SPECIAL REPORT 238

RADON POTENTIAL IN WESTERN TULARE COUNTY, CALIFORNIA

2016

CALIFORNIA GEOLOGICAL SURVEY
Department of Conservation

STATE OF CALIFORNIA
EDMUND G. BROWN, JR.
GOVERNOR

THE NATURAL RESOURCES AGENCY
JOHN LAIRD
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DAVID BUNN
DIRECTOR

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

SPECIAL REPORT 238

RADON POTENTIAL IN WESTERN TULARE COUNTY, CALIFORNIA

By

Ronald K. Churchill, Ph.D.
PG #4265

2016

CALIFORNIA GEOLOGICAL SURVEY'S PUBLIC INFORMATION OFFICES:

Southern California Regional Office
320 W 4th Street, Suite #850
Los Angeles, CA 90013
(213) 239-0878

Library and Headquarters Office
801 K Street, MS 14-31
Sacramento, CA 95814-3531
(916) 327-1850

Bay Area Regional Office
345 Middlefield Road, MS 520
Menlo Park, CA 94025
(650) 688-6327

TABLE OF CONTENTS

FIGURES

TABLES

Page Intentionally Blank

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 from underlying soil and rock into homes and concentrate in the indoor air, posing a significant lung cancer risk for the residents. The U.S. Environmental Protection Agency (U.S. EPA, 2012) estimates indoor-radon exposure results in 21,000 lung cancer deaths annually in the United States. The U.S. EPA recommended action level for indoor radon is 4.0 picocuries per liter (pCi/L).

Between December 2009 and April 2010, the California Department of Public Health (CDPH), Indoor Radon Program, surveyed 498 homes in Tulare County for indoor-radon using short-term radon detectors. Survey results range from 0.5 pCi/L, the detection limit, to 33.0 pCi/L. The highest indoor-radon measurement in CDPH records for a Tulare County home is 82.3 pCi/L, made in 2003.

This report documents the data and procedures used by the California Geological Survey (CGS) to develop the radon potential map for western Tulare County. Data used are:

- 2009-2010 CDPH-indoor-radon survey data for Tulare County
- National Uranium Resource Evaluation (NURE) Airborne gamma-ray survey data for uranium in soil and rocks
- NURE Laboratory data for uranium in stream sediment and soil samples
- An unpublished 1:100,000-scale digital map layer of western Tulare County surficial geologic units
- CGS Bakersfield and Fresno 1:250,000-scale Geologic Atlas geologic maps (1 inch equals 3.946 miles)
- Natural Resources Conservation Service (NRCS) Tulare County soil maps and soil permeability data

Evaluating the geologic unit radon potentials involved linking indoor-radon data to individual units using a geographic information system (GIS), then assigning each unit a preliminary radon potential based on percent of indoor-radon data at or exceeding 4.0 pCi/L as follows:

- High potential—20 percent or more
- Moderate potential—5 to 19.9 percent
- Low potential—less than 5 percent; and
- Unknown potential—insufficient data to assign a potential.

Next, National Uranium Resource Evaluation program (NURE), soil uranium data, Natural Resource Conservation Service (NRCS) soil permeability data, and geologic unit radon potentials determined in previous California radon studies were reviewed. For units with few or no indoor-radon data, unless the additional data review supported a different potential their preliminary potential became their final potential.

To create radon potential zone areas for the western Tulare County map, geologic units with the same radon potential ranking were grouped together to define the radon potential zones. All high radon potential unit occurrences, collectively, define high potential zone areas, low potential units the low potential zone areas, and unknown potential units the unknown potential zone areas. This study found no moderate potential geologic units in western Tulare County, so the western Tulare County radon potential map shows no moderate radon potential areas. A final map validity check involved statistical comparison of high and low potential zone radon-data populations to confirm each population was statistically distinct. The resulting map (Plate 1) shows high potential zone areas comprising 33.3 percent of western Tulare County, low potential zone areas 60.7 percent, and unknown potential areas 6.0 percent.

The CGS 1:100,000-scale radon potential zone map for western Tulare County is informational, not regulatory. Its purpose is as a guide for prioritizing areas for public education about radon, and for targeting additional indoor-radon testing activities. A building's location on the map does not indicate its indoor-radon concentration. All radon zones typically contain some homes with radon above 4.0 pCi/L and some below 4.0 pCi/L. The only way to identify specific homes and buildings exceeding 4.0 pCi/L is through testing. Although the CDPH survey did not identify homes above 4.0 pCi/L within Tulare County low zone areas, additional testing will likely identify some such homes.

Based on CDPH indoor-radon survey results, the CGS radon potential zone map, and 2010 U.S. Census data, an estimated 95,468 people live in residences with indoor-air radon concentrations at or exceeding 4.0 pCi/L in western Tulare County. An estimated 9,938 people live in homes that will test 10.0 pCi/L or higher, and an estimated 602 people live in homes that will test at 20.0 pCi/L or higher. Indoor-radon testing should be encouraged in Tulare County, especially in high radon potential zone areas, which represent 33.3 percent of western Tulare County. In addition, testing should be encouraged within unknown potential areas and the Sierra Nevada Mountains—where available data are insufficient for radon potential map construction. Those considering building a new home may wish to consider radon resistant new construction practices, particularly at sites within high radon potential areas. Post construction radon mitigation is possible, if necessary, but will be more expensive than the cost of adding radon-reducing features during home construction.

INTRODUCTION

Purpose

This report documents the data and procedures used by the California Department of Conservation, California Geological Survey (CGS) to develop the 2016 radon potential zone map for western Tulare County. CGS produced the map for the California Department of Public Health-Indoor Radon Program (CDPH-Indoor Radon Program) through an interagency agreement. The report includes radon potentials for individual geologic units and estimates of the county population exposed to 4 picocuries per liter (pCi/L) or higher indoor-radon concentrations. The report contains only minimal radon background, health and testing information. No information on radon remediation of homes and buildings is included in the report.

The following websites have information about radon, related health issues, testing, and remediation:

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

Background Information about 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 concentrations of five to several tens of ppm and occasionally higher. All buildings have some potential for elevated indoor-radon levels because radon is always present in the underlying soils and rocks. Buildings located on rocks and soils containing higher concentrations of uranium often have an increased likelihood of elevated indoor-radon levels. Breathing air with elevated radon gas abundance over long periods 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, 2012) estimated 21,000 people die in the United States annually from lung cancer caused by to radon exposure.

Indoor-radon concentrations are reported in picocuries per liter (pCi/L) in the United States. The average indoor-radon concentration in American homes is about 1.3 pCi/L (U.S. EPA, 2012). Average outdoor air radon concentration 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 one in 15 homes (6.7 percent) in the United States has radon levels ≥ 4.0 pCi/L.

Indoor-radon concentration is used as a guide for determining potential exposure and for identifying building that require remedial action. However, it is inhalation of two radon decay products, polonium-218 and polonium-214, that most likely leads to lung cancer. These polonium isotopes have very short half-lives (see Table 1). When they enter the lungs, they attach to lung tissue or trapped dust particles and quickly undergo radioactive decay, emitting high-energy alpha particles. The alpha particles are thought to damage the DNA in lung tissue cells, causing cancer (Brookins, 1990). In contrast, most longer-lived radon-222 is exhaled before undergoing radioactive decay.

Radon gas readily moves through rock and soil along micro-fractures and 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 underlying soil into buildings when air pressure inside the buildings is lower than air pressure in the soil, and pathways for radon entry are available. Heating indoor air, using exhaust fans, and wind blowing across a building will all lower a building's internal air pressure. Pathways include cracks in slab foundations or basement walls, pores and cracks in concrete blocks, through-going floor-to-wall joints, and openings around pipes. Because radon enters buildings from the adjacent soil, indoor-radon concentrations 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).

Nuclide (Isotope)	**Principal mode of radioactive decay**	**Half-life**
Uranium-238	Alpha	4.5 X 10^{9} years
Thorium-234	Beta	24.1 days
Protactinium-234	Beta	1.2 minutes
Uranium-234	Alpha	2.5 X 10^{5} years
Thorium-230	Alpha	7.5 X 10^{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 X 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-does not show branching or some short-lived isotopes. Modified from Appleton, 2013, p. 241)

The most common indoor-radon testing methods utilize either charcoal (for 2 to 3 day short-term tests) or alpha-track type detectors (for 90 day to one-year long-term tests). These tests are simple to perform, inexpensive, and homeowners can do this testing. Homeowners expose the radon detector according to manufacturer instructions and then send it to a laboratory for analysis, which is included in the detector cost. Typical turnaround time for test results from the laboratory is one to two weeks. Alternatively, one may hire professional certified radon testers to do the testing. The CDPH Radon Program maintains lists of currently certified radon testers, mitigators and laboratories on its website: http://www.cdph.ca.gov/healthinfo/environhealth/Pages/RadonServiceProviders.aspx .

Long-term tests have advantages over short-term tests. Longer exposure times "average out" short-term fluctuations in radon levels, such as those caused by daily and seasonal weather changes. In addition, long-term tests utilize open-house conditions with windows and doors open or shut based on residents preferences. Short-term tests utilize closed house conditions to maximize radon concentration during the measurement period. Consequently, long-term measurements should more accurately represent a person's exposure to indoor-radon. However, short-term measurements are more common because of the shorter time required. More often than not, if a short-term indoor radon test result is several pCi/L above 4 pCi/L, follow-up short-term and long-term tests will also be above 4 pCi/L (see Appendix D).

Radon Potential Map Characteristics, Use and Limitations

Radon potential maps developed by CGS for the CDPH-Indoor Radon Program show areas where geologic conditions create higher or lower likelihoods for homes exceeding 4 pCi/L. Also shown are areas lacking data for radon potential determination. The number of individuals exposed to excessive radon levels for an area can be estimated using U.S. Census track data and a radon zone map.

Radon potential maps are advisory, not regulatory. Their purpose is as guides to help federal, state and local government agencies and private organizations target and prioritize radon program activities and resources. A building's location on the map does not indicate it has excessive indoor radon levels. In addition to geology, local variability in soil permeability, climatic conditions, and factors such as home design, construction, condition, and usage preferences may influence indoor radon levels. Testing is the only way to accurately determine the radon concentration in a specific building or home, regardless of the radon zone. All radon zones typically have some buildings and homes with indoor radon levels ≥ 4.0 pCi/L as well as some with radon levels < 4 pCi/L.

Development of the Western Tulare County Radon Potential Map

The western Tulare County radon potential zones were developed using data from the following sources:

- CDPH-Radon Program 2009-2010 Tulare County indoor-radon survey test data for 498 residences and the 2010 CDPH-Radon Zip Code database.

- NURE (National Uranium Resource Evaluation) Project Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) Program soil and sediment uranium data for the Bakersfield, Fresno and Mariposa 1X2 degree quadrangles.

- NURE (National Uranium Resource Evaluation) Project Aeroradiometric Survey data for equivalent uranium (eU) for the Bakersfield and Fresno 1X2 degree quadrangles.

- An unpublished 1:100,000-scale digital shape file of surficial geology—alluvial fans, other alluvial deposits, basins and bedrock in western Tulare County developed for this project by Clifton Davenport, Senior Engineering Geologist, California Geological Survey (Figure 1, Appendix E)

- Soil Survey Geographic (SSURGO) database for Tulare County, Western Part, California, ca659; U.S. Department of Agriculture, Natural Resources Conservation Service (2013)

- Soil Survey Geographic (SSURGO) database for Tulare County, Central Part, California, ca660; U.S. Department of Agriculture, Natural Resources Conservation Service (2013)

- Soil Survey Geographic (SSURGO) database for Kern County, Northeastern Part, and Southeastern Part of Tulare County, California, ca668; U.S. Department of Agriculture, Natural Resources Conservation Service (2013)

- Soil Survey Geographic (SSURG) database for Sequoia National Forest Parts of Fresno, Kern and Tulare Counties, California, ca760; U.S. Department of Agriculture, Natural Resources Conservation Service (2013)

- U.S. Census Bureau 2010 census block data for Tulare County, California

The Tulare County radon potential map development steps were:

1) Group indoor-radon survey data by surficial geologic unit using a geographic information system (GIS)

2) Preliminarily assign surficial geologic units to one of four radon potential categories based on the percentage of indoor-radon measurements at or exceeding 4 pCi/L (see step 7 for categories), and the number and magnitude of indoor-radon measurements per unit exceeding 10.0 pCi/L, and the total number of measurements.

3) Grouping NURE project uranium soil and sediment data and airborne equivalent uranium (eU) data by surficial geologic unit using GIS.

4) Rating western Tulare County surficial units as to their likelihood of having problem radon homes based on the percentage of NURE eU data exceeding 5.0 ppm uranium (twice the average crustal uranium abundance of 2.5 ppm).

5) Grouping 2009-2010 CDPH-Radon Program indoor-radon survey data for Tulare County by NRCS soil unit using GIS.

6) Reviewing soil permeability, shrink-swell character, hydrologic soil group information for soil units and indoor-radon data to see if these soil characteristics relate to higher or lower indoor-radon concentration homes.

7) Assigning final radon potentials to all 1:100,000-scale surficial geologic units in western Tulare County using information from steps 2, 4, 6 and 7. Radon potential categories are defined by percentages of short-term tests likely to exceed 4.0 pCi/L as follows:

    - High—20.0 percent or more ≥ 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—units with insufficient data for estimating the percent of ≥ 4.0 pCi/L indoor measurements

8) Group surficial unit areas with similar radon potentials to form radon potential zones using GIS.

9) Statistically compare indoor-radon data populations for the high and low radon potential zones to confirm that each zone represents a distinct indoor-radon data population.

10) Estimate the number of people living in each radon zone by using GIS to compare the census tract data to the radon zones and estimate the number of people residing in homes at or above 4 pCi/L.

Following sections of this report provide more details on data used and the results of these steps.

Portions of radon potential zones with faults and shear zones often have increased potential for elevated indoor-radon concentrations because such features provide pathways for radon flow. However, the 1:100,000 scale Tulare County radon potential zone map does not show fault and shear zone locations. Fractures less than an inch wide can be significant radon pathways. Accurate representation of such fractures on a 1:100,000-scale map is not possible. A feature must be at least 100-200 square feet in size to show on a map at this scale and the accuracy of that feature's location is commonly +/- tens to hundreds of feet. Additionally, soil and alluvium may obscure faults and shear zones, especially smaller ones, or prevent their precise location. Consequently, at 1:100,000-scale mapping, it is better to base radon testing priorities on zone designation rather than attempt to target fault and shear zone locations. Detailed investigations of indoor-radon and fault or shear zone relationships require use or development of 1:24,000 or more detailed scale geologic maps.

WESTERN TULARE COUNTY SURFICIAL GEOLOGY DIGITAL LAYER

CGS radon potential map development requires appropriate geologic maps at 1:100,000-scale or more detailed scales. Geologic maps at smaller scales (less detail) typically do not work well for radon mapping. This is because geologic units from smaller-scale maps are more likely to be a composite of multiple lithologies, and each lithology may have a distinctly different radon potential. Ideal geologic maps for radon potential map development are those with geologic units having a dominant lithology with relatively narrow ranges of variation in chemical and physical properties.

Western Tulare County geology consists largely of alluvial fans and other surficial geologic units. This is where most of the county's population and towns are located. No geologic maps showing surficial geologic units at 1:100,000-scale or at more detailed scales have been published for western Tulare County as a whole. Consequently, part of the radon potential map development for western Tulare County required compilation of a digital layer of these surficial geologic units for use at 1:100,000-scale. Clifton Davenport, of the CGS Regional Mapping Program, developed a surficial geology digital layer for use in this radon-mapping project using GIS and a number of information sources (Appendix E). Figure 1 shows Davenport's surficial geology layer (at reduced scale) overlain on a simplified Tulare County base map. Note that he divided the large Kaweah River alluvial fan into five subfans.

Briefly, western Tulare County consists of a number of alluvial fan deposits, inter- and intra-fan basin deposits, with lacustrine (Tule Lake) sediments present in the southwest portion of the study area. Three alluvial fans are dominant, Kaweah River, Kings River and Tule River. Moderate to relatively large size watersheds extending into the central and eastern portions of the Sierra Nevada Mountains supply sediment to these fans.

Kaweah, Kings and Tule fan sediments are predominantly arkosic gravel, sand silt and clayey silt derived from granitic rocks. The older (Pleistocene and Recent) and younger (Recent) alluvium in these fans is generally moderately to highly permeable (Croft and Gordon, 1968). The younger (Recent) sediments in the Kaweah River fan are about 25 feet thick at Visalia and about 55 feet thick in the Tule River Fan. The older (Pleistocene and Recent) sediments consist of upper highly permeable oxidized deposits, 600 feet in maximum thickness, and underlying moderately permeable reduced deposits, about 1000 feet in maximum thickness (Croft and Gordon, 1968).

