U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Digital map of major bedrock lithologic units for the Pacific Northwest: a contribution to the Interior Columbia River Basin Ecosystem Management Project

by

Bruce R. Johnson[1] and Gary L. Raines[2]

Open File Report 95-680

Prepared in cooperation with the U.S. Forest Service and Bureau of Land Management.

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards or with the North American Stratigraphic Code. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

1995

[1] Spokane, WA 99201

[2] Reno, NV 89557

CONTENTS

List of Figures:

List of Tables:

List of Plates:

Acknowledgments

Digital compilation products such as this map would not exist without the geologic mapping of generations of geologists whose work contributed to the small-scale state geologic maps that have been published by most states. Our task of constructing a digital compilation of the geology of the Interior Columbia Basin Ecosystem Management Project area was far simpler because of the existence of these state geologic maps, and we gratefully acknowledge the work of the geologists and agencies that supported compilation of the maps. Those agencies include the U.S. Geological Survey, the California Division of Mines and Geology, the Idaho Bureau of Mines and Geology, the Montana Bureau of Mines and Geology, the Nevada Bureau of Mines and Geology, the Oregon Department of Geology and Mineral Industries, the Utah Geological and Mineral Survey, the Washington State Department of Natural Resources, and the Geological Survey of Wyoming.

USGS geologists, Thor Kiilsgaard and Fred Miller, provided useful advice about regional geology and the identification of unlabeled features on the published state geologic maps. Art Bookstrom, Steve Box, Jim Evans, Tom Frost, and Michael Zientek, USGS geologists, contributed to the development of the major lithology classification scheme and to the classification of individual bedrock units for the map.

We particularly wish to acknowledge Patrick Geehan, the Bureau of Land Management Project coordinator for the Interior Columbia River Basin Ecosystem Management Project, for recognizing the importance of geology to ecosystem management and for supplying funds to digitize the Washington, Idaho, and Montana state geologic maps.

Introduction

This report is one in a series of digital maps, data files, and reports generated by the U.S. Geological Survey (USGS) to provide geologic process and mineral resource information for the Interior Columbia Basin Ecosystem Management Project (ICBEMP), a U.S. Forest Service and Bureau of Land Management interagency project. The various digital maps and data files which were provided by the USGS, and which are available in this and other reports, are being used in a geographic information system (GIS)-based ecosystem assessment which includes a comprehensive analysis of past, present, and future ecosystem conditions within the general area of the Columbia River Basin east of the Cascade Mountains.

The Interior Columbia Basin Ecosystem Management Project

In January of 1994, the Chief of the U.S. Forest Service (USFS) and the Director of the Bureau of Land Management (BLM) initiated what was then called the Eastside Ecosystem Management Project to, “develop a scientifically sound and ecosystem-based strategy for management of eastside forests.” The project was further directed to, “develop an ecosystem management framework and assessment for land administered by the Forest Service and the Bureau of Land Management on those lands east of the Cascade crest in Washington and Oregon and within the interior Columbia River Basin.” The driving force behind the project was the need to develop a strategy for dealing with anadromous fish habitat and watershed conservation in eastern Oregon and Washington. Subsequently, when it became clear that similar strategies were needed for anadromous fish in the remainder of the Columbia River Basin (particularly in Idaho and Montana), the project was extended to include all of the Columbia River drainage basin in the United States, east of the Cascade Mountain divide plus the remainder of southeastern Oregon which is not within the drainage basin (fig. 1). At that time, the project was renamed the Interior Columbia Basin Ecosystem Management Project (ICBEMP).

The ICBEMP is producing scientific assessments of current and historic landscape conditions; of aquatic and terrestrial habitat, species distributions, and populations; and of economic and social conditions. The project is also producing scientific assessments of the potential future conditions and possible tradeoffs likely to result from a range of possible disturbances and management practices on public lands in the basin. Although scientific assessments are being conducted for the entire basin, management decisions that are based on the assessments will apply to public lands (USFS and BLM) only.

The goal of the ICBEMP management strategy is to provide management tools which can be used to sustain or restore ecosystem integrity and to promote products and services desired by society over the long term. The management strategy is intended to provide tools to balance ecosystem conditions, resource uses, and competing values of ecosystem users. The intent of the project is to understand the ramifications of past, present, and future management practices and man-made or natural disturbances both in the area subject to the management practice or disturbance and in areas which may be remote, in time and/or space.

The project is organized around two teams, the Science Integration Team and the Environmental Impact Statement Team, with overlapping membership. Both teams are further sub-divided into staff areas (sub-teams of subject experts) including: landscape ecology, aquatic/riparian, terrestrial, forest policy and economics, and social sciences. Many staff scientists work on both the Science Integration Team and the Environmental Impact Statement Team.

Specific objectives of the project are:

- To conduct a <u>broad scientific assessment of the resources</u> within the interior Columbia River basin to characterize and assess landscape, ecosystem, social, and economic processes and functions and describe probable outcomes of various management practices and trends.
- To develop an <u>ecosystem management framework</u> that includes principles and processes which may be used in a National Environmental Protection Act (NEPA) process to develop management direction for federal agencies at all levels within the basin.
- To write an <u>Eastside Environmental Impact Statement</u> (EIS) proposing a broad array of alternative strategies for an area that encompasses ten national forests and portions of four BLM districts in eastern Washington and Oregon (fig. 1).
- To write an <u>Upper Columbia River Basin EIS</u> with a similar array of alternative strategies for an area that encompasses lands administered by the BLM and USFS in Idaho, western Montana, Wyoming, Utah, and Nevada within the Columbia River Basin (fig. 1).
- To conduct a <u>scientific evaluation of issues and alternatives</u> identified through the NEPA scoping process for the Eastside EIS.

The ICBEMP is an intense, short term project to develop several regionally-consistent, land-management alternatives. These alternatives, derived from basin-wide analyses of highly generalized data, will form a framework for land-management decisions at the local level. This framework will be modified as better data and understanding of the basin are developed. Under the project, a flexible, basin-wide, digital database will be developed that will evolve and improve as higher resolution data become available. All data are being collected in a GIS-compatible format for digital display, analysis, and distribution. Information on the availability of all digital data sets, paper maps, and other reports generated by the ICBEMP can be obtained from:

Interior Columbia Basin Ecosystem Management Project
ATTN: Cindy Dean
112 E. Poplar Street
Walla Walla, WA 99362
(509) 522-4030

or from:

Bureau of Land Management
ATTN: Becky Gravenmeier, OR99.2
Oregon - Washington State Office
P.O. Box 2965
Portland, OR 97208
(503) 952-6273

Project extent and scale

The scope and extent of the project area varies as a function of the objective. The scientific assessment, for example, includes all lands, not just those that are federally managed. This objective is focused on the Columbia River Basin but is not strictly limited to the actual drainage basin boundaries. Moreover, some scientific assessment subject sub-teams, by necessity, have extended their work beyond the limits of the formal project because factors such as wildfires and wildlife migration are not limited by drainage divides or political boundaries. Most subject sub-team project areas are restricted to the Landscape Characterization boundary developed by the Landscape Ecology group (fig. 1). The scientific assessment is primarily based on information suitable for compilation at a scale of 1:1,000,000.

