PRELIMINARY MAPS OF LIQUEFACTION SUSCEPTIBILITY FOR THE RENTON AND AUBURN 7.5′ QUADRANGLES, WASHINGTON

by

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PRELIMINARY MAPS OF LIQUEFACTION SUSCEPTIBILITY FOR THE RENTON AND AUBURN 7.5' QUADRANGLES, WASHINGTON

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SUMMARY

Liquefaction susceptibility maps are presented for the Renton and Auburn 7.5' topographic quadrangles. These maps are based on analyses of 140 geotechnical borings; these data were obtained from the Washington Department of Transportation and the King County Department of Building and Land Development. Four categories of geologic deposits found in the study area are assigned a susceptibility ranking on the basis of analysis of the geotechnical data and historical reports of liquefaction during the 1949 magnitude 7.1 Olympia and 1965 magnitude 6.5 Seattle-Tacoma earthquakes.

These maps are intended to provide land-use planners, emergency-response personnel, geotechnical consultants, building developers and contractors, and private citizens with a qualitative assessment of the potential for soil liquefaction during an earthquake. The maps are meant only as a general guide to delineate areas more or less prone to liquefaction and cannot be used to determine the presence or absence of liquefiable soils beneath any specific locality because of the regional nature of these maps (as determined by their scale, 1:24,000) and because the data used in the liquefaction susceptibility assessment have been subdivided on the basis of regional geological mapping.

These maps cannot be substituted for a site-specific geotechnical investigation, which must be performed by qualified practitioners and is required to assess the potential for liquefaction for a given project.

Category I deposits, comprising manmade fill and modified land, as well as post-Vashon alluvium, are ranked as having a high susceptibility to liquefaction. The Renton quadrangle map shows the historic pre-Lake Washington Ship Canal shoreline of Lake Washington and associated freshwater marshes and delineates the pre-Ship Canal courses of the Black and Cedar Rivers. Also, abandoned-channel segments of the Green River are mapped in the study area. These particular areas may have a locally higher susceptibility to liquefaction either because they have been filled during this century as a consequence of the development of the Duwamish River valley, or because they are topographically low areas that likely have a shallow ground-water table compared to the adjacent flood plain.

Category II deposits, consisting of post-Vashon lacustrine deposits and colluvium, are ranked as having a low to high liquefaction susceptibility. Few geotechnical data were available for this category of deposit, and the existing data were insufficient to quantify the behavior of these deposits during an earthquake. The post-Vashon lacustrine deposits are primarily composed of peat and silt, with only scattered sandy sections and, on this basis, would typically be considered as having a low liquefaction susceptibility. However, there was one reported instance of liquefaction in a post-Vashon lacustrine deposit in the Big Soos Creek drainage; this report indicates that these deposits can liquefy. Colluvium consists primarily of landslide debris and slope wash and, in places, alluvium plastered on valley walls. Landslides and ground cracks were reported in colluvial deposits during the 1949 and 1965 earthquakes, but these ground failures may not necessarily have been caused by liquefaction. Nevertheless, it seems prudent to express the variations in the observed nature of the lacustrine and colluvial deposits and the historic record of earthquake-induced liquefaction and other ground failures by assigning a low to high susceptibility to Category II deposits.

Category III deposits include all Vashon and older glacial and nonglacial deposits, as well as the Osceola Mudflow. Quantitative evaluation of geotechnical data obtained from the pre-Vashon glacial and nonglacial deposits indicates a low susceptibility to liquefaction. The Osceola Mudflow is composed of bedrock clasts in a clayey matrix, and the nongranular nature of this matrix material precludes the possibility of earthquake-induced liquefaction. The historic record corroborates the low ranking assigned to Category III deposits, as there are no reported instances of liquefaction in these deposits during the 1949 and 1965 earthquakes.

Category IV deposits are Tertiary bedrock, which is clearly not liquefiable; however, small, unmapped areas of colluvium or other potentially liquefiable deposits may lie in the areas mapped as bedrock. For this reason, Category IV deposits area ranked as having low to no liquefaction susceptibility.

INTRODUCTION

The Washington Department of Natural Resources, Division of Geology and Earth Resources (DGER), is actively investigating earthquake hazards statewide and currently receives funding from the National Earthquake Hazards Reduction Program to conduct earthquake hazard mitigation studies. DGER has concentrated its technical program on mapping Quaternary deposits in the Puget Sound region that are subject to seismically induced ground failures. The purpose of this study is to present preliminary maps showing liquefaction susceptibility in the Renton and Auburn 7.5' quadrangles. These areas include the alluvial valley along the lower reach of the Green River and are just upstream of the Seattle North and South 7.5' quadrangles mapped for liquefaction susceptibility by Grant and others (1991) (Fig. 1).

Liquefaction occurs when a water-saturated, granular (sandy) soil loses strength during vibratory shaking such as that generated by an earthquake. Below the ground-water table the void spaces among sand grains are filled with water. The weight of the overlying soil mass is supported both by grain-to-grain contact and by the pressure of water in the pore spaces. The strong shaking during a large earthquake can disrupt the grain-to-grain contact, causing a decrease in the grain support. If strong shaking lasts long enough, the grain structure of the liquefiable soil may completely collapse. If the pore water cannot flow out of the collapsing pore space, the pore-water pressure increases. In the extreme case where the grain support is completely lost, the water pressure must bear the entire weight of the overlying soil mass. At this point the granular soil is liquefied and will behave as a fluid. The liquefied soil is then subject to extreme lateral deformation because it does not provide much resistance to horizontal forces.

These maps are intended to provide land-use planners, emergency-response personnel, geotechnical consultants, building developers and contractors, and private citizens with a qualitative assessment of the potential for soil liquefaction during an earthquake. These maps are meant only as a general guide to delineate areas prone to liquefaction. *These maps are not a substitute for a site-specific investigation to assess the potential for liquefaction for any development project.* Because of the regional nature of these maps (scale 1:24,000) and because the data used in the liquefaction susceptibility assessment have been subdivided on the basis of regional geological mapping, these maps cannot be used to determine the presence or absence of liquefiable soils beneath any specific locality. *Site-specific geotechnical investigations performed by qualified practitioners are required to make this determination.*

GEOLOGY OF THE RENTON AND AUBURN QUADRANGLES

The oldest rocks exposed in the study area are lower Tertiary sedimentary rocks termed the Puget Group, subdivided into the Tukwila and Renton Formations, and unnamed sedimentary rocks of Oligocene age correlative with the Blakeley Formation. Tertiary andesite sills and irregularly shaped bodies intrude the

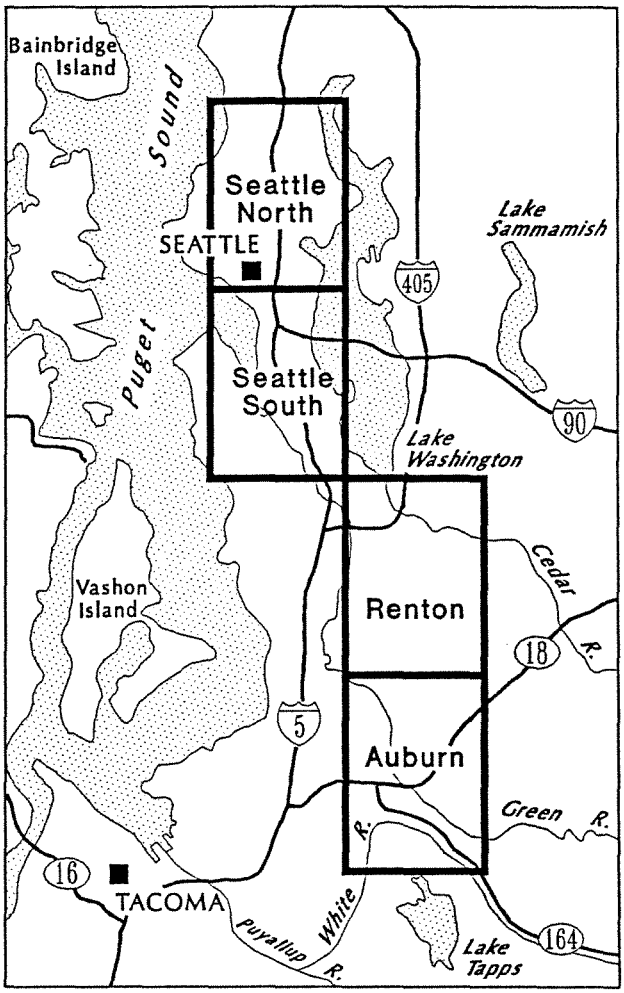

Figure 1. Location map showing the Renton (1) and Auburn (2) 7.5' quadrangles and Seattle North and South 7.5' quadrangles.

Tukwila Formation, but their age relation to the younger Tertiary sedimentary rocks is unknown. These bedrock units crop out only in the northern part of the Renton quadrangle. Generalized geologic maps for the Renton and Auburn quadrangles are given in Figures 2b and c, respectively; the explanation for these maps is shown in Figure 2a.

Pleistocene glacial and nonglacial deposits unconformably overlie Tertiary bedrock in the study area (Figs. 2b and c). The youngest of these glacial units was deposited during the Vashon Stade of the Fraser Glaciation (ca 15,000 years ago). Vashon till and outwash form a veneer on the broad drift plain that occupies the lowland between the Olympic Mountains and the foothills of the Cascade Range. In the study area this drift plain stands a few hundred feet above valley floors cut by the major river systems draining into Lake Washington and Puget Sound.

Sedimentary and volcanic deposits younger that the Vashon Drift are also present in the study area (Figs. 2b and c). The 5,400-year-old Osceola Mudflow (Crandell, 1971) is found in the southeast corner of the Auburn quadrangle. This mudflow originated on the northeast side of Mount Rainier and flowed into and down an earlier White River drainage. The pre-Osceola White River was a tributary of the Puyallup River that followed the South Prairie Creek valley northeast of Orting. The White River channel was filled by the

Osceola Mudflow, and the new course cut by the White River was directed into the study area near Auburn. Before 1906, the White River bifurcated as it reached the floor of the Duwamish valley, with the White River flowing northward into the Green River and the Stuck River flowing southward as a tributary of the Puyallup River. After a flood in 1906, most of the flow was directed into the Stuck River, and engineering projects permanently diverted the north-flowing White River into the Stuck River (which was renamed the White River). Figure 3 delineates the current and historic names and courses of rivers traversing the study area. Other post-Vashon deposits also occur in the Renton and Auburn quadrangles. Holocene lake deposits, chiefly peat but with some sand, silt, and clay, are found in low areas on the drift plain. Alluvial sand, silt, and gravel are found in the Duwamish valley, in the valleys cut by the Cedar, Green, and White Rivers, and along Big Soos Creek. Thin, peaty lake deposits have formed on flood-plain basins in the Duwamish valley. Water-well data for the area northwest of Auburn show that the Osceola Mudflow is at a depth of approximately 260-280 feet below present-day sea level, indicating that the Duwamish valley was formerly an embayment of Puget Sound. The alluvial and lacustrine deposits in the Duwamish valley post-date the Osceola Mudflow; consequently, they are of mid- to late Holocene age. Colluvial deposits mapped by Mullineaux (1965a, 1965b) consist primarily of landslide debris and slope wash and, in some places, alluvium plastered on valley walls.

