SPECIAL REPORT 211

RADON POTENTIAL IN THE LAKE TAHOE AREA, CALIFORNIA

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CALIFORNIA GEOLOGICAL SURVEY
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CALIFORNIA GEOLOGICAL SURVEY
JOHN G. PARRISH, PH.D., *STATE GEOLOGIST*

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RADON POTENTIAL IN THE LAKE TAHOE AREA, CALIFORNIA

By

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PG #4265

2009

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EXECUTIVE SUMMARY

Radon is a radioactive gas formed by decay of small amounts of uranium and thorium naturally present in rock and soil. Sometimes radon gas can move out from underlying soil and rock into houses and become concentrated in the indoor air, posing a significant lung cancer risk for the residents. The U.S. Environmental Protection Agency (EPA, 2007) estimates indoor-radon exposure results in 21,000 lung cancer deaths annually in the United States.

Between December 2006 and April 2007, the California Department of Public Health Radon Program (CDPH-Radon Program) conducted an indoor-radon survey of 443 homes in the Lake Tahoe area using short-term charcoal detectors. Radon survey test results range from 0.2 picocuries per liter (pCi/L), the detection limit, to 86.1 pCi/L for a basement measurement. The highest first-floor measurement obtained was 55.5 pCi/L. The U.S. EPA recommended radon action level is 4.0 pCi/L.

The Radon Potential Zone Map for the Lake Tahoe Area, California was developed by CGS utilizing:

- The 1:100,000 scale *Geologic Map of the Lake Tahoe Basin, California and Nevada*, by Saucedo (2005)
- 2006-2007 California Department of Public Health Radon Program Lake Tahoe indoor-radon survey data
- Background uranium data from National Uranium Resource Evaluation (NURE) project and other sources
- Soil property information from Natural Resources Conservation Service (NRCS) and U.S. Forest Service (USFS) reports

Applicable data and information contained in the 1994 Nevada Bureau of Mines and Geology publication titled *Radon in Nevada* (Bulletin 108) and in U.S. Geological Survey Open-file Report 85-389 on uranium in recent valley-fill sediments were reviewed and also considered in radon potential map development. The indoor-radon and uranium data were linked to Lake Tahoe area geologic units using a geographic information system (GIS). The geologic units were then ranked for radon potential based on the characteristics of their associated data.

Five radon potential categories defined by the percentage of homes with indoor radon likely to equal or exceed 4.0 pCi/L were used: very high (≥ 50 percent), high (≥ 20 to 49.9 percent), moderate (≥ 5 to 19.9 percent), low (< 5 percent), and unknown (for geologic units with few or no data). Geologic unit occurrences with the same radon potentials were grouped to define the radon potential zones on the Lake Tahoe radon map. A final map development step involved statistical comparison of indoor-radon data for the resulting radon potential zones to confirm that each zone represents a distinct radon potential. The highest radon potential areas found during the mapping process are located in the South Lake Tahoe area, the Truckee area, and in an area immediately north of Emerald Bay. Very high and high radon potential areas account for 28.9 percent of the Lake Tahoe radon potential map area. Moderate and low potential areas account for 40 percent and 23.5 percent respectively. Unknown radon potential areas account for 7.6 percent.

The Radon Potential Zone Map for the Lake Tahoe Area, California is informational, not regulatory. It is intended as a guide to prioritize areas for public education about radon, and for targeting additional indoor-radon testing activities. The map cannot be used to determine the indoor-air radon level of a particular building. All radon zones will contain some homes testing above 4 pCi/L and some homes testing below 4 pCi/L. The only way to identify specific buildings with indoor-radon levels exceeding 4 pCi/L is through testing.

Based on indoor-radon survey results, the radon potential zone map for Lake Tahoe developed by California Geological Survey (CGS) in this study, and 2000 census data, an estimated 23,400* people in the Lake Tahoe area live in residences likely to equal or exceed 4.0 pCi/L. An estimated 6,100 people live in houses that will likely test at 10 pCi/L or more, and about 900 are estimated to live in houses that will likely test at 20 pCi/L or higher . On a county basis, within the Lake Tahoe radon map area, the number of people residing in homes with radon of 4 pCi/L or above in short-term tests is estimated at: 19,100 in El Dorado County; 2,700 in Nevada County; and 1,600 in Placer County.

Because a relatively high percentage of available indoor-radon measurements for the Lake Tahoe area exceed 4 pCi/L, and almost 69 percent of the Lake Tahoe radon potential map consists of moderate to very high radon potential areas, indoor-radon testing should be encouraged throughout the Lake Tahoe area. Individuals planning new home construction in the Lake Tahoe area may wish to consider incorporating radon-resistant features into their building plans, particularly if the building site is located in a higher-radon potential area. If necessary, radon mitigation after construction is still possible but it will be more costly. Information on radon remediation and radon resistant construction is available on the CDPHRP website at: http://www.cdph.ca.gov/healthinfo/environhealth/Pages/Radon.aspx

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*All radon zone population estimates are derived from 2000 census data

INTRODUCTION

Purpose

This report describes radon potentials for geologic formations in the Lake Tahoe area and suggests several geologic models for elevated radon potential areas. Additionally, this report documents the procedures and data used by the California Department of Conservation, California Geological Survey (CGS), to produce the 2009 radon Potential Zone Map of the Lake Tahoe Area, California. CGS produced the map for the California Department of Public Health Radon Program (CDPH-Radon Program) through an inter-agency agreement. Only minimal background information on radon and radon health issues is included, and detailed radon testing and remediation practices are not discussed. The following websites contain information about radon and health issues, testing and remediation:

http://www.cdph.ca.gov/healthinfo/environhealth/Pages/Radon.aspx
and http://www.epa.gov/iaq/radon/pubs.

Background Information on Radon and Health

Radon gas is a naturally occurring odorless and colorless radioactive gas. It forms from the radioactive decay of small amounts of uranium and thorium naturally present in rocks and soils. The average uranium content for the earth's continental crust is about 2.5-2.8 parts per million (ppm). Typical concentrations of uranium and thorium for many rocks and soils are a few ppm. Certain rock types, such as organic-rich shales, some granitic rocks, and silica-rich volcanic rocks may have uranium and thorium present at levels of tens to hundreds of ppm. While all buildings have some potential for elevated indoor-radon levels, buildings located on rocks and associated soils containing higher concentrations of uranium often have an increased likelihood of elevated indoor radon levels. Breathing air with elevated radon gas abundance increases one's risk of developing lung cancer. Not everyone exposed to radon will develop lung cancer. However, the U.S. Environmental Protection Agency (U.S. EPA, 2007) estimates 21,000 people die in the United States annually from lung cancer attributed to radon exposure.

Radon in indoor-air is measured in units of picocuries per liter (pCi/L). The average radon concentration for indoor air in American homes is about 1.3 pCi/L (U.S. EPA, 2007). The average radon concentration in outdoor air is about 0.4 pCi/L. The U.S. EPA recommends that individuals avoid long-term exposures to radon concentrations ≥ 4.0 pCi/L (*4.0 pCi/L is the U.S. EPA recommended indoor-radon action level*). Based on long-term radon test statistics, the U.S. EPA estimates about 1 out of 15 (6.7 percent) homes in the United States has radon levels ≥ 4.0 pCi/L

Although radon levels are used as a guide for acceptable exposure and for remedial action, it is inhalation of two radon radioactive decay products that primarily lead to lung cancer: polonium-218 and polonium-214. These daughter elements have very short half-lives, and when they enter the lungs they attach to lung tissue or trapped dust particles and quickly undergo radioactive decay. In contrast, longer-lived radon-222 is mostly exhaled before it undergoes radioactive decay. Alpha particles emitted during decay of radon-222, polonium-218 and polonium-214 are thought to cause cancer by damaging the DNA (deoxyribonucleic acid) in lung tissue cells, resulting in abnormal or tumorous cell growth (Brookins, 1990).

Radon gas readily moves through rock and soil along micro-fractures and through interconnected pore-spaces between mineral grains. Radon movement away from its site of origin is typically limited to a few feet to tens of feet because of the relatively short half-lives of radon isotopes (3.8 days for radon-222, 55.6 seconds for radon-220 and 3.96 seconds for radon-219), but movement may be hundreds of feet in some cases. Additional conditions, such as soil moisture content, also affect how far radon can move in the subsurface. Because radon-222 (a radioactive-decay product of uranium-238, see Table 1) has the longest half-life of the several radon isotopes, it is usually the predominant radon isotope in indoor air rather than shorter lived radon-220 (a radioactive-decay product of thorium-232) or radon-219.

Radon gas moves from the soil into buildings in various ways. It can move through cracks in slab foundations or basement walls, pores and cracks in concrete blocks, through-going floor-to-wall joints, and openings around pipes. Radon enters buildings from the soil when air pressure inside the buildings is lower than air pressure in the soil. When exhaust fans are used, inside air is heated, or wind is blowing across a building, the building's internal air pressure is lowered. Because radon enters buildings from the adjacent soil, radon levels are typically highest in basements and ground floor rooms. Radon can also enter a building in water from private wells. All ground water contains some dissolved radon gas. The travel time of water from an aquifer to a home in a private well is usually too short for much radon decay so radon is available to be released in the house during water usage, for example through use of a bathroom shower. However, normal water usage typically adds only about 1 pCi/L of radon to indoor air per 10,000 pCi/L of radon in water (Grammer and Burkhart, 2004).

The most common indoor-radon testing methods utilize either charcoal or alpha-track type detectors. These detectors are exposed to the air in a building according to the manufacturer's instructions and then sent to a laboratory for analysis. Charcoal detectors are usually exposed for a few days under closed building conditions (i.e., a short-term test), while alpha-track detectors are typically exposed for periods of weeks, months or as long as a

Nuclide (Isotope)	**Principal mode of radioactive decay**	**Half-life**
Uranium-238	Alpha	$4.5X10^9$ years
Thorium-234	Beta	24.1 days
Protactinium-234	Beta	1.2 minutes
Uranium-234	Alpha	$2.5X10^5$ years
Thorium-230	Alpha	$7.5X10^4$ years
Radium-226	Alpha	1,602 years
Radon-222	**Alpha**	**3.8 days**
Polonium-218	Alpha	3.1 minutes
Lead-214	Beta	26.8 minutes
Astatine-218	Alpha	1.5 seconds
Bismuth-214	Alpha	19.9 minutes
Polonium-214	Alpha	$1.6\text{-}10^{-4}$ seconds
Thallium-210	Beta	1.3 minutes
Lead-210	Beta	22.6 years
Bismuth-210	Beta	5.0 days
Polonium-210	Alpha	138.4 days
Thallium-206	Beta	4.2 minutes
Lead-206	Stable	Stable

Table 1. The Uranium-238 Radioactive Decay Series (Generalized-doesn't show branching or some short-lived isotopes. Modified from Appleton, 2005, p. 229)

year under normal (open) building conditions (i.e., a long-term test). These tests are simple and inexpensive and homeowners can do this testing themselves. Test results are reported in pCi/L. Long-term tests (alpha-track detector measurements) have an advantage because they “average out” short-term fluctuations in radon levels that relate to factors such as weather changes. Consequently, long-term measurements should be more representative of annual average indoor-radon levels. However, short-term measurements are more commonly used because of the shorter time required. More often than not, if a short-term indoor radon test is several pCi/L above 4 pCi/L, follow-up short-term tests or long-term tests will also be above 4 pCi/L (e.g. Appendix B).

Radon Potential Maps

Radon potential maps indicate areas where the likelihood of a house exceeding 4 pCi/L (the U.S. EPA recommended radon action level) is relatively higher or lower. They may also be used with population data to estimate the number of individuals exposed to excessive radon levels within the area of map coverage. Radon potential maps and related population estimates can help government agencies and private organizations identify priority areas for future radon testing and public education efforts.

Use and Limitations of Radon Potential Maps

Radon potential maps developed by CGS for the CDPH-Radon Program identify areas where geologic conditions are more likely to contribute to excessive indoor radon levels. They are advisory, not regulatory, intended to assist federal, state and local government agencies, and private organizations in targeting their radon program activities and resources. These maps are not intended for determining which buildings have excessive indoor radon levels. In addition to geology, local variability in soil permeability and climatic conditions, and factors such as building design, construction, condition, and usage may influence indoor radon levels. Radon levels for a specific building can only be determined accurately by indoor radon testing of that building, regardless of what radon zone it is located within. All radon zone categories will likely have some buildings with indoor radon levels ≥ 4.0 pCi/L.

Development of the Lake Tahoe Area Radon Potential Map

The Lake Tahoe area radon potential zones were developed utilizing the following data:

- CDPH-Radon Program 2006-2007 Lake Tahoe indoor-radon survey test data for 443 residences
- NURE Project Airborne Survey data for equivalent uranium (eU)
- NURE Project stream sediment and soil sample uranium data

- Other (non-NURE) whole rock uranium data
- Lake Tahoe area soil unit data and maps from the Natural Resources Conservation Service (NRCS) and U.S. Forest Service (USFS)
- The California Geological Survey 1:100,000 scale *Geologic Map of the Lake Tahoe Basin, California and Nevada* (Saucedo, 2005)

Additional information considered during development of the Lake Tahoe area radon zone map includes:

- Indoor-radon data for Lake Tahoe zip code areas in the CDPH-Radon Program Radon Zip Code Database http://www.cdph.ca.gov/HealthInfo/environhealth/Documents/Radon/CaliforniaRadonDatabase.pdf .
- Indoor-radon and soil gas radon measurements and geology information for the Lake Tahoe area contained in Nevada Bureau of Mines and Geology Bulletin 10, Radon in Nevada (Rigby and others, 1994).
- Uranium data in Holocene valley-fill sediments in the Lake Tahoe-Carson range area contained in U.S. Geological Survey Open-file report 85-389 (Otton and others, 1985).

The Lake Tahoe radon potential map development steps are as follows:

1) Utilizing a geographic information system (GIS), 2006-2007 CDPH-Radon Program indoor-radon survey data (test measurements) for the Lake Tahoe area were grouped by geologic unit and soil unit.

2) Geologic units with associated indoor-radon data were preliminarily assigned to one of 5 radon potential categories based on the percentage of radon data at or exceeding 4 pCi/L, the number and magnitude of radon data per unit exceeding 10 pCi/l, and the total number of data.

3) Using a GIS, NURE project airborne equivalent uranium (eU) data and soil and sediment uranium (U) data for the Lake Tahoe area, and other uranium data were grouped by geologic unit.

4) Using NURE data, geologic units were rated as more likely or less likely to be related to problem radon homes based on the percentage of eU data and/or the percentage of soil, sediment or rock U data exceeding 5 ppm uranium (i.e., twice 2.5 ppm, the average crustal uranium abundance).

5) 2006-2007 CDPH-Radon Program indoor-radon survey data were grouped by NRCS and USFS soil units.

6) Permeability, shrink-swell character, frost-action character, depth to bedrock, the presence of duripan and fragipan (low permeability) horizons, and depth to water saturation information were reviewed for soil groups with

Indoor-radon data to see if these features are associated with higher or lower indoor radon concentrations.

7) Using the information from steps 2, 4 and 6, final radon potentials were assigned to all geologic units in the California portion of the Lake Tahoe map area based on percentages of short-term indoor radon tests likely to exceed 4.0 pCi/L as follows:

- Very High--50 percent or more ≥ 4.0 pCi/L indoor-measurements
- High--20 to 49.9 percent ≥ 4.0 pCi/L indoor-measurements
- Moderate--5 to 19.9 percent ≥ 4.0 pCi/L indoor-measurements
- Low--0 to 4.9 percent ≥ 4.0 pCi/L indoor-measurements
- Unknown--areas with insufficient data for estimating the percent of ≥ 4.0 pCi/L indoor measurements

8) Geologic unit areas with similar radon potentials were grouped to form radon potential zones.

9) The indoor-radon data for each radon zone were compared statistically with other zones to confirm that each zone represents a statistically distinct indoor-radon data population.

10) The final radon zones were compared with 2000 census block data to estimate radon impacts on the Lake Tahoe area population. These estimates are included in the report accompanying the Lake Tahoe Area Radon Potential Map.

The data and information utilized and the results for each of these steps are provided and discussed in more detail in the following portions of this report.

Portions of radon potential zones underlain by faults and shear zones often have increased potential for elevated indoor-radon because such features provide pathways for radon flow. However, faults and shear zones are not identified on the 1:100,000 scale Lake Tahoe Radon Potential Zone map because the minimum fault or shear zone width that can be depicted on a map at this scale is about 150-200 feet whereas fractures of an inch width or less can be significant pathways for radon movement to a building’s foundation. Soil and alluvium may obscure faults and shear zones or prevent their precise location on geologic maps, except where detailed site-specific investigations have been conducted. Consequently, at 1:100,000-scale mapping, it is better to base priority for indoor testing on zone designation rather than attempt to target fault and shear zone locations. Where situations require a local detailed investigation of indoor radon and fault or shear zone relationships, accurate fault or shear zone maps of 1:24,000 or a more detailed scale should be used or developed to guide testing.

Alpine and Amador Counties

The *Geologic Map of the Lake Tahoe Basin, California and Nevada* by Saucedo (2005) utilized in this project contains portions of Alpine and Amador counties in addition to portions of El Dorado, Nevada and Placer counties. The final Lake Tahoe radon potential map assigns radon potentials for these portions of Alpine and Calaveras counties based on geologic relationships observed in El Dorado, Nevada, and Placer counties, and on NURE project data, some of which is from samples collected in Alpine and Amador counties. Because the 2006-2007 CDPH Lake Tahoe indoor-radon survey did not cover Alpine and Amador counties, estimates for radon population impacts were not developed for these counties nor were recommendations made for future radon studies. A CDPH radon survey is currently underway for Amador, Calaveras and Tuolumne counties. A radon potential map with information on Amador County will be developed in the future utilizing data from this current survey.

THE LAKE TAHOE AREA SHORT-TERM INDOOR-RADON SURVEY

Overview

The CDPH-Radon Program conducted a survey of indoor-radon in Lake Tahoe area homes between December 2006 and April 2007. The CDPH-Radon Program solicited participation via direct mailing to 7,313 homeowners in the Lake Tahoe area (3,032 in El Dorado County, 2,568 in Nevada County, and 1,713 in Placer County). Four-hundred and forty-three (6.1 percent) of solicited homeowners participated in the survey. The survey participants received a free charcoal detector with instructions for placement and exposure, which they subsequently mailed to the Radon Program contract lab for measurement. Test results were provided directly to the survey participants by the contract lab within several weeks of detector receipt. The primary survey goal was to obtain sufficient indoor-radon data for homes located on specific geologic units to evaluate the radon potentials of these units. The percentage of homes exceeding the 4.0 pCi/L U.S. EPA recommended radon action level was used to evaluate geologic unit radon potential and the results are presented below in the section titled *Preliminary Geologic Unit Radon Potentials* (page 17).

Figure 1 shows the geographic distribution of the CDPH radon survey homes in the Lake Tahoe area. One hundred and seventy-seven homes tested ≥ 4.0 pCi/L and their geographic distribution is shown in Figure 2. The survey data radon concentrations range from 0.2 pCi/L-- the detection limit, to 86.1 pCi/L-- a basement measurement. The highest first-floor measurement recorded was 55.5 pCi/L. Table 2a summarizes survey results by Zip Code zone and City/Region. For comparison, Table 2b summarizes CDPH On-line Zip Code radon database test data for Lake Tahoe area Zip Code zones accumulated by CDPH since 1989. The CDPH on-line database includes the 2006-2007 Lake Tahoe radon survey data in Table 2a. Table 2b data cannot be used for evaluating the radon potential of particular geologic units because much of its data are only known to have come from homes within a particular Zip Code area. More precise location information is need for geologic unit radon potential evaluation. Another complication with the Table 2b data is that it likely includes multiple radon measurements for some homes (e.g., follow-up measurements or simultaneous measurements in multiple rooms) that cannot be identified as such. In spite of these limitations, Table 2b data are still useful for identifying which Lake Tahoe Zip Codes may contain radon problem areas, and for suggesting general indoor-radon trends in the Lake Tahoe area. Both the 2006-2007 survey and the Zip Code radon data sets show close agreement on overall percentage of homes in the Lake Tahoe area ≥4 pCi/L (i.e., 40.4 percent for the 2006-2007 survey versus 41.3 percent for the online Zip Code data). Not surprisingly, there is general agreement on percentages of ≥ 4 pCi/L homes between the two databases for Zip Codes with more than 25 tests, and often little or no agreement between Zip Codes with fewer tests.

The overall 40.4 percent and 41.3 percent results for ≥4 pCi/L homes in California Lake Tahoe communities are similar to the 38 percent of ≥4 pCi/L homes observed for Lake Tahoe communities in Nevada during 1989-1992 testing by Rigby and others (1994, p. 22).

In summary, both the 2006-2007 indoor-radon survey data and the Zip Code radon data suggest significant high radon potential areas occur in the southern Lake Tahoe region and in the northern Lake Tahoe region. These data suggest moderate to high radon potential areas occur in the central Lake Tahoe region.

Radon Survey Data--Exposure Duration and Data Quality

Most Lake Tahoe radon survey participants exposed their radon test kits for two days as instructed, but some exposed them for 3 days. Differences between two-day and three-day test results should be negligible.

Appendix A lists results for 39 duplicate (concurrent) tests made during the survey. For the four homes with indoor-radon levels at 1 pCi/L or less, test pair differences ranged from 0.3 to 0.5 pCi/L. For 14 homes with indoor-radon levels ranging from 1.1 pCi/L to 4 pCi/L, test pair differences were 0.1 to 1.7 pCi/L. For the 21 test pairs in homes with indoor-radon levels ranging from 4 pCi/L to 33.5 pCi/L, test pair differences ranged from 0.3 pCi/L to 5.3 pCi/L. Concurrent tests having one test above and one test below 4.0 pCi/L only occurred twice, in homes with indoor-radon levels close to 4 pCi/L (pair averages in these homes were 4.1 and 4.3 pCi/L).

Appendix B shows the analytical results of 10 field blank radon detectors (not exposed to radon) and eight spiked radon detectors (exposed to a known quantity of radon) submitted for analysis during the Lake Tahoe area radon survey. The blank samples measured below 0.5 pCi/L for 8 of 10 samples. One blank measured 0.7 pCi/L and one blank could not be analyzed. Appendix C shows that results for seven of eight spiked samples differed by +/- 1.0 pCi/L or less from the mean chamber radon concentration of 6.0 pCi/L. One spiked sample measured 1.1 pCi/L below the minimum chamber radon concentration. All detectors exposed to air averaging 6.0 pCi/L radon measured above 4.0 pCi/L, the U.S. EPA recommended action level.

In summary, duplicate, blank and spiked sample test results support the validity of the CDPH-Radon Program Lake Tahoe radon survey test data.