U.S. Geological Survey involvement

In June, 1994, the USGS was asked to provide estimates on the value of undiscovered mineral resources for the Columbia basin. In the course of discussions with members of various sub-teams from both project teams, it became apparent that additional earth science information was also highly relevant to the assessment of historic, current, and future ecological, economic, and social systems, and that the USGS could provide this information in a digital format. Within the ICBEMP's tight schedule (7 months from the USGS start date until the information had to be available to the rest of the Science Integration Team), the USGS was able to provide basin-wide, integrated, digital information about bedrock lithology, rock chemistry, potential animal habitat, stream sediment geochemistry, volcanic and earthquake hazards, geothermal resources, and mineral resources. The bedrock chemistry information is summarized in Raines, Johnson, Frost, and Zientek (1996). Potential animal habitat information is summarized in Frost, Raines, Almquist, and Johnson (1996), and stream sediment geochemistry is summarized in Raines and

Smith (1995). Digital hazards information was derived from Algermissen, et al (1990) and Hoblitt, Miller, and Scott (1987). Geothermal resources information is summarized in Derkey and Johnson (1995). Mineral resources information is summarized in Bookstrom, Raines, and Johnson (1995); Bookstrom, Zientek, et al (1996); Box, et al (1996); and Zientek, Bookstrom, Box, and Johnson (1996).

Information on the bedrock lithology portion of the study is covered by this report. This report also summarizes the strategy that was used for rapid analyses of regional geologic map data using GIS techniques to produce the bedrock lithology, rock chemistry, and potential animal habitat maps, which were all derived from the state geologic maps. Considerably more information was identified as potentially useful to the ICBEMP, but integrated digital products could not be provided for the entire study area within the time frame of the assessment.

Data Sources, Processing, and Accuracy

The starting points for the major bedrock lithologic map and other derivative maps were the geologic maps of California (Jennings, 1977), scale, 1:750,000; Idaho (Bond and Wood, 1978), scale, 1:500,000; Montana (Ross, Andres and Witkind, 1955), scale, 1:500,000; Nevada (Stewart and Carlson, 1978), scale, 1:500,000; Oregon (Walker, MacLeod, 1991), scale, 1:500,000; Utah (Hintze, 1980), scale, 1:500,000; Washington (Hunting and others, 1961), scale, 1:500,000; and Wyoming (Love and Christiansen, 1985) scale, 1:500,000. Characteristics of the source materials of each of these maps are summarized in Table 1. All of the maps were processed using the GIS package, ARC/INFO, and based on the results presented in Table 1 are considered accurate geographic representations of the original maps for the purposes of regional assessments.

State	Date	Scale	Source Material	Registration Error (RMS) input (inches), output (meters)
California	1977	1:750,000	Mylar	?
Idaho	1978	1:500,000	Paper	0.011, 145.720
Montana	1955	1:500,000	Paper	Western Montana: 0.076, 965.561 Eastern Montana: 0.011, 133.434
Nevada	1978	1:500,000	Mylar	?
Oregon	1991	1:500,000	Digital	N.A.
Utah	1980	1:500,000	Mylar	?
Washington	1961	1:500,000	Mylar	0.015, 189.092
Wyoming	1985	1:500,000	Mylar	?

Table 1. Source of materials and registration errors for the digital, state geologic maps. The registration root-mean-square (RMS) errors are obtained while transforming from scanner units of inches (input in table) to real world coordinates of meters (output in table). These errors are the RMS difference between the scanned latitude-longitude location points from the source material and the calculated locations of these points. Where the registration error is queried the data are not available; however, these maps were all digitized by scanning mylar copies of original publication material. These normally have an input RMS error of approximately 0.003, much smaller than the errors obtained from the paper sources used here. The Oregon geologic map was created using digital techniques so no additional processing was required. The large transform error for the western Montana sheet was caused by distortion in the southeastern corner of the paper map sheet.

State geologic maps were selected as the basis for the major lithology map because their scale provides an appropriate level of information to satisfy project objectives, and because they cover large areas, thereby reducing errors inherent in resolving correlation differences between maps. In addition, several state maps were available in digital form, and the others could be quickly digitized. The state maps provide considerably more detail and, in some areas, more current interpretations of the geology than the 1:2,000,000-scale geologic map of the United States (King and Beikman, 1974), even though some of the state maps are relatively old and, in places, do not represent the most current geologic understanding.

Digital processing of the state geologic maps was accomplished by scanning the source materials; the scanned images were then vectorized and topologically structured, the lines and polygons were edited and proofed, attributes were added and proofed, the maps were transformed from scanner units to geographic coordinates, and finally, map distortions were removed by rubber-sheeting. The initial objective was to obtain a digital representation that, when plotted, would overlay the source materials within a line width. Each of the digital state maps meet this test.

In each state map used, approximately 100 to 200 extremely small polygons were found that were either ambiguously attributed or un-attributed. These polygons were assigned map-unit attributes by consultation with regional experts and inspection of more detailed maps.

Geometric accuracy of the digitized source materials was determined by comparing the calculated locations of 15-25 points with known latitudes and longitudes with the locations of the same points on the source materials. Table 1 contains the results of this comparison as the registration root-mean-square error. Except for the western Montana sheet, these errors range from much less than to slightly larger than the national standard for 1:500,000-scale topographic base maps which is plus or minus 140 meters horizontally. The Montana maps (2 sheets) were scanned from old paper versions of the published map because the map is out of print and original materials are no longer available. The large transform error for the western Montana sheet was caused by distortion in the southeastern corner of the paper map sheet. To correct for the geographic distortion of the source maps, the digital maps were then rubber-sheeted to move the scanned latitude-longitude points to the correct calculated locations. This rubber-sheet correction provides the most accurate representation of the individual state geologic maps.