Smaller fans in western Tulare County relate to small to moderate size watersheds within the foothills and the westernmost portion of the Sierra Nevada Mountains. These watersheds supply their associated fans with sediment derived from one or more of the following rock types: metasedimentary, metagabbro, ultramafic and mafic intrusive rocks, and granitic intrusive rocks.

Basin deposits interfinger with younger alluvium and consist of gray, fossiliferous clay, silt and fine-grained sand overlying lacustrine and marsh deposits. These deposits are less than 50 feet thick (Croft and Gordon, 1968). Basin deposits are associated with fans in two ways. Some basin deposits are located between fans (inter-fan basins). Other basin deposits are surrounded by sediments of a particular fan (intra-fan basins). The latter mostly occur in the western distal portions of the fans.

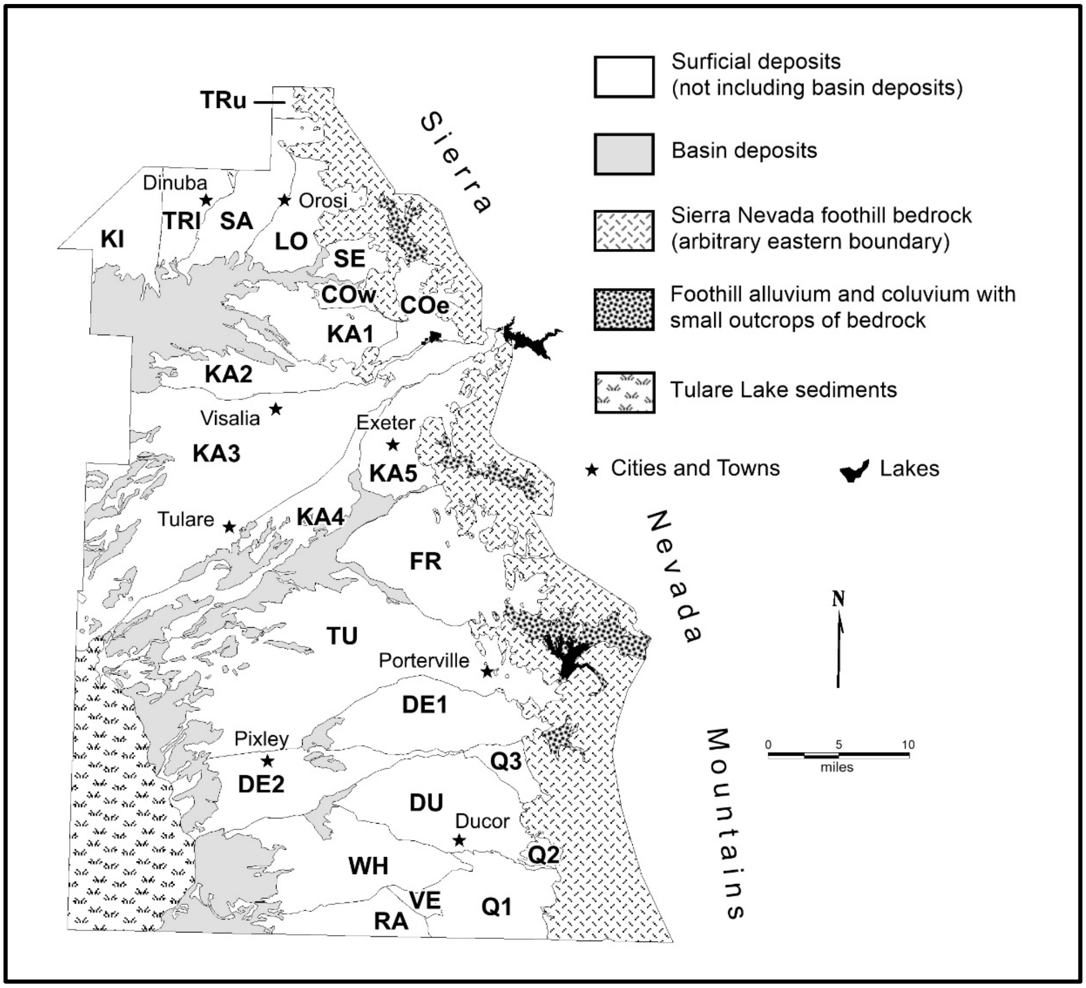

Figure 1. Map showing surficial geologic units for western Tulare County, California, developed by Davenport (2013)

Unit Code	Unit Name	Unit Code	Unit Name
COe	Cottonwood East Fan	LO	Long Creek Fan
COw	Cottonwood West Fan	Q1	Very Old Fan 1
DE1	Deer Creek 1 Fan	Q2	Very Old Fan 2
DE2	Deer Creek 2 Fan	Q3	Very Old Fan 2
DU	Ducor Fan	RA	Rag Gulch Fan
FR	Frazier Creek Fan	SA	Sand Creek Fan
KA1	Kaweah 1 Fan	SE	Seville Fan
KA2	Kaweah 2 Fan	TRl	Traverse Creek Lower Fan
KA3	Kaweah 3 Fan	TRu	Traverse Creel Upper Fan
KA4	Kaweah 4 Fan	TU	Tulare River Fan
KA5	Kaweah 5 Fan	VE	Vestal Fan
KI	Kings River Fan	WH	White River Fan

THE TULARE COUNTY SHORT-TERM INDOOR-RADON SURVEY AND OTHER AVAILABLE INDOOR-RADON DATA

Overview

The CDPH-Radon Program conducted a survey of indoor radon in Tulare County homes between December 2009 and April 2010. The CDPH-Radon program solicited participation via direct mailing to 14,411 Tulare County homeowners. Four hundred ninety-eight homeowners (3.5 percent) participated in the survey. Each participant received a free charcoal detector with instructions for placement and exposure. After exposure, participants mailed their detector to the Radon Program contract lab for measurement. The contract lab provided test results directly to survey participants within several weeks of detector receipt.

The primary goal of the survey 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.

Figure 2 shows the geographic distribution of radon survey homes in Tulare County. Areas of high and low survey sample densities reflect high and low population density variations in the county. Figure 3 shows the geographic distribution of the 142 survey homes testing ≥ 4.0 pCi/L.

The CDPH radon survey concentrations range from 0.5 pCi/L, the reported detection limit, to 33.0 pCi/L, the latter for a second floor measurement of a home in Posey. The highest indoor-radon measurement in CDPH records for Tulare County is 82.3 pCi/L, from Three Rivers. No specifics regarding floor, room or foundation type are available for this measurement. Table 2 provides foundation type, test floor and test room information and the name of the geologic unit present for those homes with radon survey measurements of 10.0 pCi/L or above.

Table 3a summarizes Tulare County indoor-radon survey results by Zip Code zone and City/Region. For comparison, Table 3b summarizes CDPH on-line Zip Code radon database data for Tulare County Zip Code zones accumulated by CDPH since 1989. The CDPH on-line Zip Code database includes the 2009-2010 Tulare County radon survey data shown in Table 3a. The 1989-2010 CDPH data, summarized in Table 3b cannot be used for evaluating the radon potential of particular geologic units because the only location information for many of the data is Zip Code. More precise test location information is required for geologic unit evaluation. Another complication with the CDPH 1989-2010 database is

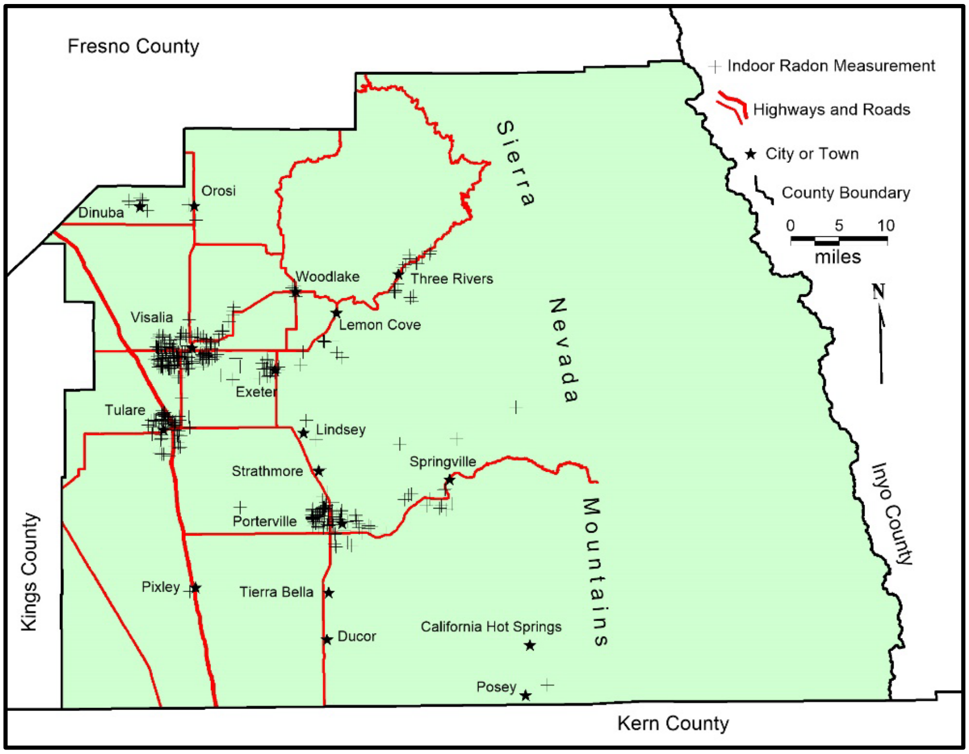

Figure 2. CDPH 2009-2010 Tulare County radon survey test locations

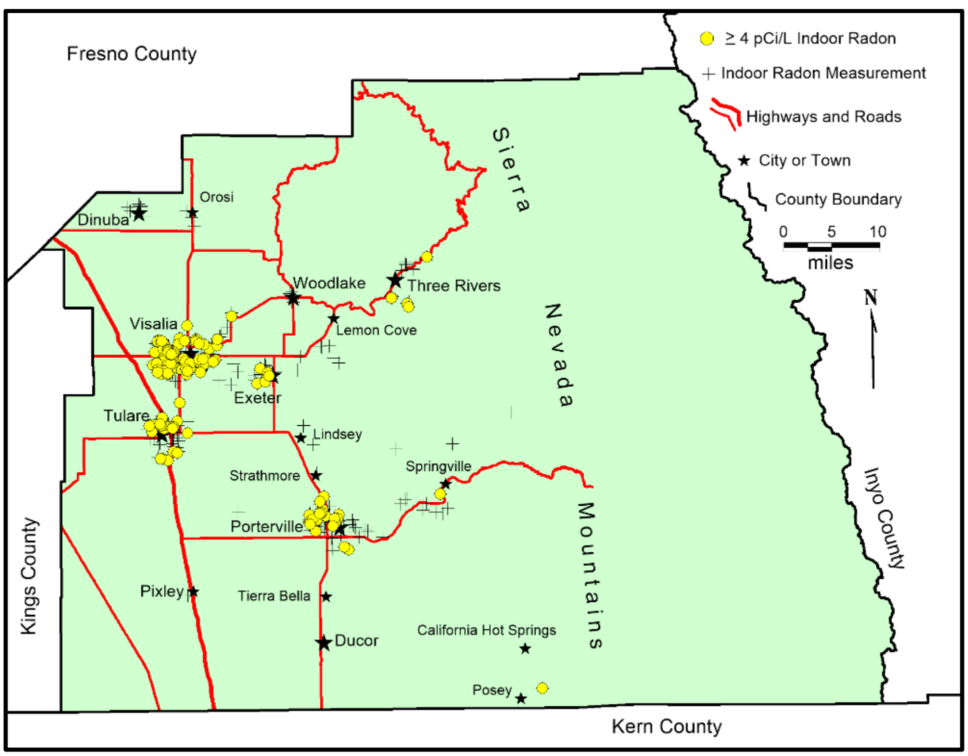

Figure 3. CDPH 2009-2010 Tulare County radon survey test locations with 4.0 pCi/L or greater sites (shown as yellow circles)

Home	Radon pCi/L	Zip Code	Floor	Location	Surficial Geologic Unit
1	33.0	93260	2nd		*Sierra Nevada**
2	22.9	93257	1st		Tule River Fan
3	17.3	93274	1st	Living room	Kaweah 3 Fan
4	16.1	93291	1st		Kaweah 2 Fan
5	15.4	93257	1st		Tule River Fan
6	14.2	93277	1st		Kaweah 3 Fan
7	13.7	93271	1st		Sierra Nevada
8	13.6	93221	1st		Kaweah 5 Fan
9	12.6	93274	1st	Dining room	Kaweah 3 Fan
10	12.3	93274	1st		Kaweah 3 Fan
11	12.2	93291	unknown		Kaweah 2 Fan
12	11.4	93274	1st	Great room	Kaweah 3 Fan
13	11.2	93274	1st		Kaweah 3 Fan
14	10.9	93292	1st		Kaweah 3 Fan
15	10.6	93271	1st	Living room	*Sierra Nevada**
16	10.1	93221	1st	Living room	Kaweah 5 Fan
17	10.1	93291	1st		Kaweah 3 Fan

*General reference to granitic and metamorphic rocks present in the Sierra Nevada Mountains in the eastern part of Tulare County. Not within the western Tulare County Radon Map area.

Table 2. Tulare County CDPH survey indoor-radon measurements ≥ 10.0 pCi/L by Zip Code, floor, room, fan/area and geologic unit.

that it likely includes multiple measurements for some homes not documented as such. Examples of these measurements include follow-up measurements after initial tests, simultaneous measurements in multiple rooms, multiple measurements from apartment or condominium complexes, and even a few measurements after radon mitigation projects. Survey results, summarized in Table 3a, suggest elevated indoor-radon is an issue for Exeter, Porterville, Three Rivers, Tulare and Visalia. Subtracting Table 3a measurements and ≥ 4 pCi/L measurements from corresponding Zip Codes in Table 3b yields the 1989-2009 radon data available for Tulare County prior to the CDPH survey. This earlier data, from undirected voluntary testing between 1989 and 2009, support elevated indoor radon as an issue for Three Rivers and part of Visalia (Zip Code 93277).

Note that the number of ≥ 4 pCi/L measurements in Table 3b for Zip Codes 93257 and 93292 are less than listed in Table 3a even though the CDPH survey data are included in Table 3b. This is because the latest update of the CDPH Zip Code database, May 4, 2010, did not include two data completed late in the Tulare County survey.

Zip Code	City/Region	Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
93221	Exeter	32	6	18.8
93223	Farmersville	2	0	0
93227	Goshen	1	0	0
93235	Ivanhoe	3	1	33.3
93247	Lindsay	3	0	0
93256	Pixley	1	0	0
93257	Porterville	104	24	23.1
93260	Posey	1	1	100
93265	Springville	12	1	8.3
93267	Strathmore	1	0	0
93271	Three Rivers	25	4	16.0
93274	Tulare	73	26	35.6
93277	Visalia	106	30	28.3
93286	Woodlake	4	0	0
93291	Visalia	51	25	49.0
93292	Visalia	67	24	35.8
93615	Cutler	1	0	0
93618	Dinuba	9	0	0
93647	Orosi	2	0	0
Tulare County Zip Code Totals from the CDPH Radon Survey Data				
		498	142	28.5

Table 3a. CDPH indoor-radon short-term test results for the December 2009 to April 2010 Tulare County radon Survey—by Zip Code Zone.

Zip Code	City/Region	Measurements	Measurements ≥ 4 pCi/L	Percent ≥ 4 pCi/L
93207	California Hot Springs	6	3	33.3
93208	Camp Nelson	1	0	0
93218	Ducor	1	0	0
93219	Earlimart	1	0	0
93221	Exeter	41	6	14.6
93223	Farmersville	5	0	0
93227	Goshen	2	1	50.5
93235	Ivanhoe	5	1	20.0
93237	Kaweah	1	0	0
93244	Lemon Cove	3	0	0
93247	Lindsay	14	0	0
93256	Pixley	1	0	0
93257	Porterville	148	23	15.5
93260	Posey	1	1	100.0
93261	Richgrove	1	0	0
93265	Springville	33	3	9.4
93267	Strathmore	5	0	0
93270	Terra Bella	13	9	69.2
93271	Three Rivers	49	20	29.9
93272	Tipton	1	0	0
93274	Tulare	92	27	29.4
93275	Tulare	1	0	0
93277	Visalia	157	42	26.6
93079	Visalia	3	0	0
93286	Woodlake	5	0	0
93290	Visalia	1	0	0
93291	Visalia	78	27	30.7
93292	Visalia	73	22	30.1
93603	Badger	1	0	0
93615	Cutler	1	0	0
93618	Dinuba	28	0	0
93647	Orsosi	3	0	0
Tulare County Zip Code Totals from the CDPH Zip Code Database				
		775	185	23.9

Table 3b. Radon test results for Tulare County Zip Code Zones from the CDPH on-line Radon Zip Code Database for California (1989-2010). This database includes the 498 data from the 2009-2010 CDPH Tulare County radon survey.