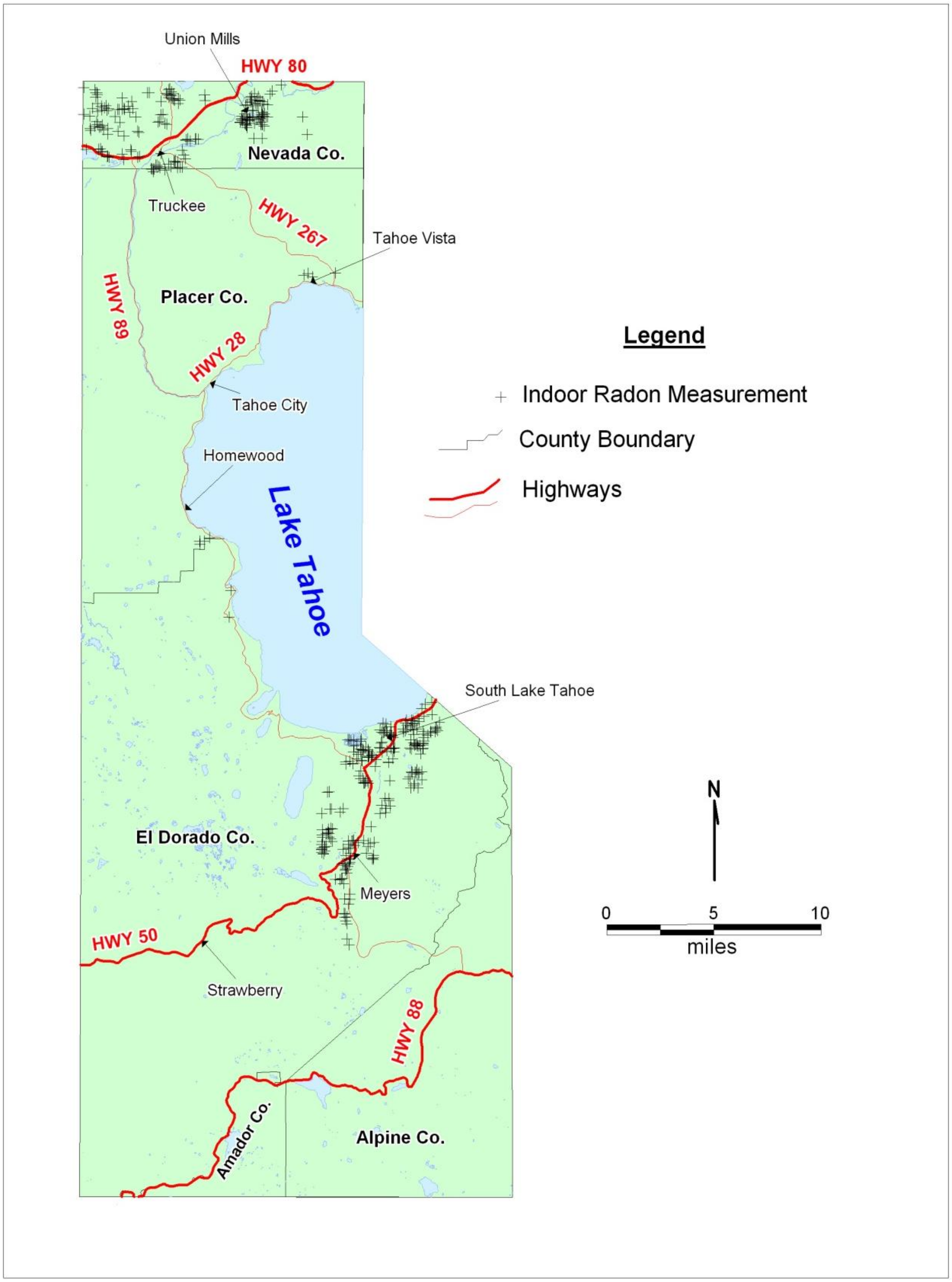

FIGURE 1. CDPH 2006-2007 Lake Tahoe Radon Survey Test Locations

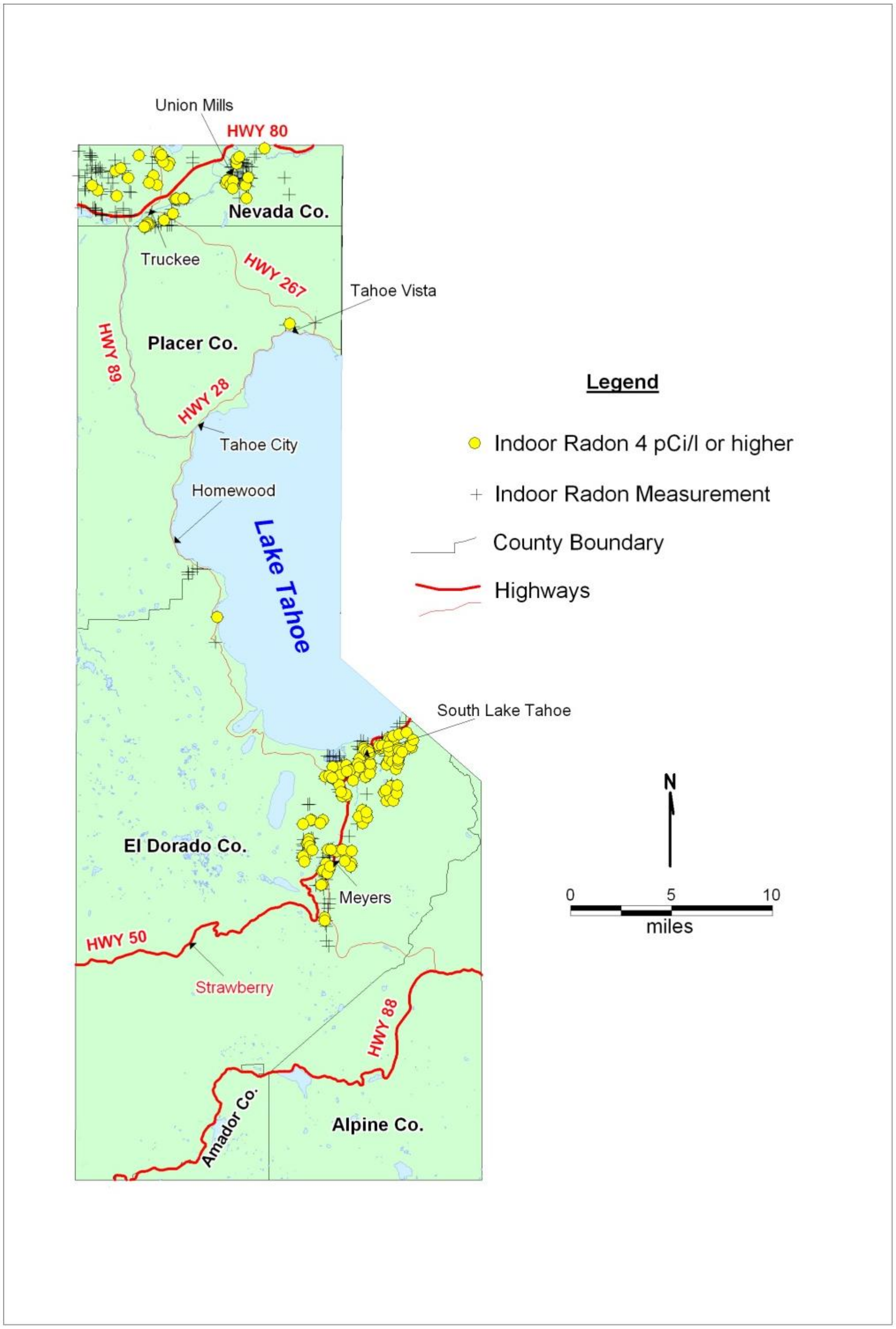

Figure 2. CDPH 2006-2007 Lake Tahoe Radon Survey Test Locations with 4.0 pCi/L or Greater Sites (Shown as Yellow Circles)

Zip Code	County-City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/L	Percent ≥ 4.0 pCi/L
Placer County				
96140*	Carnelian Bay	3	0	0
96141*	Homewood	1	0	0
96142*	Tahoma	3	0	0
96143*	Kings Beach	--	--	--
96145*	Tahoe City	--	--	--
96146	Olympic Valley	--	--	--
96148*	Tahoe Vista	3	1	33.3
	Placer County-Lake Tahoe Area Totals	10	1	10.0
El Dorado County				
96150	South Lake Tahoe	212	119	56.1
96151*	South Lake Tahoe	4	1	25.0
96152*	South Lake Tahoe	3	0	0
96153*	South Lake Tahoe	--	--	--
96154*	South Lake Tahoe	--	--	
96155*	South Lake Tahoe	3	1	33.3
96156*	South Lake Tahoe	4	3	75.0
96157*	South Lake Tahoe	--	--	--
96158*	South Lake Tahoe	16	8	50.0
	El Dorado County-Lake Tahoe Area Totals	242	132	54.5
Nevada County				
96160*	Truckee	28	9	32.1
96161	Truckee	143	34	23.8
96162*	Truckee	20	3	15
	Nevada County-Lake Tahoe Area Totals	191	46	24.1
Totals for Study Area				
All Tests for El Dorado, Placer and Nevada Counties within the Tahoe Radon Study Area from the winter 2006-2007 CDPH-Radon Program Lake Tahoe Area Radon Survey		443	179	40.4

Table 2a. CDPH Indoor-Radon Short-Term Test Results for the Winter 2006- 2007 Lake Tahoe Area Radon Survey by Zip Code Zone

*P.O. Box Only Zip Code.

Zip Code	County-City/Region	Number of Measurements	Measurements ≥ 4.0 pCi/L	Percent ≥ 4.0 pCi/L
Placer County				
96140*	Carnelian Bay	29	8	27.6
96141*	Homewood	9	1	11.1
96142*	Tahoma	10	1	10.0
96143*	Kings Beach	46	7	15.2
96145*	Tahoe City	98	26	26.5
96146	Olympic Valley	25	4	16.0
96148*	Tahoe Vista	23	4	17.4
	Placer County-Lake Tahoe Area totals	240	51	21.3
El Dorado County				
96150	South Lake Tahoe	474	263	55.5
96151*	South Lake Tahoe	74	42	56.8
96152*	South Lake Tahoe	9	3	33.3
96154*	South Lake Tahoe	6	6	100.0
96155*	South Lake Tahoe	22	5	22.7
96156*	South Lake Tahoe	28	20	71.4
96157*	South Lake Tahoe	9	8	88.9
96158*	South Lake Tahoe	68	36	52.9
	El Dorado County-Lake Tahoe Area totals	690	383	55.5
Nevada County				
96160*	Truckee	66	19	28.8
96161	Truckee	266	73	27.4
96162*	Truckee	49	16	32.7
	Nevada County-Lake Tahoe Area totals	381	108	28.3
Totals for Study Area				
All Tests for El Dorado, Placer and Nevada Counties within the Lake Tahoe Radon Study Area compiled by the CDPH-Radon Program as of 07/01/2008		1,311	541	41.3

Table 2b. Short-Term Test Results for Lake Tahoe Area Zip Code Zones from the CDPH On-line Radon Zip Code Database for California (*Results as of July 1, 2008; includes winter 2006-2007 CDPH survey results***)**

*P.O. Box Only Zip Code. Note: Zip Code 96153, listed in the On-line 2008 CDPH Test Results, is not a valid Zip Code Area and must be a typo. Exclusion of the 4 tests attributed to 96153 does not significantly impact the overall results.

Follow-up Radon Testing Results

Follow-up tests for 13 locations with the number of days between tests ranging from 17 to 79 are shown in Appendix D. In 11 instances the follow-up test confirmed the original test result of > 4.0 pCi/L, or < 4.0 pCi/L. Follow-up testing results suggest that homes with a short-term test of 6 pCi/L or above are very likely to have indoor-radon levels above 4 pCi/L in the spring and likely during a similar temperature period in the fall. Short-term tests made during the summer may be slightly lower.

Indoor-Radon Testing in South Lake Tahoe Schools

Not part of the CDPH-Radon Program radon survey or CGS radon mapping project, the Lake Tahoe Unified School District (LTUSD) conducted 463 48-hour indoor radon tests in all district buildings, including schools, between November 28 and December 5, 2007 (LTUSD, 2008). Three of the nine facilities tested, two schools and a warehouse facility, had 48 to 56 percent of their rooms ≥ 4 pCi/L, two facilities had 8 to 16 percent of their rooms ≥ 4 pCi/L, and four facilities had 0 to 2.6 percent of their rooms ≥ 4 pCi/L. Overall, 15.6 percent of school district rooms had test results ≥ 4 pCi/L for this initial testing period. For comparison, combined CDPH-Radon Program home radon tests for South Lake Tahoe zip code zones (Table 1a) have 54.5 percent of tests ≥ 4 pCi/L.

Analysis of school test data by district personnel found that most rooms with ≥ 4 pCi/L measurements had various issues with their HVAC systems (George Faggella, oral communication). The initial testing results showed that buildings with modernized HVAC systems consistently had rooms with lower radon levels than those buildings with older HVAC systems. However, subsequent adjustment and proper operation of the older HVAC systems reduced radon levels in rooms in buildings with these older HVAC systems. Follow-up radon tests by the district were made on 430 rooms between February 13 and April 10, 2008, after inspections and adjustments of HVAC systems. Eight of these tests (1.9 percent) were ≥ 4 pCi/L, with the highest measuring 6.6 pCi/L (Tahoe Daily Tribune, 2008). Subsequent work by district staff was successful in reducing these eight rooms to 4 pCi/L or less (George Faggella, oral communication, 2009)

LAKE TAHOE AREA GEOLOGIC UNIT RADON POTENTIALS

Indoor Radon Data and Geologic Unit Information

Indoor-radon data from the CDPH Radon Program 2006-2007 survey of Lake Tahoe Area homes are tabulated by geologic unit in Appendix E for the 24 geologic units with indoor-data. The 1:100,000-scale *Geologic Map of the Lake Tahoe Basin, California and Nevada* (Saucedo, 2005) was used to determine which geologic unit is present at each radon test location.

Preliminary Geologic Unit Radon Potentials

Tables 3a and 3b list 18 geologic units likely to have very high, high, moderate, or low radon potential. Radon potentials are assigned to these units based on indoor-radon data and radon potential definitions listed in Step 7 on page 6. The radon potential of 12 units listed in Tables 3a and 3b are provisional, less certain because they have fewer than 25 indoor-radon measurements. Provisional status is indicated in the following manor: "High?", "Moderate?", or "Low?". Other data (airborne radiometric data, uranium data from soil and sediment samples, and soil data) were reviewed to see if they supported either high or moderate designations for the provisional units in Tables 3a and 3b, and to identify additional geologic units that may have elevated radon potential but lack indoor-radon measurements. Following sections of this report discuss these data and their ramifications. Final geologic unit radon potentials are discussed on page 35 and listed in Appendix J-1.

The following radon potential classification categories for geologic units are based on indoor-radon survey results and geologic units as defined and located on the *Geologic Map of the Lake Tahoe Basin-California and Nevada* (Saucedo, 2005). The bullets identify common unit types in each category.

Very high and high radon potential units:
- Granodiorite (certain granodiorite units);
- Lake terrace deposits
- Glacial till and glacial outwash sedimentary deposits (with significant amounts of alluvial materials derived from granodiorite);
- Latite volcanic flows

Moderate radon potential units:
- Glacial-till, outwash and lake terrace sediment deposits (probably containing significant alluvial material from granodiorite);
- Latite volcanic flows and certain basalt-andesite units

Low radon potential units:
- Alluvium consisting of altered and unaltered andesite and little or no latite
- Artificial fill-variable in geologic unit content, most likely locally derived

Geologic Unit	**Incidence Rate (R) of CDPH ≥ 4 pCi/L, Indoor Measurements in percent**	**Radon Potential Designation**
Kbmg-Bryan Meadow granodiorite	R = 70.0% N = 30 N ≥ 4.0 pCi/L = 21 Maximum = 86.1pCi/L	Very High R ≥ 50%
Qlt and Qlt?-Lacustrine terrace deposits (Pleistocene)	R = 64.8% N = 91 N ≥ 4.0 pCi/L = 59 Maximum = 55.5 pCi/L	Very High R ≥ 50%
Qog-Older glacial deposits—pre-Tahoe deposits-Till (Pleistocene)	R = 58.3% N = 24 N ≥ 4.0 pCi/L = 14 Maximum = 14.3 pCi/L	Very High R ≥ 50%
Qogo-Older glacial deposits—pre Tahoe deposits-Outwash deposits (Pleistocene)	R = 52.9%? N=17 N ≥ 4.0 pCi/L = 9 Maximum = 36.9 pCi/L	Very High? Apparent R ≥ 50%
QPvd4-Dry Lake volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene)—youngest flow	R = 52.9% N = 17 N ≥ 4.0 pCi/L = 9 Maximum = 33.5 pCi/L	Very High? Apparent R ≥ 50%
Qfp and Qfp?--Flood-plain deposits (Holocene)	R = 50.0%? N = 6 N ≥ 4.0 pCi/L = 3 Maximum = 11.6	Very High? Apparent R ≥ 50%
Qta-Tahoe glacial deposits-Till (Pleistocene)	R = 44.8% N = 58 N ≥ 4.0 pCi/L = 26 Maximum = 20.6 pCi/L	High 20% ≥ R < 50%
Qvbm-Bald Mountain olivine latite of Birkeland (1961) (Pleistocene)	R = 38.5%? N = 13 N ≥ 4.0 pCi/L = 5 Maximum = 10.2	High? 20% ≥ R < 50%
Pvah-Alder Hill basalt of Birkeland (1961) (Pliocene)	R = 25.5% N = 47 N ≥ 4.0 pCi/L = 12 Maximum = 38.8 pCi/L	High 20% ≥ R < 50%
Keg-Granodiorite of East Peak (Cretaceous)	R = 59% in the Zephyr Cove, NV area, which is underlain by Keg (see Rigby and thers,1997, pp. 22-23)	Very High or High? 20% ≥ R < 50%

Table 3a. Very High and High Radon Potential Geologic Units in the Lake Tahoe Radon Area Based on 2006-2007 CDPH Short-term Indoor Radon Data N=the number of CDPH indoor-radon data available from houses located on the geologic unit indicated in the first column of the table. ?=Increased uncertainty because N < 24

Geologic Unit (Age)	**Incidence Rate (R) of CDPH ≥ 4 pCi/L, Indoor Measurements in percent**	**Radon Potential Designation**
Qti-Tioga glacial deposits-Till (Pleistocene)	R = 18.2 N = 33 N ≥ 4.0 pCi/L = 6 Maximum = 12.8 pCi/L	Moderate 5 % ≥ R < 20%
Mva-Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments (Miocene)	R = 17.6? N = 17 N ≥ 4.0 pCi/L = 3 Maximum = 4.6 pCi/L	Moderate? Apparent 5% ≥ R<20%
QPvd2-Dry Lake volcanic flows of Birkeland (1961)—second oldest flow; Wise and Sylvester (2004) (Pliocene and /or Pleistocene)	R = 16.7? N = 12 N ≥ 4.0 pCi/L = 2 Maximum = 12.3 pCi/L	Moderate? Apparent 5% ≥ R<20%
Qvh-Hirschdale olivine latite of Birkeland (1961) (Pleistocene)	R = 12.5? N = 16 N ≥ 4.0 pCi/L = 2 Maximum = 7.4 pCi/L	Moderate? Apparent 5% ≥ R<20%
Ql-Lake deposits (Holocene)	R = 14.3?? N = 7 N ≥ 4.0 pCi/L = 1 Maximum = 5.3 pCi/L	Moderate? Apparent 5% ≥ R<20%
Qpc-Prosser Creek alluvium of Birkeland (1961) (Pleistocene)	R = 16.7? N = 6 N ≥ 4.0 pCi/L = 1 Maximum = 6.0 pCi/L	Moderate? Apparent 5% ≥ R<20%
Qjf-Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	R = 4.8? N = 21 N ≥ 4.0 pCi/L = 1 Maximum = 4.0 pCi/L	Low? Apparent 0 % ≥ R< 5%
af-Artificial fill (late Holocene)	R = 0 N = 12 N ≥ 4.0 pCi/L = 0 Maximum = 1.9 pCi/L	Low? Apparent 0 % ≥ R< 5%

Table 3b. Moderate and Low Radon Potential Geologic Units in the Lake Tahoe Area Based on 2006-2007 CDPH Short-term Indoor Radon Data N=the number of CDPH indoor-radon data available from houses located on the geologic unit indicated in the first column of the table. ?=Increased uncertainty because N < 24

Several possible geologic models for very high, high, and moderate radon potential areas are discussed in Appendix K.

Comparison of California-Lake Tahoe and Nevada-Lake Tahoe Indoor-radon and Geology Associations

Rigby and others (1994, pp. 22-23) contains indoor-radon test results for homes in several Nevada communities along the eastern shore of Lake Tahoe. These measurements were made between 1989 and 1992. The Nevada testing found that 59 percent of tests in Zephyr Cove, 44 percent of tests in Glenbrook, and 18 percent of tests in Incline Village exceeded 4.0 pCi/L. Single measurements made in Crystal Bay and Stateline did not exceed 4.0 pCi/L. Overall, about 38 percent of all indoor radon measurements made in Nevada Lake Tahoe communities exceeded 4.0 pCi/L. This percentage is similar to the 40.4 percent of ≥ 4.0 indoor measurements obtained in the 2006-2007 CDPH survey of California homes in the Lake Tahoe area.

Rigby and others (1994) report that the Nevada Lake Tahoe communities tested are located on, or very close to, granitic or related rocks of the Sierra Nevada batholith. Zephyr Cove is underlain by granodiorite bedrock (Keg-granodiorite of East Peak), alluvium derived from weathering of granitic rocks (Keg), and organic-rich marsh deposits. Stateline is underlain mostly by young alluvium derived from nearby outcrops of granodiorite (shown as Keg-Granodiorite of East Peak and Kbmg-Bryan Meadow granodiorite in Saucedo, 2005) with part of Stateline underlain by artificial fill of unknown origin. Glenbrook is underlain by alluvium derived either from granodiorite and related igneous rocks, volcanic rocks (latite and trachyte), and older metamorphic volcanic rocks and monzogranite. Incline Village is underlain by alluvial and fluvial deposits derived from nearby granodiorite and andesitic volcanic rocks. Crystal Bay is underlain by granodiorite (Kgr-undivided granite and granodiorite). Faults within or near these Lake Tahoe communities may contribute to localized high radon concentrations.

The geologic unit-radon associations identified by Rigby and others (1994) for Nevada Lake Tahoe communities are similar to those observed by CGS in the California portion of the Lake Tahoe area. The Indoor Radon Potential Hazard map produced by Rigby and others shows the Nevada portion of the Lake Tahoe area as having high radon potential (defined as > 25% of houses exceeding 4 pCi/L). For California, very high and high radon zone areas in South Lake Tahoe are underlain by granitic rocks (Kbmg) and fluvial and glacial alluvium derived from granitic rocks. In the Truckee area, very high and high radon zone areas appear related to certain volcanic rocks (latites and possibly trachytes?) and glacial deposits with alluvium presumably derived from these volcanic rock types.

NURE PROJECT AND OTHER URANIUM DATA

Background

Between 1975 and 1983, the United States government funded the National Uranium Resource Evaluation (NURE) project. The goal of NURE was to identify new domestic sources (ore deposits) of uranium for energy and national defense. NURE uranium exploration activities included airborne gamma-ray spectral surveys that estimated the uranium content of soils and rocks at points along a grid of flight-lines, and (in some parts of California) the collection and laboratory analysis of soil and stream sediment samples for uranium content. Locations with unusually high uranium abundance were considered targets for additional work to determine whether or not economically recoverable uranium deposits were present.

Airborne Radiometric Data

NURE airborne radiometric data used in this study were compiled from the original digital data files by Duval (2000). The Lake Tahoe radon study area is covered by parts of three NURE airborne radiometric surveys: the Chico 1X2 degree quadrangle survey; the Sacramento 1X2 degree quadrangle survey; and the Walker Lake 1X2 degree quadrangle survey. A total of 267.7 miles of flight-line data are available for the Lake Tahoe study area from these surveys. The flight-line grid pattern, shown in Figure 3, consists of east-west flight lines 2-4 miles apart, and north-south flight lines generally about 12 miles apart. A specially equipped helicopter flew a few hundred feet above ground surface at about 90 miles per hour along these flight lines and recorded approximately 11,800 gamma-ray spectral measurements. The average distance between data measurements is about 120 feet.

One of the gamma-ray energies measured during the NURE airborne radiometric survey is generated during the decay of bismuth-214. Bismuth-214 is a radioactive daughter product of uranium-238 which forms and decays quickly after radon-222 decay. The NURE program used bismuth-214 gamma-ray data to calculate estimates of the soil-rock uranium content, in parts-per-million (ppm), at each of the 11,800 flight line measurement locations. Under the NURE flight survey conditions, each airborne uranium measurement represents the average uranium content within the upper 18 inches of surficial material (rock or soil) over an area of approximately 48,000 square feet (approximately 1.1 acres; see High-Life Helicopters, 1980a and 1980b) . Because the uranium values are calculated from bismuth-214 gamma-ray data, they are referred to as equivalent uranium (eU) data to distinguish them from uranium data determined by direct chemical methods (i.e., typical laboratory determinations for rock and soil samples by delayed neutron activation, fluorescence or other laboratory method).

Soil moisture, atmospheric inversion and other conditions can impact airborne eU data measurements (Grasty, 1997). Consequently, eU data are treated as qualitative to semi-quantitative indicators of areas with increased uranium in rock or soil in the Lake Tahoe radon potential study.

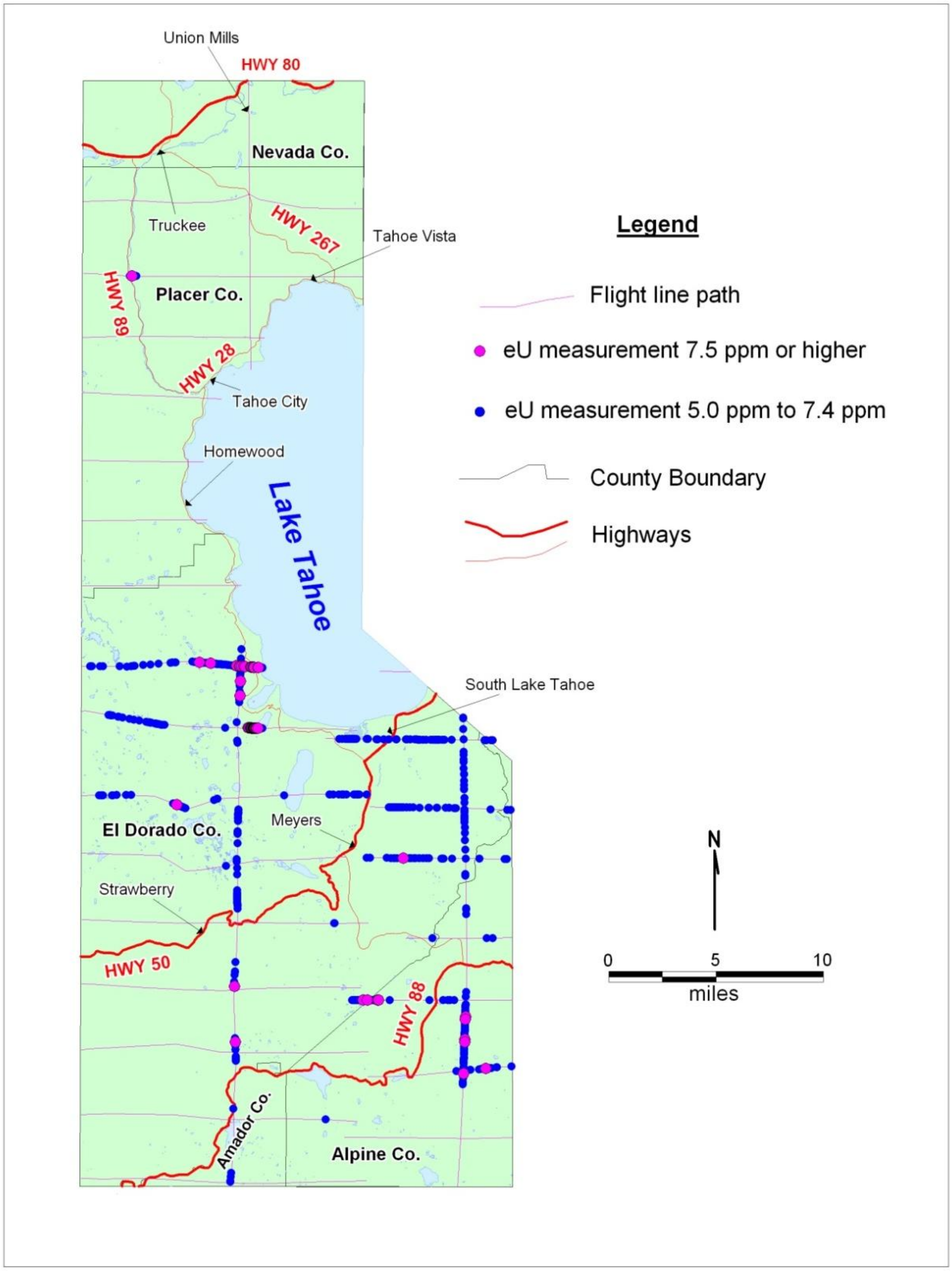

FIGURE 3. NURE Project Flight Lines and Equivalent Uranium Anomalies

Figure 3 shows flight-line data locations where eU data equal or exceed 7.5 ppm and where data range from 5.0 to 7.4 ppm eU. The average uranium content of the earth's crust is about 2.5 ppm, so 7.5 ppm or higher data are about 3 times more than the uranium crustal average, and 5.0 to 7.4 is about 2 to 3 times more. Equivalent uranium data of ≥ 5.0 ppm are considered anomalously high in this study. In this study Lake Tahoe geologic units with higher percentages of ≥ 5.0 ppm eU data are assumed more likely to have houses with radon levels exceeding 4.0 pCi/L than geologic units with low percentages of ≥ 5.0 ppm eU data.