Digital versions of individual state geologic maps are available as follows:

California:	California Division of Mines and Geology, 1416 Ninth Street, Room 1341, Sacramento, CA 95814
Idaho:	Descriptive report: Johnson and Raines (1996); digital files can be download from the USGS public access World Wide Web site on the Internet:

URL = http://geology.wr.usgs.gov/docs/geologic/id/idaho.html

Montana: Descriptive report: Raines and Johnson (1996a); digital files can be download from the USGS public access World Wide Web site on the Internet:

URL = http://pubs.usgs.gov/of/1995/ofr-95-0691/

Nevada: Turner and Bawiec, 1991 — CD-ROM

Oregon: Data files are available: **http://geology.wr.usgs.gov/docs/geologic/or/oregon.html**

Utah: Data files are available from **http://geology.wr.usgs.gov/docs/geologic/ut/utah.html**

Washington: Descriptive report: Raines and Johnson (1996b) ; digital files can be download from

URL = http//pubs.usgs.gov/of/1995/of95-684/

Wyoming: Descriptive report: Green and Drouillard, 1994; the data files are available from **http://pubs.usgs.gov/of/1994/ofr-94-0425/**

As a final step, the individual state maps were edge-matched by rubber-sheeting along their boundaries to fit the adjacent state maps. because of the differences in how the digital maps had been prepared, there are differences in geometric accuracy from state to state. The Oregon state map was originally prepared digitally; so the published and digital version are identical. The Wyoming map was digitized from original source materials, and the California, Nevada, and Utah maps were prepared from base-stable copies of original source materials. These four maps have an root-mean-square error of registration near 0.003 inches. Because these maps have higher geometric accuracy than the Idaho, Montana, and Washington maps, the later three maps were rubber-sheeted to fit the more accurate California, Oregon, Nevada, Utah, and Wyoming maps along their common boundaries. The maximum translation needed to match boundaries was approximately 400 meters; in most areas 200 meters or less were needed. The remaining borders were then rubber-sheeted to a compromise boundary to make a composite of all of the states. Because the Idaho-Montana border is very irregular and the two state maps used different base materials, many adjustments were required. Consequently this is the area of largest residual geometric error. Because of the differences in geologic representation between the state maps, the state boundaries were maintained in the bedrock lithology digital composite and were only eliminated in derivative maps.

As a partial test of the digitizing and attributing of the individual state maps, all derivative maps were checked for differences at the state boundaries. A few incorrectly labeled map units and areas where the map units were defined differently across state boundaries were identified. Examples include a rock unit mapped as granitic gneiss in one state and granite in the adjacent state, and several sedimentary facies changes that occur in the vicinity of state boundaries. To evaluate these problems and refine some of the interpretive maps, newer, larger-scale, geologic maps were examined and regional geology experts were consulted. National Uranium Resource Evaluation stream sediment geochemistry was also used where available to test the geochemical interpretations of the lithologic information (Raines and Smith, 1995).

Major Bedrock Lithology Map

The composite digital map of the entire study area, which was generated from the state geologic maps, facilitates interpretation and re-classification of the bedrock geology for specific tasks such as those required by the ICBEMP. The following section describes a major bedrock lithology map that was derived from the composite state geology for the ICBEMP's Columbia River Basin analyses.

There are a number of possible approaches to creating a lithologic map of a large region, each emphasizing different features of the rocks and each appropriate for particular applications. Regional ecosystem management analyses of the Columbia River Basin required a means of integrating bedrock lithology into the Landscape Characterization process, which was the method by which the basin was divided into a small number of subsections, each with its own unique character. Each subsection, or landscape type, in the basin is relatively consistent in terms of geomorphology, bedrock geology, climate, and vegetation. The characterization process required a geologic map having a limited number of lithologies which could be consistently applied throughout the basin. We are confident that the digital map presented here defines the dominate lithologic character of the Pacific Northwest in 38 units; we consider this the minimum number of lithologic units needed to adequately represent the region. The major lithologic units used for this map are defined in Table 2. Plate 1 contains the explanation for the major lithology map; plate 2 is a reduced version of the complete map.

Category	Description
Alluvium	Unconsolidated sediment (clay, silt, sand, gravel). Includes glacial outwash deposits
Dune sand	Wind deposited sand
Loess	Windblown silt deposits
Lake sediments	Lake sediment and playa deposits
Landslide	Landslide deposits
Glacial drift	Material deposited by glacial processes. Includes till and moraine (unstratified) as well as outwash (stratified)
Shale and mudstone	Fine-grained sedimentary rock derived from clay
Argillite and slate	Fine-grained metamorphic rock formed from shale
Tuff	Volcanic ash. Includes minor amounts of detrital sediment
Siltstone	Fine-grained detrital sedimentary rock derived from silt
Meta-siltstone	Fine-grained metamorphic rock formed from siltstone
Sandstone	Medium-grained detrital sedimentary rock derived from sand
Meta-sandstone	Medium-grained metamorphic rock formed from sandstone
Quartzite	Medium-grained metamorphic rock formed from quartz-rich sandstone
Conglomerate	Coarse-grained detrital sedimentary rock derived from gravel. Locally includes angular-fragment breccia
Meta-conglomerate	Coarse-grained metamorphic rock formed from conglomerate
Carbonate	Sedimentary rock, mostly composed of limestone and dolomite, locally metamorphosed to marble
Mixed miogeosynclinal rocks	Mixed sequences of miogeosynclinal sedimentary rocks. Includes interlayered shale, siltstone, lithic sandstone, quartzite, and conglomerate
Mixed eugeosynclinal rocks	Mixed sequences of eugeosynclinal sedimentary rocks having abundant dark rock fragments and mafic minerals. Includes interlayered shale, siltstone, greywacke, conglomerate, and melange with subordinate mafic volcanic rock, chert, and calcareous rock
Phyllite and schist	Meta-sedimentary phyllite and schist. Fine-grained metamorphic rocks derived from shale, mudstone, and siltstone
Interlayered meta-sediment	Fine- to coarse-grained metamorphic rocks derived from clastic and carbonate sedimentary rocks
Carbonate and shale	Mixed sequences of carbonate rock and shale with subordinate sandstone and conglomerate
Meta-carbonate and shale	Mixed sequences of metamorphosed carbonate rock and shale with subordinate sandstone and conglomerate