Radon Survey Data—Exposure Duration and Data Quality

Most Tulare County CDPH radon survey participants exposed their radon tests for two days as instructed, but some exposed them for three or four days. Differences between two-day, three-day and four-day test results should be negligible. Appendix A lists results for 19 concurrent (duplicate) tests made during the survey. Table 3c summarizes these test results and shows consistency between most concurrent test results.

High Measurement Group Range pCi/L	Associated Concurrent Group Measurement Ranges pCi/L	Differences pCi/L
6.5	5.0	1.5
5.1-5.6	4.5-5.1	0.2-0.6
4.5-4.7	3.0-4.2	0.3-1.7
3.2-3.8	2.5-3.5	0.2-1.1
2.0-2.9	0.9-2.8	0.1-1.2
1.1-1.7	0.6-1.0	0.1-0.9*

*The 0.9 pCi/L difference is for concurrent measurements with one detector on the first floor and the other detector and the second floor of a home.

Table 3c. Summary of concurrent indoor-radon test data from the Tulare County CDPH survey.

Appendices B and C show the analytical results for nine field blank radon detectors (i.e., not exposed to radon) and nine spiked radon detectors (exposed to a known concentration of radon). The nine detector blanks all measured below the reported lab detection limit of 0.5 pCi/L. Five of the nine laboratory spike samples measured within 10 percent of the mean radon chamber concentration of 13.9 pCi/L. One detector differed by 11.5 percent and three detectors differed by between 22.3 and 22.7 percent (all measured above the mean chamber concentration). Only one detector measured lower than the mean chamber concentration, by only 0.1 pCi/L. In summary, duplicate, blank and spiked sample test results support the validity of the CDPH-Radon Program Tulare County radon survey data.

Follow-up Radon Testing Results

Appendix D compares 10 follow-up radon measurements with initial survey measurements for eight different homes in Tulare County. The number of days between original and follow-up measurements range from 17 to 55. In four cases, follow-up measurements confirmed the initial ≥ 4 pCi/L measurement and in four cases, the follow-up measurement was below the initial ≥ 4 pCi/L measurement. Twice the initial < 4 pCi/L measurement was followed by a later measurement > 4 pCi/L.

Unfortunately, the locations of the detectors for the first and second tests in each house are unknown so location differences could account for part or the entire measurement differences. Note that for measurements where the first or second test is above 6.4 pCi/L the other test is always above 4 pCi/L.

WESTERN TULARE COUNTY SURFICIAL GEOLOGIC UNIT RADON POTENTIALS

Introduction

The first step in developing the radon potential map for western Tulare County was determining preliminary radon potentials for the surficial geologic units. Using a GIS, we compared CDPH survey test locations with the Tulare surficial geology digital layer (Figure 1) to determine the surficial unit present at each test location. Appendix F shows surficial units and their associated radon data compiled by this activity.

Preliminary Radon Potentials for Surficial Geologic Units

Tulare County surficial units were assigned preliminary radon potentials based on radon data in Appendix F and radon potential definitions in step 7 (page 6). Table 4a lists high potential units, 4b low potential units and Table 4c units with unknown radon potential because they have few or no indoor-radon measurements. No units with indoor-radon data met the step 7 moderate radon potential classification requirement. Some unit radon potentials listed in Tables 4a and 4b are provisional—less certain because they have significantly less than 25 indoor-radon measurements. A “(P)” indicates the radon potential status is provisional in Tables 4a and 4b.

Use of Additional Data in Determining Geologic Unit Radon Potential

Besides indoor-radon data, other data useful for assessing unit radon potentials are available for western Tulare County and were considered in assigning final radon potentials to surficial geologic units. These are soil and sediment uranium data, airborne radiometric uranium data, and soil permeability data. For surficial geologic units without indoor-radon measurements, uranium and soil permeability data may be sufficient to allow assignment of a radon potential. The next two report sections describe these data, indicate their degree of support for unit preliminary radon potentials, and suggest radon potentials for units without indoor-radon data.

Surficial Geologic Unit	Indoor-Radon Data	Radon Potential Designation
Kaweah River 2 Subfan	R = 42.5% n = 40 n ≥ 4 pCi/L = 17 Maximum = 16.1 pCi/L	High R ≥ 20%
Kaweah River 3 Subfan	R = 34.0% n = 241 n ≥ 4 pCi/L = 82 Maximum = 17.3 pCi/L	High R ≥ 20%
Kaweah River 4 Subfan	R = 30.0% n = 10 n ≥ 4 pCi/L = 3 Maximum = 6.5 pCi/L	High (P) R ≥ 20%
Kaweah River 5 Subfan	R = 22.2% n = 27 n ≥ 4 pCi/L = 6 Maximum = 13.6 pCi/L	High R ≥ 20%
Tule River Fan	R = 22.7% n = 97 n ≥ 4 pCi/L = 22 Maximum = 22.9 pCi/L	High R ≥ 20%

Table 4a. Western Tulare County surficial geologic units assigned preliminary high radon potential status based on 2009-2010 CDPH indoor-radon survey data R=the percent of indoor-radon data at or above 4 pCi/L; (P)=Unit radon potential is provisional (less certain) because unit has significantly less than 25 tests

Surficial Geologic Unit	Indoor-Radon Data	Radon Potential Designation
Bedrock (foothill metamorphic and granitic rock areas)	R = 0.0% n = 9 n ≥ 4 pCi/L = 0 Maximum = 2.5pCi/L	Low (P) R < 5%
Cottonwood Creek East Fan	R = 0.0% n = 4 n ≥ 4 pCi/L = 0 Maximum = 2.8 pCi/L	Low (P) R < 5%
Travers Creek Lower Fan	R = 0.0% n = 8 n ≥ 4 pCi/L = 0 Maximum = 3.1pCi/L	Low (P) R < 5%

Table 4b. Low radon potential surficial geologic units in western Tulare County based on 2009-2010 CDPH short-term indoor radon data R=the percent of indoor-radon data at or above 4 pCi/L; (P)=Unit radon potential is provisional (less certain) because unit has significantly less than 25 tests

Surficial Geologic Unit	Indoor-Radon Data	Radon Potential Designation
Basin (intra-fan areas) *(See basin discussion page 8)*	R = uncertain % n = 9 n ≥ 4 pCi/L = 3 Maximum = 5.8 pCi/L	Unknown or Mixed Potentials
Basin (inter-fan areas)	No indoor-radon data	Unknown
Cottonwood Creek-West Fan	No indoor-radon data	Unknown
Deer Creek 2 Fan	R = uncertain % n = 1 n ≥ 4 pCi/L = 0 Maximum = 1.6 pCi/L	Unknown
Ducor Fan	No indoor-radon data	Unknown
Frazier Creek Fan	R = 0% n = 2 n ≥ 4 pCi/L = 0 Maximum = 2.1 pCi/L	Unknown
Kaweah River Subfan 1	R = uncertain % n = 2 n ≥ 4 pCi/L = 1 Maximum = 7.5 pCi/L	Unknown
Kings River Fan	No indoor-radon data	Unknown
Long Creek Fan	R = 0% n = 2 n ≥ 4 pCi/L = 0 Maximum = 0.5 pCi/L	Unknown
Qvof1 Fan	No indoor-radon data	Unknown
Qvof2 Fan	No indoor-radon data	Unknown
Qvof3 Fan	No indoor-radon data	Unknown
Rag Gulch Fan	No indoor-radon data	Unknown
Sand Creek	R = uncertain % n = 2 n ≥ 4 pCi/L = 0 Maximum = 1.9 pCi/L	Unknown
Seville Fan	No indoor-radon data	Unknown
Travers Creek-Upper Fan	No indoor-radon data	Unknown
Tulare Lake Sediments	No indoor-radon data	Unknown
Vestal Fan	No indoor-radon data	Unknown
White River Fan	No indoor-radon data	Unknown

Table 4c. Unknown radon potential surficial geologic units in western Tulare County because of few or no 2009-2010 CDPH short-term indoor radon data R=the percent of indoor-radon data at or above 4 pCi/L

NURE PROJECT 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 production 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. Locations with unusually high uranium abundance were targets for additional work to determine whether economically recoverable uranium deposits were present. In parts of California, including Tulare County, NURE project contractors collected soil and stream sediment samples for uranium determinations at various U.S. government laboratories. These data are available from the U.S. Geological Survey at: http://mrdata.usgs.gov/geophysics/nurequads.html and http://mrdata.usgs.gov/nuresed/.

Because radon is a radioactive decay product of uranium, areas with higher natural background amounts of uranium are more likely to have higher quantities of radon in the subsurface. Buildings in these areas have a greater potential for indoor-radon problems. Consequently, NURE uranium data for rock units, soils and sediments are valuable for radon-potential mapping projects, particularly where indoor-radon measurements are sparse or absent.

Uranium in Soil and Sediment Samples

NURE project sub-contractors collected 1,026 soil and sediment samples in Tulare County. Figure 4 shows relatively consistent sample coverage in western Tulare County with sample spacing generally ranging from 1.7 to 2.5 miles. However, numerous gaps exist in the sample coverage of the Sierra Nevada Mountains. These gaps result from the steep topography and lack of roads limiting access to sample sites, the NURE policy not to collect samples within National Parks, and no samples collected within the Tule River Indian Reservation.

Solid blue symbols in Figure 4 show sample locations with uranium contents at or exceeding 5.0 ppm (i.e., approximately twice the average uranium content of the earth's crust). Appendix G lists soil and sediment uranium data grouped by associated western Tulare County surficial geologic, and soil and uranium data for watershed areas in the Sierra Nevada Mountains that supply alluvial fans in western Tulare County. The 5.0 ppm and higher uranium data exhibit several distribution patterns within Tulare County. The most prominent is the triangular shaped pattern extending west-southwest from Lemon Cove that includes Visalia and Tulare. There is also a small linear trend of elevated uranium data extending west from between Porterville and Strathmore, and a small group of elevated data southwest of Dinuba. Within the Sierra Nevada Mountains, the elevated uranium data appear in several clusters along a line extending roughly from north-northwest to south-southeast that passes through the Three Rivers, Springville and the Posey areas. The following report section examines the relationship between elevated uranium in Tulare County soil and sediment and county geology.

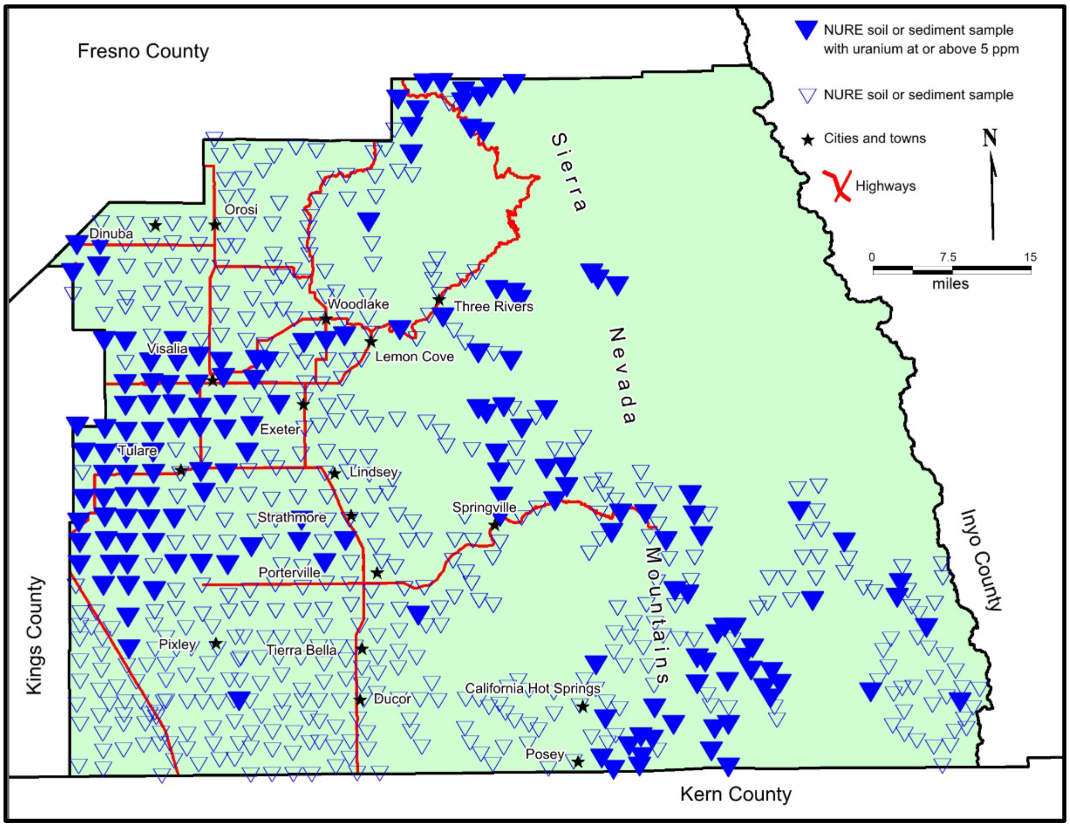

Figure 4. NURE project soil and sediment uranium data for Tulare County

Geologic controls on distribution of background uranium concentrations in Tulare County

Figure 5 shows five Sierra Nevada watersheds that include portions of the central and eastern Sierra Nevada batholith and their associated alluvial fans in western Tulare County. Individual watershed and fan symbols are defined in the figure caption. Note that the Kings River and Kaweah River

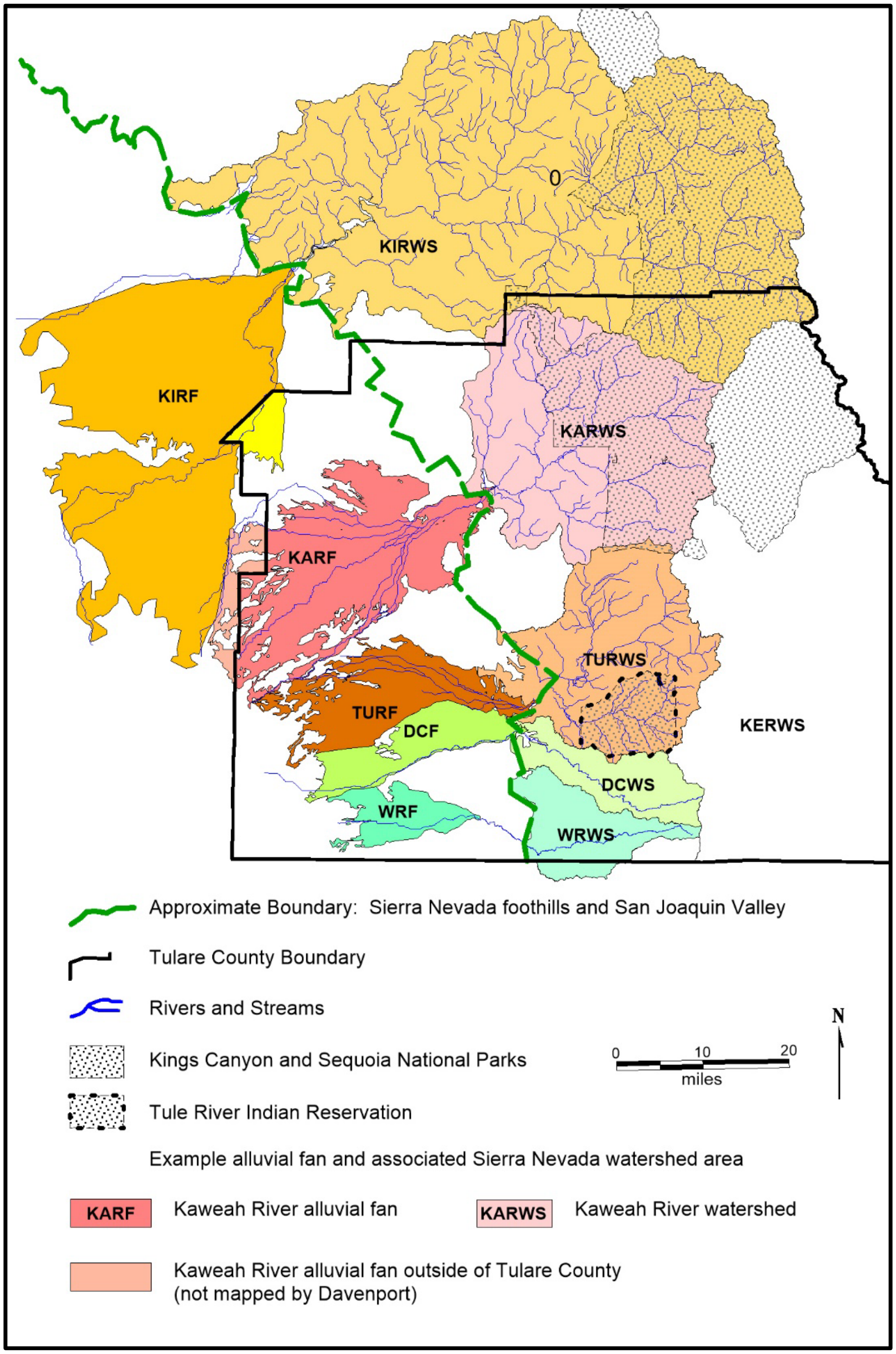

Figure 5. Major Tulare County alluvial fans and associated Sierra Nevada watersheds

<u>Alluvial fan and watershed abbreviations</u>: Kings River—KIRF, KIRWS (yellow fan area is within Tulare County, mapped by Davenport); Kaweah River—KARF, KARWS (light pink-orange fan area is outside Tulare County, not mapped by Davenport); Tule River—TURF, TURWS; Deer Creek—DCF, DCWS; White River—WRF, WRWS; Kern River—KERWS (associated fan is not in Tulare County and not shown)

watersheds are within Kings Canyon and Sequoia National Parks and part of the Tule River watershed is within the Tule River Indian Reservation.