Appendix F summarizes eU NURE aeroradiometric data for 92 geologic units in the Lake Tahoe area (for units and portions of units within California). These data suggest the following geologic units are more likely to have areas with elevated radon potentials (see Appendix E for geologic unit names):

- **Granitic rocks**: Krpa, Kppg, Kbla, Kdg, ap, Kcfg, Kdvg, Kbmg, Kelg
- **Lake terrace and flood-plain deposits**: Qlt, Qfp
- **Glacial deposits**: Qgt, Qti, Qta, Qtio, Qog
- **Volcanic rocks-fluvial deposits**: Mvs (some of which are designated as "Mvs?" on the geology map by Saucedo (2005) indicating unit identification uncertainty)

Note that indoor-radon data and eU data both support a very high radon potential classification for units Kbmg, Qlt, Qfp and Qog, a high radon potential classification for unit Qta, and a moderate radon potential classification for unit Qti (*see Tables 2a and 2b*).

Airborne eU data in Appendix F also suggest the following geologic units are more likely to have low radon potentials:

- **Intrusive igneous rocks**: Ja, Jdg, Jpgr, Kcpt, Kepg, KJdg, Ktlg
- **Volcanic rocks**: Mia, Mva, Mvaf, Mvbf, Mvs (some, those with geologic map designation "Mvs?" as discussed above), Mvul, Mvulr, QPvd1, QPvd4, Qvbm
- **Alluvial and talus deposits**: Q, Qc, Qf, Qls, Qpot, Qt

Note that eU data do not support the following indoor-radon data based radon potential classifications: very high potential for QPvd4; high potential for Qvbm, and moderate potential for Mva (*see Tables*

3a and 3b). Geologic units not listed in the bulleted lists above have insufficient numbers of eU data for their radon potential classification.

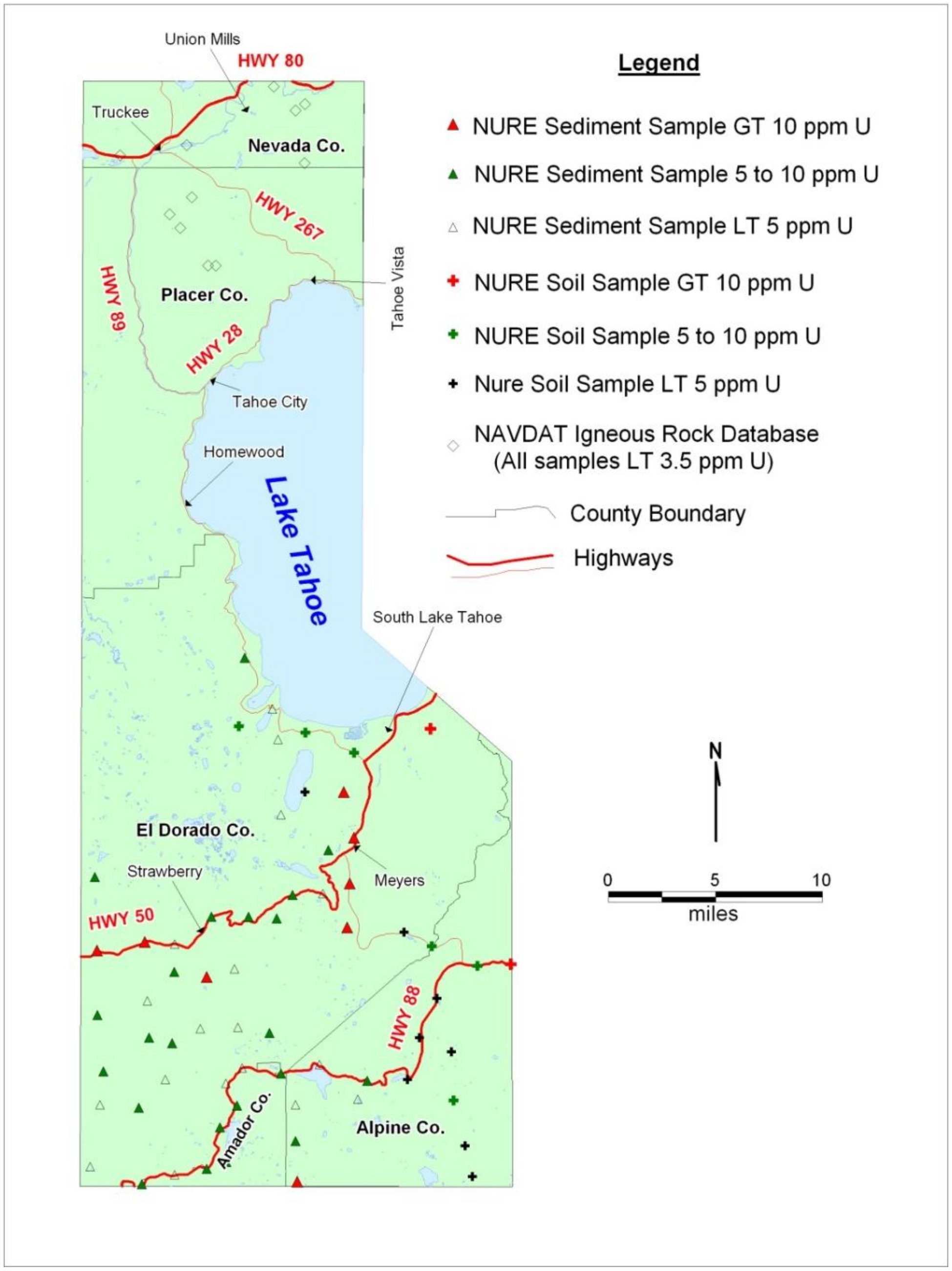

FIGURE 4. NURE Project Soil and Stream Sediment Sample Locations and NAVDAT Database Rock Sample Location

Uranium in Soil and Stream Sediment Samples

NURE project activities in the Lake Tahoe area also included collection of 16 soil and 48 stream sediment samples within the Sacramento and Walker Lake 1X2 degree quadrangles for laboratory analysis of uranium content. Figure 4 shows NURE soil and stream sediment sample locations and groups them into three ranges of uranium abundance. Appendix G lists the NURE soil and sediment uranium data by the geologic unit present at the sample location.

In general, soil uranium abundance is similar to that of the underlying rock from which the soil was developed (Otton, 1992), so soil uranium abundance should be somewhat representative of the radon potential of the underlying rock, barring major differences in radon emanation rates. Radon emanation is the ability of radon, once formed, to exit minerals and enter pore-space and fractures. Stream sediment uranium data are more complicated to interpret regarding their relationship to the radon potential of underlying geologic units. Stream sediment is a composite of debris derived both from rock units present at or near the sample site and farther upstream of the sample site. Consequently, stream sediment uranium abundance may be similar to the underlying bedrock, if the sediment is predominantly derived from that rock unit, or somewhat different if the sediment is predominantly derived from other rock units upstream. Detailed sediment source information is not available for the NURE data. However, sediment collected further downstream from the upstream contact of the underlying bedrock is more likely to have a greater component of sediment derived from that underlying rock type and, consequently, similar uranium abundance.

Table 4 lists geologic units more likely to have elevated radon potentials, based on their highest single soil or stream sediment uranium analysis, and on

Geologic Unit and NURE sample type	**Number of Samples**	**Median Uranium (ppm)**	**Highest Uranium Analysis (ppm)**
Kbmg-soil	3	10.0	88.6
Qti-stream sediment	4	15.0	28.4
af-stream sediment	1	--	17.5
Qta-stream sediment	2	12.7	16.8
Kwlg-stream sediment	3	5.2	14.5
Qfp?-stream sediment	1	--	12.7
Kclg-stream sediment	13	5.6	12.2
Qls-stream sediment (within Kwlg area)	1	--	10.2

Table 4. Geologic Units with One or More Associated NURE Soil or Stream Sediment Uranium Analyses Exceeding 10 ppm (See Appendix G for unit names)**.**

relatively high median soil or stream sediment uranium values. Note that based on indoor-radon data, previously discussed , Kbmg and Qfp have been classified as having very high radon potential, Qta as having high potential, and Qti as having moderate radon (see Tables 3a and 3b). Comparison of NURE soil and stream sediment uranium data listed in Appendix G with the crustal average uranium abundance of 2.5 ppm, suggests relatively low radon potentials for the following units:

- **Metamorphosed intermediate to mafic volcanic breccia:** Jtlb
- **Granitic intrusive Igneous rocks:** Kbla, Kepg
- **Andesitic and dacitic volcanic rocks:** Mva
- **Fluvial deposits with volcanic clasts and debris:** Mvs

Note that indoor-radon survey data in Table 3b suggest geologic unit Mva has a moderate radon potential.

Other (non-NURE) Whole Rock Uranium Samples

Soil and stream sediment samples were not collected as part of the NURE project work in the northern part of the Lake Tahoe study area (in the Chico 1X2 degree quadrangle). However, the Western North America Volcanic and Intrusive Rock Database (NAVDAT) located at www.navdat.org contains uranium data for 11 volcanic units north and northwest of Lake Tahoe (the sample locations shown in Figure 5). Most of the NAVDAT data for the Lake Tahoe area are from Latham (1985). The NAVDAT uranium data with their associated geologic unit information are listed in Table 5. The uranium contents of these samples are significantly below average crustal abundance of uranium of 2.5-2.7 ppm, except for the two Qvbm samples.

Dr. Brian Cousens, Assistant Professor of Earth Sciences at Carleton University, Canada, kindly allowed the author to examine his unpublished geochemical database for volcanic rocks in the Lake area (Cousens, written communication, 2009). Cousens' database contained 56 whole rock uranium analyses for sites within the Lake Tahoe radon study area. The data range from 0.45 ppm to 3.42 ppm uranium, with a median value of 1.37 ppm. This data range is similar to the range for NAVDAT uranium data listed in Table 4, and the range for NURE eU data (see Appendix F and the northern portion of the Figure 4 map).

The NAVDAT and Cousens' volcanic rock uranium data suggest relatively low radon potential for Mva, Mvaf, Pva, Pvp, Qls (*for andesitic composition debris*), QPvd2, Qtio (*for andesitic composition sediment*); and Qvbm. For comparison, NURE eU data also support low radon potential for Mva, Mvaf, Qls and Qvbm. In opposition to the uranium and eU data, indoor-radon survey data (Tables 3a and 3b) support a high radon potential for Qvbm and a moderate radon potential for Mva. The fact that some very high and high radon potential areas have been documented associated with volcanic units having low to average uranium contents suggests additional geologic factors or other non-geological factors may be at work to provide radon to houses in these areas. Some geologic models for high radon potential areas in Lake Tahoe are suggested in Appendix K.

NAVDAT Sample Number	Lake Tahoe Basin Geologic Unit	Lake Tahoe Basin Geologic Unit Name	NAVDAT Rock Name	Uranium (ppm)
386170	Mva	Unnamed volcanic and intrusive rocks-undivided andesitic and dacitic lahars, flows, breccia and volcaniclastic sediments	Hawaiite	1.48
462467	Mvaf	Unnamed volcanic and intrusive rocks-Andesite and dacite flows	Basalt	1.5
452850	Pva	Unnamed volcanic and intrusive rocks-andesite and basaltic andesite flows	Andesite	1.07
452786, 452836	Pvp	Polaris olivine latite of Birkeland (1961)	Andesite	1.12, 1.69
452834	Qls	Landslide deposits	Andesite	1.46
452796	QPvd2	Dry Lake volcanic flows of Birkeland (1961) and Wise and Sylvester (2005) -- second oldest flow	Andesite	1.12
452839, 452837	Qtio, Qtio?	Tioga glacial deposits-Outwash deposits	Andesite	1.17, 1.33
452864, 452849	Qvbm	Bald Mountain olivine latite of Birkeland (1961)	Andesite	3.19, 3.45

Table 5. NAVDAT Whole Rock Uranium Data for Volcanic Rocks North and Northwest of Lake Tahoe.

Otton and others, 1985, report uranium analyses for two East Peak granodiorite samples of 4.56 and 4.09 ppm. They also report uranium analyses for Bryan Meadow granodiorite of 5.12, 4.90 and 10.10 ppm. These uranium data are significantly above average crustal uranium abundance of 2.5-2.7 ppm and suggest moderate to high radon potentials for East Peak granodiorite and Bryan Meadow granodiorite. Indoor-radon data discussed above support a very high radon potential classification for the Bryan meadow granodiorite (Kbmg).

Uranium in Organic Rich Sediments

Uranium concentrations may occur in marshes, peat bogs, mountain meadows and similar locations where plant debris can accumulate (Vine, 1962). Organic matter in these anoxic reducing environments will readily extract and hold uranium ions from aqueous solution. No uranium analyses of Lake Tahoe area marsh sediment within California were identified during this study. However, a study by Otton and others (1985) found uranium values ranging from 82 to 2100 ppm (on a dry weight basis) in upper two meters of organic-rich sediment in a marsh near Zephyr Cove, Nevada. Otton and others (1985) also identified a second area 3-4 kilometers upstream, which they refer to as the upper Zephyr fen, containing organic rich sediments with uranium values ranging up to 5,760 ppm and averaging 1,500 ppm. The uranium in these two deposits was likely leached from surrounding granitic rocks during weathering, and transported in groundwater at low concentrations to the Zephyr marsh and fen (Otton and others, 1985; Rigby and others, 1994). The uranium occurrences at Zephyr suggest the possibility that shallow horizons of high uranium organic rich sediments in fluvial or lacustrine sediments may be a potential source for radon to overlying buildings in the Lake Tahoe area (in both Nevada and California). However, uranium residence time in these organic-rich sediments is a significant issue impacting radon availability in this geologic setting. Enough time is needed for sufficient uranium-238, with a $4.5\text{X}10^9$ year half-life, to decay to produce significant amounts of radon. Preliminary estimates suggest one thousand to several thousand years may be sufficient for organic rich soils with high uranium contents to become a significant radon source, but additional evaluation of this issue is needed.

LAKE TAHOE AREA SOIL DATA

Soil Properties and Indoor-Radon

Soil permeability data can be useful in developing radon potential maps. Radon is more easily released from host minerals and can migrate further within higher permeability soils. In soils with low permeability, radon release and migration can be significantly restricted. Besides permeability, soil moisture is also an important factor. Radon is more readily released and migrates further in dry soils than wet soils because it is captured (dissolved) and held in the water (Brookins, 1990, Appleton, 2005).

Soils exhibiting moderate to high shrink-swell character may also be associated with indoor-radon problems. These soils change permeability, exhibiting low permeability during periods of precipitation and high permeability (cracks) during dry periods because they contain clays that expand or contract in relation to soil moisture content. High shrink-swell soils also stress and sometimes crack foundations, creating radon entry pathways into homes. Frost action, or frost heave, in soils is caused by the expansion of soil water during freezing and also may cause foundations to crack. Cracks in slabs and basement walls are pathways for radon moving from the soil into a home.

Summary of Lake Tahoe Area Soil Properties

The NRCS soil map and report for the Lake Tahoe Basin (USDA, 2007), and the USFS soil map and report for the Tahoe National Forest Area California (USDA, 2002) were used to determine soil type at each radon test site. Soil unit names and associated indoor-radon survey data are provided in Appendix H-1 and Appendix H-2. Soil unit names and permeability, shrink/swell and frost action information are provided in Appendix I-1 and Appendix I-2.

NRCS and USFS soil property data and associated radon survey data are summarized in Tables 6a, 6b and 6c. NRCS soil data are from within the Lake Tahoe Basin and USFS soil data are from outside of the Lake Tahoe Basin. Tables 6a, 6b, and 6c are tabulations of soil properties for each house tested in the CDPH Lake Tahoe radon survey. Soil properties percentages and numbers in Tables 6a and 6b predominantly relate to South Lake Tahoe area soils because South Lake Tahoe is the largest community within the NRCS Lake Tahoe soil study area and a large number of homes were tested for radon there. These soils are most often developed on granitic rocks, or on glacial, lake or fluvial sedimentary deposits dominated with granitic derived material. Soil properties listed in Table 6c are dominated by Truckee area soil properties because Truckee is the largest community and has the largest number of radon tests within the USFS soil study area. Truckee area soils are developed on volcanic rocks, or glacial or fluvial sedimentary deposits containing volcanic material.

Some Lake Tahoe area soils contain duripan or fragipan horizons. A duripan is a subsurface soil horizon that is cemented with opal or microcrystalline silica (USDA, 2007). A fragipan is a loamy brittle subsurface horizon low in porosity, low in organic matter, with low to moderate clay content but high in silt or very fine sand (USDA, 2007). It appears cemented. When moist, fragipans tend to

Soil Permeability	**% all soil permeability groups***	**N**	**N ≥ 4 pCi/L**	**% ≥ 4 pCi/L**	**Minimum pCi/L**	**Maximum pCi/L**
Very Rapid over slow horizon w duripan	14.7	37	11	29.7	0.2	20.6
Very Rapid	nd	nd	nd	nd	nd	nd
Rapid over Very Rapid	1.1	3	1	nd	2.2	12.8
Rapid	29.4	74	48	64.9	0.2	55.5
Rapid over Impermeable (duripan)	4.0	10	4	nd	0.2	9.7
Moderately Rapid to Rapid over slow horizon	7.5	19	11	57.9?	0.2	19.6
Moderately Rapid to Rapid over slow horizon w duripan	2.4	6	nd	nd	0.6	2.2
Moderately Rapid	8.7	22	16	72.7	0.6	16.2
Moderate to Rapid	0.4	1	nd	nd	nd	0.3
Moderate	nd	nd	nd	nd	nd	nd
Moderately Slow to Rapid over slow horizon	2.0	5	2	nd	1.0	8.0
Slow to Moderate	1.2	3	nd	nd	0.7	3.7
Slow	5.6	14	1	nd	0.2	5.3
Slow w fragipan	4.4	11	10	nd	3.2	86.1
Very Slow	2.8	7	6	nd	1.0	15.0
Impermeable to very slow	0.4	1	nd	nd	nd	0.2
Very Slow (fragipan)	15.5	39	23	59.0	1.4	36.9
totals/weighted average	***100.0***	***252***	***133***	***52.8***		

Table 6a. Lake Tahoe Soil Permeability and Indoor-Radon Survey Data by NRCS Soil permeability characteristics

nd = no data, or insufficient data for a reliable ≥ 4 pCi/L percentage;
? = increased uncertainty because N < 25

rupture suddenly under pressure rather than deform slowly. Because both duripans and fragipans have very slow permeability or are impermeable with regard to water, it is possible they influence radon potentials where they are present by limiting radon migration to the surface.

Within the Lake Tahoe Basin (the NRCS soils mapping area), moderate to very rapid permeability soils are present at 68 percent of the CDPH-radon survey sites, and very slow to moderate permeability soils are present at 32 percent of the survey sites. Both permeability groups have virtually the same percentages of survey homes exceeding 4 pCi/L; 52.3 percent for moderate to very rapid permeability soils, and 52.5 percent for the very slow to moderate permeability soils. This similarity suggests soil permeability is not a useful indicator of radon potential in the Lake Tahoe area, at least in regard to identifying high or low radon potential areas. Additional support for this conclusion can be found by comparing these individual soil permeability categories in Table 6a with significant numbers of indoor-radon measurements (e.g., N ≥ 19). All

Soil Characteristics	**Number***	**Number ≥ 4 pCi/L**	**Percent ≥ 4 pCi/L**	**Maximum pCi/L**
Soils with duripan horizon	53	15	28.3	20.6
Soils with fragipan horizon	50	33	66.0	86.1
Low shrink-swell soils	222	117	52.7	86.1
Moderate shrink-swell soils	5	2	nd	8.0
High shrink-swell soils	1	0	nd	0.2
Low Frost action soils	44	19	43.2	15.0
Low to Moderate Frost action soils	184	105	57.1	86.1
Low to High Frost action soils	44	21	47.7	20.6
Moderate Frost action soils	3	1	nd	5.3
High Frost action soils	nd	nd	nd	nd
High to Moderate Frost action soils	3	nd	nd	3.7

Table 6b. Comparison of Lake Tahoe Indoor-Radon Survey Data by NRCS Data on Low-permeability Horizons, Shrink-swell Character, and Frost Action Character.

nd = no data, or insufficient data for a reliable ≥ 4 pCi/L percentage these categories show relatively high ≥ 4 pCi/L percentages even though they span permeabilities from very slow (with a fragipan horizon), moderately rapid, moderately rapid (over a slow permeability horizon), very rapid, to very rapid (over a duripan horizon). The ≥ 4 pCi/L percentages for these soil horizons and permeability groups also show that soils with duripan or fragipan horizons may still have very high or high radon potentials. Table 6b also shows soils with duripan or fragipan horizons are associated with significant numbers of ≥ 4 pCi/L homes and some relatively high indoor radon measurements. Possibly the presence of the duripan horizon at the 37 very rapid permeability sites (first row entry, Table 6a) moderated the number of ≥ 4pCi/L occurrences, but a 29.7% ≥ 4 pCi/L rate still falls within the high radon potential category. Supporting evidence for this possibility can be seen by comparing percentages of ≥ 4 pCi/L data the first row entry in Table 6--very rapid over slow soil permeability with duripan and the fourth row entry--rapid permeability (with no duripan).

In addition to radon data for soils with duripan or fragipan horizons, Table 6b shows radon data for soils according to shrink-swell and frost action properties. Over 97 percent of the indoor-radon data sites represented in Table 6b have low shrink-swell soils. Unfortunately, the number of sites with moderate and high shrink-swell soils is too few to allow evaluation of soil shrink-swell characteristics and radon potential. Three categories of frost-action soils are predominant in Table 6b: low, low to moderate, and low to high, and their percentages of ≥ 4 pCi/L occurrences are similar. This similarity, and the lack of data for moderate and high frost action soils, precludes evaluation of frost action as a soil property predictor of radon potential.

Table 6c shows indoor-radon data by soil and substrate permeability for USFS mapped soils outside of the Lake Tahoe Basin but still within the Lake Tahoe radon study area. Moderate to moderately slow soil permeabilities and moderate to very slow substrate permeabilities are the dominant permeabilities for radon measurement sites within this portion of the study area. Overlap between soil in and substrate permeabilities in these categories, and the small number of data moderate to very rapid permeability categories preclude evaluation and use of soil permeability for prediction of radon potential within this portion of the Lake Tahoe radon study area.

In summary the NRCS and USFS soil data on permeability do not seem to be a useful predictor of radon potential in the Lake Tahoe area. In particular, the presence of very slow permeability to impermeable horizons of duripan or fragipan in the subsurface does not preclude an area from having a high or very high radon potential. Too few data are currently available to evaluate the impacts of soil shrink-swell character or frost action character on radon potential in the Lake Tahoe area. While available “off-the-shelf” permeability

Soil Permeability	**Substrate Permeability**	**Number**	**Number ≥ 4 pCi/L**	**Percent ≥ 4 pCi/L**	**Minimum pCi/L**	**Maximum pCi/L**
Rapid --* Very Rapid	Very Slow --* Very Rapid	1	0	nd	nd	1.5
Moderately Rapid	Slow	5	0	nd	0.7	3.2
Moderately Rapid	Very slow	2	0	nd	1.7	2.0
Moderate -- Rapid	Rapid -- Slow	8	1	nd	0.3	4.5
Moderately Slow	Rapid	12	6	nd	0.5	24.8
Moderate to Moderately Slow	Moderately Slow	47	6	12.8	0.5	38.8
Moderately Slow	Moderate	20	2	10 ?	0.2	7.4
Moderately Slow	Moderately Slow	60	18	30.0	0.2	14.2
Moderately Slow	Very Slow	1	1	nd	nd	5.4
Slow -- Moderately Slow	Very Slow -- Moderately Slow	27	12	44.4	0.2	33.5
Very Slow to Slow	Moderately Slow	8	nd	nd	0.5	3.9
totals/ weighted average		***191***	***46***	***24.1***		

Table 6c. Comparison of Lake Tahoe Indoor-Radon Survey Data by USFS Soil data on Soil and Substrate Permeability

For permeability columns, a "--" indicates multiple horizons with different permeabilities, the top most listed permeability is the shallower horizon
nd = no data, or insufficient data for a reliable ≥ 4 pCi/L percentage

data from the NRCS and USFS soil studies did not prove useful for radon potential prediction, it must be pointed out that these data are generalized, and may somewhat differ from the permeabilities actually present at some radon survey sites. If sufficient site-specific soil permeability data are collected at indoor-radon measurement sites in the future, it is still possible that a correlation between soil permeability and radon potential may be identified for the Lake Tahoe area.

Soil Gas Radon Data for Eastern Lake Tahoe Area Sites

Previous soil gas radon studies for the California portion of the Lake Tahoe area were not identified during this study. However, a limited number of soil gas radon measurements were taken by the Nevada Bureau of Mines and Geology (NBMG) along the eastern (Nevada) side of Lake Tahoe and are described in Rigby and others (1994). Three soil gas measurements are in soil derived from the Keg geologic unit (*Granodiorite of East Peak*) and one in soil on Qlt (*Lacustrine terrace deposits*), or possibly Qfp (*Flood-plain deposits*). For the soils derived from Keg, the sample near Elk Point measured 3,830 pCi/L, the sample at Zephyr Cove measured 1,810 pCi/L, and a sample approximately mid-way between Zephyr Cove and South Point measured 660 pCi/L. A sample taken from soil on Qlt (or Qfp?), approximately 1 mile southeast of Elk Point measured 2,120 pCi/L. To put these data into perspective, the “normal” range for soil gas radon is about 200 pCi/L to 2,000 pCi/L (Otton, 1992). The proximity of these locations to South Lake Tahoe and presence of these geologic units suggest that similar soil gas radon levels may be present there.

