the classification methods that are currently used by most environmental managers. EPA is to be commended for its accomplishments and leadership in developing and promoting the use and understanding of the concept. We have recently learned that EPA plans to cut ecoregion research program in order to meet this years budget. The Subcommittee believes that such a decision would be unfortunate because it is one the few techniques available to address ecological issues on a broad regional and global scale that is needed to reduce ecological risks. In addition, many states that plan to use this concept need technical support that can be sustained through an active research program.

Several states have demonstrated that the Ecoregions Concept also has application as a water quality management tool within states. The Subcommittee believes that states need assistance from EPA in applying the Ecoregion Concept to the development of water quality criteria and standards to promote reproducible results. In a few cases, states have developed biological criteria for those areas. The Subcommittee did not review the basis for biological criteria for water quality; rather it recommends that a separate review be made of the concepts and technical guidance for biological criteria. In addition, more technical guidance and assistance is needed to help users address complex problems such as rivers that cross ecoregion boundaries.

The Subcommittee concluded that the Ecoregion Concept has many other potentially useful applications. In addition to the water quality management uses, land, wildlife, and timber management have been aided by this regionalization approach which helps to identify areas of similar ecological potential. Some regulatory programs are considering using ecoregions to designate areas for chemical releases. In the future, ecoregions may be useful to develop the criteria for multimedia or cluster regulatory approaches. Finally the Ecoregions Concept may have application to identify areas for monitoring and assessment activities, including the Environmental Monitoring and Assessment Program (EMAP).

Further research and evaluation is needed on the Ecoregion Concept which should include the following: a pilot test to determine whether and to what degree ecoregions perform better than other less sophisticated regionalizations, methods for defining and locating boundaries, methods for selecting reference sites, and formal procedures for delineating and subdividing ecoregions. We recommend that much of the research on ecoregions be coordinated with EMAP.

Although we expect that the program office will address all of the issues presented in this report, we particularly direct your attention to the following ones:

- the lack of support for research or technical assistance and specific written guidance that is essential for states and other potential users.
- the potential applications of the ecoregion concept to many resource management issues, including strategies for reducing risk.
- the need for objective procedures to select reference sites, define boundaries, and subdivide ecoregions.

The SAB appreciates the opportunity to conduct this scientific review and looks forward to receiving your response to the scientific advice transmitted herein.

Sincerely,

Raymond C. Loehr

Dr. Raymond Loehr, Chairman
Executive Committee
Science Advisory Board

Kenneth L. Dickson

Dr. Kenneth Dickson, Chairman
Ecological Processes and
Effects Committee

EPA U.S. Environmental Protection Agency Washington, DC
EPA-SAB-EPEC-91-003

Report of The Ecoregions Subcommittee of The Ecological Processes and Effects Committee

Evaluation of The Ecoregion Concept

A SCIENCE ADVISORY BOARD REPORT January 1991

U.S. ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

This report presents the conclusions and recommendations of the U.S. Environmental Protection Agency's Science Advisory Board following a review of EPA research on the Ecoregion Concept and presentation of the results of its application for water quality management by three states. The Ecoregion Concept is method of dividing large geographic areas in regions or subunits in which the variability of selected ecological and physical characteristics is less than that of the entire area. The Ecoregion Concept, as published by EPA, is being used by states for water quality management. The principal concerns of the Subcommittee are that limited guidance and documentation is available to users for defining and locating the boundaries and establishing adequate reference sites and that informal methods are used to subdivide areas. The Subcommittee endorsed the concept but recommended that EPA renew and sustain its research in critical areas, conduct a pilot project to compare the effectiveness of Ecoregions with other regionalization techniques, and develop a user guidance with case studies to assist future applications.

Key Words: Ecoregions; Regionalization; Environmental Management.

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DRAFT EVALUATION OF ECOREGIONS

1.0 EXECUTIVE SUMMARY

EPA has conducted extensive research to develop Ecoregions of the conterminous United States (Omernik, 1987). Ecoregions are derived qualitatively by geographers working with environmental scientists and they show areas where several

environmental variables are more similar within a region than between regions. Ecoregions have been used by several states, with support from EPA, as a framework for environmental quality management and pollution control. EPA's research program on the development of the Ecoregion Concept was completed in June, 1989.

The Ecoregions Subcommittee was asked to review the Ecoregion Concept for scientific merit, adequacy for use by states, other potential applications, and to identify research needs. The review was conducted at Corvallis, Oregon in April, 1990 included briefings by the developers of the Ecoregion Concept and presentations by several state users and a scientist from Environment Canada. In support of the research and its applications, EPA and collaborating scientists have published more than twenty peer reviewed articles over a five year period which were consulted as part of this review.

Overall, the Subcommittee finds that the Ecoregion Concept is defensible for classifying large (multi-state) areas when used by skilled professionals. EPA is to be commended for its accomplishments and leadership in developing and promoting the use and understanding of the concept. The Subcommittee believes that the Ecoregion Concept will lead to a method of subdividing geographic areas that is superior to the methods that are currently used by most environmental managers. The Subcommittee believes that it is unfortunate that after promoting the method and eliciting interest among state and Federal users, EPA has stopped its research on the concept and eliminated its efforts toward technology transfer. The Subcommittee further notes that continued research is in keeping with the new emphasis on ecology, in general, in the "Reducing Risk ..." report of the SAB. The Subcommittee recommends that EPA develop a pilot project with the explicit aim of determining whether and to what degree defined ecoregions perform better than other less sophisticated regionalizations in ecological management.

