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Radium distribution map and radon potential in the Bonneville Power Administration Service Area

by

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RADIUM DISTRIBUTION MAP AND RADON POTENTIAL IN THE BONNEVILLE POWER ADMINISTRATION SERVICE AREA

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ABSTRACT

Aerial gamma-ray data covering an area from 41 to 49 degrees north latitude and 108 to 125 degrees west longitude were compiled to produce a map showing the distribution of radium (^{226}Ra) in near-surface materials in the Bonneville Power Administration service area covering Washington, Oregon, and Idaho, and parts of Montana and Wyoming. Northern parts of California, Nevada, and Utah also show on the map. A comparison of measurements of indoor concentration levels of radon (^{222}Rn) in homes with the apparent surface concentration of radium shows that aerial gamma-ray data provide a first order estimate of the relative amounts of indoor radon for township-sized areas where soils have low to moderate permeability. The comparison also shows areas with significantly higher indoor radon levels than the general trend of the data. These unusually high areas are almost all characterized by soils that have higher intrinsic permeabilities, based on available county soil descriptions. The greatest permeability effect occurs for drier soils in the eastern part of the area. Some unusually high areas are also characterized by steep slopes. Eighty soil surveys for Washington, Oregon, Idaho, and Montana were examined for the presence of highly permeable soils and a map showing large areas of highly permeable soils for the counties studied was created. The radon potential of areas covered by both the radium map and the permeability map may be estimated.

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INTRODUCTION

In 1984, a house located in Pennsylvania within the Reading Prong physiographic province was discovered to have indoor radon (^{222}Rn) concentrations exceeding 2000 picocuries per liter (pCi/L) and other houses with elevated indoor radon levels (greater than 4 pCi/L) were quickly identified in the same neighborhood (Gaertner, 1987). The State of Pennsylvania immediately began an extensive program to determine the extent of the problem by distributing radon detection kits to homeowners located within the Reading Prong (Gerusky, 1987). The results of this program showed that about sixty percent of the houses measured had indoor radon concentrations exceeding a 4 pCi/L guideline later set by the U.S. Environmental Protection Agency (EPA, press release, August, 1986). Data from other parts of the United States soon made it obvious that the Reading Prong is not the only place with an indoor radon hazard. The possibly widespread nature of the indoor radon hazard made efficient identification of those parts of the nation with the greatest potential for indoor radon problems an important concern. Because aerial gamma-ray measurements provide an estimate of the near-surface concentrations of radium (^{226}Ra), the immediate precursor of radon, aerial gamma-ray data can be used to make maps showing the distribution of ^{226}Ra. Such maps can be used to estimate the relative concentrations of radon in soil gas which can be used as an important indicator of relative radon hazards.

The U.S. Geological Survey (USGS), under an interagency agreement with the Bonneville Power Administration (BPA) and the EPA, undertook the compilation of existing aerial gamma-ray data to produce a map showing the distribution of radium within the BPA service area. The data used were acquired as part of the National Uranium Resource Evaluation (NURE) Program sponsored by the U.S. Energy and Research Development Administration and its successor the U.S. Department of Energy during the period 1975-1983. Under the terms of the interagency agreement BPA supplied the USGS with indoor radon data obtained as part of a program designed to assess indoor radon levels in the BPA service area. The indoor radon data and the aerial gamma-ray data were examined to determine whether a relationship exists between them. Available geologic maps were also used to investigate any correlations with mapped geology. County soil maps were used to investigate those soil properties that could play a role in controlling the levels of indoor radon.

This report 1) describes the geology of the Pacific Northwest; 2) describes how aeroradiometric data may be used to derive a radium map and presents a map showing the distribution of radium in surface materials in the Pacific Northwest (including the Bonneville Power service area and some adjacent areas); 3) discusses the relation between geology and radon; 4) develops the relation between surface radium, indoor radon, and other geologic factors in the Pacific Northwest; and 5) describes how data in this report may be used to evaluate indoor radon potential.

GEOLOGIC SETTING

The area studied (Figure 1 and Figure 2) extends from the western edge of the High Plains of the north-central U.S. westward through the northern Rocky Mountains and the northern Cordillera to the Cascade Range of the Pacific coast. In general, as one traverses from east to west, the rocks exposed are of progressively younger age, those of the eastern part being derived from Precambrian continental crust, and those in the western part being derived from progressively younger oceanic crust. Uranium and related radionuclides are typically more abundant in older continental crust than in young oceanic crust. The average uranium and radium content of the rocks is therefore expected to decrease from east to west across the area. The aerial gamma-ray data confirm this expectation.

The post-Precambrian geologic history of the area is characterized by successive periods of accretion of oceanic crustal material at the western edge of a craton composed of Precambrian continental crust. These accretions occurred through subduction of oceanic crust beneath the continental margin and subsequent orogenesis characterized by periods of eastward thrusting of sedimentary rocks, extensive volcanism in continental margin volcanic arcs, emplacement of batholithic intrusives, and subsequent relaxation, extension, uplift, and extrusion of plateau volcanic rocks. The earliest stages of orogenesis also involved the western edge of the Precambrian craton and the sedimentary section that had accumulated on it. The result is a complex pattern of interior mountain ranges underlain by folded and faulted sedimentary and intrusive rocks, basins filled with sedimentary or volcanic rocks, high plateaus underlain by volcanic rocks, and coastal volcanic mountain ranges.

In most recent geologic time, the northern part of the area was subjected to continental glaciation which significantly altered the landscape and surface geology. For example, floodwaters from melting glacial ice transported coarse alluvium down the valley of the Columbia River, its tributaries, and other rivers. This coarse alluvium was deposited along valley bottoms in areas like those in and adjacent to the city of Spokane. Accompanying and following glaciation, strong winds redistributed the fine-grained part of some of the glacial materials into locally significant deposits of loess and windblown sand. In the Puget Lowland, glaciers left behind thick deposits of glacial till and outwash gravels.

Finally, volcanic activity during the past several thousand years has also affected parts of the area. Locally, thick layers of ash from volcanoes in western Washington and Oregon have periodically covered the ground east of the volcanic sources. In valleys draining the slopes of the major volcanoes, periodic eruptive events have triggered major debris flows.

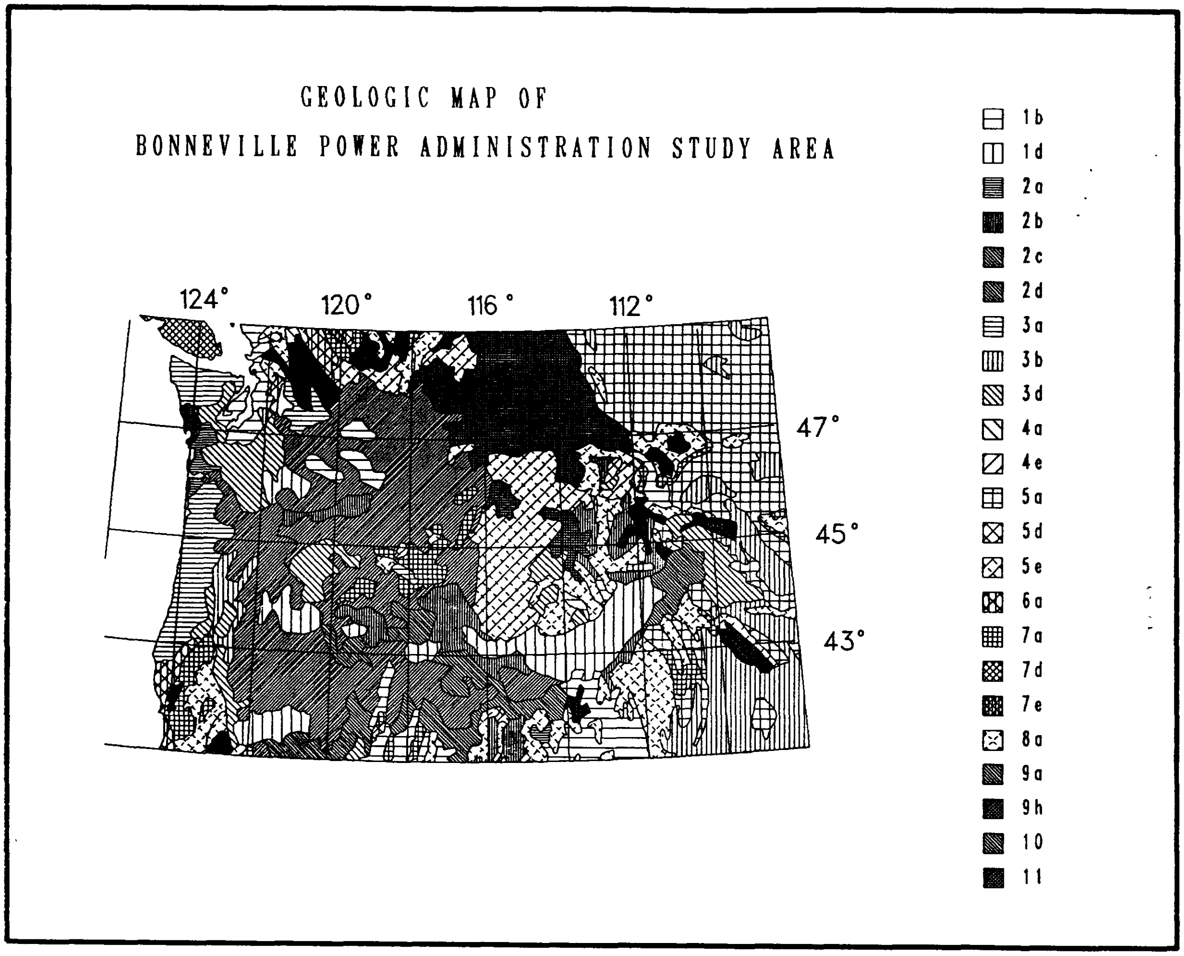

Figure 1. Generalized geologic map of the study area. Label key - - Ages:
1 - Quaternary; 2 - Tertiary, Neogene; 3 - Tertiary, Paleogene; 4 - Tertiary and Cretaceous; 5 - Cretaceous; 6 - Cretaceous and Jurassic; 7 - Jurassic and Triassic; 8 - Paleozoic; 9 - Proterozoic; 10 - Precambrian (undivided); 11 - ultramafic rocks.
Lithologies:
a - marine sedimentary rocks; b - continental sedimentary rocks; c - felsic volcanic rocks; d - intermediate and mafic volcanic rocks; e - felsic intrusive rocks; h - undifferentiated igneous and metamorphic rocks.
Figure modified from Drummond (1983).

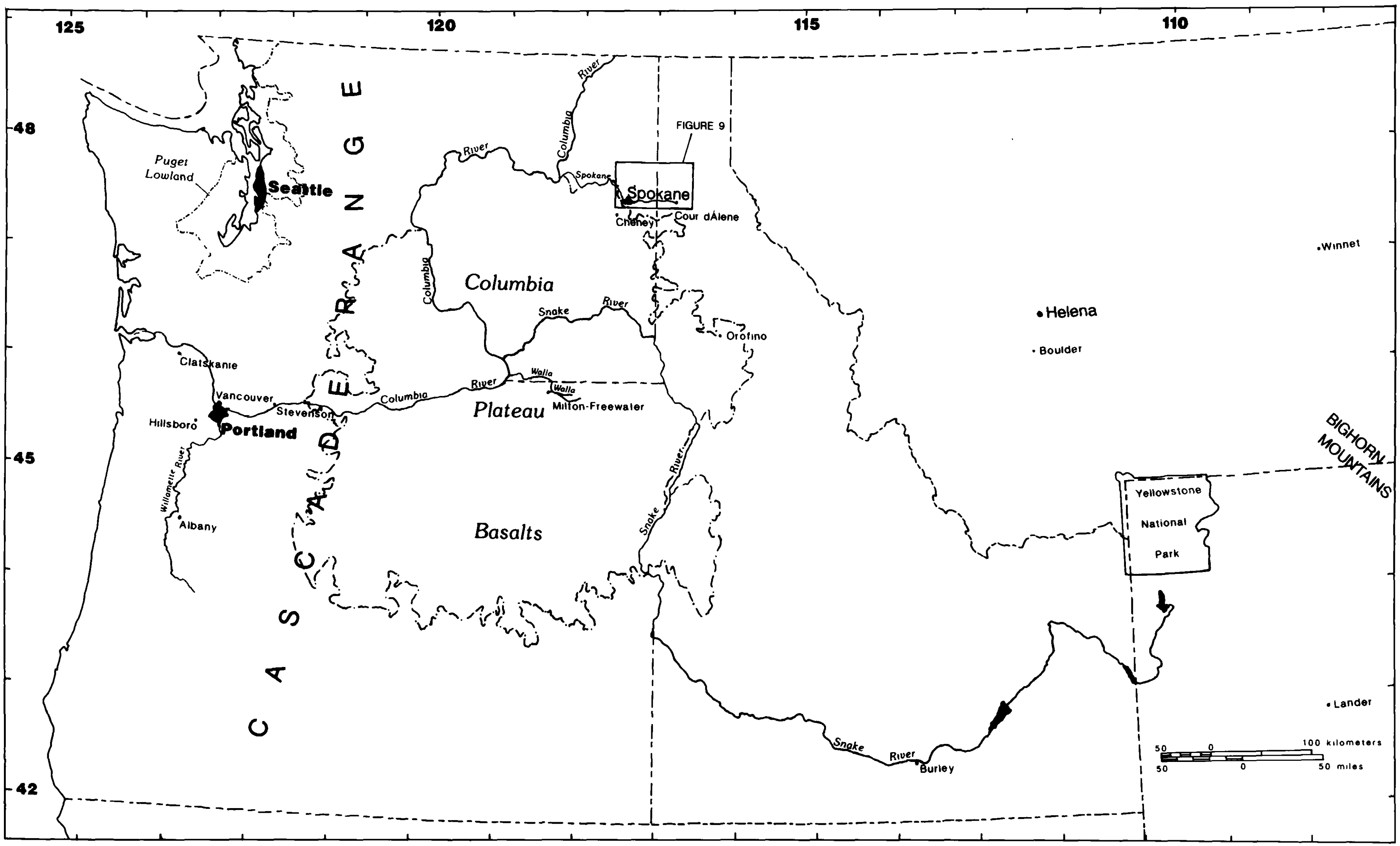

Figure 2- Map of the study area showing locations of various cultural and physiographic features discussed in the text

AERIAL GAMMA-RAY DATA

Aerial gamma-ray surveys of the natural environment measure the intensities of certain gamma rays produced by the radioactive decay of ^{40}K, ^{214}Bi, and ^{208}Tl. ^{214}Bi and ^{208}Tl are members of the ^{238}U and ^{232}Th decay series, respectively. Because ^{214}Bi is produced by the decay of ^{226}Ra and its intermediate short-lived isotopes (^{222}Rn, 3.8 days; ^{218}Po, 3 min.; ^{214}Pb, 27 min.), the ^{214}Bi gamma-ray flux density can be used to estimate the concentration of ^{226}Ra in the ground. The radium concentrations can then be used as an indication of the relative amounts of radon in the soil gas if a consistent fraction of the radon generated escapes to the soil pores. Figure 3 shows the study area and the names of the two-degree quadrangles (one degree of latitude by two degrees of longitude) whose data were used to compile the map of radium concentrations in the study area. A list of the Open File Reports that describe the surveys and data collection for the two-degree quadrangles can be found in Bendix Field Engineering Corporation (1983). The aerial surveys were flown using fixed-wing and helicopter systems with 33-50 L of thallium-activated sodium iodide (NaI(Tl)) crystals. The nominal survey altitude used was 122 m. The data were corrected by the contractors for background from aircraft contamination and cosmic rays, altitude variations, airborne ^{214}Bi, and Compton scattering. The gamma-ray systems were calibrated using the calibration pads at Grand Junction, Colorado (Ward, 1978) and the dynamic test strip at Lake Mead, Arizona (Geodata International, 1977).

DATA PROCESSING AND MAP COMPILATION

Although most of the data gathering systems were calibrated to convert the data to the apparent surface concentrations of potassium (percent K), uranium (parts per million (ppm) eU), and thorium (ppm eTh), the data were found to need datum leveling both within and between quadrangles. (Note that the "e" referred to means "equivalent" because the uranium and thorium contents are calculated rather than measured directly.) Figure 4 shows the data for the Havre Quadrangle in Montana before and after levelingcorrections were applied. In all cases the leveling corrections applied were done using multiplication factors. The use of multiplication factors assumes that the level differences are the result of changes in the effective calibration factors. Such changes could be caused by instrument gain drift or differences in soil moisture content in the survey area.

After all leveling corrections were applied, the data were gridded using a minimum curvature algorithm (Briggs, 1974; Webring, 1981). The gridding interval used is 2.54 km. The data were converted to concentrations of ^{226}Ra expressed as picocuries per gram (pCi/g) using the relationship that 1 ppm eU is equal to 0.33267 pCi/g ^{226}Ra. The resulting map is shown in Figure 5.

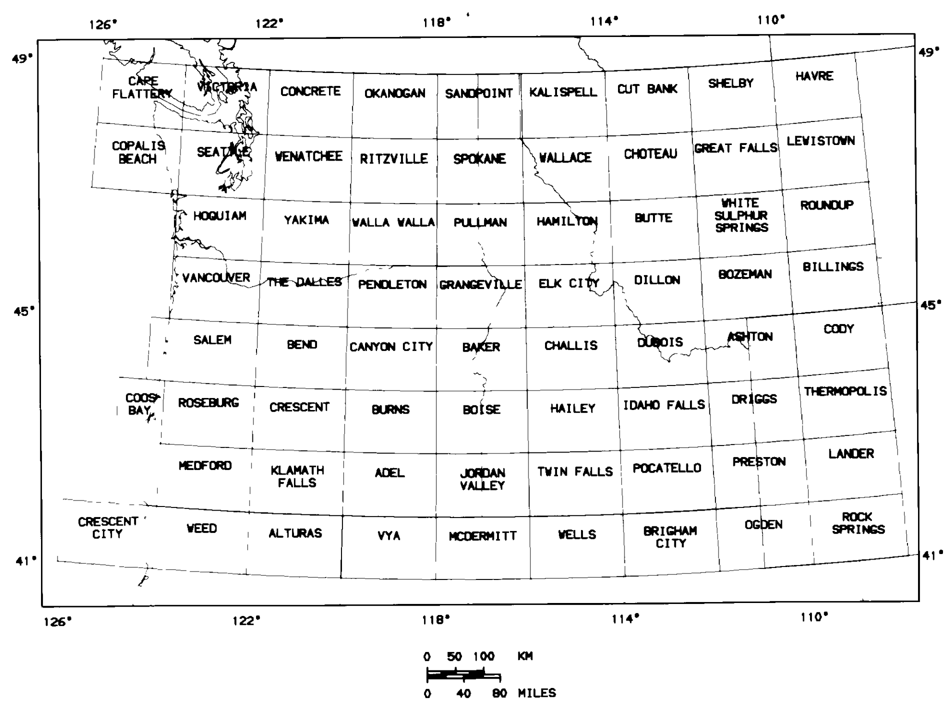

Figure 3. Index map showing the names of the National Two-degree Mapping Sheets (NTMS) quadrangles that were used to compile the ^{226}Ra map from the NURE data.

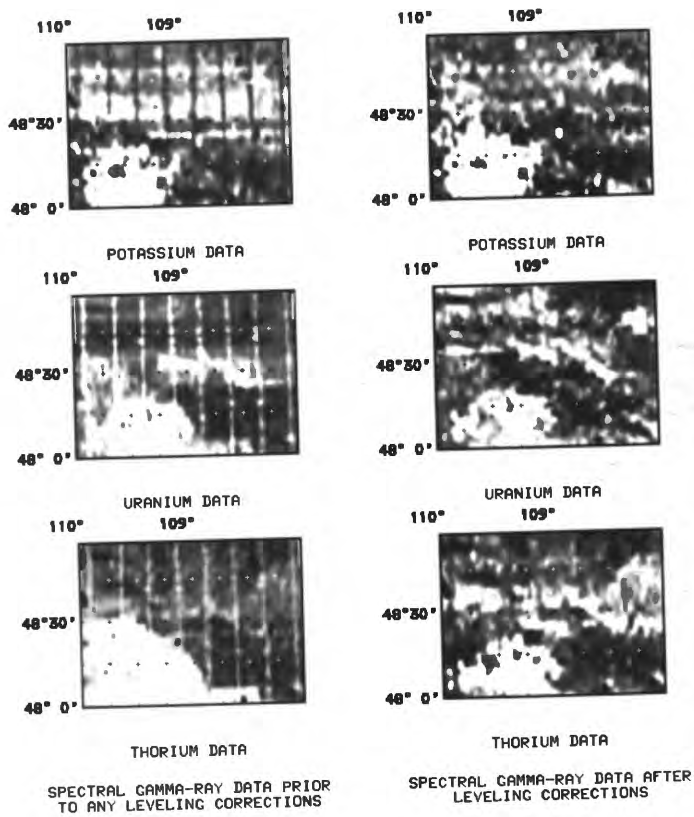

Figure 4. Illustration showing the type of leveling errors frequently encountered in the aerial gamma-ray data and the results after corrections have been applied. Data from the Havre quadrangle, Montana. For location see Figure 3, upper right-hand corner.

RADIUM DISTRIBUTION

The surface radium distribution across the Pacific Northwest (Figure 5) generally reflects the regional geochemistry of the bedrock. (For the location of geographic features discussed below please refer to Figure 2.) Most of the study area west of longitude 120°W has low surface radium content (less than 0.5 pCi/g); however, within this area a zone which extends from Portland southward along the Willamette River valley to coastal areas along the southern coast of Oregon is somewhat higher than elsewhere. This somewhat higher area is underlain, in part, by early Tertiary sedimentary and volcanic rocks. These sedimentary rocks include arkosic and feldspathic sandstones that were derived from source areas more uraniferous than the rocks that now surround them. East of 120°W longitude surface materials generally show moderate radium concentrations (0.5-1.0 pCi/g) to locally high radium concentrations (>1.0 pCi/g) except for a broad area of lower values (<0.3 pCi/g) that extends from north-central Oregon to southeast Washington (see discussion of this area below). The high radium areas (>1.0 pCi/g) are associated with three groups of rocks: 1) Tertiary to Quaternary felsic volcanic rocks and the Tertiary to Quaternary sedimentary rocks derived from them; 2) Cretaceous and Tertiary felsic intrusive rocks and the Tertiary to Quaternary sedimentary rocks derived from them; and 3) Cretaceous sedimentary rocks, specifically dark, marine, locally phosphatic shales, of the western High Plains.

Several areas with high radium felsic volcanic rocks and sedimentary rocks derived from them occur near the Snake River Plain in southern Idaho including volcanic rocks that underly most of Yellowstone National Park, an area south of Burley, Idaho, and the southwesternmost corner of Idaho. High radium soils associated with felsic intrusive rocks occur near Boulder, Montana, east of Orofino, Idaho, west of Salmon, Idaho, just west of Stanley, Idaho and throughout various parts of northeast Washington and northernmost Idaho. In the latter area, the aeroradiometric signature of the radioactive intrusive rocks has been subdued by a cover of glacial sediments. High radium Cretaceous sediments occur near Lander, Wyoming and Winnett, Montana, and surround the Bighorn Mountains in northern Wyoming and southern Montana. Young, high radium sedimentary rocks derived from the granites near Boulder, Montana extend along the river valley from Helena, Montana to the northwest several tens of miles.

The area underlain by the Columbia Plateau basalt has two areas with distinctly different average radium levels that are separated by a curved line that extends from north-central Oregon to the southeast corner of Washington. Southeast of that line the average radium values are generally less than 0.3 pCi/g (the area mentioned above) whereas to the northwest the values are generally greater than 0.6 pCi/g radium. Values less than 0.3 pCi/g are normal for rocks of basaltic composition; thus the values northwest of the line seem anomalous. The cause for this difference is uncertain. One possible explanation is that the surficial materials in the northern part of the area underlain by the Columbia Plateau basalt are materials brought in by the Columbia River and its tributaries during post-glacial flooding from more

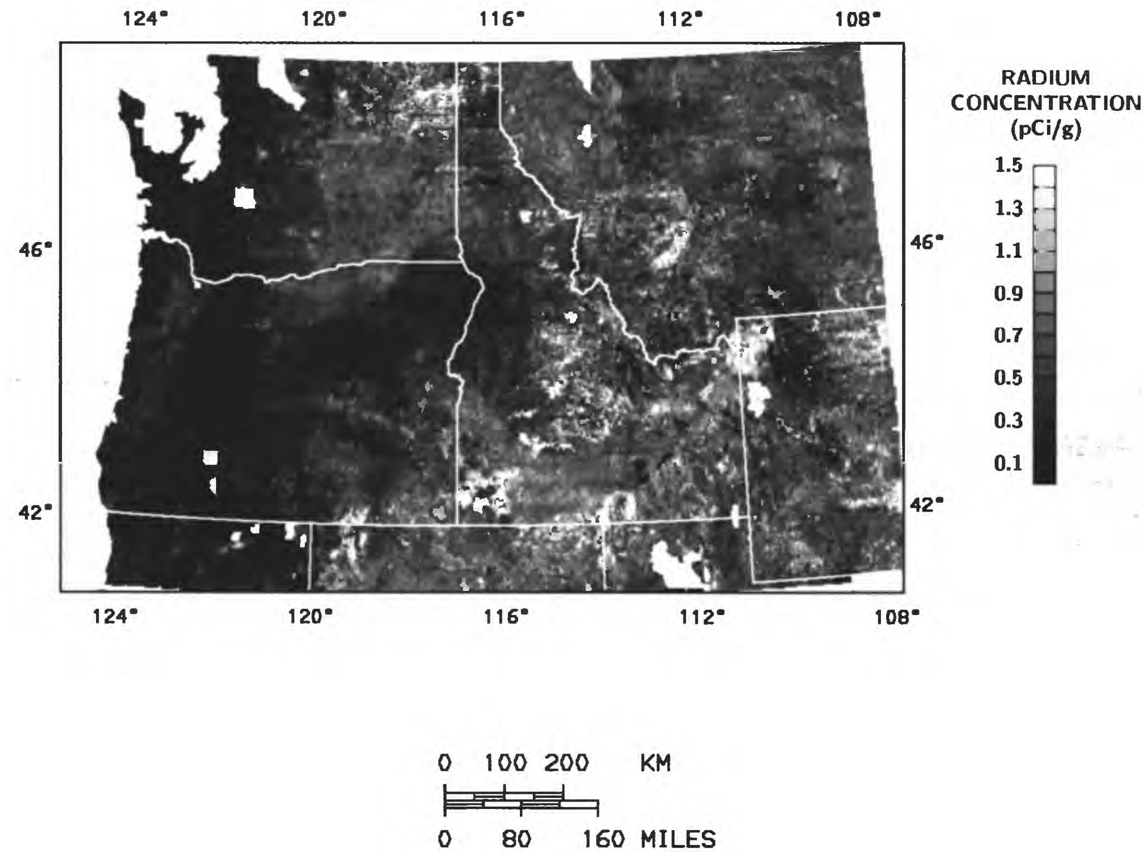

Figure 5. Gray scale map of the Bonneville Power service area and adjacent areas showing the apparent surface concentration of ^{226}Ra. Great Salt Lake, Puget Sound, state boundaries, various national park areas, and other small blocks are areas of no data and show as white in the figure.

radioactive rocks along the Canadian border. These materials might then have been redistributed by winds. The curved line along which the change in average radium levels occurs is approximately coincident with a regional drainage divide between tributaries of the Columbia River and tributaries of other river systems to the south. This divide may have limited the redistribution of river alluvium by winds.