Many soils with typical background uranium abundances (about 1 to 3 ppm) have soil gas radon values of a few hundred pCi/L (Brookins, 1990; Otton, 1992). This contrasts significantly with the average radon concentrations in outdoor air, which averages 0.4 pCi/L in the United States (Hopper and others, 1991). The air in most houses is typically made up of less than one percent of air from the soil and the remainder from outdoor air (Otton, 1992). However, for houses with low indoor air pressure, poorly sealed foundations, or several entry points (e.g., holes through a concrete slab), soil air may make up as much as 20% of the indoor air (Appleton, 2005, p. 247). If soil gas radon levels of several thousand pCi/L are common in the South Lake Tahoe area, as suggested by the Nevada data, then South Lake Tahoe houses could exceed the 4.0 pCi/L recommended U.S. EPA radon action level by drawing in as little as 0.2-0.3% of their air from the underlying soil.

Soil gas radon measurements may be used as a relatively reliable indirect indicator of radon potential on local and national scales (Appleton, 2005). Future studies in the Lake Tahoe area involving soil gas radon sampling may be useful in refining the Lake Tahoe radon potential zone boundaries. However, many factors can affect soil gas radon concentrations in the subsurface and make data interpretation difficult (e.g., soil moisture, diurnal and seasonal variations related to weather and climate, see discussion in Appleton, 2005, pp. 255-256). Such soil gas radon surveys must be well designed and numerous samples would be required. Appleton (2005) states that at least 10-15 soil gas radon measurements from depths greater than 70 cm are generally required to characterize a site or a geologic unit. Where soil gas radon measurements are not possible due to various local conditions, surface gamma-ray spectral measurements of eU may be useful (for example, see Duval and others, 2004)

RADON POTENTIAL ZONES

Final Lake Tahoe Area Geologic Unit Radon Potentials

Lake Tahoe area radon potential zones are based on the locations of geologic units classified as having very high, high, moderate, low or unknown radon potential. The data used for ranking Lake Tahoe geologic units are: 1) indoor-radon data; 2) NURE airborne eU data, NURE soil and sediment uranium data, and uranium data from other (non-NURE) sources. In several cases, geologic units with few indoor-radon measurements but one or more relatively high pCi/L measurements were included in the high radon potential category. NRCS and USFS soil permeability data were not used for Lake Tahoe area geologic unit radon potential rankings because they do not appear to be a significant predictor of radon potential, as previously discussed.

Appendix J-1 contains the criteria used for low to very high radon potential ranking of 60 Lake Tahoe area geologic units (all units or portions of units within California). Table 7a summarizes data support for geologic units ranked as having very high radon potential or high radon potential. Table 7b summarizes data support for geologic units ranked as having “moderate radon potential.” Appendix J-2 lists 81 Lake Tahoe area geologic units within California with uncertain radon potential because of insufficient data to allow ranking.

Figure 5 shows the Lake Tahoe radon zone locations, and Figure 6 shows the Lake Tahoe radon zones in relationship to anomalous ≥ 4 pCi/L indoor measurements and NURE data. Tables 8a and 8b contain information about the radon data characteristics for each radon zone. Tables 9a and 9b provide information about the incidence rates of ≥ 4 pCi/L indoor measurements and the density of indoor-radon survey measurements per radon zone.

Some possible geologic models for Lake Tahoe areas with higher radon potential are provided in Appendix K. The models are based on relationships observed between geologic units, indoor-radon survey data, uranium data from the NURE project and other sources, soil permeability data, and previous research related to radon and uranium in the Lake Tahoe area by the Nevada Bureau of Mines (Rigby, 1994) and Geology the U.S. Geological Survey (Otton and others, 1985). Validation of the models would require detailed research projects beyond the scope of the Lake Tahoe radon potential mapping project. Other models than those listed in Appendix K are possible and may be developed in the future as additional data or new insights about factors related to indoor-radon in the Lake Tahoe area become available.

Geologic Unit (abbreviated unit names)	CDPH Indoor Radon Survey Data	NURE Airborne eU Data (% GE 5 ppm eU)	NURE Sediment and Soil Data for U; Other U data	Assigned Radon Potential
Kbla-Burnside Lake adamellite	nd	XXX	-	Very High?
Kbmg-Bryan Meadow granodiorite	XXX	X	++	Very High
Kppg-Phipps Pass granodiorite	nd	XXX	nd	Very High?
Krpa?-Alaskite at Rubicon Point	nd	XXX	+	Very High?
Pvp-Polaris olivine latite	X	nd	---	Very High?
Qfp and Qfp?-Flood-plain deposits	X	X	X	Very High?
Qlt and Qlt?-Lacustrine terrace deposits	XXX	X	nd	Very High
Qog-Older glacial deposits--pre Tahoe deposits--Till	XXX	X	nd	Very High
Qogo-Older glacial deposits-pre Tahoe deposits--Outwash	XXX	XXX	nd	Very High
QPvd4-Dry Lake volcanic flows of Birkeland (1961); Wise and Sylvester (2004) youngest flow	XXX	---	nd	Very High
Jtls-Tuttle Lake Formation	nd	X	nd	High?
Kcfg-Camper Flat granodiorite	nd	X	nd	High?
Kdvg-Desolation Valley granodiorite	nd	X	nd	High?
Keg-Granodiorite of East Peak	XXX	X	X	High?
Kelg-Echo Lake granodiorite	X	X	nd	High?
Kfpg-Freel Peak granodiorite	nd	X	nd	High?
Mvs?-Unnamed volcanic and intrusive rocks-Miocene-fluvial	nd	X	---	High?
Pvah-Alder Hill basalt	XXX	nd	nd	High
Qgt-Tahoe and Tioga glacial deposits, undivided-Till	nd	X	X	High?
Qta-Tahoe glacial deposits--Till	XXX	X	X	High
Qvbm-Bald Mountain olivine latite	XXX	-	?	High?

Table 7a. Lake Tahoe Very High and High Radon Potential Geologic Units Supporting Data

nd = no data
XXX = data strongly support classification
X = data support classification
"-" = data unsupportive of classification
"---" = data strongly unsupportive of classification
? = less certain or uncertain

Geologic Unit (abbreviated unit names)	CDPH Indoor Radon Survey Data	NURE Airborne eU Data (% GE 5 ppm eU)	NURE Sediment and Soil Data for U; Other U data	Assigned Radon Potential
Kclg and Kclg?-Granodiorite of Caples Lake	nd	X	X	Moderate?
Kkqm-Keiths Dome quartz monzonite	nd	X	nd	Moderate?
Kllg-Lovers Leap granodiorite	nd	X	X	Moderate?
Kvrg?-Rockbound Valley granodiorite	nd	X	nd	Moderate?
Mva-Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments	X	X	?	Moderate?
Qg-Glacial deposits undivided-Till	nd	X	X	Moderate?
Ql-Lake deposits (Holocene)	X	X	nd	Moderate?
Qpc- Qpc-Prosser Creek alluvium	X	-	nd	Moderate?
QPvd2-Dry Lake volcanic flows	X	-	-	Moderate?
Qti-Tioga glacial deposits-Till	X	X	X	Moderate
Qvh-Hirschdale olivine latite	X	?	nd	Moderate?

Table 7b. Lake Tahoe Moderate Radon Potential Geologic Units Supporting Data

nd = no data
X = data support classification
"-" = data unsupportive of classification
? = less certain or uncertain

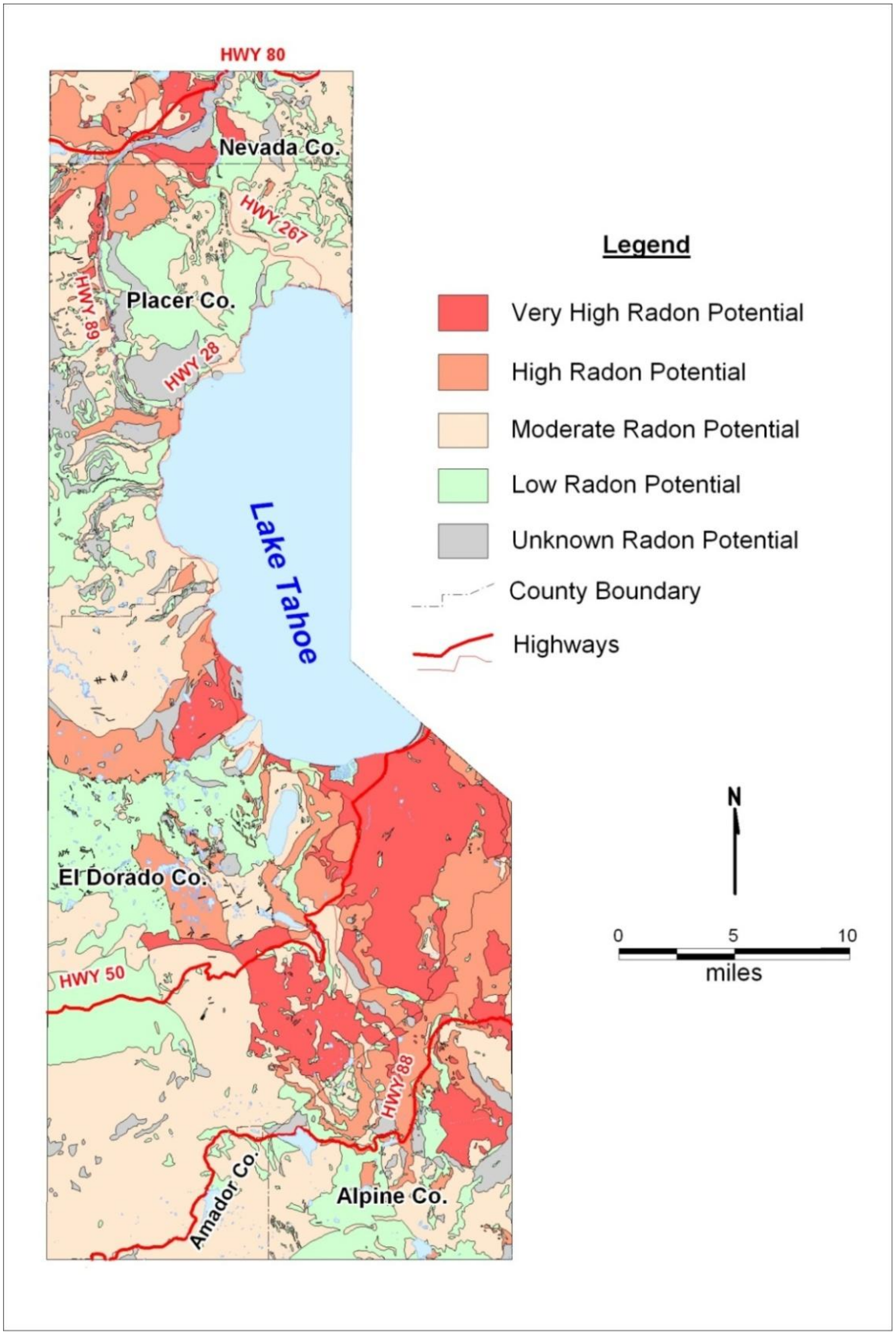

FIGURE 5. Lake Tahoe Area Radon Potential Zones

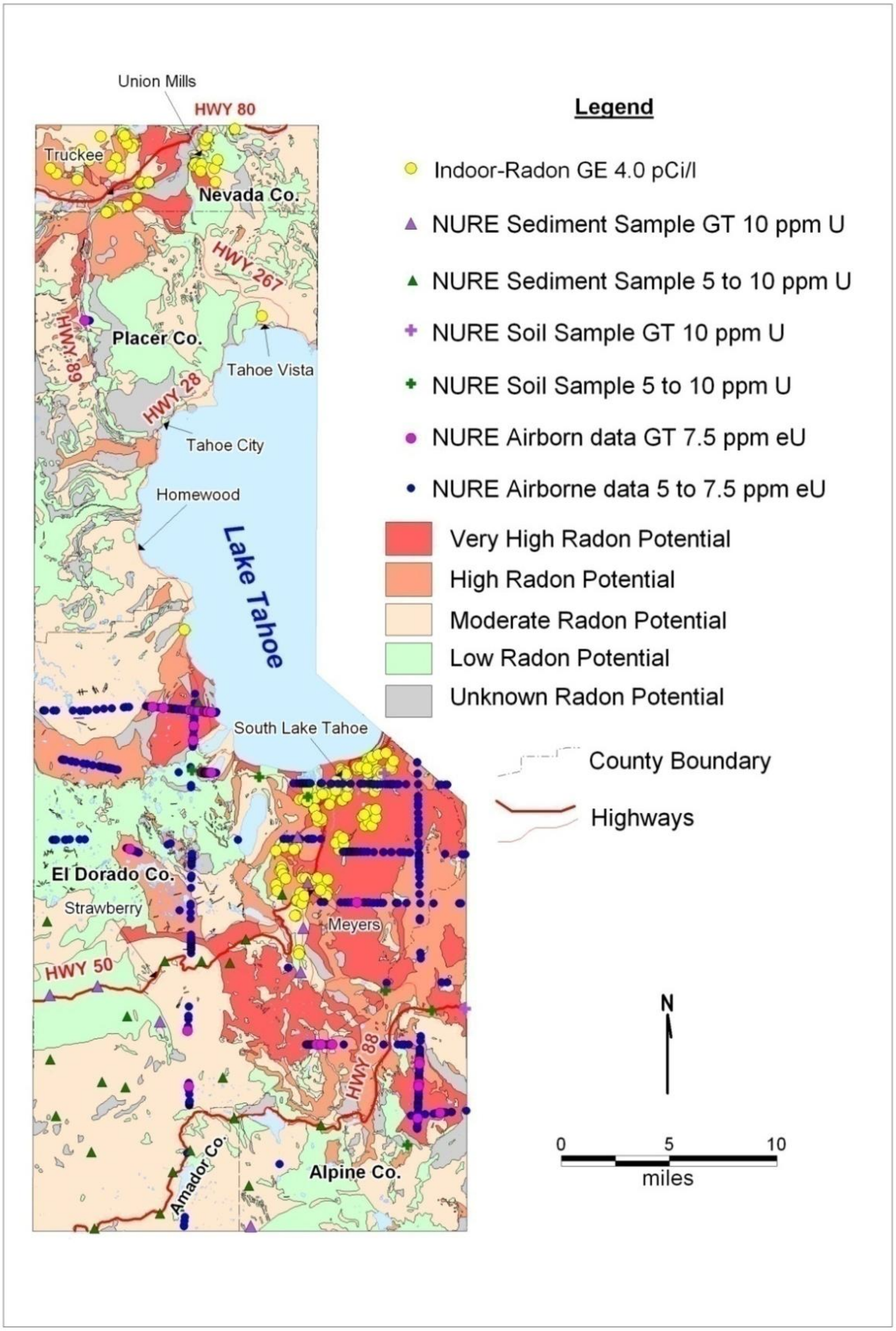

FIGURE 6. Lake Tahoe Area Radon Zones and Supporting Elevated Indoor-Radon Survey Data and NURE Project Data

Note: GE = Greater than or equal to; GT = Greater than

Zone	n	Median pCi/L	pCi/L at 25%	pCi/L at 75%	Min pCi/L	Max pCi/L
Very High	188	5.6	3.1	9.2	0.2	86.1
High	120	3.1	1.8	5.4	0.2	38.8
Moderate	91	2.2	1.4	3.2	0.2	12.8
Low	37	1.3	0.8	2.0	0.2	4.0
Unknown	7	3.2	0.5	4.3	0.2	4.9
All	443	5.1	1.7	6.2	0.2	86.1

Table 8a. Radon Zone Data Characteristics

Zone	n	n ≥ 4.0 pCi/L data	% data ≥ 4.0 pCi/L	n ≥ 10.0 pCi/L data	% data ≥ 10.0 pCi/L	n ≥ 20.0 pCi/L	% data ≥ 20.0 pCi/L	Area (sq-mi) (land only)
Very High	188	117	62.2	40	21.3	7	3.7	101.8
High	120	44	36.7	9	7.5	2	1.7	99.8
Moderate	91	15	16.5	3	3.3	0	0.0	280.4
Low	37	1	2.7	0	0.0	0	0.0	164.4
Unknown	7	2	28.6	0	0.0	0	0.0	53.5
All	443	179	40.4	52	11.7	9	2.0	699.9

Table 8b. ≥ 4.0 pCi/L Incidence per Radon Potential Zone

Zone	% of all ≥ 4.0 pCi/L measurements	% of all ≥ 10.0 pCi/L measurements	% of all ≥ 20.0 pCi/L measurements	% Area	Cumulative % of ≥ 4.0 pCi/L measurements	Cumulative % of Lake Tahoe Study Area
Very High	65.4	76.9	77.8	14.5	65.4	14.5
High	24.6	17.3	22.2	14.3	90.0	28.8
Moderate	8.4	5.8	0.0	40.1	98.4	68.9
Low	0.6	0.0	0.0	23.5	99.0	92.4
Unknown	1.1	0.0	0.0	7.6	100.1*	100.0
All	100.1*	100.0	100.0	100.0		

Table 9a. ≥ 4.0 pCi/L Incidence Rates for the Lake Tahoe Area by Radon Potential Zone

*Does not sum to 100.0% due to round-off error

Zone	Average Rate: n ≥ 4.0 pCi/L measurements per square mile	Average Rate: All measurements per square mile
Very High	1.1493	1.8468
High	0.4409	1.2024
Moderate	0.0535	0.3245
Low	0.0061	0.2251
Unknown	0.0374	0.1308
All	0.2554	0.6320

Table 9b. Radon Data Distribution by Radon Potential Zone

The Lake Tahoe Area Radon Potential Map and South Lake Tahoe Schools

School facilities in South Lake Tahoe are located within high or very high radon potential areas of the Lake Tahoe radon potential map. Radon testing by the Lake Tahoe Unified School District (LTUSD) in 2007 (see LTUSD, 2008) identified three facilities where 48 percent or more of the rooms tested ≥ 4 pCi/L. This observed ≥ 4 pCi/L rate is consistent with their location within high, or very high, radon potential zones. Based on percentages of ≥ 4 pCi/L rooms, two other school sites would fit a moderate radon potential classification, and four other school sites would appear to fit a low radon potential classification.

These results suggest the high and very high radon potential classifications of these sites, based on the Lake Tahoe radon potential map, are justified for three LTUSD sites and perhaps not justified for six LTUSD sites. However, the Lake Tahoe radon potential map is based on indoor-measurement data from homes, not schools or other large buildings. Larger buildings, such as schools, may have some differences from homes in their susceptibility to indoor-radon problems for a given geologic setting. Consequently, it is not surprising that the incidence rates of ≥ 4 pCi/L tests for large buildings such as schools in the Lake Tahoe radon potential zones may be somewhat different than for homes.

For both homes and larger buildings, building related factors such as design, condition, and preferences of the inhabitants for heating and ventilation may override geologic factors related to elevated indoor-radon levels. These factors may result either in cases of relatively low indoor-radon levels in buildings located in high radon potential geologic settings or, conversely, in relatively high indoor-radon levels in buildings located in a low radon potential geologic setting. This is why the only way to be certain of the indoor-radon level in a building, small or large, is to test.

RADON POTENTIAL ZONE STATISTICS

Indoor-Radon Measurement Data Characteristics

Descriptive statistics of indoor-radon survey data for each radon potential zone, non-transformed and log-transformed, are provided in Appendix L and Appendix M.

Indoor-Radon Measurement Frequency Distributions

Frequency distributions of trace elements, such as uranium and radon, in rocks and soils are often approximated using the lognormal distribution. However, because of the variety of geologic units and complex history of processes affecting them, geochemical data such as radon data cannot always be fit to a specific frequency distribution (Rose and others, 1979, p. 33). The indoor radon data for the Lake Tahoe area are an example of this situation. Taken as a whole, the indoor radon test data from the CDPH Lake Tahoe survey fail the Kolmogorov-Smirnov normality test in both untransformed and log-transformed modes (Appendix N). Consequently, the data population (of 443 measurements) is neither normally nor lognormally distributed. These data may be non-normally distributed because they are a combination of samples from several different populations—each rock unit radon population having its own unique distribution. On an individual basis, the rock unit radon populations may be lognormal, but an aggregate population is not lognormal.

Data non-normality has important implications for certain statistical operations. For example, T-test comparisons should not be used for comparing non-normal (non-parametric) populations. For this reason, the Mann-Whitney rank sum test is used for comparisons of sub-populations of the indoor-radon test data by radon zone in this study. The Mann-Whitney comparison results for the radon potential zones are discussed in the following section. Non-normality may also have negative consequences for predictions of percentages of homes with indoor radon levels exceeding 4.0 pCi/L, if the predictions are based on a lognormal population distribution for the radon data.

Statistical Comparison of Indoor Radon Data by Radon Potential Zone

The results of the statistical comparisons of indoor-radon data for the Lake Tahoe area radon potential zones are listed in Appendix O-1, Appendix O-2 and Appendix O-3. The indoor-radon data population for each radon potential zone is statistically distinct according to the Mann-Whitney rank sum test. This result, along with the medians for each radon zone population decreasing in rank order (very high > high > moderate > low) is statistical evidence supporting the validity of the Lake Tahoe radon potential zone definitions.

Estimated Population Exposed to 4.0 pCi/L Radon or Greater Indoor Air in the Lake Tahoe Area.

Population estimates for each radon potential zone were obtained utilizing GIS methods to overlay the Lake Tahoe area radon potential zones with 2000 census block data (U.S. Census, 2008). For a census block not completely within a radon potential zone, the population contribution from that tract was considered equal to the percentage area of the block within the radon zone. Table 10 lists the resulting population estimates and estimated number of homes for the different radon potential zones. Tables 11a, b, and c contain population estimates for each radon potential zone and estimates for individuals exposed to ≥ 4 pCi/L, ≥ 10 pCi/L and ≥ 20 pCi/L indoor radon concentrations. These estimates are based on the population estimates for each zone multiplied by the ≥4.0 pCi/L, ≥ 10 pCi/L and ≥ 20 pCi/L county percentages for each zone using the CDPH-Radon Program Lake Tahoe radon survey data. Note that while the very high zone for the overall Lake Tahoe area has 62.2 percent ≥4.0 pCi/L houses, the finalized very high zone has 65.4 percent ≥4.0 pCi/L houses in El Dorado County and 48.5 percent ≥4.0 pCi/L houses in Nevada County. The reason the final very high zone in Nevada County is below 50 percent is that portions of the very high potential units Qog and Qogo are less than 50 percent in Nevada County, lowering the overall very high potential zone percentage of to slightly less than 50 percent there.

Because of the few CDPH-Radon Program survey data, radon exposure estimates for Placer County were made using the radon potential zone ≥ 4 percentages for Nevada County. The Lake Tahoe area portions of Placer and Nevada counties are geologically similar in having more volcanic units and fewer granitic units at the surface than the Lake Tahoe portion of El Dorado County.

Tables 11 a, b, and c contain two groups of population totals. Totals in the row titled “Population Estimates weighted by ...” in Tables 11a, b and c is obtained by summing these data for the individual radon zones. Totals in the row titled “Population Estimates by proportion...” are obtained by taking the percentages of ≥4.0 pCi/L, ≥ 10 pCi/L and ≥ 20 pCi/L measurements obtained from the CDPH indoor-radon survey and multiplying them by the total population. A second estimate for ≥4.0 pCi/L was made using the CDPH-Radon Program Zip Code data for Lake Tahoe Zip Codes. There is good agreement between the different estimates. The estimates in the “Population Estimates weighted by...” group are probably the better estimates because they take into consideration the number of people residing in each radon potential zone. Estimates in the “Population Estimates by proportion...” group are independent of which radon potential zone individuals inhabit.

