Forest

Slope Stability Project

Phase I

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FOREST

SLOPE STABILITY PROJECT

PHASE 1

for
Washington State
Department of Ecology

by

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DOE 80 - 2a

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ABSTRACT

Phase I of the DOE Slope Stability Project focused on a regional evaluation of slope stability in the nonfederal forest land in western Washington State and identification of representative watersheds that would be studied in more detail during Phase II. High altitude (1:63,000 scale black and white) airphotos were analyzed and mass wasting features were identified and plotted on 1:250,000 scale maps. General zones of instability are indicated on the seven regional maps by areas of concentrated landslide incidence.

Two basic types of landslides were identified throughout western Washington. These are shallow, rapid debris avalanches and torrents, and deep-seated slump-earthflows. The factors and processes causing these types of failures may or may not be related. The rapid shallow mass movements most commonly occur in areas of steep topography and thin soils, where the slump-earthflows occur most commonly in areas of deeper soils or where rock composition or structure (i.e. bedding planes, lithologic contacts, differential weathering rates, and mineralogy) provide environments for deep-seated mass wasting.

During Phase I we found that developing a regional slope stability map that provided a stability rating and delineated unstable slopes was not within the scope of existing data. The critical geologic and soils data was either too generalized or nonexistent to provide specific limits and boundaries for stability rating or delineation. We therefore chose to just display the landslides we identified from the airphotos and gleaned from other sources on the 1:250,000 scale maps. There are, however, obvious "zones" or areas where high concentrations of mass wasting events occur. These zones helped us zero in on drainages for the Phase II study. We also used size, access, existence of background data, and regional similarity as the other criteria for our drainage choices.

We chose the Middle Fork of the Nooksack River to represent the North Cascade region, the North Fork of the Toutle River to represent the Southern Cascades, the Clearwater River for the Olympic Peninsula region, and the Grays River to represent the Willapa Hills area. We also felt that a significant area of the "Middle" Cascades was not being represented by the Nooksack or Toutle drainages, so we chose the Green River drainage to represent the North-South Cascade region interface.

Another product of the Phase I study period is the formation of an advisory group of professionals to criticize and guide the study team during Phase II. The group is comprised of individuals from private, state, and federal agencies and has a good background in geology, soils, geomorphology, and forestry.

INTRODUCTION

In steep forested areas of western Washington, there is potential for water quality degradation resulting from mass wasting caused by forest practices. To assist forest managers and resource planners, the Department of Natural Resources (DNR) is conducting a study to evaluate slope stability on nonfederal forested terrain in western Washington, develop information for identification of critical watersheds which exhibit a greater than average susceptibility to stream sedimentation due to mass wasting, and map slope stability in critical watersheds which are representative of geologic, geographic, and climatic conditions in the project area. The project is funded through the Washington State Department of Ecology and is referred to as the DOE Slope Stability Project.

This work was actually begun in the Fall of 1978, when the division, under a separate contract with DOE, conducted a pilot study of the slope stability of the upper Deschutes River basin. Among the recommendations of this pilot study was that important timber harvest areas of the state with similar slope stability characteristics be identified and individual basins representative of these areas be selected for detailed study.

This Slope Stability Project is being conducted in two phases. Phase I (September 1, 1979 through January 31, 1980) is a general analysis of forest slope stability on a regional basis, and Phase II (February 1, 1980 through December 31, 1980) will analyze slope stability for specific drainages in differing areas of western Washington. This is a final report of the findings for Phase I.

The general objective for Phase I was to set the stage for detailed analysis of specific drainages during Phase II of the study. Phase I consisted of mapping of landslides from 1:63,000 air photos, trying to determine possible relationships between mass wasting and the physical environment, and identifying areas of concentrated mass wasting. Also during Phase I, an interdisciplinary group of professionals was organized to provide constructive criticism throughout the project.

For Phase I, seven base map sheets were developed from AMS 1^{o} by 2^{o} 1:250,000 scale topographic quadrangles. All of the 44,000 square kilometer study area is covered by these sheets. Figure 1 indicates the distribution of the lands covered by this study and the base sheets developed to cover western Washington. Federal lands and Indian reservations are excluded, except where checkerboard or small areas of federal ownership are surrounded by private or state lands.

Shown on these maps are various types of landslides that were identified from airphoto analysis. We attempted to create a stability map of western Washington but found specific and regional data lacking for determining potential stability. The accompanying seven maps, however, do give a general feeling of relative stability or numbers of mass wasting events throughout western Washington.

Included in the Phase I tasks was the formation of an advisory group for this study. The advisory group consists of individuals from federal, state, and private agencies that have interest in forest slope problems. The members of the advisory committee are Jerry Thorsen, Ken Solt, Stan Duncan, Wes Jennings, and Tom Dunne.

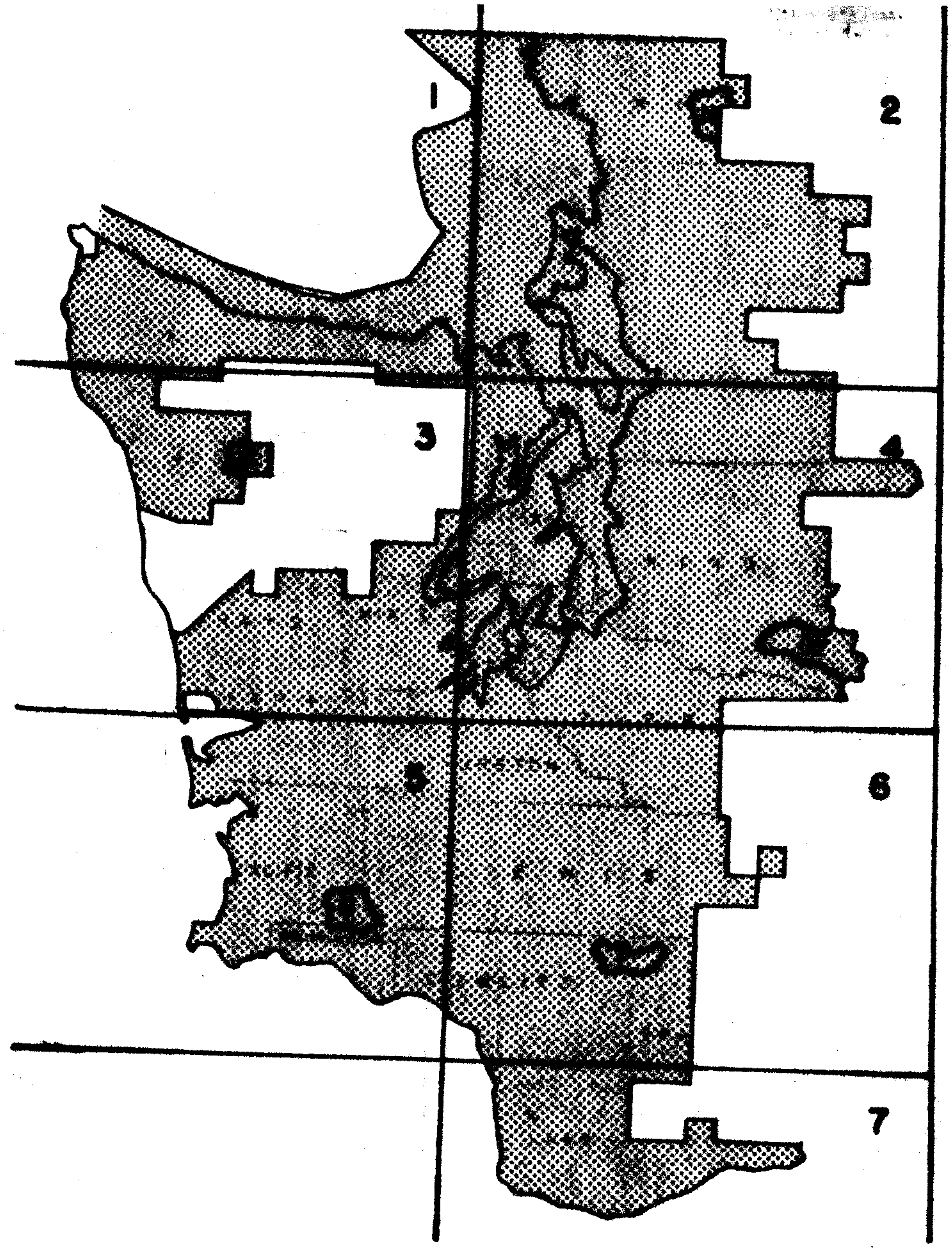

Figure 1. Index Map

Phase I study area.

3 Landslide Maps - Sheets numbered from 1 - 7.

Proposed Phase II study basins.

N - Middle Fork Nooksack R.

Gr- Green River

T - North Fork Toutle River

G - Grays River

C - Clearwater River

Jerry Thorsen is a geologist with the Department of Natural Resources and is a coauthor of the DOE Slope Stability Pilot Project; Ken Solt is a forester and administrator for DNR in charge of the Forest Practice Act; Stan Duncan is a geologist with the Weyerhaeuser Company and has been working on forest slope stability; Wes Jennings is a forester with the U.S. Forest Service and had worked in cooperation with DNR on the Forest Land Grading program mapping soils in southwest Washington; and Tom Dunne is a professor at the University of Washington and is an authority on hydrology and geomorphology. The advisory group will help to guide and serve as resource personnel for the field team during Phase II.