Several states have used the Omernik Ecoregions as a basis for dividing their states into water quality use areas and in a few cases, they have developed biological criteria for those subdivisions. While the state record of achievement is good, it was developed under the tutelage of EPA, and several topics require further research and testing: the definition and location of boundaries, selection and number of reference sites, and formal procedures for delineating and subdividing ecoregions. Due to these research needs, the lack of quantitative methods for testing regionalizations and limited user guidance, the Subcommittee believes that a relatively high level of expertise is required to produce defensible and reproducible subdivisions within state areas. The Subcommittee recommends that EPA develop guidance and analyze the results of past applications of ecoregions to assist future use by the states. The Subcommittee

did not review the basis for the states' biological criteria; however, it recommends that a separate review be made of biocriteria, perhaps after technical support documents become available.

The Subcommittee concluded that the Ecoregion Concept has many potential useful applications. In addition to the water quality management uses, land and timber management have been aided by this regionalization approach which helps to identify areas of similar ecological potential. In some cases, ecoregion boundaries may replace political boundaries that are used by some regulatory programs to designate areas for restricted chemical uses. In the future, the Ecoregion Concept may be used to develop criteria for multimedia regulations. Finally the Ecoregions Concept may be used to identify areas for monitoring and assessment activities, including the Environmental Monitoring and Assessment Program (EMAP).

2.0 INTRODUCTION

EPA has conducted extensive research on the techniques for identifying environmental regions that can be used for ecosystem management. Most of the research on regionalization in EPA has been conducted at the Office of Research and Development (ORD) Environmental Research Laboratory (ERL) at Corvallis, Oregon. In 1987, EPA published maps in the peer reviewed literature of Ecoregions for the Conterminous United States (Omernik, 1987). EPA has worked with several states to apply the concept to the water quality standards process (Gallant, et al., 1989). Even though EPA's effort on the Ecoregion Concept ceased; however, several states and EPA program offices are now investigating further applications of the Ecoregion Concept. Recently, the Office of Water (OW) established a policy (EPA, 1990) that encourages states to develop biological criteria for water quality protection. The Ecoregion Concept is being used by states in the development of biological criteria.

The Science Advisory Board was aware of the widespread and growing interest and potential applications of the Ecoregion Concept. In December 1989, the SAB agreed to undertake this review because the ecoregion concept is being used by other Federal agencies, several states, and potentially could be used by many others. Furthermore the concept is closely related to the new and developing field of landscape ecology.

The review was assigned to the Ecological Processes and Effects Committee (EPEC) by the Executive Committee of the SAB. EPEC formed the Ecoregions Subcommittee to conduct the review. The review was hosted by the U.S. EPA Environmental Research Laboratory at Corvallis, Oregon on April 16-18, 1990.

2.1 Charge to the Subcommittee.

The Subcommittee received an informal charge from the Office of Environmental Processes and Effects Research that was modified by the Subcommittee at the review meeting to reflect the concerns of the EPA researchers and the needs of the state users of the Ecoregion Concept. The Subcommittee accepted the charge to address the following questions:

a. Can the Ecoregion Concept be used to establish defensible and reproducible classifications for any size areas? What is the nature and extent of the uncertainty associated with establishing boundaries?

b. Is the biogeographic and ecological science embodied in the Ecoregion Concept developed well enough to justify states using this concept in their water quality standards program? Are there limitations or qualifications which should be noted as part of such an application?

c. What are some current and/or future applications which one might envision for the Ecoregion Concept?

d. What research is needed to develop the concept further and assure the validity of its results?

2.2 Subcommittee Review Procedures.

The Agency provided the Subcommittee with a number of publications and reports (see Literature Cited) which were reviewed by the subcommittee members in preparation for the evaluation. From the background material, the subcommittee developed preliminary impressions and questions for follow-up at the review. Nearly two days of presentations were made at the review, including a report from Canada on their use of ecological regions and the experience of three states that had used the Omernik (1987) ecoregions as a basis for defining use attainability and biological criteria as part of their water quality standards program. One of the States had used ecoregions to classify lakes.

3.0 EVALUATION OF THE ECOREGION CONCEPT

The concept of ecoregions has continued to evolve from the original term of Crowley (1967) and the first mapped classification of ecological regions of the United States by Bailey (1976). The Ecoregion Concept is a special method of regionalization for subdividing a geographic area into regions of relative homogeneity in ecological systems or in relationships between organisms and their environments. The resulting

ecoregions can provide a valuable framework for environmental resource managers and scientists to use for monitoring, assessment, and control measures. This is unfortunate since the development of Ecoregions Concept by the Corvallis ERL was done with modest financial support from ORD and the Office of Water, however, since June 1989 there has been no active research program on the Ecoregions Concept. The development of the Ecoregions Concept is an example of creative and proactive scientific research in the Agency. **Overall, the Subcommittee finds that Ecoregions and regionalisation are valuable concepts with many potentially useful applications for environmental management, and further the Subcommittee encourages the Agency to resume development and testing of the concept to assess its strengths and limitations for further applications.**

EPA has used the regionalization process to develop several different kinds of ecoregions, ranging from single variable maps of alkalinity regions for the acid rain program to maps (Omernik, 1987) which describe areas of similar vegetative and hydrological characteristics. The Omernik ecoregions were used to illustrate applications by states and were the primary focus for this review. However, the comments in this report can be broadly applied to any form of regionalization, and ecoregions are not restricted to those specifically developed by Omernik.