Radon Potential Zone	**Estimated Total Population within Zone--2000 Census Statistics**	**Estimated Total Homes within Zone--2000 Census Statistics**	
El Dorado County*		**Average Household Population***	**Homes****
Very High	25,610	2.487	10,298
High	4,708	2.447	1,924
Moderate	1,843	2.350	784
Low	1,646	2.443	674
Unknown	106	1.915	55
Total for El Dorado County	33,913	(2.46)***	13,735
Nevada County*		**Average Household Population***	**Homes****
Very High	2,686	2.786	964
High	3,120	2.475	1,260
Moderate	3,970	2.737	1,450
Low	1,653	2.807	589
Unknown	1,365	2.800	488
Total for Nevada County	12,794	(2.69)***	4,751
Placer County*		**Average Household Population***	**Homes****
Very High	15	2.190	7
High	1,338	2.401	557
Moderate	8,513	2.362	3,604
Low	3,030	2.269	1,335
Unknown	1,759	2.292	767
Total for Placer County	14,665	(2.34)***	6,270
Totals for Lake Tahoe Study Area		**Homes**	
Very High	28,311	11,269	
High	9,166	3,741	
Moderate	14,326	5,838	
Low	6,329	2,598	
Unknown	3,230	1,310	
Total within Lake Tahoe Area	61,362	24,756	

Table 10. Population and Home Estimates by Radon Potential Zone and County within the Lake Tahoe Area

*Estimated Using 2000 Census Block Data and the Lake Tahoe Area Radon Potential Zone Map;
**Est. Population ÷ Avg. Household Pop
***Est. Population ÷ Homes

Radon Potential Zone	Estimated Total Population for Zone	Estimated Population at ≥ 4.0 pCi/l Conditions	Estimated Population at ≥ 10.0 pCi/l Conditions	Estimated Population at ≥ 20.0 pCi/l Conditions	Percent Area/Square Miles
Very High	25,610	16,749 65.4%* ≥ 4.0 pCi/l	5,532 21.6%* ≥ 10.0 pCi/l	666 2.6%* ≥ 20.0 pCi/l	21.3% 76.4 sq. mi
High	4,708	1,944 41.3%* ≥ 4.0 pCi/l	306 6.5%* ≥ 10.0 pCi/l	? no Rn data	14.4% 51.5 sq. mi.
Moderate	1,843	369 20.0%* ≥ 4.0 pCi/l	? no Rn data	? no Rn data	39.8% 142.5 sq. mi.
Low	1,646	81 no Rn data, used 4.9% ≥ 4.0 pCi/l	? no Rn data	? no Rn data	20.8% 74.4 sq. mi.
Unknown	106	? no Rn data	? no Rn data	? no Rn data	3.8% 13.5 sq. mi.
Population Estimates Weighted by Radon Zone and Population Distribution					
Totals (*weighted, i.e., sum of zone population estimates*)	33,913	19,143	5,838	666	100.1%*** 358.3 sq. mi.
Population Estimates by Proportion to Radon Survey Results Without Regard to Radon Zone or Population Distribution					
All El Dorado County within the Lake Tahoe Study Area	33,913	18,279* 18,822**	5,392*	678*	

Table 11a. Estimates of El Dorado County Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data)

*estimated using CDPH Indoor-Radon Survey Results for El Dorado County Zones; ** estimated using CDPH Zip Code database data for South Lake Tahoe Zip Codes; ***Does not sum to 100.0% due to round-off error

Radon Potential Zone	Estimated Total Population for Zone	Estimated Population at ≥ 4.0 pCi/l Conditions	Estimated Population at ≥ 10.0 pCi/l Conditions	Estimated Population at ≥ 20.0 pCi/l Conditions	Percent Area/Square Miles
Very High	2,686	1,303 48.5%* ≥ 4.0 pCi/l	537 20.0%* ≥ 10.0 pCi/l	231 8.6%* ≥ 20.0 pCi/l	15.1% 7.9 sq. mi.
High	3,120	780 25.0%* ≥ 4.0 pCi/l	215 6.5%* ≥ 10.0 pCi/l	? no Rn data	15.5% 8.1 sq. mi.
Moderate	3,970	504 12.7%* ≥ 4.0 pCi/l	71 1.8%* ≥ 10.0 pCi/l	? no Rn data	40.3% 21.1 sq. mi.
Low	1,653	81 few Rn data, used 4.9%	? no Rn data	? no Rn data	17.4% 9.1 sq. mi.
Unknown	1,365	? no Rn data	? no Rn data	? no Rn data	11.8 % 6.2 sq. mi.
Population Estimates Weighted by Radon Zone and Population Distribution					
Totals (*weighted, i.e., sum of zone population estimates*)	12,794	2,668	823	231	100.1%*** 52.4 sq. mi.
Population Estimates by Proportion to Radon Survey Results Without Regard to Radon Zone or Population Distribution					
All Nevada County within the Lake Tahoe Study Area	12,794	3,109 (3,621)**	883	269	

Table 11b. Estimates of Nevada County Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data)

* estimated using CDPH Indoor-Radon Survey Results for Nevada County zones; ** estimated using CDPH Zip Code database data for South Lake Tahoe Zip Codes; ***Does not sum to 100.0% due to round-off error

Radon Potential Zone	Estimated Total Population for Zone	Estimated Population at ≥ 4.0 pCi/l Conditions	Estimated Population at ≥ 10.0 pCi/l Conditions	Estimated Population at ≥ 20.0 pCi/l Conditions	Percent Area/Square Miles
Very High	15	8 no Rn data, used 48.5%*	? no Rn data	? No Rn data	1.7% 2.6 sq. mi.
High	1,338	335 few Rn data, used 25.0%*	? no Rn data	? no Rn data	8.0% 12.8 sq. mi.
Moderate	8,513	1081 few Rn data, used 12.7%*	? no Rn data	? no Rn data	41.7% 66.9 sq. mi.
Low	3,030	148 few Rn data, used 4.9%	? no Rn data	? no Rn data	33.4% 53.7 sq. mi.
Unknown	1,759	? no Rn data	? no Rn data	? no Rn data	15.3% 24.6 sq. mi.
Population Estimates Weighted by Radon Zone and Population Distribution					
Totals (*weighted by zone and population distribution*)	14,665	1,572 few Rn data	? no Rn data	? no Rn data	100.1% 160.6 sq. mi.
Population Estimates by Radon Level Without Regard to Radon Zone or Population Distribution					
All Placer County within the Lake Tahoe Study Area	14,665	1,467 3,124**	? no Rn data	? no Rn data	

Table 11c. Estimates of Placer County Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data)

* insufficient Placer County data, estimated using CDPH Indoor-Radon Survey Results for Nevada County; ** estimated using CDPH Zip Code database data for South Lake Tahoe Zip Codes; ***Does not sum to 100.0% due to round-off error

Table 11d shows population estimates for indoor-radon exposures for the overall Lake Tahoe radon map area. These estimates are totals of the individual county estimates.

Radon Potential Zone	**Estimated Total Population for Lake Tahoe Study Area**	**Estimated Population at ≥ 4.0 pCi/l**	**Estimated Population at ≥ 10.0 pCi/l**	**Estimated Population at ≥ 20.0 pCi/l**
All of the Lake Tahoe Study Area (Rn Zone weighted and CDPH Zip Code Database proportional totals)	**61,362**	**23,383** weighted radon survey total **25,567** Zip Code database total	**6,069** weighted radon survey total **6,275** Zip Code database total	**897** weighted radon survey total 947 Zip Code database total

Table 11d. Estimates of the Total Lake Tahoe Study Area Population Exposed to 4.0 pCi/l or Greater Indoor Radon Levels in Residences (based on 2000 U.S. Census Data; *excludes population in portions of Alpine and Amador counties within the Lake Tahoe map coverage area*)

LAKE TAHOE RADON MAPPING PROJECT SUMMARY AND RECOMMENDATIONS

Procedures and Results

Short-term indoor radon test data from CDPH, NURE project airborne radiometric data, NURE soil and stream sediment data, and other whole rock uranium data, were used to identify geologic units with relatively higher or lower radon potential in the Lake Tahoe area. Geologic units were classified as having very high, high, moderate, low or unknown radon potential based on the percentage of 4.0 pCi/L or higher indoor-radon measurements, the presence of airborne radiometric uranium anomalies, and the presence of soil, stream sediment or whole rock uranium data exceeding 5.0 ppm.

The final radon potential zones have the following characteristics:

Very High Radon Potential Zone: this zone comprises 14.5 percent (101.8 square miles) of the Lake Tahoe study area and contains 65.4 percent of ≥4.0 pCi/L short-term radon measurements in the CDPH database.

High Radon Potential Zone: this zone comprises 14.2 percent (99.8 square miles) of the Lake Tahoe study area and contains 24.6 percent of ≥4.0 pCi/L short-term radon data in the CDPH database.

Moderate Radon Potential Zone: this zone comprises 40.1 percent (280.4 square miles) of the Lake Tahoe study area and contains 8.4 percent of ≥4.0 pCi/L short-term radon data in the CDPH database.

Low Radon Potential Zone: this zone comprises 23.5 percent (164.4 square miles) of Lake Tahoe study area and contains 0.6 percent of ≥4.0 pCi/L short-term radon data in the CDPH database.

Unknown Radon Potential Zone: this zone comprises 7.6 percent (53.5 square miles) of Lake Tahoe study area and contains 1.1 percent of ≥4.0 pCi/L short-term radon data in the CDPH database.

Every radon zone contains short-term indoor-radon measurements equal to or above 4.0 pCi/L as well as below 4.0 pCi/L. The maximum measurement for each zone is: Very High, 86.1 pCi/L; High, 38.8 pCi/L; Moderate, 12.8 pCi/L; Low, 4.0pCi/L and Unknown, 4.9 pCi/L.

Statistical comparison of the indoor radon data populations for the radon potential zones, using the Mann-Whitney rank sum test, shows the zones differ from each other statistically. Note the P values for these tests (the probability of being wrong in concluding that there is a true difference in the two groups) listed in Appendices O-1, O-2 and O-3 are less than 0.001. This is strong statistical support for the different Lake Tahoe radon potential zones represent distinct populations of indoor-radon measurements.

Recommendations for Future Radon Testing and Studies

Indoor-radon testing should be encouraged in Lake Tahoe area homes, as very high, high and moderate radon potential zones account for almost 69 percent of the Lake Tahoe area. Additional indoor-radon measurements in Placer County would improve map accuracy there.

Those considering new home construction may wish to consider radon resistant new construction practices. Post construction radon mitigation is still possible, if necessary, but will be more expensive than the cost of adding radon reducing features during house construction.

Future detailed studies involving radon soil gas measurements and/or surface gamma-ray spectral surveys may improve the radon potential map in areas without homes or with few or no indoor-measurements. New radon high potential and new low radon potential areas may be discovered using these methods.

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APPENDIX A

Concurrent Indoor-Radon Test Data--In decreasing order by pCi/L.

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent* Difference
33.5	29.8	3.7	11.0
26	24.7	1.3	5.0
20.0	14.7	5.3	26.5
17.9	16.2	1.7	9.5
15.0	13.7	1.3	8.7
12.6	9.5	3.1	24.6
12.2	11.7	0.5	4.1
11.5	10.3	1.2	10.4
9.1	8.8	0.3	3.3
8.6	4.4	4.2	48.8
8.0	6.2	1.8	22.5
7.4	6.1	1.3	17.6
7	5.7	1.3	18.6
6.7	6.3	0.4	6.0
6.6	5.3	1.3	19.7
6.1	5.7	0.4	6.6
5.4	5.1	0.4	7.4
5.4	5.0	0.4	7.4
5.3	4.7	0.5	9.4
5.3	2.9	2.4	45.3
4.6	3.9	0.7	15.2
3.7	2	1.7	46.0
3.5	3.2	0.3	8.6
3.4	3.3	0.1	2.9
3.1	3.0	0.1	3.2
3.0	2.7	0.3	10.0
2.8	2.4	0.4	14.3
2.7	2.5	0.2	7.1
2.2	2.0	0.2	9.1
2.1	1.7	0.4	19.1
2.0	0.5	1.5	75.0
1.9	1.8	0.1	5.3
1.6	1.1	0.5	31.3
1.4	0.2	1.2	85.7
1.1	0.7	0.4	36.4
1.0	0.5	0.5	50.0
0.9	0.3	0.6	66.7
0.7	0.5	0.2	28.6
0.7	0.2	0.5	71.4

APPENDIX B

Charcoal Detector Field Blanks

Date Analyzed	Results pCi/L
12/27/2006	<0.5
12/22/2006	0.2
12/27/2006	<0.5
12/22/2006	<0.5
12/22/2006	<0.5
12/27/2006	<0.5
--	error
12/27/2006	<0.5
12/27/2006	0.7
12/27/2006	<0.5

APPENDIX C

Laboratory Spikes of Charcoal Detectors

Charcoal detectors were exposed for 2-days (ending 11/29/2006) at 21.9 degrees C and 45.3 percent mean relative humidity						
Date	**Mean Chamber Radon Conc. pCi/L***	**Test Result pCi/L**	**Difference from Mean Chamber Conc. pCi/L**	**Minimum Chamber Conc. pCi/L**	**Maximum Chamber Conc. pCi/L**	**Test result within 10% of the Maximum and Minimum Radon Concentrations for the Chamber?**
12/5/06	6.0	6.4	0.4	5.4	6.5	Yes
12/5/06	6.0	7.0	1.0	5.4	6.5	Yes
12/5/06	6.0	6.5	0.5	5.4	6.5	Yes
12/5/06	6.0	4.3	1.7	5.4	6.5	No
12/5/06	6.0	5.3	0.7	5.4	6.5	Yes
12/5/06	6.0	6.6	0.6	5.4	6.5	Yes
12/5/06	6.0	6.4	0.4	5.4	6.5	Yes
12/5/06	6.0	5.7	0.3	5.4	6.5	Yes

* Minimum chamber concentration 5.4 pCi/L; Maximum chamber concentration 6.5 pCi/l

APPENDIX D

Results of Follow-up Tests in Homes

Test 1 (pCi/L)	Test 2 (pCi/L)	Difference (pCi/L)	%* Difference	Days Between Tests	Dates Test 1	Dates Test 2
23.0	36.9	13.9	+37.7	47	12/24/06-12/26/06	02/08/07-02/011/07
23.2	13.1	10.1	-43.5	46	01/16/07-01/18/07	03/03/07-03/05/07
16.6	14.7	1.9	-11.5	28	02/10/07-02/12/07	03/10/07-03/12/07
14.0	13.1	0.9	-6.4	17	01/03/07-01/05/07	01/20/07-01/22/07
13.0	9.4	3.6	-27.7	79	12/21/06-12/23/06	03/10/07-03/12/07
12.7	4.6	8.1	-63.8	23	02/08/07-02/10/07	03/03/07-03/05/07
12.2	10.5	1.7	-13.9	35	01/17/07-01-19/07	02/21/07-02/23/07
8.3	7.1	1.2	-14.5	37	01/22/07-01/24/07	02/28/07-03/02/07
5.0	6.2	1.2	+20.0	29	01/03/07-01/05/07	02/01/07-02/03/07
3.9	6.1	2.2	+36.1	41	12/27/06-12/29/06	02/06/07-02/08/07
4.5	5.7	1.2	+21.1	39	01/31/07-02/2/07	03/10/07-03/12/07
5.6	1.4	4.2	-75.0	58	12/28/06-12/30/06	02/24/07-02/26/07
3.0	0.6	2.4	-80.0	15	02/05/07-02/07/07	02/20/07-02/22/07

APPENDIX E

Geologic Map Units and Indoor Radon Data for the Lake Tahoe Area(*Asterisks are defined at the end of the table*.)

Geo Unit Description [unit symbol] (Age)	**N**	**N ≥4 pCi/L**	**R (%)****	**Low pCi/L**	**High pCi/L**	**Cities**	**Zip Codes**
Artificial fill [af]	12	0		0.2	1.9	South Lake Tahoe; Carnelian Bay	96140*, 96150, 96152, 96158*
Byran Meadow granodiorite [Kbmg] (Cretaceous)	30	21	70.0	0.7	86.1	South Lake Tahoe	96150, 96155*, 96158*
Echo Lake granodiorite [Kelg] (Cretaceous)	1	1			15.0	South Lake Tahoe	96150
Undivided andesitic and dacitic lahars, flows, breccia and volcaniclastic sediments [Mva] (Miocene)	17	3	17.6	0.9	4.6	Truckee	96160*, 96161, 96162*
Andesite and dacite flows [Mvaf] (Miocene)	1	0			3.7	Tahoe Vista	96148*
Alder Hill basalt of Birkeland (1961) [Pvah] (Pliocene)	48	12	25.0	0.5	38.8	Truckee	96160*, 96161, 96162*
Polaris olivine latite of Birkeland (1961) [Pvp] (Pliocene)	3	2		3.5	24.8	Truckee	96160*, 96161
Alluvium [Q] (Holocene and Pleistocene)	3	0		1	3.2	Truckee	96161

Geo Unit Description [unit symbol] (Age)	**N**	**N ≥4 pCi/L**	**R (%)****	**Low pCi/L**	**High pCi/L**	**Cities**	**Zip Codes**
Flood-plain deposits [Qfp] (Holocene)	2	1		1.1	11.6	South Lake Tahoe	96150
Flood-plain deposits? [Qfp?] (Holocene)?	4	2		1.5	6.1	South Lake Tahoe	96150, 96156*, 96158*
Juniper Flat alluvium of Birkeland (1961) [Qjf] (Pleistocene)	21	1	4.8	0.2	4.0	Truckee	96160*, 96161, 96162*
Lake deposits [Ql] (Holocene)	7	1		0.2	5.3	Tahoe Vista	96140*, 96141, 96142, 96148*, 96160*
Lacustrine terrace deposits [Qlt] (Pleistocene)	64	43	67.2	0.2	55.5	South Lake Tahoe, Olympic Valley	96150, 96151*, 96156*
Lacustrine terrace deposits? [Qlt?] (Pleistocene)	27	16	59.3	0.8	16.6	Homewood, South Lake Tahoe, Kings Beach	96150, 96152, 96156*, 92158*
Older beach deposits [Qob] (Pleistocene)	2	0		0.2	1.0	South Lake Tahoe	96150
Older glacial deposits-pre-Tahoe deposits--Till [Qog] (Pleistocene)	24	14	58.3	0.2	14.3	South Lake Tahoe, Truckee	96150, 96151*, 96158*, 96161 96162*
Older glacial deposits-pre-Tahoe deposits—Outwash deposits [Qogo] (Pleistocene)	17	9	52.9	1.8	36.9	South Lake Tahoe, Truckee	96150, 96161, 96162
Prosser Creek alluvium of Birkeland (1961) [Qpc] (Pleistocene)	6	1		0.5	6	Truckee	96160*, 96161

Geo Unit Description [unit symbol] (Age)	**N**	**N ≥4 pCi/L**	**R (%)****	**Low pCi/L**	**High pCi/L**	**Cities**	**Zip Codes**
Unnamed Volcanic Rocks-- Basalt flows, flow breccia and basaltic ash [QPvb] (Pliocene and/or Pleistocene)	1	0			3.2	Truckee	96161
Dry Lake volcanic flows of Birkeland (1961)l; Wise and Sylvester (2004)--second oldest flow [QPvd2] Pliocene and/or Pleistocene	12	2		0.2	12.3	Truckee	96160*, 96161, 96162*
Dry Lake volcanic flows of Birkeland (1961)l; Wise and Sylvester (2004)--youngest flow [Qpvd4] Pliocene and (or) Pleistocene	17	9	52.9	0.2	33.5	Truckee	96160*, 96161, 96162*
Tahoe glacial deposits--Till [Qta] (Pleistocene)	58	26	44.8	0.2	20.6	South Lake Tahoe, Truckee	96142, 96150, 96158*, 96160*, 96161
Tahoe glacial deposits— Outwash deposits [Qtao] (Pleistocene)	1	1			4.5	Truckee	96161
Tioga glacial deposits--Till [Qti] (Pleistocene)	33	6	18.2	0.7	12.8	South Lake Tahoe, Truckee	96150, 96155*, 96158*, 96161, 96162*

Geo Unit Description [unit symbol] (Age)	**N**	**N ≥4 pCi/L**	**R (%)****	**Low pCi/L**	**High pCi/L**	**Cities**	**Zip Codes**
Tioga glacial deposits--Outwash deposits [Qtio] (Pleistocene)	2	0		0.3	3.7	Truckee	96161, 96162*
Bald Mountain olivine latite of Birkeland (1961) [Qvbm] (Pleistocene)	13	5	38.5	0.2	10.2	Truckee	96160*, 96161, 96162*
Hirschdale olivine latite of Birkeland (1961) [Qvh] (Pleistocene)	16	2	12.5	0.2	7.4	Truckee	96160*, 96161
Hirschdale olivine latite of Birkeland (1961)--Cinder cone deposits [Qvhcc] (Pleistocene)	1	1			4.9	Truckee	96161
Totals	***443***	***179***	***40.5***	***0.02***	***86.1***		

*P.O. Box Zip Code Only

**Percentages only shown for geologic units with 15 or more radon tests

APPENDIX F

NURE Airborne Radiometric Survey Equivalent Uranium (eU) Data for the Lake Tahoe Area by Geologic Unit

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
af	Artificial fill (late Holocene)	35	8	22.9	0.8	6.6	3.7
Ja	Anorthosite (Late? and Middle Jurassic) [*undifferentiated noritic anorthosite through hypersthene diorite intrusive suite*]	84	0	0	0.5	3.6	1.6
Jaqd	Quartz diorite at Azure Lake (Late? and Middle Jurassic)	13	1	7.7	1.3	5.0	2.9
Jdg	Diorite and gabbro (Late? and Middle Jurassic)	114	1	0.9	0.5	5.0	2.4
Jdi	Diorite (Jurassic?)	5	0	0	0.0	1.0	0.8
Jlb	Lake Tahoe Sequence of Harwood (1992)--Blackwood Creek Formation (Jurassic) [*slate, hornfels, limestone, sandstone*]	18	0	0	0.0	2.1	1.1
Jle	Lake Tahoe Sequence of Harwood (1992)--Blackwood Creek Formation (Jurassic)--Ellis Peak Formation (Jurassic) [*quartz arenite and quartzose metasiltstone*]	18	0	0	0.2	2.8	1.1
Jlp	Lake Tahoe Sequence of Harwood (1992)--Blackwood Creek Formation (Jurassic)--Pelite unit (Jurassic?) [slate and hornfels]	8	0	0	1.1	4.1	3.3
Jmib	Mafic intrusive breccia (Late? and Middle Jurassic)	17	0	0	1.5	4.7	2.6
Jpgr	Pyramid Peak granite (Jurassic)	77	1	1.3	0.8	6.2	2.2
Jsc	Tuttle Lake Formation of Harwood (1992) (Late? and Middle Jurassic)--Saylor Canyon Formation (Middle and Early Jurassic [*sandstone and siltstone*]	44	0	0	0.8	3.6	2.3

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Jtlb	Tuttle Lake Formation of Harwood (1992) (Late? and Middle Jurassic)--Volcanic breccia [*mafic to intermediate composition*]	49	0	0	0.8	3.8	2.4
Jtld	Tuttle Lake Formation of Harwood (1992) (Late? and Middle Jurassic)--Diamictite	7	0	0	2.0	3.4	3.1
Jtlf	Tuttle Lake Formation of Harwood (1992) (Late? and Middle Jurassic)--Lava flows [*basaltic to andesitic*]	39	0	0	0.9	3.8	2.4
Jtls	Tuttle Lake Formation of Harwood (1992) (Late? and Middle Jurassic)--	81	13	16	1.2	6.9	3.3
JTrms	Metasedimentary rocks (Jurassic and/or Triassic [*metasandstone, calc. siltstone, silty limestone*]	19	0	0	0.5	3.2	1.9
Kbla	Burnside Lake adamellite of Parker (1961) (Cretaceous) [*porphyritic biotite granite*]	216	72	33.3	0.2	8.1	4.3
Kbmg	Bryan Meadow granodiorite	845	75	8.9	0.0	7.5	3.0
Kcfg	Camper Flat granodiorite (Cretaceous or Jurassic?)	234	36	15.4	1.3	7.6	3.5
Kcld	Diorite of Caples Lake (Cretaceous)	24	0	0	0.6	2.6	1.6
Kclg	Granodiorite of Caples Lake (Cretaceous)	327	7	2.1	0.3	5.6	2.2
Kclg?	Granodiorite of Caples Lake (Cretaceous) ?	719	18	2.5	0.4	8.4	1.9
Kcpt	Carson Pass tonalite of Parker (1961) (Cretaceous) [*granodiorite to quartz diorite*]	105	0	0	0.0	4.1	1.7
Kcvg	Granodiorite of Charity Valley (Cretaceous)	8	1	12.5	2.2	5.3	3.4
Kdg	Unnamed granitic rocks of the Sierra Nevada batholith-Diorite and gabbro (Cretaceous)	13	3	23.1	1.2	5.9	4.0
Kdlg	Dicks Lake granodiorite (Cretaceous)	182	3	1.6	0.2	5.5	2.3
Kdvg	Desolation Valley granodiorite (Cretaceous or Jurassic?)	269	29	10.8	1.0	7.5	3.2

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Keg	Granodiorite of East Peak (Cretaceous)	52	2	3.8	0.9	5.2	3.1
Kelg	Echo Lake granodiorite (Cretaceous)	133	11	8.3	0.9	6.8	3.0
Kepg	Ebbetts Pass granodiorite of Wilshire (1957) (Cretaceous)	221	0	0	0.6	4.4	2.2
Kfpg	Freel Peak granodiorite (Cretaceous)	343	17	5	0.5	6.4	3.2
Kgqd	Quartz diorite of Grass Lake (Cretaceous)	20	0	0	1.8	1.8	1.4
Kgr	Unnamed granitic rocks of the Sierra Nevada batholith-Granite and granodiorite, undivided (Cretaceous)	20	6	30	0.3	12.3	2.9
KJdg	Unnamed granitic rocks of the Sierra Nevada batholith-Diorite and gabbro (Cretaceous and/or Jurassic)	50	0	0	0.6	4.9	2.2
KJgr	Unnamed granitic rocks of the Sierra Nevada batholith-Granite (Cretaceous and/or Jurassic)	7	0	0	0.7	2.8	1.4
Kkgg	Granodiorite of Kingsbury Grade (Cretaceous)	3	1	33.3	3.9	5.4	4.2
Kkqm	Keiths Dome quartz monzonite (Cretaceous or Jurassic?)	144	5	3.5	1.0	6.1	2.6
Kllg	Lovers Leap granodiorite (Cretaceous)	398	14	3.5	0.6	6.9	1.9
Kppg	Phipps Pass granodiorite (Cretaceous)	105	51	48.6	1.8	10.4	4.9
Krpa	Alaskite at Rubicon Point (Cretaceous)	3	1	33.3	4.5	5.9	4.5
Krpa?	Alaskite at Rubicon Point (Cretaceous) ?	81	48	59.3	2.7	9.8	5.2
Krvg	Rockbound Valley granodiorite (Cretaceous)	5	0	0	1.7	4.9	4.1
Krvg?	Rockbound Valley granodiorite (Cretaceous)?	401	19	4.7	0.0	6.2	3.1
Ktcg	Granodiorite of Thornburg Canyon (Cretaceous)	2	0	0	0.7	2.4	1.6
Ktlg	Tyler Lake granodiorite of Sabine (1992) (Cretaceous)	69	0	0	1.3	4.8	2.3
Kwlg	Wrights Lake granodiorite (Cretaceous)	509	9	1.8	0.2	6.1	1.5

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Mia	Unnamed volcanic and intrusive rocks (Miocene)--Intrusive rocks--andesite, basaltic andesite and latite	38	0	0	0.0	2.7	0.8
Mia?	Unnamed volcanic and intrusive rocks (Miocene)--Intrusive rocks--andesite, basaltic andesite and latite ?	7	0	0	1.6	2.6	2.0
Mva	Unnamed volcanic and intrusive rocks (Miocene)--Undivided andesitic and dacitic lahars, flows, breccia and volcaniclastic sediments (Miocene) [*andesite, trachyandesite, basaltic andesite and dacitic lahars, flows, breccia and volcaniclastic sediments; local basalt flows; locally includes rhyolite tuff. Map unit includes Mehrten, Relief Peak and Kate Peak formations.]*	1602	3	0.2	0.0	8.0	1.3
Mvaf	Unnamed volcanic and intrusive rocks (Miocene)--Andesite and dacite flows	165	0	0	0.0	3.8	1.4
Mvbf	Unnamed volcanic and intrusive rocks (Miocene)--Basalt flows	25	0	0	0.7	3.1	1.4
Mvll	Lower lahar sequence of Harwood and Fisher (2002) (Miocene)--Andesitic lahars	11	0	0	0.7	3.6	1.5
Mvs	Unnamed volcanic and intrusive rocks (Miocene)--Fluvial deposits [*composed of mafic to intermediate volcanic composition sediments*]	67	0	0	0.5	4.2	1.3
Mvs?	Unnamed volcanic and intrusive rocks (Miocene)--Fluvial deposits [*composed of mafic to intermediate volcanic composition sediments*] ?	93	15	16.1	0.5	7.8	1.7
Mvul	Upper lahar sequence of Harwood and Fisher (2002) (Miocene)--Andesitic lahars	45	0	0	0.0	2.2	0.9