Figure 6 shows the distribution of NURE soil and sediment sample sites in relation to watersheds and alluvial fans identified in Figure 5. Figure 6 shows that sampling is absent or very limited within the national parks and the Indian reservation, and less regular within the Sierra Nevada Mountains. Figures 6 and 7 do not show the Sequoia National Monument because it did not exist at the time of NURE survey. Consequently, NURE soil and sediment uranium data are available within Monument areas. In the San Joaquin Valley spatial distribution of sediment and soil uranium data is more even with fewer and smaller gaps than in the Sierra Nevada Mountains because sample sites were more accessible.

Figure 7 shows the distribution of 5.0 ppm uranium or greater soil and sediment NURE samples in relation to the watersheds and alluvial fans. Note the presence of these elevated uranium samples in the central Sierra Nevada batholith. Also of note is the lower background uranium concentrations in soils and sediments along the westernmost portions of the Sierra Nevada batholith, immediately to the east of the dashed green line in Figure 7. This is consistent with the eastward increase in concentration of uranium in the central Sierra Nevada batholith to the north observed by Wollenberg and others (1968) and Dodge (1972). This eastward increasing uranium trend would likely appear more continuous and conspicuous in Tulare County if NURE data were available from within national park and Indian reservation areas.

The presence of higher background uranium in the eastern Sierra Nevada batholith and lower background uranium in the western portions of the batholith influences the uranium levels in Tulare County alluvial fans. Figure 7 shows significant portions of the Kings River, Kaweah River and Tule River alluvial fans have background uranium concentrations exceeding 5.0 ppm. Figure 7 also shows the watersheds for these fans extend sufficiently eastward to include areas of the Sierra Nevada batholith where background uranium exceeds 5.0 ppm. The Deer Creek and White River watersheds do not extend sufficiently east into the higher uranium parts of the Sierra Nevada batholith to provide significant amounts of elevated uranium sediments to their fans and these fans have lower background uranium concentrations.

In Figure 7, the white areas along the Sierra Nevada Mountains-San Joaquin Valley boundary contain a number of small watersheds and fans (see Figure 1). The watersheds are entirely within the westernmost lower uranium portions of the Sierra Nevada batholith and foothill areas with lower background uranium intrusive and metamorphic rocks. Their

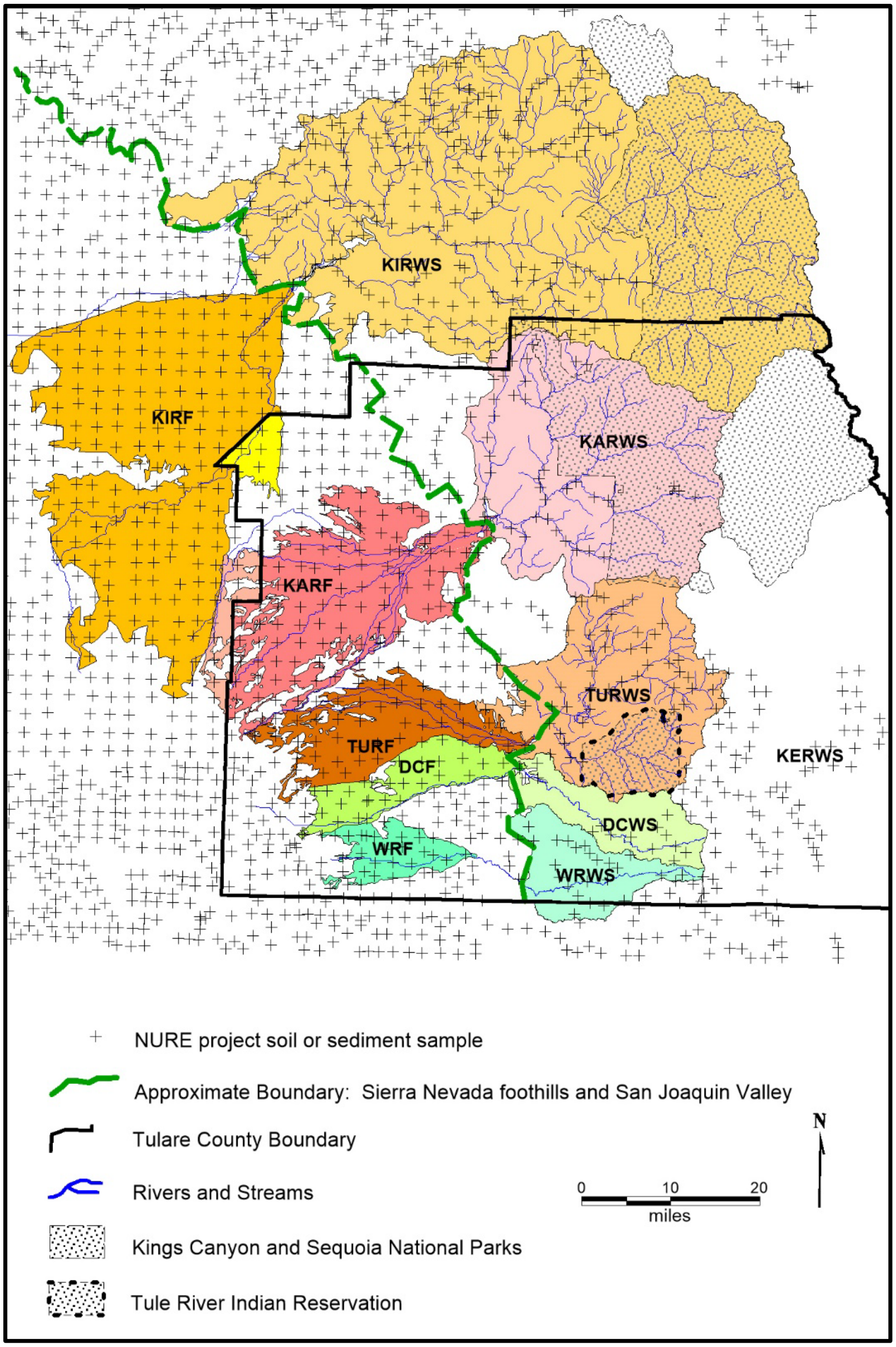

Figure 6. NURE project soil and sediment sample locations, major Tulare County alluvial fans, and associated Sierra Nevada watersheds

Fan and watershed abbreviations: Kings River—KIRF, KIRWS (yellow area is within Tulare County); Kaweah River—KARF, KARWS (light pink-orange area is outside Tulare County); Tule River—TURF, TURWS; Deer Creek—DCF, DCWS; White River—WRF, WRWS; Kern River—KERWS (associated fan not in Tulare County)

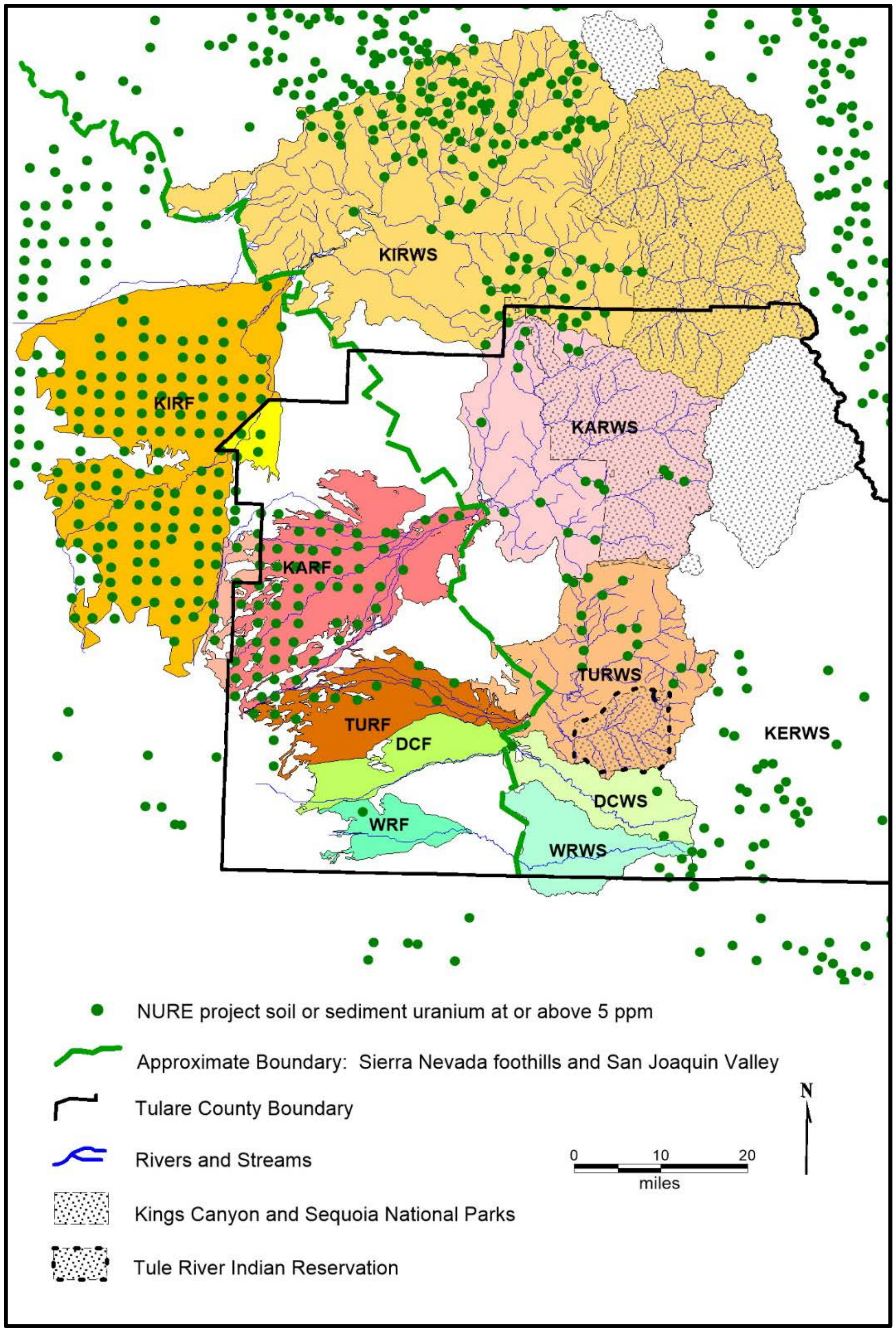

Figure 7. NURE project soil and sediment uranium concentrations ≥ 5.0 ppm, major Tulare County alluvial fans, associated Sierra Nevada watersheds

Fan and watershed abbreviations: Kings River—KIRF, KIRWS (yellow area is within Tulare County); Kaweah River—KARF, KARWS (light pink-orange area is outside Tulare County); Tule River—TURF, TURWS; Deer Creek—DCF, DCWS; White River—WRF, WRWS; Kern River—KERWS (associated fan not in Tulare County)

associated fans have distinctly lower uranium background concentrations than the Kings, Kaweah and Tule River alluvial fans.

The distribution of soil and sediment uranium data at or above 5.0 ppm in Tulare County suggests the following trends in county radon potentials. Areas within the Kings River, Kaweah River and Tule River alluvial fans are more likely to have higher radon potentials than other fan areas. The westernmost Sierra Nevada batholith and foothills areas are more likely to have lower radon potentials but areas of higher radon potential occur further east.

NURE Airborne Radiometric Data

Another approach used by the NURE project to obtain uranium data for soil, sediments and rocks involved airborne radiometric surveys. These surveys utilized helicopters equipped with gamma-ray spectrometers to make measurements along a grid of flight lines. The spectrometers could detect trace amounts of gamma radiation characteristic of the bismuth-214 isotope. Because this isotope is a member of the uranium-238 radioactive decay chain (see Table 1), its related gamma-ray data can be used to estimate uranium contents of the soils, sediments and rocks along the helicopter's flight paths. These estimated uranium concentrations, in ppm, are referred to as "equivalent uranium" (eU) data, to distinguish them from uranium (U) data obtained by analyzing soil, sediment or rock samples in a laboratory by other methods. Locations with anomalously high eU concentrations could be subject to further investigation to determine if economically viable uranium deposits were present. NURE airborne radiometric data used for developing the Tulare County radon potential map are from a compilation by Duval (2000).

The radon isotope most often responsible for elevated indoor-radon concentrations is radon-222. This radon isotope is also a member of the uranium-238 decay chain, in a position between uranium and bismuth-214. Because bismuth-214 is created just a few minutes after radon-222 decays (see Table 1), it can be a good indicator of radon abundance just below the earth's surface at particular locations; usually from within about 18 inches of the surface. However, airborne eU survey data can be impacted by soil moisture (Grasty, 1997), topography, atmospheric inversion and other local conditions. Radon entering buildings can come from depths of several 10s of feet and occasionally deeper, while eU estimates are usually averages of the uppermost 18 inches of the subsurface. Consequently, eU measurements are sometimes not representative of local availability of subsurface radon. The NURE flight-line grid pattern for Tulare County consists of east-west flight lines, 2 to 6.5 miles apart, and north-south flight lines, generally 8 to 12 miles apart.

With this spacing, it is possible to miss moderate to relatively large anomalous eU areas with increased radon potential. For these reasons, CGS radon mapping studies do not treat NURE airborne eU data as quantitative in defining anomalous radon areas as NURE laboratory uranium analyses of soil, sediment and rock samples. Instead, airborne eU data are considered qualitatively suggestive of areas with higher or lower radon potentials.

Figure 8 shows the location of approximately 1,517 miles of flight lines within Tulare County flown during the 1979 NURE airborne radiometric surveys of the Bakersfield and Fresno 1X2 degree quadrangles. Figure 8 also shows ≥ 5.0 ppm eU locations along the flight lines. Gamma-ray spectral measurements at 70,274 locations were recorded along these flight lines.

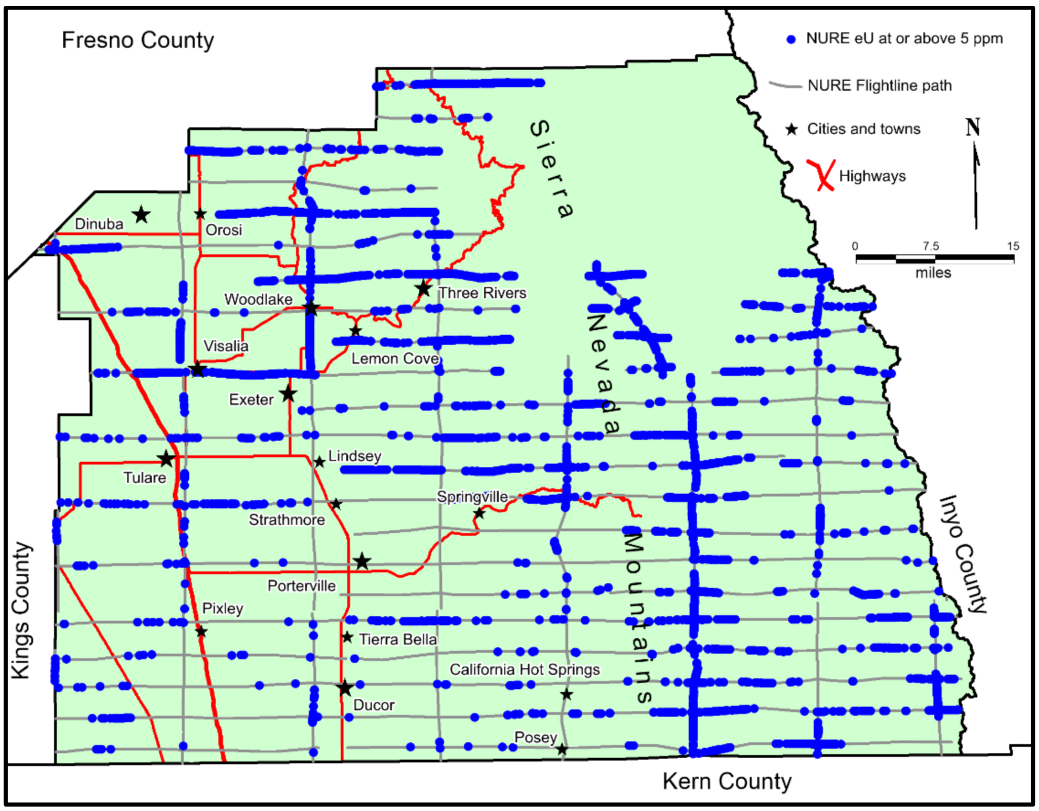

Figure 8. NURE project airborne radiometric survey flight line paths and eU data at or above 5.0 ppm for Tulare County

NURE airborne eU data for 27 geologic units in western Tulare County (23,131 measurements).