Modified or filled land is concentrated in alluvial valleys and includes extensive fill of Lake Washington and embankments for railroad lines, roadways, and water impoundments. A significant area of northern Renton was filled in the early 1900s as a result of the Lake Washington Ship Canal project. That project also affected the natural river drainage pattern in the study area. Before 1900 (Fig. 3), the Black River drained from Lake Washington, and the Cedar River was a tributary of the Black River. The Black River had a westward course and flowed into the Green River just west of the western edge of the Renton quadrangle. After completion of the Ship Canal project, the outlet feeding the Black River was blocked, and the Cedar River was channelized and redirected into Lake Washington (Fig. 3). Flow in the Black River effectively ceased except for the drainage originating on the adjacent drift plain highland. The level of Lake Washington was lowered approximately 9 feet (Chrzastowski, 1983), and in the northern part of Renton both the newly exposed lakebed and surrounding freshwater marshes were filled or otherwise modified by development.

EXPLANATION

af	manmade fill
Qa	Holocene alluvium
Ql	Holocene lacustrine sediments
Qo	Osceola Mudflow (Holocene)
Qm	Holocene mass-wasting deposits (colluvium)
Qu	undifferentiated Pleistocene glacial and nonglacial deposits, including Vashon Stade drift and outwash deposits
Tu	undifferentiated Tertiary sedimentary and intrusive rocks

Figure 2a. Explanation for the generalized geology maps of the Renton and Auburn quadrangles. (See p. 5 and 6; maps modified from Mullineaux, 1965a, b.)

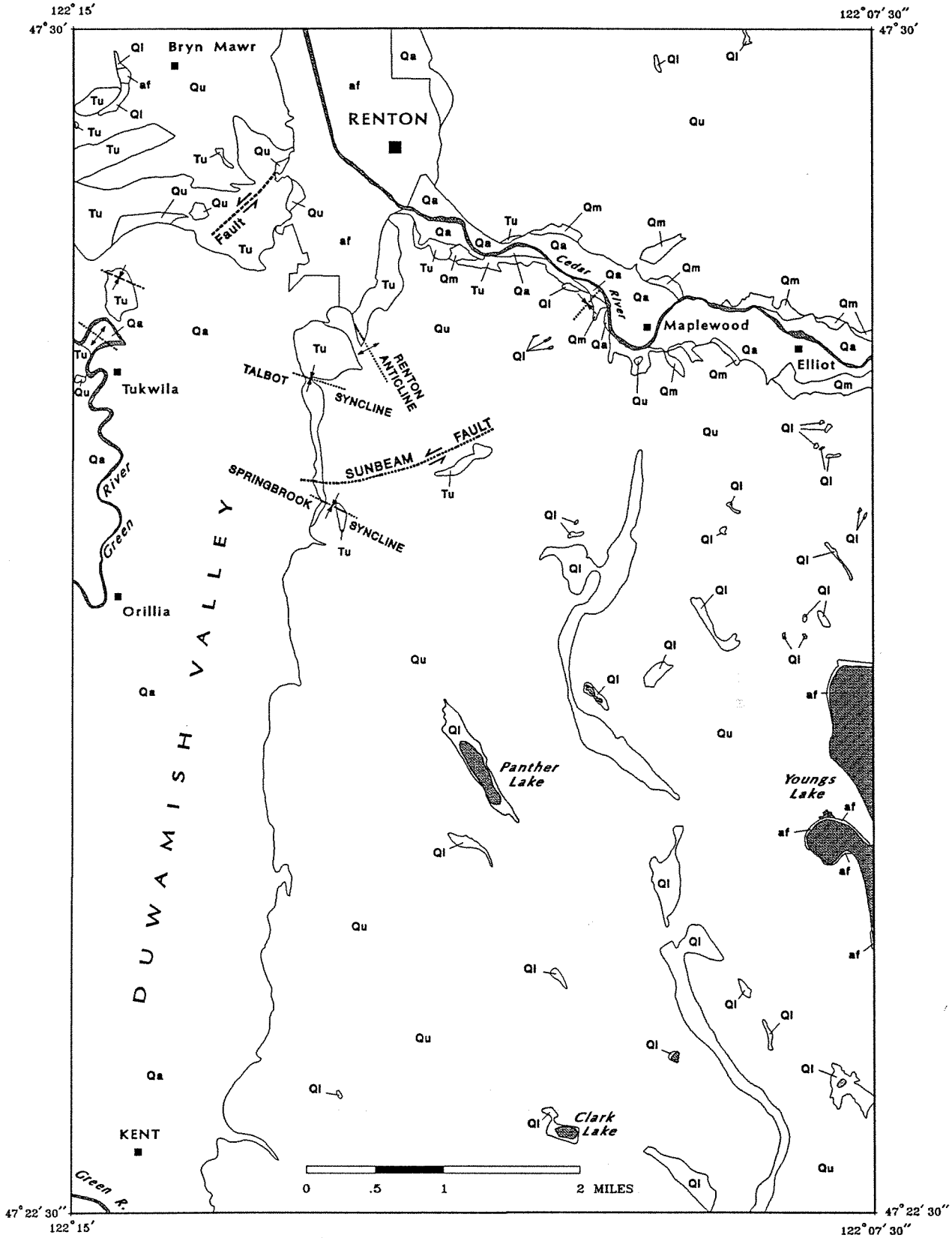

Figure 2b. Generalized geology of the Renton quadrangle.

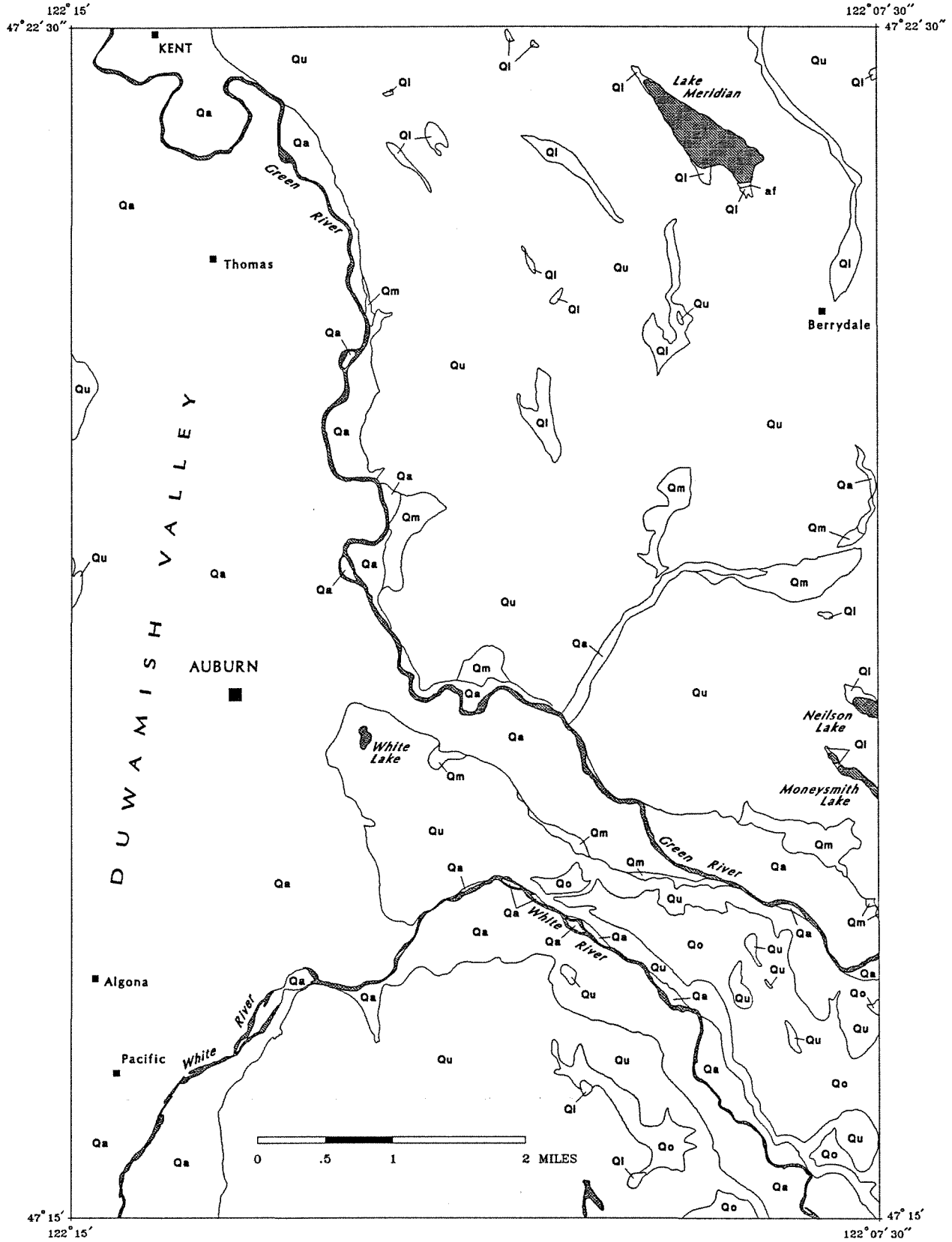

Figure 2c. Generalized geology of the Auburn quadrangle.