3.1 Validity of the Ecoregion Concept

The Subcommittee was asked to assess 1) if the Ecoregion Concept could be used to establish defensible and reproducible classifications for any size areas and 2) the uncertainty and decisions associated with establishing ecoregion boundaries.

EPA must demonstrate not only that the Ecoregion Concept is useful but that it outperforms other forms of regionalization in its particular applications. This is a challenging task. It is important to find out where ecoregions perform well and where they do not, and it is worth expending significant resources on this effort.

The Ecoregion Concept is based on the premise, long a tenet in the professions of geography and environmental sciences, that the world becomes more understandable when its surface is divided into logical units based on some process, feature or activity. The variance of selected parameters within these units is reduced. Local outliers are more easily discernible (if local data, independent of the ecoregion map are available).

The Subcommittee considers classification and regionalization (mapping) to be an evolving process. Regionalization often depends on assumptions, judgments, opinions and some data and it is not easily quantified. The initial regionalization schemes are developmental and need more testing.

As experience is gained and as different sets of regions are evaluated with respect to different questions, particular schemes should become more readily supported by facts and amenable to quantification.

3.1.1 **Geographic Considerations.**

Many professional judgments were made to develop the Omernik (1987) ecoregions. These include judgments on the appropriate variables, ecoregion size, the number of subdivisions, contiguity, hierarchy, homogeneity and unique assignment. The implications of these judgement for users of ecoregions are detailed in the following paragraphs.

3.1.1.1 Variables. The Omernik ecoregions are based broadly on four primary variables: land surface form, soils, natural vegetation and land use. A continuum of possible regionalizations can exist. At one end are special-purpose regionalizations based on single variables, e.g., soils, and serving limited purposes. At the other end is a regionalization based on all climatic and geological variables which attempts to serve all purposes. **By using four primary variables and choosing others in some situations, EPA made decisions which can limit the future applications and subdivisions of the regionalization map. Such limitations or special precautions should be explained and documented to guide further users of the map.**

3.1.1.2 Ecoregion Size. Gallant et al. (1989) indicated that there may be areas where the mapped numerical field data do not correspond with the distribution of environmental features. They suggest that it may be useful to map such areas as separate regions if they are of comparable size to other regions being mapped. This advice is somewhat confusing, because the nature of geographic variation suggests that minimizing heterogeneity will not lead to regions of similar area. In fact quite the opposite is true. Geography consists of large areas of uniformity, with relatively small areas of complex variation, so a regionalization based on minimizing heterogeneity would lead to very high variability in region size. Perhaps the authors should clarify their definition of comparable size areas.

3.1.1.3 Number of subdivisions. It is possible to divide the surface of the United States into any number of regions. There is a simple monotonic relationship between the number of regions and their homogeneity. More regions will always result in less heterogeneity or a more accurate representation of true spatial distributions (Jensen et al., 1989) within each region. For example, one might specify the number of regions indirectly by deciding that a certain mean region area was desirable for management purposes. The criteria need not be scientific. **The Subcommittee recommends that the criteria used to establish the**

number of subdivisions be laid out as explicitly as possible.

The consensus of the numerical taxonomy literature (see for example Sneath, P.H. and R.R. Sokal Numerical Taxonomy, San Francisco, Freeman, 1973; Jardine, N. and R. Sibson Mathematical Taxonomy New York, Wiley, 1971.) is that there is no satisfactory, objective way of defining the number of regions or clusters "naturally" present in data. Information is lost when the specific attributes of a case are replaced by the attributes of a cluster, and the information loss increases from zero, when every case is its own cluster, to a maximum when all cases belong to one cluster. The increase is monotonic on most measures of information loss, even though measures can be devised for which that is not true (e.g., the slope of the so-called "scree" diagram).

3.1.1.4 Contiguity. If places are classified solely on the basis of the characteristics present, then when the classes are mapped, the resulting regions may not be contiguous (singly bounded). One class may consist of several islands, such as the Western Forested Mountains Ecoregion (Omernik, 1987). It is possible to require single boundedness, but in general 10 singly-bounded regions will not be as homogeneous as 10 unconstrained classes. **The decision as to when to require single-boundedness is an important part of the regionalization process, which should be explained in documentation supporting the regionalization.**