RADON AND GEOLOGY

Background

The radon potential of rocks and soils is controlled by 1) the radium content of the mineral matter; 2) the emanating power of the mineral matter; 3) the permeability of the soil and underlying rock; and 4) the moisture content of the soil pores. These four parameters control how much radon is produced by the soil and escapes to the pores and how readily it can migrate through the soil. The indoor radon potential is further influenced by house construction and related characteristics which control the rate of soil gas entry into the structure. In this study we attempt to relate geologic data to indoor radon levels, we do not deal with the non-geologic causes of variability.

Because ^{222}Rn is directly produced by the decay of ^{226}Ra, the total amount of radon produced in the soil is directly proportional to the radium concentration in the mineral matter. The radium map of the Pacific Northwest developed during the course of this study provides us with direct information on the radium content of soils.

The amount of radon in the gas contained in the soil pores is, however, dependent upon the fraction of radon that emanates from the mineral matter of the soil into the pores (and to a lesser degree on the density and porosity of the soil). This fraction is known as the emanating power and is largely controlled by the size of the mineral grains and the distribution of the radium within the materials that compose the rocks and soils (Tanner, 1964). Where the radium is disseminated throughout the volume of each mineral grain, emanating power is low. Where radium largely occurs as coating on mineral grains next to pores, the emanating power is high. Emanating power for most soils is in the range of 0.20 to 0.50. Regional and areal variations in emanating power are not well known for any part of the country and we have assumed for the purposes of this study that emanating power remains within a relatively narrow range in the Pacific Northwest. With this assumption, the relative concentrations of radium in the ground can be used as a first order estimate of the relative radon concentrations in the soil gas.

The intrinsic permeability of the soil controls the relative effectiveness of the two principal modes of transport of radon, molecular diffusion and convective flow. Molecular diffusion of radon in soil gas (or the gas in rock pores or fractures) occurs through the random motion of radon atoms through the gas in the pores. Convective flow occurs wherever air pressure differences occur and the soil gas itself moves carrying the entrained radon with it. Radon has a fixed lifespan with about one half of the radon disappearing every 3.8 days. Nazaroff and others (1986), Sextro and others (1987), Nazaroff, Moed, and Sextro (1988), and

Tanner (written commun., 1988, 1989) present theoretical equations and calculations that show that radon transport by diffusion is dominant for materials with intrinsic permeabilities of 10^{-7} cm^2 or less and that convection is the dominant process for permeabilities of 10^{-7} cm^2 or greater. For typical dry materials of average porosity (about 0.3) the radon diffusion length is on the order of 1 m and for water-saturated materials the diffusion length is 1 cm or less. This suggests that dry materials with permeabilities less than 10^{-7} cm^2 will supply radon for distances of 1 m or less. For materials with permeabilities greater than 10^{-5} cm^2, the transport by convective flow can be 5 m or more (Nazaroff, Lewis, and others, 1986; Tanner, written commun., 1989).

A permeability of 10^{-7} cm^2 corresponds to soil materials that are somewhere between a fine to medium clean sand. Coarse clean gravel has a permeability of about 10^{-5} cm^2. Such materials are unusual as soils thus it is somewhat unusual for convective flow to be the dominant means of soil gas transport. Even where medium to coarse sand and gravel are present in soil or substrate they are often mixed with finer sand- and silt-sized materials which lower the permeability of the soil.

In working with soil surveys to evaluate the effects of permeability two permeability terms used by soil scientists, rapid and very rapid, are important because they lie across and above this permeability threshold between diffusion- and convective-dominated soil gas transport. Soils with rapid permeability (6 to 20 in/hr) have intrinsic permeabilities of 0.5 to 1.7 x 10^{-7} cm^2 whereas soils with very rapid permeability (>20 in/hr) have intrinsic permeabilities >1.7 x 10^{-7} cm^2. Soils described as rapidly permeable thus include the permeability value where the transition from diffusion-dominated to flow-dominated transport occurs. Soils described as very rapidly permeable are clearly flow-dominated unless soil moisture lowers the effective permeability.

Soil moisture content affects emanating power and also affects transport processes. Moisture in the soil pores increases the emanating power of a material to the soil gas for moisture contents up to about 30 percent of water saturation. For soil moisture contents up to about 30 percent the water occurs as films on the mineral grains. The water slows or stops more radon atoms in the pore space as they recoil out of the mineral matter into the pore space rather than letting them traverse the pore space and embed in another mineral grain (Kirikov, Bogoslovskaya, and Gorshkov, 1932; Hahn, 1936; Starik and Melikova, 1957). The radon then diffuses from the thin water film into the pore space. However, with increasing soil pore moisture content the effective emanating power approaches zero because the water fills the soil pores, replaces the soil gas, and retains the radon (Morozova and Mukhraneli, 1971). Diffusion of radon in water is about 10^{-2} times slower than diffusion in air. Filling of the pore spaces with water thus lowers the mean diffusive migration distance. Increases in soil pore moisture affects convective transport of soil gas by lowering the effective gas permeability of the soil, and saturation with water stops all convective transport of soil gas.

Empirical evidence from site specific studies of indoor radon levels suggest that topography can affect radon levels indoors locally (Nelson Thurman, written commun., 1987; A.B. Tanner, oral commun., 1988). In this study we do not have site specific information however we have noted that for some townships where soils are moderately permeable but the housing is largely built on steep slopes (Clatskanie, Oregon area, ORR04WT07N, Appendices 1 and 2) elevated average radon levels occur (2.8 pCi/L for 114 houses). Houses on hillslopes or near the edges of hillslopes often have higher radon readings than similar houses sited on similar rocks and soils nearby. The mechanisms that influence greater radon availability on sloped surfaces are not known but some of the factors may include 1) higher permeability of sloped soils due to the washing out of fine-grained material by moving water and due to cracks in soil and underlying bedrock caused by mass movement downslope; 2) better drainage for soils on hillslopes, this lowers the average soil moisture level and thus increases diffusive and convective transport; and 3) thinner soils on hillslopes usually cause most foundations to be dug into bedrock where air moving through bedrock fractures has direct access to the foundation.

Analysis of the Pacific Northwest data

In our study of the indoor radon, geologic, and soil data for the Pacific Northwest we used the following approach:

1. We established the relationship between the surface radium content and indoor radon levels for townships across the study area and compared this data to other areas of the country;

2. We evaluated the geology and soils of the townships for other factors (permeability, slope, and soil moisture) that influence the relationship; and

3. We developed a procedure for estimating indoor radon potential using the most critical factors (radium content and permeability).

Other investigators have studied the relation between surface radium and radon in soil gas and indoor radon. Gundersen and others (1988) measured the apparent surface concentrations of radium and concentrations of radon in soil gas at 0.75 m depth at the same sites in a variety of rocks in Montgomery County, Maryland. The average values for the different rock types show an approximately linear dependency of the soil gas concentration of radon upon the radium concentrations as shown in Figure 6. The data points presented in the figure are average values for the different rock types and the line represents a calculated linear fit to the data. The linear fit results in the equation:

$$1)\ \text{Soil gas } {}^{222}\text{Rn (pCi/L)} = -654.2 + 2367.5\ {}^{226}\text{Ra (pCi/g)}$$

The use of the linear equation to fit the data was justified by the following: 1) the available data are few in number and do not cover a large range of values and 2) a linear dependency is the simplest case. Because ^{226}Ra is the direct parent of ^{222}Rn, it is possible to calculate the total amount of radon produced by the decay of radium in the mineral matter, but not all of the radon escapes from mineral grains into the soil gas. For that reason an equation of

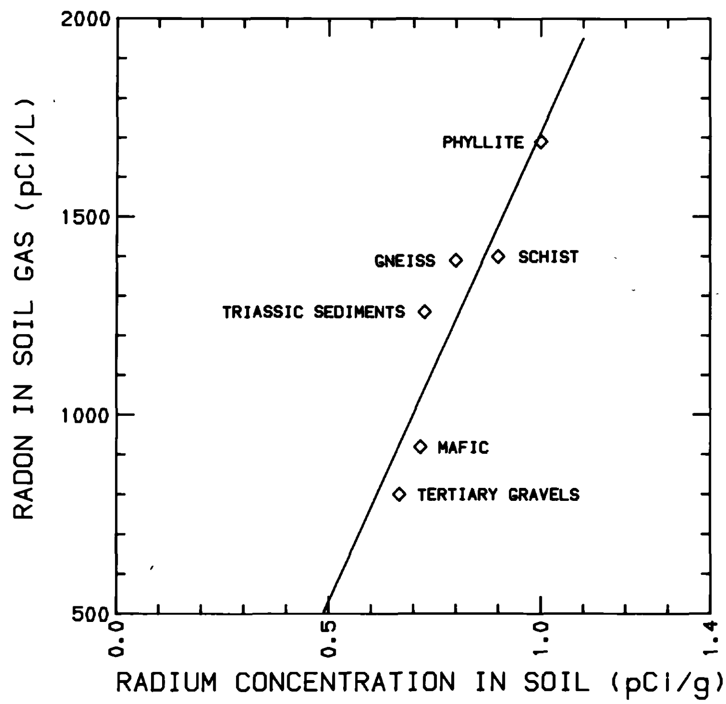

Figure 6. Average radon concentrations in soil gas versus average surface gamma-ray measurements of radium for various rock types in Montgomery County, Maryland.

the general form given by equation 1) should apply to any geologic material, but there is no reason to expect that the same coefficients in the equation will apply to various geologic materials unless the radon emanating powers of the different materials are approximately the same. The fact that the linear equation reasonably represents the data suggests that the general geologic and geochemical conditions of the measured geologic units in Montgomery County, Maryland have resulted in near-surface radium distributions that produce approximately equal radon emanating powers. Because the equation provides a predictive capability, these data provide corroboration and support for the use of surface gamma-ray measurements to predict relative amounts of radon in soil gas.

In September of 1987, the New Jersey Department of Environmental Protection (NJDEP) released data showing the regional distribution of indoor radon concentrations in New Jersey (NJDEP, 1987). The data consisted of more than 5000 measurements of indoor radon concentrations. Figure 7 presents the average indoor radon data versus average radium concentrations from aeroradiometric surveys for counties in New Jersey. These data exhibit an approximately linear trend up to radium concentrations on the order of 1 pCi/g (picocuries per gram). The solid line in the figure represents a linear least-squared fit to the data with the equation:

$$2)\quad \text{Indoor } ^{222}\text{Rn (pCi/L)} = -2.05 + 8.14\ ^{226}\text{Ra (pCi/g)}$$

The correlation coefficient calculated for these data is 0.77. This suggests that aeroradiometric data may be used to predict indoor radon levels as well.

BPA conducted a survey of indoor radon levels in homes within its service area (covered by the map in Figure 3). The data were furnished to us by BPA with the data located by township and range. In order to have a common coordinate system with the radium data, each township and range area was assigned the longitude and latitude coordinates of its approximate geographic center. Thesecoordinates were then used to determine the location of a corresponding grid cell in the radium data set. The apparent surface radium content of the grid cell (2.5 by 2.5 km) was then calculated and used as the surface radium content for the township. Variations in the size of the grid cell did not significantly change the calculated radium content of the cell. Appendix 1 contains a listing, by township, of the latitude, longitude, number of radon measurements (points), average, median, and maximum radon measurement for the township, and the calculated surface radium content from the radium map. All townships where at least five houses were measured are reported in this appendix.

Figure 8 shows the average indoor radon level versus the apparent surface concentration of radium for townships where the number of sampled houses (points) is 25 or more (these data are listed separately in Appendix 2 with annotations regarding the geology and soils). We used only those townships with at least 25 sampled houses in order to eliminate townships where indoor radon levels are not well characterized; however, a brief examination of

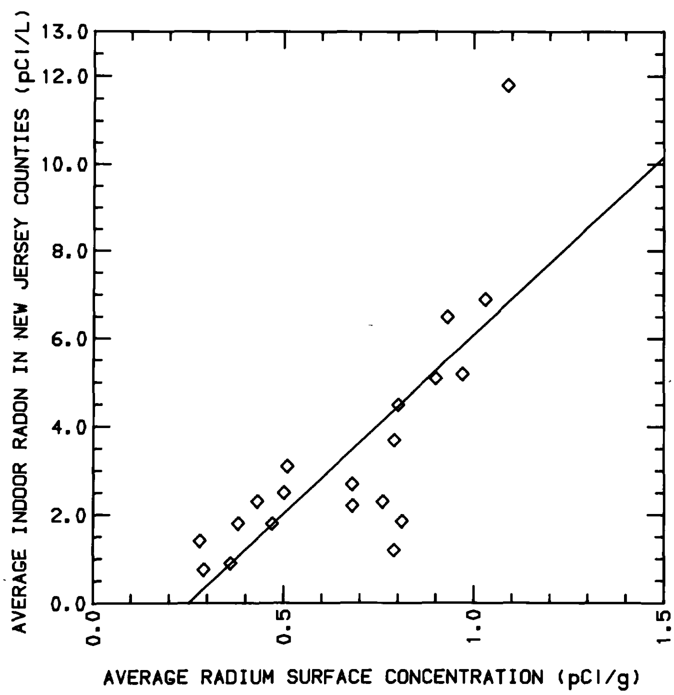

Figure 7. Average indoor radon concentrations versus average surface radium concentrations for counties in New Jersey .

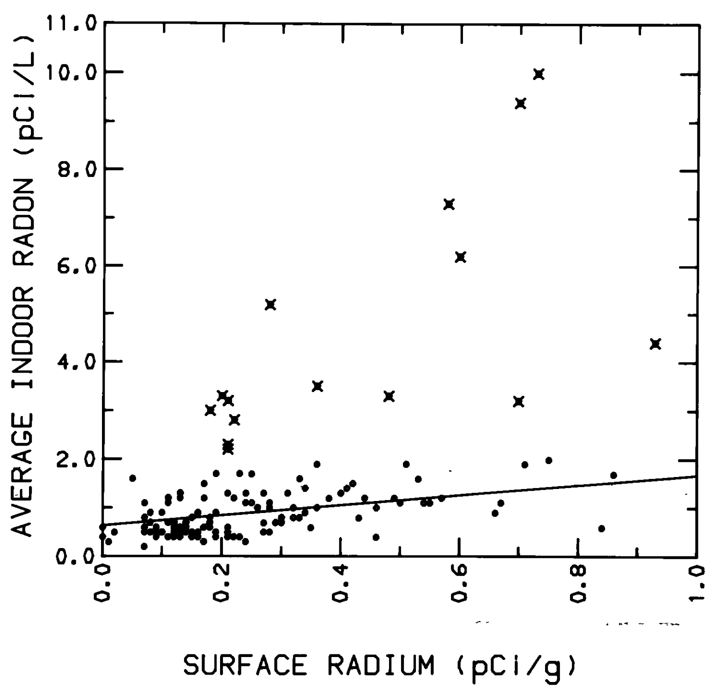

Figure 8. Graph showing the average indoor radon within various townships versus the apparent surface radium concentration in the Bonneville Power study area. Only townships with at least 25 sampled houses (data points) are included in this graph. Points marked by an X are interpreted to be unusually high areas (statistical outliers) that have unusual geologic or soil characteristics (see text discussion). The solid line represents a linear fit to the data with the outliers excluded.

the townships with 5 to 25 sampled houses (in Appendix 1) shows that the findings described below apply more generally. The majority of the data follow an approximately linear trend. The solid line in the figure represents a linear least-squared fit to the data with the unusually high data points excluded. The linear equation is:

$$3)\quad \text{Indoor } {}^{222}\text{Rn (pCi/L)} = 0.64 + 1.03\ {}^{226}\text{Ra (pCi/g)}$$

The calculated correlation coefficient for the data used to calculate the least-squared fit is 0.42. The difference in the slope between the New Jersey data (8.1 pCi/L per pCi/g) and the Pacific Northwest data (1.0 pCi/L per pCi/g) has significance to understanding regional differences in radon potential of rocks and soils, but a discussion of this is beyond the scope of this report. However, our tentative conclusion is that soils in New Jersey and possibly much of the east have a higher average emanating power than soils in the Pacific Northwest.

Figure 9 shows the maximum indoor radon versus the radium concentrations for each township. The townships marked with an "X" (high average indoor radon) in Figure 8 were retained in this figure. Note that many of the townships marked "X" in Figure 8 for high average indoor radon values are not yielding high maximum values. The calculated correlation coefficient for these data is 0.26. Because of the poor correlation between these parameters, no attempt was made to calculate a linear equation for the data. We suspect that the lack of a linear relation between maximum indoor radon and radium concentrations may be, in part, due to other sources of variation in indoor radon readings that may locally permit maximum readings well above the average. As noted above (p. 17), unusual housing construction may be a source of such variation. For example, in one township in the Puget lowland area near Seattle, all the readings accumulated during the course of the study were below 3 pCi/L with an average below 1.0 pCi/L, except for 1 reading of about 16 pCi/L. Followup investigation showed that the structure with the high reading was an underground house. Such a structure would be expected to have an unusually high entry rate for radon-bearing soil gas.

Available geologic maps and county soil maps were used to characterize the townships in the Bonneville Power study with 25 or more indoor radon readings in terms of geologic formations and soil characteristics (see annotations in Appendix 2). Of particular interest are the 15 data points (marked by an X in Figure 8) that lie significantly above the general trend of the majority of the data points (those defined by us as abnormally high or outliers). These data points do not follow a predictive model using only the aerial gamma-ray data. In the case of the highest 12 of the 15, the populated parts of the townships are entirely or mostly underlain by glacial outwash deposits, river terrace deposits, mixed debris flow and alluvial sediments, or other coarse, permeable materials (see detailed discussion below). Soils developed on these materials often have permeabilities that exceed 20 in/hr (1.6×10^{-7} cm^2) in the lowest soil horizons and the substrata. The higher average indoor radon in these townships is

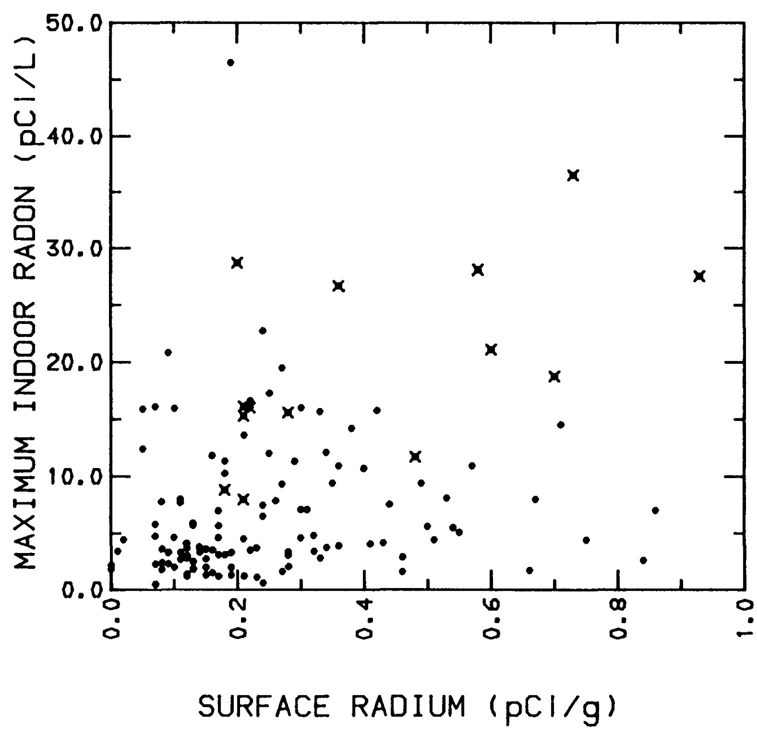

Figure 9- Maximum indoor radon readings versus the apparent radium in surface materials for selected townships in the Bonneville Power study area (townships used here are the same as in Figure 8). Note that many of the townships marked "X" in Figure 8 for high average indoor radon values are not yielding high maximum values.

likely due to the fact that soils with very rapid permeability permit radon to long diffusion distances and allow significant convective transport of radon-bearing soil gas into the disturbed zone surrounding the foundation. Soil gas from the disturbed zone is then readily transported indoors. The higher proportion of soil gas to normal atmospheric air indoors produces higher indoor radon levels because the radon content of most soil gas is in the range of 100 to 1500 pCi/L.

We investigated the geology and soils characteristics of each of the 15 townships where the data point was well above our general trend. The 4 highest townships (Fig. 8, the points above 6.0 pCi/L) occur in the Spokane-Coeur d'Alene area (labelled 1,2,3,4 in Fig. 10). These 4 townships were the only ones in this area with at least 25 readings. Townships 1,3, and 4 are located in the Rathdrum Prairie area north and northwest of Coeur d'Alene, Idaho. The populated parts of these 3 townships are underlain by glacio-fluvial outwash that contains detritus derived from bedrock to the north of the area. This material is covered with thin (25 to 125 cm or 10 to 50 inches) surface layers of loess and volcanic ash. The soil maps for Kootenai County (Weisel, 1981) show that the Rathdrum Prairie is underlain by the Avonville-Garrison-McGuire and Kootenai-Bonner soil map units. The subsoil and substrata for these map units consist of sand and gravel with >20 in/hr permeability (about 1.6×10^{-7} cm^2 or greater). Township 2 (Fig. 10) is located east of the city of Spokane, WA within the westward extension of the same glacio-fluvial outwash area underlying the Rathdrum Prairie. The populated parts of this township are underlain by the Garrison-Marble-Springdale soil map unit (Spokane County map, Donaldson and Giese, 1968) which has very rapid permeability (described as >10 in/hr in the county report).

The next 8 highest townships occur in the following areas: 1) the eastern Vancouver, Washington suburbs which are underlain by coarse gravels on which the Lauren-Sifton Wind River soils have formed; 2) the Burley, Idaho area where various highly permeable soils have formed on sediments deposited by the Snake River; 3) theCheney, Washington area underlain by outwash gravels on which the Hesseltine-Cheney-Uhlig soils have formed; 4) the Stevenson, Washington and nearby areas along the Columbia River where various highly permeable soils have formed on terrace gravels deposited by the Columbia River and on debris flows derived from volcanic rocks in the mountains to the north; and 5) the Milton-Freewater area where the Yakima gravelly loam has formed on gravels deposited by the Walla-Walla River. In each case soils with >20 in/hr (>1.6×10^{-7} cm^2) permeability are a principal or dominant soil type in the township.

The next 2 highest townships occur in the Clatskamie area, Columbia County, Oregon and an area in Benton County northwest of Albany, Oregon. The dominant soil types underlying both of these areas are silty loams derived from arkosic to feldspathic, micaceous sandstones and siltstones. The permeability of these soils is not high enough to appeal to permeability as a cause of the elevated readings. In the Clatskamie township however, the soils are unusually steep and thus well drained and this likely contributes to elevated radon indoors (see discussion above). One

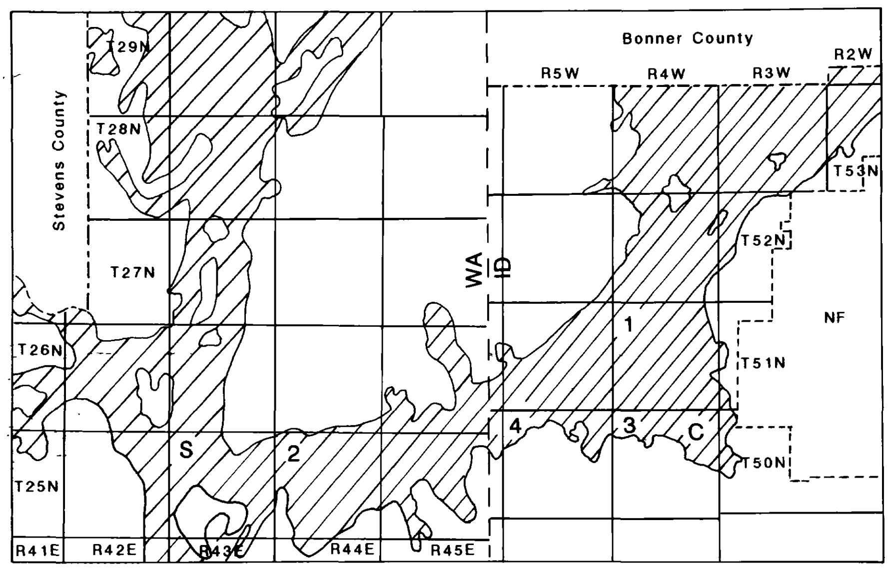

Figure 10- Map showing distribution of highly permeable glacio-fluvial outwash and associated soils in parts of Spokane County, Washington and Kootenai County, Idaho. S- Spokane, C- Coeur d'Alene, NF- National Forest area. Indoor radon and surface radium data for Townships labeled 1, 2, 3, and 4 can be seen in Fig. 8; they are the 4 highest readings (all those above 6 pCi/L). Map modified from Weisel (1981) and Donaldson and Giese (1968)

alternative explanation is that the surface radium readings indicated by the aeroradioactivity do not reflect the radium content of the soil layers below 30 cm, the effective limit of the gamma signal. This may occur in humid, temperate climates where deep, residual soils have formed on bedrock materials and the radionuclides have been leached from the near surface layers and redeposited at depth. Susceptible bedrock materials may include some granites and sedimentary rocks derived from granites (such as arkosic sandstones) where uranium is readily leached from surface horizons during the formation of soil, but is then trapped in lower horizons. Surface gamma-spectrometer readings do not reflect the soil gas radon levels at depth. We have observed this for soils formed on the Occoquan granite in Fairfax County, Virginia (Otton and others, 1988).