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Mvulp	Upper lahar sequence of Harwood and Fisher (2002) (Miocene)--Rockslide-avalanche deposits [*dacite with some andesite*]	19	0	0	0.1	2.4	1.1
Mvulr	Upper lahar sequence of Harwood and Fisher (2002) (Miocene)--Pumiceous tuff	78	0	0	0.0	2.7	0.6
Omvr	Unnamed volcanic and sedimentary rocks--Rhyolite tuff (Oligocene and Miocene?) [*non-welded rhyolite tuff; map unit includes Valley Springs Formation, Lenihan Canyon Tuff and Mick Pass Tuff*]	3	0	0	1.7	2.1	1.9
Pva	Unnamed volcanic and intrusive rocks (Pliocene)--Andesite and basaltic andesite flows	147	2	1.4	0.0	6.3	1.6
Pval	Unnamed volcanic and intrusive rocks (Pliocene)--Andesite lahars	21	0	0	0.0	1.4	0.7
Pvta	Tahoe City trachyandesite of Wise and Sylvester (2004) (Pliocene)	4	0	0	0.0	3.0	1.5
Q	Alluvium (Holocene and Pleistocene)	323	0	0	0.0	4.9	2.2
Qc	Colluvium (Holocene)	40	0	0	1.2	4.7	2.2
Qf	Alluvial fan deposits (Holocene and Pleistocene)	57	0	0	0.1	3.2	1.2
Qfp	Flood-plain deposits (Holocene)	26	2	7.7	1.3	5.2	2.9
Qfp?	Flood-plain deposits (Holocene)	107	14	13.1	1.0	6.7	3.4
Qg	Glacial deposits undivided (Pleistocene and Holocene?)--Till	378	9	2.4	0.1	9.1	1.8
Qg?	Glacial deposits undivided (Pleistocene and Holocene?)--Till	10	0	0	0.9	4.0	2.2
Qgt	Tahoe and Tioga glacial deposits--undivided (Pleistocene)--Till	333	28	8.4	0.1	7.5	3.0
Qjf	Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	7	0	0	1.4	3.2	1.9
Ql	Lake deposits (Holocene)	75	2	2.7	0.0	6.2	1.6
Qls	Landslide deposits (Holocene and Pleistocene)	90	0	0	0.1	3.7	1.3

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Qlt	Lacustrine terrace deposits (Pleistocene)	56	8	16.1	2.3	5.8	4.1
Qog	Older glacial deposits (Pleistocene)--Pre-Tahoe deposits--Till	141	7	5	0.1	7.1	2.8
Qogo	Older glacial deposits (Pleistocene)--Pre-Tahoe deposits--Outwash	18	10	55.6	3.0	6.8	5.1
Qol	Older lake deposits (Pleistocene)	16	0	0	0.2	2.7	1.2
Qpc?	Prosser Creek alluvium of Birkeland (1961) (Pleistocene) ?	4	0	0	1.7	2.6	2.3
Qpot	Older talus deposits (Pliocene and/or Pleistocene)	32	0	0	1.3	3.9	2.2
QPvbc	Big Chief basalt of Birkeland (1961) (Pliocene and/or Pleistocene)	23	0	0	0.2	3.1	1.4
QPvd1	Dry Lake volcanic flows of Birkeland (1961) and Wise and Sylvester (2004) (Pliocene and/or Pleistocene)--Oldest Flow	40	0	0	0.0	2.7	1.0
QPvd2	Dry Lake volcanic flows of Birkeland (1961) and Wise and Sylvester (2004) (Pliocene and/or Pleistocene)--Second Oldest Flow	10	0	0	0.2	2.3	1.4
QPvd4	Dry Lake volcanic flows of Birkeland (1961) and Wise and Sylvester (2004) (Pliocene and/or Pleistocene)--Youngest Flow	33	0	0	0.2	2.2	1.0
QPvlf	Lake Forest basalt of Wise and Sylvester (2004) (Pliocene and/or Pleistocene)	18	0	0	1.1	3.1	1.7
QPvpm	Page Meadow basalt of Wise and Sylvester (2004) (Pliocene and/or Pleistocene)	5	0	0	1.1	2.1	1.6
Qt	Talus deposits (Holocene)	54	0	0	0.0	4.0	2.3
Qta	Tahoe glacial deposits (Pleistocene)--Till	274	18	6.6	0.1	5.9	2.5
Qti	Tioga glacial deposits (Pleistocene)--Till	431	29	6.7	0.0	13.5	1.9

Geologic Unit Symbol	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
Qtio	Tioga glacial deposits (Pleistocene)--Outwash deposits	32	2	6.3	0.0	6.6	1.5
Qvbm	Bald Mountain olivine latite of Birkeland (1961) (Pleistocene)	87	0	0	0.0	3.8	0.9
Qvh	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)	23	0	0	0.0	3.7	2.2
Qvhcc	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)--cinder cone deposits	10	0	0	0.0	3.1	1.8
Qvht	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)--basaltic tuff	2	0	0	0.6	1.9	1.3

APPENDIX G

NURE Stream Sediment Sample (SS) and Soil Sample (SL) Uranium Data by Geologic Unit—Lake Tahoe Area

Geologic Unit	Geologic Unit Description	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)
af-SS	artificial fill (Sacramento 1X2 Degree Quadrangle)	1	17.5							17.5
Jtlb-SS	Tuttle Lake Formation—Volcanic Breccia (Sacramento 1X2 Degree Quadrangle)	1	2.2							2.2
Kbla-SL	Burnside Lake adamellite of Parker (1961) (Walker Lake 1X2 Degree Quadrangle)	1	2.6							2.6
Kbmg-SS	Bryan Meadow granodiorite (Sacramento 1X2 Degree Quadrangle)	2	5.3	7.5			6.4	6.4	5.3	7.5
Kbmg-SL	Bryan Meadow granodiorite (Walker Lake 1X2 Degree Quadrangle)	3	3.0	10.0	88.6		33.8	10.0	3.0	88.6
Kclg-SS	Granodiorite of Caples Lake (Sacramento 1X2 Degree Quadrangle)	13	2.5 3.5 4.7 5.1	5.4 5.6 5.6 5.7	6.5 6.7 6.9 7.7	12.2	6.0	5.6	2.5	12.2
Kdlg-SL	Dicks Lake granodiorite (Sacramento 1X2 Degree Quadrangle)	1	5.5							5.5
Kepg-SL	Ebbetts Pass granodiorite of Wilshire (1957) (Walker Lake 1X2 Degree Quadrangle)	1	1.9							1.9
KJdg-SS	Unnamed granitic rocks of the SN Batholith—Diorite and Gabbro (Sacramento 1X2 Degree Quadrangle)	1	4.9							4.9
Kllg-SS	Lovers Leap granodiorite (Sacramento 1X2 Degree Quadrangle)	2	0.8	6.1			3.5	3.5	0.8	6.1
Krpa?-SS	Alaskite at Rubicon Point (Sacramento 1X2 Degree Quadrangle)	1	9.6							9.6

Geologic Unit	Geologic Unit Description	N	NURE Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)
Kwlg-SS	Wrights Lake granodiorite (Sacramento 1X2 Degree Quadrangle)	3	2.8	5.2	14.5		7.5	5.2	2.8	14.5
Mva-SS	Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments (Sacramento 1X2 Degree Quadrangle)	6	2.1 2.3	2.4 2.5	4.6 5.2		3.2	2.5	2.1	5.2
Mva-SL	Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments (Walker Lake 1X2 Degree Quadrangle)	1	1.8							1.8
Mvs-SS	Unnamed Miocene Volcanic and Intrusive Rocks—Fluvial deposits (Sacramento 1X2 Degree Quadrangle)	1	1.7							1.7
Q-SS	Alluvium (Sacramento 1X2 Degree Quadrangle)	2	2.9	5.8			4.4	4.4	2.9	5.8
Q-SL	Alluvium (Walker Lake 1X2 Degree Quadrangle)	3	2.0	3.5	8.6		4.7	3.5	2.0	8.6
Qf-SL	Alluvial fan (Walker Lake 1X2 Degree Quadrangle)	1	7.5							7.5
Qfp?-SS	Flood-plain deposits (Sacramento 1X2 Degree Quadrangle)	1	12.7							12.7
Qg-SS	Glacial deposits undivided—Till (Sacramento 1X2 Degree Quadrangle)	6	3.6 4.5	5.2 6.1	7.3 7.6		5.7	5.7	3.6	7.6
Qgt-SS	Tahoe and Tioga glacial deposits—undivided—Till (Sacramento 1X2 Degree Quadrangle)	1	6.4							6.4
Qgt-SL	Tahoe and Tioga glacial deposits—undivided—Till (Walker Lake 1X2 Degree Quadrangle)	2	4.2	5.5			4.9	4.9	4.2	5.5
Qls-SS (*Kwlg*)	Landslide deposits (Sacramento 1X2 Degree Quadrangle) (*Wrights Lake granodiorite*)	1	10.2							10.2

Geologic Unit	Geologic Unit Description	N	NURE Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)
Qta-SS	Tahoe glacial deposits—Till (Sacramento 1X2 Degree Quadrangle)	2	8.5	16.8			12.7	12.7	8.5	16.8
Qta-SL	Tahoe glacial deposits—Till (Sacramento 1X2 Degree Quadrangle)	1	7.0							7.0
Qti-SS	Tioga glacial deposits—Till (Sacramento 1X2 Degree Quadrangle)	4	2.4	4.9	25.0	28.4	15.2	15.0	2.4	28.4
Qti-SL	Tioga glacial deposits—Till (Sacramento 1X2 Degree Quadrangle)	2	4.3	5.6			5.0	5.0	4.3	5.6

APPENDIX H-1

Geologic Units, NRCS Soil Units and Indoor Radon Data

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name *[Parent Rock/Permeability]*	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
af	Artificial Fill	7051	Oxyaquic Xerothents-Water association, 0-5% slopes ***[Granodiorite/Slow]***	12	0		0.2	1.9
Kbmg	Bryan Meadow granodiorite	7041	Tahoe complex, 0-2% slopes ***[Granitic and Volcanic/Slow]***	2	0		0.7	3.1
	"	7412	Cagwin-Rock outcrop complex, 15-30% slopes, extremely stony ***[Granodiorite/Very Slow]***	3	2		2.4	7.6
	"	7421	Cassenai gravelly loamy coarse sand, 5 to 15 % slopes, very stony ***[Granodiorite/Mod Rapid]***	16	13	81.3	1.3	16.2
	"	7422	Cassenai gravelly loamy coarse sand, 15 to 30 % slopes, very stony ***[Granodiorite/Mod Rapid]***	4	2		2.1	6.6
	"	7443	Christopher loamy coarse sand, 0-9 percent slopes ***[Granodiorite/Rapid]***	1	1			5.1
	"	7461	Jabu coarse sandy loam, 0-9% slopes ***[Granodiorite/Very Slow]***	2	2		9.6	9.9
	"	7485	Meeks gravelly loamy coarse sand, 15-30% slopes ***[Granodiorite/Slow]***	1	0			2.0

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name *Parent Rock/Permeability*	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
Kmbg continued	Bryan Meadow granodiorite	7492	Oneidas coarse sandy loam, 5-15% slopes ***[Granodiorite/Slow]***	1	1			86.1
Kelg	Echo Lake granodiorite	7411	Cagwin-Rock outcrop complex, 5-15% slopes, extremely stony ***[Granodiorite/Very Slow]***	1	1			15.0
Mvaf	Unnamed Miocene andesite and dacite flows	7222	Tahoma-Jorge complex, 2-15% slopes ***[Andesite/Slow]***	1	0			3.7
Qfp	Flood-plain deposits (Holocene)	7444	Christopher-Gefo complex, 0-5% slopes ***[Granodiorite/Rapid]***	4	1		1.1	11.6
	“	7462	Jabu coarse sandy loam, 9-30% slopes ***[Granodiorite/Very Slow]***	1	1			4.7
	“	7471	Marla loamy coarse sand, 0-5% slopes ***[Granodiorite/Slow]***	1	1			6.1
Ql	Lake Deposits (Holocene)	7161	Kingsbeach stony sandy loam, 2-15% slopes ***[Andesite/Impermeable-very slow]***	1	0			0.2
	“	7222	Tahoma-Jorge complex, 2-15% slopes ***[Andesite/Slow]***	1	1			5.3
	“	7524	Tallac gravelly coarse sandy loam, moderately well drained, 0 to 5% slopes ***[Mixed Sources/Slow]***	4	0		0.6	1.9

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name** ***Parent Rock/Permeability***	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
Ql continued	Lake Deposits (Holocene)	9011	Oxyaquic Cryorthents-Aquic Xerothents-Tahoe complex, 0-15% slopes ***[Mixed Sources/Moderate]***	1	0			0.3
Qlt	Lacustrine terrace deposits	7421	Cassenai gravelly loamy coarse sand, 5 to 15 % slopes, very stony ***[Granodiorite/Mod Rapid]***	1	1			7.2
	"	7441	*Christopher loamy coarse sand, 0-9% slopes* ***[Granodiorite/Rapid]***	4	3		2.8	5.8
	"	7444	Christopher-Gefo complex, 0-5% slopes ***[Granodiorite/Rapid]***	56	37	66.1	0.2	55.5
	"	7461	Jabu coarse sandy loam, 0-9% slopes ***[Granodiorite/Very Slow]***	9	5		1.9	16.6
	"	7471	Marla loamy coarse sand, 0-5% slopes ***[Granodiorite/Slow]***	16	10	62.5	0.8	19.6
	"	7541	Ubaj sandy loam, 0-9% slopes ***[Granodiorite/Very Slow***	5	2	40.0	1.0	8.0
	"	7491	Oneidas coarse sandy loam, 0-5% slopes ***[Granodiorite/Slow]***	1	1			7.4
Qob	Older beach deposits (Pleistocene)	7471	Marla loamy coarse sand, 0-5% slopes ***[Granodiorite/Slow]***	2	0		0.2	1.0
Qog	Older glacial deposits-pre-Tahoe deposits--Till	7441	Christopher loamy coarse sand, 0-9% slopes ***[Granodiorite/Rapid]***	3	0		0.7	3.7

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
Qog continued	Older glacial deposits-pre-Tahoe deposits--Till	7442	Christopher loamy coarse sand, 9-30% slopes ***[Granodiorite/Rapid]***	8	6		0.2	13.7
	“	7461	Jabu coarse sandy loam, 0-9% slopes ***[Granodiorite/Very Slow]***	1	1			1.4
	“	7491	Oneidas coarse sandy loam, 0-5% slopes ***[Granodiorite/Slow]***	4	3		3.2	12.5
	“	7492	Oneidas coarse sandy loam, 5-15% slopes ***[Granodiorite/Slow]***	1	1			14.0
Qogo	Older glacial deposits-pre-Tahoe deposits—Outwash deposits	7461	Jabu coarse sandy loam, 0-9% slopes ***[Granodiorite/Very Slow]***	1	0			3.2
	“	7462	Jabu coarse sandy loam, 9-30% slopes ***[Granodiorite/Very Slow]***	4	1		3.9	36.9
	“	7492	Oneidas coarse sandy loam, 5-15% slopes ***[Granodiorite/Slow]***	4	4		6.5	13.0
Qta	Tahoe glacial deposits--Till	7411	Cagwin-Rock outcrop complex, 5-15% slopes, extremely stony ***[Granodiorite/Very Slow]***	3	3		5.3	7.9
	“	7431	Celo loamy coarse sand, 0-5% slopes ***[?/Rapid over Duripan]***	9	3		0.2	9.7
	“	7461	**Jabu coarse sandy loam, 0-9% slopes** ***[Granodiorite/Very Slow]***	16	8	50.0	1.9	8.8

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
Qta continued	Tahoe glacial deposits--Till	7462	Jabu coarse sandy loam, 9-30% slopes ***[Granodiorite/Very Slow]***	5	4		3.1	12.7
	"	7481	Meeks gravelly loamy coarse sand, 0-5% slopes ***[Granodiorite/Slow]***	8	5		1.4	20.6
	"	7483	Meeks gravelly loamy coarse sand, 0-5% slopes, very stony ***[Granodiorite/Slow]***	10	2		1.3	12.0
	"	7525	Tallac gravelly coarse sandy loam, moderately well drained, 5-15% slopes ***[Mixed Sources/Slow]***	2	0		1.1	2.2
	"	7541	Ubaj sandy loam, 0-9% slopes ***[Granodiorite/Very Slow]***	1	0			1.0
Qti	Tioga glacial deposits--Till	7041	Tahoe complex, 0-2% slopes ***[Granitic and Volcanic/Slow]***	1	0			3.7
	"	7431	Celo loamy coarse sand, 0-5% slopes ***[?/Rapid over Duripan]***	1	1			8.8
	"	7451	Gefo gravelly loamy coarse sand, 2-9% slopes ***[Granodiorite/Rapid]***	3	1		2.2	12.8
	"	7481	Meeks gravelly loamy coarse sand, 0-5% slopes ***[Granodiorite/Slow]***	6	1		1.2	5.3
	"	7483	Meeks gravelly loamy coarse sand, 0-5% slopes, very stony ***[Granodiorite/Slow]***	11	2		0.9	6.3

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
Qti continued	Tioga glacial deposits--Till	7485	Meeks gravelly loamy coarse sand, 15-30% slopes ***[Granodiorite/Slow]***	1	1			11.4

APPENDIX H-2

Geologic Units, U.S. Forest Service Soil Units and Indoor Radon Data(*Asterisks are defined at the end of the table*.)

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
Mva	Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments	FRE, FRF	Fugawee-Rock outcrop-Tahoma complex, 2- 30% and 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow ; Tahoma moderately slow**] (Fugawee substratus @35” weathered andesite; rock outcrop weathered volcanic rock; Tahoma substratus@41” highly weathered andesitic tuff)	4	0	0	0.9	3.1
	Undivided andesitic and dacitic lahars, flows, breccias and volcaniclastic sediments	FTE, FTF	Fugawee-Tahoma complex, 2-30% and 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow; Tahoma-moderately slow**] (Fugawee substratus @35” weathered andesite; Tahoma substratus@41” highly weathered andesitic tuff)	10	1	10	1.0	4.2
Pvah	Alder Hill basalt of Birkeland (1961) (Pliocene)	FRE	Fugawee-Rock outcrop-Tahoma complex, 2- 30% slopes [**Fugawee-moderate to moderately slow, and moderately slow ; Tahoma moderately slow**] (Fugawee substratus @35” weathered andesite; rock outcrop weathered volcanic rock; Tahoma substratus@41” highly weathered andesitic tuff)	8	2	25.0	0.7	11.2

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Alder Hill basalt of Birkeland (1961) (Pliocene)	FTE	Fugawee-Tahoma complex, 2-30% slopes [**Fugawee-moderate to moderately slow, and moderately slow; Tahoma-moderately slow**] (Fugawee substratus @35" weathered andesite; Tahoma substratus@41" highly weathered andesitic tuff)	18	2	11.1	0.5	38.8
	Alder Hill basalt of Birkeland (1961) (Pliocene)	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34" –weathered andesitic rock; Trojan substratum @67"-slightly fractured andesite)	12	4	33.3	0.2	7.5
	Alder Hill basalt of Birkeland (1961) (Pliocene)	KRE	Kyburz-Rock outcrop-Trojan complex, 2-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34" weathered andesitic rock; Rock outcrop-volcanic rock; Trojan substratum @67" slightly fractured andesite)	4	3	75.0	2.2	11.0
	Alder Hill basalt of Birkeland (1961) (Pliocene)	TBE	Tallac-Cryumbrepts, wet complex, 2-30% slopes [**Tallac-moderately rapid, very slow; Cryumbrepts, wet-moderately rapid, very slow**] (Tallac substratum @41" weakly cemented till)	1	0	0		1.7

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
Q	Alluvium (Holocene and Pleistocene)	AQB	Aquolls and Borolls, 0-5% slopes [**Aqolls-variable-slow and very slow; Borolls-variable-moderately slow and slow**] Aquolls-high water table most of the year; Borolls-high water table part of the year	3	0	0	1.0	3.2
Qjf	Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	AQB	Aquolls and Borolls, 0-5% slopes [**Aqolls-variable-slow and very slow; Borolls-variable-moderately slow and slow**] Aquolls-high water table most of the year; Borolls-high water table part of the year	2	0	0	1.7	3.9
	Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	ARE	Aldi-Kyburz complex, 2-30% slopes [**Aldi-slow, very slow; Kyburz-moderately slow**] (substratum weathered andesite; Aldi-18” to bedrock (may perch water in spring); Kyburz-34” to bedrock)	3	0	0	0.8	1.6
	Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	6	0	0	0.3	3.1
	Juniper Flat alluvium of Birkeland (1961) (Pleistocene)	ULC	Kyburz loam, 2-9% slopes [**moderately slow, moderate**] Substratum @24” weathered andesite)	9	1	11.1	0.2	4.0

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Older glacial deposits-pre-Tahoe deposits--Till	FRF	Fugawee-Rock outcrop-Tahoma complex, 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow ; Tahoma moderately slow**] (Fugawee substratus @35” weathered andesite; rock outcrop weathered volcanic rock; Tahoma substratus@41” highly weathered andesitic tuff)	1	0	0		0.9
	Older glacial deposits-pre-Tahoe deposits--Till	FTF	Fugawee-Tahoma complex, 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow; Tahoma-moderately slow**] (Fugawee substratus @35” weathered andesite; Tahoma substratus@41” highly weathered andesitic tuff)	1	0	0		3.1
	Older glacial deposits-pre-Tahoe deposits--Till	MEB	Martis-Euer Variant complex, 2-5% slopes [**Martis-gravelly sandy clay loam-moderately slow, rapid; Euer very gravelly clay loam-moderately slow-rapid**]	5	4	80.0	0.5	14.3
	Older glacial deposits-pre-Tahoe deposits—Outwash deposits	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	3	0	0	1.8	2.8

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Older glacial deposits-pre-Tahoe deposits—Outwash deposits	MEB	Martis-Euer Variant complex, 2-5% slopes [**Martis-gravelly sandy clay loam-moderately slow, rapid; Euer very gravelly clay loam-moderately slow-rapid**]	3	0	0	1.9	3.8
	Older glacial deposits-pre-Tahoe deposits—Outwash deposits	SIE	Sierraville-Trojan-Kyburz complex, 2-30% [**Sierraville-moderately slow; Trojan-moderately slow; Kyburz-moderately slow**] (Sierraville substratum @75” slightly weathered andesite; Trojan substratum @67” slightly fractured andesite; Kyburz substratum @34” weathered andesitic rock)	1	0	0		7.1
Qpc	Prosser Creek alluvium of Birkeland (1961)	EUB	Euer-Martis Variant complex, 2-5% slopes [**Euer-moderate, rapid; Martis-rapid over slow; rapid**] (Euer substratum @47”-65”)	2	0	0	1.0	2.3
	Prosser Creek alluvium of Birkeland (1961)	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	1	0	0		2.7

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Prosser Creek alluvium of Birkeland (1961)	KME	Kyburz-Aldi complex, 2-30% slopes [**Kyburz-moderately slow; Aldi-slow, very slow**] (Kyburz substratum @34" weathered andesitic rock; Aldi substratum @18" weathered andesite)	1	1	100		6.0
	Prosser Creek alluvium of Birkeland (1961)	SIE	Sierraville-Trojan-Kyburz complex, 2-30% [**Sierraville-moderately slow; Trojan-moderately slow; Kyburz-moderately slow**] (Sierraville substratum @75" slightly weathered andesite; Trojan substratum @67" slightly fractured andesite; Kyburz substratum @34" weathered andesitic rock)	1	0	0		0.5
QPvb	Basalt flows, flow breccias and basaltic ash	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34" –weathered andesitic rock; Trojan substratum @67"-slightly fractured andesite)	1	0	0		3.2
QPvd2	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—second oldest flow	ARE	Aldi-Kyburz complex, 2-30% slopes [**Aldi-slow, very slow; Kyburz-moderately slow**] (substratum weathered andesite; Aldi-18" to bedrock (may perch water in spring); Kyburz-34" to bedrock)	3	0	0	0.2	2.3

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—second oldest flow	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	7	1	14.6	0.7	12.3
QPvd4	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—youngest flow	ARE	Aldi-Kyburz complex, 2-30% slopes [**Aldi-slow, very slow; Kyburz-moderately slow**] (substratum weathered andesite; Aldi-18” to bedrock (may perch water in spring); Kyburz-34” to bedrock)	11	7	63.6	1.3	33.5
	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—youngest flow	FUE	Kyburz-Trojan complex, 9-30% slopes [**Kyburz-moderately slow; Trojan-moderately slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	3	0	0	0.2	1.4
	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—youngest flow	MRE	Fugawee Variant-Fugawee complex, 2-30 percent slopes [**Fugawee Variant-slow, very slow; Fugawee-Moderate to moderately slow, moderately slow**] (Fugawee Variant substratum @18” weathered andesitic rock; Fugawee substratum @35” weathered andesite)	1	1	100		4.1

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Dry Land volcanic flows of Birkeland (1961); Wise and Sylvester (2004) Pliocene and (or) Pleistocene—youngest flow	TTE	Trojan-Sattley-Kuburz complex, 2-30% slopes [**Trojan moderately slow; Sattley-moderate; Kyburz-moderately slow**] (Trojan substratum @67" slightly fractured andesite; Sattley substratum @46" cemented andesitic conglomerate; Kyburz substratum @34" weathered andesitic rock)	1	0	0		2.9
	Tahoe glacial deposits--Till	FRF	Fugawee-Rock outcrop-Tahoma complex, 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow ; Tahoma moderately slow**] (Fugawee substratum @35" weathered andesite; rock outcrop weathered volcanic rock; Tahoma substratum@41" highly weathered andesitic tuff)	1	0	0		1.6
	Tahoe glacial deposits--Till	MEB	Martis-Euer Variant complex, 2-5% slopes [**Martis-gravelly sandy clay loam-moderately slow, rapid; Euer very gravelly clay loam-moderately slow-rapid**]	1	0	0		1.5
Qtao	Tahoe glacial deposits—Outwash deposits	EUE	Euer-Martis Variant complex, 5-30% slopes [**Euer-moderate, rapid; Martis-rapid over slow, rapid**] (Euer substratum @47" to 65")	1	1	100		4.5