PROCEDURES

Two objectives for Phase I were to: 1) evaluate slope stability on a regional basis, and 2) select river basins that exhibit a greater than average susceptibility to mass wasting and are representative of the different physiographic regions of western Washington. Western Washington is divided into five physiographic regions because of similarities in geology, soils, topography, and geologic history, each having specific physical characteristics common throughout that region. These five physiographic regions are the North Cascades, South Cascades, Olympic Peninsula, Willapa Hills, and the Puget Lowland (Figure 2). All of these regions except the Puget Lowland have zones where mass wasting on forest lands is common. Because the Puget Lowland is relatively flat (compared to the mountainous terrain of the other regions) and mass wasting problems predominantly occur along the Puget Sound shoreline, we did not consider it in our stability analysis.

To evaluate slope stability on a regional basis and choose drainages for our Phase II study we had to delineate unstable areas. Our first task was to analyze existing data. Several landslide and slope stability maps are available for different areas of western Washington. The Division of Geology has been most active in this type of mapping and have landslides and slope stability maps for the Longview-Kelso Urban area (Fiksdal, 1973), Thurston County (Artim, 1976), Gig Harbor Peninsula (Smith, 1976), Chehalis-Centralia (Fiksdal, 1978), Hood Canal (Carson, 1975), Clark County (Fiksdal, 1975), and Puget Sound Shorelines (DOE, 1978-79), and throughout western Washington (Thorsen, personal communication). In Seattle, Tubbs (1974) and existing geologic maps all contributed to our mapping of landslides. However, most of the slope stability mapping is around population centers and not in forest lands.

We filled this data gap by mapping landslides from 1:63,000 scale airphotos covering the entire 44,000 square kilometers of western Washington.

Air Photos

Most of the work of Phase I involved the identification of mass movement features on high-altitude airphotos. We used photos taken under DNR contracts between 1966 and 1976 at a scale of 1:63,000 (see Figure 3 for map of photo coverage and dates). The scale of these photos allowed a compromise between the amount of detail observable and the ability to cover a large area (approximately 44,000 square kilometers) in a few months.

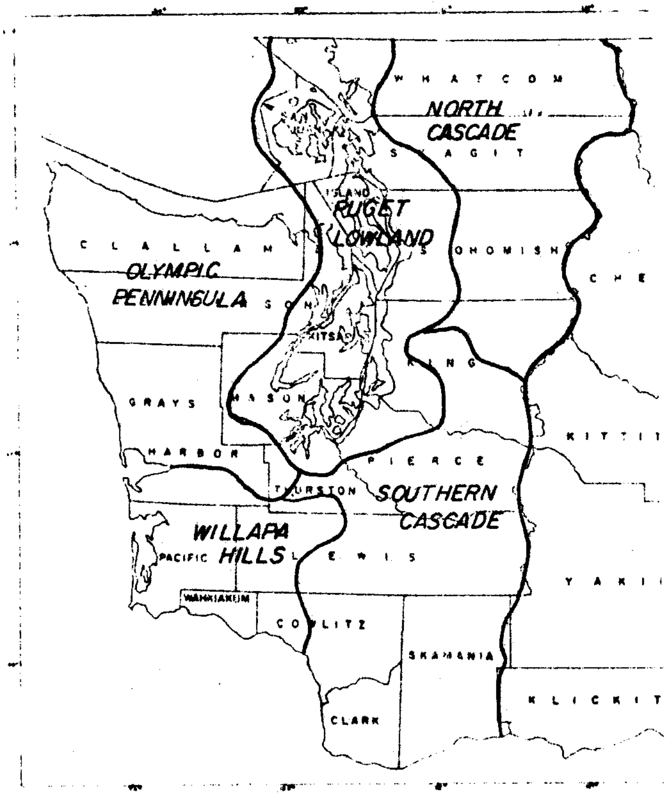

Figure 2. Regions of Western Washington

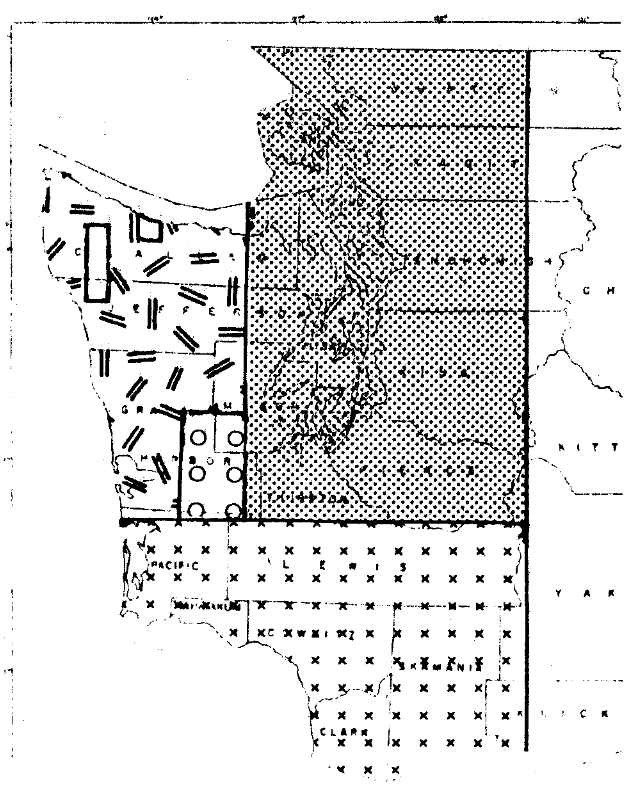

Figure 3. Air Photo Coverage*

Symbol	Year
SW-H-76	1976
NW-H-74	1974
OL-H-73	1973
NW-H-71	1971
WFPA-66	1966

*All photos approximately 1:63,000 scale

On these photos, we looked for evidence of several types of mass movement: large landslides and flow topography, slumps, debris avalanches and debris torrents. We concentrated on private and state forest lands, and skimmed over or ignored urban areas, national forests (except areas of checkerboard ownership), and national parks.

Mass movement features were traced directly onto mylar photo overlays and were then transferred onto topographic base maps (scale 1:250,000). Features larger than 0.5 square kilometers were mapped and smaller features were located with a letter indicating the type of feature.

Two types of mass movement features were generally not mapped:

1. Failures (mostly slumps) are almost ubiquitous along stream terrace scarps and actively incising streams, so only the largest and most obvious examples are indicated on the maps.

2. Snow avalanche chutes in the subalpine zones of the Cascades and Olympics were not mapped because they are not indicators of the instability of earth materials, and are usually located in areas less suitable for logging.

Existing surficial geologic maps aided in the identification only of large landslides (no debris avalanches or torrents were mapped in most of these studies). Also, early in the airphoto analysis we visited Whatcom County to compare the mapping with features that could be seen on the ground.

Several problems and biases in the mapping should be mentioned. First, accuracy is affected by several factors, such as the size of the features, their age (debris avalanches and debris flows usually become unrecognizable after three to five years, for example), and vegetation cover. Second, it is sometimes hard to distinguish one type of feature from another (e.g. slumps vs. avalanches on coastlines, where the debris is removed), or mass movement features from manmade features (such as mine tailings or gravel borrow cuts). Third, though efforts were made to promote consistency, there might be some differences in the mapping done by Fiksdal in the west and Brunengo in the east.

Landslide Maps

Mass movement features were mapped on seven topographic base maps of the U.S. Geological Survey Western U.S. 1:250,000 series. Each is 1^{o} latitude by 2^{o} longitude wide.

The mapped units are described below. For further reference, see Swanston and Swanson (1976), and Rickert and others (1978).

1) Landslide (LS): Features larger than approximately 0.5 square kilometers are mapped with solid contacts and an arrow or arrows indicating the directions of predominant movement. Most of these features are large slump-earthflow failures

in which failure has occurred along surfaces deep in the ground, and regolith and in many cases bedrock have moved out and then flowed down the slope. Some of the landslides, however, are large areas with many contiguous debris avalanches, such as along coasts and incising streams.

Landslides were identified on the airphotos by several characteristics. They usually possessed hummocky topography in a large depression, and have definable headscarps and debris deposition areas. Other identifying features include large arcuate or spoon-shaped depressions, truncated ridges and spurs, and discontinuities in structural trends. Because of their large sizes, identification of these features is relatively accurate; only very old failures and small ones in subdued, flow-formed topography were difficult to locate.

Large landslides are generally little influenced by management activities such as logging and roading. Most of them are deep-seated failures and many are very old (early post-glacial?), and so the geologic structure and processes of stream incision are much more important than what is happening in the top few meters of the ground. However, these slides can still be important contributors of sediment to streams. Most are near rivers and if active or reactivated, they could shed debris into those streams. Even if not active, the material in the slides is highly broken and weathered, and susceptible to small-scale slumping and debris avalanche, which can affect stream quality.

2) <u>Slump-earthflows (E)</u>: Mass movements involving slump (movement downward and outward, combined with backward rotation along an arcuate failure surface) and earthflow (slow flowage of broken slump debris downslope) that are smaller than 0.5 square kilometers are located by an E. These features are deep-seated compared to debris avalanches and may involve bedrock (usually volcanic or sedimentary) or deep unconsolidated sediments as well as soil.