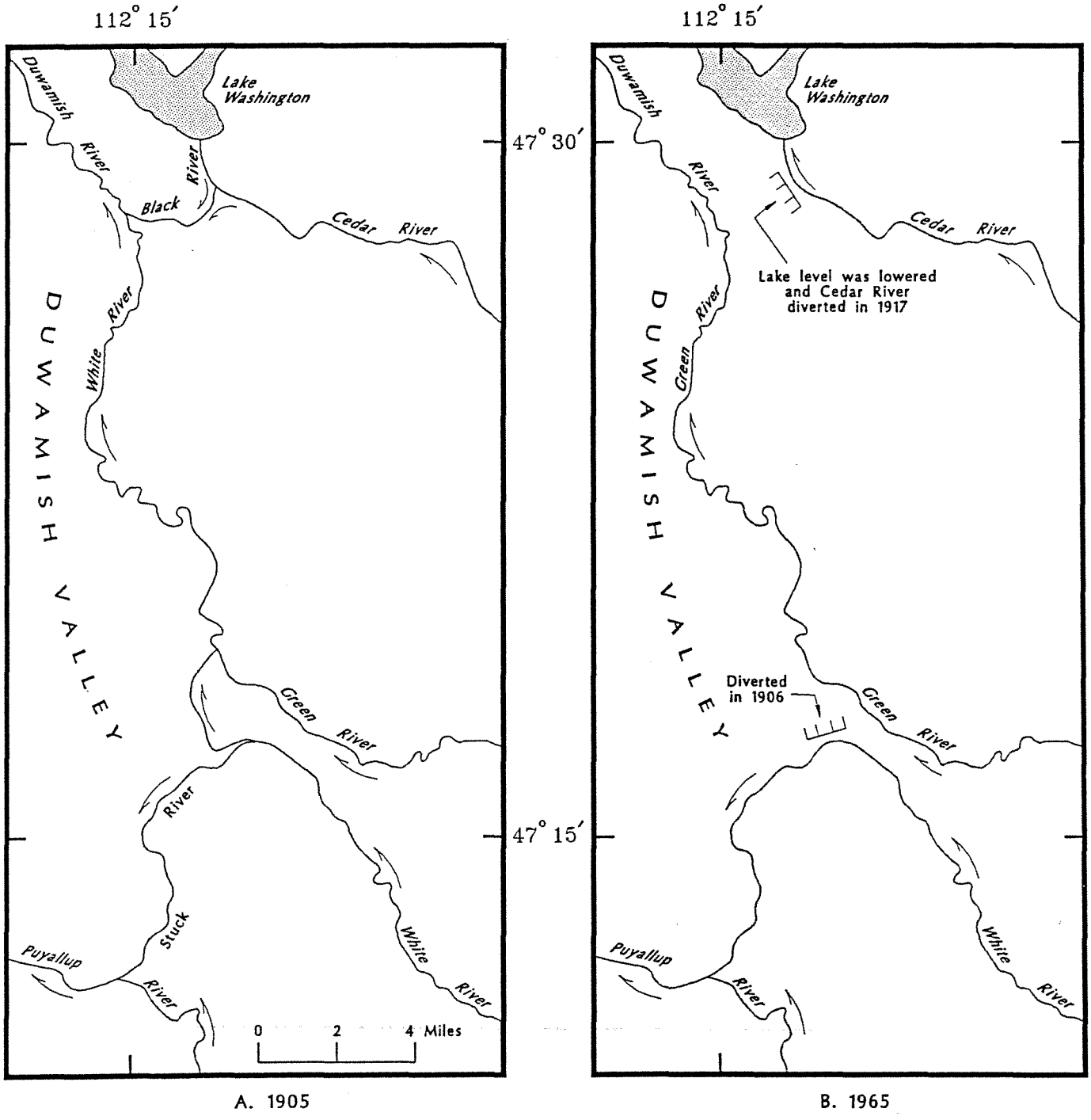

Figure 3. Current and historic waterways in the Renton and Auburn quadrangles (modified from Luzier, 1969).

LIQUEFACTION SUSCEPTIBILITY MAPS FOR THE RENTON AND AUBURN QUADRANGLES

Geological mapping of the Renton and Auburn 7.5' quadrangles is provided by Mullineaux (1965a, 1965b). I have generalized Mullineaux's map units into four categories of deposits as follows:

- Category I: manmade fill and modified land (excepting fills along transportation roadways), and post-Vashon alluvium;
- Category II: post-Vashon lacustrine deposits and colluvium;
- Category III: all Pleistocene glacial and nonglacial deposits, and the Osceola Mudflow;
- Category IV: all Tertiary bedrock.

Table 1 summarizes the four categories of deposits used in this study and the corresponding map units of Mullineaux (1965a, 1965b) for the Renton and Auburn quadrangles. Plates 1 and 2 show the distribution of the four categories on the basis of Mullineaux's mapping in the Renton and Auburn quadrangles. The historic shoreline of Lake Washington, the associated freshwater marshes, and the pre-Ship Canal courses of the Black and Cedar Rivers mapped by Chrzastowski (1983) are shown on Plate 1. Plate 2 shows the pre-1906 course of the White River as mapped by Willis and Smith (1899).

Table 1. The four categories of geologic deposits used in this study and the corresponding map units of Mullineaux (1965a, 1965b)

Category	Geologic description	Map units in the Renton quadrangle (Mullineaux, 1956a)	Map units in the Auburn quadrangle (Mullineaux, 1956b)
I	post-Vashon alluvium of the Cedar, Green, and White Rivers, and fill and modified land	Qac, Qaw, Qas, af, afm	Qaw, Qag, Qas, af, afm
II	post-Vashon lacustrine and colluvial deposits	Qlp, Qlm, Qmc	Qlp, Qlm, Qlc, Qmc, Qms
III	Vashon and older glacial and nonglacial deposits, and the Osceola Mudflow	Qik, Qit, Qiv, Qpa, Qis, Qg, Qsr, Qgt, Qss, Qu	Qom, Qpo, Qpv, Qpd, Qik, Qit, Qiv, Qg, Qgt, Qsa, Qss, Qpy, Qid, Qu
IV	Tertiary bedrock	Ts, Tr, Tt, Ttu, Tta, Ttl, Ti	(none exposed)

Mullineaux (1965a) mapped two abandoned channels of the Green River in the Duwamish valley between Kent and Renton. He conjectured that the avulsion of these channels was caused by aggradation of the river as the profile was lengthened by construction of a delta in the Puget Sound and by slow bank cutting at the outside of meander bends (Mullineaux, 1961). In this model, long segments of the channel were abandoned after aggradation had built up the channels to nearly the level of the adjacent flood plain, and the river shifted to a new course. Abandoned channels were not mapped by Mullineaux (1965b) in the Auburn quadrangle.

A series of U.S. Army Corps of Engineers (USACE) 1944-vintage aerial photo mosaics of the Duwamish valley were reviewed in this study to evaluate the mapping of Mullineaux (1965a). Abandoned channels mapped from these photo mosaics were transferred to Plates 1 and 2. An example of an USACE aerial photo mosaic (showing the area near Longacres Race Track) is given in Figure 4. In addition to the two long abandoned segments mapped by Mullineaux (1965a) in the Renton quadrangle, other shorter abandoned segments and meanders were mapped from the USACE photo mosaics. Further mapping was attempted using a series of 1976-vintage 1:24,000-scale stereo air photos (Washington Department of Natural Resources Flight Index Symbol NW-C-76). However, development of the Duwamish River valley between 1944 and 1976 has obscured many of the abandoned channels mapped by Mullineaux (1965a) and shown on the USACE aerial photo mosaics.

Two types of abandoned channels are mapped in Plates 1 and 2. The hatchured features mark the trace of clearly identifiable abandoned channels that do not appear to contain intermittent streams or support riparian vegetation. The dot-and-dash lines denote drainages and streams that appear to be continuations or parts of abandoned river channels. The overall pattern of these features suggests that the Green River channel changes position both by avulsion of long segments and by meander migration and abandonment, as noted by Mullineaux (1961). It is likely that additional abandoned channels could be mapped using older (probably pre-1960) aerial photographs, if these exist.

METHODOLOGY USED TO EVALUATE LIQUEFACTION SUSCEPTIBILITY

The analysis of liquefaction susceptibility in the Renton and Auburn quadrangles closely follows the methodology of Grant and others (1991) in their study of the Seattle North and South 7.5′ quadrangles. The susceptibility of a soil to liquefy is estimated using the field evaluation methodology developed by Seed and Idriss (1971) and modified by Seed and others (1983, 1985). This field evaluation procedure uses Standard Penetration Test (SPT) N-values (ASTM D 1586-84[1]), sample descriptions, grain-size analyses, and measured ground-water elevations obtained from geotechnical borings to estimate the factor of safety for a hypothetical earthquake with a specified magnitude and peak ground acceleration (PGA). I wrote a personal computer program implementing this modified field evaluation procedure for use in this study.

The SPT N-values and other data are obtained from sampled depths in a geotechnical boring so that the thicknesses and depths of individual liquefiable soil units and the total thickness of liquefiable material in that boring can be estimated. The procedure used in this study characterizes the liquefaction susceptibility of various Quaternary deposits using a cumulative frequency histogram of the aggregate thickness of liquefiable material penetrated in the borings. In the methodology used by Grant and others (1991) and in this study, boring data are grouped into three categories comprising Quaternary units that have similar engineering properties. Tertiary bedrock is treated as a separate category.

The liquefaction susceptibility of each categorized unit is quantified using geotechnical data from borings drilled only in that unit. The four categories of geologic deposits used in this study (Categories I through IV) were discussed in the preceding section.

This study is primarily concerned with evaluating liquefaction that would have potential to cause damage at the ground surface. A relationship presented by Ishihara (1985) suggests that for accelerations of 0.3 g or less, liquefaction that occurs at depths greater than 40 to 50 feet will probably not cause noticeable effects or damage at the surface. Thus, this study limits the evaluation of liquefaction to only the upper

[1]American Society for Testing and Materials (ASTM) D 1586-84: 1991 Annual book of ASTM standards, vol. 04.08, Soil and rock; dimension stone; geosynthetics, p. 232-236, Standard method for penetration test and split-barrel sampling of soils.

