GEOLOGY IN LAND USE PLANNING

By

ERNEST R. ARTIM

Prepared cooperatively by the
UNITED STATES GEOLOGICAL SURVEY

DEPARTMENT OF NATURAL RESOURCES
DIVISION OF MINES AND GEOLOGY
INFORMATION CIRCULAR 47
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GEOLOGY IN LAND USE PLANNING
Some Guidelines for the Puget Lowland

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1973
This dramatic picture shows several houses in the process of being destroyed by a landslide. The original photograph was furnished by the Oakland Tribune and appeared in the Association of Engineering Geologists, Special Publication—1969, "Urban environmental geology in the San Francisco Bay region," page 73.
ERRATA SHEET

Washington State Division of Mines and Geology Information Circular 47
"Geology and Land Use Planning; Some Guidelines for the Puget Lowland"

Plate I.—Correlation chart—Quaternary deposits of the Puget Lowland

Under Northern Puget Lowland, Geologic Climate Units

Whidbey Glaciation should read——Whidbey Interglaciation
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"Woe unto them that join house to house, that lay field to field, till there be no place, that they may be placed alone in the earth."
(Isaiah 5:8)

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INTRODUCTION

The State of Washington has a population of 3.4 million people, of which 60 percent live in the Puget Lowland on approximately 8 percent of the state's land surface (fig. 1). As in other metropolitan regions of the United States, increased urbanization is causing human activity to sprawl over previously bypassed areas of hazardous geologic conditions.

Inadequate building and slope designs and the resulting construction failures suggest that planning capabilities are hampered by an incomplete understanding of the geologic environment. Municipal and county governments, critically in need of detailed urban geologic maps and information, have seldom established direct sources for geologic guidance, much less employ a staff geologist. Thus, the application of geology to planning and local affairs is often a do-it-yourself operation, with planners and local authorities not utilizing any geologic knowledge, or else trying to apply highly technical research-type geologic mapping to purposes for which it was never intended. Unfortunately, the present geologic maps, with very few exceptions, have been basic data-gathering efforts of a research nature. Emphasis has been primarily on the age and history of the various geologic units rather than on how the units would perform under a given land use. Some of the engineering properties of geologic units to various land use applications can be estimated in retrospect merely by becoming acquainted with the basic units; however, this is no substitute for remapping. The State of Washington has begun a more detailed environmental geologic mapping of the Puget Lowland. Until this remapping is completed, we must incorporate the existing data the best way we can into current planning. It is hoped that the accompanying tables will be of assistance in this effort.

The purpose of this report is to summarize in tabular form descriptions of the Quaternary sedimentary deposits that make up the Puget
Lowland, to discuss briefly some of the important geologic processes that affect the land, and to emphasize the significance of geology in land use planning. Specifically, this report has been prepared for use by land-planning individuals and agencies.

**EXPLANATION OF TERMS**

In order to better understand the context of this report, the following definition of terms is included:

**Alluvium**
Clay, silt, sand, gravel, or other material that has been transported by water and then left along stream channels, river banks, valleys, or other places.

**Aquiclude**
A body of underground rock that absorbs and transmits water very slowly. Springs usually result at the top of the aquiclude if it is located on a hillside.

**Aquifer**
A body of underground rock that absorbs and transmits water rapidly enough to supply significant quantities of water for wells and springs.

**Consolidated material**
Consolidation is the process whereby unconsolidated sediments become more firm, dense, and compact. Mud and sand and gravel are originally unconsolidated sediments. There are several ways in which consolidation can occur: natural processes include chemical, organic, or mechanical means, while manmade processes include pressure and mechanics.

**Deltaic deposit**
An alluvial deposit at the mouth of a river. Generally, the Pleistocene deltaic deposits of the Puget Lowland are composed of sand and gravel.

**Glacial maximum**
Position or time of greatest advance of a glacier.

**Glaciomarine**
Refers to the interaction of glaciers and ocean waters—glacial debris, marine organisms, and marine sediments are deposited together at the same time.