Slump-earthflow features were identified on the photos by spoon-shaped depressions, arcuate headwall scarps (often with bare ground), and hummocky topography in the depositional (earthflow) area. Identification of these smaller features is harder than for the landslides; in many places the slumps have been covered by vegetation, or the vegetation has been maintained during slow movement, so if the light or camera angle was wrong, the failure might go unrecognized. Because of this, there is probably a slight bias in the mapped distribution of slump-earthflows toward open areas.

The contribution of slump-earthflows to stream sedimentation varies with their size, proximity to streams, and degree of activity. As with larger landslides, fractured and weathered debris is subject to reactivation by nature or management activities (slope undercutting or loading, drainage changes) and debris so mobilized could cause degradation if it gets into a channel.

3) <u>Flow topography (F)</u>: Some areas exhibit the irregular, hummocky topography of earthflow terrain, but without any obvious headscarps or other indications of recent slumping from a definite source area. These zones have been mapped with a dashed line if greater than 0.5 square kilometers, or located with an F if smaller.

Most flow topography is located in the Willapa Hills and adjacent southern Cascades, where it probably represents old slump-earthflow failures in highly weathered sedimentary and volcanic rocks. Some is in glacial-margin and proglacial lake deposits surrounding the Puget Lowland, where these sediments are collapsing irregularly. In both cases, location and delineation of flow topography are judgmental. Nevertheless, we believe that such terrain is caused by mass movement (though perhaps very long ago), and should be indicated on the maps. Like landslides and slumps, the materials involved are subject to secondary failure that could cause sedimentation of streams.

4) Debris avalanches (A): Debris avalanches occur when a thin layer of soil, weathered material, or fill fails, and then slides, flows, or falls rapidly downslope. This type of mass movement commonly takes place on steep slopes, often in depressions where concentrations of subsurface water cause reduction of shear strength. The failure surface is usually a well-defined interface between weathered regolith and relatively unweathered material, such as bedrock or till. Road fill is also subject to failure by avalanche.

On the airphotos, debris avalanches are identified by narrow streaks of light color where soil and vegetation have been stripped away; they begin at V-shaped headwalls (as opposed to the U-shaped headscarps of slumps). There usually is little local debris accumulation. If the debris becomes channelized and mixed with water, they become debris torrents (see below).

Because debris avalanches are shallow failures, they are strongly affected by management activities which remove support by undercutting (as in road cuts), by destroying root strength (by logging),or by altering soil moisture content and movement (by logging, compaction, disruption of drainage). Thus, debris avalanches and the often-resultant debris torrents are the types of mass movement most susceptible to aggravation by road building and logging. Therefore, the mapped distribution of debris avalanches is biased towards roaded and logged areas, because of this causal relationship as well as better exposure in clearcut areas.

On the other hand, debris avalanche scars heal over within a few years. Therefore, the mapped avalanches are those which have occurred within about three to five years before the time any photo was taken.

Debris avalanches and torrents are the most significant contributors of sediment to streams on forest lands. Avalanches occur on steep slopes, and generally deposit debris directly into first- and second-order stream channels. Therefore, great care must be taken to evaluate the potential for these types of mass movements when planning forest management activities.

5) Debris torrents(D): When debris from a slump or avalanche reaches a stream, it can mix with the water to become a thick slurry which flows down the channel. This fast-moving slurry or debris torrent usually scours the channel to bedrock; when it finally stops (usually where it flows into a larger stream with a lower gradient) it can deposit a mass of rock, soil, and organic debris several orders of magnitude greater than the volume of the initial failure.

Debris torrents are identified on airphotos by the light color of the channels, where alluvium and vegetation have been stripped away and bedrock exposed. Often the initiating debris avalanche is identifiable; if so, it too has been mapped. Sometimes it was difficult to differentiate between a long avalanche and a short torrent on the photos; if the failure was mostly in a drainageway or channel, it was mapped as a torrent.

As with debris avalanches, the distribution of debris torrents is biased toward the logged areas because roading and logging increase this kind of mass movement activity. Also, the mapped torrents are mainly a three- to five-year sample; most channels are subject to this kind of mass movement at varying intervals as part of the natural processes of erosion, but the scars heal within a few years.

When they occur, debris torrents destroy stream quality in the affected reaches. Vegetation and sediment are scoured from channels, leaving little food or hiding or spawning areas for invertebrates and fish. Deposition of debris often dams the stream, prohibiting fish passage, and reworking of the debris deposits by water can affect the channel downstream.

SLOPE STABILITY CLASSIFICATION

We attempted to generate a slope stability map for western Washington from the landslide distribution data. At first, we wanted to incorporate precipitation, soils, and geologic information into the classification system. For precipitation, we chose maps of mean annual rainfall, 2-year 24-hour storm intensity (Miller and others, 1973) and the ratio of these as indices. Unfortunately, these isohyetal and isopluvial contour maps are prepared by extrapolation, the extrapolation being controlled by elevation; therefore, the maps mixed the effects of climate, elevation, relief, and slope. Thus, the precipitation comparison was unusable at this scale. And, though we recognize the importance of surficial earth materials ("soil" in the engineering sense of the term, or regolith to the geologist) to mass movement occurrence, soils maps were not available or adequate in scope to be incorporated into this phase of the project.

Therefore, we were left with geologic factors as the only large-scale, easily defined and mappable characteristics that relate to mass movement. We prepared overlays for the landslide maps of geologic units, drawn from various geologic maps. However, the correlation between mapped geologic units and failure distribution was irregular at best.

In any case, we assigned a rating number (one to five) to each mapped geologic unit, based on the number of failures in the unit, plus our judgment of the susceptibility of the unit to failure (based on published descriptions and our own experience). Very stable units (such as hard coherent rock) received a rating of one or two; materials highly susceptible to failure (such as glacial lake sediments) received a rating of four to five.

However, we realized that rock types alone could not even account for all of the geologic factors involved in mass movement. So, we assigned each of our regions a number (one to three) based on our judgment of the effects recent geologic/geomorphic history have had upon mass movement. The Willapa Hills received a rating of three on account of the long exposure, deep weathering, and dense distribution of failures. The Puget Lowland was rated a one, due to its low relief, and the Cascades and Olympic provinces received intermediate values.

The lithologic ratings and the geomorphic history ratings were then added, and the sums (potentially two to eight) were then to be mapped as slope stability rating factors. Since slope gradient is also a critical factor in mass movement, but is not mappable at this scale, we incorporated the slope factor in the application of the regional map to specific sites. A matrix of slope gradient classes (0-12%, 12-20%, 20-60%, $>$60%) and stability rating factors would give any site a final stability rating of low, average, high, or very high susceptibility.

We abandoned this attempt at classification (at least at this stage) for several reasons. First, the basic data were flawed: some of the geologic maps were of poor quality, and based on time-stratigraphic rather than lithologic classification, and there is only fair to poor correlation between mass movement features and mapped geologic units. Second, the classification ignored or downplayed factors that are very important to mass movement susceptibility, but which could not be handled at this scale: slope gradient, surficial materials, precipitation, and rock structure (interbedding and attitude of beds). In combination, these characteristics are probably more critical than lithology to mass movement activity.

Third, and most important, we realized that any regional slope stability classification such as this should be generated inductively from information on the mechanics of movement under various combinations of rock type, soil, precipitation, structure, etc., rather than being deduced from one or two regional characteristics. We hope that this regional generalization can be done after the intensive study of representative drainage basins to be undertaken in Phase II.

REGIONAL DISCUSSIONS

The following is a discussion of mass wasting in each western Washington physiographic region. A discussion of geology, geologic history, and precipitation can be found in the Appendix.

North Cascades - There are some patterns to the distribution of mass movement features in the North Cascades. Many of the large landslides are in Chuckanut sandstone and shale (Slide Mountain, Sumas Mountain, and Chuckanut Mountain in Whatcom County), probably where the bedding is dipping out of the hillslopes. Large slumps have also occurred in older carbonate rocks (Black Mountain, Whatcom County), phyllites and greenschists (Goat Mountain and Cultus Mountain, Skagit County), and in glacial-marginal or proglacial lake terraces along the Nooksack, Skagit, Stillaguamish, and Snoqualmie Rivers. Three large landslides are located in an area of mixed rock types (faulted together?) along the Middle Fork of the Nooksack. A few big slides are failures in granitic rocks (Skykomish River) and young pyroclastic deposits (near Concrete).

The rock types most susceptible to debris avalanche and debris torrent are the Chuckanut sandstones (e.g. in the Clearwater Creek drainage, west of Mt. Baker, and in the Sultan basin), the phyllites, the Mt. Baker pyroclastics, and early Tertiary volcanic rocks in the Skykomish and Snoqualmie basins. Due to the steep slopes and glacial tills in this province, though, debris avalanches can occur on practically any rock type, depending on the surficial materials.

Southern Cascades - Landslide activity in the Southern Cascades is only partly related to rock types, and is more often related to rock structure. Volcanic rocks are by far the most susceptible to slumping, but some areas are more susceptible than others, even of the same mapped formation. In general, units with a greater proportion of volcaniclastics, such as tuffs and breccias, are the most unstable. A related factor is the amount of interbedding of dense, hard flow rocks (andesites and basalts) with softer volcaniclastics (which often weather to weak clay-rich layers). When such interbedded layers dip out of the hillslope, failure is likely to occur.