Data collection occurred at an average of about 121 feet above ground surface at a flight speed of about 90 miles per hour. Under such conditions, measurements approximately represent an average uranium content within the upper 18 inches of surficial material over an area of approximately 48,000 square feet (or 1.1 acres; see High-Life Helicopters, 1980a and U.S. Department of Energy, 1980). Appendix I summarizes NURE airborne uranium data for western Tulare County geologic units and Sierra Nevada foothill bedrock.

Figure 9 shows NURE project airborne radiometric survey flight-line grid overlain on alluvial fans and associated watersheds previously discussed. Note in Figure 9 that north-south flight-line spacing is closer in some parts of the area than in others. Additionally, flight line data are generally absent from national park areas but were collected over the Tule River Indian Reservation.

Comparing the ≥ 5.0 ppm uranium areas identified in the airborne eU survey (Figure 9) and the surface U soil and sediment survey (Figure 7) shows some similarities and some differences. Both surveys identify parts of the Kings River, Kaweah River and Tule River watersheds as having background uranium concentrations ≥ 5.0 ppm. Airborne survey data fill in some gaps in the soil and sediment survey sampling in the Sierra Nevada Mountains. The combined data from both surveys show the continuous nature of the ≥ 5.0 ppm background uranium area in the eastern Sierra Nevada Mountains better than either data set alone. This elevated background uranium area may extend further east but insufficient soil, sediment and airborne uranium data are available within national park lands to document this extension. Both data sets show that most of the Deer Creek and White River watersheds have background uranium concentrations < 5.0 ppm.

The soil and sediment uranium survey shows few ≥ 5.0 ppm U locations in the westernmost Sierra Nevada batholith area as previously discussed. The airborne eU survey shows similar lower-background uranium for this area except in the western Kaweah River watershed and in the undifferentiated watersheds area west and northwest of the Kaweah River watershed. Here airborne survey data generally exceed 5.0 ppm. In both surveys, the undifferentiated fan areas (shown in white on figures 7 and 10 immediately west of the Sierra Nevada-San Joaquin Valley boundary), have few background uranium data ≥ 5.0 ppm.

Both the airborne and surface soil and sediment surveys identify the parts of the Kings River and Kaweah River alluvial fans within Tulare County as having background uranium concentrations ≥ 5.0 ppm. Both surveys show < 5.0 ppm background uranium concentrations for the Deer Creek and White River alluvial fans. However, the soil and sediment survey shows the northern part of the Tule River alluvial fan having background uranium concentrations ≥ 5.0 ppm while the airborne eU survey does not.

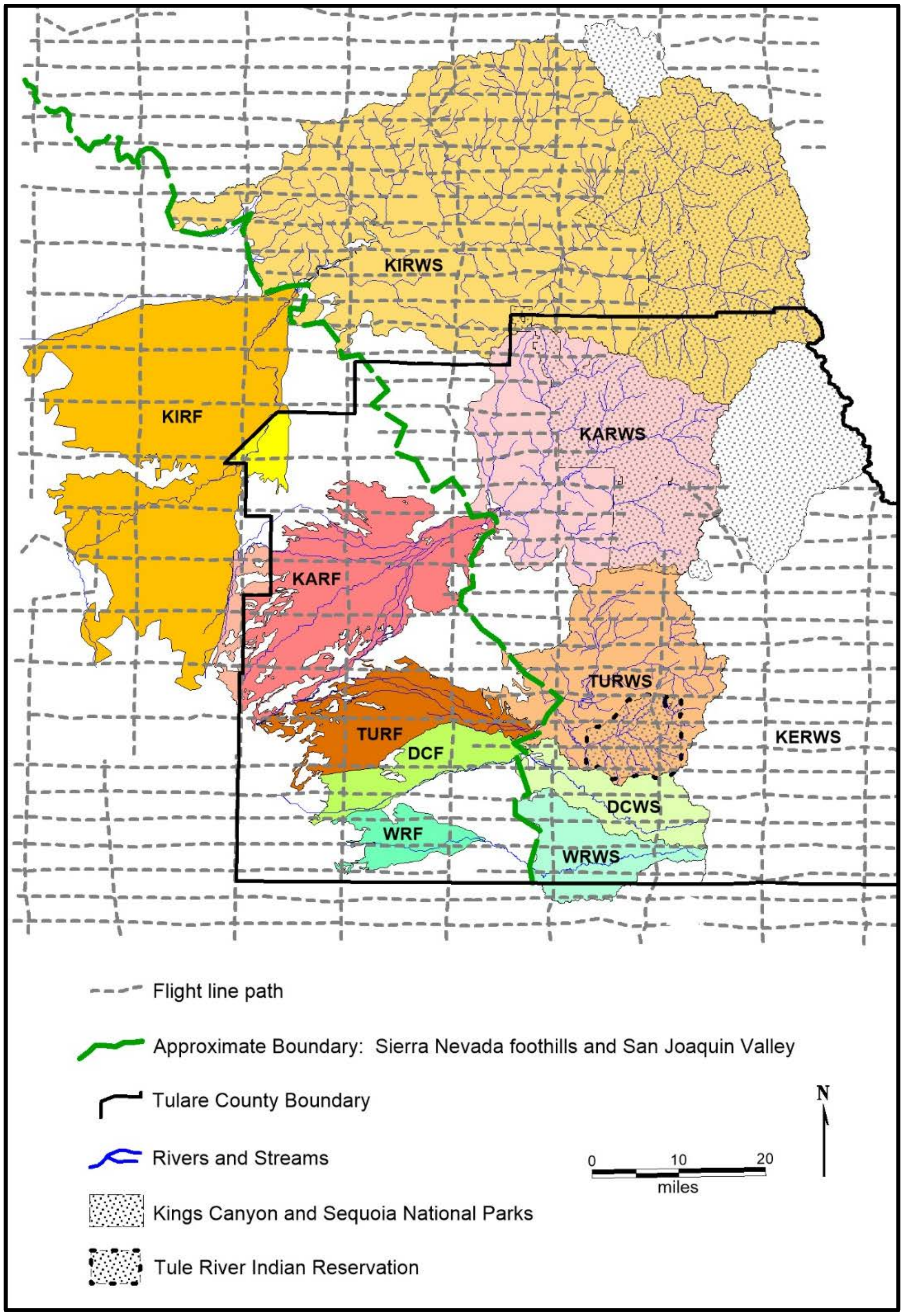

Figure 9. NURE project airborne radiometric survey flight line paths, major Tulare County alluvial fans, associated Sierra Nevada watersheds

Fan and watershed abbreviations: Kings River—KIRF, KIRWS (yellow area is within Tulare County); Kaweah River—KARF, KARWS (light pink-orange area is outside Tulare County); Tule River—TURF, TURWS; Deer Creek—DCF, DCWS; White River—WRF, WRWS; Kern River—KERWS (associated fan not in Tulare County)

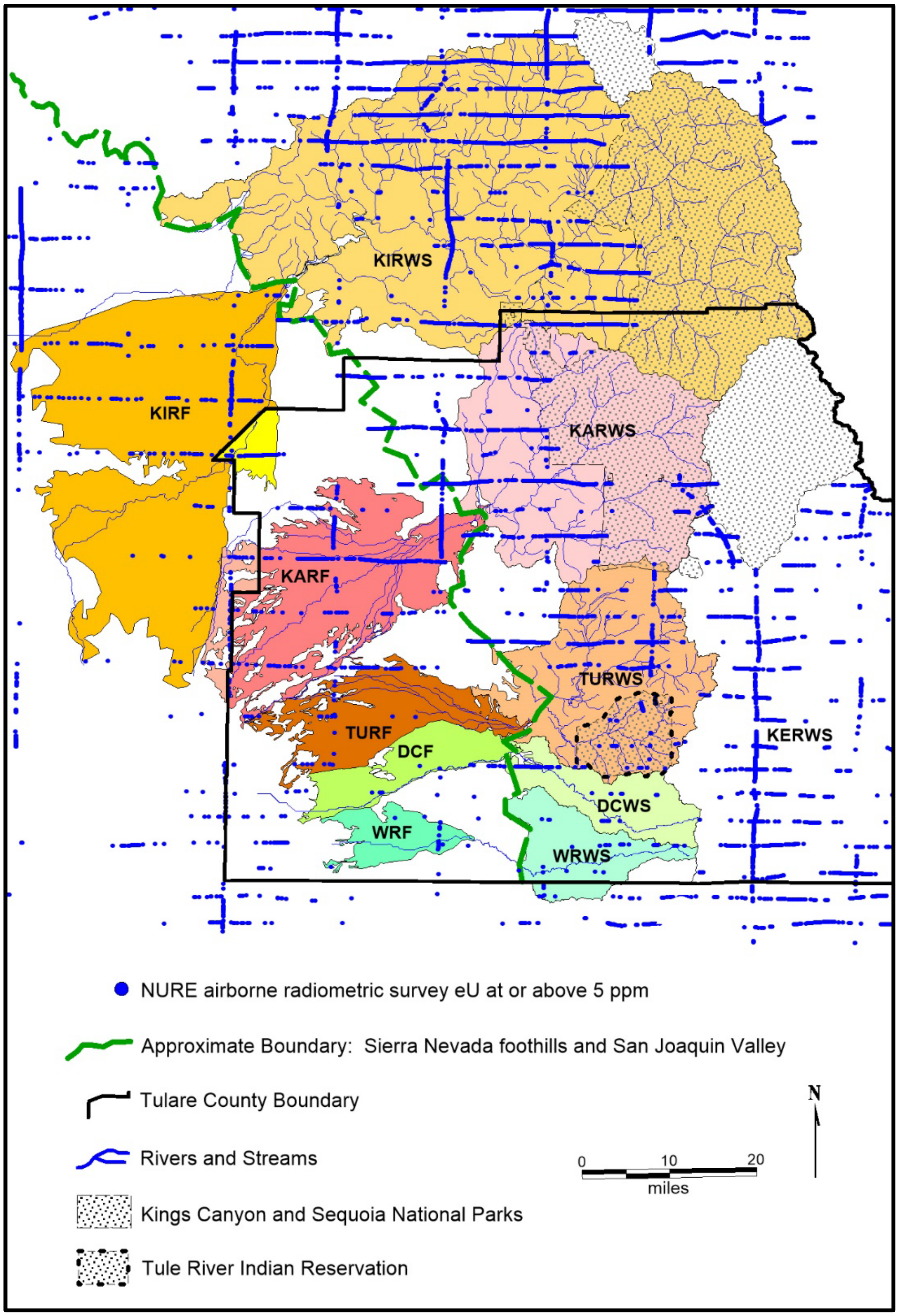

Figure 10. NURE project airborne radiometric survey eU data ≥ 5.0 ppm, major Tulare County alluvial fans, and associated Sierra Nevada watersheds

<u>Fan and watershed abbreviations</u>: Kings River—KIRF, KIRWS (yellow area is within Tulare County); Kaweah River—KARF, KARWS (light pink-orange area is outside Tulare County); Tule River—TURF, TURWS; Deer Creek—DCF, DCWS; White River—WRF, WRWS; Kern River—KERWS (associated fan not in Tulare County)

Finally, both airborne and surface soil and sediment surveys show areas of ≥ 5.0 ppm background uranium in the Kern River watershed. Both the Kern River watershed and its associated fan deposit are outside of the western Tulare County radon potential map area. Although not contributing to radon potential in western Tulare County, the elevated background uranium occurrence within the Kern River watershed suggests elevated radon potential areas may be associated with Kern River related alluvium in Kern County.

TULARE COUNTY NRCS SOIL DATA

Background

Natural Resource Conservation Service (NRCS) soil physical property data are sometimes useful in identifying areas with higher radon potential. Higher permeability soils facilitate radon release from host minerals and migration in the subsurface. Radon release and migration can be significantly restricted in soils with low permeability. Soil moisture is also impacts radon availability and migration in the subsurface. Soils exhibiting moderate to high shrink-swell character may 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. Radon is more readily released from its point of origin and may migrate further in dry soils than wet soils because it is captured (dissolved) and held in water (Brookins, 1990). Appendix J provides information on the relationships between soil types and western Tulare County surficial geologic units.

Several things limit the usefulness of soil data for radon potential mapping. One limitation is that it often is only available for soil from the surface to depths of five to seven feet. Typically, some or most of the radon entering buildings originates below this depth where permeability data are not available. Another limitation is uncertainty about how to interpret vertical radon permeability of radon in soil with vertical stacks of multiple horizons, each having significant permeability differences. Finally, NRCS soil permeabilities are for water while radon is a gas. Although radon potential mapping projects routinely consider soil water permeabilities, these do not always represent radon soil permeability well. In spite of these limitations, soil permeabilities sometimes correlate with areas of higher or lower radon potential.

Most soils in western Tulare County formed from alluvium deposited by rivers originating in the Sierra Nevada. This alluvium primarily consists of various types of granitic rocks, along with some metamorphic rocks. Soil permeabilities mostly range between very high to low and soil shrink-swell is generally low. Less common very-low permeability and high shrink-swell soils generally occur in inter-fan areas and near mafic and ultramafic bedrock exposures

Soils in western Tulare County often have multiple sub-layers with different thicknesses and permeabilities, which can make judgements about a soil's radon potential difficult. Using soil hydrologic groups can help with assessing a soil's radon potential in these situations because each hydrologic group treats its corresponding soil as a unit having a single overall permeability. The western Tulare County project takes this approach.

Hydrologic soil group is determined by the water transmitting soil layer with the lowest saturated hydraulic conductivity and the depth to any layer that is water impermeable (e.g., fragipan or duripan), or depth to a water table if present (NRCS, 2009). The least transmissive layer is any soil horizon that transmits water at a slower rate relative to horizons above or below it. For simplicity in hydrologic soil group assessment, an impermeable horizon is one with a saturated hydrologic conductivity of 0.0 to 0.1 inches per hour (or 0 micrometers per second to 0.9 micrometers per second). Table 5 shows the NRCS hydrologic soil group definitions with soil group A having the highest permeability and soil group D the lowest permeability for soils with depth to water impermeable layer >40 inches (>100 cm) and depth to high water table (during any month of the year) >40 inches (>100 cm).

Soil Property	**NRCS Hydrologic Soil Group**			
	A	B	C	D
Saturated hydraulic conductivity of the least transmissive layer	> 1.42 in/h (>10.0 μm/s)	≤1.42 to >0.57 in/h (≤10.0 to >4.0 μm/s)	≤0.58 to >0.06 in/h (≤4.0 to >0.40 μm/s)	≤0.06 in/h (≤0.40 μm/s)
Old permeability classification	Very high to moderate permeability	Moderate to moderately slow permeability	Moderately slow to slow permeability	Very slow permeability

Table 5. Definitions of Hydrologic Soil Groups (Modified from NRCS, 2007)

Figure 11 shows the distribution of hydrologic soil group areas and the principal alluvial fan boundaries in western Tulare County. Note that higher permeability groups A and B are most common in the upper parts of the fans and group C is more common in the lower parts of the fans.

This pattern reflects coarser size alluvium being deposited in the fans nearer the Sierra Nevada Mountains and finer size alluvium particles being deposited farther away. Hydrologic group A occurrences also appear to be along distributary channels within group B areas (e.g., Subfan KARF-3 in Figure 11). Note the presence of lower permeability group D soils in basins between the alluvial fans, the Tulare Lake basin, and areas with older fans near the Sierra Nevada foothills. Also, note that lower-permeability groups C and D soils are dominant in the Sierra Nevada Mountains portion of Figure 11.