The last outlier township is located just west of Hillsboro, in Washington County, Oregon. No plausible explanation for relatively high average indoor radon values is apparent from our examination of the soil maps and the geologic maps. The soils are clay loams and clay silt loams that typically have moderate to low permeabilities. We see no evidence that the underlying rocks and soils should have higher concentrations of radium than seen in the surface materials or any other evidence that lowering of the radium content of the surface materials by unusual weathering has occurred. The soil descriptions for the township make no mention of any factors that may enhance the permeability of soils such as cracking. We observe only that the area has locally abundant apple orchards and apples are noted for requiring well-drained soils. Non-geologic factors may be influencing elevated radon levels in this area.

Study of the large group of townships not considered outliers (Figure 8) show that geologic and soil characteristics also influence average indoor radon levels. Many of the townships above the trend line are underlain by high percentages of rapidly permeable (6 to 20 in/hr) and even some very rapidly permeable (>20 in/hr soils). Most of these townships however, are in the interior parts of the study area east of the Cascade Mountains where the rainfall levels are low (mostly 9 to 20 inches per year). Other townships in coastal areas (ORR12WT18S, Appendix 2) or the Puget Lowland and the Willamette River Valley and nearby areas (WAR01WT18S, WAR03ET19N, WAR03WT30N, ORR01WT17S, ORR02WT18S, ORR03ET21S, Appendix 2) include high percentages of rapidly permeable or even very rapidly permeable soils that do not seem to have influenced the average radon level for the township. These areas however, have high (40 to 70 inches per year) to very high (>70 inches per year) rainfall and we have concluded that the effective permeability of these soils has been significantly reduced by high soil moisture. There is some evidence to suggest that high permeability and steep slopes or extreme permeabilities (>>20 in/hr) may still influence average indoor radon levels in some townships or that such conditions may be responsible for local values well above the township average. Without site-specific data for individual townships this can't be demonstrated more conclusively.

From Figure 8 and from our examination of the geology and soils for the well-characterized townships in Appendix 2 we have come to the following conclusions:

1) a linear relation between surface radium and average indoor radon can be defined for most of the townships in the BPA study area (Figure 8), this relation is a good estimator of indoor radon for soils with low to moderate permeability;

2) extreme outlier townships (high average indoor radon to surface radium ratio) are almost all characterized by very rapidly permeable soils (>20 in/hr) in areas east of the Cascades (low to moderate rainfall;

3) steep slopes or steep slopes combined with highly permeable soils increase the average indoor radon level;

4) rapidly permeable soils (6 to 20 in/hr) in areas east of the Cascades may elevate the average indoor radon above the general trend or cause an outlier but the effect is not consistent;

5) rapidly permeable soils and very rapidly permeable soils do not appear to increase average indoor radon levels in townships in high rainfall areas except possibly where the soils are extremely rapidly permeable (10^{-6} or 10^{-5} cm^2 for example, the Spanaway soils of Pierce Co. Washington, WAR03ET18N, Appendix 1); and

6) the higher the radium content the higher the average indoor radon level in an outlier township is likely to be.

INDOOR RADON POTENTIAL ASSESSMENT

Techniques for indoor radon potential assessment in the United States are still in developmental stages. Two demonstration projects by USGS scientists in Montgomery County, Maryland (Gundersen and others, 1988) and in Fairfax County, Virginia (Otton and others, 1988) used geologic maps, soil maps, aeroradiometric data, radon soil gas data, indoor radon data, and surface gamma-ray measurements to define radon potential categories in areas the size of a county. Areas within the two counties were mapped and ranked (five tiers of radon potential in Fairfax County- low, low to moderate, moderate, moderate to high, and high; three tiers of radon potential in Montgomery County- low, moderate, and high). The relative radon potential of the variously ranked areas was defined by showing indoor radon data compiled for the areas. These two counties were geologically complex and the ability to estimate indoor radon potential was dependent on the availability of detailed geologic information and soil maps, and the opportunity to rapidly measure radon in soil gas in the two areas.

Hand and Banikowski (1988) compared indoor radon measurements with geologic maps near Syracuse, New York and found that specific rock formations had significantly different averages and ranges of indoor radon concentrations. Two sequences of rock formations had low average indoor measurements and essentially no readings above 4 pCi/L, whereas a third sequence had high average readings and 77 percent of the values were above 4 pCi/L. Although not expressly stated by the authors, the geologic map of the county could be used as a radon potential map because the indoor radon data are distinctly different for the various rock types. This area, however is relatively small and the ability to characterize radon potential is dependent on the relatively simple geology and the substantial site-specific indoor radon data set.

Government researchers in Sweden have used other approaches to conduct geologic radon assessments. Lindmark and Rosen (1985) used two factors to evaluate radon "risk" for the land on which houses are sited in Sweden: the radon content of the soil gas measured at a depth of 0.5 m below the surface and a rough estimate of the permeability based on the material predominant in the soil (gravel and sand; silt; or clay). Where gravel and sand were present, "low" risk areas would have radon soil gas measurements less than 160 pCi/L and "high" risk areas would have measurements greater than 675 pCi/L (please note that these are radon readings in soil gas not radon indoors). Values in between would be "normal" (at least for Sweden). For silty soils, the cutoff values were 270 pCi/L and 946 pCi/L and for clayey soils the cutoff values were 405 pCi/L and 1350 pCi/L separating "low" and "normal", and "normal" and "high" risk areas, respectively. In later studies (Akerblom, 1986; Wilson, 1987) Swedish government researchers simplified the criteria for radon risk assessment to state that soils with less than 270 pCi/L are "low" risk. In such "low" areas, Sweden recommends no special construction methods for houses. The range of 270-1350 pCi/L is classified as "normal" and the government recommends "radon protective" construction. Values greater than 1350 pCi/L are "high" and the government recommends "radon safe" construction. They qualified this general classification by noting that the permeability of the "bedrock" must be taken into consideration when judging the risk involved.

Because public policy, housing construction methods, and the geologic environment in Sweden differ from those in the United States, these criteria are not likely to be appropriate for the entire United States. They do, however, provide us with a general approach that can be tested. In the absence of adequate data to define limits on radon in soil gas appropriate to the Pacific Northwest, we can use the cutoff values used in Sweden and use the apparent surface radium data to estimate the amounts of radon to be expected in the soil gas according to the following equation:

$$4) \quad \text{Soil gas Rn (pCi/L)} = 1000\, nde/p$$

where n is the radium concentration expressed as pCi/g, d is the soil bulk density (g/cm^3), e is the radon emanating power of the soil, and p is the effective porosity. The bulk density can be used to calculate the total porosity using the equation:

$$5) \quad P = 1 - d/2.65$$

where P is the total porosity and 2.65 g/cm^3 is assumed to be the average density of the mineral particles in the soils. The effective porosity can be estimated by the equation:

$$6) \quad p = (1 - s)P$$

where s is the fractional water saturation of the pores. Using these relationships, Equation 4 becomes:

7) Soil gas Rn = 2650 nde/[(1 - s)(2.65 - d)]

Figure 11 shows how the radon soil gas concentrations will vary with the moist bulk density assuming constant values for the radium concentration, emanating power, and soil pore water content. Moist bulk density measurements in the study area commonly fall in the range 1.0-1.5 g/cm^3 and soil water content is typically 20 percent for soils in this area (e.g. Mayko and Smith, 1966; McGee, 1972; Hosler, 1983; Gerig, 1985; Cahoon, 1985; Pringle, 1986). If we use1.3 g/cm^3 as an average value for the moist bulk density with an assumed emanating power of 0.3 and the low, normal (moderate), and high cutoff values for soil gas radon used by the Swedish researchers, low radon in soil gas will be expected where surface radium concentrations are less than 0.28 pCi/g; moderate radon in soil gas will be expected where radium concentrations are in the range of 0.28-1.41 pCi/g; and high radon in soil gas will occur where radium concentrations are greater than 1.41 pCi/g. Figure 12 shows the Bonneville Power study area classified for low, moderate, and high radon in soil gas. However, for the Pacific Northwest this map of expected radon in soil gas does not translate directly into radon potential of the rocks and soils <u>or</u> indoor radon potential because of the apparent effect of permeability.

From our investigations of the outlier townships in Figure 8, the work of Nazaroff and others (1986), and the studies by Swedish researchers, permeability (and related soil moisture and slope factors) <u>must</u> be used to estimate the radon potential of the rocks and soils. The presence of materials whose permeability exceeds 20 in/hr (1.6 x 10^{-7} cm^2, described by soil scientists as very rapidly permeable) or whose grain size is equal to or greater than that of medium sand or is composed of mixtures of materials with grain sizes largely greater than medium sand significantly affects the average indoor radon levels. Materials whose permeability is in the range of 6-20 in/hr (0.5-1.6 x 10^{-7} cm^2, described by soil scientists as rapidly permeable) are in the range where the effect on average indoor radon seems variable but may locally be significant.

These materials need not be found at the surface, indeed throughout the Pacific Northwest surface layers are typically much finer grained than lower horizons because of the abundance of recently deposited volcanic ash and other windblown material. The more permeable sand and gravel occurs at depths varying from several inches to greater than 5 feet. The presence of highly permeable (as used by us this includes both rapidly permeable and very rapidly permeable) materials can be determined using soil surveys where detailed descriptions of the soils are given or using geologic maps, especially where the surficial material has been carefully mapped.

Soil moisture also plays a role in indoor radon in the Pacific Northwest and we have suggested that for areas of high rainfall, largely those within and west of the Cascade Mountains, soils with high intrinsic permeability do not affect average indoor radon probably because the effective permeability of these soils has been reduced. Local elevated indoor radon values may occur where these

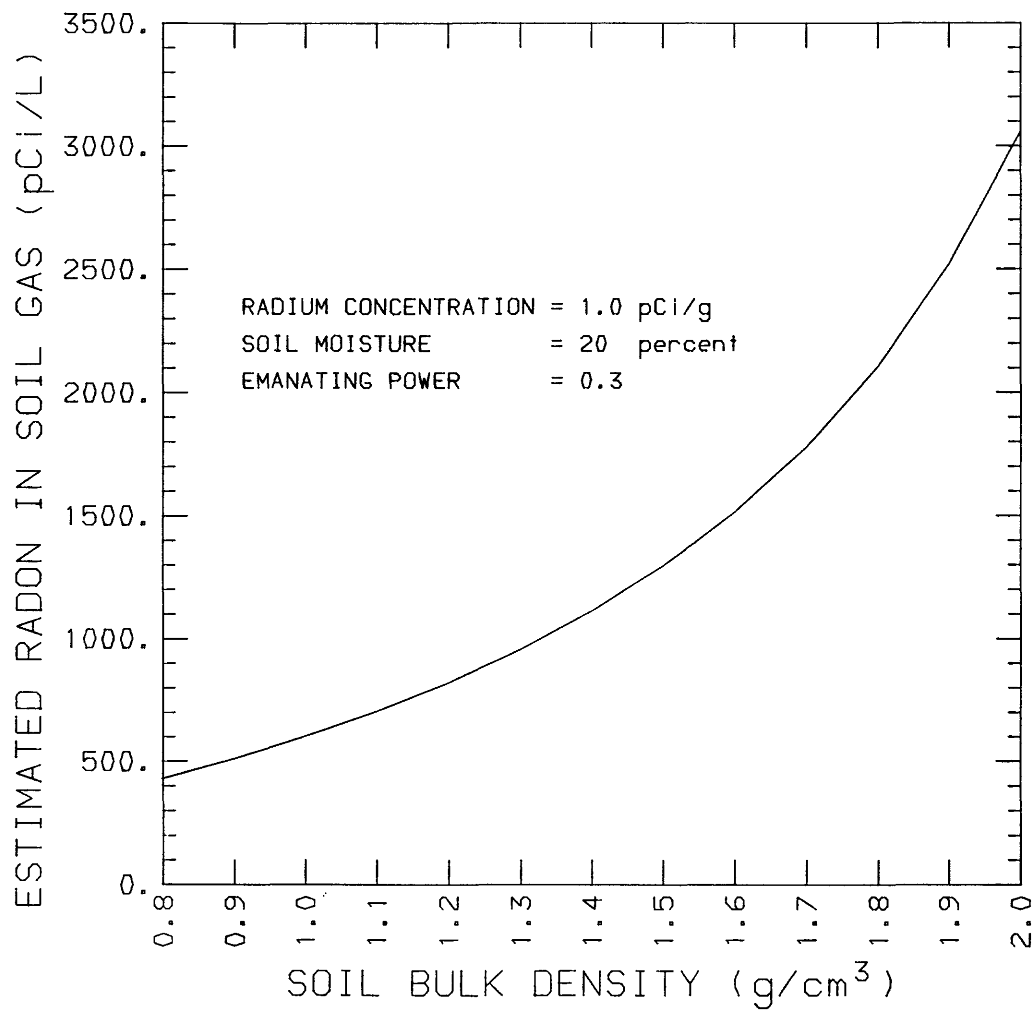

Figure 11. Radon soil gas concentrations versus the soil bulk density assuming constant values for radium concentration, emanating power, and soil moisture content.

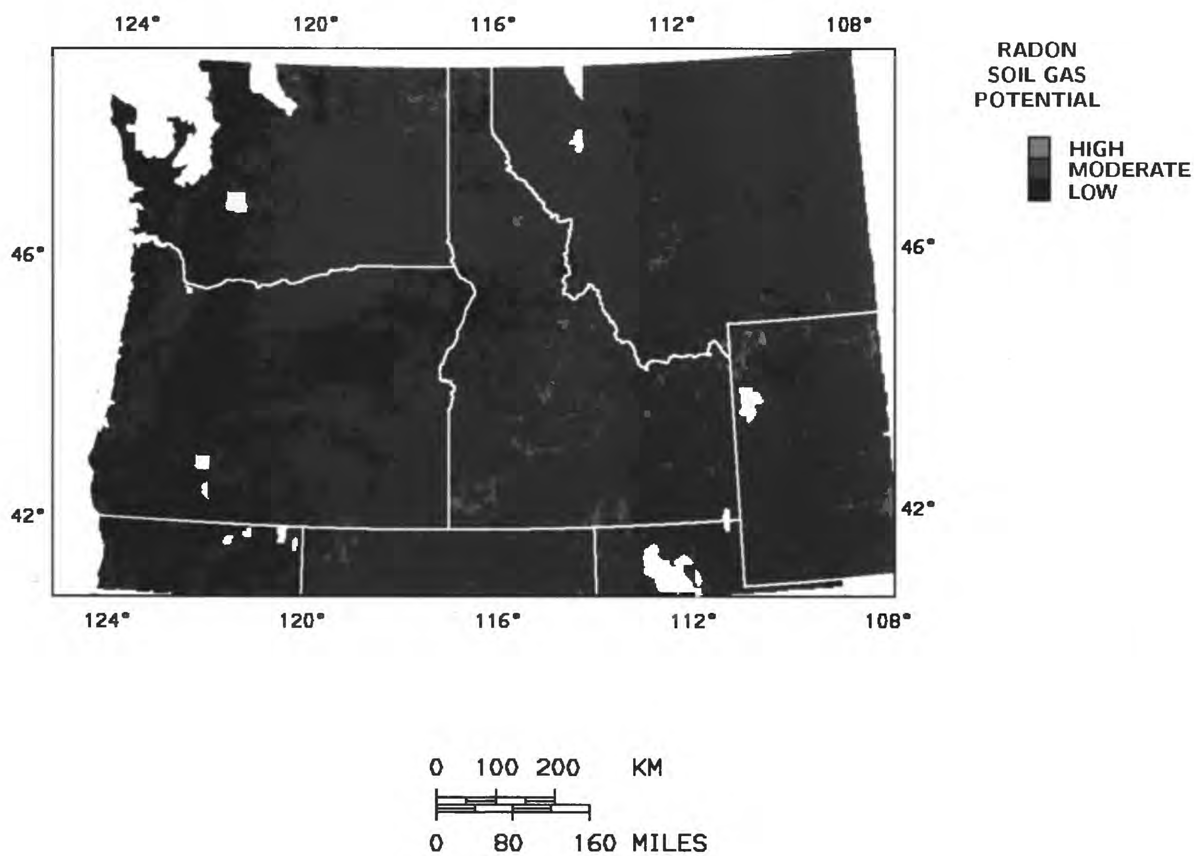

Figure 12- Map showing areas of low, moderate and high radon in soil gas in the Bonneville Power service area (calculated from radium content, assumes constant emanating power).

permeable soils are also well-drained or where the permeabilities are extreme (>> 20in/hr) but such conditions generally do not occur over an area the size of a township. As noted above, increases in the soil moisture decrease the ability of radon to diffuse through the soil pores and inhibit the movement of radon-bearing soil gas by convective flow. We note in the indoor radon data that areas of high rainfall in the western part of the study area (regions along the Pacific coast, the Puget Lowland, and the Willamette River Valley) are generally low in radon. These areas, however, are also low in surface equivalent radium for geologic reasons described above.

EVALUATION OF SOIL SURVEYS FOR PERMEABILITY DATA

It is clear that, in addition to determining radium content of surface materials, evaluation of soil permeability is critical to radon potential. Soil surveys published by the U.S. Department of Agriculture usually in cooperation with state and county agencies show the distribution of and describe the physical, chemical, and morphological properties of the various soils mapped in the area studied. Such soil surveys also describe rainfall data for the area and in modern surveys rainfall data for each of the major soil associations is often given. The properties most often described are those that are important to the agricultural and engineering uses of the soil. As noted above, the important physical properties with respect to radon migration through soil gas are the intrinsic permeability, soil moisture (as it affects permeability), and slope (which affects both permeability and soil moisture).

In soil surveys, two sets of information seem to be most useful in determining which soils are highly permeable: 1) the table of physical and chemical properties of the soil types which lists permeability estimates (in inches/hour); and 2) the table of construction materials which describes whether a given soil is a good source of sand and gravel. (In addition, most soil surveys map according to slope of the soil). In older county soil reports where such tables are lacking, other, less reliable, indicators such as USDA soil texture descriptions or estimates of "internal drainage" may be used. Textural terms where the last descriptor is "sand" rather than loam is a good indicator of highly permeable materials. The terms "loamy fine sand" and "fine sand" correspond approximately to soil horizons that have permeabilities of 6 to 20 in/hr whereas the terms "coarse sand", "gravelly sand", and others correspond to soils that have permeabilities of >20 in/hr. Soils whose internal drainage is described as "rapid" or "very rapid" corresponds approximately to 6 to 20 in/hr and >20 in/hr, respectively. An additional guide to permeability, available in more recent reports, is an evaluation of the soil as a source of sand and gravel (usually given in a table evaluating availability of construction materials). A good or fair source of gravel is usually highly permeable in subsoil or substrata layers. Sometimes a soil is described as a fair source of sand and/or gravel, but is noted as having "excessive fines". Such descriptions are more difficult to evaluate because the percent of excessive fines is not quantified. If the fines are abundant enough that the pore spaces between the gravel- and sand-sized material are well blocked then the soil may have low permeability. Sometimes the sand or gravel is described as being deep (greater than 60" below the surface). If the area being evaluated has all slab on grade housing and the excavation for the slab doesn't penetrate down to the highly permeable horizons then the presence of that material may not increase the radon potential.

Drainage terms ranging from "very poorly drained" through "moderately well drained" to "excessively drained" are used in many soil surveys. These terms refer to the relative rapidity and extent of water removal from the surface and from within the soil. In many cases these terms correspond to intrinsic permeability terminology (very slow, moderately rapid, etc.) except where the slopes are steep and the water is rapidly removed by simple runoff. Thus a soil with moderate intrinsic permeability on a steep slope is likely to be excessively drained. However, there is some empirical evidence (Tanner, oral commun., 1987, 1988) to suggest that hillslopes may be associated with higher indoor radon levels, but the causes are uncertain. The terms "somewhat excessively drained" and "excessively drained" are the approximate equivalents of the terms "rapidly permeable" and "very rapidly permeable" and can be used, in our judgment, as equivalents in evaluating soil descriptions.

Superposition of maps showing the distribution of highly permeable soils (rapidly permeable and very rapidly permeable) on the surface radium map (Fig. 4) will permit a subjective estimation of the radon potential of the rocks and soils for a given area. We suggest, from the relationships seen in Figure 8, that the occurrence of highly permeable soils can significantly increase the indoor radon potential of an area (the average indoor radon levels) above that which might be predicted from the radon content of the soil gas alone. Because we have no means of quantifying the "average permeability" of a township in the same way that we have quantified the surface radium content of the soils and rocks in the township, we cannot quantify the expected increase in the average indoor radon level where the permeability is above the critical values. Some subjective estimates are possible. An examination of Figure 8 suggests that the average indoor radon levels may be increased as much as almost one order of magnitude for a given radium content where the soils are very rapidly permeable throughout the area east of the Cascade Mountains. Where the soils are dominantly rapidly permeable.

We have evaluated 78 soil survey reports for counties and other political units in the Pacific Northwest (Appendix 3, Figure 13A, 13B) with the goal of identifying those soil map units and soil associations that may contribute to elevated indoor radon levels in the homes sited on them because of their high permeability (rapidly and very rapidly permeable). The soil survey reports we examined were those available in the USGS library in Reston, Virginia at the time this part of the study was conducted. These soil surveys include the areas of residence of about 94 percent of the population in Washington, 83 percent of the population in Oregon, 68 percent of the population in Idaho, and about 160,000 people in 10 counties in western Montana (based on the 1970 census).

In these county summaries, we have split the high permeability classes into ">20 in/hr" (very rapidly permeable) and "6-20 in/hr" (rapidly permeable). In some reports ">10 in/hr", "5-10 in/hr", "2-20 in/hr", or ">6 in/hr" are used. We have tabulated those soils where the subsoil or substrata have those permeabilities and the interval(s) where they occur (see detailed discussion in Appendix 3). Where a soil association is dominated (50 to 60 percent or more) by one or more of the highly permeable soil types, that association is listed in an additional tabulation. Finally, comments are offered regarding the geology and distribution of these highly permeable soil types and soil associations and a brief statement regarding the precipitation for the area with the highly permeable soils is given.

Figure 13 is a compilation of those areas of highly permeable soil associations in the Pacific Northwest identified in the above study of the soil surveys. Figure 13A shows the county surveys studied whereas Figure 13B shows the mapped areas of highly permeable soil associations. Only those soil associations that are large enough to be seen at the scale of the map are shown. Areas less than a few square miles are not shown. Only areas covered by the 78 reports we examined are shown. Please see Figure 13A and Appendix 3 to see if an area of interest has been evaluated. In those areas east of the Cascades, significant increases in the average indoor radon readings above those predicted by Equation 3 (the linear trend of Figure 8) may be expected if the soils are very rapidly permeable. Lesser increases are possible in the areas east of the Cascades where the soils are rapidly permeable. In areas west of the Cascades where rainfall is generally much higher, the permeability effect is less pronounced but still locally observable for very rapidly permeable soils such as the Spanaway soils near Tacoma. Steep, well-drained soils west of the Cascades locally appear to increase average indoor radon levels as at Clatskanie, Oregon, but such soils are not mapped in Figure 13B unless they are also highly permeable.

Our evaluation of the geology and soils throughout the Pacific Northwest shows that soils with highly permeable substrates occur in a limited number of geologic settings including: 1) river terraces along the major rivers (for example, the Columbia, Snake, and Willamette Rivers); 2) glacial outwash plains; 3) older alluvial fans near the mouths of canyons; 4) areas of windblown sand close to the larger rivers; 5) debris flows in valleys in steep volcanic topography; and 6) older marine or lacustrine beach and deltaic deposits.

The effect of the presence of highly permeable soils on average indoor radon levels for township-sized areas is also dependent on how housing is distributed and this must be considered in evaluating Figure 13B. For example, if highly permeable soils underly 50 percent of a township, but no one builds on those soils for whatever reason, then the presence of those soils will not influence indoor radon readings. This occurs along many of the river valley floodplains throughout the study area. Conversely, in some areas houses may be constructed on the more highly permeable

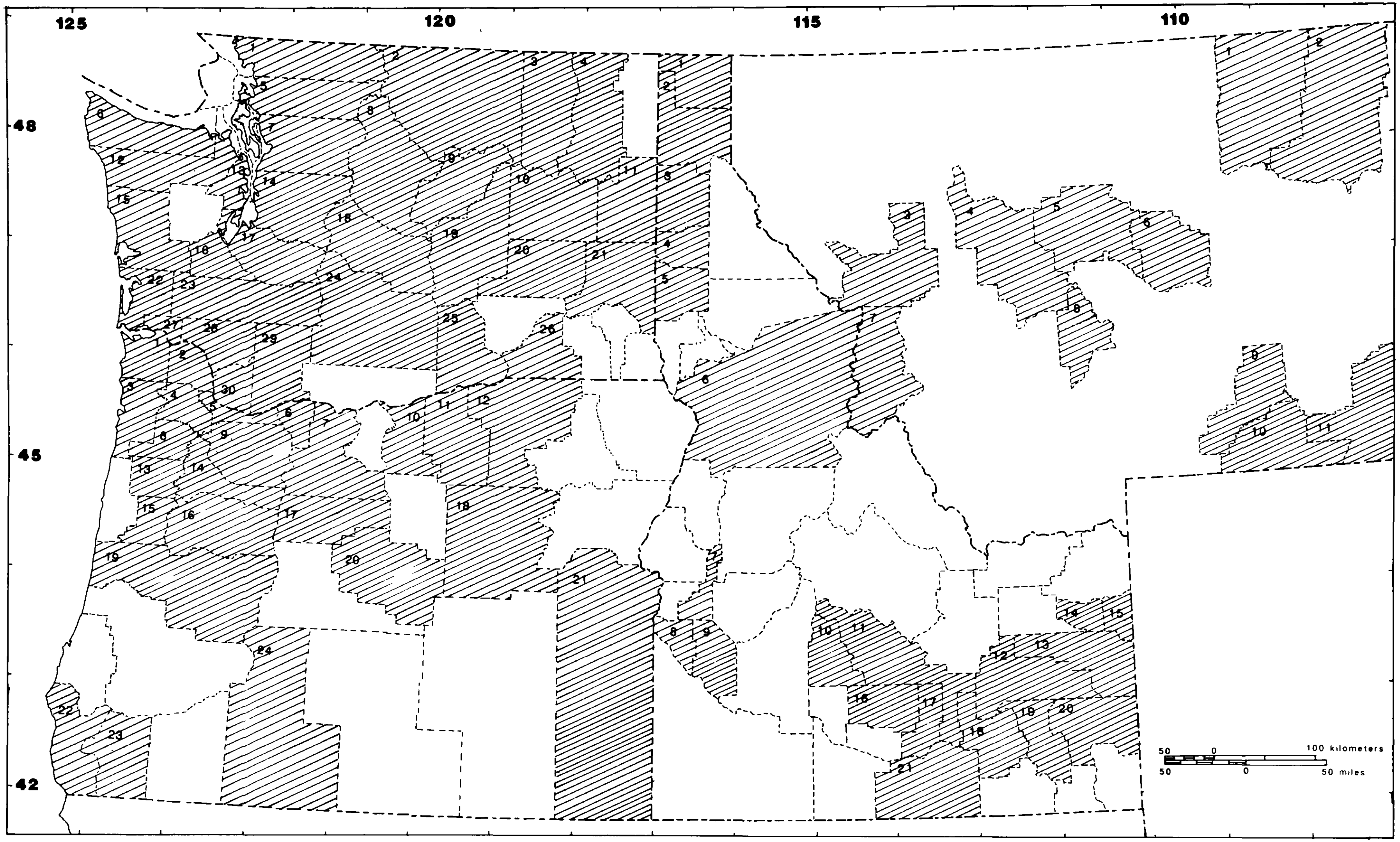

Figure 13A- Map showing counties in the Pacific Northwest for which soil surveys were examined for permeability data. Counties studied are lined. Many soil surveys did not cover all of the county but focussed on the populated and privately owned parts of the county. Indian reservations, national forest land, and other government lands within many of the counties are not included.