Such a combination is known to be responsible for the large slides along the Columbia River in Skamania and Wahkiakum Counties, and is probably also a contributing cause to the concentrations of landslides along the south side of the White and Greenwater Rivers, north of the Nisqually River, south of the Cowlitz River, and in the foothills in Cowlitz County. The dense concentration of slumps in the Skookumchuck and Deschutes basins are in interbedded flows and pyroclastics as well.

Unconsolidated sediments are also subject to slump failure in this region. Continental glacial and glacial margin deposits at the mountain front are collapsing in the Puyallup and Nisqually valleys, and fluvial and outwash sediments commonly fail in terrace scarps along the Cowlitz River and near Chehalis.

Debris avalanches and torrents occur wherever there are steep slopes, and we noticed little correlation with lithology in this region. Concentrations of debris failures are located in volcanic and volcaniclastic rocks along the White River; in both sedimentary and volcanic rocks west and south of Mt. Rainier National Park, and in the Tilton River basin north of Morton; and in young pyroclastic deposits east of Mt. St. Helens. Elsewhere, debris avalanches and torrents have taken place in granitic rocks, volcaniclastics, sedimentary rocks, andesites, and basalts. Again, weathering, slope gradient, interbedding, and the dip of strata have much to do with failure, in addition to lithology.

Olympic Peninsula - In the northern Olympic region, mass wasting events seem uniform in intensity over most of the area. We found that rock type seemed not to be a significant factor. There seemed to be no difference in numbers of landslides between igneous or sedimentary rock types, and that slope steepness was probably the determining factor as far as mappable stability. There are a few large landslides found near Lake Crescent. These slides were probably the result of deglaciation or climatic or hydrologic factors related to the glacial period. There are numerous slump-earthflows mapped along the shoreline of the Strait of Juan de Fuca. These are mostly in areas of steep banks being actively undercut by shoreline erosional processes.

One interesting feature we noticed was in the area north of Ozette Lake. This area appears to be undergoing rapid down cutting. Where the vegetation has been removed, we could see numerous gullies, many more than were observed elsewhere. This does not appear to be related to logging but perhaps some sort of recent(?) change in base level or other process.

As the study progressed we noticed, particularly along the west coast of the Olympic region, several individual drainages that also appeared to be undergoing rapid down cutting or lateral erosion. We observed, particularly along the West Fork of the Satsop and the Pysht Rivers, a proportionally large number of mass wasting events caused by streambank erosion. These and the area north of Ozette Lake seem to be undergoing rapid differential erosion when compared to other drainages in this region.

The largest concentration of mass wasting events is in the "Clearwater-Hoh" block of land on the western slopes of the Olympic Mountains. This area is underlain by highly fractured and faulted siltstone, sandstone, and mudstone, has intense topographic relief, thin colluvial soils, and rainfall of up to 500 centimeters per year. It is currently undergoing intense forest management and is known for its potential for mass wasting.

In the southern portion of the Olympic region subdued topography (due to easily eroded tuffaceous and micaceous sediments and glacial outwash) give little chance for debris avalanches or debris torrents to occur; however, some slump earthflows are present. This region appears to have relatively good stability except in the steep, rugged mountainous terrain near the Olympic National Forest boundary. In this area, steep slopes add to any potential instability factor resulting in numerous rapid mass wasting events.

<u>Willapa Hills</u> - The Willapa Hills region is quite different from the other areas of western Washington in terms of geologic and geomorphic history, resulting in significant slope stability problems. Three basic factors result in the great instability of this area. These are 1) the easily-weathered, soft tuffaceous marine sediments; 2) inherent unstable contacts between sedimentary and volcanic rock types; and 3) the deep soils.

The large number of landslides mapped west and east of Centralia are located in very easily weathered Skookumchuck sandstones and siltstones. In this area total drainages have undergone mass wasting. Most of these landslides appear to have stabilized, but because the surficial material has been disturbed by previous failure, it no longer has the stability that "in place" sediments may have. To the south slope angle seems to dictate the type of mass wasting. In the steep areas most events mapped were debris avalanches, and in the less steep areas slump-earthflows were most common. Also in this area, one basic lithology seems to have no more susceptibility than another, at least at this 1:250,000 scale. Both sedimentary and igneous rock types had many mass wasting features mapped.

The contacts between the volcanic rocks overlying sediments form another very unstable condition. Because of the mineralogy of the sediments, they weather faster in most cases when exposed than the overlying volcanic rocks. This differential weathering causes the underlying rock to lose strength when the minerals weather to clay, resulting in slope failure. One of the best examples of an obvious unstable contact is in T. 14 N., R. 7 W. where competent basalt overlies incompetent sediments, resulting in a high concentration of mass wasting events.

The Willapa Hills region has deep, clay-rich soils. The area has not undergone glaciation like most other parts of western Washington, so soil development has been able to proceed for the past several million years and soil depths can reach as much as two to three meters. Most slopes have developed to their natural angle of stability, forming in equilibrium between gravity and internal soil strength. When these slopes are altered by forest activities, instability may result.

In the southern Willapa Hills there are large areas we mapped as flow topography. These flow topography zones are probably more widespread, but we mapped just the most well-defined areas. In this region, most drainages have probably undergone some slumping or flowage. The more detailed Phase II investigation should reveal the extent.

Puget Lowland - Since the focus of this study is on mass movement in forest lands that can cause stream degradation, little emphasis is placed here on the Puget Lowland, since most of the region is relatively flat, and most of the failures are on coastlines and do not affect streams. However, noteworthy concentrations of flow topography and slumping are located in glacial-margin sediments near the confluence of the Skykomish and Snoqualmie Rivers, in mudflow deposits along the Green River east of Auburn, and in mixed glacial and fluvial sediments along the Puyallup and Carbon Rivers near Orting. The distribution of slumps and debris failures understandably increases in the higher, steeper areas close to the mountain fronts.

DRAINAGE CHOICES

One of the main objectives for Phase I was to select specific drainages that exhibit greater than average susceptibility for stream sedimentation due to mass wasting in the different geomorphic regions of western Washington. To determine specific drainages to study, we set up the following criteria. First, the drainage had to have more than the average number of mapped mass movements; second, the drainage area should not be so large that it could not be studied in less than approximately two field months; third, access should be available to all parts of the drainage so time would not be wasted on travel; fourth, there should be existing data concerning hydrology, geology, etc., so our analysis can be more thorough; and fifth and probably most important, the drainage should be representative of the area in which it is located.

Determining if a basin had more than the average number of mass movements was accomplished by inspecting landslide maps. It is quite obvious that there are many areas where there are groups of landslides. As discussed previously, the exact causes and specific boundaries for zones of instabilities was not specifically determined; however, certain drainages or parts of drainages fell in areas that seem to have numerous mapped landslides.

We determined that approximately eight months of field time would be available for Phase II. This meant that only reconnaissance-type field mapping could be accomplished in the allotted time, and large drainage areas could not be given adequate coverage. Therefore, to meet the second criterion, we determined that the area of each drainage should not be greater than approximately 200 to 400 square kilometers. This area, however, should be flexible during Phase II as actual field time, access, and judgment may provide for a reassessment of size limitations.

The third criterion is access. To provide us time to concentrate on analysis, we looked at the ease of travel within the drainages. The drainage must have a good network of roads for easy access so valuable field time would not be wasted on hiking into the study areas; also, a good network of roads usually provides good exposures (road cuts) that enable rapid and frequent examination of surficial materials. Most areas of the state lack detailed surficial geologic mapping, therefore we anticipate a great deal of our field time will be filling this data gap. Without sufficient numbers of exposures, much geologic data necessary for stability analysis will be lacking.

The fourth criterion is availability of existing data. Important information such as geologic and soils mapping, climatic and hydrologic information, old photographs for comparing incidence of landsliding, and timber cutting records are all desirable for analysis of slope stability.

The fifth and last criterion is the representation of the area by an individual drainage. The most desirable study area would have numerous rock types, range in elevation, and other physical relationships similar to the surrounding area, so extrapolation of the study's findings to the rest of the region may be possible. The drainages that fit the criteria best and have been chosen for our Phase II studies are the Middle Fork of the Nooksack River, the Green River, the North Fork of the Toutle River, the Grays River, and the Clearwater River (see Figure 1 and Landslide Maps 2-6).

The Middle Fork of the Nooksack River has a relatively high number of landslides, has rock types typical of the northern Cascade Mountains, has been glaciated, and has a U.S. Geological Survey published river survey. These factors along with good access lend to its choice as the representative basin for the North Cascades.

Most areas of the Southern Cascades region appear more stable than the other regions. But because this province contains a large amount of nonfederal forest land, spread over a variety of geologic, geomorphic, and climatic conditions, we have chosen two study basins in this region. We chose the Green River basin because it is representative of the rock types in King and Pierce Counties, has a moderate number of mass movement features, occupies a wide range of elevations, has good access, and contains many stations monitoring hydrologic and climatic conditions. To the south, we chose the basin of the North Fork of the Toutle River as representative of the rock types, extent of glaciation, young mudflow and tephra deposits, and mass movement conditions prevalent in this part of the range.

The Olympic Peninsula is dominated by Olympic National Park and Olympic National Forest. We have chosen the Clearwater drainage as our study basin because of the volume of research data that exists on the hydrology, climate, sedimentology, and mass wasting of this basin. It satisfies another criterion by having a very good road network for access, and is also important because of its close proximity to the national park.