3.1.1.5 Hierarchy. Geography is characterized by the expression "the closer you look, the more you see". It is appealing to think that subregions are hierarchically nested within one region. By subdividing regions into smaller and smaller areas, we can capture a closer and closer approximation to the truth. However, hierarchical nesting is not a natural property of regions, but rather an artifact of the regionalization process. For example, on a broad scale of regionalization, using data or maps with low resolution, data for several parameters may be aggregated so that a boundary line may represent a zone of transition for a single linear feature (e.g., elevation). At a finer scale of regionalization, data may be aggregated for individual parameters and there will be more subregions. And it is likely that the zone of transition between regions will become one or more subregions. In such cases, two or more regions may have areas that are common to a single subregion. In principle, then, subdividing large regions does not always allow us to locate boundaries of the subregions more accurately. Therefore, imposing hierarchical nesting on the different levels of regionalization may be useful from a management perspective, but may be more likely to conflict with the accurate representation of spatial variation. **Thus one must weigh the desirability of having nested regions against the need for greater accuracy.**

3.1.1.6 Homogeneity. Although it is natural to assume that regions are defined by uniform characteristics, it is not uncommon for a region to be defined as a mixture of substantially different characteristics. For example, the "ridge and valley province" is uniform in its intermingling of two very different landforms. **One of the decisions to be made in setting the goals of a regionalization activity is the degree to which homogeneity will be required.** This has implications for the definition of archetypes or reference sites, since there may be no archetypical location in a region that is defined by a mixture of characteristics.

3.1.1.7 Unique Assignment. The regionalization for Ecoregions assigns each location on the earth's surface to exactly one class, and thus it has precise linear boundaries. But for scientific purposes it is possible to work with other models of regionalization. We might, for example, define a number of reference sites across the United States typifying its geographical variation, and then characterize each location of interest by its similarity to the reference sites. Presumably each place would be similar to more than one, but not to all reference sites. From a scientific perspective this is perhaps a more effective way of characterizing multivariate spatial distributions than regionalization. While such an approach is more difficult to map, modern spatial database technology makes it feasible using digital information. **The usefulness of one approach over another for environmental management and ecological research should be evaluated by a well-designed pilot test.**

3.1.2 Ecological Considerations.

As mentioned earlier, the process of ecoregion definition must be an evolutionary one. Ecoregions can be distinguished by measuring the variance of indicators of ecological condition or health and designating reference sites in which those indicators exhibit nominal conditions. **The Environmental Monitoring and Assessment Program (EMAP) will be measuring a variety of ecological indicators across the nation and it could provide a useful framework for testing and refining the Ecoregion Concept.**

The attributes on which some ecoregions are determined may change over time. The two most obvious changing conditions are land-use and vegetative successional states, but climate may also change. Thus, depending upon the scale of resolution, regional delineation may also need to change. **EPA should provide advice to the users for monitoring to determine when the original regionalization is no longer valid for its intended purpose and how one should go about altering the regionalization.**

3.2 Use of Ecoregions for Water Quality Management

The Subcommittee was asked to evaluate whether the biogeographical and ecological sciences embodied in the Ecoregion Concept are well enough developed to justify states using this concept in their water quality management program.

The Subcommittee responded to this request with positive but reserved reactions. The effort is an innovative approach to environmental quality management. It is potentially very useful in recognizing deviation of ecosystems, from a regional norm, in response to changing water, soil and air quality. It provides a sounder (and much more equitable) basis than is currently used (state boundaries) for establishing environmental quality standards for defined ecosystems within an ecoregion context.

The Subcommittee have had reservations about the use of ecoregions by states because additional guidance is needed to assist them with selection of reference sites, resolution of boundaries, and further subregionalization of the Omernik ecoregions. While several states have successfully applied ecoregions in their water quality standard programs, they have had substantial assistance from EPA. Currently, it is unclear what type of assistance will be available for state needs in the future. **Therefore, the Subcommittee recommends that EPA develop guidance for states to use ecoregions and provide technical assistance as well.**

3.2.1 Reference Sites. It is important to use regional reference sites when the Ecoregion concept is applied to protect ecosystems. The biological, physical and chemical characteristics of these regional reference sites can be used to establish the recovery potential for impacted aquatic systems in the same ecoregion.

Users of the ecoregion concept are instructed to identify "minimally impacted sites" (Hughes et al., 1986) as benchmark conditions for a specific ecoregion. **The Subcommittee strongly recommends that EPA develop user guidance with criteria for the unbiased selection and appropriate number of regional reference sites.**

Currently, criteria to select regional reference sites may differ depending on the application of the Ecoregion Concept. For example, if the application is to develop biological criteria for impacted stream segments in an Ecoregion, it may be necessary to identify and monitor only minimally impacted reference sites. However, if the application of the Ecoregion Concept is to assess the efficacy of best management practices for non-point source pollution control, then the regional reference sites should represent sites that are impacted by a variety of non-point source problems of different intensities. In this application, reference sites provide estimates of biological, chemical and physical attributes that may be expected using different degrees

of best management practices.

A stochastic sampling approach may be used to select reference sites. In this case using a set of criteria (see for example Hughes et al, 1986) one would define the universe of potential reference sites for a particular ecoregion, then use an unbiased selection process to make the final selection (i.e., enumerate all the potential reference sites and then make random choice of sites).

The number of reference sites is not only a function of the statistical variance of the selected parameters, but also of the size of the potential universe of such sites and of the funds available.