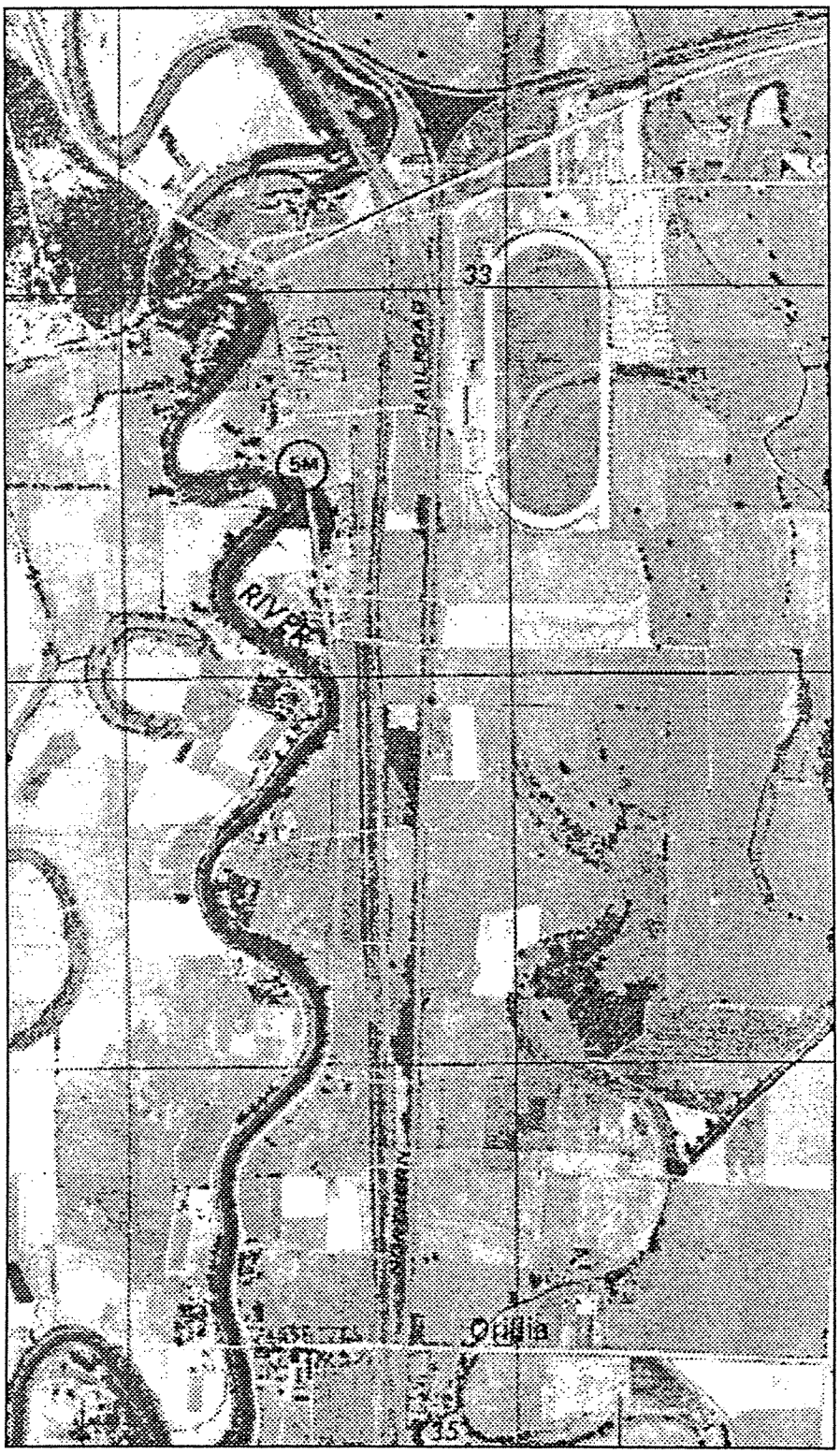

Figure 4. Sample of the U.S. Army Corps of Engineers aerial photo mosaic in the vicinity of Longacres Race Track. Dark sinuous band running vertically left of center is the Green River; abandoned channels can be seen on either side of its present course.

40 feet of the borings. In many instances the borings used in this study are less than 40 feet deep--the average depth of the borings is 24 feet. Restricting the evaluation of liquefaction to shallow depths allows a more direct comparison to historic reports.

The field evaluation methodology of Seed and others (1984, 1985) requires an estimate of the silt fraction (the fraction of a sample that passes a 200-mesh sieve) as a necessary parameter. Measured grain-size data are used when available to provide this required value. If measured data were not available, the silt fraction of a sample was estimated from the soil category assigned from the Unified Soil Classification System (ASTM D 2487-90[2]) and the conversions given in Table 2.

Table 2. Conversion of Unified Soil Classification System (USCS) soil class to silt fraction used as input to the liquefaction susceptibility analysis

USCS soil category	Silt fraction (%)
SP	5
SM	30
SP-SM	10

Cumulative frequency histograms for Category I and III deposits were made for a hypothetical earthquake of magnitude 7.3 (M 7.3) that produces a PGA of either 0.15 g or 0.30 g. This is consistent with the scenario earthquakes used by Grant and others (1991) in evaluating liquefaction susceptibility in the Seattle North and South quadrangles. Insufficient boring data were available for analyzing Category II deposits using cumulative frequency plots, and evaluation of liquefaction susceptibility for this category is based primarily on historic reports of liquefaction and generalizations about the engineering properties of Category II deposits.

The scenario earthquakes used in this study are intended to represent a major earthquake similar to the 1949 or 1965 events. It is presumed that the 7.3 magnitude would represent a large Puget Sound region earthquake occurring within or just above the subducting Juan de Fuca plate at a depth of 50-60 km. The two values of PGA used in the scenario earthquakes are presumed to bracket the range of damaging ground motions that would arise from a M 7.3 event at these depths. The choice of these scenario earthquakes is somewhat arbitrary, but consistency with the work of Grant and others (1991) was paramount.

GEOTECHNICAL BORING DATA USED IN EVALUATION OF LIQUEFACTION SUSCEPTIBILITY

The geotechnical boring data used in this study were obtained primarily from the Washington Department of Transportation (WDOT), with some additional data supplied by the King County Department of Building and Land Development. A total of 140 borings were obtained from these agencies, with the majority of these borings (97) located in the Duwamish River valley. Sample density for these data is low, and the available borings are clustered around the state highway routes and construction projects in King County that required geotechnical evaluations. The lack of data on the drift plain separating the alluvial valleys reflects the lack of engineering projects requiring extensive subsurface investigation in this area. More boring data may be available from municipalities in the Duwamish valley and the adjacent drift plain, but were not used in this preliminary liquefaction susceptibility mapping.

[2]ASTM D 2487-90, also from vol. 04.08, p. 309-319, Standard test method for classification of soils for engineering purposes.

Drilled depths for these borings ranged from 4 feet to 109 feet. Seventy-eight and sixty-two borings are located in the Renton and Auburn quadrangles, respectively. The geologic distribution of borings is as follows: 106 borings in Category I, 3 borings in Category II, 30 borings in Category III, and 1 boring in Category IV deposits. All boring logs included sample descriptions and SPT N-values; most boring logs or reports contained measured ground-water depths, a general description of drilling and sampling procedures, accessory geotechnical data (such as grain-size analyses), and a site plan showing boring locations. For this study, boring locations, geotechnical data, drilling parameters, and source of data were entered on a personal computer spreadsheet to assist in data management.

Drilling methods and sampling procedures used in geotechnical borings vary and can significantly affect the measured SPT N-values (Seed and others, 1985). The ideal drilling and sampling practice (Seed and others, 1984) for obtaining SPT N-values for evaluating liquefaction susceptibility is as follows:

- 4- to 5-in.-diameter rotary boring drilled using an upward-directed flow of bentonite mud (typically a tri-cone bit configuration);
- a sampling tube with 2.00-in. O.D. and 1.38-in. I.D. without a liner;
- AW drill rods for depths less than 50 ft, and N, BW, or NW rods for greater depths;
- 30 to 40 blows per minute delivered to the sampler;
- SPT N-value measured between 6 in. and 18 in. penetration of the sampler at the bottom of the hole; and
- 2,520 in.-lb energy delivered to the sampler (60% of theoretical maximum).

The energy delivered to the sampler is not directly measured, but it has been shown to depend on the type of hammer and size of the drill rods used in the measurement. In the United States, the most commonly used hammer configuration is a rope and pulley system using a so-called safety hammer (Seed and others, 1984). AW drill rods are typically used in most shallow geotechnical borings drilled in the Puget Sound region; consequently, SPT N-values obtained from these borings follow the recommended practice of Seed and others (1984). Use of a rope and pulley safety hammer system with AW rods would result in a 60 percent transfer of energy to the sampler at depths less than 50 feet (Seed and others, 1984), which would satisfy the recommended parameters delineated above.

However, most boring logs or reports used in this study do not completely identify the type of hammer or drill rods used in the measurement, and the drilling method is commonly not documented. Thus, there is no assurance that the recommended practices of Seed and others (1984) have been partially or completely followed. Use of AW drill rods and the safety hammer is common practice of WDOT and many of the geotechnical consultants in the Puget Sound region. Also, these practitioners regularly follow the standards given in ASTM D 1586-84 regarding the sampling tube, sampling rate, and penetration depth over which the SPT N-value is measured.

As a minimum criterion, all borings used in this study explicitly adhered to ASTM D 1586-84 in the measurement of the SPT N-value. Because the use of AW drill rods and the safety hammer is typical practice in drilling and testing conducted by the geotechnical community in the Puget Sound region, it was assumed for the purposes of this study that 60 percent of theoretical maximum energy is transferred to the sampler.

The most significant departure from the recommended procedures of Seed and others (1984) is the regular use of hollow-stem augers instead of rotary methods in drilling geotechnical borings in the Puget Sound region. A standard auger has an 8-inch O.D. and a 4-inch I.D., and drills a hole larger than the 4- to 5-inch optimal size. Water, rather than bentonite mud, is often used as the drilling fluid.

Shannon & Wilson, Inc. (1990) suggested that SPT N-values measured in borings drilled using hollow-stem augers are consistently lower than those measured in rotary-drilled borings. The certainty of this observation is obscured by the mixed use of safety- and donut-type hammers in measurement of the SPT N-values used in Shannon & Wilson, Inc. (1990). Less than 10 percent of the borings available for use in the Renton-Auburn study were drilled using rotary methods; the majority were drilled using hollow-stem augers. Thus, this study ignores the possible bias introduced into SPT N-values measured in hollow-stem auger borings on pragmatic grounds: it would not be possible to perform a defensible evaluation of liquefaction susceptibility using only the approximately 10 rotary-drilled borings distributed over the study area.