In the Willapa Hills area, the Grays River was chosen to be the study drainage. This basin has several different topographic environments that are underlain by both sedimentary and volcanic rocks. The Grays River area is generally recognized as an unstable drainage, and because it covers many different geologic units found throughout the Willapa Hills region, it is an excellent drainage to be included in our study.

PHASE II

Phase II procedures and methodology are basically outlined in the DOE Slope Stability Pilot Project (Thorsen and Othberg, 1978) and Oregon's Procedure for Assessing the Impacts of Land Management Activities on Erosion Related Nonpoint Source Problems (Rickert and others, 1979). These studies differ somewhat in their approaches, but during Phase II we hope to integrate both. The DOE Pilot Project uses a landscape mapping approach, identifying typical landscapes in a basin that may or may not be susceptible to mass wasting, and the Oregon study uses the parametric approach, identifying ground factors (i.e., geology, slope, soil) influencing mass wasting. Our goal is to identify the parameters controlling stability within each study basin and attempt to integrate them into landform analysis.

The work of Phase II will involve review of the literature on the geology, climate, soils, and hydrology of each basin, analysis of low-altitude airphotos, and field reconnaissance of surficial geology, mass movement features, and erosional processes. Also, we will examine older air photographs, forest management history, and conditions on contiguous basins.

The team, along with the advisory committee, will set goals and specific procedures during the initial stages of Phase II. Also, periodically throughout Phase II the project team will meet with the advisory committee for constructive criticism of their work and findings.

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APPENDIX

North Cascades

Our North Cascades region includes the western parts of the North Cascade Range, from the Canadian border to the vicinity of Snoqualmie Pass. The rocks of this region include early Paleozoic gneisses; late Paleozoic marine sandstones, shales, and volcanics (Chillwack Group) and phyllite and greenschist (Shuksan Suite); Mesozoic marine sandstones, shales, conglomerates, and volcanics (Nooksack Group and others); early Tertiary continental sandstones (Chuckanut or Swauk Formation), and felsic and intermediate volcanics and plutonic intrusions of a variety of compositions and ages, most importantly middle Tertiary granodiorites of the Snoqualmie and Index batholiths. These units have been telescoped together by a series of thrust faults, as well as being cut by other faults. Mt. Baker and Glacier Peak have erupted repeatedly within the last half million years, and some of their pyroclastic material has been deposited in the valleys of the Nooksack, Skagit, Suiattle, and Sauk Rivers.

The area north of the Skykomish River was all overrun by continental ice during the last glaciation; most of the southern part was covered by alpine glaciers. Tills are ubiquitous and outwash and glacial-margin deposits are common along the mountain front and in the river valleys. Fluvial erosion has cut deep gorges into the mountains, forming steep slopes and high relief with generally thin soils, especially in the eastern sections.

Average annual precipitation in the North Cascades ranges from 180 centimeters to about 300 centimeters on most of the higher mountains, with a maximum of 380 centimeters on Mt. Baker, 400 centimeters in the Middle Snoqualmie headwaters, and 480 centimeters near Stevens Pass. The intensity of the 2-year 24-hour storm is generally 7.5 to 14 centimeters per hour.

Southern Cascades

The rocks of this terrane include early to middle Tertiary volcanic flows, breccias, and pyroclastics (both marine and continental; "Keechelus", Ohanapecosh, Stevens Ridge, Fife's Peak, Goble) early Tertiary marine sandstones, shales, and continental deposits (Puget Group coals, conglomerates, and sandstone), late Tertiary fluvial and glacial-outwash sediments in the Chehalis-Centralia basin and in Clark County, and young volcanic flows, pyroclastics, and mudflows from Mt. Rainier and Mt. St. Helens. There are many small Tertiary plutonic intrusions scattered in the region.

This area has not been as intensely glaciated as the North Cascades. Continental ice piled up against the mountains in the Puget Lowland, and large alpine icecaps covered the range from Mt. Rainier north, extending into the valleys of the Cedar, Green, White, Puyallup, Nisqually, and Cowlitz Rivers. South of the Cowlitz, the alpine icecap was smaller, but valley glaciers occupied the Toutle, Kalama, and Lewis Rivers.

The less intensive glaciation has allowed longer weathering and somewhat deeper soils to develop than in the North Cascades. However, stream erosion, aided by glacial scour in many valleys, has formed high relief and steep slopes in the Southern Cascades.

Annual precipitation in this province ranges from about 130 to 200 centimeters, with maximum of 360 centimeters on Mt. Rainier and Mt. St. Helens. The intensity of the 2-year 24-hour storm is 7.5 to 13 centimeters per hour in most of the region, but may be as high as 15 centimeters per hour on the highest peaks.

Olympic Peninsula

The geology of the Olympic Peninsula consists of highly folded, faulted, and fractured marine sediments in the core and on the west side of the peninsula. These sediments are bordered on the north, east, and south by the peripheral Crescent Formation consisting of submarine basalt flows and sedimentary rocks. Along the northern edge of the peninsula paralleling the Strait of Juan de Fuca are folded sandstones, siltstones, and conglomerates, and along the southern margin are tuffaceous and micaceous siltstones, sandstones, and mudstones. During the Pleistocene there was extensive valley glaciation, and on the western side the valley glaciers coalesced to form piedmont glaciers past the mountain front. The northern and eastern edges of the peninsula were overrun by the continental ice sheet emanating from Canada.

Precipitation varies dramatically in the Olympic region. Along the western mountain slopes there is as much as 500 or more centimeters of rainfall per year, and on the lee side of the mountains, near Sequim, only 35 centimeters per year. Two-year 24-hour storm intensity ranges from 5 centimeters per hour near Sequim, 11 to 13 centimeters per hour on the north side, and up to 20 centimeters per hour on the west side.

Willapa Hills

The geology of the Willapa Hills area is generally tuffaceous, micaceous, and carbonaceous marine and nonmarine sediments with basalt flows overlying them in some areas. The Skookumchuck, Astoria, Lincoln Creek and Cowlitz Formations form most of the sedimentary rock types and the Cowlitz, Crescent, Goble, and Yakima basalts are the volcanic rock types.

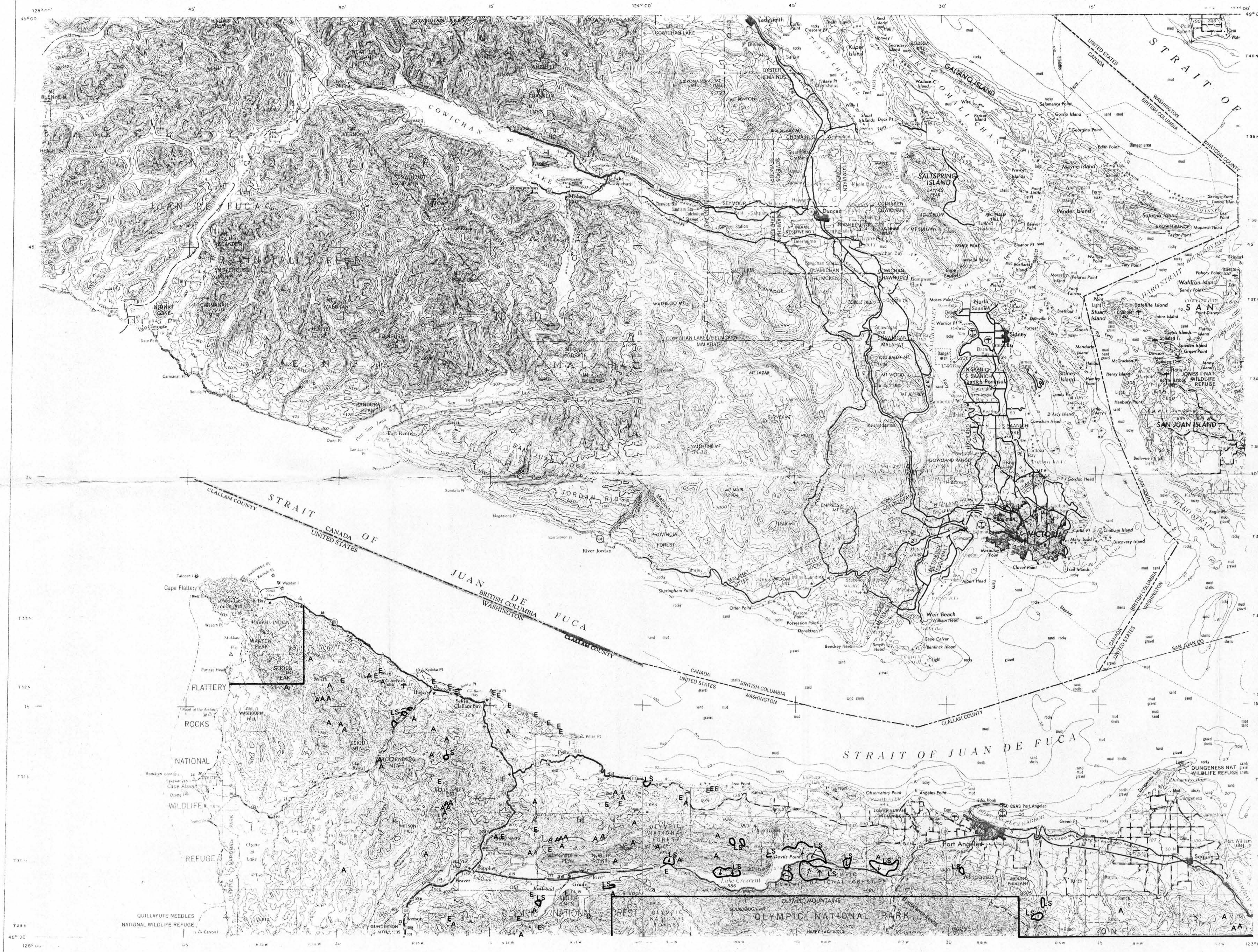
The precipitation in this region varies markedly with elevation and east-west location. Annual rainfall rises from 180 centimeters on the coast to 300 centimeters on the highest hills, then declines sharply to about 100 centimeters in the Centralia-Chehalis basin. Likewise, 2-year 24-hour storm intensity is 9 to 14 centimeters per hour over most of the province, but as low as 5 centimeters per hour in the east.