Geologic Unit	Geologic Unit Name	Soil Unit	Soil Unit Name [permeability] (substratus)	N	N ≥ 4 pCi/L	R %	Low PCi/L	High pCi/L
	Tioga glacial deposits--Till	AQB	Aquolls and Borolls, 0-5% slopes [**Aqolls-variable-slow and very slow; Borolls-variable-moderately slow and slow**] Aquolls-high water table most of the year; Borolls-high water table part of the year	1	0	0		3.6
	Tioga glacial deposits--Till	CEE	Celio-Gefo-Aquolls complex, 2-30% slopes [**Celo-rapid, slow; Gefo-very rapid to rapid, very rapid; Aquolls-variable, substratum slow or very slow**] (Celo substratum @40”; Gefo substratum @40”60”; Aquolls substratum = stratified alluvium)	1	0	0		1.5
	Tioga glacial deposits--Till	EUB	Euer-Martis Variant complex, 2-5% slopes [**Euer-moderate, rapid; Martis-rapid over slow; rapid**] (Euer substratum @47”-65”)	3	0	0	1.8	2.9
	Tioga glacial deposits--Till	TAE	Tallac very gravelly sandy loam complex, 2-30% slopes [**Moderately rapid, very slow**] (Substratum @41” weakly cemented till)	1	0	0		2.0
	Tioga glacial deposits--Till	WAE	Waca-Windy complex, 2-30% slopes [**Waca-moderately rapid, slow; Windy-moderately rapid, slow**] (Waca substratum @32” weathered andesitic tuff breccias; Windy substratum @ 46” weathered andesitic tuff breccias)	3	0	0	0.7	1.6

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
Qtio	Tioga glacial deposits—Outwash deposits	EUB	Euer-Martis Variant complex, 2-5% slopes [**Euer-moderate, rapid; Martis-rapid over slow; rapid**] (Euer substratum @47”-65”)	1	0	0		3.7
	Tioga glacial deposits—Outwash deposits	EWB	Inville-Riverwash-Aquolls complex, 2-5% slopes [**Inville-moderately rapid, rapid; Aquolls-variable, substratum slow and very slow**] (Inville substratum @30-60”; Aquolls substratum-stratified alluvium)	1	0	0		0.3
Qvbm	Bald Mountain olivine latite of Birkeland (1961) (Pleistocene)	FTF	Fugawee-Rock outcrop-Tahoma complex, 30-50% slopes [**Fugawee-moderate to moderately slow, and moderately slow ; Tahoma moderately slow**] (Fugawee substratum @35” weathered andesite; rock outcrop weathered volcanic rock; Tahoma substratus@41” highly weathered andesitic tuff)	1	0	0		2.2
	Bald Mountain olivine latite of Birkeland (1961) (Pleistocene)	FUE	Kyburz-Trojan complex, 9-30% slopes [Kyburz-moderately slow; Trojan-moderately **slow**] (Kyburz substratum @34” –weathered andesitic rock; Trojan substratum @67”-slightly fractured andesite)	1	0	0		2.6

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
	Bald Mountain olivine latite of Birkeland (1961) (Pleistocene)	SIE	Sierraville-Trojan-Kyburz complex, 2-30% [**Sierraville-moderately slow; Trojan-moderately slow; Kyburz-moderately slow**] (Sierraville substratum @75" slightly weathered andesite; Trojan substratum @67" slightly fractured andesite; Kyburz substratum @34" weathered andesitic rock)	6	3	50.0	0.6	10.2
Qvh	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)	AQB	Aquolls and Borolls, 0-5% slopes [**Aqolls-variable-slow and very slow; Borolls-variable-moderately slow and slow**] Aquolls-high water table most of the year; Borolls-high water table part of the year	2	0	0	0.5	0.7
	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)	ARE	Aldi-Kyburz complex, 2-30% slopes [**Aldi-slow, very slow; Kyburz-moderately slow**] (substratum weathered andesite; Aldi-18" to bedrock (may perch water in spring); Kyburz-34" to bedrock)	4	1	25.0	0.4	5.5
	Hirschdale olivine latite of Birkeland (1961) (Pleistocene)	ULC	Kyburz loam, 2-9% slopes [**moderately slow, moderate**] (Substratum @24" weathered andesite)	10	1	10.0	0.2	7.4

Geologic Unit	**Geologic Unit Name**	**Soil Unit**	**Soil Unit Name [permeability]** (substratus)	**N**	**N ≥ 4 pCi/L**	**R %**	**Low PCi/L**	**High pCi/L**
Qvhcc	Hirschdale olivine latite of Birkeland (1961) (Pleistocene) cinder cone deposits	ARE	Aldi-Kyburz complex, 2-30% slopes [**Aldi-slow, very slow; Kyburz-moderately slow**] (substratum weathered andesite; Aldi-18” to bedrock (may perch water in spring); Kyburz-34” to bedrock)	1	1	100		4.9

APPENDIX I-1

NRCS Soil Properties and Associated Indoor-Radon Data (*Asterisks are defined at the end of the table*.)

NRCS 2007 Lake Tahoe Basin Area Soil Units and Information					Indoor-Radon Data			
Soil Unit Symbol(s)	**Soil Unit**	**Slowest Permeability by Soil Sub-unit**	**Shrink-Swell**	**Parent Material**	**N**	**N ≥ 4**	**R (%)***	**Max pCi/l**
7041	Tahoe Complex, 0-2% slopes Location: Southern Tahoe Basin	Tahoe silt loam (55%)--Slow @ 3”-11” and 20”-30” Tahoe silt loam, wet (20%)--Moderate @ 0”-27” Minor Components (20%)	Low Frost action potential: high-moderate	granitic and volcanic rock alluvium	3	0		3.7
7051	Oxyaguic Xerothents-Water association, 0-5% slopes Location: Tahoe Keys	Oxyaquic Xerothents (60%)--Slow @ 0”-48” and 53”-63” Water (38%) Minor components (2%)--Slow	Low Frost action potential: low	granodiorite earth fill (filled marshland)	12	0		1.9
7161	Kingsbeach stony sandy loam, 2-15% slopes Location: Northern Tahoe Basin	Kingsbeach (80%)--Impermeable (very slow) @ 20”-61” Minor Components (20%)	High Frost action potential: moderate	Andesite alluvium and/or colluvium over lacustrine deposits	1	0		0.2

Soil Unit Symbol(s)	**Soil Unit**	**Slowest Permeability by Soil Sub-unit**	**Shrink-Swell**	**Parent Material**	**N**	**N ≥ 4**	**R (%)***	**Max pCi/l**
7222	Tahoma-Jorge complex, 2-15% slopes Location: Northwestern Tahoe Basin	Tahoma (50%)--Slow @ 38”-81” (above the bedrock) Jorge very gravelly sandy loam (30%)--Slow @ 32”-84” Minor components (20%)	Low Frost action potential: moderate	Colluvium over residuum weathered from andesite Bedrock @40”-80”	2	1		5.3
7411, 7412	Cagwin-Rock outcrop complex, 5-15% slopes, extremely stony and 15-30% slopes, extremely stony Location: Eastern and southern Tahoe Basin	Cagwin (50%)--Very slow @ 27”-37” (above the bedrock) Rock outcrop, granitic (20%) Minor components (30%)	Low Frost action potential: low	Colluvium over granodiorite grus Paralithic bedrock at 20”-39”	7	6		15.0
7421, 7422	Cassenai gravelly loamy coarse sand, 5-15% slopes, very stony and 15-30% slopes, very stony Location: Southern and eastern Tahoe Basin	Cassenai (73%)--Moderately rapid @ 1”-79” Minor components (27%)	Low Frost action potential: low-moderate	Granodiorite colluvium	21	16	76.2	16.2

Soil Unit Symbol(s)	Soil Unit	Slowest Permeability by Soil Sub-unit	Shrink-Swell	Parent Material	N	N ≥ 4	R (%)*	Max pCi/l
7431	Celio Loamy coarse sand, 0-5% slopes Location: Southern Tahoe Basin	Celio (80%)--impermeable Duripan @ 39”-59” (rapid permeability above duripan) Minor components (20%)	Low Frost action potential: low-high	Alluvium and/or glacial outwash Duripan @39”-59”	10	4		9.7
7441, 7442	Christopher loamy coarse sand, 0-9% slopes and 9-30% slopes Location: Southern Tahoe Basin	Christopher (80%)--Rapid @ 1”-62” Minor components (20%)	Low Frost action potential: low-moderate	Granodiorite glacial outwash	15	9	60.0	13.7
7443	Christopher gravelly loamy coarse sand, 9-30% slopes Location: Southern Tahoe Basin	Christopher (80%)--Rapid @ 1”-62” Minor components (20%)	Low Frost action potential: low-moderate	Granodiorite glacial outwash	1	1		5.1
7444	Christopher-Gefo complex, 0-5% slopes Location: Southern Tahoe Basin	Christopher (45%)--Rapid @ 1”-62” Gefo (35%)--Rapid @ 0”-15” (over Very Rapid @15”-75”)	Low Low Frost action potential: low-moderate	Granodiorite glacial outwash	60	38	63.3	55.5

Soil Unit Symbol(s)	Soil Unit	Slowest Permeability by Soil Sub-unit	Shrink-Swell	Parent Material	N	N ≥ 4	R (%)*	Max pCi/l
7451	Gefo gravelly loamy coarse sand, 2-9% slopes Location: Southern Tahoe Basin	Gefo (80%)--Rapid @ 0”-15” (over Very Rapid @15”-75”) Minor components (20%)	Low Low Frost action potential: low-moderate	Granodiorite glacial outwash	3	1		12.8
7461, 7462	Jabu coarse sandy loam, 0-9% slopes and 9-15% slopes Location: Southern Tahoe Basin	Jabu (80%)--Very Slow (fragipan) @ 39”-79” with dense bedrock @ 59”-79” Minor components (20%)	Low Low Frost action potential: low-moderate	Granodiorite glacial outwash Fragipan** @ 39”-79” with dense bedrock below	39	23	59.0	36.9
7471	Marla loamy coarse sand, 0-5% slopes Location: Southern Tahoe Basin	Marla (80%)--Slow @ 47”-59” (with moderately rapid to rapid permeability above and below) Minor components (20%)	Low Frost action potential: low-high	Granodiorite glacial outwash	19	11	57.9	19.6

Soil Unit Symbol(s)	Soil Unit	Slowest Permeability by Soil Sub-unit	Shrink-Swell	Parent Material	N	N ≥ 4	R (%)*	Max pCi/l
7481	Meeks gravelly loamy coarse sand, 0-5% slopes, stony Location: Southern Tahoe Basin	Meeks (85%)--Slow 63"-73"(with very rapid permeability above) and duripan @ 41"-73" Minor components (15%)	Low Frost action potential: low-high	Granodiorite glacial outwash and/or till Duripan*** @ 41"-71"	14	6	42.9	20.6
7483	Meeks gravelly loamy coarse sand, 0-5% slopes, very stony Location: Southern Tahoe Basin	Meeks (85%)--Slow 63"-73"(with very rapid permeability above) and duripan @ 41"-73" Minor components (15%)	Low Frost action potential: low-moderate	Granodiorite outwash and/or till Duripan @ 41"-71"	21	4	19.0	12.0
7485	Meeks gravelly loamy coarse sand, 15-30% slopes, extremely boulder Location: Southern Tahoe Basin	Meeks (80%)--Slow 63"-73"(with very rapid permeability above) and duripan @ 41"-73" Minor components (20%)	Low Frost action potential: low-moderate	Granodiorite glacial outwash and/or till Duripan @ 41"-71"	2	1		11.4

Soil Unit Symbol(s)	**Soil Unit**	**Slowest Permeability by Soil Sub-unit**	**Shrink-Swell**	**Parent Material**	**N**	**N ≥ 4**	**R (%)***	**Max pCi/l**
7491, 7492	Oneidas coarse sandy loam, 0-5% slopes and 5-15% slopes Location: Southern Tahoe Basin	Oneidas (80%)--Slow 12”-65” with fragipan @ 10”-20” Minor components (20%)	Low Frost action potential: low-moderate	Granodiorite outwash and/or till Fragipan @ 10”-20”	11	10		86.1
7524, 7525	Tellac gravelly coarse sandy loam, moderately well drained, 0-5% slopes and 5-9% slopes Location: Southwestern Tahoe Basin	Tallac (80%)--Slow 43”-66” (moderately rapid to rapid above) with duripan @39”-71” Minor components (20%)	Low Frost action potential: low-moderate	Colluvium over till derived from mixed sources Duripan @ 39”-71”	6	0		2.2
7541	Ubaj sandy loam, 0-9% slopes Location: Southern Tahoe Basin	Ubaj (80%)--Very slow @ 42”-120” (moderately slow to rapid above)	Moderate Frost action potential: low-moderate	Granodiorite alluvium and/or colluvium over lacustrine deposits	5	2		8.0

Soil Unit Symbol(s)	Soil Unit	Slowest Permeability by Soil Sub-unit	Shrink-Swell	Parent Material	N	N ≥ 4	R (%)*	Max pCi/l
9011	Oxyaquic Cryorthents-Aquic Xerothents-Tahoe complex, 0-15% slopes Location: Scattered throughout the Lake Tahoe Basin, most prevalent in eastern part (Landform = drainage ways)	Oxyaquic Cryorthents (30%)--Moderate-rapid @ 0”-112” Aquic Xerothents (28%)--Moderate-rapid @ 1”-59” Tahoe (15%) Moderate-rapid (0-17” (over rapid-very rapid) Minor components (27%)	Low Frost action potential: low-high	Alluvium and/or colluvium from mixed sources	1	0		0.3

*R(%)= [(number of ≥ 4.0 tests)/(total number of tests)]X100

**Fragipan--a loamy, brittle subsurface horizon low in porosity and content of organic matter and low or moderate in clay but high in silt or very fine sand. A fragipan appears cemented and restricts roots. When high, it is hard or very hard and has a higher bulk density than the horizon or horizons above. When moist, it tends to rupture suddenly under pressure rather than to deform slowly.

***Duripan-a subsurface soil horizon that is cemented with illuvial silica, commonly opal or microcrystalline forms, to the degree that less than 50 percent of the volume of air-dry fragments will slake in water or hydrochloric acid

Soil unit names and properties are summarized from the following reference: Unites States Department of Agriculture, Natural Resources Conservation Service, 2007, Soil survey of the Tahoe Basin Area, California and Nevada; Accessible online at: http://soils.usda.gov/survey/printed_surveys/.

Note: paralithic contact definition--The boundary between soil and underlying weathered rock which is a barrier to root penetration and water movement. Material retains rock structure but when moist can be dug with a spade--from the USFS Soil Survey Tahoe National Forest Area California report

APPENDIX I-2

USFS Soil Properties and Associated Indoor-Radon Data

USFS Soil Units				Indoor-Radon Data				
Soil Unit Symbol(s)	**Soil Unit**	**Permeability by Soil Sub-unit**	**Substratum**	**N**	**N ≥ 4**	**R (%)***	**Min pCi/l**	**Max pCi/l**
AQB	Aquolls and Borolls, 0-5% slopes	Aquolls (45%)-variable permeability, slow and very slow substratum permeability; high water table most of year Borolls (45%)-variable permeability, moderately slow and slow substratum permeability; high water table part of year	Stratified alluvium Stratified alluvium	8	0	0.5	0.5	3.9
ARE	Aldi-Kiburz complex, 2-30% slopes	Aldi (55%)-slow permeability, substratum very slow permeability Kyburz (30%)-moderately slow permeability, moderately slow substratum permeability	Aldi-@18” weathered andesite Kyburz-@34” weathered andesitic rock	25	11	44.0	0.2	33.5

Soil Unit Symbol(s)	Soil Unit	Permeability by Soil Sub-unit	Substratum	N	N ≥ 4	R (%)*	Min pCi/l	Max pCi/l
CEE	Celio-Gefo-Aquolls complex, 2-30 %slopes	Celo (55%)-rapid permeability, slow substratum permeability Gefo (15%)-very rapid permeability, very rapid substratum permeability Aquolls (15%)-variable permeability, slow or very slow substratum permeability	Celo-@ 40" extremely gravelly loamy coarse sand weakly cemented with silica Gefo-@40"-60" loamy fine sand, massive Aquolls-stratified alluvium	1	0			1.5
EUB, EUE	Euer-Martis Variant complex, 2-5% slopes and 5-30% slopes	Euer (55-60%)-moderate permeability, rapid substratum permeability Martis variant (35-30%)-rapid permeability over slow permeability, rapid substratum permeability	Euer-@47"-65" extremely gravelly sandy loam, massive Martis variant-	7	1	14.3	1.0	4.5

Soil Unit Symbol(s)	Soil Unit	Permeability by Soil Sub-unit	Substratum	N	N ≥ 4	R (%)*	Min pCi/l	Max pCi/l
EWB	Inville-Riverwash-Aquolls complex, 2-5% slopes	Inville (55%)-moderately rapid permeability, rapid substratum permeability Riverwash (20%)-N.A. Aquolls (15%)-variable permeability, slow and very slow substratum permeability; high water table most of year	Inville-@30”-60” extremely cobbly coarse sandy loam, weak subangular blocky structure Riverwash-N.A. Aquolls-stratified alluvium	1	0	0		0.3
EXE	Lorack Variant gravelly loam, 2-30% slopes	Lorack Variant (85%)-moderately slow permeability, very slow substratum permeability	@ 25”-36” extremely gravelly sandy loam, massive over weakly cemented till	1	1	100		5.4
FRE, FRF	Fugawee-Rock outcrop-Tahoma complex, 2-30% slopes and 30-50% slopes	Fugawee (40-50%)-moderate to moderately slow permeability, moderately slow substratum permeability Rock Outcrop (20%)-N.A. Tahoma (15%)-moderately slow permeability, moderately slow substratum permeability	Fugawee-@ 35” weathered andesite Tahoma-@ 41”highly weathered andesitic tuff	14	1	7.1	0.7	11.2

Soil Unit Symbol(s)	**Soil Unit**	**Permeability by Soil Sub-unit**	**Substratum**	**N**	**N ≥ 4**	**R (%)***	**Min pCi/l**	**Max pCi/l**
FTE, FTF	Fugawee- Tahoma complex, 2-30% slopes and 30-50% slopes	Fugawee (50%)-moderate to moderately slow permeability, moderately slow substratum permeability Tahoma (40%)-moderately slow permeability, moderately slow substratum permeability	Fugawee-@ 35” weathered andesite Tahoma-@ 41” highly weathered andesitic tuff	33	5	15.2	0.5	38.8
FUE, FUF	Kyburz-Trojan complex, 9-30% slopes and 30-50% slopes	Kyburz (60%)-moderately slow permeability, moderately slow substratum permeability Trojan (25%)-moderately slow permeability, moderately slow substratum permeability	Kyburz-@34” weathered andesitic rock Trojan-@ 67” slightly fractured andesite	39	7	17.9	0.2	14.2
KME	Kyburz-Aldi complex, 2-30% slopes	Kyburz (65%)-moderately slow permeability, moderately slow substratum permeability Aldi (25%)-slow permeability, substratum very slow permeability	Kyburz-@34” weathered andesitic rock Aldi-@18” weathered andesite	1	1	100		6.0

Soil Unit Symbol(s)	Soil Unit	Permeability by Soil Sub-unit	Substratum	N	N ≥ 4	R (%)*	Min pCi/l	Max pCi/l
KRE	Kyburz-Rock outcrop-Trojan complex, 2-30% slopes	Kyburz (55%)-moderately slow permeability, moderately slow substratum permeability Rock outcrop (20%)-N.A. Trojan (15%)-moderately slow permeability, moderately slow substratum permeability	Kyburz-@34" weathered andesitic rock Trojan-@ 67" slightly fractured andesite	5	3	60.0	2.2	11.0
MEB	Martis-Euer Variant complex, 2-5% slopes	Martis (60%)-moderately slow permeability, rapid substratum permeability Euer Variant (25%)-moderately slow permeability, rapid substratum permeability	N.A. N.A.	12	6	50.0	0.5	24.8
MRE	Fugawee Variant-Fugawee complex, 2-30% slopes	Fugawee Variant (55%)-slow permeability, very slow substratum permeability Fugawee (30%)-moderate to moderately slow permeability, moderately slow substratum permeability	Fugawee Variant @18" weathered andesitic rock Fugawee @35" weathered andesite	2	1	100	1.9	4.1

Soil Unit Symbol(s)	Soil Unit	Permeability by Soil Sub-unit	Substratum	N	N ≥ 4	R (%)*	Min pCi/l	Max pCi/l
SIE	Sierraville-Trojan-Kyburz complex, 2-30% slopes	Sierraville (45%)-moderately slow permeability, moderately slow substratum permeability Trojan (25%)-moderately slow permeability, moderately slow substratum permeability Kyburz (20%)-moderately slow permeability, moderately slow substratum permeability	Sierraville @75" slightly weathered andesite Trojan @67" slightly fractured andesite Kyburz @34" weathered andesitic rock	14	7	50.0	0.5	10.2
TAE	Tallac very gravelly sandy loam complex, 2-30% slopes	Tallac (85%)-moderately rapid permeability, very slow substratum permeability	@41" weakly cemented till	1	0	0		2.0
TBE	Tallac-Cryumbrepts, wet complex, 2-30% slopes	Tallac (60%)-moderately rapid permeability, very slow substratum permeability Cryumbrepts, wet (25%)-moderately rapid permeability, very slow substratum permeability	Tallac-@41" weakly cemented till Cryumbrepts, wet-stratified loam to clay loam; gravelly, cobbly, or stony	1	0	0		1.7

Soil Unit Symbol(s)	**Soil Unit**	**Permeability by Soil Sub-unit**	**Substratum**	**N**	**N ≥ 4**	**R (%)***	**Min pCi/l**	**Max pCi/l**
TTE	Trojan-Sattley-Kyburz complex, 2-30% slopes	Trojan (45%)-moderately slow permeability, moderately slow substratum permeability Sattley (25%)-moderate permeability, moderate substratum permeability Kyburz (15%)-moderately slow permeability, moderately slow substratum permeability	Trojan @67” slightly fractured andesite Sattley @46” cemented andesitic conglomerate Kyburz @34” weathered andesitic rock	1	0	0		2.9
ULC	Kyburz loam, 2-9% slopes	Kyburz (85%)-moderately slow permeability, moderate substratum permeability	@26” weathered andesite	20	2	10.0	0.2	7.4
WAE	Waca-Windy complex, 2-30% slopes	Waca 60%)-moderately rapid permeability, slow substrate permeability Windy 30%)-moderately rapid permeability, slow substratum permeability	Waca @32” weathered andesitic tuff breccias Windy @46” weathered andesitic tuff breccias	4	0	0	0.7	2.7

Soil Unit Symbol(s)	Soil Unit	Permeability by Soil Sub-unit	Substratum	N	N ≥ 4	R (%)*	Min pCi/l	Max pCi/l
WDF	Waca-Meiss complex, 30-50% slopes	Waca (65%)-moderately rapid permeability, slow substratum permeability Meiss (25%)-moderately rapid permeability, very slow substratum permeability	Waca @32" weathered andesitic tuff breccias Meiss @19" hard volcanic rock	1	0	0		3.2

Reference: U.S. Department of Agriculture, U.S. Forest Service, 2002, Soil Survey Tahoe National Forest Area California, PDF Version 2.0, January, 2002, 444 p.

APPENDIX J-1

Criteria for Radon Potential Ranking of 60 Lake Tahoe Area Geologic Units within California Units are from the *Geologic Map of the Lake Tahoe Basin, California and Nevada*, Saucedo, 2005. *Symbols are defined at the end of the table*.

Geologic Unit	**Radon Survey Data**		**NURE Airborne eU Data**		**NURE and Other Uranium Data**		**Radon Potential**
	% ≥ 4 pCi/L	**Max. pCi/L**	**% GE 5 ppm**	**Max. ppm**	**Median ppm**	**Max. ppm**	**(*other reference*)**
Kbla-Burnside Lake adamellite of Parker (1961)	nd	nd	33.3	8.1	fd	2.6	Very High?
Kbmg-Bryan Meadow Granodiorite	70.0	86.1*	8.9	7.5	fd *fd*	88.6 *5.12, 4.90, 10.10*	Very High (*Otton and others, 1985)*
Kppg-Phipps Pass granodiorite	nd	nd	48.6	10.4	nd	nd	Very High?
Krpa?*-Alaskite at Rubicon Point	nd	nd	58.3	9.8	fd	9.6	Very High?
Pvp-Polaris olivine latite of Birkeland (1961)	fd	24.8	nd	nd	nd *fd*	nd *1.12, 1.69*	Very High? *(NAVDAT)*
Qfp and Qfp?—Flood-plain deposits (Holocene)	fd	11.6	12.0	13.1	fd	12.7	Very High?
Qlt and Qlt?-Lacustrine terrace deposits	64.8	55.5**	16.1	5.8	nd	nd	Very High
Qog-Older glacial deposits-pre-Tahoe deposits--Till	58.3	14.3	5.0	7.1	nd	nd	Very High
Qogo-Older glacial deposits-pre- Tahoe deposits--Outwash	52.9	36.9	55.6	6.8	nd	nd	Very High
QPvd4-Dry Lake volcanic flows of Birkeland (1961)' Wise and Sylvester (2004) youngest flow	52.9	33.5	0.0	2.2	nd	nd	Very High
Jtls-Tuttle Lake Formation of Harwood (1992)	nd	nd	16.0	6.9	nd	nd	High?
Kcfg-Camper Flat granodiorite	nd	nd	15.4	7.6	nd	nd	High?
Kdvg-Desolation Valley granodiorite	nd	nd	10.8	7.5	nd	nd	High?