COUNTY KEY:

Washington: 1-Whatcom; 2-Okanogan; 3-Ferry; 4-Stevens; 5-Skagit; 6-Clallam; 7-Snohomish; 8-Chelan; 9-Douglas; 10-Lincoln; 11-Spokane; 12-Jefferson; 13-Kitsap; 14-King; 15-Grays Harbor; 16-Thurston; 17-Pierce; 18-Kittatas; 19-Grant; 20-Adams; 21-Whitman; 22-Pacific; 23-Lewis; 24-Yakima; 25-Benton; 26-Walla Walla; 27-Wahkiakum; 28-Cowlitz; 29-Skamania; 30-Clark

Oregon: 1-Clatsop; 2-Columbia; 3-Tillamook; 4-Washington; 5-Multnomah; 6-Hood River; 7-Wasco; 8-Yamhill; 9-Clackamas; 10-Gilliam; 11-Morrow; 12-Umatilla; 13-Polk; 14-Marion; 15-Benton; 16-Linn; 17-Jefferson; 18-Grant; 19-Lane; 20-Crook; 21-Malheur; 22-Curry; 23-Josephine; 24-Klamath

Idaho: 1-Boundary; 2-Bonner; 3-Kootenai; 4-Benewah; 5-Latah; 6-Idaho; 7-Gem; 8-Canyon; 9-Boise; 10-Camas; 11-Blaine; 12-Bingham; 13-Bonneville; 14-Madison; 15-Teton; 16-Lincoln; 17-Minidoka; 18-Power; 19-Bannock; 20-Caribou; 21-Cassia

Montana: 1-Blaine; 2-Phillips; 3-Missoula; 4-Lewis & Clark; 5-Cascade; 6-Judith Basin; 7-Ravalli; 8-Broadwater; 9-Stillwater; 10-Carbon; 11-Bighorn

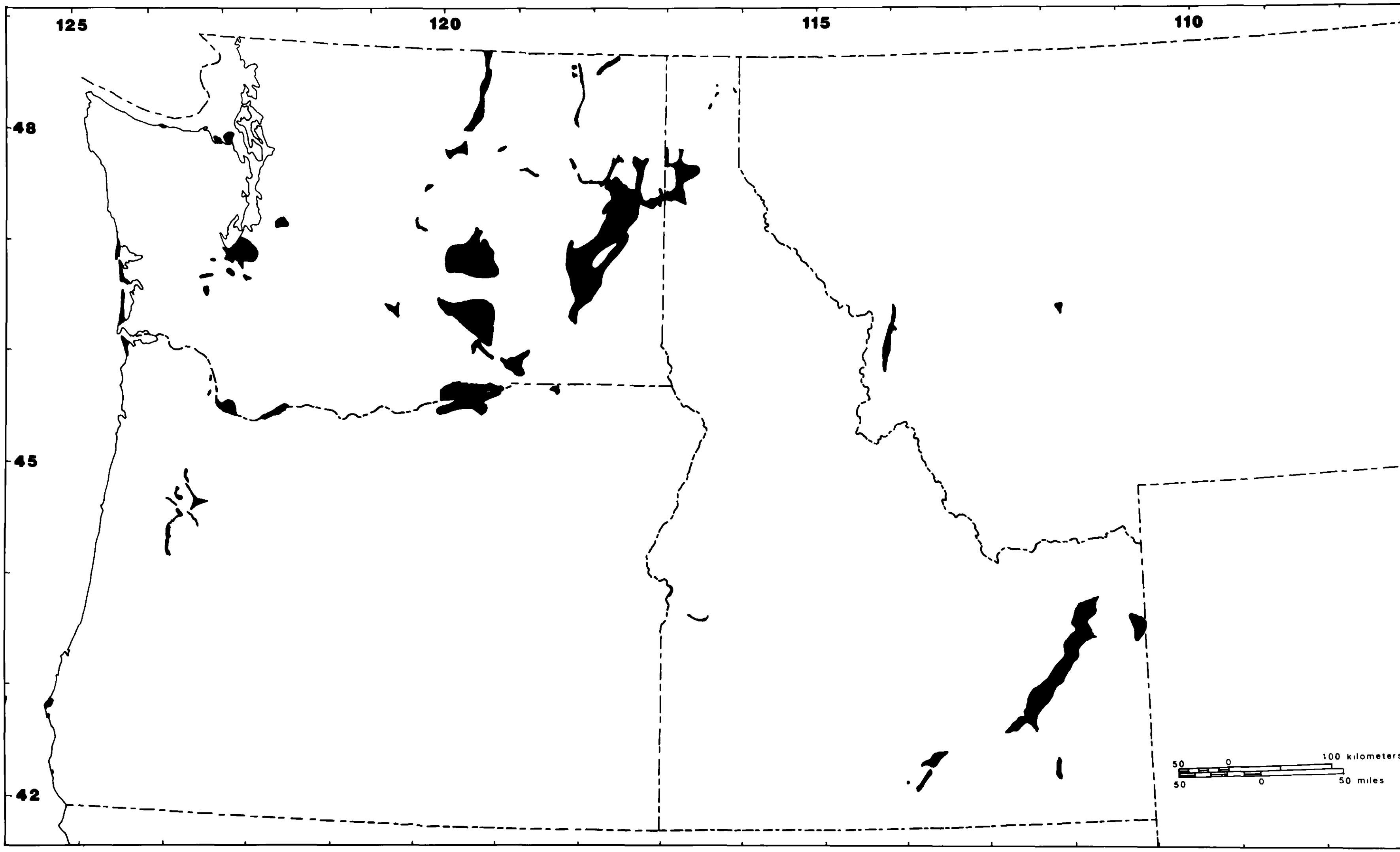

Figure 13B- Map showing areas of highly permeable soil associations for the soil surveys in the counties shown in Figure 13A. Very small areas (less than a few square miles) of highly permeable soils are not shown. All contacts are approximately located and designed to show the general area where highly permeable soils dominate in the study area. These highly permeable soils include both rapidly permeable (6 to 20 in/hr) and very rapidly permeable (>20 in/hr) soils. The reader is referred to Appendix 1 for a survey by survey discussion of the highly permeable soils and to the original soil surveys for more exact location information.

soils in preference to other less permeable parts of the township. For example, in the Rathdrum Prairie and Coeur d'Alene areas of Kootenai County, Idaho houses are generally built down on the prairie which is underlain by the coarse glacial outwash rather than on adjacent hillslopes which are underlain by less permeable soils.

CONCLUSIONS

Comparisons of surface gamma-ray (expressed as equivalent radium) data with radon in soil gas and with indoor radon levels support the use of gamma-ray data to estimate the relative radon potential of the soils and rocks with the proviso that highly permeable soil and bedrock (those with permeabilities greater than 10^{-7} cm^2) also be considered. Because aerial gamma-ray surveys typically provide data for less than 10 percent of the ground surface within the survey area (Pitkin and Duval, 1980), geologic maps can and should be used to improve the spatial definition of the gamma-ray data, that is, to more clearly define the distribution of rocks and soils with a specific radiometric signature. However, as the data for the Columbia Plateau basalt indicate, the bedrock geology can be subordinate in importance to the characteristics of the surficial materials. Bedrock maps are most useful if the surface materials are largely derived from the bedrock they overlie and were not transported significant distances by the action of ice, water, or wind. Surficial geologic maps should be used wherever available to supplement bedrock maps.

HOW TO USE THIS REPORT TO EVALUATE RADON POTENTIAL

The radon potential of rocks and soils in those areas of the Pacific Northwest covered by Figure 5 (the radium in soil map) and Figure 13 (the map of areas of highly permeable soils) of this report can be estimated in terms of a expected <u>average</u> indoor radon levels for areas the size of a township (36 square miles) or greater by comparison to Figure 8. For example, if local officials wanted to evaluate the radon potential of a given county, they would examine Figure 5 to determine the soil radium content of the various areas of the county. Using the soil radium value(s) obtained from Figure 5, they would then examine Figure 8 to determine the expected range of values of average indoor radon from the linear trend and the scatter of normal values about the linear trend. Next, they should evaluate possible effects of highly permeable soils by examining Figure 13A and Appendix 3 to see if the county of interest has been evaluated for their presence. If it has, then they should look at Figure 13B to see if the county of interest has large areas of highly permeable soils (each of these shaded areas may include rapidly and very rapidly permeable soils). Those areas of the county where highly permeable soils are present should be expected to have average indoor radon levels above that suggested by the linear trend in Figure 8, dependent on rainfall conditions and whether these soils were rapidly permeable or very rapidly permeable as described above. A subjective estimate of the expected average indoor radon levels can then be made.

Let us consider a hypothetical example. If a part of a county had 0.6 pCi/g surface radium, from Figure 8 one could expect the average indoor radon levels for houses might be about 1.2 pCi/L$\pm$0.4pCi/L if the soils are of low to moderate permeability. If an examination of Figure 13B shows that substantial areas of highly permeable soils are present and the county has low to moderate rainfall, the levels could be expected to be higher. If closer examination shows that most of the soils are rapidly permeable, the increase in average indoor radon levels may be modest perhaps in the range of +.2 to +.8 pCi/L. If the soils are dominantly very rapidly permeable, the increase could be on the order of 2 to 10 fold. How high the average expected level might be within that range cannot be quantified at this time and can only be subjectively estimated.

Where the county of interest does not have any large areas of highly permeable soils mapped in Figure 13B, the detailed county description in Appendix 3 should be checked to see if small areas of highly permeable soils are present. Where Appendix 3 indicates that they are present, the local soil survey covering the county should be examined to determine where those areas are. These small areas should be considered as having the potential for indoor radon levels higher than that predicted from the radium data.

Areas not covered by Figures 13A and 13B may be evaluated by the local officials using Figures 4 and 8 and soil permeability information that may be available from sources not available to us during the preparation of this report, such as local county extension agents, unpublished soil surveys, and published soil surveys available in other libraries. Evaluation of such soil permeability data should follow the suggestions provided above and summarized in Appendix 3 below.

Figures 4 and 13 and Appendix 3 are best used to evaluate the radon potential of rocks and soils in township- and county-sized areas. They cannot be used to evaluate the radon potential of individual homes. There is too much local variability in radium content and permeability of the soil immediately surrounding the house to make individual predictions. If measurements of radium content (or soil gas content) and permeability are available for sites and tracts however, the likelihood of a radon problem could be estimated. An in depth discussion of site- and tract-scale indoor radon potential evaluations is beyond the scope of this report.

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Appendix 1
Tabulated indoor radon and surface radium data for all reporting townships in the Bonneville Power Administration service area

This appendix contains data for all townships for which indoor radon readings are reported in the Bonneville Power dataset. Average, median, and maximum radon values for each township are given. The grid radium value is calculated from the radium map of the study area. The average reported is an arithmetic average. The median value was calculated using standard procedures but for townships with less than 10 indoor radon measurements, the median value was arbitrarily set equal to the average value. The longitude is shown as a negative number because it is west of the zero meridian at Greenwich. The townships are identified by a two letter code for the state (ID = Idaho, OR = Oregon, WA = Washington, MT = Montana) and by the range (R) and township (T) numbers as designated on the USGS topographic maps. Where the notation "ND" occurs in the table, the aerial survey did not provide coverage of that particular township.

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
IDR02WT53N	-116.800	47.9200	7.	13.4	13.4	42.3	0.52
IDR02WT57N	-116.800	48.2800	8.	1.4	1.4	4.3	0.38
IDR03WT51N	-116.700	47.7500	13.	4.4	3.0	21.5	0.21
IDR03WT52N	-116.700	47.8500	16.	5.4	3.4	27.5	0.52
IDR04WT47N	-116.830	47.4200	8.	4.9	4.9	13.3	1.04
IDR04WT49N	-116.830	47.6000	6.	6.6	6.6	17.5	0.34
IDR04WT50N	-116.830	47.6700	42.	7.3	4.4	28.1	0.58
IDR04WT51N	-116.830	47.7500	50.	10.0	8.6	36.5	0.73
IDR04WT52N	-116.830	47.8500	17.	16.3	11.9	63.3	0.56
IDR04WT53N	-116.830	47.9300	9.	15.1	15.1	46.4	0.60
IDR04WT59N	-116.830	48.4700	5.	4.0	4.0	11.6	0.38
IDR05WT50N	-116.950	47.6700	38.	6.2	5.2	21.1	0.60
IDR05WT51N	-116.950	47.7500	15.	14.0	14.1	43.3	0.62
IDR19ET13N	-114.200	44.4500	7.	5.5	5.5	7.5	1.14
IDR19ET14N	-114.200	44.5300	17.	4.3	4.2	8.4	0.88
IDR22ET10S	-113.870	42.5500	38.	3.3	3.1	11.7	0.48
IDR23ET09S	-113.750	42.6500	29.	1.7	1.6	7.0	0.86
IDR23ET10S	-113.750	42.5500	88.	4.4	2.5	27.6	0.93
IDR23ET11S	-113.750	42.4500	8.	4.2	4.2	12.2	1.33
IDR24ET09S	-113.650	42.6500	8.	1.0	1.0	1.6	0.64
IDR24ET10S	-113.650	42.5500	5.	2.0	2.0	3.5	0.45
IDR24ET11S	-113.650	42.4500	15.	2.8	1.6	12.3	1.22
IDR38ET02N	-112.000	43.5000	281.	1.9	1.5	14.6	0.71
IDR41ET09S	-111.670	42.6300	5.	1.7	1.7	3.3	0.71
MTR20WT05N	-114.150	46.1750	9.	2.3	2.3	4.2	0.69
MTR20WT06N	-114.150	46.2700	10.	1.7	1.4	3.4	0.62
MTR20WT07N	-114.150	46.3500	7.	2.8	2.8	12.8	0.77
MTR20WT10N	-114.150	46.6200	5.	6.1	6.1	16.5	0.69
MTR21WT07N	-114.200	46.3500	7.	2.3	2.3	3.2	0.76

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
ORR01ET03S	-122.670	45.0500	12.	3.2	2.8	6.8	0.38
ORR01ET17S	-122.670	44.0750	13.	0.8	0.7	4.6	0.04
ORR01ET39S	-122.670	42.1700	137.	0.6	0.5	2.6	0.84
ORR01WT04N	-122.800	45.8200	8.	1.4	1.4	4.6	0.22
ORR01WT17S	-122.800	44.0800	43.	0.5	0.5	2.4	0.08
ORR01WT18S	-122.800	44.0000	10.	0.9	0.6	2.1	0.27
ORR01WT19S	-122.800	43.9200	29.	0.9	0.9	2.5	0.01
ORR02ET16S	-122.570	44.1700	14.	0.9	0.5	2.6	ND
ORR02ET21S	-122.570	43.7500	8.	0.5	0.5	0.9	0.19
ORR02WT04N	-122.925	45.8250	5.	1.6	1.6	3.7	0.24
ORR02WT12S	-122.925	44.5250	10.	0.8	0.6	2.1	0.39
ORR02WT16S	-122.925	44.1700	15.	1.0	0.8	2.4	0.09
ORR02WT17S	-122.925	44.0800	109.	0.9	0.5	15.9	0.10
ORR02WT18S	-122.925	44.0000	52.	1.0	0.7	3.4	0.32
ORR02WT19S	-122.925	43.9200	11.	1.0	0.6	2.7	0.15
ORR03ET18S	-122.450	44.0000	55.	0.4	0.5	1.5	0.16
ORR03ET21S	-122.450	43.7500	111.	0.8	0.6	4.1	0.43
ORR03WT01N	-123.050	45.5700	40.	2.0	1.8	4.4	0.75
ORR03WT01S	-123.050	45.4700	51.	1.9	1.6	4.4	0.51
ORR03WT07N	-123.050	46.0750	20.	1.9	1.6	5.0	0.34
ORR03WT07S	-123.050	44.9500	307.	1.6	1.2	15.7	0.33
ORR03WT08N	-123.100	46.1500	10.	2.5	1.4	5.6	0.29
ORR03WT16S	-123.050	44.1700	12.	0.5	0.5	1.2	0.20
ORR03WT17S	-123.050	44.0800	662.	0.8	0.6	14.1	ND
ORR03WT18S	-123.050	44.0000	551.	0.7	0.5	11.3	0.29
ORR03WT19S	-123.050	43.9200	20.	0.7	0.5	2.4	0.18
ORR03WT20S	-123.050	43.8500	19.	0.7	0.7	2.1	0.15
ORR03WT21S	-123.050	43.7500	13.	0.5	0.6	0.8	0.09
ORR04WT01N	-123.170	45.5500	33.	2.3	1.9	8.0	0.21
ORR04WT04N	-123.170	45.8250	6.	1.1	1.1	1.9	0.32
ORR04WT04S	-123.170	45.2000	369.	1.5	1.3	15.8	0.42
ORR04WT07N	-123.170	46.0750	114.	2.8	2.2	16.0	0.22
ORR04WT08N	-123.170	46.1500	25.	1.7	1.4	3.7	0.23
ORR04WT08S	-123.170	44.8700	17.	1.2	1.2	3.2	0.50
ORR04WT10S	-123.170	44.7000	63.	2.2	1.1	15.3	0.21
ORR04WT15S	-123.170	44.2500	9.	1.3	1.3	3.0	0.28
ORR04WT16S	-123.170	44.1700	27.	1.0	0.6	6.6	ND
ORR04WT17S	-123.170	44.0800	973.	0.8	0.6	10.3	0.18
ORR04WT18S	-123.170	44.0000	311.	0.7	0.5	8.0	0.11
ORR04WT21S	-123.170	43.7500	5.	1.3	1.3	3.8	0.46
ORR05ET16S	-122.200	44.1700	7.	0.5	0.5	0.9	0.06
ORR05WT07N	-123.300	46.0700	15.	2.4	1.6	10.9	0.18
ORR05WT08S	-123.300	44.8700	12.	2.3	1.4	8.3	0.48
ORR05WT10S	-123.300	44.7000	5.	1.4	1.4	2.1	0.30
ORR05WT11S	-123.300	44.6000	18.	1.2	0.8	6.5	0.31
ORR05WT17S	-123.300	44.0800	35.	0.9	0.8	3.7	0.34
ORR05WT18S	-123.300	44.0000	57.	1.2	0.9	9.4	0.49
ORR05WT22S	-123.300	43.6500	26.	1.4	1.2	4.1	0.41
ORR05WT23S	-123.300	43.5700	13.	0.8	0.6	2.4	0.29
ORR05WT24S	-123.300	43.5000	5.	0.6	0.6	1.8	0.42
ORR05WT25S	-123.300	43.4000	5.	0.6	0.6	1.1	0.33

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
ORR06WT11S	-123.420	44.6000	6.	0.8	0.8	1.2	0.21
ORR06WT12S	-123.420	44.5250	6.	1.3	1.3	3.7	0.11
ORR06WT16S	-123.420	44.1700	5.	2.6	2.6	4.0	0.29
ORR06WT17S	-123.420	44.0800	24.	2.0	0.9	7.6	0.39
ORR06WT18S	-123.420	44.0000	10.	1.1	0.7	3.1	0.40
ORR06WT22S	-123.420	43.6500	11.	2.3	0.9	11.0	0.42
ORR06WT27S	-123.420	43.2250	9.	0.5	0.5	1.2	0.10
ORR07ET02N	-121.950	45.6500	26.	3.0	2.4	8.8	0.18
ORR07WT26S	-123.530	43.3000	15.	1.1	1.1	2.2	0.52
ORR07WT27S	-123.530	43.2250	7.	1.1	1.1	2.3	0.39
ORR08WT29S	-123.650	43.0500	8.	0.8	0.8	1.5	0.49
ORR09ET01N	-121.670	45.5700	6.	0.9	0.9	1.5	0.12
ORR09ET01S	-121.670	45.4700	7.	1.5	1.5	4.2	0.23
ORR09WT01S	-123.750	45.4700	67.	1.3	0.8	9.3	0.27
ORR09WT02S	-123.750	45.4000	19.	1.5	0.8	8.1	0.01
ORR09WT03S	-123.750	45.3000	9.	1.6	1.6	7.0	0.06
ORR10ET01N	-121.550	45.5700	239.	1.3	0.7	22.8	0.24
ORR10ET01S	-121.550	45.4700	31.	1.7	0.9	17.3	0.25
ORR10ET02N	-121.550	45.6500	693.	1.7	1.0	46.5	0.19
ORR10ET03N	-121.550	45.7500	804.	1.3	0.9	13.6	0.21
ORR10ET21S	-121.550	43.7000	11.	1.6	0.8	5.0	0.34
ORR10ET22S	-121.550	43.6500	19.	0.9	0.9	1.8	0.45
ORR10WT01N	-123.875	45.5700	37.	0.9	0.6	3.6	0.08
ORR10WT01S	-123.875	45.4700	61.	1.2	0.8	7.0	0.17
ORR10WT02N	-123.875	45.6500	18.	0.4	0.3	1.2	0.10
ORR10WT02S	-123.875	45.4000	10.	0.9	0.5	2.7	0.08
ORR10WT03N	-123.875	45.7500	23.	0.7	0.6	1.7	0.06
ORR10WT04S	-123.875	45.2000	17.	0.9	0.4	4.6	0.15
ORR10WT10S	-123.875	44.7000	8.	1.6	1.6	6.6	0.45
ORR10WT11S	-123.875	44.6000	60.	1.3	1.0	6.5	0.24
ORR10WT18S	-123.875	44.0000	10.	1.6	1.4	4.0	0.43
ORR11ET02N	-121.420	45.6500	78.	1.3	1.0	5.7	0.13
ORR11ET19S	-121.420	43.9200	19.	1.2	1.0	4.3	0.10
ORR11WT10S	-124.000	44.7000	5.	0.4	0.4	0.5	0.14
ORR11WT11S	-124.000	44.6000	169.	0.7	0.4	11.3	0.18
ORR11WT12S	-124.000	44.5250	9.	0.3	0.3	0.9	0.11
ORR11WT13S	-124.000	44.4250	40.	0.5	0.4	1.9	ND
ORR11WT14S	-124.000	44.3500	18.	0.6	0.4	2.4	0.05
ORR11WT19S	-124.000	43.9300	5.	1.2	1.2	2.3	0.29
ORR12ET17S	-121.300	44.0800	19.	0.7	0.6	1.5	0.09
ORR12ET18S	-121.300	44.0000	20.	0.8	0.8	1.4	0.24
ORR12WT17S	-124.120	44.0800	11.	1.1	0.6	4.3	0.04
ORR12WT18S	-124.120	44.0000	98.	0.5	0.5	1.8	0.13
ORR12WT19S	-124.120	43.9300	38.	0.9	0.6	3.3	0.19
ORR12WT21S	-124.120	43.7000	11.	0.6	0.6	1.3	0.11
ORR12WT22S	-124.120	43.6500	31.	1.1	0.9	2.7	0.11
ORR12WT23S	-124.120	43.5700	7.	1.0	1.0	2.8	0.25
ORR13ET01N	-121.175	45.5700	77.	1.3	1.0	7.1	0.31
ORR13ET02N	-121.175	45.6500	9.	1.2	1.2	3.6	0.53
ORR13ET15S	-121.175	44.2500	7.	0.9	0.9	1.5	0.24
ORR13ET17S	-121.175	44.0800	9.	0.5	0.5	0.8	0.18