HISTORIC LIQUEFACTION

The two largest earthquakes in recent historic times in the Puget Sound region are the 1949 magnitude 7.1 Olympia and the 1965 magnitude 6.5 Seattle-Tacoma earthquakes. The study area was exposed to Mercalli Modified Intensity (MMI) VIII and VII shaking in the 1949 and 1965 events, respectively (Murphy and Ulrich, 1951; Roberts and Ulrich, 1951; von Hake and Cloud, 1967). Locations of liquefaction-caused ground failures in the study area have been summarized by Hopper (1981) and Chleborad and Schuster (1990). Seven liquefaction sites identified by the corresponding reference number in Chleborad and Schuster (1990) are shown on Plates 1 and 2. Table 3 (p. 14-16) reproduces the quotations and comments given for these sites in Chleborad and Schuster (1990).

Five of the seven sites are located in the Duwamish valley in post-Vashon alluvial deposits, and a sixth site is located along the retaining dikes at Lake Youngs. The last site lies in a post-Vashon lacustrine deposit in the Big Soos Creek valley. Thus, six of the seven historical liquefaction sites are in Category I deposits, and the remaining historical site occurs in a Category II deposit.

Table 3. Descriptions of selected ground failures in the Renton and Auburn 7.5' quadrangles (excerpted from table 2 of Chleborad and Schuster, 1990)

Location numbers correspond to ground-failure location numbers found on plate 2. Location Accuracy: A, available information allow accurate relocations, B, available information allows relocation to within a kilometer; C, available information allows relocation to within a few kilometers; D, information insufficient to locate accurately.

Quotations referenced as "written commun., 1949", or "written commun., 1965", are responses to University of Washington intensity surveys. Copies of the questionnaire responses are on file in the offices of the U.S. Geological Survey in Golden, Colorado. Metric values and explanatory information in brackets have been added to the quotations by the authors. Comments following quotations are those of the authors and are based on field observations, information from cited references, and interviews with local residents.

Loc. No.	Failure Type; (year of earthquake)	Reference Municipality or Geographic Location; County	Location Accuracy	Quotation and (or) Comment
100	Ground crack (49) Sand boils (49) Misc. effects (49)	Pacific, Wash. (south, near county line); King and Pierce Counties	A	"Beginning in the south side of Pacific (Pacific City) and running almost straight south for a 1/2 mile [0.8 km] into Pierce County, a fissure opened up, out of which at various points water boiled out (according to one observer * * * to a height of 2 feet [0.6 m]. Several inches of water were on the surface before the action stopped. The water carried with it a considerable amount of very fine sand, * * *." (Ralph Pommert, written commun., 1949). "The ground out here is peat and sand, and very pliable. The water bubbled in one place * * * approximately 1 ft [0.3 m] out of ground. Bubbled on all of our land out here and pushed up various types of soil. A very large crack on place next to ours * * * crack runs NW to SW. Imagine it was much deeper than it is now for soil and silt washed in. On next place to above a large crack * * * in berry patch. Their strawberries sank several inches. At trunks of trees fence posts, all bubbled and soil washed up. Water lines broke." (Margaret E. Farr, written commun., 1949).
	Sand boils (65)	do.	A	"Among the strange things that came along with the earthquake Thursday was one out on Roy Road, on the way to Auburn, when a housewife saw a field near her home develop its own sprinkler irrigation system. * * * As it spouted out it brought with it a foamy sand which was in piles all over the two fields." (Sumner News-Index, 5/6/65, p.1). The sand boils occurred just SW of the intersection of 2nd Street East and Valentine Road. (Mrs. Palmer Johnson, personal commun., 1988)
101	Sand boils (49)	Auburn, Wash.; King County	A	Co-workers reported seeing numerous water-sand geysers in fields adjacent to the shop at the north end of the Auburn General Depot [at the time of the 1949 quake]. (Larry Lunderg, personal commun., 1988).

Loc. No.	Failure Type; (year of earthquake)	Reference Municipality or Geographic Location; County	Location Accuracy	Quotation and (or) Comment
103	Ejection of ground water (65)	Auburn, Wash. (north side); King County	B	[Photo caption] "GROUND SEEPAGE--Jerry Keesee, city sewage plant superintendent, * * * checks seriousness of seepage around manhole on line leading into plant in North Auburn. Keesee said later it appeared to be relief point for ground water - not sewage - and that there was no apparent break in the line." (Auburn Globe-News, 5/5/65, p. 2-1).
105	Slump (49) Sandboils (49) Misc. effects (49)	Kent, Wash. (NE on Big Soos Creek); King County	A	"Water system is gravity line taken from springs east side of creek, 2 and 3 inch [5.1 and 7.6 cm] wooden pipe--about 950 feet [298.6 m]. Went to inspect pipelines 1 hour after quake, nearly all were leaking where line crosses creek and swamp, emitting white water (water mixed with clay). Water reservoir (earth constructed) all white and all springs giving more water. Above reservoir crack in earth about 100 feet [30.5 m] long north and south. At that time lower, or west side of crack, had slipped about 3 inches [8 cm] but after 24 hrs it was about 8 inches [20 cm] and appeared to be slowly settling. At one spot that was dry I could slip my hand into the crack. I went to inspect other springs, one on adjoining property about 1000 ft [300 m] north of my reservoir was emitting white water with about 4 times the volume as before the quake and brought up considerable fine sand and clay. Between this spring and mine there were numerous spots where seepage of new water occurred in spots that were dry." (John Haverinen, written commun., 1949). The reservoir mentioned in the letter [above] was located on hillside just east of Big Soos Creek and below the powerlines that cross the upper part of the hillside. The reservoir was very small, not more than a few tens of feet across. (John Haverinen Jr., personal commun., 1988).

Loc. No.	Failure Type; (year of earthquake)	Reference Municipality or Geographic Location; County	Location Accuracy	Quotation and (or) Comment
106	Sand boil (65) Ground crack (65)	Kent, Wash. (208th St. near O'brien); King County	A	"Cracked cement driveway * * * water and sand spurted through cement driveway--several ground cracks and erosions of water and sand." (Mrs. Milton Botts, written commun., 1965).
111	Settlement (65)	Renton, Wash. (Burnett and Seventh Streets); King County	B	"Mayor Custer said filling and paving to repair settling of the entire length of Burnett Street and Seventh Avenue would cost an estimated $15,000 to $20,000. Custer said the settling was along the route of the Metro sewer line, but Robert Hillis of Metro reported there was no damage to the line. * * * City Engineer Jack Wilson said Burnett and Seventh had dropped as much as two feet [0.6 m] in some places." (The Record-Chronicle, 5/5/65, p. 1,2).
	Settlement (65)	Renton, Wash. (Shattuck Street between S. 6th and S. 7th Streets); King County	A	"Foundation cracked open under house. Cement walk from street to house cracked open. House settled about 2-1/2 inches [6 cm]. Front and backyard upheaved and sunken in spots." (A.F. Salisbury, written commun., 1965).
114	Slides (49) Ground cracks (65)	Mapel Valley, Wash. (Lake Youngs); King County	C	"It has been determined * * * that [due to the 1949 earthquake] 575 yards of material were required to repair slumping in one of the retaining dikes at Lake Youngs. Also, one gate chamber casting was broken due to soil displacement. * * * Dike around Lake Youngs - cracks in three places [as a result of the 1965 earthquake]." (Kennedy-Jenks-Chilton Consultants, 1990).

LIQUEFACTION ANALYSIS

Figure 5 is a cumulative frequency histogram that shows the percentage of the total borings located in Category I deposits that equal or exceed an aggregate thickness of liquefiable soils. This figure shows the histograms for both earthquake scenarios, that is, for M 7.3 earthquakes that produce a PGA of either 0.15 g or 0.30 g at the boring site. The abscissa of the histograms measures the aggregate thickness of liquefiable material in a boring expressed as a percentage of the total depth of the boring. For borings drilled deeper than 40 ft, only the upper 40 ft were analyzed for susceptibility to liquefaction. The ordinate delineates the percentage of the total number of borings that contain a percentage of liquefiable material greater than or equal to the abscissa. Figure 5 demonstrates the logical conclusion: that more intense level ground shaking (as measured by PGA) will produce a higher incidence of liquefaction.

Figures 6 and 7 compare the cumulative histograms produced by Grant and others (1991) and this study for the two scenario earthquakes. These figures illustrate results from Category I deposits in the Renton and Auburn quadrangles and Duwamish River valley alluvium in the Seattle North and South quadrangles. Grant and others (1991) did not normalize the aggregate thickness of liquefiable material by the total depth of the boring, but report their aggregate thickness in feet. Thus, the abscissa in these figures measures the aggregate thickness in feet rather than as a percentage of total boring depth. Comparison of unnormalized thicknesses is strictly valid only if the average depth of borings in the two studies are equivalent. The average depth of the borings drilled in Category I deposits (this study) is 25 feet.

Figure 6 shows excellent agreement between cumulative frequency histograms presented in this study and by Grant and others (1991) for the 0.15 g scenario earthquake. The comparison of histograms for the 0.30 g earthquake in Figure 7 is also quite good. It appears for this case that there is a higher frequency of minor liquefaction (less than 5 feet of total thickness) in the Renton and Auburn quadrangles, but otherwise the differences between these two histograms are well within the expected variability.

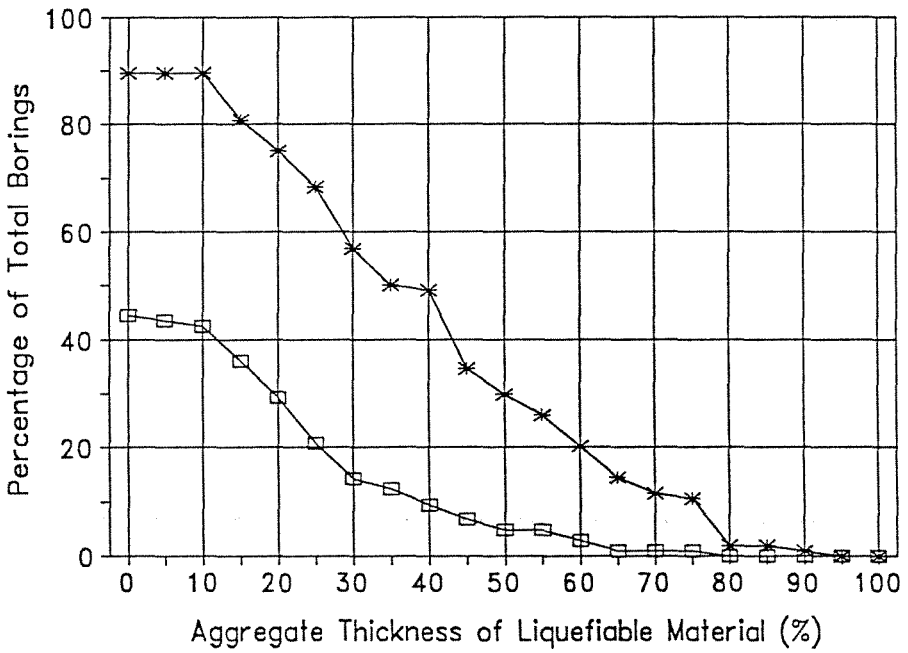

Figure 5. Cumulative frequency histogram for Category I deposits, M 7.3 event. Open boxes are data for 0.15 g PGA; crosses are data for 0.30 g PGA.