Category	Description
Felsic pyroclastics	Rhyolitic pyroclastic rocks
Felsic volcanic flows	Rhyolitic volcanic flows
Calc-alkaline volcanic rocks	Calc-alkaline suite of pyroclastic rocks and volcanic flows. Generally andesite to quartz-latite
Calc-alkaline meta-volcanics	Calc-alkaline suite of meta-volcanic rocks
Mafic pyroclastics	Basaltic pyroclastic rocks
Mafic volcanic flows	Basaltic volcanic flows
Greenstone	Mafic meta-volcanic rocks. Includes subordinate spillite, slate, argillite, and greywacke
Granite	Includes intrusive rhyolitic rocks
Alkalic bodies	Alkalic intrusive rocks
Calc-alkaline intrusive rocks	Calc-alkaline suite of intrusive rocks. Generally granodiorite to diorite
Mafic intrusive rocks	Generally dioritic or gabbroic
Ultramafic rocks	Includes associated gabbroic rocks
Mixed granitic gneiss	Dominantly granitic gneiss, migmatite, augen gneiss, and hornblende gneiss. Includes subordinate anorthosite, amphibolite, calc-silicate gneiss, schist, marble, and quartzite
Mafic schist and greenstone	Dark-colored, fine-grained, foliated, mafic metamorphic rocks. Mostly metamorphosed basaltic to dioritic rocks
Mafic gneiss	Dark-colored, medium- to coarse-grained, layered metamorphic rocks. Includes amphibolite

Table 2. Major lithologic categories used to classify rock-stratigraphic units from state geologic maps.

Map units from the state geologic maps are regrouped here solely on the basis of rock type (lithology); criteria such as age, tectonic province, or other characteristics that may have been used to distinguish map units on state maps are not considered. Appendix A of this report contains an example showing the method used to classify state map units. Appendix B contains detailed tables for each state geologic map showing which mapped bedrock units are included in each major lithologic category. The grouping of map units into lithologic categories used for this map is only one of many ways the lithologic information could be represented; starting from tables describing the map units of each state map, other groupings of lithologies could easily be devised which would serve different purposes.

Because many geologic map units are (1) a mixture of lithologic types, (2) have misleading names, or (3) have unit names which give insufficient information regarding lithology, individual map units on each state map were evaluated to assure that each was assigned to the most representative lithologic unit on our map. These assignments were made using data tables summarizing the lithologic information from the state map legends. The assignment of each state geologic map unit to one of our lithologic units was based primarily on the dominant lithology; consideration was also given, however, to other lithologies and the degree of mixing of lithologies. In classifying each unit, it was assumed that the first lithology listed in the map legend was the dominant lithology. Due to differing concepts between state maps of how to compile regional geologic maps and describe units, this assumption is only partially correct. Several approaches were used to test this assumption and make corrections. On our initial compilation, lithologic differences at state lines pointed out obvious problems. Where lithologic differences were observed at state boundaries, the descriptions of the state map units were checked for consistency, in some cases more detailed maps were consulted, and lithologic assignments were adjusted to be consistent between the states. This test proved reasonably comprehensive because the borders of these states are so extensive that most map units are found somewhere next to a state-line boundary. Based on this testing, most of the differences associated with state boundaries were resolved. To further avoid inconsistencies in unit assignment, maps were checked in some detail by regional geology experts.

Obtaining Digital Data

The digital files which were used to make the major lithology map are available as GIS coverages and associated data files. All data files and map images are maintained in the projection used for all ICBEMP products:

Projection:	Albers Equal Area
1st Standard Parallel:	43° N
2nd Standard Parallel:	48° N
Central Meridian:	117° W
Origin of Projection:	41° N

Y-offset (digital files): 700,000 m

To obtain copies of the digital data, do the following:

1. Download the digital files from the USGS public access World Wide Web site on the Internet.

URL = http://pubs.usgs.gov/of/1995/ofr95-680/

These Internet sites contain the major lithology GIS coverage in Arc/Info Export file format as well as the associated data files and Arc/Info macro programs which are used to plot the map at 1:1,000,000 and 1:2,000,000 scales. Use of this data requires a GIS that is capable of reading Arc/Info Export formatted files and a computer capable of reading UNIX ASCII files. To use these files on a DOS computer, they must be put through a unix-to-dos filter. Or,

2. Obtain the digital files from the ICBEMP project office. Contact information is given in the section, **U.S. Geological Survey involvement**, above.

Obtaining Paper Maps

Paper copies of the major lithology map are not available from the USGS at this time. However, with access to the Internet and access to a large-format color plotter, a 1:2,000,000-scale paper copy of the map can be made, as follows:

1. Download the digital version of the complete map from the USGS public access World Wide Web site on the Internet.

URL = http://pubs.usgs.gov/of/1995/ofr95-680/

These Internet sites contain a file, **lith2m.hp** which is in HPGL2 graphics language.

2. This file can be plotted by any large-format graphics plotter which can interpret the HPGL2 language. The finished plot is 27 by 38 inches.

Paper copies of the map can also be created by obtaining one of the versions of the digital files as described above, and then creating a plot file in a GIS.

Concluding Remarks

The major lithology map presented here was derived from digital versions of existing state geologic maps. Descriptions of the 800+ individual map units on the state geologic maps were tabularized for rapid interpretation. The complex geologic vocabulary used in the map legends was then systematically classified into a small number categories based strictly on lithology. By this methodology, the state geologic maps could be rapidly combined into a new, derivative map representing a particular, restricted feature of the original map units. This and other new maps constructed by this method are derivative maps that can be used to answer focused questions.

Derivative maps produced from state map scale geology are an appropriate first step to providing a regional context for land management decisions. The applications these maps are intended to address are very general. The 1:500,000 scale of the data is appropriate to regional applications concerning the entire Columbia River Basin. Although some of the state geologic maps are old, much of the evolution of geologic knowledge since the 1970's has been concerned with the temporal correlation of rock units, with details of the compositions of the individual units, and with how the existing arrangement of rock units came to exist. These types of information have little bearing on the derivative maps presented here. Thus, the dominate lithologic character of the rock units is well represented in the state geologic maps and the maps are appropriate to regional applications.

Fundamental geologic information is a critical portion of any ecosystem study and should be part of the basis for land management decisions. Future ecosystem monitoring and adaptive management planning within the Columbia River Basin should include studies to improve the quality of the geologic data base.

References Cited

Algermissen, S. T., Perkins, D. M., Thenhaus, P. C., Hanson, S. L., and Bender, B. L., 1990, Probabilistic earthquake acceleration and velocity maps for the United States and Puerto Rico: U.S. Geological Survey Miscellaneous Field Studies Map, MF-2120, scale 1:7,500,000.