Puget Lowland

This province covers the area between the mountain fronts of the Cascades and the Olympics, extending south to the hills between Olympia and Centralia. Bedrock types in this region include Paleozoic and Mesozoic rocks in the San Juan Islands, rocks of the Crescent Volcanics and sandstones and shales on the east flank of the Olympics, and sedimentary and volcanic rocks related to those of the Southern Cascades on the south and east.

However, most of the Puget Lowland contains unconsolidated sediments. Most are related to the last glaciation: tills, outwash sands and gravels, and proglacial lake clays and silts. Others were deposited by processes acting in the last 10,000 years to fill up the lowland; especially fluvial sediments, such as those which have created large deltas at the mouths of the Nooksack and Skagit Rivers, and filled large fjords which once existed in the Puyallup-Green-Duwamish Valley.

Average annual precipitation ranges from 40 to 75 centimeters in the San Juans and northeastern Olympic Peninsula, 75 to 115 centimeters in the Seattle and Tacoma areas, and up to 130 to 180 centimeters in the foothills. Maximum 2-year 24-hour storm intensity is generally 5 to 10 centimeters per hour.



LANDSLIDE MAP OF WESTERN WASHINGTON

by

Allen J. Fiksdal

and

Matthew J. Brunengo

1980

EXPLANATION

D Debris Torrent --- Rapid movement of water-charged soil, rock, and organic matter down steep stream channels.

A Debris Avalanche --- Rapid downslope mass movements usually in areas of shallow soils on steep slopes.

E Slump-Earthflow --- Slumps with downward and backward rotational movement at the headwall, earthflows with movement downslope by flowage or gliding, and commonly combinations of both slump and earthflow characteristics.

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F Flow Topography --- Areas interpreted to have undergone extensive mass wasting, but having indistinct morphological characteristics.

—— Landslide boundaries

⟶ Direction of Movement

- - - Flow Topography boundaries

—— Study area boundaries

Scale 1:250,000

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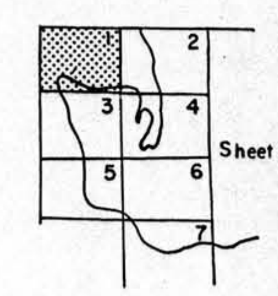

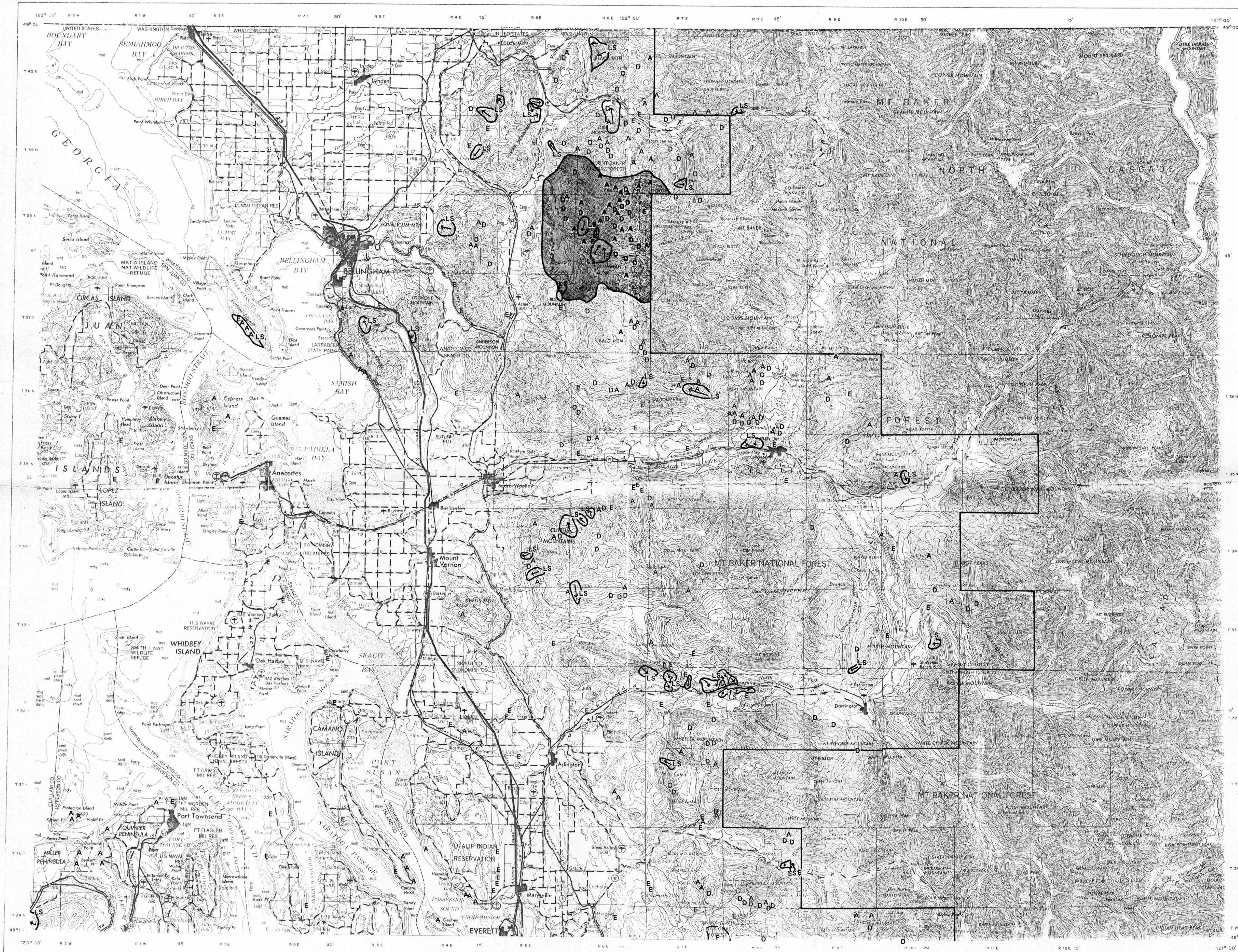

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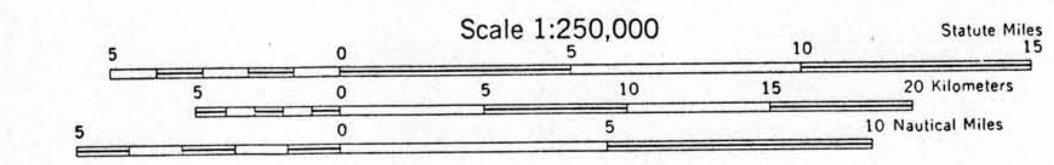

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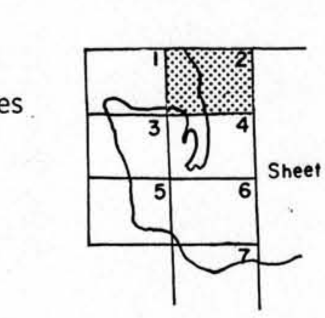