3.2.2 Resolution of Boundaries.

For the Ecoregion Concept, boundaries take on a critical importance because the interiors of ecoregions are treated as homogeneous. However, with the exception of perhaps political boundaries, boundaries of regions are fuzzy because they represent a transition or a gradient of change between regions. These gradients may differ in steepness. Regionalization at the required level of resolution can provide the basis for the extrapolation of results from one basin to another, from one habitat to another, and from one biological assemblage to another within a region. Thus, the research questions are how to define the locations of boundaries, how to represent them on useful maps, and how to interpret them in the context of the attributes that define the ecoregion.

Ecoregions can be developed for various spatial scales and can be narrowly or broadly focused depending on the desired application. A regionalization scheme that is broad-based and appropriate for a large variety of uses will most likely be based on processes which control ecological conditions. For example, the Omernik ecoregions represent the controlling processes of geology and climate (physiography, soils, land use and potential vegetation). The more variables or maps that support the location of an ecoregion boundary, the more robust that boundary should be. Omernik ecoregions were developed for aquatic systems; they may be quite useful for terrestrial systems because the same component data/maps would likely be used; however, the exact location of some of the boundaries might be different for terrestrial systems. Specialized ecoregions also have been developed and used for acid rain research (alkalinity patterns) and lake trophic state (phosphorus patterns).

Present ecoregions should continue to be subdivided by higher resolution boundaries until maps are available at the appropriate resource level for different applications. Once

ecoregion boundaries are fine tuned to the level that they will answer the general questions being asked, then the ecoregions could be subdivided for specific purposes, e.g., to determine and monitor proper Best Management Practices for livestock grazing, logging and road construction, fisheries, and mining. Platts et al. (submitted, 1990) examined the relationship between classification and the stream flow requirements which are necessary to maintain riverine-riparian habitat and valley bottom type. They recommended a specific sequence of analysis to classify land to the valley bottom type level of resolution.

The value and usefulness of an ecoregion map improves when the decisions on geographic characteristics are documented. The level of confidence for the location and width of a region's boundary also needs to be documented in the future. The components that played a primary role in boundary placement can even be indicated (Clarke et al., submitted, 1990).

3.2.3 Subdividing Ecoregions.

The most useful approach to ecological regions for a national framework is a set of broad-based regions at different spatial scales. An excellent example of such a national framework is Environment Canada's ecological regions (Wiken 1986) which have seven levels of regionalization classes. These ecological regions are still evolving and are being successfully used for planning, assessment, and management of many resources including wildlife, forests, wetlands, agriculture, as well as for addressing issues such as acid deposition and climate change. EPA's work with ecoregions provides regions appropriate at the (1) national scale (7 classes, Omernik and Gallant 1989), (2) regional scale (57 classes, Omernik 1986), and (3) regional/state scale (Omernik and Gallant 1986, 1987a, 1987b, 1987c, 1988; Omernik 1987a, 1987b, 1987c). The same regionalization process could be used to develop even smaller ecoregions (higher resolution) for other uses such as biological criteria.

It is clear that the Ecoregions Concept is more useful for states if the national map of ecoregions is subdivided to reflect the ecological systems that occur within states. At the state level, more explicit decisions and criteria are required because of the proximity to regulatory and planning decisions. Moreover, there is some advantage for having uniform rules from state to state. **Therefore, the Subcommittee recommends that EPA develop a process for creating subdivisions that is defensible in many if not all states.**

EPA should consider subdividing Ecoregion map so maps are available at the land type and valley bottom type levels of analysis. To date most time and effort has been spent working at the national level of ecoregion analysis. **This fundamental level had to be established, but now effort should be directed to**

demonstrate the effectiveness of regionalization at the level where state and local management decisions are being made.

3.2.4 Formalization.

Formalization of the process for delineating ecoregions and subregions offers the prospect of making the task of creating regional maps more rapid and inexpensive. Regionalizations could be more reproducible, more nearly uniform, and more objective. Finally it could define general standards of performance to judge specific regionalization applications.

In a formalized context, the quality of the product can be described in terms of uncertainties in quantities, such as location of boundaries and inhomogeneities between sites within a given boundary, that are important to management and policy uses of the product. A paper submitted by Clarke et al provides a useful approach toward documenting the uncertainties associated with some ecoregion boundaries. The tolerances for uncertainty in the product can be used to calculate the input data quality which is required. Once the requirements for input data quality are known, a Quality Assurance/Quality Control program can be developed.

The regionalization process should include a formal objective protocol, with explicit QA/QC standards, and regionalization maps should include quantitative statements on their expected performance. Very little has been done, to date, in the direction of accomplishing this.

3.2.5 Qualitative versus Quantitative Methods.

The Subcommittee did not reach consensus with respect to the status of currently available methodology for regionalization. All of the Subcommittee members agreed that a formal, quantified approach would be desirable in principle, but there was uncertainty over whether such an approach could be implemented without further, extensive work on methods development. Some members felt that the present state of the relevant mathematical and statistical science and computational technology is adequate for immediate adoption of a formal quantified method; other members were not so certain.

The Subcommittee wishes to reiterate that, notwithstanding the absence of consensus on presently feasible methodology for regionalization, the committee was unanimous in its enthusiasm for the Ecoregions Concept. While Omernik Ecoregions, as presently implemented, rely extensively on informal, qualitative "professional judgement", the concept still represents an advance over other, more subjective, frameworks for deciding questions such as regional standards for attainable environmental quality.