**Impermeable**
Capacity of material to resist penetration by water.

**Interstade**
A relatively short period of decreased glacial activity during a longer period of glaciation.

**Moraine**
An accumulation of glacial sediment that is deposited chiefly by direct glacial contact or action.

**Outwash material**
An accumulation of silt, sand, and gravel that is deposited by water from melting ice in front of glaciers.

**Permeable**
Capacity of rocks or sediments to allow water to enter or pass through.

**Pleistocene**
A period of time in the history of the earth usually referred to as the ice age. The time interval is approximately 10,000 years ago to 2½ million years ago.
FIGURE 1.—Location of Puget Lowland and major population centers in Washington.
Porous
A term which refers to the amount of open spaces in rocks or sediments that contain air and(or) water. Generally, unconsolidated sediments are more porous than consolidated sediments.

Quaternary
A period of time in the history of the earth that is considered to extend from the present to 2.5 million years ago. The Quaternary is subdivided into two times—Pleistocene and Recent.

Recent
The period of time in the history of the earth following the ice ages. It also roughly corresponds to the earliest recorded history of civilizations. It generally extends from the present time to approximately 10,000 years ago.

Richter magnitude (scale)
A measure of the strength of an earthquake or the energy released by an earthquake as determined by monitoring devices (seismographs). This scale was introduced by C. F. Richter in 1935 and is in use today.

Seismic
The rate or flow of energy through rocks or sediments. Usually pertaining to the earth vibrations resulting from an earthquake or vibrations artificially induced through explosions or other sound waves.

Stade
A relatively short period of increased glacial activity during a longer period of glaciation.

Stratigraphic unit
An assemblage of rocks or sediments that has been grouped into a unit for convenience in describing or mapping.

Topographic
The physical features of a region as shown on a map.

GEOLOGIC SETTING
The Puget Lowland is an elongate topographic depression bounded on the east by the Cascade Mountains and on the west by the Olympic Mountains and Vancouver Island. Approximately 10,000 to 2.5 million years ago glacial ice invaded the Puget Lowland at least four times, leaving a complex series of sediments up to 2,000 feet thick. As the continental ice moved southward from the north, it was split into two fronts by the Olympic Mountains; one front turned west into the Strait of Juan de Fuca and the other moved into the southern part of the Puget Lowland. At this stage the ice front spanned the lowland between the Olympic and Cascade Mountains, and formed a dam across the lowland. This dam impounded the drainage of all the rivers that flowed into the southern Puget Lowland and formed a large lake (fig. 2). The lake, which covered large parts of what are now Kitsap, King, Pierce, and Thurston Counties, was where the familiar "blue clays" of the Puget Lowland were deposited.

As each of the four or more successive ice sheets moved southward (fig. 3), water from the melting ice deposited thick layers
A glacial lake occupied the Puget Lowland to an elevation of about 200 feet above present sea level, draining out the Black River channel in Thurston County to the Chehalis River. The glacial Black River was comparable in size to the present Columbia River.

FIGURE 2.—Advance of the Cordilleran ice sheet.
At the time of the greatest extent of the glaciers, ice was about 5,000 feet thick at Bellingham, 3,500 feet thick at Seattle, and 2,000 feet thick at Tacoma. Direction of ice movement indicated by lines of medial moraines on the ice surface.

Marginal drainage from the Puget Lobe and the flanking Cascade Mountains flowed in the trough between the ice and the mountain front from lake to lake, gathering all the drainage southward to Mount Rainier into a stream near Eatonville about the size of the Columbia River at Grand Coulee Dam. The Columbia River has an average gradient of about 1 foot per mile; this stream had an average gradient of about 9 feet per mile.

FIGURE 3.—Maximum extent of the Cordilleran ice sheet.
FIGURE 4.—Simplified illustration of sedimentation during glaciation of the Puget Lowland.
of sediments known as outwash deposits in front of the glacier. The outwash material, generally composed of sand and gravel, is the rock debris that was washed out of the glacier as the ice melted. The outwash materials were later overridden by the glacier, which in turn deposited a concretelike material called "till" on top of the outwash. As the ice melted during glacial retreat, new layers of outwash material were deposited over the top of the "till" (fig. 4).