Based on soil permeability alone, one would expect higher radon potentials in the group A and B areas, and lower potentials in the group C, and D areas. This appears to be confirmed in Figure 12, which shows numerous ≥ 4.0 pCi/L homes within group A and B soils in Visalia, Tulare and Exeter (Kaweah River Fan) and Porterville (Tule River fan). However, Table 6 shows little difference in percentages of indoor-radon data ≥ 4.0 pCi/L between the four hydrologic groups. All four hydrologic groups have high radon potential because more than 20 percent of their CDPH survey measurements exceed 4.0 pCi/L (see step 7 page 6). This suggests differences in soil hydrologic group permeabilities are not useful for identifying high and low radon potential areas in western Tulare County. However, the number of indoor-radon data associated with group D is relatively small and not evenly distributed over the group D areas shown in Figure 12, making interpretation of its radon data less certain. After consideration of these results, the decision was made not to use hydrologic soil group information in developing the radon potential map for western Tulare County.

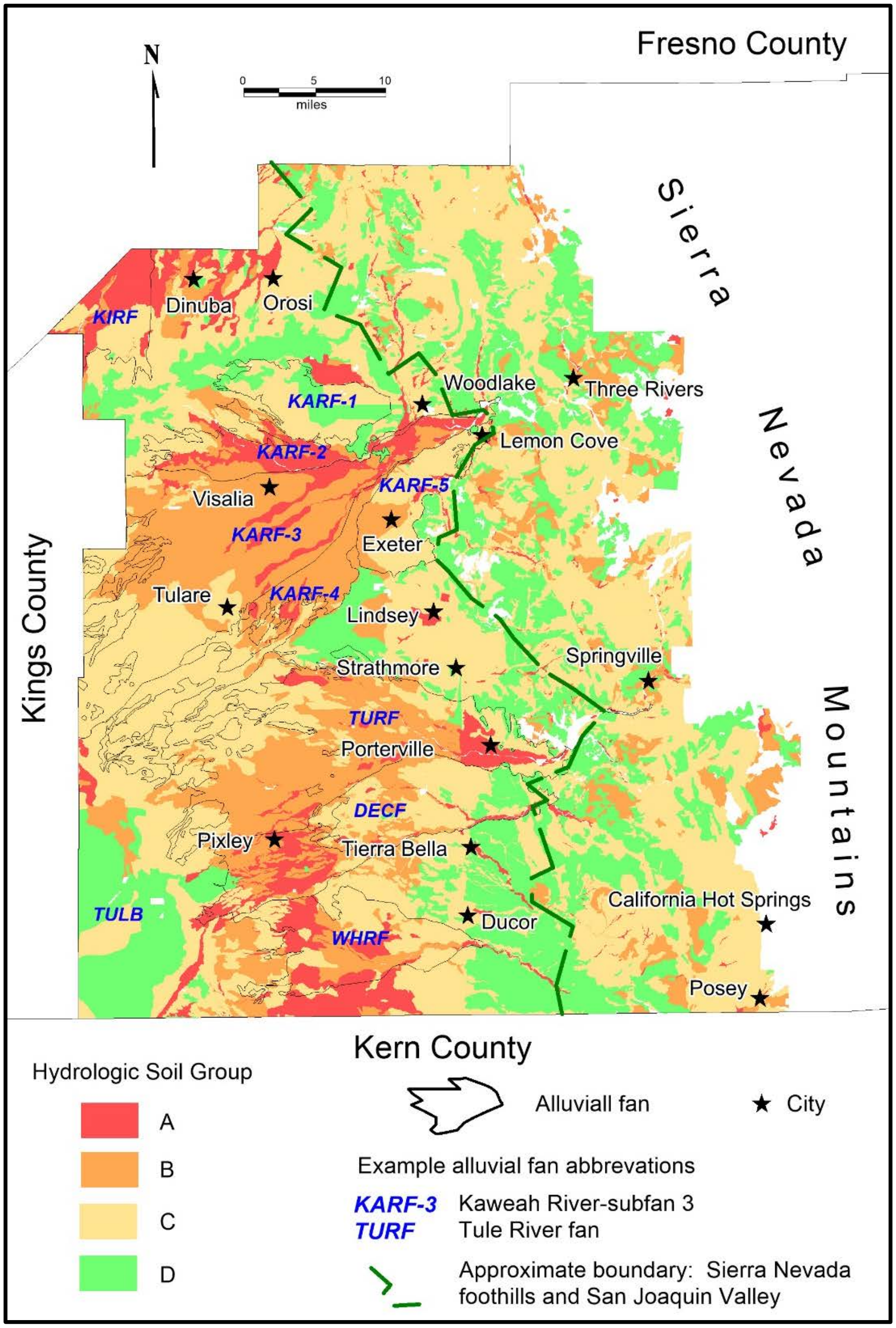

Figure 11. Map of western Tulare County NRCS hydrologic soil groups and alluvial fans receiving alluvium from the central and eastern Sierra Nevada

Abbreviations: DECF, Deer Creek alluvial fan, KARF-1 to 5, Kaweah River alluvial fan, subfans 1 through 5; KIRF, Kings River alluvial fan; TURF, Tule River alluvial fan; WHRF, White River alluvial fan; TULB, Tulare Lake bed.

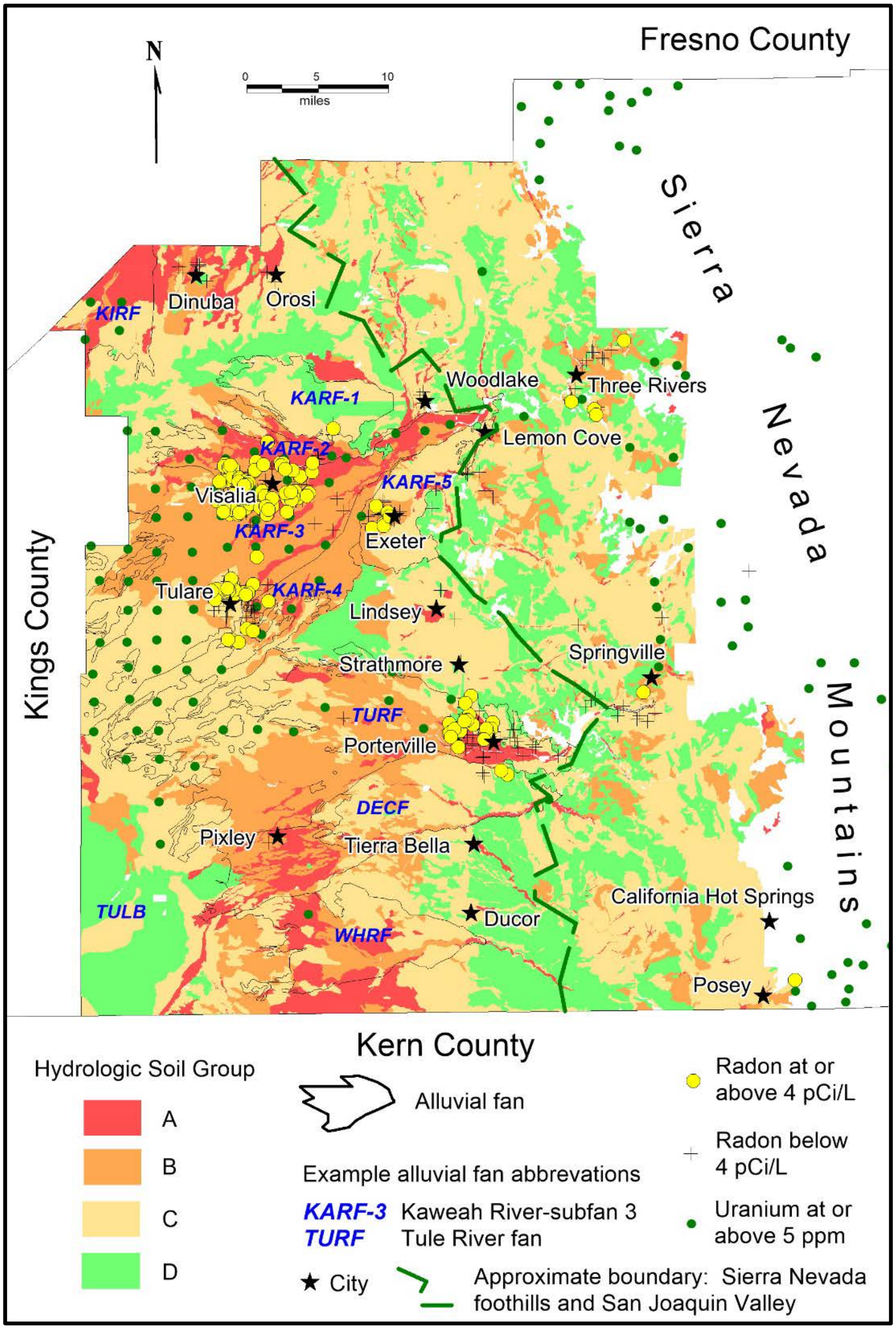

Figure 12. Map of western Tulare County NRCS hydrologic soil groups and alluvial fans receiving alluvium from the central and eastern Sierra Nevada with radon and soil/sediment uranium data

Abbreviations: DECF, Deer Creek alluvial fan, KARF-1 to 5, Kaweah River alluvial fan, subfans 1 through 5; KIRF, Kings River alluvial fan; TURF, Tule River alluvial fan; WHRF, White River alluvial fan; TULB, Tulare Lake bed.

Table 6 also summarizes soil and sediment uranium data by hydrologic soil group. All four groups have significant numbers of uranium data. Although Figure 12 does not show < 5.0 ppm uranium data sites, the NURE soil and sediment sample sites are well distributed and representative of the occurrences of each soil group. Note that the hydrologic group D soils have much fewer ≥ 5.0 ppm uranium occurrences than the other groups and lower maximum and median uranium values. A possible explanation could be greater clay-size particle amounts in permeability group D soils and that the clay-size particles are relatively low in uranium content.

HSG*	N Rn Data	Rn Med. pCi/L	Rn Max. pCi/L	% Rn ≥ 4.0 pCi/L	N U Data	U Med. ppm	U Max. ppm	% U ≥ 5.0 ppm
A	91	2.700	22.9	27.47	48	2.865	7.8	31.25
B	289	2.900	17.3	30.45	80	4.250	10.0	37.50
C	100	2.100	13.7	25.00	198	3.035	11.4	21.21
D	13	1.800	15.4	23.08	67	2.300	5.3	2.99

Table 6. Comparison of Indoor-radon data and soil-sediment uranium data by hydrologic soil group

*Hydrologic soil group

RADON POTENTIAL ZONES

Final Western Tulare County Geologic Unit Radon Potentials

Final western Tulare County geologic unit radon potentials were assigned using review results for:

1) Indoor-radon data
2) NURE surface soil and sediment U data, and
3) NURE airborne eU data

NRCS soil permeabilities (hydrologic soil groups) were not considered in geologic unit rankings based on results discussed in the previous section of this report. Western Tulare County geologic units with insufficient indoor-radon data available were assigned radon potentials of units with radon data based on similarities in NURE soil, sediment and airborne

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Soil and Sediment Uranium Data**	**NURE Airborne eU data**	**Assigned Radon Potential (comments)**
Kaweah 2 Fan	XX	X	X	High
Kaweah 3 Fan	XX	XX	X	High
Kaweah 4 Fan	X	X	X	High
Kaweah 5 Fan	XX	ID	X	High
Kings River Fan	ND	x	X	High (P) (numerous ≥ 5.0 ppm U soil and sediment similar to Kaweah 2, 3 and 4 subfans)
Tule River Fan	XX	X	--	High

Table 7. Western Tulare County geologic units and strength of supporting data for high radon potential designation

XX = More than 25 measurements available and they support assigned potential
X = 10 to 24 indoor radon measurements available and they support assigned potential
x = Less than 10 measurements available and they support assigned potential
-- Limited available data does not support assigned potential
ID = Insufficient data to evaluate support or non-support of assigned potential
ND = No data
(P) = Provisional, radon potential confidence less certain (additional data needed)

uranium data. Table 7 lists units with high final radon potentials. Table 8 lists units with low final radon potentials. No units in western Tulare County met the criteria for moderate radon potential.

A unit received an unknown potential ranking if few or no data suitable for radon ranking are available. Two units in western Tulare County with both insufficient indoor-radon and insufficient uranium data were classified as having unknown radon potential, Deer Creek 1 Fan and Kaweah River 1 Fan. The Deer Creek 1 Fan has four associated indoor-radon measurements, two above 4.0 pCi/L and two below 4.0 pCi/L. These limited indoor-radon data and limited uranium data make it unclear if the Deer Creek 1 Fan should be assigned high or low radon potential, hence

Geologic Unit (symbol and name)	**Indoor Radon Data**	**NURE Soil and Sediment Uranium Data**	**NURE Airborne eU data**	**Assigned Radon Potential**
Cottonwood East Fan	x	x	X	Low
Cottonwood West Fan	ND	ID	X	Low (P) (source geologic units are low U)
Deer Creek 2 Fan	ID	X	X	Low
Ducor Fan	ND	X	X	Low
Frazier Creek Fan	ID	X	X	Low
Long Creek Fan	ID	x	X	Low
Very Old Fan 1	ND	x	X	Low
Very Old Fan 2	ND	ID	X	Low (P) (similar to Very Old Fans 1 and 3)
Very Old Fan 3	ND	x	X	Low
Rag Gulch Fan	ND	x	X	Low
Sand Creek Fan	ID		X	Low
Seville Fan	ND	x	X	Low
Traverse Creek Lower Fan	x	x	X	Low
Traverse Creek Upper Fan	ND	x	X	Low
Vestal Fan	ND	x	X	Low
White River Fan	ND	X	mixed	Low

Table 8. Western Tulare County geologic units and strength of supporting data for low radon potential designation

(see Table 7 footnotes for abbreviation and symbol definitions) the uncertain potential classification. Similarly, the Kaweah River 1 Fan with two associated indoor-radon data, 7.5 pCi/L and 1.7 pCi/L, and limited uranium data resulted in its uncertain potential classification.

Radon Potential Zone Creation

Radon zone development utilizes GIS procedures. As previously discussed, western Tulare County has geologic units with high, low or unknown radon potential, so it will have high, low and unknown radon potential zones. Zones are created by simply combining the geologic units into groups based on their final assigned radon potential. The high potential zone is all of the occurrences of high potential geologic units. Some occurrences adjoin each other creating a larger high potential area; others are isolated creating smaller high potential areas. Low and unknown potential zone creation also uses this approach. Figure 13 is a miniature and simplified version of the western Tulare County radon potential map showing the high, low and unknown zones. Figure 14 shows the radon potential zones with supporting data. Plate 1 is the final radon potential map for western Tulare County, showing radon potential zones and hydrologic, road and other base data.

Radon Potential Zone Characteristics

Tables 9, 10, 11 and 12 summarize indoor-radon data for each radon zone in western Tulare County. Summarized separately in Tables 9 and 10 are CDPH survey data for homes outside of western Tulare County in the Sierra Nevada Mountains.

Table 9 shows the number of radon measurements, the median, 25 percent and 75 percent quartile radon concentrations, and the minimum and maximum radon concentrations for each radon potential zone and for western Tulare County as a whole.

Table 10 shows the number and percentage of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 20.0 pCi/L radon measurements. It also lists the area, in square miles, for each radon potential zone in the western Tulare County radon potential map area.

Table 11 shows the percentages of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 20.0 pCi/L radon measurements distributed between the radon potential zones, and the percent land area for each zone. It also shows the cumulative percent of ≥ 4.0 pCi/L measurements and land area for each zone from high potential to unknown potential. Note that the high potential zone only represents 33.3 percent of the western Tulare County map area but contains 97.8 percent of all ≥ 4.0 pCi/L home survey measurements. Table 12 shows the number of ≥ 4.0 pCi/L measurements per square mile and the total number of radon measurements per square mile in western Tulare County. Western Tulare County averages about 0.25 measurements per square mile.