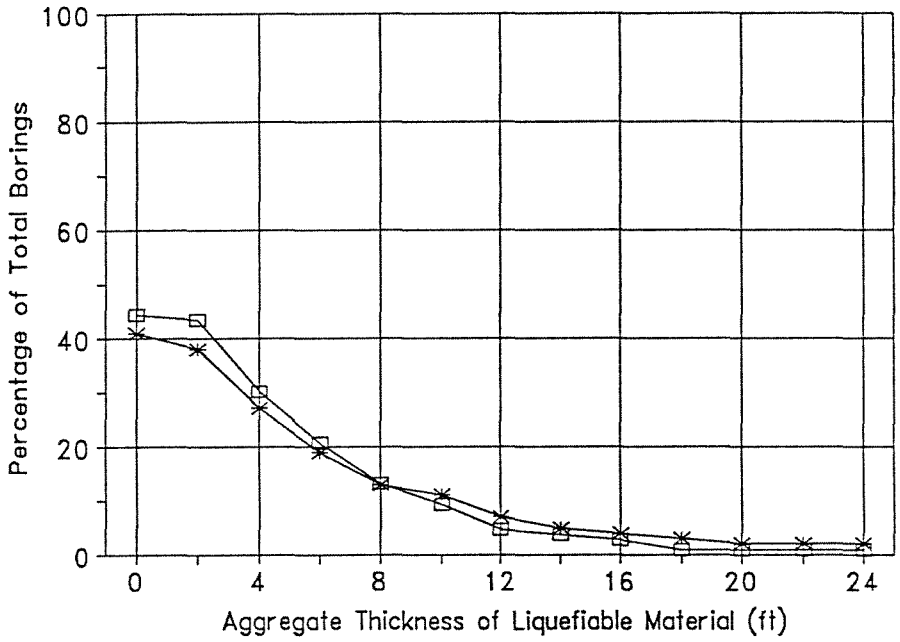

Figure 6. Comparison of data for Category I deposits, this study (open boxes), and for Holocene alluvium, Grant and others, 1991 (crosses), for M 7.3, 0.15 g events.

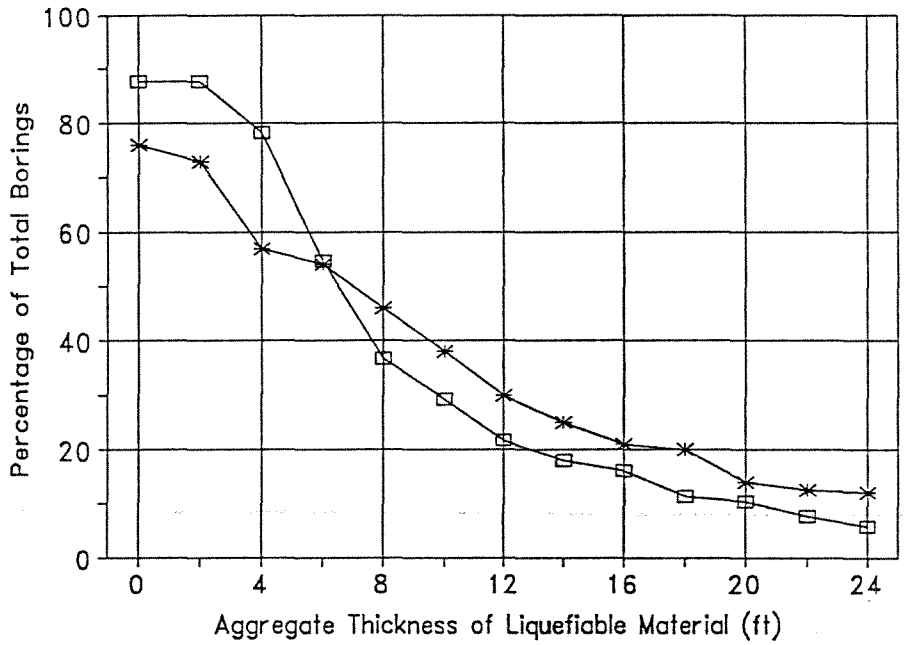

Figure 7. Comparison of data for Category I deposits, this study (open boxes), and for Holocene alluvium, Grant and others, 1991 (crosses), for M 7.3, 0.30 g events.

Table 4 presents the criteria used by Grant and others (1991) to rank the relative liquefaction susceptibility of the various soil units in their study area. Figure 6 shows that 44 percent of the borings had at least 1 foot of liquefiable material for the 0.15 g event, and 49 percent had at least 10 feet of liquefiable soils for the 0.30 g earthquake using the 25-foot average depth of borings in Category I deposits. Using these criteria, Category I deposits fall at the upper end of a moderate rating.

Table 4. Criteria used by Grant and others (1991) for rating the hazard due to liquefaction based on analysis of geotechnical boring data in the Seattle North and South quadrangles

Percentage of borings in geographic location with thickness of liquefied sediment greater than or equal to: (a) 3.05 m (10 ft) for a 0.30 g event, and, (b) 0.305 m (1 ft) for a 0.15 g event	Hazard rating
>50	High
25-50	Moderate
<25	Low

A second method of ranking the liquefaction susceptibility of a soil deposit is presented by Youd and Perkins (1987). They calculate a relative susceptibility to liquefaction using the following equation:

$$\text{Relative susceptibility (\%)} = (A \times B \times C)/10, \text{ where,}$$

A = percent of sandy soils that lie below the surface, expressed as a decimal fraction;

B = percent of these sandy soils that are liquefiable if saturated, expressed as a decimal fraction;

C = percent of these sandy soils that are saturated, expressed as a decimal fraction.

Their hazard rating scheme is based on the relative susceptibility, which is summarized in Table 5.

Table 5. Relative (liquefaction) susceptibility and associated hazard rating from Youd and Perkins, (1987)

Relative susceptibility	Hazard rating
1.0 to 10.0	High
0.1 to 1.0	Moderate
0.01 to 0.1	Low

Youd and Perkins (1987) estimate the liquefaction susceptibility of soil deposits in San Mateo County, California, using a scenario earthquake of magnitude 6.75 that produces a PGA of 0.20 g (Youd and others, 1975). This is roughly equivalent to a magnitude 7.3 earthquake with a PGA of 0.15 g with regard to the

liquefaction evaluation methodology of Seed and others (1983, 1985); their methodology is used by Youd and Perkins (1987), Grant and others (1991), and in this study.

For the 104 borings drilled in Category I deposits, an average of 72 percent of the total drilled depth above 40 feet was composed of sandy soils. This value is the factor A in the relative susceptibility calculation of Youd and Perkins (1987). Figure 6 shows that 44 percent of the borings contained some amount of liquefiable material (sandy soils that are liquefiable and are saturated). This value is the product of factors B and C of Youd and Perkins (1987). Thus, the relative susceptibility for the Category I deposits is then 3.2 percent, which corresponds to a high rating.

Six of the seven historical liquefaction sites occurred in Category I deposits. Two methods of ranking liquefaction susceptibility indicate that Category I deposits rank from the upper end of the moderate hazard to the lower end of the high hazard ratings. I interpret these somewhat arbitrary rankings, coupled with the historical record, to indicate that the Category I deposits have a high liquefaction susceptibility. *This ranking does not indicate that any specific locality within a Category I deposit will be underlain by liquefiable sands; the presence or absence of liquefiable material can only be determined by a site-specific geotechnical investigation performed by a qualified practitioner.*

On the basis of the following line of reasoning, the abandoned channels mapped in Plates 1 and 2 may represent areas of locally higher liquefaction susceptibility. Three of the historic liquefaction sites in the Duwamish valley (locs. 106, 103, and 100 on Plates 1 and 2) are close to abandoned channels. The abandoned channels are low points in the local topography and would likely have higher ground-water tables than the adjacent flood plain. Since loose, near-surface sandy soils are common throughout the Duwamish valley, the presence of a high ground-water table would significantly increase the liquefaction susceptibility of these sandy soils. Lastly, many of these abandoned channels have been filled during the development of the Duwamish valley in this century; the Longacres Race Track (section 24, T23N, R4E; Mullineaux, 1965a) is an example of a filled channel. Any or all of these factors could result in a locally higher susceptibility to liquefaction near these abandoned channels.

Only five borings used in this study are drilled in areas mapped as Category II deposits. Three borings, drilled in section 8, T21N, R5E, at the base of a slope on the eastern side of the Green River valley, penetrated less than 8 feet of colluvium before reaching pre-Vashon stratigraphic units. The ground-water table at this site generally lies below the colluvium, so this colluvial soil unit has a low susceptibility to liquefaction.

Mullineaux (1965a, 1965b) mapped only thick and continuous colluvial deposits; these typically occur on the lower parts of steep slopes. The mapped colluvium consists primarily of landslide debris and slope wash, and this material has a widely varied composition reflecting the diversity of deposits that outcrop along steep slopes in the map area. Liquefaction-induced soil failures on steep slopes would be indistinguishable from earthquake-induced landslides if a thorough post-earthquake geotechnical investigation is not made. Chleborad and Schuster (1990) report a number of landslides and associated ground cracks along steep slopes underlain by colluvium in the study area; however, little is known regarding the failure mechanism of these reported downslope movements.

Two borings, in section 35, T22N, R5E, along Big Soos Creek, were drilled in Category II deposits mapped as post-Vashon lacustrine sediments (Mullineaux, 1965b). The sample descriptions indicate that these borings were drilled in a discontinuous, thin (less than 4 ft) sandy gravel (probably recent alluvium deposited by Big Soos Creek) overlying Vashon glacial material, not in lacustrine deposits as mapped by Mullineaux (1965b). These borings were considered as part of the Category III grouping and were used in generating the Category III cumulative frequency histograms.