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
ORR13WT40S	-124.250	42.0750	14.	0.9	0.6	2.2	0.86
ORR13WT41S	-124.250	42.0250	36.	1.6	0.6	15.9	0.05
ORR14WT28S	-124.350	43.1200	17.	0.6	0.4	2.6	0.17
ORR14WT35S	-124.350	42.5500	8.	0.9	0.9	2.2	0.25
ORR14WT36S	-124.350	42.4500	10.	0.6	0.5	1.0	0.11
ORR14WT37S	-124.350	42.3500	20.	0.7	0.6	1.9	0.09
ORR14WT40S	-124.350	42.0750	7.	1.0	1.0	1.9	0.01
ORR15WT28S	-124.470	43.1200	41.	0.6	0.5	1.9	ND
ORR15WT32S	-124.470	42.7800	7.	0.3	0.3	0.4	0.16
ORR15WT33S	-124.470	42.7000	6.	0.5	0.5	0.7	0.01
ORR15WT36S	-124.470	42.4500	7.	0.6	0.6	1.0	ND
ORR28ET04N	-119.350	45.8250	6.	1.5	1.5	2.8	0.46
ORR35ET05N	-118.420	45.9000	213.	3.2	2.3	18.8	0.70
ORR35ET06N	-118.420	46.0000	24.	4.9	1.7	24.4	0.58
ORR36ET05N	-118.300	45.9000	8.	1.9	1.9	4.2	0.67
WAR00ET00N	-122.738	45.5175	7.	1.3	1.3	1.8	0.37
WAR01ET01N	-122.675	45.5500	5.	1.8	1.8	3.8	0.27
WAR01ET02N	-122.675	45.6500	882.	1.4	1.0	12.1	0.34
WAR01ET03N	-122.675	45.7500	326.	1.2	1.0	16.6	0.22
WAR01ET04N	-122.675	45.8250	104.	1.2	0.9	7.6	0.44
WAR01ET05N	-122.675	45.9000	69.	0.8	0.7	2.8	0.33
WAR01ET20N	-122.675	47.2000	11.	1.1	0.4	5.1	0.18
WAR01ET21N	-122.675	47.3000	54.	0.4	0.3	1.2	0.12
WAR01ET22N	-122.675	47.4000	36.	0.5	0.3	2.8	0.15
WAR01ET24N	-122.675	47.5700	9.	0.8	0.8	1.4	0.11
WAR01ET25N	-122.675	47.6500	9.	0.9	0.9	1.9	0.08
WAR01ET33N	-122.675	48.3500	7.	0.6	0.6	1.2	0.17
WAR01WT05N	-122.800	45.9000	38.	0.6	0.3	9.4	0.35
WAR01WT06N	-122.800	46.0000	44.	0.7	0.5	3.7	0.14
WAR01WT07N	-122.800	46.0750	41.	0.5	0.4	1.6	0.27
WAR01WT08N	-122.800	46.1700	17.	0.5	0.4	2.0	0.22
WAR01WT09N	-122.800	46.2500	11.	0.3	0.3	0.8	0.06
WAR01WT10N	-122.800	46.3500	11.	0.4	0.4	0.8	0.16
WAR01WT11N	-122.800	46.4250	8.	0.8	0.8	3.3	0.20
WAR01WT12N	-122.800	46.5000	8.	0.7	0.7	1.2	0.26
WAR01WT13N	-122.800	46.6000	11.	1.3	0.6	6.4	0.27
WAR01WT17S	-122.800	46.9500	11.	0.7	0.7	1.4	0.21
WAR01WT18S	-122.800	47.0500	36.	1.0	0.8	3.4	0.28
WAR01WT20N	-122.800	47.2000	12.	0.4	0.3	0.9	0.14
WAR01WT21N	-122.800	47.3000	15.	0.3	0.3	0.6	0.11
WAR01WT22N	-122.800	47.4000	26.	0.5	0.4	1.2	0.21
WAR01WT23N	-122.800	47.4750	8.	0.4	0.4	0.8	0.09
WAR01WT30N	-122.800	48.0750	7.	0.6	0.6	1.3	0.08
WAR01WT37N	-122.800	48.7000	6.	0.3	0.3	0.8	ND
WAR02ET01N	-122.550	45.5500	13.	1.1	0.8	4.0	0.40
WAR02ET02N	-122.550	45.6500	1117.	1.5	4.1	15.6	0.28
WAR02ET03N	-122.550	45.7500	183.	1.2	1.0	5.9	0.13
WAR02ET04N	-122.550	45.8250	63.	1.2	1.0	7.7	0.11
WAR02ET05N	-122.550	45.9000	13.	0.9	0.8	2.2	0.24
WAR02ET21N	-122.550	47.3000	137.	0.6	0.5	5.7	0.17
WAR02ET22N	-122.550	47.4000	21.	0.6	0.4	3.6	0.15

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
WAR02ET31N	-122.550	48.1750	6.	0.3	0.3	0.5	ND
WAR02ET32N	-122.550	48.2500	9.	0.4	0.4	1.3	0.03
WAR02WT07N	-122.940	46.0750	34.	0.4	0.2	1.6	0.46
WAR02WT08N	-122.940	46.1700	1247.	0.5	0.9	7.5	0.24
WAR02WT09N	-122.940	46.2500	98.	0.8	0.5	16.0	0.30
WAR02WT10N	-122.940	46.3500	18.	0.6	0.5	1.3	0.37
WAR02WT12N	-122.940	46.5000	23.	1.0	0.6	5.8	0.44
WAR02WT13N	-122.940	46.6000	36.	1.3	0.5	10.7	0.40
WAR02WT14N	-122.940	46.7000	18.	0.8	0.4	1.8	0.31
WAR02WT17S	-122.940	46.9500	17.	0.6	0.6	1.0	0.18
WAR02WT18S	-122.940	47.0500	59.	0.7	0.6	1.8	0.08
WAR02WT19N	-122.940	47.1250	17.	0.6	0.5	1.9	0.10
WAR02WT20N	-122.940	47.2000	10.	0.5	0.3	1.7	0.15
WAR02WT21N	-122.940	47.3000	5.	0.6	0.6	1.0	0.10
WAR02WT22N	-122.940	47.4000	28.	0.6	0.4	2.5	0.13
WAR02WT25N	-122.940	47.6500	5.	0.3	0.3	0.6	0.13
WAR02WT30N	-122.940	48.0750	6.	0.5	0.5	1.7	0.00
WAR03ET01N	-122.425	45.5500	91.	1.6	1.1	8.1	0.53
WAR03ET02N	-122.425	45.6500	89.	1.5	1.1	4.6	0.17
WAR03ET03N	-122.425	45.7500	72.	1.6	1.0	12.4	0.05
WAR03ET04N	-122.425	45.8250	23.	1.0	0.9	4.6	0.03
WAR03ET05N	-122.425	45.9000	9.	1.2	1.2	2.1	0.18
WAR03ET12N	-122.425	46.5000	9.	0.7	0.7	1.8	0.01
WAR03ET17N	-122.425	46.9500	11.	0.8	0.6	2.4	ND
WAR03ET18N	-122.425	47.0500	23.	3.2	1.0	22.1	0.36
WAR03ET19N	-122.425	47.1250	354.	1.2	0.7	14.2	0.38
WAR03ET20N	-122.425	47.2000	518.	0.7	0.5	19.5	0.27
WAR03ET21N	-122.425	47.3000	33.	0.8	0.7	3.6	0.15
WAR03ET23N	-122.425	47.4750	31.	0.5	0.4	2.1	0.28
WAR03ET24N	-122.425	47.5700	94.	0.4	0.3	2.3	0.09
WAR03ET25N	-122.425	47.6500	53.	0.5	0.4	2.0	0.10
WAR03ET26N	-122.425	47.6120	60.	0.5	0.4	2.2	ND
WAR03ET27N	-122.425	47.8200	110.	0.6	0.4	16.1	0.07
WAR03ET29N	-122.425	48.0000	7.	0.5	0.5	1.2	0.20
WAR03ET30N	-122.425	48.0750	10.	0.3	0.2	0.9	ND
WAR03ET31N	-122.425	48.1750	30.	0.4	0.2	2.2	0.01
WAR03ET32N	-122.425	48.2500	58.	0.3	0.2	1.3	0.01
WAR03WT08N	-123.050	46.1700	63.	0.7	0.4	4.6	0.30
WAR03WT09N	-123.050	46.2500	11.	2.6	0.7	13.2	0.21
WAR03WT10N	-123.050	46.3500	9.	0.7	0.7	1.4	0.26
WAR03WT13N	-123.050	46.6000	14.	1.2	0.5	7.5	0.30
WAR03WT14N	-123.050	46.7000	10.	1.0	0.5	2.8	0.28
WAR03WT15N	-123.050	46.7700	8.	0.6	0.6	0.7	0.27
WAR03WT17N	-123.050	46.9500	10.	0.8	0.7	1.7	0.06
WAR03WT19N	-123.050	47.1250	25.	0.6	0.5	1.4	0.12
WAR03WT20N	-123.050	47.2000	97.	0.6	0.5	3.1	0.17
WAR03WT21N	-123.050	47.3000	15.	0.5	0.4	1.4	0.11
WAR03WT22N	-123.050	47.4000	8.	0.4	0.4	1.5	0.17
WAR03WT23N	-123.050	47.4750	5.	0.4	0.4	0.6	0.01
WAR03WT29N	-123.050	48.0000	9.	2.1	2.1	5.8	0.08
WAR03WT30N	-123.050	48.0750	184.	0.6	0.5	4.5	0.21

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
WAR04ET01N	-122.300	45.5500	84.	1.8	1.2	22.1	0.01
WAR04ET02N	-122.300	45.6500	14.	1.3	1.2	3.0	0.06
WAR04ET12N	-122.300	46.5000	11.	0.5	0.5	1.0	0.08
WAR04ET16N	-122.300	46.8700	5.	0.4	0.4	0.7	0.20
WAR04ET17N	-122.300	46.9500	12.	0.5	0.4	1.2	0.20
WAR04ET18N	-122.300	47.0500	5.	5.8	5.8	23.8	0.22
WAR04ET19N	-122.300	47.1250	16.	0.9	0.5	3.2	0.26
WAR04ET20N	-122.300	47.2000	42.	0.7	0.5	7.1	0.30
WAR04ET21N	-122.300	47.3000	57.	0.9	0.6	11.8	0.16
WAR04ET22N	-122.300	47.4000	16.	0.5	0.5	1.2	0.19
WAR04ET23N	-122.300	47.4750	53.	0.5	0.4	2.0	0.19
WAR04ET24N	-122.300	47.5700	74.	0.5	0.4	3.5	0.16
WAR04ET25N	-122.300	47.6500	116.	0.5	0.4	3.3	0.09
WAR04ET26N	-122.300	47.7120	186.	0.5	0.4	4.8	0.07
WAR04ET27N	-122.300	47.8200	1504.	0.4	0.7	5.8	0.07
WAR04ET28N	-122.300	47.9000	439.	0.4	0.3	2.8	0.12
WAR04ET30N	-122.300	48.0700	71.	0.6	0.5	2.1	0.01
WAR04ET31N	-122.300	48.1750	39.	0.4	0.2	2.0	0.15
WAR04ET32N	-122.300	48.2500	38.	0.4	0.4	1.1	0.23
WAR04WT08N	-123.175	46.1700	5.	1.4	1.4	3.3	0.22
WAR04WT12N	-123.175	46.5000	6.	0.5	0.5	0.6	0.10
WAR04WT22N	-123.175	47.4000	16.	0.6	0.4	2.2	0.09
WAR04WT30N	-123.175	48.0750	142.	0.7	0.4	5.8	0.01
WAR04WT31N	-123.175	48.1750	19.	0.5	0.3	2.2	ND
WAR05ET01N	-122.175	45.5500	13.	3.4	1.4	16.0	0.10
WAR05ET02N	-122.175	45.6500	6.	0.8	0.8	1.3	0.07
WAR05ET19N	-122.175	47.1250	9.	2.2	2.2	13.7	0.20
WAR05ET20N	-122.175	47.2000	12.	0.6	0.5	1.2	0.22
WAR05ET21N	-122.175	47.3000	60.	1.1	0.6	12.0	0.25
WAR05ET22N	-122.175	47.4000	11.	0.8	0.5	1.7	0.27
WAR05ET23N	-122.175	47.4750	8.	1.1	1.1	3.2	0.20
WAR05ET24N	-122.175	47.5700	6.	1.1	1.1	2.4	0.16
WAR05ET25N	-122.175	47.6500	15.	0.8	0.6	2.4	0.11
WAR05ET26N	-122.175	47.7120	13.	0.8	0.6	2.2	0.10
WAR05ET27N	-122.175	47.8200	439.	0.5	0.4	3.3	0.14
WAR05ET28N	-122.175	47.9000	616.	0.4	0.3	3.3	0.11
WAR05ET29N	-122.175	48.0000	481.	0.4	0.3	3.0	0.12
WAR05ET30N	-122.175	48.0750	587.	0.4	0.3	2.1	0.01
WAR05ET31N	-122.175	48.1750	149.	0.4	0.3	3.5	0.22
WAR05ET32N	-122.175	48.2500	29.	0.3	0.2	1.2	0.17
WAR05WT18N	-123.300	47.0500	38.	0.6	0.4	3.1	0.18
WAR06ET02N	-122.050	45.6500	5.	12.9	12.9	48.3	0.18
WAR06ET21N	-122.050	47.3000	9.	0.9	0.9	1.4	0.17
WAR06ET27N	-122.050	47.8200	109.	0.5	0.3	4.6	0.10
WAR06ET28N	-122.050	47.9000	153.	0.4	0.4	1.9	0.13
WAR06ET29N	-122.050	48.0000	135.	0.5	0.3	4.1	0.12
WAR06ET30N	-122.050	48.0750	68.	0.4	0.3	1.3	0.21
WAR06ET31N	-122.050	48.1750	31.	0.4	0.4	1.3	0.19
WAR06ET32N	-122.050	48.2500	19.	0.3	0.3	1.2	0.10
WAR06WT18N	-123.425	47.0500	14.	0.4	0.4	0.7	0.12
WAR06WT30N	-123.425	48.0750	764.	0.5	0.4	4.4	0.02

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
WAR06WT31N	-123.425	48.1750	18.	0.6	0.4	1.9	ND
WAR07ET02N	-121.900	45.6500	22.	6.6	5.3	19.4	0.19
WAR07ET03N	-121.900	45.7500	45.	3.2	2.3	16.1	0.21
WAR07ET27N	-121.900	47.8200	31.	0.6	0.4	1.8	0.01
WAR07ET28N	-121.900	47.9000	47.	0.6	0.4	3.8	0.14
WAR07ET30N	-121.900	48.0750	12.	0.5	0.2	1.9	ND
WAR07WT17N	-123.550	46.9500	37.	0.8	0.5	4.8	0.32
WAR07WT30N	-123.550	48.0750	26.	0.8	0.4	2.7	ND
WAR08ET03N	-121.750	45.7500	20.	3.3	1.5	22.2	0.14
WAR08ET27N	-121.750	47.8200	15.	0.3	0.3	0.6	0.05
WAR08ET28N	-121.750	47.9000	41.	0.4	0.3	1.3	0.15
WAR08WT13N	-123.675	46.6000	5.	1.4	1.4	2.9	0.01
WAR08WT14N	-123.675	46.7000	54.	1.0	0.6	7.9	0.26
WAR08WT17N	-123.675	46.9500	44.	0.7	0.5	3.7	0.12
WAR08WT30N	-123.675	48.0750	14.	0.6	0.6	1.1	ND
WAR09ET03N	-121.650	45.7500	5.	4.7	4.7	13.7	0.34
WAR09ET13N	-121.650	46.6000	7.	0.8	0.8	2.7	0.22
WAR09ET27N	-121.650	47.8200	15.	0.4	0.3	0.9	0.01
WAR09ET29N	-121.650	48.0000	34.	1.1	1.0	2.3	0.07
WAR09ET30N	-121.650	48.0750	18.	1.1	1.0	2.1	0.20
WAR09ET32N	-121.650	48.2500	19.	0.5	0.4	1.8	0.24
WAR09WT10N	-123.800	46.3500	5.	0.9	0.9	1.8	0.16
WAR09WT14N	-123.800	46.7000	24.	0.7	0.6	2.5	0.01
WAR09WT17N	-123.800	46.9500	151.	0.6	0.3	20.8	0.09
WAR10ET03N	-121.500	45.7500	27.	3.3	1.5	28.7	0.20
WAR10ET06N	-121.500	46.0000	8.	0.5	0.5	0.9	0.10
WAR10ET27N	-121.500	47.8200	7.	0.2	0.2	0.5	0.20
WAR10WT17N	-123.925	46.9500	89.	0.3	0.3	3.4	0.01
WAR11ET03N	-121.350	45.7500	15.	1.4	1.4	2.8	0.19
WAR11WT10N	-124.050	46.3500	7.	0.3	0.3	0.8	0.01
WAR11WT12N	-124.050	46.5000	7.	0.4	0.4	1.1	0.17
WAR11WT15N	-124.050	46.7700	13.	0.3	0.2	0.9	0.06
WAR11WT16N	-124.050	46.8700	7.	0.3	0.3	0.5	0.02
WAR12ET03N	-121.300	45.7500	5.	0.8	0.8	1.2	0.29
WAR13WT28N	-124.370	47.9000	39.	0.9	0.5	7.8	0.08
WAR15ET02N	-120.970	45.6500	11.	0.7	0.6	2.3	0.85
WAR16ET04N	-120.870	45.8250	58.	1.0	0.7	3.9	0.36
WAR18ET17N	-120.575	46.9500	190.	1.9	1.4	10.9	0.36
WAR21ET03N	-120.200	45.7500	6.	0.9	0.9	1.9	0.70
WAR24ET08N	-119.800	46.1700	24.	2.8	1.7	21.4	0.60
WAR26ET09N	-119.550	46.2500	6.	2.0	2.0	7.6	0.68
WAR27ET09N	-119.425	46.2500	15.	1.4	0.9	4.0	0.69
WAR27ET10N	-119.425	46.3500	11.	1.3	1.2	2.4	0.63
WAR28ET08N	-119.300	46.1700	20.	1.5	0.9	5.5	ND
WAR28ET09N	-119.300	46.2500	459.	1.1	0.9	5.6	0.50
WAR28ET10N	-119.300	46.3500	153.	1.1	1.0	5.5	0.54
WAR29ET08N	-119.175	46.1700	242.	1.1	0.9	8.0	0.67
WAR29ET09N	-119.175	46.2500	115.	1.1	1.0	5.1	0.55
WAR29ET13N	-119.175	46.6000	7.	0.9	0.9	2.2	0.61
WAR30ET08N	-119.050	46.1700	60.	1.0	0.9	2.9	0.46
WAR30ET09N	-119.050	46.2500	81.	1.2	0.9	10.9	0.57

TOWNSHIP	LONG.	LAT.	# PTS	AVG Rn	MED Rn	MAX Rn	GRID Ra
WAR30ET11N	-119.050	46.4250	6.	1.0	1.0	1.8	ND
WAR31ET14N	-118.925	46.7000	6.	1.0	1.0	1.4	0.57
WAR33ET39N	-118.650	48.8700	10.	2.4	0.8	8.8	0.81
WAR41ET23N	-117.670	47.4750	62.	3.5	1.6	26.7	0.36
WAR41ET25N	-117.670	47.6500	12.	2.5	1.6	12.4	0.61
WAR41ET27N	-117.670	47.8200	20.	12.8	9.4	47.3	0.40
WAR42ET24N	-117.500	47.5700	10.	1.6	1.1	4.0	0.42
WAR43ET24N	-117.370	47.5700	11.	5.4	3.4	22.8	0.59
WAR43ET27N	-117.370	47.8200	18.	4.1	3.2	9.8	0.47
WAR43ET29N	-117.370	48.0000	6.	5.3	5.3	21.3	0.70
WAR44ET24N	-117.250	47.5700	8.	1.7	1.7	3.0	0.72
WAR44ET25N	-117.250	47.6500	171.	9.4	6.3	92.4	0.70
WAR44ET26N	-117.250	47.7120	5.	3.8	3.8	10.4	0.76
WAR45ET26N	-117.120	47.7120	6.	0.9	0.9	1.7	0.66

Appendix 2
Tabulated indoor radon and surface radium data for townships with 25 or more indoor radon readings with comments regarding geology and soils