Interglacial periods in the Puget Lowland refer to times when the continental ice was completely absent from the lowland and the climate was much like that of today.

GEOLoGIC HAZARDS

The definition of a geologic hazard is a naturally occurring or manmade geologic condition or phenomenon that presents a risk or a potential danger to life and property (Gary and others, 1972, p. 292).

There are many types of geologic hazards that could affect a community or region. The greatest hazards are in areas of large population concentrations, not always because of the geologic setting but because of people. Without people there are no geologic hazards.

The types of geologic hazards that can be expected to occur with some regularity in the Puget Lowland are land subsidence or settlement, landslides, and seismic shocks from earthquakes.

LAND SUBSIDENCE AND SETTLEMENT

The most subtle and evasive geologic hazards are those related to the reaction a structural foundation undergoes when it is built on a compressible type of earth material. The damages caused by settlement often go unnoticed because of the slowness with which it occurs. This type of hazard is usually amplified by other geologic hazards such as the seismic shocks from earthquakes. Land subsidence in the Puget Lowland is usually related to differential settlement, which is the uneven gradual downward movement of different parts of an engineering structure due to compression of the soil below the foundation and often results in damage to the structure. Porous, permeable, unconsolidated sediments such as lake deposited silt and peat may be compressed when subjected to loading. In the Puget Lowland, alluvial and lake deposits, especially peat bogs, are the most subject to differential settlement.

LANDSLIDES

The process of landsliding is essentially a continuous series of events from cause to effect. Landslides usually take place under the influence of geologic, topographic, and climatic conditions that are common to the Puget Lowland. These factors or causes must be understood if slides are to be avoided, controlled, or prevented.

A phenomenon known as liquefaction—
the temporary transformation of material into a fluid mass—may occur when porous alluvial type sediments, containing a high percentage of water, are subjected to strong vibrations or seismic shocks. When liquefied, the sediment flows in a fluidlike manner. The liquefaction can be initiated by an earthquake shock or by vibrations from moving heavy machinery and equipment.

Landslides occur when the pull of gravity on earth materials on a slope overcomes their frictional resistance to downslope movement. The diversity of factors that affect slope stability are briefly described as follows:

1. **Type of earth materials**—surficial deposits or unconsolidated, soft sediments will move downslope easier than consolidated or partly consolidated sediments.

2. **Ground shaking**—strong shaking during earthquakes, from large-scale explosions, or vibrations of heavy machinery can jar and loosen surface materials and consolidated or unconsolidated sediments, thus making them less stable.

3. **Water**—landsliding is generally more frequent in areas of seasonally high rainfall because the addition of water to earth materials commonly decreases their resistance to sliding.

4. **Steepness of slopes**—new landslides occur more readily on steeper slopes; however, low natural slopes may also be indicative of existing landslides.

5. **Proximity to areas undergoing active erosion**—rapid undercutting and downcutting along stream courses and shorelines makes slopes in these areas particularly susceptible to landsliding.

6. **Type of vegetation**—trees with deep penetrating roots tend to maintain the stability of slopes by mechanical effects and contribute to the drying of slopes by absorbing part of the ground water.

All the natural factors that promote landsliding are present in the Puget Lowland. In addition, man has increased the potential for slope failures by increasing slope angles through road construction and site preparation for building construction; adding water to marginally stable slopes by watering lawns, improperly handling rainwater runoff and choosing poor sites for septic tank drainfields; adding to the weight of stable and marginally stable slopes by building structures as well as by adding fill for foundations; and removing the natural vegetation, especially by deforestation.

A definite correlation has been established between time and place of major landslides and a combination of climatic and geologic conditions. Nearly all landslides can be related to periods of intense precipitation, during a general period of inferred high ground-water table. Future episodes of widespread landsliding might be expected during the late-winter period of high ground-water table if a daily rainfall of about 1.5 inches or more occurs. The major landslides generally have occurred at or near the contact between an overlying permeable stratigraphic unit, such as sand or gravel, and an underlying impermeable unit, such as till or clay, and at or near the con-
EXPLANATION

M > 6 (FROM INTENSITY)

M > 6 (RECORDED)

M 5-6 (FROM INTENSITY)

FIGURE 5.—Location of epicenters and magnitudes of strong-motion earthquakes in southern Puget Lowland area since 1870.
CRITICAL RESOURCES AND LAND USE PLANNING

tact between glacial and nonglacial sediments.