The current practice is that delineation on maps is carried out with some mixture of quantitative and qualitative techniques, with their respective advantages and disadvantages. **The Subcommittee recommends that future research should seek to increase the degree of formality and quantification, by using computational (including multivariate statistics and artificial intelligence) techniques wherever possible, and by stating the implicit 'rules' for the remaining qualitative components as explicitly as possible, so that the remaining margin of subjectivity can be understood by the user.** The statistical properties, including reproducibility, of the boundaries generated by the state-of-the-art regionalization process should be quantified, at intervals, as the methods evolve.

3.2.6 **Testing**.

Testing of regionalizations presents several important technical problems related to the difficulty of dealing with statistical data in a spatial domain. These problems are evident in several of the papers dealing with validation. An example of validating a regionalization hypothesis was discussed in section 3.1.1.7. The results of several applications of ecoregions are tested and discussed further in appendix A.

While a program or method for quantitative delineation of regions does not currently exist, it is likely that a few years' effort could develop such a technique, given the modern accomplishments in computer pattern recognition, computer image enhancement, and spatial statistics. EPA should demonstrate that "qualitative" methods are reproducible and attempt to apply quantitative methods so that the performance of ecoregions relative to other regionalization schemes can be evaluated.

Regionalization is a potentially powerful method, both for science and management. It represents a way of viewing spatial variation which is particularly valuable when land is classified into discrete categories. For other types of applications it may be less appropriate, and certainly should not be seen as a universal solution to spatial data management. For variables measured on continuous scales, such as elevation or atmospheric pressure, contours are a more efficient method of representation involving much less information loss. However, the map of summer total phosphorus in lakes in Minnesota, Wisconsin and Michigan (Omernik et al., 1986) shows a continuous variable that is quite homogeneous within some regions with abrupt changes between regions. For example, the low phosphorus concentrations in lakes of region 50-6 (less than 5-14 micrograms/l) occur adjacent to region 50-7 (25 to greater than 50 micrograms/l). Variation within other regions frequently approaches the full range of phosphorus variation shown on the map (e.g. region 50-9). Omernik attributes this pattern to the underlying geological formations. This example shows the options open in mapping

spatial variation, and the existence of arguments both for and against the regional model. In cases like this it is important to have access to data quality statements, for example an index expressing the percentage of information lost by grouping (or clustering) heterogeneous observations into uniform regions.

On the one hand, since the concept has now been used in some states one could argue that if further development is necessary, it could be done by the states. A careful analysis, however, demonstrates that there are a number of remaining research questions, many of which are more efficiently addressed at the national level. Also, some national coordination will help states to use a consistent regionalization process and solve the need for states to cooperate on shared ecoregions. Therefore, EPA is the logical source for further development.

3.2.7 State Water Quality Uses.

The successful use of ecoregions by several states is a strong testimonial to the usefulness of ecoregions at the state level. Arkansas adopted an ecoregional framework to identify natural differences in existing and achievable chemical quality and biotic assemblages in streams.

The Ohio EPA has used the ecoregional framework to develop biological criteria. The Minnesota Pollution Control Agency used an ecoregional framework to summarize existing lake chemistry and derive appropriate achievable regional goals and criteria for lake quality. The ecoregional framework is also a convenient and effective way to organize, present, and interpret lake and stream water quality information.

A variety of data analyses can be used to test/evaluate the correspondence between ecoregions and spatial patterns of data - dot maps, boxplots, multivariate ordination (e.g., principal components analyses, detrended correspondence analysis) and species profiles. These techniques have been used to evaluate ecoregions in a qualitative way (i.e., do data distributions look different for the regions?). See for example Lyons (1989) and Hughes et al. (1987). Some of these techniques can also be used to more rigorously test the ecoregions in a statistical manner that incorporates an acceptable level of uncertainty. One has to make sure the scale and resolution of the ecoregions fit the application. At the national level, less resolution means giving up some of the scientific precision; however, the larger geographic ecoregions are needed for a national framework.

EPA has a significant role to help states and other agencies to perform similar evaluations. The Ecoregion Concept is being adopted by several states, and extended to lower levels of generalization (smaller regions). The Subcommittee recommends that EPA provide advice on methods for determining regions at

lower levels, defining reference areas and also for validating them through statistical and other tests. EPA should provide technical support, training and research to help states develop local regionalizations.

3.3 Applications

The Subcommittee was asked to identify some current and future applications for the Ecoregion Concept.

In order to illustrate the appropriate applications for regionalizations, it would be useful to have examples of ecological problems for which Omernik's ecoregions and other ecoregions are not useful, to contrast with the appropriate applications in the documentation (Gallant et al., 1989). Several additional pieces of information about the variables used to delineate the boundaries would make the maps more useful. The scale and accuracy of the individual variables should be linked objectively to the applications. What resolution of soil mapping is needed to support a particular number of eventual regions? The weights given to each of the variables should be made explicit in the documentation for the regionalization.