This appendix contains the data used to make the graphs in figures 8 and 9. Only townships with 25 or more data points (indoor radon readings) were used to make the graphs. Please see the heading to Appendix 1 for further details. The comments regarding the geology and soils focus on the populated parts of the township as determined from the air photos and maps that accompany the soil survey. The comments also focus on the percentage of the township underlain by highly permeable soils. In many townships the populated parts are restricted to one or two geologic environments within the township such as a river bottom and its terraces rather than adjacent hillslopes.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR01ET02N	882.	1.4	12.1	0.34	River floodplain and alluvial terraces. Highly permeable soils underlie about 30-40% of housing.
WAR01ET03N	326.	1.2	16.6	0.22	River terraces, less than 10% of the housing on highly permeable soils.
WAR01ET04N	104.	1.2	7.6	0.44	River terraces, minor floodplain. Minor highly permeable Pyallup soils present in populated areas.
WAR01ET05N	69.	0.8	2.8	0.33	High river terraces, minor floodplain areas. Minor highly permeable Pyallup soils present in populated areas.
WAR01ET21N	54.	0.4	1.2	0.12	Glacial till, less than 10% of housing on highly permeable soils.
WAR01ET22N	36.	0.5	2.8	0.15	Glacial till, less than 10% of housing on highly permeable soils.
WAR01WT05N	38.	0.6	9.4	0.35	Basalt and andesite hills, low terraces, some river alluvium. Less than 10% of housing on highly permeable soils.
WAR01WT06N	44.	0.7	3.7	0.14	Basalt and andesite, river floodplain. Town of Kalama on rock land.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR01WT07N	41.	0.5	1.6	0.27	Basalt and andesite, river floodplain. Highly permeable Toutle and Pilchuck soils present but underlie less than 10% of housing.
WAR01WT18N	36.	1.0	3.4	0.28	Glacial drift and outwash. About 50% of housing is located on highly permeable soils on outwash.
WAR01WT22N	26.	0.5	1.2	0.21	Glacial till. Less than 10% of housing on highly permeable soils.
WAR02ET02N	1117.	1.5	15.6	0.28	Alluvial terraces, more than 50% of populated areas are underlain by highly permeable Lauren-Sifton-Wind River soils
WAR02ET03N	183.	1.2	5.9	0.13	Alluvial terraces, about 10% of township is underlain by highly permeable soils
WAR02ET04N	63.	1.2	7.7	0.11	Low and high alluvial terraces, minor soils on basalt and andesite, less than 10% of township is underlain by highly permeable soils
WAR02ET21N	137.	0.6	5.7	0.17	Glacial till, minor outwash, less than 10% of the township is underlain by highly permeable soils
WAR02WT07N	34.	0.4	1.6	0.46	Alluvial floodplain, and minor terraces. Highly permeable Pilchuck soils underlie about 5-10% of township, mostly commercial/industrial
WAR02WT08N	1247.	0.5	7.5	0.24	Alluvial floodplain, and terraces, minor residual soils on basalt. Highly permeable Pilchuck soils underlie about 5% of housing.
WAR02WT09N	98.	0.8	16.0	0.30	Most housing is on alluvium surrounded by hills underlain by basalt, sandstone and shale. Less than 10% of soils are highly permeable.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR02WT13N	36.	1.3	10.7	0.40	Floodplain, terraces, minor glacial till and outwash. Most housing on low permeability loamy soils.
WAR02WT18S	59.	0.7	1.8	0.08	Till and outwash, about 15% highly permeable Tumwater and Everett soils.
WAR02WT22N	28.	0.6	2.5	0.13	No soil map available. Till and minor outwash ?
WAR03ET01N	91.	1.6	8.1	0.53	River terraces. Highly permeable Washougal and Lauren soils underlie about 10 to 20% of area.
WAR03ET02N	89.	1.5	4.6	0.17	River terraces and minor mountain soils. Highly permeable Lauren soils underlie about 10% of the township.
WAR03ET03N	72.	1.6	12.4	0.05	Mountain soils on basalt, minor river terraces. Highly permeable soils underlie less than 10% of the township.
WAR03ET19N	354.	1.2	14.2	0.38	Glacial outwash. Highly permeable Spanaway soils underlie about 60% of populated area.
WAR03ET20N	518.	0.7	19.5	0.27	Glacial till and outwash. Mostly unmapped but includes some highly permeable soils.
WAR03ET21N	33.	0.8	3.6	0.15	Glacial till. Highly permeable soils form less than 10% of the area.
WAR03ET23N	31.	0.5	2.1	0.28	Glacial till. Highly permeable soils form less than 10% of the area.
WAR03ET24N	94.	0.4	2.3	0.09	Glacial till and river alluvium. Soils not mapped but we infer that less than 10% are highly permeable.
WAR03ET25N	53.	0.5	2.0	0.10	Glacial till. Soils not mapped but we infer that less than 10% are highly permeable.
WAR03ET27N	110.	0.6	16.1	0.07	Till, minor outwash. Highly permeable Everett soils underlie about 15% of the area.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR03ET31N	30.	0.4	2.2	0.01	Till, minor outwash. Highly permeable Everett soils underlie about 25% of the area.
WAR03ET32N	58.	0.3	1.3	0.01	Floodplain. No highly permeable soils.
WAR03WT08N	63.	0.7	4.6	0.30	Floodplain alluvium. Residual soils on basalt, sandstone, and shale. Less than 5% of the area is underlain by highly permeable soils.
WAR03WT19N	25.	0.6	1.4	0.12	Glacial till and outwash. Partly unmapped. Infer that about 15% of the area is underlain by highly permeable soils.
WAR03WT20N	97.	0.6	3.1	0.17	No soil map available. Glacial till and outwash?
WAR03WT30N	184.	0.6	4.5	0.21	Alluvial fan, terraces, floodplain and glacial till. 70 to 80% of populated areas underlain by highly permeable soils especially Sequim gravelly sandy loam.
WAR04ET01N	84.	1.8	22.1	0.01	Floodplain and alluvial terraces. Minor Lauren and Washougal soils underlie populated areas along the Columbia R.
WAR04ET20N	42.	0.7	7.1	0.30	Till and outwash. Puyallup and other highly permeable soils underlie about 30% of the area.
WAR04ET21N	57.	0.9	11.8	0.16	Glacial till and minor outwash. Highly permeable soils underlie less than 10% of the area.
WAR04ET23N	53.	0.5	2.0	0.19	Till, outwash and river alluvium. Highly permeable soils underlie 10-20% of the area.
WAR04ET24N	74.	0.5	3.5	0.16	Till, minor outwash and river alluvium. Soils not mapped, but we infer about 10% of the soils are highly. permeable.
WAR04ET25N	116.	0.5	3.3	0.09	Till, minor outwash. 10-20% of the soils are highly permeable.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR04ET26N	186.	0.5	4.8	0.07	Till, minor outwash. About 20% of the soils are highly permeable.
WAR04ET27N	1504.	0.4	5.8	0.07	Till, minor outwash. Highly permeable Everett soils form less than 10% of the area.
WAR04ET28N	439.	0.4	2.8	0.12	Till, minor outwash. Highly permeable Everett soils form less than 10% of the area.
WAR04ET30N	71.	0.6	2.1	0.01	Till, minor outwash. Highly permeable Everett soils form less than 10% of the area.
WAR04ET31N	39.	0.4	2.0	0.15	Till, outwash, floodplain alluvium. Less than 5% of the soils are highly permeable.
WAR04ET32N	38.	0.4	1.1	0.23	Till, terraces, floodplain. Less than 5% of the soils are highly permeable.
WAR04WT30N	142.	0.7	5.8	0.01	Glacial till, outwash, terraces, alluvial fan, and floodplain. 20 to 30% of area underlain by highly permeable Carlsborg and Hoypus soils.
WAR05ET21N	60.	1.1	12.0	0.25	Glacial till, outwash, and river alluvium. About 20 to 30% of soils are highly permeable.
WAR05ET27N	439.	0.5	3.3	0.14	Till and minor outwash. Highly permeable Everett soils underlie about 10% of the area.
WAR05ET28N	616.	0.4	3.3	0.11	Till with minor outwash, floodplain and terrace. Highly permeable Everett soils present but less than 10% of area.
WAR05ET29N	481.	0.4	3.0	0.12	Till with minor outwash, floodplain and terrace. Highly permeable Everett soils present but less than 5% of area.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR05ET30N	587.	0.4	2.1	0.01	Outwash, till, terraces. Highly permeable Custer and Lynnwood soils underlie about 10-15% of township mostly in the northern part.
WAR05ET31N	149.	0.4	3.5	0.22	Outwash, floodplain, till and terrace deposits. Highly permeable Everett, Lynnwood and Custer soils underlie about 20% of area.
WAR05ET32N	29.	0.3	1.2	0.17	Outwash, terrace, till, and floodplain deposits. Highly permeable Everett and Lynnwood soils underlie about 10% of area.
WAR05WT18N	38.	0.6	3.1	0.18	Hilly areas have residual soils on sandstone and siltstone. Valleys contain floodplain, terrace and fan deposits. Highly permeable Lyre and Udipsamment soils underlie about 10-20% of populated area.
WAR06ET27N	109.	0.5	4.6	0.10	Glacial till and floodplain deposits. Highly permeable soils less than 5% of area.
WAR06ET28N	153.	0.4	1.9	0.13	Till, terrace, outwash and floodplain deposits. Highly permeable soils form less than 5% of area.
WAR06ET29N	135.	0.5	4.1	0.12	Till, terrace, and flood-plain deposits. Highly permeable Everett and Winston soils form less than 10% of the area.
WAR06ET30N	68.	0.4	1.3	0.21	Till, terrace and outwash deposits. Highly permeable Everett and Ragnar soils underlie about 10-15% of the township mostly along the eastern edge.
WAR06ET31N	31.	0.4	1.3	0.19	Till, terrace and outwash, with mountain soils in east. Highly permeable Ragnar soils underlie about 10% of the township mostly in the northwestern part.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR06WT30N	764.	0.5	4.4	0.02	Till and outwash, hills underlain by siltstone, sandstone, conglomerate and basalt. About 20-30% of populated area underlain by highly permeable Hoypus soils developed on outwash.
WAR07ET03N	45.	3.2	16.1	0.21	Volcanic debris flow and landslide area. Steep slopes on hills overlooking Columbia River. Greater than 50% of housing on highly permeable, well-drained soils.
WAR07ET27N	31.	0.6	1.8	0.01	Till, terrace and flood-plain deposits. Highly permeable soils underlie less than 5% of area.
WAR07ET28N	47.	0.6	3.8	0.14	Till and terrace deposits. Highly permeable soils underlie 5-10% of area.
WAR07WT17N	37.	0.8	4.8	0.32	Siltstone and sandstone underlie hills, floodplain, terrace, and alluvial fans in valley. About 10% of populated valley area is underlain by highly permeable Carstairs and Lyre soils.
WAR07WT30N	26.	0.8	2.7	ND	Till, outwash, and floodplain, sandstone and siltstone in hilly areas. Minor highly permeable Neilton soils in upland valley areas.
WAR08ET28N	41.	0.4	1.3	0.15	Till and terrace deposits. Highly permeable Pilchuck, Puyallup, Winston, Everett, and Ragnar soils underlie about 20% of entire area but less under populated areas.
WAR08WT14N	54.	1.0	7.9	0.26	Uplands underlain by sandstone and siltstone. River valley occupied by floodplain. Less than 10% of the soils under populated areas are highly permeable.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR08WT17N	44.	0.7	3.7	0.12	Sandstone and siltstone on hills, glacial drift and floodplain deposits in valleys. Less than 5% of populated areas have highly permeable soils.
WAR09ET29N	34.	1.1	2.3	0.07	Mislocated?
WAR09WT17N	151.	0.6	20.8	0.09	Sandstone and siltstone on hills, glacial drift and floodplain deposits in valleys. Most of the population on silty floodplain deposits and dredged and diked fill of moderate permeability.
WAR10ET03N	27.	3.3	28.7	0.20	Colluvial material and residual soils on basalts and andesites. Steep slopes. More than 50% of housing on highly permeable Underwood soils.
WAR10WT17N	89.	0.3	3.4	0.01	Glacial drift on uplands, floodplain in valleys. Most population on silty floodplain and dredged and diked fill of low to moderate permeability.
WAR13WT28N	39.	0.9	7.8	0.08	Hills underlain by sand-stone, siltstone and con-glomerate, valleys by floodplain and low terraces. Moderately permeable soils throughout area.
WAR16ET04N	58.	1.0	3.9	0.36	No soil map available. Hills underlain by basalts with alluvium in narrow river valley.
WAR18ET17N	190.	1.9	10.9	0.36	No soil map available. Hills underlain by basalts. Alluvium and aeolian sand in valleys.
WAR28ET09N	459.	1.1	5.6	0.50	River alluvium, basalt, lake sediments, and loess. Highly permeable Quincy and Burbank soils underlie about 100% of populated area.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
WAR28ET10N	153.	1.1	5.5	0.54	River alluvium, basalt, lake sediments, and loess. Highly permeable Quincy, Hezel, and Burbank soils underlie about 100% of populated area.
WAR29ET08N	242.	1.1	8.0	0.67	Loess over basalt, older alluvium, and lake sediments. About 10-15% of the populated area underlain by highly permeable Finley and Burbank soils.
WAR29ET09N	115.	1.1	5.1	0.55	Only Benton County part of area had soil map available. Old alluvium, lake sediments, and minor basalt. Estimate that about 30% of soils are highly permeable.
WAR30ET08N	60.	1.0	2.9	0.46	Alluvium and aeolian sand. About 80-90% of the populated area is underlain by highly permeable Quincy and Burbank soils.
WAR30ET09N	81.	1.2	10.9	0.57	No soil map available. Alluvium, aeolian sand, and minor outwash.
WAR41ET23N	62.	3.5	26.7	0.36	Loess and outwash. About 60% of the populated area is underlain by highly permeable Hesseltine silt loam.
WAR44ET25N	171.	9.4	92.4	0.70	Glacial outwash sand and gravel. 80-90% of the populated area is underlain by highly permeable Garrison, Marble, and Springdale soils
ORR01ET39S	137.	0.6	2.6	0.84	No soil survey available. The township is underlain by river alluvium, tuffaceous ss and shale, and intrusive rocks.
ORR01WT17S	43.	0.5	2.4	0.08	Floodplain and terraces along river valley in basalt hills, 40 to 50% of populated areas underlain by highly permeable Sifton and Salem soils.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
ORR01WT19S	29.	0.9	2.5	0.01	River valley and terraces in mafic volcanic area, 20% of populated areas underlain by highly permeable Salem soils.
ORR02WT17S	109.	0.9	15.9	0.10	Terraced river valley in basalt area, about 20% of populated areas on highly permeable Salem and Chapman soils.
ORR02WT18S	52.	1.0	3.4	0.32	Broad terraced river valley, about 40 to 50% of housing on highly permeable Chapman and Salem soils.
ORR03ET18S	55.	0.4	1.5	0.16	Mislocated? Township occurs in National Forest area.
ORR03ET21S	111.	0.8	4.1	0.43	Narrow river valley in mafic volcanic area, 50 to 60% of housing on highly permeable Camas and Salem soils.
ORR03WT01N	40.	2.0	4.4	0.75	Floodplains and terraces in broad valley floor, less than 2% of the soils are highly permeable
ORR03WT01S	51.	1.9	4.4	0.51	Floodplains and terraces in broad valley floor, less than 2% of the soils are highly permeable
ORR03WT07S	307.	1.6	15.7	0.33	Floodplain and river terraces along Willamette River, minor hills underlain by basalt. Highly permeable Salem and Clackamas soils underlie about 10% of this township immediately S and SE of the capitol building.
ORR03WT18S	551.	0.7	11.3	0.29	Township underlain by basalts, tuffaceous, micaceous, continental sedimentary rocks and floodplain alluvium. Most housing on continental sediments. Less than 10% of housing on highly permeable soils.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
ORR04WT01N	33.	2.3	8.0	0.21	Mixed basalts and marine sedimentary rocks underlie township. Less than 2 % of the housing is on highly permeable soils. Orchards are present.
ORR04WT04S	369.	1.5	15.8	0.42	Broad terraced river valley, 90% of the soils are of moderate perme- ability, orchards are present.
ORR04WT07N	114.	2.8	16.0	0.22	Mixed basalt, feldspathic, micaceous sandstone, and river bottomlands. 70 to 90% of housing on steep (5 to 305 slopes) Braun- Scaponia-Arunde soils of moderate permeability.
ORR04WT08N	25.	1.7	3.7	0.23	Basalt on hills, Columbia River bottomlands. About 50% of housing on highly permeable Multnomah soils on low terraces.
ORR04WT10S	63.	2.2	15.3	0.21	River valley bottomland, terraces and marine sedi- ments, less than 10% of housing on highly permeable soils.
ORR04WT17S	973.	0.8	10.3	0.18	Older alluvium in broad river valley, about 10% of housing on highly permeable Salem-Chapman soils.
ORR04WT18S	311.	0.7	8.0	0.11	Basalt and other volcanic rocks, some river alluvium and terraces. Less than 10% of housing is on soils that are highly permeable.
ORR05WT17S	35.	0.9	3.7	0.34	High terraces and river alluvium, less than 5% of housing on highly permeable soils.
ORR05WT18S	57.	1.2	9.4	0.49	Marine rocks, basalts, high old terraces. Less than 5% of housing on highly permeable soils.
ORR05WT22S	26.	1.4	4.1	0.41	No soil survey available. Basalt, feldspathic, micaceous marine sedi- ments,minor alluvium.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
ORR07ET02N	26.	3.0	8.8	0.18	Landslide debris, Columbia River alluvium. Nearly 100% of housing on highly permeable Multnomah soils developed on alluvium.
ORR09WT01S	67.	1.3	9.3	0.27	Basalt hills, marine tuff. sediments in foothills, alluvium in valley. Highly permeable Ginger soils underlie about 10% of E. Tillamook.
ORR10ET01N	239.	1.3	22.8	0.24	Basalt, volcanic ash, water-laid volcanic rock, andesite, loess. Less than 10% of housing is on highly permeable soils.
ORR10ET01S	31.	1.7	17.3	0.25	Basalt, volcanic ash, water-laid volcanic rock, andesite, loess. Less than 10% of housing is on highly permeable soils.
ORR10ET02N	693.	1.7	46.5	0.19	Basalt, water-laid volcanic rocks, river alluvium. About 20% of housing on highly permeable Wind River variant and Van Horn soils.
ORR10ET03N	804.	1.3	13.6	0.21	Basalt, water-laid volcanic rocks, river terrace alluvium. Less than 10% of housing is sited on highly permeable soils.
ORR10WT01N	37.	0.9	3.6	0.08	Basalts, marine sediments, alluvium and dunes. Less than 10% of housing is on highly permeable soils.
ORR10WT01S	61.	1.2	7.0	0.17	Alluvium, marine sediments, and basalt. About 10% of housing is on highly permeable Ginger soils.
ORR10WT11S	60.	1.3	6.5	0.24	No soil survey available. Marine sediments (some tuffaceous), alluvium along Yaquina R.
ORR11ET02N	78.	1.3	5.7	0.13	Water-laid volcanics and basalt. Most housing on loamy soils developed on basalt. Less than 10% of housing on highly permeable soils.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
ORR11WT11S	169.	0.7	11.3	0.18	No soil survey available. Marine sandstone and siltstone, dune sands.
ORR11WT13S	40.	0.5	1.9	ND	No soil survey available. Marine sandstone and siltstone, some alluvium.
ORR12WT18S	98.	0.5	1.8	0.13	Dunes, minor marine sediments. Nearly 100% of housing on highly permeable soils on dune sands.
ORR12WT19S	38.	0.9	3.3	0.19	Coastal dunes, minor marine sediments. About 10% of housing on highly permeable Waldport soils.
ORR12WT22S	31.	1.1	2.7	0.11	No soil survey available. Estuarine and marine sediments, some alluvium.
ORR13ET01N	77.	1.3	7.1	0.31	Basalts, water-laid volcanics, some alluvium. Highly permeable Tygh soils underlie about 5-10% of the west end of the city of The Dalles.
ORR13WT41S	36.	1.6	15.9	0.05	Marine mudstone, marine terraces along the coast. Less than 10% of housing on highly permeable soils.
ORR35ET05N	213.	3.2	18.8	0.70	Basalt and other volcanic rocks on hills, alluvium in the valley. About 70% of housing on highly permeable Yakima gravelly loam.
IDR04WT50N	42.	7.3	28.1	0.58	Highly permeable (mostly McGuire) soils developed on glacial outwash underlie 90%+ of populated areas in the valley.
IDR04WT51N	50.	10.0	36.5	0.73	Highly permeable (mostly Avonville) soils developed on glacial outwash underlie 90%+ of populated areas in the valley.
IDR05WT50N	38.	6.2	21.1	0.60	Highly permeable (McGuire, Avonville, and Garrison) soils developed on glacial outwash underlie 90%+ of populated areas in the valley.

TOWNSHIP	# PTS	AVG Rn	MAX Rn	GRID Ra	Geology and soil characteristics
IDR22ET10S	38.	3.3	11.7	0.48	Highly permeable Abo, Buko and Paniogue soils developed on river terraces along the Snake R. underlie about 30-40% of the populated area.
IDR23ET09S	29.	1.7	7.0	0.86	Highly permeable Abo, Paulville, and Wodskow soils developed on river alluvium and low terraces underlie 60 to 70% of the populated areas.
IDR23ET10S	88.	4.4	27.6	0.93	Less than 20% of the highly populated areas situated on river alluvium are underlain by highly permeable soils.
IDR38ET02N	281.	1.9	14.6	0.71	Floodplain, about 80% of the populated area is underlain by highly permeable soils.

APPENDIX 3

EVALUATION OF COUNTY SOIL REPORTS

Soil surveys provide a description of and maps of the soils that underlie the area described. In a modern soil survey, the various named soils are mapped directly on aerial photos of the study area. In addition, soils are grouped together by the writers of the survey in genetically related associations or map units that are also mapped at a smaller scale. These modern reports include extensive descriptions of the physical and chemical properties of the soils, engineering tests of the soils, projected uses of the soils, and related information. This tabular information includes estimates of the permeability for the various soil horizons, sieve size analyses, potential of the soil as a source of sand and gravel, and textural descriptions.

The permeability data are the most useful. In modern soil descriptions, permeability is broken down into 7 ranges in inches per hour (<0.06, 0.06-0.2, 0.2-0.6, 0.6-2.0, 2.0-6.0, 6.0-20.0, >20.0 in/hr). Our evaluation of the data in Figure 8 and the experience of other researchers has led us to conclude that highly permeable soils (those 2 classes greater than 6.0 in/hr) permit significant convective flow of soil gas, permit radon to diffuse more readily through soil, and thus make it more available to structures sited on those soils. Houses sited on such soils should consistently yield higher indoor radon levels for the same radium content of the soil or radon content of the soil gas. These two highest classes of permeability have equivalent expressions: "rapidly permeable" (6-20 in/hr) and "very rapidly permeable" (>20 in/hr). In some modern reports ">6 in/hr" and "2-20 in/hr" are used as estimates for some soils. The first one offers no practical problem; however, the second requires some additional evidence to judge whether the soils so described are permeable enough to contribute to radon availability in soils.

In most soil reports, the characteristics of the soil are evaluated for only the upper 60 inches (5 feet); thus the estimates of permeability (and other characteristics) are typically cutoff at 60 inches (see survey descriptions below).

If a soil is described as a "good" or "fair" source of sand and gravel, it generally means that the subsoil or substrata contain clean sand and/or gravel (with permeabilities >6 in/hr). In many cases, a soil may be described as a "poor" source of sand or gravel because of "excessive fines". These latter soils may contain abundant sand and gravel-sized material, but they also contain silt and clay in pore spaces. Such materials generally have permeabilities less than 6 in/hr and are described as gravelly or sandy loams.

In older reports, the two highest permeability ranges used in the table of physical and chemical properties are 5-10 in/hr and >10 in/hr. Since 5 in/hr is not significantly different from 6 in/hr, especially where the permeabilities are usually estimated, there is no practical difference in using these upper 2 permeability ranges as indicative of highly permeable soils.

In still older reports, no permeability data are given and soil names and statements regarding internal drainage must be used to evaluate permeability. In general, materials described as "fine sand" are somewhat below the limits where convective flow of soil gas becomes significant. "Loamy fine sands" generally are not expected to permit significant convective flow. "Coarse sand" permits convective flow. The terms "rapid" and "very rapid" internal drainage are indicative of soils with high permeability. In addition, in these older reports groups of genetically similar soils were not put together in soil associations and mapped at smaller scales. Evaluation of these older reports thus requires careful examination of the soil maps to understand how the highly permeable soils are distributed. In these older reports aerial photos are not used (generally because they were not available).

In our study of the soil surveys, we first evaluated the soil descriptions to determine which soils could be classified as highly permeable (6-20 in/hr or >20 in/hr or equivalents). We then examined the soil associations to determine which of them were dominated by highly permeable soils, using the percentage of the area underlain by each of the soils in the association (given in most reports). Highly permeable soils were considered to be dominant if they underlie more than half of the association. Soil associations are typically given the name of the one, two, or three dominant soils characterizing the association (for example, Spanaway in the Pierce County, Washington survey). In areas where the soils are quite mixed, the 3 most abundant soils give the name to the association. Where the highly permeable association underlay areas large enough to map at the scale of Figure 13 the information was transferred to that map.

In each of the survey descriptions below we show:

1. the reference to the survey (given here rather than in the References section of this report);
2. rainfall for the area, typically the lowest elevation;
3. lists of soils of high permeability or soils judged to have high permeability;
4. names of the soil associations judged to have high overall permeability (rapidly and very rapidly permeable). The association number shown is that given by the author(s) of the survey. These numbers are on the maps accompanying the survey report. Where we are uncertain as to whether or not more than half of the soils in the association are highly permeable because of incomplete information, the soil association is queried;
5. comments, including remarks on the distribution of the highly permeable soil associations or highly permeable soils that do not dominate an association.

WASHINGTON (27 soil surveys studied)

Adams County

Reference: Lenfesty, C.D., 1967, Soil survey of Adams County, Washington: U.S. Department of Agriculture, 110 p.

Rainfall: 12 to 14 inches in lower parts of the county.

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Beckley	23-60	Quincy	15-60
Benge	26+		0-60
Chard	44-60	Royal	0-60
Ephrata	20+		24-60
Magallon	26+	Scooteney	24-60
Neppel	28-60		
Stratford	28+		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2- Benge-Anders-Kuhl
6- Ephrata-Neppel-Royal

Comments: Other soils not listed have highly permeable surface layers composed of sand but have less permeable substrates. Stratford soils underlie part of the city of Ritzville.

WASHINGTON (Continued)

Benton County

Reference: Rasmussen, J.J., 1971, Soil survey of Benton County area, Washington: U.S. Department of Agriculture, 72 p.

Rainfall: About nine inches in valley areas.

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr

Name	Interval
Burbank	35+
Dune land	0-60
Finley	28-60
Pasco (part)	48-52
Quincy	0-65
Wamba	23-60

Hezel soils have highly permeable surface layers. Koehler soils have highly permeable surface layer but hardpan below.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

6?- Hezel-Quincy-Burbank

8-Finley-Burbank-Quincy

Comments: Soil association 8 formed on alluvium and windblown sand and underlies the town of Finley (T8N, R30E). Soils association 6 formed on alluvium, windblown sand, and lake sediments north of the Columbia River in the southern part of the county (approx. T5 and 6N, and R24-28E). Other permeable soils are scattered through the other associations elsewhere in the county.

WASHINGTON (Continued)

Chelan County (parts of Chelan and Kittitas Counties)
Reference: Beieler, V.E., 1973, Soil survey of Chelan area, Washington: U.S. Department of Agriculture, 104 p.

Rainfall: 8 to 20 inches

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Beverly	24-60	Quincy	10-60
Chiwawa	45-60	Supplee	31-60
Goddard	24-60		
Malaga	19-60		
Pogue	30-60		
Terrace esc.	6-60		
Wenatchee	51-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: The permeable soils noted above form minor parts of soils on terraces along the Columbia River and near Lake Wenatchee and recent alluvium along some river bottoms.

WASHINGTON (Continued)

Clallam County

Reference: Halloin, L.J., 1987, Soil survey of Clallam County area, Washington: U.S. Department of Agriculture, 213 p.

Rainfall: Northwest corner of the county- 85 to 120 inches; northeast corner of the county- 18-30 inches

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Neilton	0-60	Carlsborg	9-60
		Hoypus	0-60
		Dick	0-60
		Klone	6-20
		Lyre	30-60
		Sequim	0-60
		Wellman	30-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2- Hoypus-Sequim-Agnew
3?- Neilton-Lyre-Casey
5- Solduc-Klone-Calawah

Comments: Associations 2,3 and 5 form on outwash terraces, floodplains, and alluvial fans. Carlsborg soils make up 30 percent of another association. Soil association 5 is common in the Soleduck, Calawah, and Bogachiel River Valleys.

WASHINGTON (Continued)

Clark County

Reference: McGee, D.A., 1972, Soil survey of Clark County, Washington: U.S. Department of Agriculture, 113 p.

Rainfall: 45 inches in low parts of the county.

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Cispus	24-53	Lauren	33-70
McBee	44-62	Newburg	52-72
Sifton	16-60	Pilchuck	0-60
Washougal	34-60	Puyallup	27-60
		Wind River	24-62

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

1- Sauvre-Puyallup
4- Lauren-Sifton-Wind River

Comments: These two soil associations occur in bottomlands and terraces along the Columbia River. Soils association 4 underlies areas immediately east and north of Vancouver (parts of T2N, R1 and R2E) and appears to be responsible for some elevated indoor radon readings in the Vancouver area.

Cowlitz County

Reference: Call, W.A., 1974, Soil survey of Cowlitz area, Washington: U.S. Department of Agriculture, 112p.

Rainfall: 40-70 inches along the Columbia River

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	22-60	Cinnebar	
Cispus	0-60	(CmB part)	56-72
Clato	32-60	Hillsboro	43-78
Pilchuck	0-60	Toutle	0-60
Sifton	21-60		
Vader	54-68		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

No soil associations are judged to have high average permeability.

Comments: Clato and Pilchuck soils form about 35 percent of soil association 7 in alluvium on floodplains.

WASHINGTON (Continued)

Douglas County

Reference: Beieler, V.E., 1981, Soil survey of Douglas County, Washington: U.S. Department of Agriculture, 180 p.

Rainfall: 11 inches at Waterville

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Beverly	20-60	Magallon	19-60
Burbank	20-60	Quincy	0-60
Chelan	50-60		
Finley	26-60		
Malaga	28-60		
Pogue	31-60		
Strat	22-60		
Supplee	30-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

1- Pogue-Quincy-Xerothents

Comments: Association 1 underlies terraces along the Columbia River. The towns of East Wenatchee and Rock Island are located on this soil.

WASHINGTON (Continued)

Grant County

Reference: Gentry, H.R., 1984, Soil survey of Grant County, Washington: U.S. Department of Agriculture, 329 p.

Rainfall: 7 inches at Ephrata

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Benco	23-60	Ekruls	0-18
Burbank	23-60	Hermiston	21-60
Ephrata	23-60	Hezel	0-26
Malaga	18-60	Koehler	0-33
Finley	23-60	Magallon	23-60
Neppel	31-60	Quincy	0-60
Nuvark	30-60	Quinton	0-22
Strat	23-60	Royal	0-110
Stratford	30-60	Schawana	0-3
Timmerman	23-60	Wanser	0-60
		Winchester	0-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2- Timmerman-Quincy
3- Malaga
4- Ephrata-Malaga
5- Burbank-Quincy
6- Quincy
10- Strat-Magallon-Stratford

Comments: An extensive area of highly permeable soils developed on dunes, terraces, and alluvial fans occupies the central part of the county including the city of Ephrata. Much of this material is glacial outwash or material derived from glacial outwash.

WASHINGTON (Continued)

Grays Harbor area, Pacific and Wahkiakum Counties

Reference: Pringle, R.F., 1986, Soil survey of Grays Harbor County area, Pacific County, and Wahkiakum County, Washington: U.S. Department of Agriculture, 296 p.

Rainfall: 70 to 90 inches along the coast.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Carstairs	28-60	Juno	12-60
Humptulips	26-60	Lyre	23-60
Nordby	33-60	Newberg	36-60
Orcas	0-60	Newskah	37-60
Spanaway	16-60	Squally	12-60
Westport	0-60	Udipsamments	0-60
		Yaquina	24-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
4?-Yaquina-Netarts-Dune land

Comments: Soil association 4 occurs in coastal dune areas. Spanaway soils form a part of another association on floodplains, terraces, and alluvial fans.

WASHINGTON (Continued)

Jefferson County

Reference: McCreary, F.R., 1975, Soil survey of Jefferson County area, Washington: U.S. Department of Agriculture, 100 p.