EARTHQUAKES

Over 900 earthquakes have occurred in Washington between 1840 and 1972. The largest earthquake (Richter magnitude 7.1), as well as most of the damaging ones, has been in the Puget Lowland area (fig. 5). An analysis of the seismic history of the area shows that small magnitude earthquakes occur regularly, and that moderately intense shocks, capable of producing severe damage to poorly designed or poorly constructed engineering works near the center of the effected area, are frequent. Large magnitude events are characterized by widespread intense shaking, involving much of the Puget Lowland area. Apparently, none of the quakes during historic times have been accompanied by ground breakage at the surface; however, it must be pointed out that the location of faults within the Puget Lowland are poorly known.

If the historic record persists in the future, buildings, structures, and property in the Puget Lowland are potentially susceptible to damage during earthquakes from ground shaking but not from surficial fault rupture. Most of the older glacial deposits in the Puget Lowland have been compacted by the weight of an ice sheet, 3,000 feet or more thick, and are reasonably good foundation material during an earthquake. Locally, environmental conditions and the nature of the earth material may create a potential for slides. Potential for damage from ground shaking is highest in areas of artificial fill, areas underlain by peat, existing landslides, and on valley floors underlain by unconsolidated alluvial sediments.

The estimated recurrence intervals of seismic events for the Puget Lowland Region are listed below (from University of Washington, The Nisqually Delta, 1970):

<table>
<thead>
<tr>
<th>Richter Magnitude</th>
<th>Recurrence Intervals (years)</th>
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<tbody>
<tr>
<td>3.5 - 4.0</td>
<td>0.25 - 0.5</td>
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<tr>
<td>4.1 - 4.5</td>
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<td>4.6 - 5.0</td>
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<tr>
<td>5.6 - 6.0</td>
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<td>6.1 - 6.5</td>
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<td>60 - 150</td>
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<tr>
<td>7.1+</td>
<td>150+</td>
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</table>

CRITICAL RESOURCES AND LAND USE PLANNING

The most valuable mineral commodity produced and consumed in the Puget Lowland is the material used for construction such as sand and gravel. The principal, and also the largest, source of sand and gravel is the Vashon Recessional deposits, especially the Vashon deltaic deposits. The Vashon Recessional deposits are the single most important mineral revenue source in the Puget Lowland.
In the Puget Lowland only 3 percent of the land is considered to be "prime" agricultural land, although other land is under cultivation. Of the total prime agricultural land, approximately 60 percent is under cultivation, 5 percent has been urbanized, and the balance is used for pasture. The principal use of the cultivated lands, which are situated almost entirely on river valley alluvium, is for the production of specialty truck crops. Hay and grain are also produced on the cultivated land in support of beef production and dairying, which are the major uses of the pastures.

These lands and their products are critical resources that are vital to the growing and sustaining needs of an urbanized area. Careful planning can result in wise land use and conservation of our mineral and land resources. The diverse uses of land for agriculture, recreation, residential or industrial urban development, and mining can be integrated with enough foresight and determination to serve everyone's purposes.

HOW TO USE THE TABLE

At the back of this report is a list of geologic investigations "related to" the Puget Lowland. Reports that contain geologic maps are numbered, and indicate either in the title of the report or at the end of each reference, the county where the work was done. The most complete and most recent series of works are the Water Supply bulletins published by the Washington Division of Water Resources and available from the Washington State Department of Ecology. Many of the works listed are no longer in print but are available from the larger public libraries and are on file for use in the library of the Division of Mines and Geology.

The Correlation Chart, Plate 1, is a convenient reference table, necessary to distinguish subtle relationships both within and between various stratigraphic units throughout the Puget Lowland. The purpose of the Correlation Chart is to show the approximate age and stratigraphic position of the geologic deposits for a specific county in relation to other counties in the Puget Lowland.