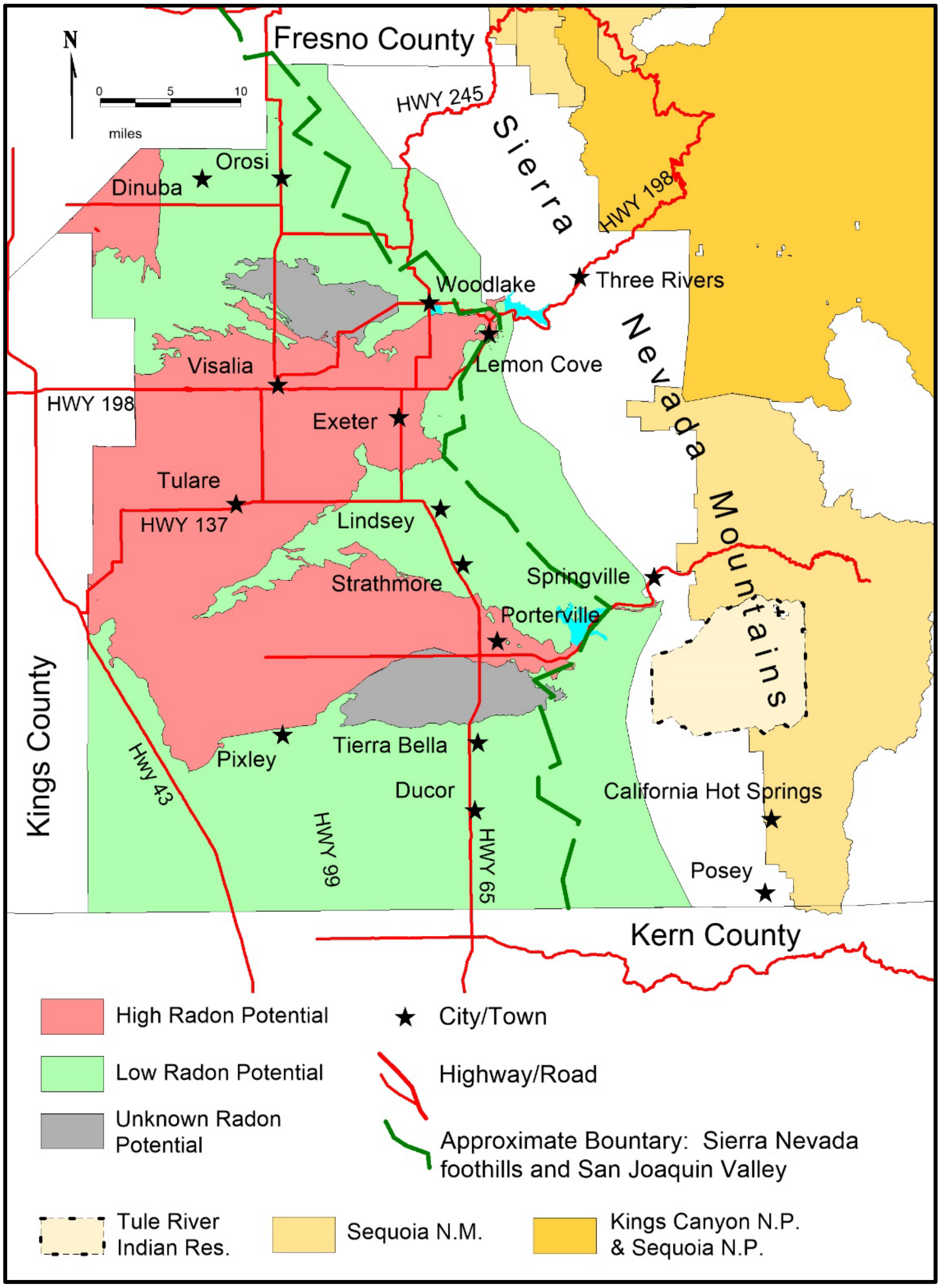

Figure 13. Western Tulare County radon potential zones

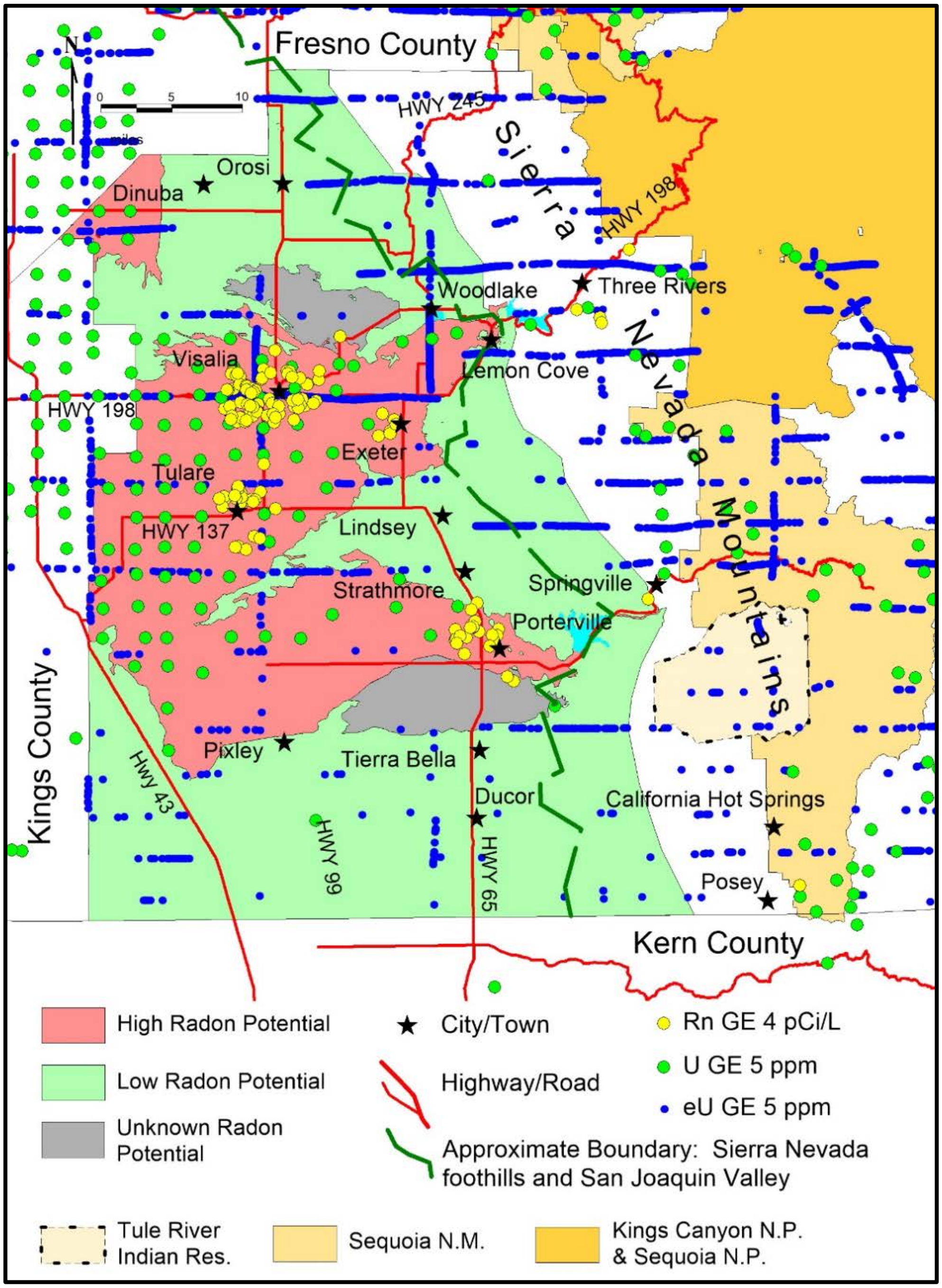

Figure 14. Western Tulare County radon potential zones with supporting anomalous indoor-radon survey data and NURE project data

Potential Zone	n	Median pCi/L	pCi/L at 25%	pCi/L at 75%	Min pCi/L	Max pCi/L
High	420	2.9	1.8	4.4	0.5	22.9
Low	41	1.5	1.05	2.0	0.5	3.7
Unknown	6	3.7	1.63	6.3	1.4	7.5
All (western Tulare County)	467	2.7	1.7	4.3	0.5	22.9
Sierra Nevada*	31	2.5	1.7	3.6	0.7	33.0
All Tulare County	498	2.7	1.7	4.2	0.5	33.0

*Combined data from Three Rivers, Springville and Posey areas

Table 9. CDPH radon-survey data characteristics for western Tulare County radon potential zones

Potential Zone	n	n ≥ 4.0 pCi/L	% data ≥ 4.0 pCi/L	n ≥ 10.0 pCi/L	% data ≥ 10.0 pCi/L	n ≥ 20.0 pCi/L	% data ≥ 20.0 pCi/L	Western Tulare County Area-land only (sq.-mi.)
High	420	133	31.7	14	3.3	1	0.2	621.9
Low	41	0	0.0	0	0.0	0	0.0	1,135.0
Unknown	6	3	50.0	0	0.0	0	0.0	111.7
All (western Tulare County)	467	136	29.1	14	3.0	1	0.2	1,868.6
Sierra Nevada*	31	6	19.4	3	9.7	1	3.2	--
All Tulare County	498	142	28.5	17	3.4	2	0.4	--

*Combined data from Three Rivers, Springville and Posey areas

Table 10. Number and percent of CDPH radon-survey measurements (n) ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L for western Tulare County radon potential zones

Zone	% of all ≥ 4.0 pCi/L data in western Tulare County study area	% of all ≥ 10.0 pCi/L data in western Tulare County study area	% of all ≥ 20.0 pCi/L data in western Tulare County study area	% Area of western Tulare County study area	Cumulative % of all ≥ 4.0 pCi/L data	Cumulative % of western Tulare County study area
High	97.8	100.0	100.0	33.3	97.8	33.3
Low	0.0	0.0	0.0	60.7	97.8	94.0
Unknown	2.2	0.0	0.0	6.0	100.0	100.0
All western Tulare County	100.0	100.0	100.0	100.0	100.0	

Table 11. Percent of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L CDPH radon-survey measurements for western Tulare County radon potential zones

Zone	Radon survey ≥ 4.0 pCi/L measurements per square mile	Radon survey total measurements per square mile
High	0.2139	0.6753
Low	0.0	0.0361
Unknown	0.0269	0.0537
All (western Tulare County)	0.0728	0.2499

Table 12. Average CDPH radon-survey measurements per square mile for western Tulare County radon potential zones

RADON POTENTIAL ZONE STATISTICS

Indoor Radon Measurements—Data Population Characteristics

Appendices K and L list indoor-radon data population statistics for each western Tulare County radon potential zone. Appendix K provides statistics for non-transformed radon data and Appendix L provides statistics for log-transformed (natural logarithm) radon data.

Indoor Radon Data—Frequency Distributions

Frequency distributions of trace element concentration data, such as for uranium and radon in rocks, soils and sediments, are often approximated using a lognormal distribution. However, because of the variety of geologic units and complex history of processes affecting them, trace element geochemical data cannot always be fit to a specific frequency distribution (Rose and others, 1979, p. 33).

Normal and log-transformed indoor-radon data for the western Tulare County radon potential zones were evaluated for normality using the Shapiro-Wilk normality test. Appendix M shows these test results. Indoor-radon data for the high radon potential zone appears to be lognormally distributed. Both untransformed and log-transformed indoor-radon data populations for low and unknown radon potential zones passed the Shapiro-Wilk test for normality. These results suggests the numbers of radon data for the low potential and unknown potential zones are too small for the Shapiro-Wilk test to distinguish which population distribution best describes the data in these zones. Indoor-radon data for the Sierra Nevada do not appear to fit either normal or lognormal population distributions. This result likely arises because Sierra Nevada radon data are a combination of samples from multiple populations—each geologic unit having its own distribution of indoor-radon data frequencies. On an individual basis, geologic unit indoor-radon populations are often lognormal, but the aggregate of indoor-radon data from several geologic units is often not lognormal.

Data non-normality has important implications for certain statistical tests. For example, t-test comparisons should not be used for comparing nonnormal (nonparametric) populations. Uncertainty about low zone and unknown zone radon population distributions is a reason this study uses the Mann-Whitney rank sum test for comparing radon zone populations. This test, not dependent upon population distribution, also has advantages in dealing with censored data (Helsel, 2012, p. 13). Having a lower reporting limit of 0.5 pCi/L, the radon survey data in this study are censored.

Non-normality also has negative consequences for predictions of percentages of homes with indoor-radon levels exceeding 4.0 pCi/L when such predictions incorrectly assume a lognormal population distribution for radon data. Consequently, this study used percentages of Tulare County radon survey data at or above ≥4 pCi/L, ≥ 10.0 pCi/L and 20.0 pCi/L and radon zone population estimates to calculate the number of individuals exposed to ≥4.0 pCi/L, ≥ 10.0 pCi/L and ≥ 20.0 pCi/L radon levels.

Statistical Comparison of Indoor Radon Data by Radon Potential Zone

Appendix N lists Mann-Whitney rank sum test statistical comparison results for the high, low and unknown radon potential zone indoor-radon data populations. The results show:

1) The high and low potential zones indoor-radon data populations are statistically different
2) The low and unknown potential zones are statistically different
3) The high and unknown zones may not be statistically different.

Result 1, along with the median of the high zone data being greater than the median of the low zone data, support the validity of the western Tulare County radon potential map. If more indoor-radon data become available for unknown zone areas, they could end up meeting the criteria for any of the radon potential categories, high, moderate or low.

Estimated Population Exposed to 4.0 pCi/L or Greater Indoor Air Radon Concentrations in Western Tulare County

The population and home estimates in Tables 13 and 14 provide some perspective about the significance of the indoor-radon issue in western Tulare County. These estimates are based on 2010 U.S. Census data which list the total Tulare County population as 442,179.

Table 13 shows estimates for the population and the number of homes for each radon potential zone within western Tulare County. To make radon zone population estimates, census tract boundaries were compared with radon zone boundaries using GIS. A census tract's population was assigned to a radon zone if the census tract area was entirely within that radon zone. A census tract located within multiple zones had its population divided among the zone in proportion to the percentage of census tract area within each zone. The number of homes per radon potential zone was estimated by dividing the estimated zone population by 3.35, the average number of persons per household in Tulare County between 2009 and 2013 (U.S. Census Bureau, State and County Quickfacts, Tulare County, California).

Radon Potential Zone	**Estimated Total Population within Zone—2010 Census Statistics**	**Estimated Household Population and Total Homes within Zone in 2010**	
Western Tulare County		**Average Household Population***	**Number of Homes****
High	301,162	3.35	89,899
Low	119,521	3.35	35,678
Unknown	10,600	3.35	3,164
Total	431,283	3.35	128,741

Table 13. Population and home estimates by radon potential zone

*Persons per household 2009-2013, U.S. Census Bureau, State & County QuickFacts, Tulare County, California

**Zone population ÷ average household population

Table 14 contains estimates of the number of residents residing in homes with radon at or above 4.0, 10.0 and 20.0 pCi/L for each radon potential zone and overall for western Tulare County. These estimates were made by multiplying the percentages of ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L measurements for each zone (from Table 12) by the estimated total population for each zone.

Table 14 contains two groups of total population estimates for radon exposures for western Tulare County. For the first, under table heading "*Population Estimates Weighted by Radon Zone*," the population estimate totals for the ≥ 4.0 pCi/L, 10.0 pCi/L and 20.0 pCi/L exposure categories are the sums of the high, low and unknown estimated populations for each category. The second estimate, under heading "*Population Estimate Not Weighted by Radon Zone*" was calculated by multiplying the total western Tulare County population by the Table 10 row "All (western Tulare County)" percentages for ≥ 4.0 pCi/L, 10.0 pCi/L and 20.0 pCi/L measurements. Note that the "not weighted by zone" estimates are significantly higher and are likely less accurate than the "weighted by zone" estimates.

Subtracting the estimated population within the radon potential zones in western Tulare County from the total county population provides an estimate of the population within the Sierra Nevada portion of the County. Using this population estimate and the percentages of CDPH survey data ≥ 4.0 pCi/L, ≥ 10.0 pCi/L, and ≥ 20.0 pCi/L for the Sierra Nevada in Table 10, the population estimates in Table 15 were calculated.

Radon Potential Zones	**Estimated Population for Zone**	**Estimated Population at ≥ 4.0 pCi/L**	**Estimated Population at ≥ 10.0 pCi/L**	**Estimated Population at ≥ 20.0 pCi/L**	**% Area**	**Sq. Miles**
High	301,162	95,468	9,938	602	33.3	621.9
Low	119,121	0	0	0	60.7	1,135.0
Unknown	10,600	Uncertain-too few data	Uncertain-too few data	Uncertain-too few data	6.0	111.7
Radon Exposure Estimates for western Tulare County						
Population Estimate Weighted by Radon Zone						
Totals (weighted, i.e., sum of Zone population estimates)	431,283	95,468	9,938	602	100	1,868.6
Population Estimate Not Weighted by Radon Zone						
Totals for western Tulare County	431,283	125,503	12,938	863	100	1,868.6

Table 14. Estimates of western Tulare County population exposed to 4.0 pCi/L or greater indoor radon levels in residences

Tulare County Area	**Estimated Population Total**	**Estimated Population at ≥ 4.0 pCi/L**	**Estimated Population at ≥ 10.0 pCi/L**	**Estimated Population at ≥ 20.0 pCi/L**
Sierra Nevada	10,896	2,114	1,057	349

Table 15. Estimate of Tulare County population in the Sierra Nevada exposed to 4.0 pCi/L or greater indoor radon levels in residences

By combining the estimates in Table 15 with the weighted and non-weighted estimates in Table 14, weighted and non-weighted estimates of the total Tulare County population exposed to ≥ 4.0 pCi/L radon levels in homes in Tulare County were calculated. Table 16 shows these estimates.