Bond, J. G. and Wood, C. H., 1978, Geologic map of Idaho: Idaho Department of Lands, Bureau of Mines and Geology, 1 plate, Scale 1:500,000.

Bookstrom, A. A., Raines, G. L., and Johnson, B. R., 1995, Digital mineral resource maps of phosphate and natural aggregate for the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-681, 28 p.

Bookstrom, A. A., Zientek, M. L., Box, S. E., Derkey, P. D., Elliott, J. E., Frishman, David, Ashley, R. P., Evarts, R. C., Stoesser, D. B, Moyer, L. A., Cox, D. P., and Ludington, Steve, 1996, Status and metal content of significant metallic mineral deposits in the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-688, 93 p.

Box, S. E., Bookstrom, A. A., Zientek, M. L., Derkey, P. D., Ashley, R. P., Elliott, J. E., and Peters, S. G., 1996, Assessment of undiscovered mineral resources in the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-682, 415 p.

Derkey, P. D. and Johnson, B. R., 1995, Digital maps of low- to moderate-temperature geothermal springs and wells in the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-689, 11 p.

Frost, T. P., Raines, G. L., Almquist, C. L., and Johnson, B. R., 1996, Digital maps of possible bat habitats for the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-683, 20 p.

Golterman, H. L., 1975, Chemistry in Whitton, B. A. (ed.), 1975, River ecology: Berkeley, University of California Press, 725 pp.

Green, G. N. and Drouillard, P. H., 1994, The digital geologic map of Wyoming in ARC/INFO format: U.S. Geological Survey Open-File Report 94-0425, 10 pp.

Hintze, L. F., 1980, Geologic map of Utah: Utah Geological and Mineral Survey, 2 plates, 1:500,000 scale.

Hoblitt, R. P., Miller, C. D., and Scott, W. E., 1987, Volcanic hazards with regard to siting nuclear power plants in the Pacific Northwest: U.S. Geological Survey Open-File Report 87-297, 196 pp.

Hunting, M. T., Bennett, W. A., Livingston, V. E., Jr., and Moen, W. S., 1961, Geologic map of Washington: Washington Dept. of Conservation, Division of Mines and Geology, 1 plate, scale 1:500,000.

Jennings. C. W., 1977, Geologic map of California: California Divisions of Mines and Geology, Map No. 2, 1 plate, Scale 1:750,000.

Johnson, B. R. and Raines, G. L., 1996, Digital representation of the Idaho state geologic map: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-690, 22 p.

King, P. B., and Beikman, H. M., 1974, Geologic Map of United States: U.S. Geological Survey, 2 plates, scale 1:2,500,000.

Love, J. D., and Christiansen, Ann Coe, 1985, Geologic map of Wyoming: U.S. Geological Survey, 3 Plates, Scale 1:500,000.

Raines, G. L. and Johnson, B. R., 1996a, Digital representation of the Montana state geologic map: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-691, 36 p.

_____, 1996b, Digital representation of the Washington state geologic map: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-684, 20 p.

Raines, G. L., Johnson, B. R., Frost, T. P., and Zientek, M. L., 1996, Digital maps of compositionally classified lithologies derived from 1:500,000 scale geologic mapping for the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-685, 28 p.

Raines, G. L. and Smith, C. L., 1995, Digital maps of National Uranium Resource Evaluation (NURE) geochemistry for the Pacific Northwest: a contribution to the Interior Columbia Basin Ecosystem Management Project: U.S. Geological Survey Open-File Report 95-686, 22 p.

Ross, C. P., Andres, D. A., and Witkind, I. J., 1955, Geologic map of Montana: U.S. Geological Survey, 1 plate, Scale 1:500,000.

Stewart, J. H. and Carlson, J. E., 1978, Geologic map of Nevada: U.S. Geological Survey, 1 plate, scale 1:500,000.

Turner, R. M., and Bawiec, W. J., 1991, Geology of Nevada - a digital representation of the 1978 geologic map of Nevada: U.S. Geological Survey Digital Data Series, DDS-2, 1 CD-ROM.

Walker, G. W. and MacLeod, N. S., 1991, Geologic map of Oregon: U.S. Geological Survey, 2 plates, scale 1:500,000.

Zientek, M. L., Bookstrom, A. A., Box, S. E., and Johnson, B. R., 1996, Future minerals related activity, Interior Columbia Basin Ecosystem Management Project area: an overview: U.S. Geological Survey Open-File Report 95-687, 30 p.

Appendix A: State Geologic Map Attributes.

Attributes Compiled for Classification

The table below is a list of the ARC/INFO attributes that were compiled for each state geologic map. The strategy for classification of lithologies is explained in the section, Major Bedrock Lithology Map, above.

Attribute	Description
FORMATION	The map unit symbol used on the published map. This is the item that is related to the map coverage.
UNIT_NAME	The map unit name from the map explanation.
ROCK_TYPE	The general rock category from the map explanation. Generally this is something like sedimentary, igneous, or metamorphic.
ERA, SYSTEM, SERIES	Age information from the map explanation.
LITH1, LITH2, etc.	Lithology from the map explanation. Lith1 is the first described lithology, lith2 is the next, etc.
LOCATION1, LOCATION2	Notes on location of this particular map unit within the state. Some state maps have differing lithologic descriptions for a single geologic unit in different geographic portions of the state.
COMMENTS	Other comments from map explanation that do not fit in previous attributes

Example of complete data for one stratigraphic unit from one state map

Description from map explanation:

Marine Sedimentary and Metasedimentary Rocks

> Cambrian - Sandstone, shale, limestone, dolomite, chert, quartzite, and phyllite; includes some rocks that are possibly Precambrian.