Geologic Unit	**Radon Survey Data**		**NURE Airborne eU Data**		**NURE and Other Uranium Data**		**Radon Potential**
	% ≥ 4 pCi/L	**Max. pCi/L**	**% GE 5 ppm**	**Max. ppm**	**Median ppm**	**Max. ppm**	**(*other reference*)**
Keg-Granodiorite of East Peak	nd *59.0?*	nd *> 10.0 (Zephyr Cove, NV)*	3.2	5.8	nd *fd*	nd *6.2;* *4.56, 4.09*	High? (*Rigby and others 1994; Otton and others, 1985*)
Keg-Echo Lake granodiorite	fd	15.0	8.3	6.8	nd	nd	High?
Kfpg-Freel Peak granodiorite	nd	nd	5.0	6.4	nd	nd	High?
Mvs?-Unnamed volcanic and intrusive rocks (Miocene)—Fluvial deposits	nd	nd	16.1	7.8	fd	1.7	High?
Pvah-Alder Hill basalt of Birkeland (1961)	25.0	38.8	nd	nd	nd	nd	High
Qgt-Tahoe and Tioga glacial deposits-undivided-Till	nd	nd	8.4	7.5	fd	6.4	High?
Qta and Qta?-Tahoe glacial deposits-Till	44.8	20.6	18.0	6.6	fd	16.8	High
Qvbm-Bald Mountain olivine latite of Birkeland (1961)	38.5	10.2	0.0	3.8	nd *fd*	nd *3.19, 3.45*	High *(NAVDAT)*
Kclg and Kclg?-Granodiorite of Caples Lake	nd	nd	2.3	8.4	5.6?	12.2	Moderate?
Kkqm-Keiths Dome quartz monzonite	nd	nd	3.5	6.1	nd	nd	Moderate?
Kllg-Lovers Leap granodiorite	nd	nd	3.5	6.9	fd	6.1	Moderate?
Krvg?-Rockbound Valley granodiorite	nd	nd	4.7	6.2			Moderate?
Mva-Undivided andesitic and dacitic lahars, flows breccias and volcaniclastic sediments	17.6?	4.6	0.2	8.0	fd *fd*	5.2 *1.48*	Moderate? *(NAVDAT)*
Qg-Glacial deposits undivided (Pleistocene and Holocene?)-Till	nd	nd	2.4	9.1	5.7?	7.6	Moderate?

Geologic Unit	**Radon Survey Data**		**NURE Airborne eU Data**		**NURE and Other Uranium Data**		**Radon Potential**
	% ≥ 4 pCi/L	**Max. pCi/L**	**% GE 5 ppm**	**Max. ppm**	**Median ppm**	**Max. ppm**	**(*other reference*)**
Ql-Lake deposits (Holocene)	fd	5.3	2.7	6.2	nd	nd	Moderate?
Qpc-Prosser Creek alluvium of Birkeland (1961)	fd	6	fd	2.6	nd	nd	Moderate?
QPvd2-Dry Lake volcanic flows of Birkeland (1961); Wise and Sylvester (2004) –second oldest flow	fd	12.3	fd	2.3	nd *fd*	nd *1.12*	Moderate? *(NAVDAT)*
Qti-Tioga glacial deposits—Till	18.2	12.8	6.7	13.5	fd	28.4	Moderate
Qvh-Hirschdale olivine latite of Birkeland (1961)	12.5?	7.4	0.0	3.7	nd	nd	Moderate?
af-Artificial Fill	fd	1.9	22.9	6.6	fd	17.5	Low?
Ja-Anorthosite	nd	nd	0.0	3.6	nd	nd	Low?
Jdg-Diorite and gabbro	nd	nd	0.9	5.0	nd	nd	Low?
Jpgr-Pyramid Peak granite	nd	nd	1.3	6.2	nd	nd	Low?
Jsc-Tuttle Lake Formation of Harwood (1992)-Saylor Canyon Formation	nd	nd	0.0	3.6	nd	nd	Low?
Jtlb-Tuttle Lake Formation of Harwood (1992)-Volcanic Breccia	nd	nd	0.0	3.8	fd	2.2	Low?
Jtlf-Tuttle Lake Formation of Harwood (1992)-Lava flows, basaltic to andesitic	nd	nd	0.0	3.8	nd	nd	Low?
Kcpt-Carson Pass tonalite of Parker (1961)	nd	nd	0.0	4.1	nd	nd	Low?
Kdlg-Dicks Lake granodiorite	nd	nd	1.6	5.5	fd	5.5	Low?
Kepg-Ebbetts Pass granodiorite of Wilshire (1957)	nd	nd	0.0	4.4	fd	1.9	Low?

Geologic Unit	**Radon Survey Data**		**NURE Airborne eU Data**		**NURE and Other Uranium Data**		**Radon Potential**
	% ≥ 4 pCi/L	**Max. pCi/L**	**% GE 5 ppm**	**Max. ppm**	**Median ppm**	**Max. ppm**	**(*other reference*)**
KJdg-Unnamed granitic rocks of the Sierra Nevada batholiths-Diorite and gabbro	nd	nd	0.0	4.9	nd	nd	Low?
Ktlg-Tyler Lake granodiorite of Sabine (1992)	nd	nd	0.0	4.8	nd	nd	Low?
Kwlg-Wrights Lake granodiorite	nd	nd	1.8	6.1	fd	14.5	Low?
Mia and Mia?-Unnamed volcanic and intrusive rocks (Miocene)-andesite, basaltic andesite and latite	nd	nd	0.0	2.7	nd	nd	Low?
Mvaf-Unnamed volcanic and intrusive rocks (Miocene)-Andesite and dacite flows	fd	3.7	0.0	3.8	nd *fd*	nd *1.5*	Low?
Mvbf- Mvaf-Unnamed volcanic and intrusive rocks (Miocene)-Basalt flows	nd	nd	0.0	3.1	nd	nd	Low?
Mvs-Unnamed volcanic and intrusive rocks (Miocene)—Fluvial deposits composed of mafic to intermediate volcanic sediments	nd	nd	0.0	4.2	fd	1.7	Low?
Mvul-Upper lahar sequence of Harwood and Fisher (2002)-Andesitic lahars	nd	nd	0.0	2.2	nd	nd	Low?
Mvulr-Upper lahar sequence of Harwood and Fisher (2002)-Miocene-Pumiceous tuff	nd	nd	0.0	2.7	nd	nd	Low?

Geologic Unit	**Radon Survey Data**		**NURE Airborne eU Data**		**NURE and Other Uranium Data**		**Radon Potential**
	% ≥ 4 pCi/L	**Max. pCi/L**	**% GE 5 ppm**	**Max. ppm**	**Median ppm**	**Max. ppm**	**(*other reference*)**
Pva-Unnamed volcanic and intrusive rocks (Pliocene)—Andesite and basaltic andesite flows	nd	nd	1.4	6.3	nd *fd*	nd *1.07*	Low? (*NAVDAT*)
Q-Alluvium (Holocene and Pleistocene)	fd	3.2	0.0	4.9	fd	8.6	Low?
Qc-Colluvium (Holocene)	nd	nd	0.0	4.7	nd	nd	Low?
Qf-Alluvial fan deposits (Holocene and Pleistocene)			0.0	3.2	fd	7.5	Low?
Qjf-Juniper flat alluvium of Birkeland (1961) Pleistocene	4.8?	4.0	fd	3.2	nd	nd	Low?
Qls-Landslide deposits (Holocene and Pleistocene)	nd	nd	0.0	3.7	fd *fd*	10.2 *1.46*	Low? *(NAVDAT)*
QPot-Older talus deposits (Pliocene and/or Pleistocene)	nd	nd	0.0	3.9	nd	nd	Low?
QPvd1-Dry Lake volcanic flows of Birkeland (1961) and Wise and Sylvester (2004) (Pliocene and/or Pleistocene)-Oldest flow	nd	nd	0.0	2.7	nd	nd	Low?
Qt-Talus deposits (Holocene)	nd	nd	0.0	4.0	nd	nd	Low?

?--Rock unit symbols followed by a “?” on the *Geologic Map of the Lake Tahoe Basin, California and Nevada* (Saucedo, 2005) indicate a the rock unit identification is less certain; a radon potential designation followed by a “?” indicates less certainty because there are fewer than 25 indoor-radon measurements for the geologic unit

*A basement measurement--the highest indoor-radon measurement found during the CDPH-Radon Program Lake Tahoe radon survey

**The highest first floor indoor-radon measurement found during the CDPH-Radon Program Lake Tahoe radon survey

nd = no data

fd = few data

NAVDAT=data from the Western North America Volcanic and Intrusive Rock Database (NAVDAT) www.navdat.org

APPENDIX J-2

Eighty-one Lake Tahoe Area Geologic Units with Unknown Radon Potential
(*no data or too few data for radon potential ranking*)

Unit Symbol	Unit Name
ap	Aplite and pegmatite dikes
bd	Basalt dikes
Jaqd	Quartz diorite at Azure Lake
Jdg?*	Diorite and gabbro (*uncertain*)
Jdi	Diorite
Jlb	Blackwood Creek Formation-Lake Tahoe Sequence of Harwood
Jle	Ellis Peak Formation-Lake Tahoe Sequence of Harwood
Jlp	Pelite unit-Lake Tahoe Sequence of Harwood
Jmd	Microdiorite dikes of Sabine
Jmib	Mafic intrusive breccia
Jsc?	Sailor Canyon Formation
Jtld	Diamictite
JTrm	Metamorphic rocks (undivided sedimentary and volcanic)
JTrms	Metasedimentary rocks
Kbmg?	Bryan Meadow granodiorite (*uncertain*)
Kbp	Breccia pipe
Kcfg?	Camper Flat granodiorite (*uncertain*)
Kcld	Diorite of Caples lake
Kcvg	Granodiorite of Charity Valley
Kdg	Diorite and gabbro
Kdg?	Diorite and gabbro (*uncertain*)
Kfvg	Granodiorite of Faith Valley
Kgag	Glen Alpine granodiorite
Kgqd	Quartz diorite of Grass Lake
Kgr	Granite and granodiorite, undivided
KJgd	Granodiorite, unnamed
KJgr	Granite, unnamed
Kkgg	Granodiorite of Kingsbury Grade
Kklg	Granodiorite of Kinney Lakes
Kppg?	Phipps Pass granodiorite (*uncertain*)
Kqd	Quartz diorite and diorite, unnamed
Krvg	Rockbound Valley granodiorite
Ktcg	Granodiorite of Thornburg Canyon
Kwpg	Granodiorite of Waterhouse Peak
Kwpt	Tonalite West of Waterhouse Peak
Mir	Intrusive rocks (Miocene)-rhyolite
Mls	Serena Creek Formation (Mississippian? or younger)
Mva?	Undivided andesitic & dacitic lahars, flows, breccia, volcaniclastic sediment (*uncertain*)
Mvaf?	Andesite and dacite flows (*uncertain*)

Mvll	Andesitic lahars-Lower lahar sequence of Harwood and Fischer
Mvlla	Andesite flows-Lower lahar sequence of Harwood and Fischer
Mvul?	Andesitic lahars-Upper lahar sequence of Harwood and Fischer
Mvula	Andesite flows-Upper lahar sequence of Harwood and Fischer
Mvulp	Pumiceous tuff-Upper lahar sequence of Harwood and Fischer
OMvr	Rhyolite tuff (Oligocene and Miocene?)-unnamed
Pia	Dikes and intrusive (Pliocene) andesite dikes and breccias
Pib	Dikes and intrusive (Pliocene) olivine basalt dikes and intrusives
Ps	Fluvial and lacustrine deposits (Pliocene)
Pva?	Andesite and basaltic andesite flows (Pliocene)-unnamed, uncert.
Pvahcc	Alder Hill basalt of Birkeland-cinder cone deposits
Pval	Andesite lahars (Pliocene)-unnamed
Pvb	Basalt flows (Pliocene)-unnamed
Pvpt	Polaris olivine latite of Birkeland (Pliocene)-latite tuff & tuff breccia
Pvta	Tahoe City trachyandesite of Wise and Sylvester (Pliocene)
Pvtb	Tahoe City basalt of Wise and Sylvester (Pliocene)
Pvtcc	Tahoe City Trachyandesite of Wise and Sylvester (Pliocene) - cinder cone deposits
Qb	Beach deposits (Holocene)
Qg?	Glacial deposits undivided-Till (*uncertain*)
Qgo	Older glacial deposits--Pre-Tahoe-Till
Qm	Mudflow deposits of Birkeland (Holocene and/or Pleistocene)
Qob	Older beach deposits (Pleistocene)
Qol	Older lake deposits (Pleistocene)
Qpc?	Prosser Creek alluvium of Birkeland (Pleistocene) (*uncertain*)
QPia	Unnamed intrusive rocks-intrusive andesite and latite
QPs	Unnamed gravels, sand and alluvium (Pliocene and/or Pleist.)
QPvb	Unnamed volcanic rocks (Pliocene and/or Pleistocene)
QPvb, maar	Unnamed volcanic rocks (Plio. and/or Pleist.) maar
QPvbc	Big Chief basalt of Birkeland (Pliocene and/or Pleistocene)
QPvbu	Burton Creek basalt of Wise and Sylvester (Plio. and/or Pleist.)
QPvd3	Dry Lake volcanic flows of Birkeland-second youngest)
QPvlf	Lake Forest basalt of Wise and Sylvester (Plio. and/or Pleist.)
QPvpm	Page Meadow basalt of Wise and Sylvester (Plio. and/or Pleist.)
QPvpm?	Page Meadow basalt of Wise and Sylvester (*uncertain*)
Qtao	Tahoe glacial deposits (Pleistocene)-outwash deposits
Qti?	Tioga glacial deposits (Pleistocene)-till (*uncertain*)
Qtio	Tioga glacial deposits (Pleistocene)-outwash deposits
Qvbmcc	Bald Mountain olivine latite of Birkeland-cinder cone deposits
Qvhcc	Hirschdale olivine latite of Birkeland-cinder cone deposits
Qvht	Hirschdale olivine latite of Birkeland-basaltic tuff
Qyg	Younger glacial deposits (Holocene)
Trls	Tuttle Lake Formation of Harwood-Limestone (Late Jurassic?)

*See APPENDIX J-1 note for “?”

APPENDIX K

Possible Geologic Models for Elevated Radon Potential Zones in the Lake Tahoe Area

Introduction

In most cases, areas with increased indoor-radon problems have higher radon abundances in the shallow subsurface. They also have subsurface conditions such that this radon is readily available for entry into buildings if pathways into a building and a driving force are available.

Geologic models for radon-problem areas attempt to address how increased amounts of radon become present in the subsurface, and how this radon can readily move from its point of origin in the subsurface to a building's foundation or basement walls. The following geologic models are proposed for Lake Tahoe areas with higher radon potential. Relationships observed between indoor-data, geology, uranium abundance, and soil properties, and on relationships identified by others in previous published and unpublished Lake Tahoe research are the basis for the proposed models. Detailed research projects would be needed to evaluate the validity of each proposed models listed below. The models are listed in "southern Lake Tahoe" and "northern Lake Tahoe" groups because of geologic differences between south and north Lake Tahoe.

Radon and Climate

When indoor-air is heated it rises and escapes through the upper portions of the building. This induces a difference in pressure between the building and the underlying soil, drawing soil-air with radon into the building. This is the predominant driving force for radon entry into buildings (WRRTC, 2004, unit 3 p. 10). The long duration of the heating season area must be considered an important factor contributing to elevated indoor-radon concentrations in the Lake Tahoe area. This phenomenon, along with limited ventilation with doors and windows being closed in winter, is most often the reason why indoor-radon concentrations are higher in winter than in summer. For a given geologic setting, California areas with warmer winters would be expected to have significantly fewer ≥ 4 pCi/L homes than in cooler winter areas, such as Lake Tahoe.

Proposed Geologic Models for southern Lake Tahoe areas with increased radon potential

1. Deeply weathered (decomposed) granitic rocks with elevated background uranium contents

   Argument: Granitic rocks with elevated background uranium contents in the south Lake Tahoe area have been previously documented in this study. Bonham and Burnett (1976) indicate decomposed granitic horizons (grus) extending from the surface to depths of up to 100 feet are present in the southern Lake Tahoe area. Such highly permeable horizons allow radon produced from large volumes of granitic rock to easily migrate to the shallow subsurface for entry into buildings.

2. Glacial deposits composed of sediments derived from granitic rocks with elevated background uranium contents

Argument: Glacial deposits in the southern Lake Tahoe area are largely composed of granitic derived sediments. High permeabilities of glacial deposits and associated soils are able to provide soil air to overlying structures from larger radon source volumes. This high permeability can result in moderately elevated indoor-radon concentrations even from glacial soils with relatively low uranium contents (Gundersen and others, 1992).

3a. Lacustrine or fluvial deposits composed of sediments derived from granitic rocks with elevated background uranium contents

Argument: Lacustrine and fluvial deposits in the southern Lake Tahoe area are often dominated by sediment derived from granitic rocks. Elevated background uranium granitic rocks in southern Lake Tahoe have been documented in this study so these sediments could contain significant amounts of radon in the shallow subsurface available for migration into overlying buildings.

3b. Lacustrine or fluvial deposits containing near surface organic-rich horizons with high uranium content

Argument: Organic-rich sediment containing up to several thousand parts per million uranium has been documented in a marsh near Zephyr Cove, Nevada, by Otton and others (1985). If uranium at these concentrations has been emplaced in organic rich horizons in fluvial or lacustrine sediment deposits at other places in the Lake Tahoe area for sufficient time (at least several thousand years?), such horizons could provide significant amounts of radon to overlying buildings.

Proposed Geologic Models for northern Lake Tahoe areas with increased radon potential

4. Volcanic rocks with elevated background uranium contents

Argument: Review of available uranium analyses for northern Lake Tahoe volcanic rocks identified during this study found only a few had uranium abundances exceeding 2.5-2.7ppm, average crustal background uranium. This limited support for this model suggests other features or mechanisms may be present to enhance indoor-radon concentrations in the northern Lake Tahoe area. Possibilities include enhanced areas of permeability allowing radon to be drawn from a larger volume of normal uranium abundance volcanic rocks, or the presence of unidentified higher uranium content geologic units below volcanic rock areas (see model 5).

5. Volcanic rocks with low to average uranium contents overlying volcanic, granitic, or sedimentary rock units with elevated background uranium contents

   Argument: If volcanic rock units are not too thick, radon from underlying granitic rocks or sedimentary rock units with elevated uranium contents could migrate to the shallow subsurface for entry into buildings. The presence of granitic rocks or sediments with significantly elevated uranium in the subsurface of northern Lake Tahoe is uncertain at this point. Radon migration may require movement by flow through fractures, rather than diffusion, because of volcanic unit thicknesses (tens of meters to several hundred meters, George Saucedo, 2009 written communication).

6. Glacial and fluvial deposits composed of sediments derived from volcanic rocks with elevated background uranium contents

   Argument: Currently it is unknown if glacial or fluvial deposits contain significant quantities of sediment derived from elevated uranium volcanic rocks. The presence of underlying rock units with elevated uranium contents, as discussed in model 5, is one possibility. The relatively high permeability of many glacial and fluvial deposits facilitates radon movement from either from higher these elevated uranium deposits or from underlying elevated uranium units to the shallow subsurface where it is available to enter homes. See model 7 as an alternative.

7. High permeability in glacial and certain sediment deposits with low to average uranium contents

   Argument: Many glacial deposits are highly permeable. Such glacial deposits and associated soils are able to provide soil air to overlying structures from larger source volumes than less permeable deposits and soils. Some fluvial and lacustrine sedimentary deposits and their associated soils are also highly permeable. A high permeability setting can result in moderately elevated indoor-radon concentrations even from glacial soils with relatively low uranium contents (Gundersen and others, 1992). A similar relationship is possible for high permeability non-glacial deposits.

APPENDIX L

Descriptive Statistics and Statistical Comparison of Indoor Measurements (non-transformed) by Lake Tahoe Radon Potential Zone

	All Indoor Radon Data	Very High Zone Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	443	188	120	91	37	7
Mean	5.060	7.432	4.333	2.740	1.549	2.543
Std. Dev.	6.655	8.762	4.615	2.360	1.140	2.002
Std. Error	0.316	0.639	0.421	0.247	0.187	0.757
C.I. of Mean	0.621	1.261	0.834	0.492	0.380	1.852
Range	85.900	85.900	38.600	12.600	3.800	4.700
Maximum	86.100	86.100	38.800	12.800	4.000	4.900
Minimum	0.200	0.200	0.200	0.200	0.200	0.200
Median	3.200	5.600	3.100	2.200	1.300	3.200
25%	1.700	3.100	1.800	1.425	0.775	0.475
75%	6.200	9.200	5.400	3.175	2.000	4.300
Skewness	6.128	5.231	4.237	2.441	0.849	-0.157
Kurtosis	59.257	39.274	26.625	7.206	-0.370	-2.247
K-S Dist.	0.233	0.205	0.195	0.192	0.150	0.208
K-S Prob.	<0.001	<0.001	<0.001	<0.001	0.035	0.429
Sum	2241.500	1397.200	519.900	249.300	57.300	17.800
Sum of Squares	30916.330	24739.980	4787.230	1184.270	135.530	69.320

APPENDIX M

Descriptive Statistics and Statistical Comparison of Indoor Measurements (Log 10-transformed) by Lake Tahoe Radon Potential Zone

	All Indoor Radon Data	Very High Zone Radon Data	High Zone Radon Data	Moderate Zone Radon Data	Low Zone Radon Data	Unknown Zone Radon Data
Size	443	188	120	91	37	7
Mean	0.492	0.690	0.478	0.307	0.0537	0.171
Std. Dev.	0.446	0.422	0.386	0.356	0.379	0.583
Std. Error	0.0212	0.0308	0.0352	0.0373	0.0623	0.220
C.I. of Mean	0.0417	0.0607	0.0698	0.0741	0.126	0.539
Range	2.634	2.634	2.288	1.806	1.301	1.389
Maximum	1.935	1.935	1.589	1.107	0.602	0.690
Minimum	-0.699	-0.699	-0.699	-0.699	-0.699	-0.699
Median	0.505	0.748	0.491	0.342	0.114	0.505
25%	0.230	0.491	0.255	0.154	-0.111	-0.392
75%	0.792	0.964	0.732	0.502	0.301	0.632
Skewness	-0.374	-0.666	-0.457	-0.524	-0.494	-0.758
Kurtosis	0.578	1.599	1.316	1.074	-0.490	-1.485
K-S Dist.	0.0519	0.0770	0.0693	0.104	0.102	0.288
K-S Prob.	0.006	0.009	0.165	0.016	0.402	0.081
Sum	218.063	129.666	57.313	27.904	1.985	1.195
Sum of Squares	195.306	122.730	45.103	19.962	5.268	2.243

APPENDIX N

Results of the Kolmogorov-Smirnov Normality Test for Untransformed and Log(10) Transformed Indoor-Radon Data, by Radon Potential Zone

A test that fails indicates that the data varies significantly from the pattern expected if the data was drawn from a population with a normal distribution. A test that passes indicates that the data matches the pattern expected if the data was drawn from a population with a normal distribution.

Data	N	K-S Distribution	P	Result
All Data--Untransformed	443	0.233	<0.001	Failed
All Data--Log(10) Transformed	443	0.052	=0.006	Failed
Very High Zone-Untransformed	188	0.205	<0.001	Failed
Very High Zone--Log(10) Transformed	188	0.077	=0.009	Failed
High Zone-Untransformed	120	0.195	<0.001	Failed
High Zone--Log(10) Transformed	120	0.069	=0.165	Passed
Moderate Zone-Untransformed	91	0.192	<0.001	Failed
Moderate Zone--Log(10) Transformed	91	0.104	=0.016	Failed
Low Zone-Untransformed	37	0.150	=0.035	Failed
Low Zone--Log(10) Transformed	37	0.102	>0.200	Passed
Unknown Zone-Untransformed	7	0.208	>0.200	Passed
Unknown Zone--Log(10) Transformed	7	0.288	=0.081	Passed

APPENDIX O-1

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data Between the Very High Radon Potential Zone and other Radon Potential Zones

Mann-Whitney Rank Sum Test					
Indoor-Rn Population Comparisons	***N***	***Missing***	***Median***	***25%***	***75%***
Very High Zone	188	0	5.600	3.100	9.200
High Zone	120	0	3.100	1.800	5.400
Result	T=14755.500 n(small)=120 n(big)=188 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
Very High Zone	188	0	5.600	3.100	9.200
Moderate Zone	91	0	2.200	1.425	3.175
Result	T=7931.000 n(small)=91 n(big)=188 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
Very High Zone	188	0	5.600	3.100	9.200
Low Zone	37	0	1.300	0.775	2.000
Result	T=1537.000 n(small)=37 n(big)=188 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
Very High Zone	188	0	5.600	3.100	9.200
Unknown Zone	7	0	3.2	0.475	4.300
Result	T=330.000 n(small)=7 n(big)=188 (P=0.015) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.015)				

APPENDIX O-2

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data Between the High Radon Potential Zone and the Moderate, Low and Unknown Radon Potential Zones

Mann-Whitney Rank Sum Test					
Indoor-Rn Population Comparisons	***N***	***Missing***	***Median***	***25%***	***75%***
High Zone	120	0	3.100	1.800	5.400
Moderate Zone	91	0	2.200	1.425	3.175
Result	T=8105.000 n(small)=91 n(big)=120 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
High Zone	120	0	3.100	1.800	5.400
Low Zone	37	0	1.300	0.775	2.000
Result	T=1617.000 n(small)=37 n(big)=120 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
High Zone	120	0	3.100	1.800	5.400
Unknown Zone	7	0	3.2	0.475	4.300
Result	T=345.000 n(small)=7 n(big)=120 (P= 0.279) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P= 0.279)				

APPENDIX O-3

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data Between the Moderate, Low, and Unknown Radon Potential Zones

Mann-Whitney Rank Sum Test					
Indoor-Rn Population Comparisons	***N***	***Missing***	***Median***	***25%***	***75%***
Moderate Zone	91	0	2.200	1.425	3.175
Low Zone	37	0	1.300	0.775	2.000
Result	T=1750.500 n(small)=37 n(big)=91 (P= <0.001) The difference in the median values between the two groups is greater than would be expected by chance; there is a statistically significant difference (P= <0.001)				
Moderate Zone	91	0	2.200	1.425	3.175
Unknown Zone	7	0	3.2	0.475	4.300
Result	T=351.000 n(small)=7 n(big)=91 (P= 0.956) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P= 0.956)				
Low Zone	37	0	1.300	0.775	2.000
Unknown Zone	7	0	3.2	0.475	4.300
Result	T=190.500 n(small)=7 n(big)=37 (P=0.297) The difference in the median values between the two groups is not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant difference (P= 0.279)				