Rainfall: 120 to 160 inches of rain on the west (ocean) side of the county, 18 to 30 inches on the Puget Sound side (Port Townshend area)

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Grove	0-60	Carlsborg	0-60
		Dick	0-60
		Everett	0-60
		Hoh (part)	36-60
		Hoypus	0-60
		Huel	0-60
		Indianola	0-60
		Kalaloch	25-60
		Lystair	14-60
		San Juan	0-60
		Wapato	42-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3?- Clallam-Hoypus-Dick
10?- Queets-Kalaloch-Huel

Comments: These soil associations are found on glacial outwash plains and terraces. Some eskers and kames are present. Soil association 3 underlies the city of Port Townshend. Dick soils occur in another association.

WASHINGTON (Continued)

King County (older report)
Reference: Poulson, E.N., Miller, J.T., Fowler, R.H., and Flannery, R.D., 1938, Soil survey of King County, Washington: U.S. Department of Agriculture, 106 p.

Rainfall: 30 to 55 inches from sea level to 1000'

Soils with highly permeable subsoil or substrata layers (from descriptive material in this report and comparison to newer reports in adjacent counties):
Barneston, Everett, Pilchuck, Puyallup, Indianola, Snoqualamie, Greenwater, Edgewick, Lynden, and Ragnar.

Comments: Barneston and Everett soils are locally abundant in the eastern suburbs of the Puget Lowland urban corridor. Other soil types are very minor.

Kitsap County
Reference: McMurphy, C.J., 1980, Soil survey of Kitsap County area, Washington: U.S. Department of Agriculture, 127 p.

Rainfall: 30 to 65 inches near sea level.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Neilton	19-60	Grove	17-60
		Indianola	7-60
		Shelton	0-25
		Ragnar	23-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: The more permeable soils noted above form only a minor part of soils in the area. Neilton soils have formed on terraces and benches in upland areas. Ragnar and Indianola soils underly parts of the northern peninsular portions of the county but don't dominate. Shelton soils form their own association, but they are characterized by shallow sandy permeable layers (20-35") with thick hardpan below.

WASHINGTON (Continued)

Lewis County

Reference: Evans, R.L. and Fibich, W.R., 1987, Soil survey of Lewis County area, Washington: U.S. Department of Agriculture, 466 p.

Rainfall: 40 to 50 inches in the low elevations of the county. Higher in the higher elevations.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bellicum	7-18*	Cattcreek (pt)	6-29*
Benham	34-45*	Greenwater	0-60
	40-60	Indianola	5-60
Bromo	10-23*	Newberg	17-60
Cattcreek (pt)	18-31*	Schooley	21-31*
	37-06	Siler	14-21*
Cispus	15-43*	Squally	20-60
Colter	4-35*		
	54-60		
Cotteral	6-30*		
Glenoma	45-60*		
Netrac	21-60		
Nisqually	34-60		
Skate	7-15*		
Spanaway	18-60		
Trade Dollar	13-52*		
Winston	35-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
4?- Winston-Olequa
5- Spanaway

Comments: Soils marked with an asterisk have highly permeable volcanic cinder layers but they don't likely contribute to indoor radon problems because these soils horizons are typically very shallow. Highly permeable soil associations occur on glacial outwash plains and high terraces (4 and 5). Soil association 5 underlies much of the city of Centralia (T14N,R2W).

WASHINGTON (Continued)

Lincoln County

Reference: Stockman, D.D., 1981, Soil survey of Lincoln County, Washington: U.S. Department of Agriculture, 167 p.

Rainfall: 12 to 20 inches along the Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Beckley	24-60	None	
Benco	20-60		
Benge	25-60		
Cheney	25-60		
Ewall	0-60		
Farrell	41-60		
Hesseltine	20-60		
Patit (var)	38-60		
Phoebe	46-60		
Spens	0-60		
Springdale	9-60		
Strat	22-60		
Stratford	24-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
9- Ewall-Springdale

Comments: Soil association 9 occurs under terraces along the Columbia and Spokane Rivers including the towns of Little Falls, Long Lake, Miles, and Coulee Dam. The other highly permeable soils occur as minor soils with other associations on terraces and outwash along the rivers and in the scablands elsewhere in the county.

WASHINGTON (Continued)

North Ferry area

Reference: Zulauf, A.S. and Starr, W.A., 1979, Soil survey of North Ferry area, Washington: U.S. Department of Agriculture, 118 p.

Rainfall: 14 to 20 inches along Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bisbee	28-60	Chesaw	0-60
Dart	19-60	Cobey	42-60
Gahee	31-60	Kiehl	22-60
Goddard	24-60	Koepke	49-60
Goosmus	30-60	Leonardo	38-60
Karamin	13-60	Ret	20-60
Malo	51-60	Scar	0-60
Merkel	46-60	Togo	34-60
Mires	26-60		
Namakin	46-60		
Ret (var)	45-60		
Springdale	12-60		
Tarboy	17-60		
Wapal	19-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3?- Chesaw-Mires
4- Torboy-Wapal-Gahee
5-Springdale-Bisbee-Scala
6?- Malo-Ret

Comments: The soils that are consistently highly permeable are those that have formed on glacial outwash along valley bottoms (associations 3 and 4), alluvial material on terraces and fans (5), and floodplains (6).

WASHINGTON (Continued)

Okanogan County area

Reference: Lenfesty, C.D., 1980, Soil survey of Okanogan County area, Washington: U.S. Department of Agriculture, 153 p.

Rainfall: 8 to 12 inches along the Okanogan River.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Boesel	37-60	Aenas	26-60
Chesaw	5-60	Haley	25-60
Ewall	0-60	Karamin	23-60
Kartar	28-60		
Merkel	26-60		
Mires	29-60		
Okanogan (part)	40-60		
Owhi	31-60		
Pogue	29-60		
Republic (part)	40-60		
Skaha	23-60		
Springdale	30-60		
Wadams	31-60		
Winthrop	0-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3- Republic-Mires-Chesaw
9- Katar-Dinkelman-Springdale
10- Owhi-Winthrop
12?- Pogue-Cashmont-Cashmere

Comments: These highly permeable soils have formed on alluvial fans, terraces, and plains that have developed on sandy glacial till and outwash. This survey was limited to the valleys of the Okanogan and Methow Rivers.

WASHINGTON (Continued)

Pierce County

Reference: Zulauf, A.S., 1979, Soil survey of the Pierce County area, Washington: U.S. Department of Agriculture, 131 p.

Rainfall: 35-45 inches at Tacoma

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Barneston	13-60	Indianola	7-78
Briscott (var)	54-60	Puyallup	13-68
Everett	19-60	Ragnar	26-68
Neilton	21-60		
Nisqually	25-60		
Pilchuck	36-60		
Spanaway	18-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
4-Spanaway

Comments: The Spanaway association underlies most of the area south and southwest of Tacoma. Townships in this area consistently produce elevated average indoor radon readings compared to townships in the rest of the Puget Lowland to the north. Everett and Barneston soils form significant parts of other associations. Spanaway, Barneston, and Everett soils all formed on sandy to gravelly outwash or till. Pilchuck and Puyallup soils in association 5 are scattered throughout Tacoma and its eastern suburbs where they may underlie as much as 1/3 of the terrain.

WASHINGTON (Continued)

Skagit County (older report)
Reference: Ness, A.O., Buchanan, D.E., and Richins, C.G., 1951, Soil survey of Skagit County: U.S. Department of Agriculture, 91 p.

Rainfall: About 27 inches near sea level, considerably greater at higher elevations

Internal drainage

Rapid	Very rapid
Cagey (surface layer)	Coastal beach
Cokedale	Everett
Corkindale	Greenwater (part)
Klaus (part)	Indianola (part)
Kline (part)	Klaus (part)
Lynden (part)	Lynden (part)
Neptune	Pilchuck (part)
Pilchuck (part)	Skykomish
Pyallup (part)	Thornwood (part)
Thornwood (part)	
Greenwater (part)	
Indianola (part)	

Comments: The highly permeable soils of the county have formed on sandy to gravelly glacial drift and outwash on terraces along rivers and streams and on plains. Although rapidly permeable soils are fairly widespread, areas underlain by very rapidly permeable soils are small and scattered.

WASHINGTON (Continued)

Skamania County (older report)
Reference: Anderson, A.C., Kunkle, Merrill, Schlotts, F.E., Klaus, Don, and Lounsbury, Clarence, 1940, Soil survey of Skamania County: U.S. Department of Agriculture, 92 p.

Rainfall: 86 inches at North Bonneville

Soils with highly permeable subsoil layers as judged from soil texture descriptions and drainage comments:

- Bonneville stony loam- somewhat excessively drained
- Burlington fine sand- somewhat excessively drained
- Columbia gravelly sand
- Cougar gravelly sandy loam- loam with hardpan over sand and gravel
- Greenwater gravelly sand- somewhat excessively drained
- Hillsboro fine sandy loam- somewhat excessively drained
- Nesika gravelly loam- somewhat excessively drained
- Riffe fine sandy loam- somewhat excessively drained
- St. Helens pumicey sandy loam- somewhat excessively drained
- Stevenson stony clay loam and stony loam- landslide and related materials, high macropore permeability
- Toutle sand/gravelly sand- Excessively drained
- Underwood stony loam- landslide and related materials, high macropore permeability
- Washougal loam- somewhat excessively drained
- Wind River gravelly loam- somewhat excessively drained

Comments: These soils form largely on alluvial terraces along the Columbia River and on debris flows and landslides from volcanic mountain slopes. They underlie the towns of Stevenson and North Bonneville.

WASHINGTON (Continued)

Snohomish County

Reference: Debose, Alfonso and Klungland, M.W., 1983, Soil survey of Snohomish County area, Washington: U.S. Department of Agriculture, 143 p.

Rainfall: 40 inches near sea level (Everett)

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Custer	35-60	Everett	6-60
Margar	26-60	Greenwater	0-60
Orcas	0-60	Indianola	4-60
Pilchuck	50-60	Lynwood	7-60
Skykomish	19-60	Norma (var)	35-60
Sultan (var)	50-60	Puyallup	30-60
Winston	25-60	Ragnar	24-60
		Sumas	24-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Permeable soils don't dominate anywhere but Sultan, Pilchuck, and Custer soils form a small percentage of soil associations on river bottoms and outwash plains especially those near the Stillaguamish, Snohomish, and Skykomish Rivers.

WASHINGTON (Continued)

Spokane County

Reference: Donaldson, N.C. and Giese, L.D., 1968, Soil survey of Spokane County, Washington: U.S. Department of Agriculture, 143 p.

Rainfall: 17 inches at the airport west of town

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Bong	30-60	None	
Bonner	26-60		
Cheney	35-60		
Eloika	53-60		
Garrison	44-60		
Hagen ?	38-60		
Hesseltine	17-60		
Marble	6-60		
Peone	4-60		
Phoebe	44-60		
Springdale	12-64		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2- Garrison-Springdale-Marble
5- Heseltine-Cheney-Uhlig
9- Bonner-Eloika-Hagen

Comments: Associations 2 and 9 formed on glacial outwash and terraces. Associations 2 and 9 have had high average levels of indoor radon for homes sited on them with as many as 70 percent of the houses above 4 pCi/L and individual readings as much as 200 pCi/L. Association 5 has not been well sampled but it resembles soils that underlie the town of Cheney where high average radon values also occur.

WASHINGTON (Continued)

Stevens County

Reference: Donaldson, N.C. and DeFrancesco, J.T., 1982, Soil survey of Stevens County, Washington: U.S. Department of Agriculture, 459 p.

Rainfall: 25 inches at Colville

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bisbee	18-60	Dehart	11-60
Bong	24-60	Kegel	38-60
Bonner	25-60	Kiehl	22-60
Chamokane	28-60	Koerling	40-60
Cheney	24-60	Marble	0-60
Chewelak	32-60	Vassar	30-54
Dart	14-60	Whetney	28-60
Eloika	53-60		
Garrison	24-60		
Hagen	32-60		
Hesseltine	28-60		
Phoebe	36-60		
Spens	0-60		
Springdale	11-60		

In addition, Belzar, Bridgeson, and Merkel soils are good sources of sand and/or gravel.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

9- Bonner-Eloika-Scrabblers

10- Springdale-Spens-Bisbee

Comments: These highly permeable soils occur on terraces in valleys scattered throughout the county.

WASHINGTON (Continued)

Thurston County (older report)

Reference: Glassey, T.W., Lounsbury, C., and Ness, A.O., 1958, Soil survey of Thurston County, Washington: U.S. Department of Agriculture, 79 p.

Rainfall: About 50 inches at Olympia

Internal drainage

Rapid	Very rapid
Grove	Everett
Indianola (part)	Fitch
Newberg (part)	Greenwater
Pyallup (part)	Indianola (part)
	Lynden
	Nisqually
	Pilchuck
	Spanaway
	Tumwater

Comments: These highly permeable soils have formed mostly on sandy to gravelly outwash on terraces and prairie areas or on gravelly drift in upland areas. Most of the terrace and prairie areas along the Nisqually, Deschutes and Black Rivers southeast, south, and southsouthwest of Olympia/Tumwater are underlain by the very rapidly permeable Spanaway, Everett, Nisqually, and Tumwater soils. Everett, Lynden, and Fitch soils occur in scattered areas on the peninsula northeast of Olympia.

WASHINGTON (Continued)

Walla Walla area

Reference: Harrison, E.T., Donaldson, N.C., McCreary, F.R., Ness, A.O., and Krashevski, Steven, 1957, Soil survey of Walla Walla County, Washington: U.S. Department of Agriculture, 138 p.

Rainfall: 15 inches in Walla Walla

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Beverly	17-35+	Active dune ld.	0-60
Patit Creek	18+	Adkins	0-60
Quincy (part)	0-38	Magallon	38+
Touchet	64+	Quincy (part)	0-38
Yakima			

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

15- Quincy

Comments: Soil association 15 formed in windblown sands near the confluence of the Snake and Columbia Rivers. The other soils formed in sandy and gravelly material largely on bottomlands and low terraces but they do not dominate. The Yakima partly underlies the city of Walla Walla.

WASHINGTON (Continued)

Whatcom County (older report)

Reference: Poulson, E.N. and Flannery, R.D., 1941, Soil survey of Whatcom County, Washington: U.S. Department of Agriculture, 153 p.

Rainfall: About 34 inches near Bellingham

Soils judged from general descriptions to have highly permeable subsoils and substrata from descriptive material in the text:

- Kickerville- thick gravelly drift over clayey till in uplands, rapid internal drainage
- Barnhardt- thick gravelly drift over cemented gravelly sand in uplands, rapid internal drainage
- Barneston- Loam over thick gravelly drift in higher foothills and mountain valleys, rapid internal drainage
- Lynden- sandy glacial outwash on terraces, rapid internal drainage
- Smith Creek- gravels on post-outwash stream terraces, rapid internal drainage
- Kline (part)- Coarse alluvial gravels on fans, rapid internal drainage
- Skagit- gravelly alluvium mantled by finer grained material on terraces along narrow valleys, rapid internal drainage
- Pilchuck- Gravels mantled by finer grained material on floodplains, rapid internal drainage
- Neptune- older gravelly beach deposits, rapid internal drainage
- Hovde- gravelly coastal beaches, rapid internal drainage
- Giles- Silt mantled gravelly outwash on terraces, rapid internal drainage

Comments: All the soils named above occur in small scattered patches throughout the county. Smith Creek soils underlie about 1 square mile of the northwest side of Bellingham.

WASHINGTON (Continued)

Whitman County

Reference: Donaldson, N.C., 1980, Soil survey of Whitman County, Washington: U.S. Department of Agriculture, 185 p.

Rainfall: 11 to 15 inches in northeast part of the county, 8 to 9 inches in southwest part of the county.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Beckley	23-60	Alpowa	8-44
Benge	30-60	Magallon	28-60
Cheney	36-60		
Farrell	53-60		
Hesseltine	34-60		
Stratford	24-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

None

Comments: Benge and Cheney soils form parts of associations developed in outwash in channeled scablands along Rock Creek and Palousse River but these soils don't dominate those areas.

Yakima County

Reference: Lenfesty, C.D. and Reedy, T.E., 1985, Soil survey of Yakima County area, Washington: U.S. Department of Agriculture, 345 p.

Rainfall: 7 to 14 inches in the city of Yakima.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Ashue	34-60	Griskel	0-5
Finley	30-60	Hezel	0-22
Logy	33-60	Quincy	0-60
Mippon	7-60	Wanser	0-60
Naches	34-60	Wenas	47-60
Toppenish	50-60	Zillah	42-60
Track	26-60		
Weirman	21-60		
Yakima	30-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2- Weirman-Ashue

3?- Quincy-Hezel

Comments: Association 2 occurs right around the city of Yakima on floodplains and terraces.

OREGON (24 soil surveys examined)

Benton County

Reference: Krezevich, C.A., 1975, Soil survey of Benton County area, Oregon: U.S. Department of Agriculture, 119 p.

Rainfall: 40-45 inches along Willamette River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	7-60	Pilchuck	0-60
Salem	24-60		

Claquato, McAlpin, McBee and Winchuck soils are described as being sources of sand and gravel at depth (greater than 60").

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Several of the soils mentioned above form minor components of various soil associations mostly along bottom lands and low terraces

Clackamas County

Reference: Gerig, A.J., 1985, Soil survey of Clackamas County area, Oregon: U.S. Department of Agriculture, 293 p.

Rainfall: 40 to 60 inches along Willamette River.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	17-60	Dabney	0-60
Salem	24-60	Multnomah	30-60
		Multorpor	0-60
		Newberg	23-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
7?- Salem-Clackamas

Comments: Newberg and Camas soils are also present in one soil association on floodplains. Salem soils are scattered on low river and broad valley terraces. Multopor soils formed on glacial outwash on floodplains. Association 7 occurs on terraces along the Clackamas River but form only small areas.

OREGON (Continued)

Clatsop County

Reference: Smith, P.R. and Shipman, J.A., 1988, Soil survey of Clatsop County, Oregon: U.S. Department of Agriculture, 272 p.

Rainfall: 70 to 100 inches along the coast

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Gearhart	11-60	Heceta	0-60
Waldport	5-60	Warrenton	0-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
3- Waldport-Gearhart-Brallier

Comments: Highly permeable soils occur on sand dune areas along the coast including the towns of Warrenton and Seaside.

Columbia County

Reference: Smythe, R.T., 1986, Soil survey of Columbia County, Oregon: U.S. Department of Agriculture, 198 p.

Rainfall: Precipitation on valley terraces about 45"

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Sifton	24-60"	Multnomah	27-60"

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
5- Sifton-Multnomah

Comments: Soil association 5 formed on old gravelly alluvium on terraces and underlies a 2 to 3 square mile area including Columbia City (in T5N, R1W). Some Sifton soils also occur on floodplains.

OREGON (Continued)

Curry area(coastal parts of Curry County)
Reference: Buzzard, C.R. and Bowlsby, C.C., 1970, Soil survey of the Curry area, Oregon: U.S. Department of Agriculture, 70 p.

Rainfall: 70 to 80 inches

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
None		Blacklock	32-48
		Ferrelo	41-68
		Gardiner	5-10+
			17-60
		Netarts	0-40
		Stab. dune land	6-60
		Active dune ld	0-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
1- Blacklock-Netarts-Active dune land

Comments: Dune areas underly much of T31S,R15W and T32S, R15W. Ferrelo soils occur on marine terraces along the coast. Gardiner soils occur on floodplains along the Rogue and other rivers.

OREGON (Continued)

Gilliam County

Reference: Hosler, R.E., 1984, Soil survey of Gilliam County, Oregon: U.S. Department of Agriculture, 172 p.

Rainfall: 7 to 9 inches along the Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
None		Quincy	0-62

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Some Quincy soils occur in small areas along the Columbia River and Willow Creek.

Grant County (central part)

Reference: Dyksterhuis, E.L., 1981, Soil survey of Grant County, Oregon, central part: U.S. Department of Agriculture, 131 p.
Rainfall: 12 to 18 inches along valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Courtrock	50-60	Dayville	36-60
Veazie	24-60	Laycock	17-60
		Logdell	

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
1?- Hack-Veazie-Dayville

Comments: Soil association 1 forms along floodplains and bottomlands.

OREGON (Continued)

Hood River County

Reference: Green, G.L., 1981, Soil survey of the Hood River area, Oregon: U.S. Department of Agriculture, 94 p.

Rainfall: 30 inches near the Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 6 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Divers	46-60	Van Horn	
		Wind River (var)	

Wind River (variant) is a source of sand and gravel.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

12- Divers
13- Divers-Hutson

Comments: Divers soils occur in the southwest part of the county on the flanks of Mt. Hood. They formed on mixed colluvium and mudflows derived from basalt and andesite. Van Horn soils underlie parts of terraces on lakebeds adjacent to Hood River. Wind River variant underlies some upland and terrace areas immediately south and southwest of the town of Hood River. No large areas of highly permeable soils and only a few soil types have high permeability.

OREGON (Continued)

Josephine County
Reference: Borine, Roger, 1983, Soil survey of Josephine County, Oregon: U.S. Department of Agriculture, 258 p.

Rainfall: 30 to 60 inches along the river valleys

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	10-60	Newberg	24-61
		Kerby	40-60
		Takilma	18-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
1- Newberg-Camas-Evans

Comments: This soil association occurs along short segments of the Rogue, Illinois, and Appelgate Rivers. Takilma and Kerby soils also occur on low terraces in these same areas and in Deer Creek and Sunny Valleys.

Klamath County (southern part)
Reference: Cahoon, Joe, 1985, Soil survey of Klamath County, Oregon: U.S. Department of Agriculture, 269 p.

Rainfall: 10 to 14 inches in lower parts of the county

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Lapine	0-60	Collier	0-65
		Fordney	8-60
		Kirk	20-60
		Ontho	13-28
		Dilman	37-50
		Maklak	0-60
		Steiger	0-60
		Sycan	0-60
		Tutni	0-60
		Yawhee	0-28
		Zuman	17-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
7?- Fordney-Calimus
15- Shanahan-Lapine-Steiger
16?- Maset-Yawhee

Comments: This dominantly volcanic area is underlain by several soils with high permeability.

OREGON (Continued)

Lane County area

Reference: Patching, W.R., 1987, Soil survey of Lane County, Oregon: U.S. Department of Agriculture, 369 p.

Rainfall: 40 to 60 inches along the Willamette River; 60 to 80 inches along the Pacific Coast

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	14-60	Briedwell	38-60
Courtney	41-60	Chapman	50-60
Jimbo	43-60	Haflinger	17-60
Salem	26-60	Heceta	5-60
Saturn	32-60	Hembre	0-44
Sifton	15-60	Meda	40-60
Waldport	5-60	Nekoma	20-60
		Netarts	0-6
			47-60
		Yaquina	29-60
		Yellowstone	4-12

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

12- Dune land-Heceta
13- Bullards-Waldport-Yakima

Comments: Soil association 12 and 13 occur in dune areas along the coast. Other highly permeable soils form parts of soil associations on terraces along the Willamette River.

OREGON (Continued)

Linn County

Reference: Langridge, R.W., 1987, Soil survey of Linn County area, Oregon: U.S. Department of Agriculture, 344 p.

Rainfall: About 45 inches on valley floor.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	13-60	Courtney	48-60
Malabon (var)	55-60	Yellowstone	5-18
Salem	35-60	Newburg	28-64
Sifton (var)	15-60	Saturn	36-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
5?- Clackamas-Courtney-Salem

Comments: Association 5 forms a minor soil association on low alluvial stream terraces. No large areas of highly permeable soils. Newberg soils make up about 40 percent of soil association 2 which occur in recent alluvium along stream bottoms.

OREGON (Continued)

Malheur County (northeast part)
Reference: Lovell, B.B., 1980, Soil survey of Malheur County, Oregon: U.S. Department of Agriculture, 94 p.

Rainfall: 8 to 11 inches along the Snake River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		Greater than 6 in/hr	
Name	Interval	Name	Interval
Cencove	24-60	Quincy	0-60
Falk	36-62		
Feltham	31-60		
Notus	31-60		
Nyssa (part)	32-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
3- Feltham-Cencove-Quincy

Comments: Small areas of eolian sand and alluvial material along the Snake River. Hardpan is common.

Marion County
Reference: Williams: L.H., 1972, Soil survey of Marion County area, Oregon: U.S. Department of Agriculture, 132 p.

Rainfall: 40 to 45 inches on the city of Salem

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	0-60	None	
Horeb (part)	40-60		
Salem	30-60		
Sifton	24-60		

Clackamas and Courtney are noted as sources of gravel beneath deep soils.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
6- Clackamas-Sifton-Salem

Comments: Soil association 6 occurs on low terraces and underlies the southern part of the city of Salem. Camas soils underlie parts of floodplain areas.

OREGON (Continued)

Morrow County

Reference: Hosler, R.E., 1983, Soil survey of Morrow County area, Oregon: U.S. Department of Agriculture, 225 p.

Rainfall: 7-8 inches along the Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Burbank	34-60	Hezel	0-30
		Koehler	0-28
		Quincy	0-60
		Quinton	0-37
		Royal	0-6
		Winchester	0-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

1- Winchester
2?- Quincy-Koehler

Comments: Soil associations 1 and 2 formed in sandy alluvium over gravel, hardpan and basalt. Hardpan layers, if penetrated, may create favorable pathways for movement of soil gas into houses. Many soils have sandy surface layers but less permeable substrate.

Multnomah County

Reference: Green, G.L., 1983, Soil survey of Multnomah County, Oregon: U.S. Department of Agriculture, 225 p.

Rainfall: 40 to 50 inches along the Columbia River.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Sifton	30-60	Dabney	0-60
		Faloma	15-60
		Multnomah	39-60
		Pilchuck	0-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

None.

Comments: Pilchuck, Dabney, Multnomah and Sifton make up parts of various soil associations on bottom lands along the Columbia and Willamette Rivers and on terraces east of downtown Portland.

OREGON (Continued)

Polk County

Reference: Knezevich, C.A., 1982, Soil survey of Polk County, Oregon: U.S. Department of Agriculture, 250 p.

Rainfall: 42 inches along Willamette River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Camas	12-60	Newburg	26-60
Pilchuck	7-62	Yellowstone	4-18

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: Camas, Newburg, and Pilchuck soils form part of one association on bottomlands along the Willamette River and major streams. Other permeable soils are very minor.

Prineville area (western Crook County)

Reference: Mayko, R.W. and Smith, G.K., 1966, Soil survey of the Prineville area, Oregon: U.S. Department of Agriculture, 89 p.