The post-Vashon lacustrine deposits are primarily composed of peat and silt, with only a few sandy sections (Mullineaux, 1970). These would typically be considered as having a low liquefaction susceptibility. However, there was one reported instance of liquefaction in a post-Vashon lacustrine deposit in the Big Soos Creek drainage; this report indicates that loose sandy portions of these deposits can liquefy. Thus, it seems prudent to express the variability in the observed nature of the lacustrine and colluvial deposits and the historic record of liquefaction and slope failures in these units by assigning a low to high susceptibility to Category II deposits.

Figure 8 presents the cumulative frequency histograms for Category III deposits; note that only 30 borings drilled in Vashon and older glacial and nonglacial deposits were available for constructing these histograms. Within the limitations of this data set, it appears that Vashon and older glacial and nonglacial deposits have little susceptibility for liquefaction and would have a low hazard rating. Vashon outwash and till deposits and pre-Vashon/glacial and nonglacial deposits are typically quite dense and provide excellent foundation stability (Mullineaux, 1970).

The Osceola Mudflow is described by Crandell (1963, p. A46) as "...an unsorted and unstratified mixture of subround to subangular stones in a purplish-gray plastic clayey-sand matrix". The clay content of the Osceola Mudflow would preclude any susceptibility of this deposit to earthquake-induced liquefaction. Crandell (1963) indicates that the upper 10 to 12 feet of the mudflow is oxidized and cemented and that it provides sufficient bearing capacity for light construction. However, below this weathered zone the mudflow becomes highly unstable when disturbed and near its liquid limit. This behavior might lead to various forms of settlement and ground failure during the strong shaking of a major earthquake, but this behavior is not liquefaction as defined in this study. The dynamic behavior of the unweathered Osceola Mudflow should be the subject of further investigation.

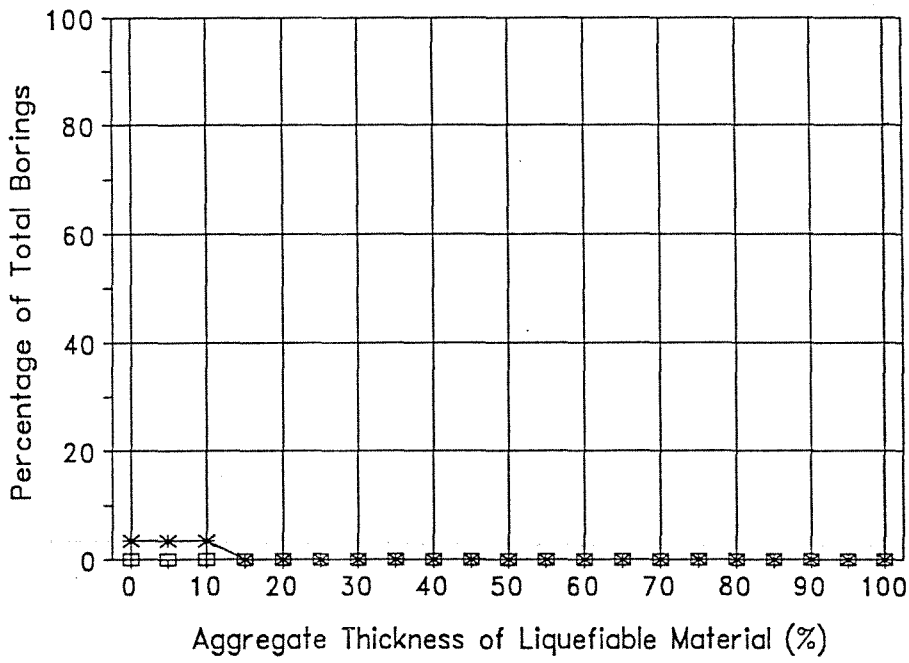

Figure 8. Cumulative frequency histogram for Category III deposits (excluding the Osceola Mudflow), M 7.3 event. Open boxes are for a 0.15 g PGA, crosses are data for 0.30 g PGA.

The Tertiary bedrock (Category IV deposits) in the study area consists of well-indurated sedimentary and igneous rocks; rock is not considered capable of liquefying during an earthquake. A single boring penetrating a part of the Tertiary sedimentary section corroborates that these rocks are well indurated. Also, there are no historical reports of liquefaction in Category IV areas. It is conceivable that there may be unmapped soil deposits of limited extent in areas of Category IV deposits and that these soil units might be susceptible to liquefaction. For this reason, Category IV deposits are considered here to have low to no susceptibility to liquefaction.

CONCLUSIONS

Table 6 summarizes this study's ranking of the liquefaction susceptibility in the Renton and Auburn quadrangles. Within the study area Holocene alluvial deposits in the Duwamish valley and the valleys of the Cedar, Green, and White Rivers are ranked as having a high liquefaction susceptibility. There are not enough borings in Holocene colluvial or lacustrine soils (Category II deposits) to determine liquefaction susceptibility for this class of deposits. The general description of these deposits (Mullineaux, 1965a, 1965b) indicates that they are comprised of materials having a low susceptibility to liquefaction. A single historical example of liquefaction in a Holocene lacustrine unit shows that liquefaction is possible in Category II deposits. In this study, Category II deposits have been ranked as having a low to high liquefaction susceptibility to reflect the variations in the observed nature of these deposits and the historic record of liquefaction. Areas underlain by Vashon and older glacial and non-glacial deposits and by the Osceola Mudflow (Category III deposits) have been assessed as having a low liquefaction susceptibility. Category IV deposits consist of all Tertiary bedrock, which is typically well indurated and not susceptible to liquefaction. However, unmapped soil deposits of limited extent may overlie Category IV units, and these soils may be susceptible to liquefaction. To accommodate this potential situation, Category IV deposits have been assigned low to nil liquefaction susceptibility.

Table 6. Ranking of the liquefaction susceptibility of the four categories of geologic deposits found in the Renton and Auburn quadrangles

Category	Liquefaction susceptibility rating
I	High
II	Low to high
III	Low
IV	Low to nil

ACKNOWLEDGMENTS

The author thanks John Bethel and Steve Bottheim (King County Department of Building and Land Development) and Al Kilian and Steve Lowell (Materials Laboratory, Washington Department of Transportation) for assisting in the compilation of their agencys' geotechnical reports and boring data for the study area. Special thanks to Carl Harris for preparing the maps and figures in this report and to the staff of the Washington Division of Geology and Earth Resources for their support. Funding to conduct this study was provided by the National Earthquake Hazard Reduction Program through U.S. Geological Survey cooperative agreement No. 14-08-001-A0509.

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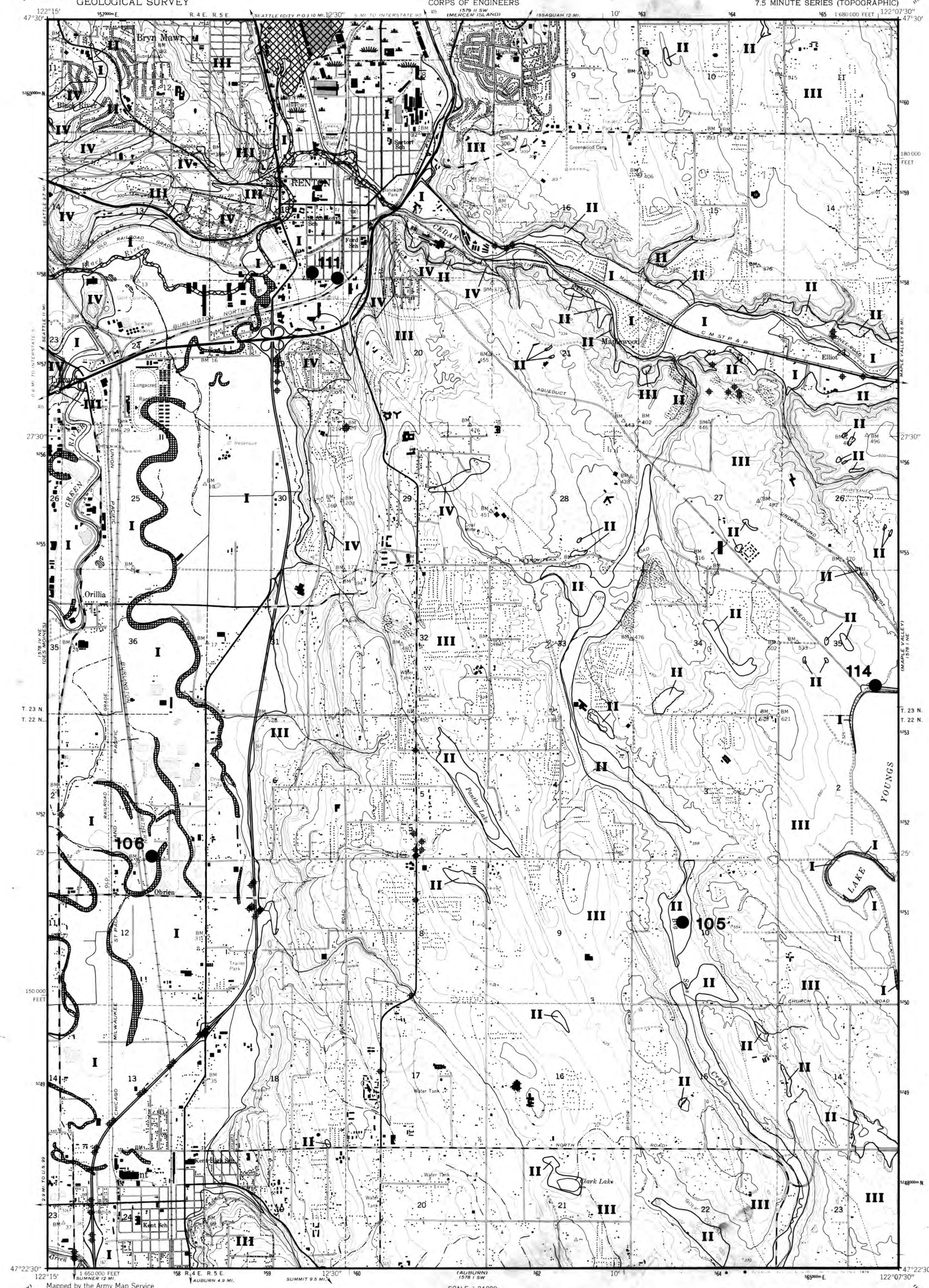
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

UNITED STATES
DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS

RENTON QUADRANGLE
WASHINGTON—KING CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)



Mapped by the Army Map Service
Published for civil use by the Geological Survey

Control by USGS, USC&GS, and USCE

Topography from aerial photographs by multiplex methods
Aerial photographs taken 1943. Field check 1949

Polyconic projection. 1927 North American datum
10,000-foot grid based on Washington coordinate system, north zone

Red tint indicates areas in which only landmark buildings are shown

No distinction is made between dwellings, barns, commercial and industrial buildings

Unchecked elevations are shown in brown

Dashed land lines indicate approximate locations

1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Revisions shown in purple compiled by the Geological Survey from aerial photographs taken 1968 and 1973. This information not field checked

Purple tint indicates extension of urban areas

SCALE 1:24000

1 0 1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 5 0 1 KILOMETER

CONTOUR INTERVAL 25 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

GN MN 0°36' 11 MILS 21½° 382 MILS
UTM GRID AND 1973 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
Interstate Route — State Route

WASHINGTON
QUADRANGLE LOCATION

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

RENTON, WASH.
N4722.5—W12207.5/7.5
1949
PHOTOREVISED 1968 AND 1973
AMS 1578 I NW—SERIES V891

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

OPEN FILE REPORT 92-7
PRELIMINARY LIQUEFACTION SUSCEPTIBILITY MAPS OF THE RENTON AND AUBURN 7.5' QUADRANGLES, WASHINGTON
PLATE 1

PRELIMINARY LIQUEFACTION SUSCEPTIBILITY MAP OF THE RENTON QUADRANGLE, WASHINGTON

by
STEPHEN P. PALMER

EXPLANATION

Geologic map units, derived from Mullineaux, 1965a.