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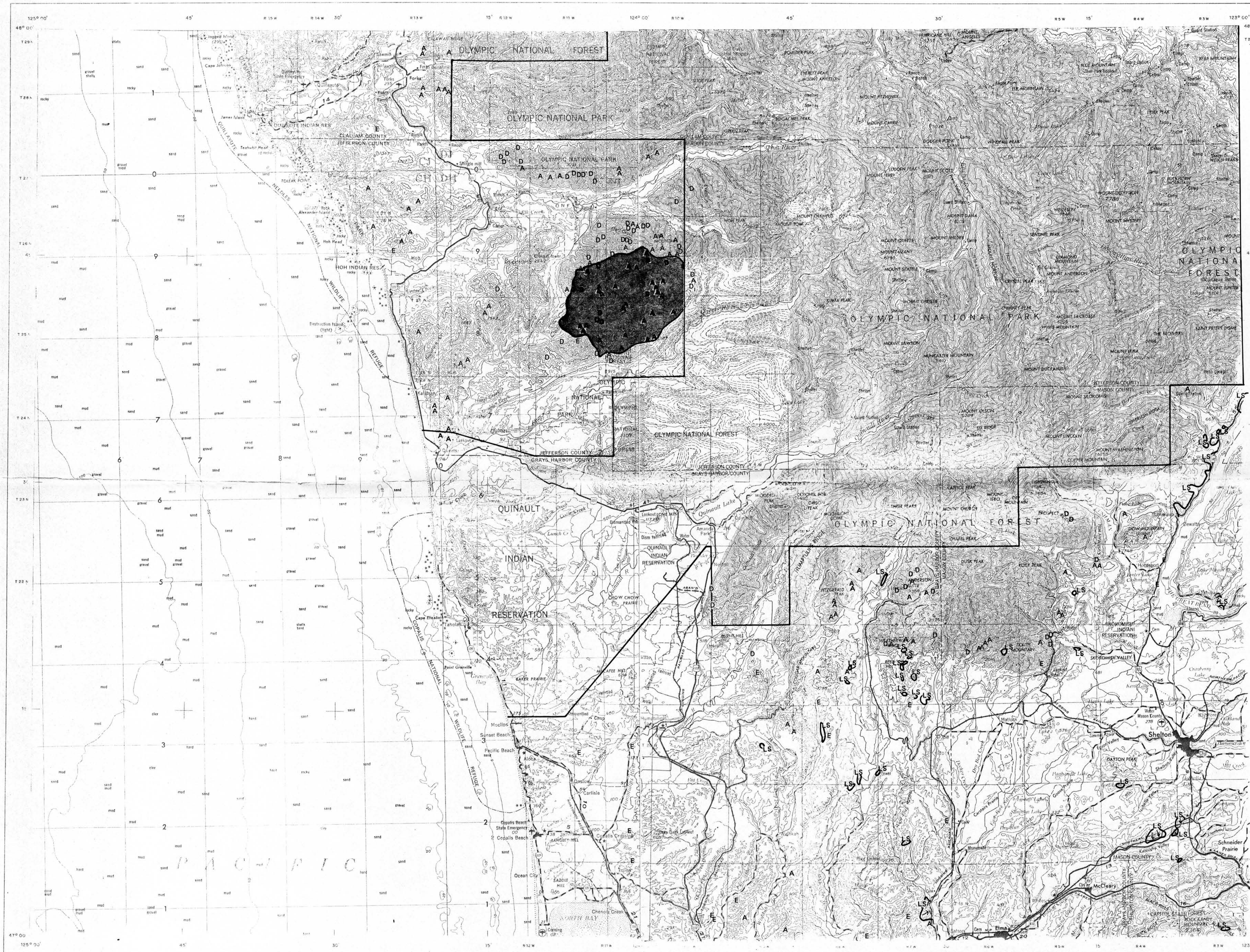

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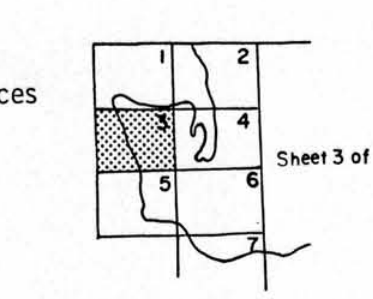

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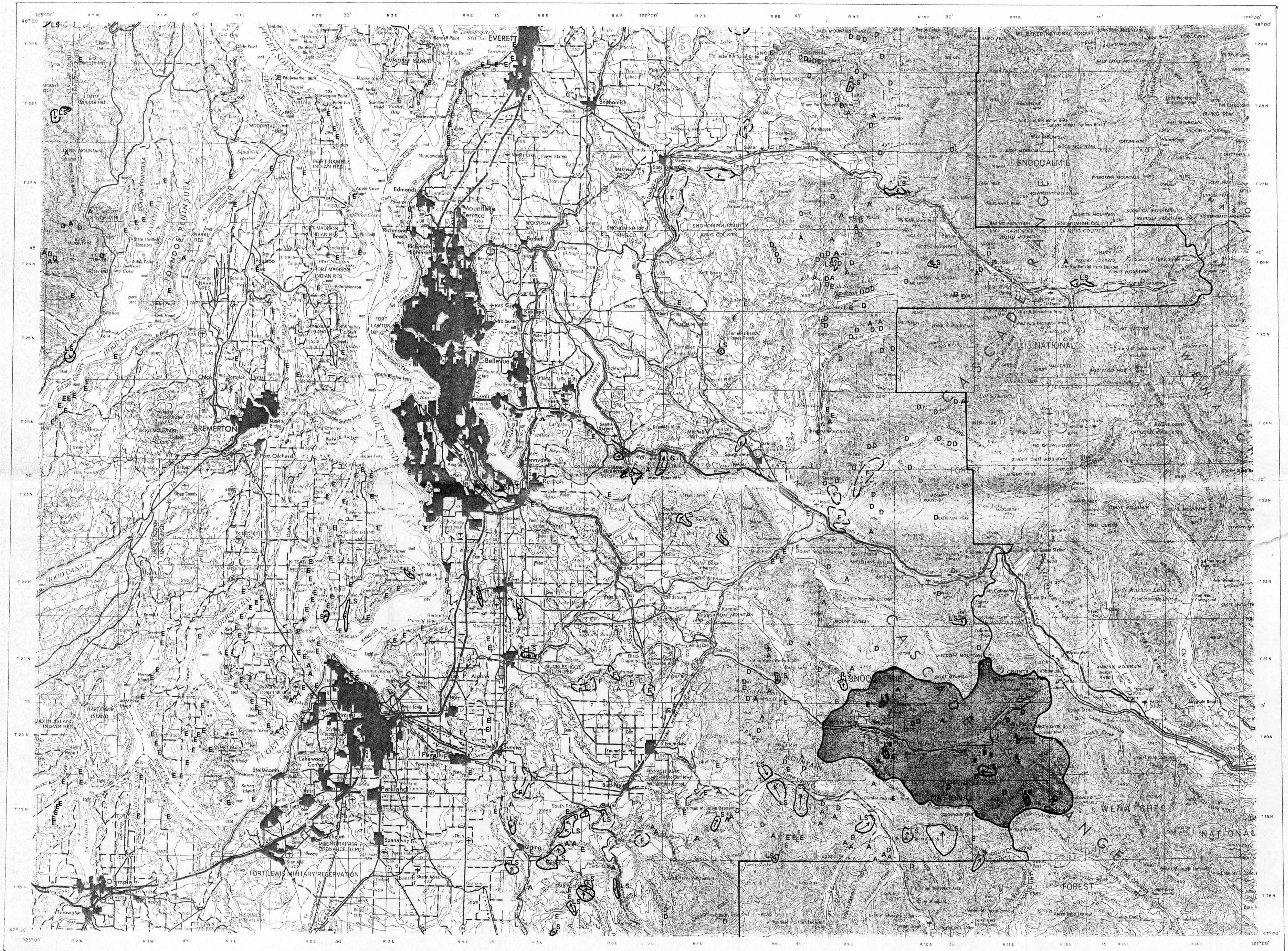

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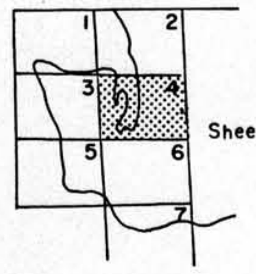

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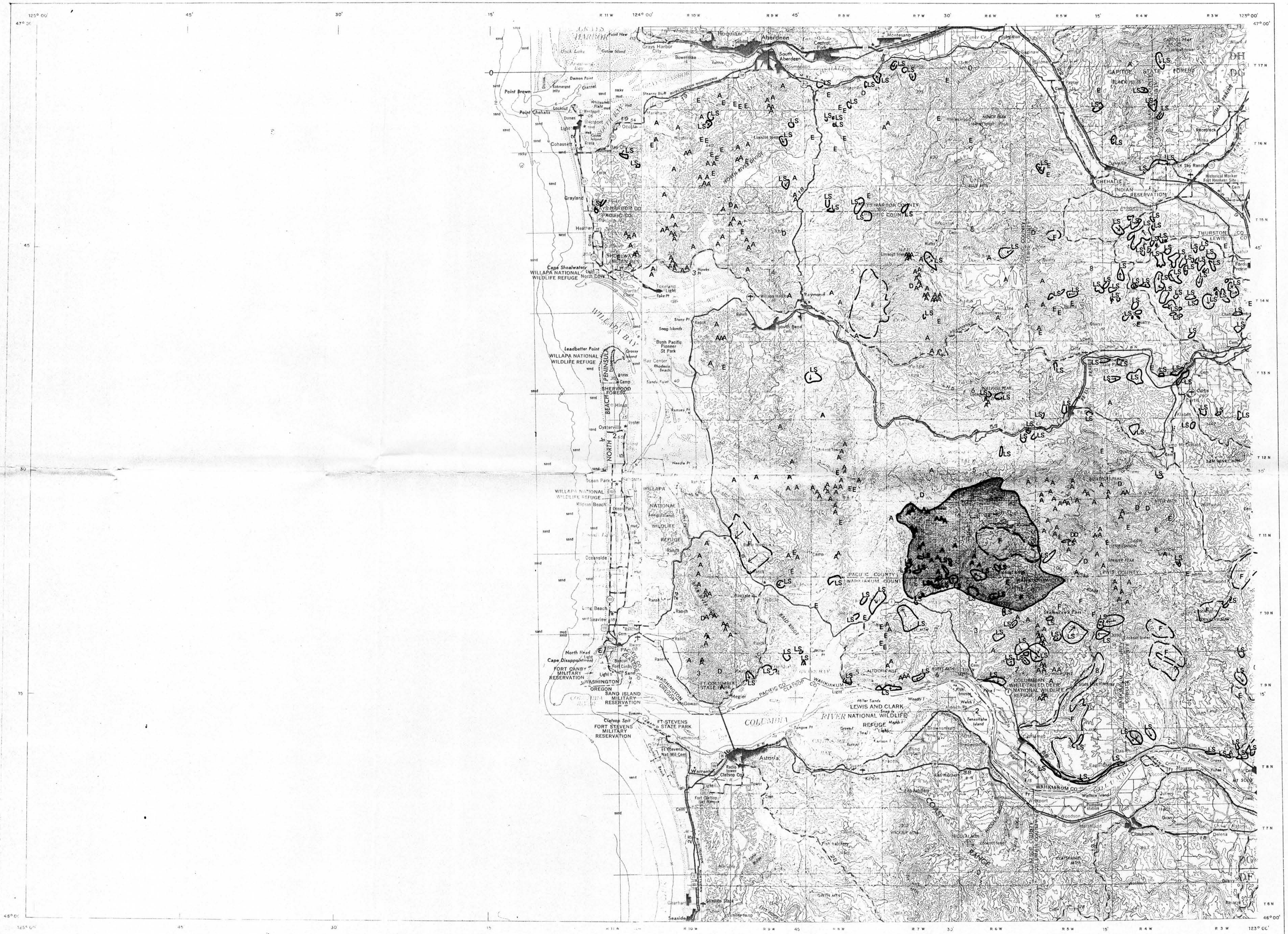