The Subcommittee concluded that the Ecoregion Concept has many potentially useful applications. It could be the scientific basis for defining the quality or characteristic of an ecosystem within a particular area that is not influenced by anthropogenic stress. This requires further development of the reference site concept within a region and a better understanding and array of biological criteria or parameters to be measured. **However, the Subcommittee feels that the concept can be used now by states in their programs to make greater use of biological criteria as a water quality management tool, if they have valid estimates of natural variability, procedures for selecting reference sites, and subdivide the ecoregions to resolve boundaries or indicate the confidence in boundaries.** The existence of the Omernik ecoregions map provides a useful initial framework for water quality and some resource management issues. Of course with time and use, boundaries may be adjusted, added, or deleted, and other regionalizations may prove more useful.

Ecoregions provide a geographic context for defining biological criteria. The Subcommittee supports the concept of developing biological criteria as complements to chemical criteria and toxicological evaluations in managing the quality of aquatic resources. **However, the Subcommittee recommends that the metrics and technical guidance for establishing biological criteria (which are suggested guidelines) be carefully reviewed prior to their implementation as water quality standards (which are regulatory requirements).** While diagnostic metrics like the Index of Biotic Integrity and Index of Community Integrity (two

metrics discussed during the review meeting), may prove to be useful and valid as biological criteria, an in depth analysis of the scientific basis and geographic limitations of these and other candidate metrics are needed. Just as the guideline for developing national water quality criteria benefited by in depth scientific review, it is likely that the same will be true for the biological criteria concept.

Some of the other potential areas of application include the following:

1. Setting priorities and compare resources needed for monitoring different types of ecosystems,

2. Providing a framework for a "Natural History" inventory of the Nation's ecosystems,

3. Selecting monitoring sites, i.e., in the Environmental Monitoring and Assessment Program, ecological study sites, bioengineered microorganism releases, new pesticide registration, etc,

4. Estimating the potential for restoration and remediation within geographic areas,

5. Transferring studies and ecological understanding from one ecoregion to another ecoregion to save the cost of duplicating studies,

6. Providing an easier means of explaining ecosystems to the Public and a holistic method of looking at ecosystems for environmental managers,

7. Using biological criteria in the concept of resource management to integrate all perturbations (point source, non-point source, habitat destruction, etc.) into a single quantifiable parameter,

8. Providing a framework for (1) assessing national issues, (2) setting national goals, (3) planning resource use, and (4) summarizing and reporting accomplishments.

The SAB subcommittee encourages support by the EPA for ecoregion programs to better assure their development and appropriate use. It is the SAB subcommittee's expectation, that ecoregions will be a valuable adjunct to existing water quality management tools, if it is properly supported with technical guidance and user assistance.

4.0 RESEARCH NEEDS

Although the Subcommittee feels that the ecoregion concept

is an effort that will ultimately contribute to achieving water goals in the United States, we recommend that its implementation into the regulatory process be done gradually along with supporting research. Our suggestions on research needs follow:

1. Develop a pilot project to determine whether defined ecoregions perform better than less sophisticated regionalizations for environmental management purposes.

2. Research on quantifying the delineation of ecoregions

3. Research on application of the ecoregion concept to large rivers, lakes, and estuaries.

4. Workshops and publications of ecosystem applications to broaden awareness.

5. Develop quantitative techniques for evaluation of ecoregion concepts for specific applications.

6. Research in support of developing criteria for selecting reference sites.

7. Research to develop methods to better describe variability within an ecoregion and the effects of perturbations.

8. Research on identifying biological endpoints or criteria and their natural variability, sensitivity, and response time.

9. Research on describing or depicting the uncertainty of boundary locations.

The Subcommittee recommends that EPA reassemble the team which has developed the Ecoregion Concept with a viable, well-funded program to advance the knowledge they have already developed and to provide technical support to users.

5.0 SUMMARY OF RECOMMENDATIONS

Overall, the Subcommittee finds that Ecoregions and regionalization are valuable concepts for environmental management and pollution control, and the Subcommittee encourages the Agency to resume development and testing of the concept to assess its strengths and limitations for further applications. EPA needs to demonstrate not only that its Ecoregion Concept is useful but that it outperforms other forms of regionalization in its particular application areas. It is important to find out where ecoregions perform well and where they do not, and it is worth expending significant resources on this effort. The Subcommittee recommends that EPA develop a pilot project to test the performance of the defined ecoregions against other regionalization schemes.

The Subcommittee recommends that the metrics and technical guidance for establishing biological criteria be carefully reviewed prior to their implementation in establishing biologically based water quality standards.

The Subcommittee is concerned that selection criteria are not sufficiently specific to encourage consistent and unbiased selection of regional reference sites. The criteria should include the use of a large number of sites within the region to get a reasonable estimate of natural variability.

The regionalization process should include a formal objective protocol, with explicit QA/QC standards, and associated quantification expected performance of a regionalization map. Very little has been done, to date, in the direction of accomplishing this.

The Subcommittee concluded that the Ecoregion Concept has many potentially useful applications if proper guidance is provided, particularly for state users. Ecoregions could be the scientific basis for defining the highest level of quality that is attainable by an ecosystem, if the reference site concept within a region is refined and other recommended research is completed. Guidance should also explain special problems, such as how to treat large rivers that cross ecoregion boundaries.