I — CATEGORY I includes manmade fill and modified land (except fills along transportation roadways) and post-Vashon alluvium.
LIQUEFACTION SUSCEPTIBILITY: HIGH

II — CATEGORY II includes post-Vashon lacustrine deposits and colluvium.
LIQUEFACTION SUSCEPTIBILITY: LOW TO HIGH

III — CATEGORY III includes all Pleistocene glacial and nonglacial deposits and the Osceola Mudflow.
LIQUEFACTION SUSCEPTIBILTY: LOW

IV — CATEGORY IV includes all Tertiary bedrock.
LIQUEFACTION SUSCEPTIBILITY: LOW TO NIL

Contacts between categories of geologic units.

Location of geotechnical borings used in this study.

● 105 — Historic liquefaction sites identified by the corresponding reference number in Chleborad and Schuster, 1990; Table 3 reproduces the quotations and comments given for the sites in table 2 of Chleborad and Schuster, 1990.

Historic shoreline of Lake Washington and the pre-Ship Canal courses of the Black and Cedar Rivers mapped by Chrzastowski, 1983.

Historic fresh-water marshes of Lake Washington.

Abandoned channels of the Green River that do not appear to contain intermittent streams or support riparian vegetation.

Drainages and streams that appear to be abandoned channels of the Green River.

Cartography by Carl F. T. Harris

This map is meant only as a general guide to delineate areas prone to liquefaction. This map is not a substitute for a site-specific investigation to assess the potential for liquefaction for any development project. Because of the regional nature of this map and because the data used in the liquefaction susceptibility assessment have been subdivided on the basis of regional geological mapping, this map cannot be used to determine the presence or absence of liquefiable soils beneath any specific locality. To make this determination requires site-specific geotechnical investigations performed by qualified practitioners.

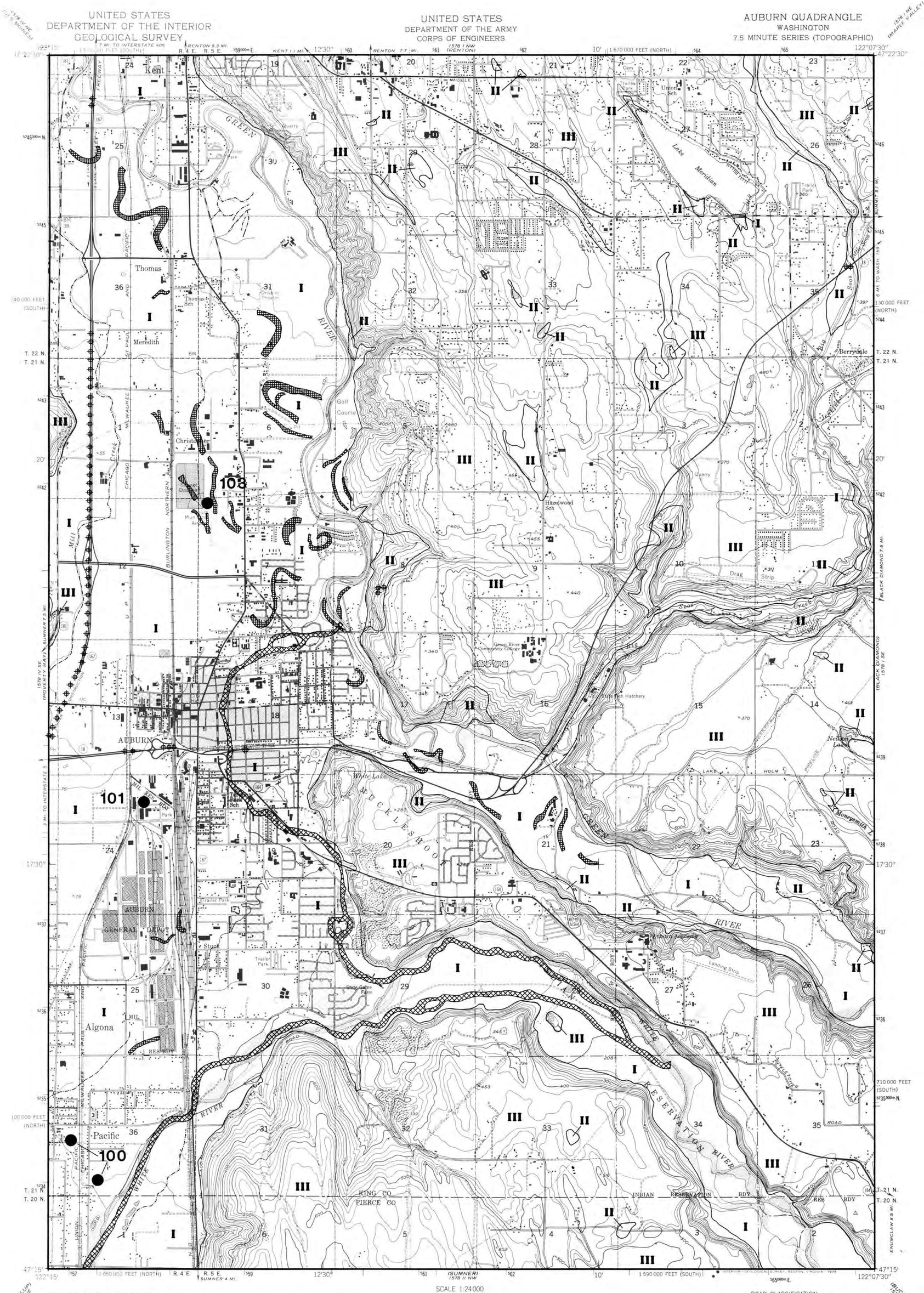
OFR 92-
PLATE 1

WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
Raymond Lasmanis, State Geologist

OPEN FILE REPORT 92-7
PRELIMINARY LIQUEFACTION SUSCEPTIBILITY MAPS OF THE
RENTON AND AUBURN 7.5' QUADRANGLES, WASHINGTON
PLATE 2

PRELIMINARY LIQUEFACTION SUSCEPTIBILITY MAP OF THE AUBURN QUADRANGLE, WASHINGTON

by
STEPHEN P. PALMER



EXPLANATION

Geologic map units, derived from Mullineaux, 1965b.

I — CATEGORY I includes manmade fill and modified land (except fills along transportation roadways) and post-Vashon alluvium.
LIQUEFACTION SUSCEPTIBILITY: HIGH

II — CATEGORY II includes post-Vashon lacustrine deposits and colluvium.
LIQUEFACTION SUSCEPTIBILITY: LOW TO HIGH

III — CATEGORY III includes all Pleistocene glacial and nonglacial deposits and the Osceola Mudflow.
LIQUEFACTION SUSCEPTIBILTY: LOW

IV — CATEGORY IV includes all Tertiary bedrock.
LIQUEFACTION SUSCEPTIBILITY: LOW TO NIL

Contacts between categories of geologic units.

Location of geotechnical borings used in this study.

● 105 — Historic liquefaction sites identified by the corresponding reference number in Chleborad and Schuster, 1990; Table 3 reproduces the quotations and comments given for the sites in table 2 of Chleborad and Schuster, 1990.

Pre-1906 courses of the White and Stuck Rivers as mapped by Willis and Smith (1899).

Abandoned channels of the Green, White, and Stuck Rivers that do not appear to contain intermittent streams or support riparian vegetation.

Drainages and streams that appear to be abandoned channels of the Green, White, and Stuck Rivers.

Cartography by Carl F. T. Harris

This map is meant only as a general guide to delineate areas prone to liquefaction. This map is not a substitute for a site-specific investigation to assess the potential for liquefaction for any development project. Because of the regional nature of this map and because the data used in the liquefaction susceptibility assessment have been subdivided on the basis of regional geological mapping, this map cannot be used to determine the presence or absence of liquefiable soils beneath any specific locality. To make this determination requires site-specific geotechnical investigations performed by qualified practitioners.

Mapped by the Army Map Service
Published for civil use by the Geological Survey

Control by USC&GS and King County Engineer Office

Topography from aerial photographs by multiplex methods. Aerial photographs taken 1943. Field check 1949

Polyconic projection. 1927 North American datum
10,000-foot grids based on Washington coordinate system, north and south zones

Red tint indicates areas in which only landmark buildings are shown

No distinction is made between dwellings, barns, commercial and industrial buildings

Unchecked elevations are shown in brown

Dashed land lines indicate approximate locations

1000-meter Universal Transverse Mercator grid ticks, zone 10, shown in blue

Revisions shown in purple compiled by the Geological Survey from aerial photographs taken 1968 and 1973. This information not field checked

Purple tint indicates extension of urban areas

UTM GRID AND 1973 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24000

CONTOUR INTERVAL 25 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION
Heavy-duty — Light-duty
Medium-duty — Unimproved dirt
State Route

QUADRANGLE LOCATION

AUBURN, WASH.
N4715—W12207.5/7.5

1949
PHOTOREVISED 1968 AND 1973
AMS 1578 I SW—SERIES V891

TUBE
QE175
A3
O6
92-7
Plate 2
copy 3