GIS attributes derived from map explanation:

Attribute Name	Contents
FORMATION	C (ASCII symbol used for Cambrian Ꞓ)
ROCK_TYPE	Marine sedimentary and metasedimentary rocks
ERA	Paleozoic
SYSTEM	Cambrian
SERIES	
LITH1	sandstone
LITH2	shale
LITH3	limestone
LITH4	dolomite
LITH5	chert
LITH6	quartzite
LITH7	phyllite
LITH8	
LOCATION1	
LOCATION2	
COMMENTS	includes some possible Precambrian rocks
LITHM	Sandstone

Time Stratigraphic Symbols used for Formation Names

Because the database tables that are used with the GIS are confined to ASCII characters, the following ASCII character substitutions were used for representing geologic time designators in formation names:

Geologic Time	Map Symbols	ASCII Equivalent
Cenozoic	Cz	CZ
Quaternary	Q	Q
Holocene	Q, Qr	Q, Qr
Pleistocene	Q, Qp	Q, Qp
Tertiary	T	T
Pliocene	P, Tp	PL, Tp
Miocene	M, Tm	MI, Tm
Oligocene	Φ, To	OL, To
Eocene	E, Te	E, Te
Paleocene	Ep, pE	EP
Mesozoic	Mz	MZ
Cretaceous	K	K
Jurassic	J	J
Triassic	TR	TR
Paleozoic	Pz	PZ
Permian	P	P
Carboniferous	C	PNM
Pennsylvanian	P	PN
Mississippian	M	M
Devonian	D	D
Silurian	S	S
Ordovician	O	O
Cambrian	Є	C

Geologic Time	Map Symbols	ASCII Equivalent
Precambrian	pꞒ	pC
Proterozoic	P̱	PR
Proterozoic Z	Z	Z
Proterozoic Y	Y	Y
Proterozoic X	X	X
Archean	W	W

Appendix B: Major Bedrock Lithology Classification Tables.

The Formations symbols shown in these tables are the ASCII equivalents given in Appendix A.

California:

FORMATIONS	LITHM
Q	Alluvium
Qs	Dune sand
Qls	Landslide
Qg	Glacial drift
E, J, TR, Pm, PNM	Shale and mudstone
QPLc, PL, MI, MIc, OL, OLc, C, Ec, EP, Tc, TK, K, Kl, Ku, KJf, SO	Sandstone
pC	Conglomerate
D, ls	Carbonate
sch	Phyllite and schist
KJfm, KJfs, PZ, m	Interlayered meta-sediment
Qrv, Qrvp, Qvp, Tvp, MZv	Calc-alkaline volcanic rocks
mv	Calc-alkaline meta-volcanics
Qv, Tv	Mafic volcanic flows
PZv	Greenstone
Ti, gr, grCZ, grMZ, grpC, grPZ	Calc-alkaline intrusive rocks
gb	Mafic intrusive rocks
um	Ultramafic rocks
pCc, gr-m	Mixed granitic gneiss

Idaho:

FORMATIONS	LITHM
Qa, Qd, Qg, Qpa, Qpg, Qplg, Qpmg, Qpug, Qs, QTg, QTs	Alluvium
Qrw	Dune sand
Qpw, Qw	Loess
Qpd, Qpmd	Lake sediments
Qpc, Qpt	Glacial drift
Kl, TRu, TRuw, DSc, Cmn	Shale and mudstone
Jwm, Y1n, Y1nm, Y4n, Y4nm	Argillite and slate
Ted	Tuff
Tmd, SOc,	Siltstone
Y2n, Y2nm	Meta-siltstone
Tpd, Ju, Cc, Y1s, Y3s, Y4s, Z2s	Sandstone
Y2s	Quartzite
TKg	Conglomerate
Ku, Jl, TRl, PNM, M, Ms, MD, D, DS, S, SO, O, Ol, Ou, OCc, Cun, PZl	Carbonate
Td, Ps, PPNc, PNs, Mc, Dc, C, PZu	Mixed miogeosynclinal rocks
Jw, PPN	Mixed eugeosynclinal rocks
OCm, PZm, pC1, pC2, pC3, Ys	Interlayered meta-sediment
J, TR, P, PPNs, DO, OC, Zs	Carbonate and shale
Y3n, Y3nm	Meta-carbonate and shale
Qplf, Qpm1f, Qpm2f, Qpm3f, Qpmf, Qpu1f, Qpu2f, Qpu3f, Tev, Tpv, Tpf	Felsic Pyroclastics
QTf, Tmf, Tov	Felsic volcanic flows
Z1s	Calc-alkaline volcanic rocks
TRPv	Calc-alkaline meta-volcanics
Qpmb, Qpu1b, Qpu2b, Qpu3b, Qpu4b, Qpub, Qrb, QTb, Tm1b, Tm2b, Tm3b, Tmb, Tpb, Pv, Zn	Mafic volcanic flows

FORMATIONS	LITHM
TRv	Greenstone
Tei	Granite
Ti, Ki, Kif, Kii, KJi, JTRi, pKi, pCi	Calc-alkaline intrusive rocks
Tmi, Kib, Zi, Zib	Mafic intrusive rocks
Kim, Km, pKim, pCim, X, mig	Mixed granitic gneiss
pC	Mafic gneiss

Montana:

FORMATIONS	LITHM
Qal, QTt, Tf	Alluvium
Qgl, Dry Lakes	Lake sediments
Qg	Glacial drift
Tfu, Twc, Twr, Kb, Kbf, Kc, Kcb, Kce, Kcl, Kf, Kg, Kmo, Kn, Kp, Ksm, Kt, Ktc, Ktm, Ku, JTR, Ju, Du	Shale and mudstone
pCap, pCc, pCe, pCg, pCga, pCp, pCs	Argillite and slate
pCm, pCnb, pCr	Meta-siltstone
Ta, Tw Keu, Kfh, Kh, Khc, Kjr, Kk, Kl, Km, Kvi, PAL, Pu, PNu	Sandstone
pCne	Quartzite
TRu	Conglomerate
Ou, pCwc, pCa, pCh, pCn, pCsi	Carbonate
Ts, Cu	Mixed miogeosynclinal rocks
Mu	Carbonate and shale
pCpi, pCw	Meta-carbonate and shale
Tv, TKl, Kv	Calc-alkaline volcanic rocks
Tg	Granite
Tga	Alkalic bodies
Td, TKb, Ki, pCgr	Calc-alkaline intrusive rocks
Kdg, pCd, pCb	Mafic intrusive rocks
pCsc	Ultramafic rocks
Kib, pCgs	Mixed granitic gneiss

Nevada:

FORMATIONS	LITHM
Qa, QToa	Alluvium
Qp, QTs	Lake sediments
Qls	Landslide
Qm	Glacial drift
JTRs, JTRsv, TRch, MDs, Ds, Ss, Ot, Ct	Shale and mudstone
Ts3, CZs, Ks, TRmt, Psc	Siltstone
Jv, JTRa, Se, Ch, Css	Sandstone
CZq, Zqs	Quartzite
Jd, TRPd, PPNa, MDmc	Conglomerate
TRc, TRPs, PPNc, PPNcd, PMc, PNc, PNcd, Mc, Ml, Dc, Dt, DCc, Sc, St, SOc, Oc, OCc, Cc	Carbonate
TKs, TKsu	Mixed miogeosynclinal rocks
Ths, Ts1, Ts2, Dsl, DCsv, Os, Osv, Csc	Mixed eugeosynclinal rocks
OCt, Zw	Interlayered meta-sediment
Trt, Tt1, Tt2, Tt3	Felsic Pyroclastics
QTr, Tr1, Tr2, Tr3	Felsic volcanic flows
QTa, Ta1, Ta2, Ta3, Tts, Tbr, TRk, TRPvs, JPu	Calc-alkaline volcanic rocks
QTb, Tb, Tba, Tbg, Tob, Msv	Mafic volcanic flows
Tri, KJim, TRlgr, Ygr	Granite
Tgr, TJgr, Kgr, Jgr, TRgr, MZgr	Calc-alkaline intrusive rocks
Ti, Tmi, KJd, Jgb	Mafic intrusive rocks
PZsp	Ultramafic rocks
Xm	Mixed granitic gneiss

Oregon:

FORMATIONS	LITHM
Qal, Qf, Qgf, Qgs, Qpl, Qt, QTg	Alluvium
Qd	Dune sand
Ql	Loess
Qs	Lake sediments
Qls	Landslide
Qg	Glacial drift
QTs, Tct, Tss, Js, Jss, JTRs, TRs	Shale and mudstone
TRPZs	Argillite and slate
Tts, QTst	Tuff
Ta, Tcss, Tms, Tmsc, Tsd, Ty	Siltstone
Tco, Tfe, Tm, Tmsm, Tmss, Tmst, Ts, Tsm, Tt, Tyq, Kc, Ks, KJds, Jop	Sandstone
Tn, KJm	Conglomerate
TRPZsn, PZs	Carbonate
Tfee, Tsfj, Jm, JTRsv, PZsv	Mixed eugeosynclinal rocks
cm, cs	Phyllite and schist
TRsv, TRPsv, TRPZm, Psv, mr	Interlayered meta-sediment
Qmp, Qma, Tat, Tlf, Trh, Tsf, Twt, Tvs	Felsic Pyroclastics
Qrd, QTvs, Tr, Tsv	Felsic volcanic flows
Qa, Qba, Tas, Tbaa, Tbas, Tca, Tfc, Tut, Tu, Tus, Jv	Calc-alkaline volcanic rocks
TRPv	Calc-alkaline meta-volcanics
QTmv, QTp, QTps, QTvm, Tp, Tps, Ttvm	Mafic Pyroclastics
Qb, Qlb, Qyb, QTa, QTb, QTba, QTib, Tb, Tba, Tc, Tcg, Tci, Tcp, Tcs, Tcw, Tfeb, Tig, Tob, Tpb, Trb, Tsff, Tsr, Tstv, Ttv, Tub, Tvm, KJdv, Jub	Mafic volcanic flows
TRv	Greenstone
Tia	Alkalic bodies
KJg, KJi, JTRgd	Calc-alkaline intrusive rock

FORMATIONS	LITHM
Thi, Ti, Tib, Tmv, Tvi, Tim, KJgu, Jc, TRPZg	Mafic intrusive rocks
Ju, TRPZu	Ultramafic rocks
bc, mc	Mafic gneiss

Utah:

FORMATIONS	LITHM
Qa, Qao, QT	Alluvium
Qe	Dune sand
Ql, Qm, Qs	Lake sediments
Qls	Landslide
Qg	Glacial drift
T2, TK, TR2, J2, M3	Shale and mudstone
T4	Siltstone
T1, T3, K1, K2, JTR, P1	Sandstone
C1	Quartzite
T5, K3	Conglomerate
J1, TR1, P2, PPN, PN, M1, M2, D, O, S, C2, C3	Carbonate
pCs	Interlayered meta-sediment
Qr, Tpr	Felsic volcanic flows
Tmr, Tov, Tma, Tmv, Tvu	Calc-alkaline volcanic rocks
Qb, Tmb, Tpb	Mafic volcanic flows
Ti, Ji, pCi	Calc-alkaline intrusive rocks
pCm	Mixed granitic gneiss

Washington:

FORMATIONS	LITHM
Qa, Qc, Qg, Qt	Alluvium
Qe	Dune sand
Qce	Loess
Qcl, Qgl	Lake sediments
Qs	Landslide
Qg1, Qg1o, Qg1t, Qg2	Glacial drift
E2, pE2, Ku, J, PNMP, SD	Siltstone
O	Meta-siltstone
MI, MIPL, MIPLc, OL, OLM, E1, Ec, EPKc, Tc, Ts, Kc, Kl, JK, JKs, Mc, D, Cq	Sandstone
MZT, pT, pJ, pJs, PNMPs, PZu	Meta-sandstone
PL, PLc, OLc, K, TRJ, P	Conglomerate
pCc	Meta-conglomerate
TR, Cls, pCd,	Carbonate
PNM	Mixed eugeosynclinal rocks
pJph, Cph, pC, pCph,	Phyllite and schist
pTm, pJsc, PZl	Interlayered meta-sediment
Ev1r	Felsic volcanic flows
PLQv, OLMIv, OLv, EOLv, Ev, Ev1, Ev1a, Tv, lTv, uTv, TKv, pTv, Jv, PNMPv, MZv	Calc-alkaline volcanic rocks
JKv	Calc-alkaline meta-volcanics
Qv, MIPLv, MIv, Ev1b, Ev2, MZTv	Mafic volcanic flows
pJv	Greenstone
Tas, MZag, MZas, pCi	Alkalic bodies
Ti, Tg, TKg, MZg, pMg	Calc-alkaline intrusive rocks
TKbi, pTbi, bi	Mafic intrusive rocks
Td, pTb, pTd	Ultramafic rocks

FORMATIONS	LITHM
pJgn	Mixed granitic gneiss
pJgs, pCv	Mafic schist and greenstone
pMm	Mafic gneiss

Wyoming:

FORMATIONS	LITHM
Qa, Qt, Qu, QTg	Alluvium
Qs	Loess
Ql	Lake sediments
Qls	Landslide
Qg	Glacial drift
QTb, Ta, Teml, Tfl, Tflt, Tgl, Tglu, Tgrw, Tgt, Tim, Tmu, Tsi, Tta, Tte, Tw, Twb, Twc, Twdr, Twg, Twl, Twlc, Twr, Twrb, Twrc, Ka, Kba, Kbr, Kc, Kcf, Kcl, Kg, Kh, Kle, Kmr, Kmt, Kp, Ks, Ksn, Kws, Jsg, JTRad, TRc, TRPs, Pp, DO	Shale and mudstone
Tsl	Tuff
TKe, Jst, TRc, TRcd, TRPcg, DO	Siltstone
Tb, Tbw, Tco, Tdb, Tf, Tft, Tftl, Tftr, Tfu, Tgw, Tgwt, Th, Tha, Tm, Tml, Tmo, Tmu, Tu, Tw, Twa, Twd, Twdr, Twim, Twm, Twn, Twru, TKf, TKu, Kal, Kav, Kb, Kbb, Kbl, Kcf, Ke, Ket, Kf, Kfb, Kfh, Kfl, Kft, Kl, Klc, Klm, Km, Kmb, Kml, Kmv, Kns, Kr, Ksb, Kso, Kss, KJ, KJg, KJk, KJs, KTR, Js, JTR, JTRgc, JTRgn, JTRn, JTRn, TRPg, TRPjs, Pp, PPNc, PPNcf, PPNh, PPNm, PPNM, PM, MzPz	Sandstone
Xdl	Quartzite
QTc, Tbi, Tbs, Tcd, Tcg, Tcr, Tcs, Tep, Tgc, Thl, Thp, Tip, Tp, Tr, Tt, Tv, Twi, Twk, Twmo, TKp, Kha	Conglomerate
Kgb, Kgbm, Kn, Knc, Knt, TRcd, Pfs, Pmo, Pzr, PPNM, PPNMa, Mm, MD, MDe, MDg, MDO, MO, Ob, OC, Sl, Cr	Carbonate
JTRnd	Mixed miogeosynclinal rocks
JTRnd	Mixed eugeosynclinal rocks
Xlc	Phyllite and schist
Ws	Interlayered meta-sediment
PPNMa	Carbonate and shale

FORMATIONS	LITHM
Tcc, Thr, Ts	Felsic Pyroclastics
Qr	Felsic volcanic flows
Toe, Tcv, Ttp, Taw, Tc, Ttl, Tts, Twp	Calc-alkaline volcanic rocks
Qb, Tbf	Mafic volcanic flows
Wg, Ys	Granite
Qi, Tai	Alkalic bodies
Ti, Tid, Tie, Tii, Ki, Yla, Yls, Yd, Xgo, Xgy, Xqd, Wgd, Wqm, WVg, Ug	Calc-alkaline intrusive rocks
YX, Xm, PRW	Mafic intrusive rocks
Wp	Ultramafic rocks
Xsv, Wgn, Ugn, shear,	Mixed granitic gneiss
WVsv, Wmu	Mafic gneiss

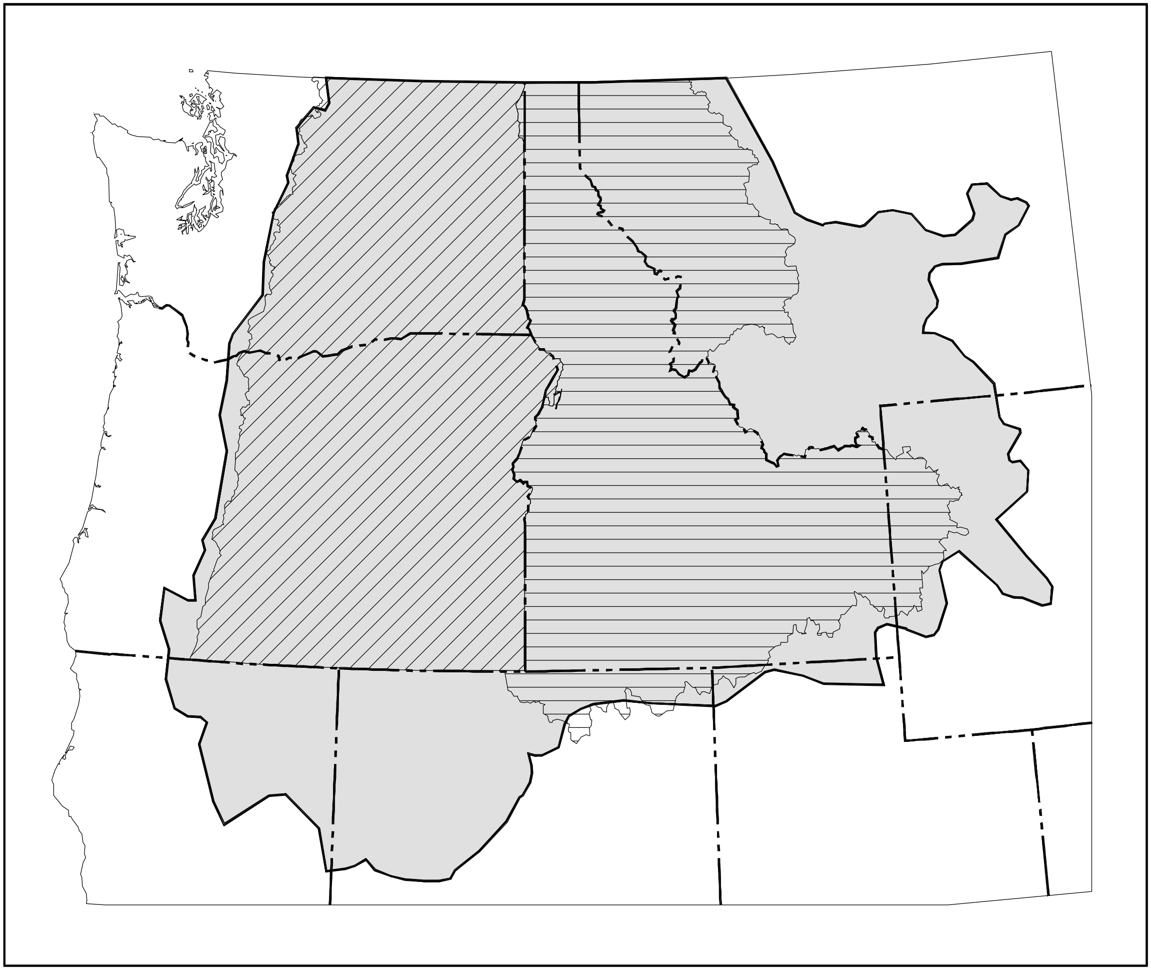

Figure 1. Index map showing the geographic extent of the Interior Columbia Basin Ecosystem Management Project. Shown on the map are the Landscape Characterization Area (grey shading) which is the study area used by most Science Integration Team staff areas, the Eastside EIS area (diagonal hatching), and the Upper Columbia EIS area (horizontal hatching).