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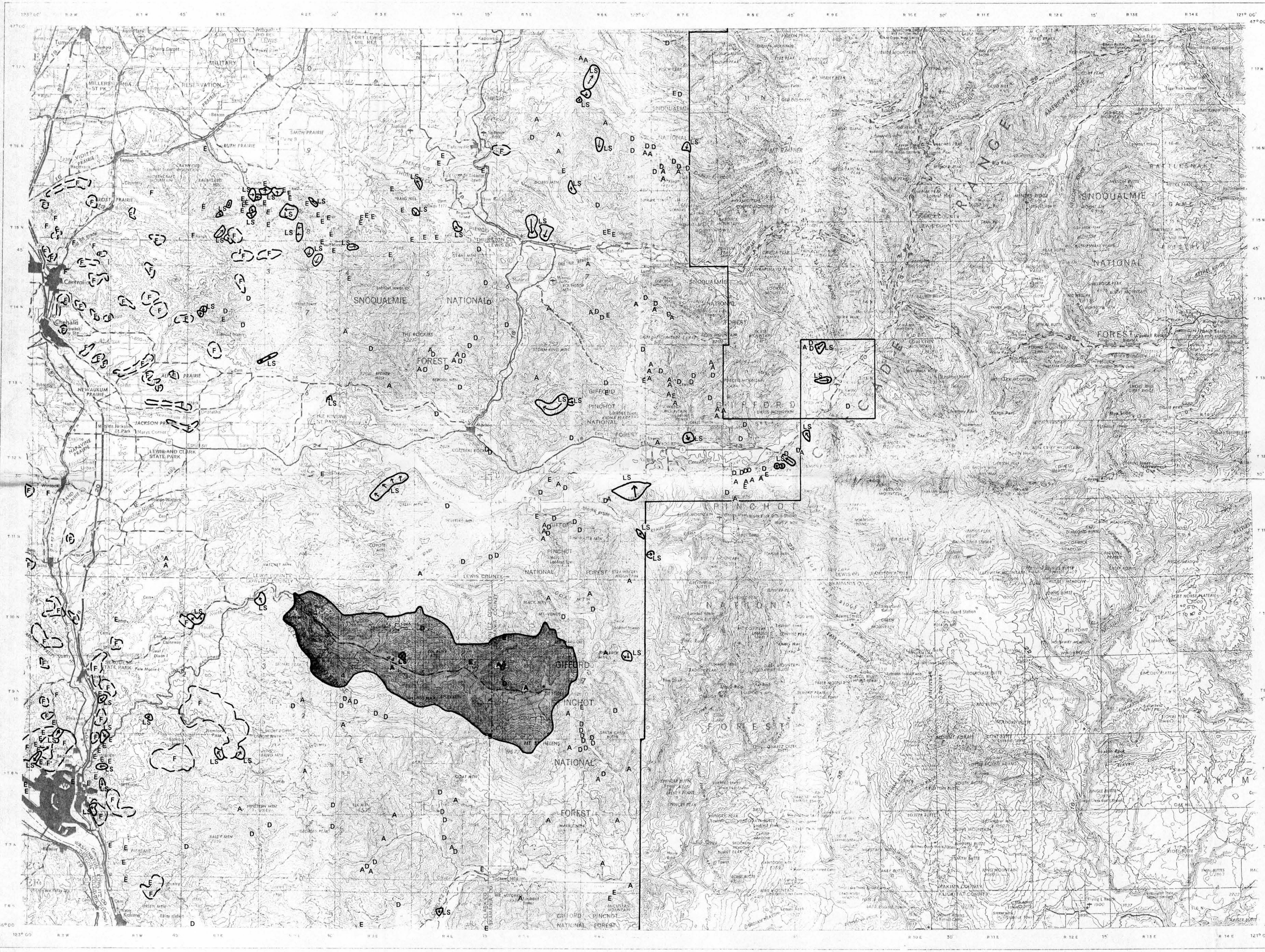

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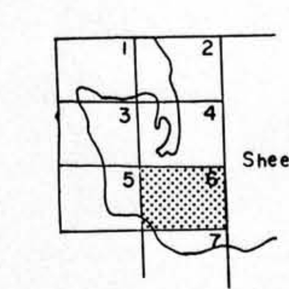

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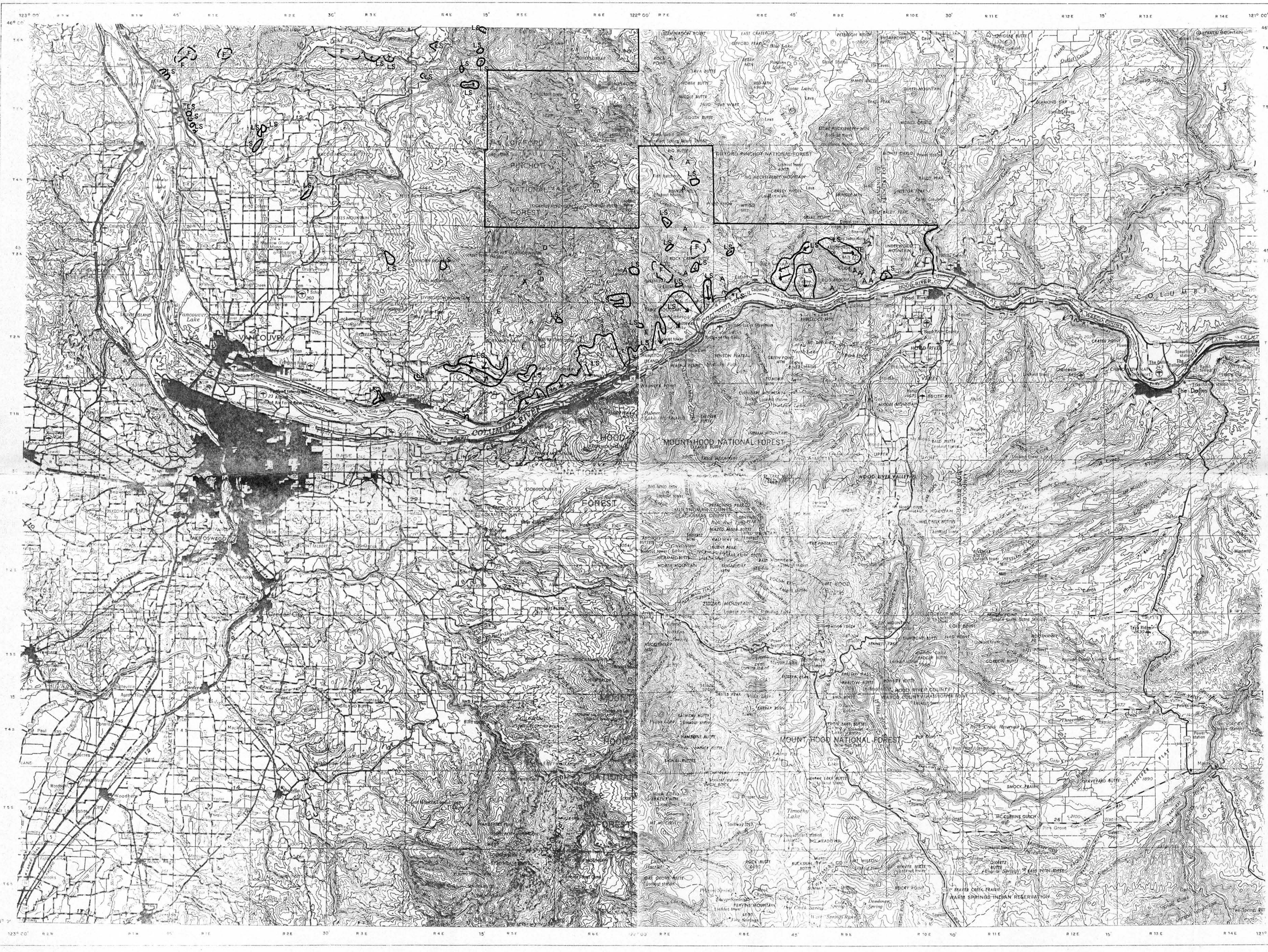

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