The Subcommittee also recommends that EPA 1) initiate additional research, an aggressive transfer of technology to users through workshops, technical support documents, and guidance; and 2) continue demonstrations of ecoregion applicability. The Subcommittee concludes that the Ecoregion Concept has applications to states for water quality management.

A specific ecoregion evaluation plan should be incorporated

into the EMAP program, a program which will have a broad network of monitoring stations established throughout the United States. The EPA team which has developed the ecoregion approach must be held together with a viable, well-funded program to advance the knowledge it has already developed. Present ecoregion boundaries should be subdivided by higher resolution boundaries when necessary to produce maps at the appropriate resource level for an assessment or research project.

While some of the above comments may appear critical, they should not be taken as a judgment on the quality of the ecoregions research at EPA, or on the underlying validity of the ecoregions concept. On the contrary, given the level of funding, the accomplishments of the ecoregions research effort are excellent.

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Appendix A. Examples of Testing Ecoregions

To test the effectiveness of a regionalization scheme is not a straightforward exercise. One approach is to evaluate the hypothesis of randomness as illustrated by the Lyons (1989) paper on Wisconsin fish assemblages. Lyons uses a form of cluster analysis to group samples of fish abundance data into four groups, using 40 samples each from brooks, creeks and small rivers in the four major ecoregions of Wisconsin. Agreements between clusters and ecoregions range from 37.5% to 45%, and are all found to be significant. However the null, or alternative hypothesis being rejected in this case is that places have been randomly and independently assigned to regions. For this to be possible, regions would have to be highly contorted and fragmented. The fact that regions are compact and singly bounded ensures a high degree of non-independence. Thus the test has merely established that a set of compact, singly bounded regions performs better than a set of fragmented, contorted ones, not that the ecoregions perform better than some other set of regions. It would not be difficult to repeat the test using random divisions of Wisconsin into four regions of approximately equal size, and determine whether the ecoregion division performed significantly better in its agreement with the fish abundance data. The chances of doing this do not seem to be very high using Lyons' data. Despite the quoted significance levels, comparison of the number of samples showing agreement between fish abundance cluster and ecoregion versus the number expected by chance (from Table 3) are shown below.

Chi-Square Values for Fish Assemblages in Wisconsin Ecoregions

Brooks	Observed	Expected
A/CHF	2	.75
B/DRT	9	6.75
C/NLF	2	1.25
D/SEP	2	1.25

Creeks	Observed	Expected
A/CHF	2	.50
B/DRT	2	1.25
C/NLF	3	2.75
D/SEP	9	6.50

Rivers	Observed	Expected
A/CHF	5	1.25
B/DRT	4	2.25
C/NLF	3	2.75
D/SEP	6	3.75

CHF North Central Hardwood Forests
DRT Driftless Area
NLF Northern Lakes and Forests
SEP Southeastern Wisconsin Till Plains

A comparison of ecoregions to river basins would also be logical since basins have been the regions most often used for water resource assessments.

Gallant et al. (1989) provides another example of the difficulty of effective testing. Figure 3-1 shows total phosphorus levels over Ohio, along with the boundaries of the five ecoregions present. Because of the high level of spatial autocorrelation of total phosphorus levels, it is unfortunately true that almost any set of regions would show some degree of within-region homogeneity of values. Homogeneity would be quite strong for any regionalization which preserved the basic structure of spatial variation in Ohio, which is strongest in a NW-SE transect. For example, division by four parallel lines aligned NE-SW would almost certainly perform as well as the division into ecoregions. Here again, the problem is not to demonstrate that ecoregions perform better than no regions, but better than other, less well informed sets of regions, and significantly better than a random regionalization. Tests such as ANOVA or Chisquare, which assume independence of observations in the null hypothesis, represent an inappropriate alternative, since independence implies infinitely contorted and fragmented regions.

The paper on Oregon fish populations (Hughes, et. al., 1987) compares the correspondence between clustered fish samples and two sets of regions, and comes closer to an effective comparison between ecoregions and other regionalizations. Figure 3 (from Hughes et. al., 1987) shows fish assemblages clustered into eight classes, and mapped over the boundaries of the eight ecoregions present in Oregon, and the 10 physiographic provinces. From these data it is possible to count the numbers of occurrences of each fish cluster in each region. One indicator of goodness of fit is the number of fish samples which do not belong to the commonest cluster found in a given region. For example, in the Coast Range ecoregion there are 13 samples in fish cluster 1 and 2 in fish cluster 3. If there were perfect correspondence between ecoregions and fish clusters we would expect all samples in this region to fall in the same cluster, presumably cluster 1. Thus we can infer 2 misclassifications.

For the 8 ecoregions the total number of misclassifications on the map is 22; for the 10 physiographic provinces it is 20. Ecoregions seem to perform no better than physiographic provinces at predicting fish populations in this example.

Given these examples, there seems to be a pressing need to find areas in which ecoregions do outperform other, less sophisticated regionalizations, and to gain a better picture of the applications for which they perform well, and those for which they are not appropriate. In fact, the Subcommittee recommends

that EPA develop a pilot project now to test the performance of the EPA ecoregions against other possible ecoregions or regionalization schemes, before embarking on major research, development or regionalization efforts. Such a project should also provide valuable information for other aspects of ecoregions and ecoregion research.