The chart has been divided into columns by counties (Thurston, Mason, Pierce, Kitsap, King, Snohomish, Island, and Whatcom) and regions (Southern Puget Lowland and Northern Puget Lowland). The chart has also been divided into an approximate south-north direction; the columns for the more southerly counties being located to the left on the chart, and the columns for the more northerly counties being located to the right on the chart.

Each column is set up with younger deposits listed toward the top of the column and older deposits listed toward the bottom of the column. For instance, in the Mason County column, "Alluvium" is listed at the top of the column and is therefore the youngest deposit, while "Salmon Springs Drift" is at the bottom of the column and is the oldest deposit. The names for the deposits are separated by either horizontal
and (or) slanted lines. The slanted lines are meant to indicate some question or doubt as to the age and stratigraphic position of the deposit, usually indicating that the materials above and below the slanted line were being deposited at or about the same time. The relationship of deposits between counties can be determined by selecting the name of a deposit in the column for a certain county, tracing horizontally to the column for another county and reading the name of that deposit. For instance, trace down the Thurston County column to the "Kitsap Formation," then trace horizontally to Whatcom County and to "Cherry Point Clay." The name "Kitsap Formation" corresponds to the name "Cherry Point Clay," or in other words the "Kitsap Formation" of Thurston County and the "Cherry Point Clay" of Whatcom County were deposited at about the same time.

Plate 2 is a compilation of general engineering properties of Quaternary geologic units within the Puget Lowland and was prepared as a guide for land use planning purposes. A geologic map can be obtained for a specific county or area by referring to the list of geologic investigations at the back of this report. The general engineering properties of the table can then be applied to the units used on the geologic map.

As an example, use the map (Plate 1) from "Geology and related groundwater occurrence, southeastern Mason County, Washington," by Molenaar and Noble (1970). The areas noted on the map by the symbol Qk are identified in the map explanation as Kitsap Formation. Use Plate 2 of this paper and trace down the second column, which is identified as Rock Stratigraphic Unit, to Kitsap Formation. The physical and engineering properties listed in the row to the right of the Kitsap Formation can then be applied to those areas noted as Qk on the map. For instance, under the Ground Water column the listing is "Poor permeability, except for a few gravel layers; serves as an aquiclude to underlying confined ground water along shoreline areas. Ground water seeps common." Under the Slope Stability column, the listing is "Variable, but generally unstable on slopes steeper than 26°. Dependent on local conditions of slope, drainage and ground water." The areas noted on the map by the symbol Qal are identified in the map explanation as Alluvium. Trace down the second column to Alluvium and apply the properties listed in the row to the right of Alluvium to those areas noted as Qal on the map. For instance, under the Seismic Stability column the listing is "Very poor. Maximum destruction during April 1949 earthquake occurred on alluvium and artificial fill." Under the Planning Significance—Major Uses column the listing is "Critical resource—prime agricultural land; fill, topsoil for lawns and gardens." Areas on the map noted as Qal such as Skokomish Valley, Egypt Valley, Shelton Valley, Isabella Valley, and Kamilche Valley are prime agricultural land and therefore critical resources. These areas would also potentially be most subject to severe damage.
during intense shaking from an earthquake.

**LIMITATIONS**

The use of the table in evaluation of geologic conditions is limited by the state of the art, available information in literature, and practical field investigations. The conclusions, data, and opinions made in this report are based on the presently available information and are made for land use planning purposes only. This report is not intended to be, nor should it be used as an engineering geology report for any given site. In all cases, a detailed engineering and geology report is recommended for individual site evaluations and investigations. Field work for this report has been limited to visual inspections, no laboratory testing or subsurface exploration has been made.
FIGURE 6.—Index of geologic mapping in the Puget Lowland for use with this report. Numbers on map correspond to those in Selected References.
**SELECTED REFERENCES**


* Numbers opposite bibliographic entries correspond to numbers on Figure 6.
1. Liesch, B. A.; and others, 1963, Geology and ground-water resources of northwestern King County, Washington: Washington Division of Water Resources Water Supply Bulletin 20, 241 p. Plate 1

Liesingon, V. E., Jr., 1971, Geology and mineral resources of King County, Washington: Washington Division of Mines and Geology Bulletin 63, 200 p.