Rainfall: About 10 inches in valleys

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Prineville	47-60	None	
Veazie	24+		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: Prineville soils form 35 percent of an association which occurs on terraces and alluvial fans derived from basalt areas. Veazie soils are 35 percent of an association which occurs on flood plains and alluvial fans in narrow valleys.

OREGON (Continued)

Tillamook area (older report)
Reference: Bowlsby, C.C. and Swanson, R.C., 1964, Soil survey of Tillamook area, Oregon: U.S. Department of Agriculture, 75p.

Rainfall:

Sand or gravel sources:

Name	Interval	Comments
Gardiner	3-45	Good for sand, bottomlands
Gauldy	55-60	Good for gravel, floodplain alluvium
Ginger	52+	Good for gravel, terraces
Netarts	52-65	Good for sand, stable dunes
Yaquina	30-42+	Good for sand, interdune swales

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
2?- Netarts

Comments: None

Trout Creek-Shaniko area (parts of Jefferson, Wasco and Crook Counties)
Reference: Green, G.L., 1976, Soil survey of the Trout Creek-Shaniko area, Oregon: U.S. Department of Agriculture, 83 p.

Rainfall: 10 to 14 inches along the valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Court	29-38		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: County has soils of low to moderate permeability throughout. Court soils occur on some alluvial fan deposits.

OREGON (Continued)

Umatilla area (older report)
Reference: Harper, W.G., Youngs, F.O., Glassey, T.W., Torgerson, E.F., and Lewis, R.D., 1948, Soils of the Umatilla area, Oregon: U.S. Department of Agriculture, 125 p.

Rainfall: About 21 inches near Milton and Freewater.

Soil map units with highly permeable subsoil layers as judged from descriptive material in the text:
Gravelly loam- Yakima
Loam over gravel- Pilot Rock silt loam, Ephrata
Coarse sand- Rupert
Sand- Winchester, Ephrata
Fine sand- Quincy, Stanfield

Comments: Most of these highly permeable soil types are minor and are scattered in various places through the area. Many sandy, highly permeable soils occur in wind blown sand areas near the Columbia River. However, most of the towns of Milton and Freewater are sited over the Yakima gravelly loam, an excessively drained soil. This is a primary cause for elevated indoor radon in this area. Most of the city of Pendleton is sited on the Yakima gravelly loam and the Pilot silt loam.

Wasco County (north)
Reference: Green, G.L., 1982, Soil survey of Wasco County, Oregon: U.S. Department of Agriculture, 125 p.

Rainfall: 14 to 20 inches at The Dalles near Columbia River

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bindle	22-60	None	
Endersby	53-60		
Tygh	46-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: The more highly permeable soils occur in small areas on the river terraces.

OREGON (Continued)

Washington County

Reference: Green, G.L., 1982, Soils of Washington County, Oregon: U.S. Department of Agriculture, 138 p.

Rainfall: 40 to 50 inches near Hillsboro.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
None		Hillsboro	57-81

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: Most soils are less than 2.0 in/hr. Hillsboro is a very minor soil type in old alluvium on terraces.

Yamhill area

Reference: Otte, G.E., Setness, D.K., Anderson, W.A., Herbert, F.J., Jr., and Kenevich, 1974, Soil survey of the Yamhill area, Oregon: U.S. Department of Agriculture, 130 p.

Rainfall: 40 to 50 inches in valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
None		None	

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Soils have low to moderate permeability throughout the county. No major river drainages occur in the county.

IDAHO (18 surveys examined)

Ada County area

Reference: Collett, R.A., 1980, Soil survey of Ada County area, Idaho: U.S. Department of Agriculture, 327 p.

Rainfall: 10 to 12 inches in Boise

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Ada	37-80	Beetville	47-60
Haw	38-64	Brent	46-64
Tindahay	23-60	Cashmere	58-72
Sebree	42-60	Chance	29-60
Elijah	43-96	Moulton	33-60
Tenmile	49-60	Van Dusen	44-60
Notus	12-60	Quincy	0-66
Payette	34-64		

Greater than 6 in/hr

Name	Interval
Bissell	46-60
Falk	26-60
Pipeline	33-65
Ridenbaugh	33-72

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2?- Quincy-Lankbush-Brent

3?- Cashmere-Tindahay

Comments: Soil association 2 occurs on alluvial fans and terraces in the foothills. It includes windblown sands and underlies the eastern suburbs of Boise. Soil association 3 occurs on alluvial fans and low terraces. Moulton, Falk and Bissell soils underly parts of floodplains and low terraces along the Boise River including some of the central part of Boise. Sebree, Elijah, and Tenmile soils form parts of other soil associations.

IDAHO (Continued)

Bannock County area (parts of Bannock and Power Counties)
Reference: McGrath, C.L., 1987, Soil survey of Bannock County area, Idaho: U.S. Department of Agriculture, 347 p.

Rainfall: 9 to 16 inches in Pocatello

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Arimo	33-60	Holmes	28-60
Bahem	49-60		
Broncho	13-60		
Broxon	25-60		
Downey	17-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
3- Arimo-Downey-Bahem

Comments: This soil association underlies the cities of Pocatello, Chubbock, Arimo, Virginia, and Downey.

Benewah County area
Reference: Weisel, C.J., 1980, Soil survey of Benewah County area, Idaho: U.S. Department of Agriculture, 188 p.

Rainfall: 30 inches on valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Garveson	21-60	Nakarna	44-60
Pokey	30-60		

Greater than 6 in/hr	
Name	Interval
Divers	40-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Pokey soils form part of one soil association on floodplains in southeast part of the county. The other three soils occur in steep mountainous areas of the county.

IDAHO (Continued)

Bingham area (Bingham County and parts of Bonneville County)

Reference: Salzman, R.A. and Harwood, J.O., 1973, Soil survey of Bingham County area, Idaho: U.S. Department of Agriculture, 123 p.

Rainfall: 11 to 13 inches along the river

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bannock	36-60	Paniogue	30-50
Bock	47-60	Presto	0-28
Hayeston	30-60	Stan	50-60
Heiseton	45-65	Weeding	0-60
Outlet (var)	32-60		
Packham	24-60		
Paesl	27-60		
Sasser	38-50		
Wahtigup	45-60		
Wardboro	11-60		
Wolverine	0-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

1- Bannock-Bock

5- Wolverine-Sasser-Stan

Comments: These two highly permeable soil associations formed on older alluvial terraces, sandy alluvium and windblown sand along the Snake River. The town of Blackfoot (T2S and T3S, R35E) and part or all of T1N,R37E; T1S,R37E; T1S,R36E; T2S,R36E; T2S,R34E; and T3S,R34E are underlain by these highly permeable soil associations. Wahtigup is a significant soil on some mountain slopes and ridges.

IDAHO (Continued)

Bonner County

Reference: Weisel, C.J., 1982, Soil survey of Bonner County area, Idaho, parts of Bonner and Boundary Counties: U.S. Department of Agriculture, 201 p.

Rainfall: About 30 inches on the valley floor

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr

Name	Interval
Capehorn	15-60
Elmira (var)	8-60
Kootenai	26-60

From 6 to 20 in/hr

Name	Interval
Elmira	0-60
Selle	20-60
Vassar	39-50

Greater than 6 in/hr

Name	Interval
Bonner	29-60
Hun	25-55
Priestlake	23-60

From 2 to 20 in/hr

Name	Interval
Colburn	24-60
Jeru	32-60
Kaniksu	26-60
Treble	27-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3?- Hun-Jeru
5?- Vassar-Moscow
7?- Priestlake-Treble
8- Bonner-Kootenai
9- Bonner

Comments: Soil associations 3, 5, and 7 form in mountainous areas on colluvium and glacial till derived from granite, gneiss, and schist. Associations 8 and 9 on terraces and glacial moraine. Selle and Elmira soils occur on alluvial fans, terraces, and dunes in the north-central part of the area.

IDAHO (Continued)

Bonneville County

Reference: Miles, R.L., 1981, Soil survey of Bonneville County area, Idaho: U.S. Department of Agriculture, 108 p.

Rainfall: About 10 inches near Idaho Falls.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		Greater than 6 in/hr	
Name	Interval	Name	Interval
Badgerton var	32-60	Hobacker	22-60
Bannock	23-60		
Bock	45-60		
Harston	25-60		
Packham	15-60		
Paesl	25-60		
Paul	58-60		
Wolverine	0-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
3- Bannock-Paul-Paesl
8- Hobacker-Badgerton var-Typic Craquolls

Comments: Soil association 3 occurs on floodplain materials along the Snake River underlying the city of Idaho Falls and adjacent areas including parts of T3N, R38E; T2N, R38E, T1N, R37E, T1N, R38E, and T3N, R39E. Soil association 8 occurs on floodplains along the Snake River in the east part of the county.

IDAHO (Continued)

Boundary County

Reference: Chugg, J.C. and Fosberg, M.A., 1980, Soil survey of Boundary County area, Idaho: U.S. Department of Agriculture, 72 p.

Rainfall: 23-30 inches

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bane	42-60	Rubson	55-60
Idamont	52-60	Elmira	0-60
Selle	15-60		
Stien	25-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3- Selle-Elmira

6- Stein-Pend Oreille

Comments: Selle-Elmira soils occur in scattered areas on high terraces. Stein soils make up 80 percent of soil association 6 and occur on glacial moraines. They occur near the town of Movie Springs along the Kootenai River.

Camas County (south part)

Reference: Case, C.W., 1981, Soil survey of Camas County area, Idaho: U.S. Department of Agriculture, 139 p.

Rainfall: 12 to 16 inches on the valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Little Wood	46-60	Brailsford	45-60
		Marshdale	47-60
		Vodermaier	43-60

Greater than 6 in/hr	
Name	Interval
Brinegar	40-60
Riceton	54-70

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

None

Comments: Brinegar and Marshdale form part of soil associations which form in alluvium on fans, terraces, and bottom lands.

IDAHO (Continued)

Canyon area (Canyon and western Owyhee County)

Reference: Priest, T.W., Case, C.W., Witty, J.E., Preece, P.K., Jr., Monroe, G.A., Biggerstaff, H.W., Logan, G.H., Rasmussen, L.M., and Webb, D.H., 1972, Soil survey of Canyon area, Idaho: U.S. Department of Agriculture, 118 p.

Rainfall: 9 to 11 inches in low valley areas

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Cencove	35-60	Feltham	0-32
Chance	23-60	Lankbush	50-65
Falk	33-60	Lolalita	36-60
Jenness	43-60	Marsing	23-60
Moulton	30-60		
Nannyton	27-60		
Notus	14-60		
Oliaga	35-60		
Quincy	0-60		
Timmerman	38-60		
Vickery	47-60		

Elijah, Minidoka and Purdam soils are also sources of sand and gravel.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
1?- Elijah-Lankbush Vickery
2- Moulton-Bram-Baldock
5?- Turbyfill-Cencove-Feltham
7?- Minidoka-Marsing-Vickery

Comments: These soils have formed on floodplains and terraces along the Snake River and on some valley uplands. Many soils have hardpans and if basement foundations penetrate the hardpan into permeable material below indoor radon potential may be enhanced. These soils are widespread in the area covered by T5N to T1S and R2W to R5W.

IDAHO (Continued)

Cassia County

Reference: Maxwell, H.B., 1981, Soil survey of Cassia County, Idaho, western part: U.S. Department of Agriculture, 150 p.

Rainfall: In Burley along the river about 10 inches.

Soil map units with highly permeable layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Paniogue	21-60"	Abo	51-60"
		Aysees	16-60"
		Beetville	49-60"
		Buko	28-60"
		Wodskow	57+"

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

2?- Aysees-Garbut
4- Paniogue-Buko
9?- Wodskow-Abo

Comments: Soil association 2 occurs in scattered areas in high alluvial fan terraces. Soil association 4 underlies stream terraces along Goose Creek. Soil association 9 occurs on floodplains. Beetville soils occur as a minor type on valley bottoms.

IDAHO (Continued)

Fort Hall area (parts of Bannock, Bingham, Caribou, and Power Counties)

Reference: McDole, R.E., 1977, Soil survey of Fort Hall area, Idaho: U.S. Department of Agriculture, 97 p.

Rainfall: 9 to 11 inches on Snake River Valley floor

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Alluv. land	10-60	Chedehap	22-54
Broncho	14-60	Declo	47-60
Paniogue	28-60	Tickason	54-60
Quincy	0-60	Tindahy	24-60

Nagitsky soils are also a source of sand and gravel.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

4- Paniogue-Declo
5- Paniogue-Broncho
6?- Tindahy-Escalante
7?- Quincy-Feltham

Comments: Soil associations 4,5, and 6 have formed alluvial fans and river terraces. Association 7 has formed on areas of windblown sand.

IDAHO (Continued)

Gem County area

Reference: Troeh, F.R., Chugg, J.C., Logan, G.H., Case, C.W., and Coulson, Virgil, 1965, Soil survey of Gem County area, Idaho: U.S. Department of Agriculture, 196 p.

Rainfall: 12 inches near Emmett

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Black Canyon	55-60+	Cashmere	
Bowman st lm	48-60	Lanktree	37-60
Catharine lm	56-60	Lolalita	36-60
Chance	35+	Odermott cl lm	32+
Chilcott		Payette	35+
Vickery	67-75	Rainey	19-20
Draper cl lm	42+	Wasatch	0-50
Emerson	30+		
Falk	35+		
Goose Ck lm	54+		
Haw lm	50-75		
Letha	43-60		
Moulton	26+		
Notus	18+		
Salisbury	25+		
Wardwell	32+		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
3- Moulton-Falk

Comments: Association 3 occurs in terraces along the Payette River. Letha, Cashmere, and Wardwell soils are abundant in other associations. Some soils in hilly areas underlain are highly permeable.

IDAHO (Continued)

Idaho County (west part)
Reference: Barker, R.J., 1982, Soil survey of Idaho County area, Idaho: U.S. Department of Agriculture, 266 p.

Rainfall: 18 to 34 inches in Riggins area

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
None.		Chard (var)	19-60
		Jughandle (var)	43-60
		Nicodemus	25-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: The permeable soils in the area have formed locally as residual soils on granitic gneiss (Jughandle), residual soils and alluvial soils derived from basalt (Chard var), and on alluvial materials in bottomlands, terraces and alluvial fans (Nicodemus).

IDAHO (Continued)

Kootenai County area

Reference: Weisel, C.J., 1981, Soil survey of the Kootenai County area: U.S. Department of Agriculture, 255 p.

Rainfall: 22 to 28 inches on the Rathdrum Prairie north of Coeur d'Alene

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr

Name	Interval
Avonville	37-60
Cougarbay	30-50
Garrison	38-60
Kootenai	26-60
McGuire	26-60

From 6 to 20 in/hr

Name	Interval
Marble	6-60

Greater than 6 in/hr

Name	Interval
Bonner	26-60
Ulricher	31-42
Lenz	23-36
Selle	24-60

From 2 to 20 in/hr

Name	Interval
Vassar	20-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

4- Avonville-Garrison-McGuire
5- Kootenai-Bonner

Comments: These two soil associations occur on outwash plains and terraces that underlie the entire Rathdrum Prairie area in the northern part of the county. These soils are responsible for high average levels of radon in the BPA study and in a survey conducted by the Idaho Department of Health and Welfare. Vassar, Lenz, and Ulricher soils form in volcanic ash and loess over weathered granite and gneiss on mountain slopes. Minor Cougarbay soils form on low floodplain and bottomlands. Selle soils form on lake terraces.

IDAHO (Continued)

Latah County
Reference: Barker, R.J., 1981, Soils survey of Latah County area, Idaho: U.S. Department of Agriculture, 166 p.

Rainfall: About 21 inches in Moscow

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
None		Vassar	39-53

No soils in the county are considered to be good sources for sand or gravel.

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Vassar soils form on weathering granite in the Moscow Mt. area.

IDAHO (Continued)

Madison County

Reference: Noe, H.R., 1981, Soil survey of Madison County area, Idaho: U.S. Department of Agriculture, 128 p.

Rainfall: About 12 inches on valley floor

Soil map units with highly permeable subsoil and substrata:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bannock	25-60"	Grassy Butte	6-60"
Bockston	50-60"		
Eginbench	39-60"		
Harston	28-60"		
Labenzo	34-60"		
Wardboro	12-60"		
Withers	36-60"		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

7?- Withers-Annis
8?- Labenzo-Blackfoot
9- Bannock-Bockston-Wardboro
10?- Heiseton-Harston
11- Eginbench
15- Harston-Heise-Labenzo

Comments: Most of these highly permeable soil associations consist of loams over gravels. They are generally located on river terraces and floodplains along the Snake and Teton Rivers. Soil association 7 underlies the towns of Salem and Sugar City. Soils associations 7 and 8 underlie Rexburg. Soil association 9 underlies Archer and Lyman.

IDAHO (Continued)

Minidoka area (parts of Minidoka, Blaine, and Lincoln Counties)
Reference: Hansen, H.L., 1975, Soil survey of Minidoka area, Idaho: U.S. Department of Agriculture, 72 p.

Rainfall: 8 to 10 inches along Snake River.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Feltham	58-66	Abo	51-60
		Arloval	0-52
		Paulville	42-47
		Quincy	0-79
		Schodson	25-50
		Tindahay	23-60
		Wodskow	55-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
9- Tindahay-Quincy
10- Schodson-Arloval-Maxey
11?- Wodsko-Decker-Abo

Comments: All associations on terraces near the Snake River have permeable soils noted above as a very minor component. Feltham soils are a minor part of 4 soil associations.

Payette County
Reference: Rasmussen, L.M., 1976, Soil survey of Payette County, Idaho: U.S. Department of Agriculture, 97 p.

Rainfall: About 9 to 12 inches in Payette

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Chance	48-60	Bowman	32-60
Falk	35-60	Emerson	26-60
Notus	14-60	Moulton	30-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
6- Moulton-Letha-Notus

Comments: Soil association 6 occurs in bottomlands along the Payette and Snake Rivers. The other highly permeable soils listed above are minor soils that also occur in the river bottomlands in this association or on low terraces in another association.

IDAHO (Continued)

Teton area

Reference: Daniels, D.M., Hansen, H.L., Priest, T.W., and Perrin, W.G., 1969, Soil survey of the Teton area, Idaho-Wyoming: U.S. Department of Agriculture, 95 p.

Rainfall: 13-20 inches in the Driggs, Idaho area

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
Badgerton	30+	None	
Cedron	42+		
Driggs	25+		
Felt	34+		
Feltonia	49+		
Foxcreek (+var)	19+		
Furniss	35+		
Packsaddle	40+		
Richvale	65+		
Tepete	43+		
Tonks	58+		
Wiggleton	14+		
Zohner	27+		
Zufelt	33+		
Zundell	42+		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

3- Driggs-Tetonia-Badgerton
4?- Driggs-Richvale-Tetonia
6- Foxcreek-Furniss-Zohner

Comments: These three associations comprise alluvium on the east side of the valley, alluvium on the west side of the valley, and alluvium on bottomlands in the center part of the valley. They thus underlie most of the valley including the town of Driggs. These soils are likely responsible for the high average levels of radon in this area. Other soils listed above form lesser parts of these 3 associations.

MONTANA (9 surveys examined)

Bighorn County area

Reference: Meshnick, J.C., Smith, J.H., Gray, L.G., Peterson, R.F., Gentz, D.H., and Smith, Ralph, 1977, Soil survey of Bighorn County area, Montana: U.S. Department of Agriculture, 223 p.

Rainfall: 10 to 14 inches.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Hesper	49-60	Bitton	11-64
Sofia	40-60		
Toluca	41-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: Highly permeable soils form a minor component of soils formed on terraces and dissected upland high terraces and fans.

MONTANA (Continued)

Bitterroot Valley area (parts of Ravalli and Missoula Counties)
Reference: Bourne, W.C., Grammons, Paul, Doll, Gene, Pile, Clarence, Cardon, W.H., McConnell, R.C., Pope, Alex, and Bullette, William, 1959, Soil survey of the Bitterroot Valley area, Montana: U.S. Department of Agriculture, 128 p.

Rainfall: About 12 inches on the valley floor.

Soil map units judged to have highly permeable subsoil or substrata layers:

Greater than 20 in/hr	From 6 to 20 in/hr
Name	Name
Burnt Fork	Bass
Chamokane	Blodgett
Chereete	Breece
Clark Fork	Lone Rock
Como	Shook
Gallatin	Skalhako
Grantsdale	Woodside
Dominic	
Hamilton	
Kenspur	
Larry	
Lone Rock	
Riverside	
Slocum	
Victor	

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
1A- Chamokane-Slocum
2A- Chamokane-Clark Fork-Breece
3-Gallatin
4A?- Blodgett-Bass
5A?- Skahalko
7- Como-Woodside
8- Hamilton-Corvallis-Grantsdale
9- Dominic-Corvallis-Gallatin
10- Lone Rock-Slocum
12- Burnt Fork-Riverside-Ravilli

Comments: Most of the soils of the Bitterroot Valley are judged to be highly permeable. The towns of Hamilton, Grantsdale, Stevensville, Victor, and Corvallis all sit on soil associations judged to be highly permeable.

MONTANA (Continued)

Blaine County, Phillips County (part)
Reference: Hilts, G.B., 1986, Soil survey of Blaine County and part of Phillips County, Montana: U.S. Department of Agriculture, 305 p.

Rainfall: About 12 inches.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr

Name	Interval
Wabek	8-60

From 6 to 20 in/hr

Name	Interval
Cozberg	26-60
Hanly	3-60
Lihen	0-60
Turner	26-60

Greater than 6 in/hr

Name	Interval
Attewan	25-60
Beaverell	17-60
Beaverton	20-60
Nesda	11-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
8-Attewan-Wabek-Beaverell

Comments: Turner and Attewan soils also form minor components on other soil associations on terraces and fans.

MONTANA (Continued)

Broadwater County area

Reference: Olsen, J.A., Haub, M.H., and Bingham, L.C., 1977, Soil survey of Broadwater County area, Montana: U.S. Department of Agriculture, 83 p.

Rainfall: 12 to 18 inches in valley area

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
		Chinook (var)	23-60
		Crago	36-60
		Dominic	0-60
		Musselshell	43-60
		Perma	43-60
		Rivra	0-60
		Scravo	17-60
		Thess	34-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

8?- Musselshell-Crago (high terraces and fans)

Comments: Other highly permeable soils are a significant component of bottomland, intermediate terrace, and fan areas but do not predominate.

MONTANA (Continued)

Carbon County area

Reference: Parker, J.L., Decker, G.L., Gray, Laverne, and Muller, Oscar, 1975, Soil survey of Carbon County area, Montana: U.S. Department of Agriculture, 137 p.

Rainfall: Averages 10 to 14 inches in the valley floor.

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Bearmouth	0-60	Maurice	0-60
Charlos	30-60		
Glenburg	24-60		
Thiel	20-60		
Tonra	29-60		
Vona	40+		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None

Comments: Soils on high terraces and valley sides near Red Lodge, Roscoe, Roberts, and Luther include some highly permeable types (Charlos and Maurice) that may influence radon readings in individual homes. Glenberg soils occur on floodplains. Tonra and Vona soils occur on stream terraces and alluvial fans in the south-central and southeast part of the county.

MONTANA (Continued)

Cascade County area

Reference: Clark, C.O., Farnsworth, D.H., Miller, F.T., and Weight, B.N., 1982, Soil survey of Cascade County area, Montana: U.S. Department of Agriculture, 329 p.

Rainfall: 11 to 19 inches near Great Falls

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Rivra	0-60	Lihen	0-60
		Ryell	28-60
		Wabek	10-60
		Turner	36-60
		Yetull	0-66

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):
None.

Comments: Rivra, Yetull, Ryell, and Lihen soils form minor parts of some associations formed on floodplain alluvium, windblown sand, terraces and fans. Wabek soils occur on some upland areas.

MONTANA (Continued)

Helena Valley (parts of Lewis & Clark County-older report)
Reference: Bingham, L.C., Silvernale, Alexandra, McCain, P.E., and Spano, S.D., 1980, Soil survey of Helena Valley, part of Lewis and Clark County, Montana: U.S. Department of Agriculture, 57 p.

Rainfall: 10 to 16 inches in the valley bottom

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Meadowcreek	35-60	Lihen	0-60
Nippt	15-60	Frenchcreek	26-36
Villy (var)	30-60	Chinook	50-60
Woodgulch	50-60	Crittenden	25-58
Attewan	23-60	Fairway	45-60
Baxendale	22-60		

In addition, Scravo gravelly loam, Thess loam, Thess-Scravo complex, Hilger gravelly loam, and Perma gravelly loam are sources of gravel in the county and may have locally high permeability.

Comments: Within the mapped area, most of the highly permeable soils are associated with alluvial deposits derived from Prickly Pear Creek. These deposits underlie East Helena and extend north and northwestward towards Lake Helena about 5 miles.

MONTANA (Continued)

Judith Basin County area

Reference: Hogan, E.K., Parker, J.L., Haderlie, V.K., McConnell, R.C., and Janssen, W.W., 1967, Soil survey of Judith Basin area, Montana: U.S. Department of Agriculture, 155 p.

Rainfall: About 15 inches in Stanford.

Soil map units with highly permeable subsoil layers:

Greater than 10 in/hr		From 5 to 10 in/hr	
Name	Interval	Name	Interval
None		Danvers	30-60+
		Judith	30-60
		Straw	25-60
		Utica	5-60

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

1?- Danvers-Judith
4?- Judith- Ashuelot

Comments: These permeable soils form on older alluvium beneath high benches between the stream valleys draining the mountains to the southwest. Other permeable soils form minor parts of associations on crests of benches, bottomlands, and low terraces. Stanford and other towns are sited on these benches.

Stillwater County area

Reference: Parker, J.L., Decker, G.L., and Jackson, M.T., 1980, Soil survey of Stillwater County area, Montana: U.S. Department of Agriculture, 131 p.

Rainfall: 10 to 14 inches

Soil map units with highly permeable subsoil layers:

Greater than 20 in/hr		From 6 to 20 in/hr	
Name	Interval	Name	Interval
Attewan	28-60	Turner	6-20
Beaverell	12-60		

Soil associations judged to have high overall subsoil and substrata permeability (queried where uncertain):

None.

Comments: Attewan and Beaverell soils form part of one association that underlies low terraces along Yellowstone River, but these soils are not widespread. Turner soils form on alluvium on terraces and fans.