3. Molenaar, Dee, 1965, Geology and ground-water resources. In Water resources and geology of the Kitsap Peninsula and certain adjacent islands: Washington Division of Water Resources Water Supply Bulletin 18, p. 24-50. Plate 1, 2 sheets. [Kitsap County and parts of Mason, Pierce and King Counties]


Mullineaux, D. R., no date, Northeast quarter of the Tacoma quadrangle: U.S. Geological Survey unpublished map. [Pierce County]


Waldron, H. H.; and others, 1962, Preliminary geologic map of Seattle and vicinity: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-354. [King County]


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<th>GEOLOGIC</th>
<th>THURSTON COUNTY</th>
<th>MASON COUNTY</th>
<th>PIERCE COUNTY</th>
<th>SOUTHERN PUGET LOWLAND</th>
<th>SOUTHWESTERN KING COUNTY</th>
<th>KING COUNTY</th>
<th>NORTHWESTERN KING COUNTY</th>
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See text for list of selected references.
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<thead>
<tr>
<th>Plate 2: Generalized Description of Properties of Quaternary Geologic Units (Puget Lowland)</th>
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<td><strong>Plutonic Basement</strong></td>
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<td><strong>Gneiss</strong></td>
</tr>
<tr>
<td><strong>Metamorphic Rocks</strong></td>
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</tbody>
</table>

**Physical Properties**
- **Infiltration**: Generally slow to very slow.
- **Drainage**: Generally moderate to good drainage.
- **Vegetation**: Generally moderate to good vegetation.
- **Soil Types**: Generally good, except where natural vegetation is absent or disturbed.

**Obstructional Features**
- **Glacial Materials**: Present in many areas.
- **Sedimentary Rocks**: Present in many areas.
- **Volcanic Rocks**: Present in many areas.

**Hydrologic Properties**
- **Water Table**: Generally low, except where natural vegetation is absent or disturbed.
- **Aquifers**: Present in many areas.
- **Permeability**: Generally moderate to good.

**Seismic Properties**
- **Seismicity**: Generally moderate to good.

**Erosional Features**
- **Coastal Features**: Present in many areas.
- **Lacustrine Features**: Present in many areas.
- **Fluvial Features**: Present in many areas.

**Groundwater Properties**
- **Groundwater Flow**: Generally moderate to good.
- **Groundwater Quality**: Generally good.

**Soil Characteristics**
- **Soil Types**: Generally good, except where natural vegetation is absent or disturbed.

**Material:**
- **Clay**: Present in many areas.
- **Silt**: Present in many areas.
- **Sand**: Present in many areas.

**Structure:**
- **Faults**: Present in many areas.
- **Folds**: Present in many areas.

**Vegetation:**
- **Forested Areas**: Present in many areas.
- **Grasslands**: Present in many areas.
- **Shrublands**: Present in many areas.

**Hydrology:**
- **Streams**: Present in many areas.
- **Ponds**: Present in many areas.

**Topography:**
- **Ravines**: Present in many areas.
- **Gullies**: Present in many areas.

**Sedimentology:**
- **Sedimentary Deposits**: Present in many areas.
- **Glacial Deposits**: Present in many areas.

**Engineering Properties:**
- **Stability**: Generally moderate to good.
- **Permeability**: Generally moderate to good.
- **Drainage**: Generally moderate to good.

**Environmental Properties:**
- **Biodiversity**: Generally moderate to good.
- **Aesthetic Value**: Generally moderate to good.

**Societal Properties:**
- **Land Use**: Generally moderate to good.
- **Recreational Value**: Generally moderate to good.

**Economic Properties:**
- **Agricultural Potential**: Generally moderate to good.
- **Mineral Resources**: Generally moderate to good.

**Cultural Properties:**
- **Historic Sites**: Present in many areas.
- **Archaeological Sites**: Present in many areas.

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**Legend:**
- **Symbol Key**: Present in many areas.
- **Color Coding**: Present in many areas.
- **Data Source**: Present in many areas.