Tulare County Area	Estimated Population Total	Estimated Population at ≥ 4.0 pCi/L	Estimated Population at ≥ 10.0 pCi/L	Estimated Population at ≥ 20.0 pCi/L
Estimated total county population exposed to ≥ 4.0 pCi/L or higher home indoor-radon concentrations using radon zone weighted population estimates for western Tulare County				
Western Tulare County—weighted population estimate	431,283	95,468	9,938	602
Sierra Nevada population estimate	10,896	2,114	1,057	349
Total All County population—weighted	**442,179**	**97,582**	**10,995**	**951**
Estimated total county population exposed to ≥ 4.0 pCi/L or higher home indoor-radon concentrations using total county (not weighted by radon zone) population estimates for western Tulare County				
Western Tulare County—not-weighted population estimate	431,283	125,503	12,938	863
Sierra Nevada population estimate	10,896	2,114	1,057	349
Total All County population—not weighted	**442,179**	**126,021**	**15,034**	**1,769**

Table 16. Estimates of Tulare County population exposed to 4.0 pCi/L or greater indoor radon levels in residences

WESTERN TULARE COUNTY RADON MAPPING PROJECT SUMMARY

Short-term radon test data from CDPH, NURE project soil and stream-sediment uranium data, and airborne eU data were used to evaluate geologic units in western Tulare County for their potential to have associated homes with indoor air exceeding the U.S. EPA recommended action level of 4.0 pCi/L. Geologic units were classified as having high, low or unknown radon potential, based on the percentage of 4.0 pCi/L or higher indoor radon measurements, the presence of anomalous data for uranium, and the amount of data available.

The final radon potential zones have the following characteristics:

High Radon Potential Zone: this zone comprises 33.3 percent (621.9 square miles) of the western Tulare County study area and contains 97.8 percent of the ≥ 4.0 pCi/L measurements and 100.0 percent of the ≥ 20 pCi/L measurements in the CDPH indoor-radon survey of western Tulare County. The maximum radon survey measurement for a home in this zone is 22.9 pCi//L (for a first floor room, foundation type not reported).

Low Radon Potential Zone: this zone comprises 60.7 percent (1,135 square miles) of the western Tulare County study area and contains 0 percent of the ≥ 4.0 pCi/L measurements 0 percent of the ≥ 20 pCi/L measurements in the CDPH indoor-radon survey in western Tulare County. The maximum radon survey measurement for a home in this zone is 3.7 pCi//L.).

Unknown Radon Potential Zone: this zone comprises 6.0 percent (111.7 square miles) of the western Tulare County study area and contains 2.2 percent of ≥ 4.0 pCi/L measurements in the CDPH indoor-radon survey in western Tulare County. The maximum radon survey measurement for a home in this zone is 7.5 pCi//L.

Sierra Nevada Data: The CDPH radon survey for Tulare County contains 31 indoor-radon measurements for homes in Sierra Nevada areas east of the western Tulare County radon mapping area (from the Three Rivers, Springville and Posey areas). Six of these data (19.4 percent) are ≥ 4.0 pCi/L. The maximum radon measurement for the Sierra Nevada data is 33.0 pCi/L.

Typically, both indoor-radon concentrations exceeding the U.S. EPA recommended action level of 4 pCi/L and indoor-radon concentrations below this action level can be found in high and in low radon potential zone areas. The CDPH radon survey did not identify any ≥ 4.0 pCi/L homes in the western Tulare County low potential areas. However, the number of low potential zone data is not large (n=41). It is likely that additional radon testing in low zone areas will identify some homes with indoor-radon concentrations exceeding 4.0 pCi/L

Indoor-radon levels are the result of very complex site-specific multi-component processes. For this reason, reliable prediction of indoor-radon levels for specific buildings through modeling is not possible. The only way to know the indoor-radon concentration in a particular home, school or other building is by testing the indoor-air for radon, regardless of the zone in which the building is located.

Statistical comparison of the indoor-radon data populations for the high and low radon potential zones, using the Mann-Whitney rank sum test, shows these populations differ from each other statistically. This result supports the increased likelihood of a building in the high potential zone having indoor-radon exceeding 4 pCi/L relative to the low potential zone.

RECOMMENDATIONS

Indoor-radon testing should be encouraged in western Tulare County, particularly in the high radon potential zone areas. Additional indoor-radon measurements within unknown radon potential zone areas should also be encouraged. Although not mapped for radon potential in this study because of limited and sparsely distributed data and population, indoor-radon testing should be encouraged in the Sierra Nevada. The cooler climate, more severe weather and areas with elevated background uranium concentrations in rocks, soil and sediment are all things in the Sierra Nevada that increase the odds for elevated indoor-radon levels in buildings.

Those considering new home construction, particularly at sites within high radon potential areas, may wish to consider radon resistant new construction practices. Post construction radon mitigation is possible, if necessary, but will be more expensive than the cost of adding radon-reducing features during house construction.

ACKNOWLEDGEMENTS

Milton Fonseca (CGS) produced the final GIS file of the western Tulare County Radon Potential Map and provided GIS support throughout this project. Clifton Davenport (CGS) developed the digital surficial geologic map layer for western Tulare County used to produce the radon potential map. John Clinkenbeard and Matt O'Neal (CGS) reviewed the map and report and provided helpful suggestions to improve the text. George Faggella, CDPH Indoor Radon program, provided Tulare County indoor-radon survey test results and QA/QC information.

REFERENCES

Appleton, J.D., Radon in Air and Water, 2013, in Selinus, Olle, ed., Essentials of Medical Geology, Springer Dordrecht, Heidelberg, pp. 239-277.

Brookins, D.G., 1990, The Indoor Radon Problem; Columbia University Press, New York, 229 p.

Davenport, Clifton W., 2013, Unpublished surficial geologic map of western Tulare County, California, 1:100,000-scale; California Geological Survey.

Duval, J.S., 2000, Aerial Gamma-Ray Surveys of the conterminous United States and Alaska, Aerial Gamma Ray Surveys of California and Oregon; U.S. Geological Survey Open-File Report 99-562K, CD-ROM.

Grammer, D., and Burkhart, J.F., 2004, 16-Hour Entry Measurement Course Manual, Western Regional Radon Training Center, University of Colorado, Colorado Springs.

Grasty, R.L., 1997, Radon emanation and soil moisture effects on airborne gamma-ray measurements; Geophysics, v. 62, no. 5 (September-October 1997), pp. 1379-1385.

Helsel, D.R., 2012, Statistics for Censored Environmental Data Using Minitab® and R, 2nd edition; John Wiley and Sons, Inc., Hoboken, New Jersey, 324.

High Life Helicopters, Inc., and QEB Inc., 1980a, Airborne gamma-ray spectrometer and magnetometer survey, Bakersfield Quadrangle (California): U.S. Department of Energy, Open-File Report GJBX-214-80.

NRCS, 2009, Hydrologic Soil Groups, Chapter 7, Part 630 Hydrology, National Engineering Handbook (210-VI-NEH, January 2009), U.S. Department of Agriculture, Natural Resources Conservation Service pp. 7-1 to 7-5. http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=22526.wba

Rose, A.W., Hawkes, H.E., and Webb, J.S., 1979, Geochemistry in Mineral Exploration, second edition; Academic Press Inc., New York, 675 p.

U.S. Department of Commerce, 2012, TIGER/Line Shapefile 2010.

Smith, D.B., Cannon, W.F., Woodruff, L.G., Solano, F., Kilburn, J.E., and Fey, D.L., 2013, Geochemical and Mineralogical Data for Soils of the Conterminous United States: U.S. Geological Survey Data Series 801, 19 p., http://pubs.usgs.gov/ds/801/ .

U.S. Department of Energy (DOE) Grand Junction Office, 1980, Airborne gamma-ray spectrometer and magnetometer survey, Mariposa Quadrangle (California, Nevada), Fresno Quadrangle (California), and Bakersfield Quadrangle (California): Grand Junction Bendix Office Report (GJBX) GJBX-231(80), DOE Grand Junction Office, Grand Junction, Colorado

U.S. EPA, 2012, A Citizen's Guide to Radon: The guide to protecting yourself and your family from radon, U.S. EPA 402-K-12-002, 16 p. Available at http://www.epa.gov/radon/pdfs/citizensguide.pdf

APPENDIX A

Tulare County Concurrent Indoor-Radon Test Data

(Multiple short-term radon measurements conducted simultaneously in residences)

High (pCi/L)	Low (pCi/L)	Difference (pCi/L)	Percent* Difference	Comments
6.5	5.0	1.5	23.1	
5.6	5.4	0.2	3.6	
5.6	5.1	0.5	8.9	
5.4	5.1	0.3	5.6	Different bedrooms
5.1	4.5	0.6	11.8	
4.7	3.0	1.7	36.2	Same location
4.5	4.2	0.3	6.7	Same location
3.8	2.7	1.1	28.9	
3.7	3.5	0.2	5.4	
3.2	2.9	0.3	9.4	
3.2	2.5	0.7	21.9	
2.9	2.8	0.1	3.4	
2.9	2.5	0.4	13.8	
2.3	2.2	0.1	4.3	
2.1	0.9	1.2	57.1	
2.0	1.8	0.2	10.0	
1.7	0.9	0.8	47.1	
1.5	0.6	0.9	60.0	1st floor vs 2nd floor
1.1	1.0	0.1	9.1	

*(Difference ÷ High) X 100

APPENDIX B

2009-2010 Charcoal Detector Field Blanks

Test Kit ID	Blank Results pCi/L
ca31518	<0.5
ca31521	<0.5
ca31526	<0.5
ca31527	<0.5
ca31528	<0.5
ca31529	<0.5
ca31530	<0.5
ca31531	<0.5
ca31532	<0.5

APPENDIX C

2009-2010 Charcoal Detector Laboratory Spikes

Test Kit ID	Mean Chamber Radon Conc. pCi/L	Test Result pCi/L	Percent Difference from Mean Chamber Conc. pCi/L*
nj31870	13.9	17.1	23.0
nj31871	13.9	14.6	5.0
nj31873	13.9	17.2	23.7
nj31874	13.9	14.0	0.7
nj31876	13.9	15.5	11.5
nj31877	13.9	14.3	2.9
nj31880	13.9	15.1	8.6
nj31881	13.9	13.8	-0.7
nj31885	13.9	17.0	22.3

*Percent difference = (difference ÷ mean chamber concentration) X 100

APPENDIX D

Results of Follow-up Tests in Homes

Test 1 (pCi/L)	Test 2 (pCi/L)	Difference (pCi/L)	Percent Difference*	Days Between Tests	Date Test 1	Date Test 2
7.1**	5.6**	1.5	21.1	33	01/29/10-02/01/10	03/03/10-03/06/10
7.1**	5.4**	1.7	23.9	33	01/29/10-02/01/10	03/03/10-03/06/10
7.1**	5.1**	2.0	28.2	33	01/29/10-02/01/10	03/03/10-03/06/10
9.0	2.2	6.8	75.6	26	01/18/10-01/21/10	02/13/10-02/15/10
3.4	6.4	3.0	46.9	17	12/31/09-01/03/09	01/17/10-01/21/10
4.3	1.8	2.5	58.2	55	01/15/10-01/18/10	03/11/10-03/14/10
5.6	2.9	2.7	48.2	38	01/16/10-01/18/10	02/23/10-02/25/10
14.2	9.5	4.7	33.1	31	01/16/10-01/18/10	02/16/10-02/18/10
1.9	5.6	3.7	66.1	17	12/29/09-12/31/09	01/15/10-01/18/10
5.7	2.3	3.4	59.6	38	01/20/10-01/22/10	02/27/10-03/01/10

*Percent Difference = (Difference ÷ the higher of test 1 or test 2) X 100
**Multiple measurements in a house

APPENDIX E

References Used by Davenport in Developing the Surficial Geologic Map for western Tulare County, California

Anderson, A.C., et al, 1942, Soil Survey of the Wasco Area, California: U.S. Department of Agriculture Soil Survey Series 1936, No. 17, issued August 1942, 1:63,360-scale.

Atwater, B.F., et al, 1986, A Fan Dam for Tulare Lake, California, and implications for the Wisconsin glacial history of the Sierra Nevada: GSA Bulletin, 1986, v. 97, pp 97-109.

Bartow, J.A., 1984, Geologic Map and Cross Sections of the southeastern margin of the San Joaquin Valley, California: U.S. Geological Survey Miscellaneous Investigation Series I-1496, 1:125,000-scale.

Bedrossian, T.L., et al, 2012, Geologic Compilation of Quaternary surficial Deposits in southern California: California Geological Survey Special Report 217, 1:100,000-scale
.

California Department of Fish and Wildlife, 2010, National Agriculture Imagery Program (NAIP) Image Server, 2009 and 2010 4-band and CIR Summer Imagery, accessed Jan.-April, 2013.

Cole, R.C., et al, 1945, Soil Survey of the Bakersfield Area California: USDA Soil Survey Series 1937, No 12, issues August 1945, 1:63,360-scale.

Croft, M.G., and Gordon, G.V., 1968, Geology, Hydrology, and Quality of Water in the Hanford-Visalia Area, San Joaquin Valley, California; U.S. Geological Survey-Water Resources Division, Open-file Report 68-67, Menlo Park, California, 63 p.

Eppes, M.C., et al, 2002, Influence of soil Development on the Geomorphic Evolution of Landscapes: An Example from the Transverse Ranges of California: Geology. March 2001, v. 30, no. 3, pp. 195-198.
ESRI, 2013, ESRI Image Server, World Imagery, Accessed Jan.-April 2013.

Matthews, R.A., and Burnett, J.L., 1965, Geologic Map of California—Fresno Sheet, 1:250,000-scale, California Division of Mines and Geology (currently known as the California Geological Survey).

Lettis, W.R., 1982, Late Cenozoic Stratigraphy and Structure of the Western Margin of the Central San Joaquin Valley, California: U.S. Geological Survey Open-File Report 82-526, 203 p.

Lettis, W.R., and Unruh, J.R., Quaternary Geology of the Great Valley, California: *in* W.R. Dupre and others (eds.), Pacific Margin, Conterminous U.S., pp. 164-176.

National Agricultural Imagery Program (NAIP) Imagery, 2012, for Tulare County, California

Smith, A.R., 1964, Geologic Map of California—Bakersfield Sheet, 1:250,000-scale, California Division of Mines and Geology (currently known as the California Geological Survey).

Storie, R.E., et al, 1940, Soil Survey of the Visalia Area, California: USDA Soil Survey Series 1935, No. 16, issued December 1940, 1:63,360-scale.
.
Storie, R.E., et al, Soil Survey of the Pixley Area, California: USDA Soil Survey Series 1935, Issued April 1942, 1:63,360-scale.

U.S. Department of Agriculture, Natural Resources Conservation Service (2013) Soil Survey Geographic (SSURGO) database for Tulare County, Western Part, California, ca659

U.S. Department of Agriculture, Natural Resources Conservation Service (2013) Soil Survey Geographic (SSURGO) database for Tulare County, Central Part, California, ca660

U.S. Department of Agriculture, Natural Resources Conservation Service (2013) Soil Survey Geographic (SSURGO) database for Kern County, Northeastern Part, and Southeastern Part of Tulare County, California, ca668

U.S. Department of Agriculture, Natural Resources Conservation Service (2013) Soil Survey Geographic (SSURG) database for Sequoia National Forest Parts of Fresno, Kern and Tulare Counties, California, ca760

U.S. Geological Survey National Elevation Data (NED) – 10m Tulare County, California, United States

U.S. Geological Survey National Elevation Data (NED) – 10m Kern County, California, United States

Weissman, G.S., Bennett, G.L. and Lansdale, A.L., Factors Controlling Sequence Development on Quaternary Fluvial Fans, San Joaquin Basin, California: *in* Harvey, A.M., Mather, A.E., and Stokes, M. (eds.) 2005, *Alluvial Fans: Geomorphology, Sedimentation, Dynamics*, Geological Society of London Special Publications 251, pp. 169-186.

Weissman, G.S., Mount, J.F. and Fogg, G.E., 2002, Glacially Driven Cycles in Accumulation Space and Sequence Stratigraphy of a Stream-Dominated Alluvial Fan, San Joaquin Valley, CA: JSR 2002, pp. 240-251.

Wollenberg, H.A., and Smith, A.R., 1968, Radiogeologic studies in the central part of the Sierra Nevada batholith, California: Journal of Geophysical Research, v. 73, no. 4, pp. 1481-1495.

APPENDIX F

CDPH Indoor-Radon Survey Data by Alluvial Fan, Basin and Bedrock in western Tulare County California

Unit	Description	N	Indoor-Radon Data pCi/L				Mean pCi/L	Median pCi/L	Low pCi/L	High pCi/L	% ≥ 4 pCi/L
Basin Deposits	Inter-fan areas	9	5.8 4.4 4.0	3.7 3.0 2.9	2.8 2.0 0.7		3.26	3.0	0.7	5.8	33.3
Bedrock	Foothill metamorphic and granitic rock areas	9	2.5 1.8 1.7	1.6 1.5 1.2	1.1 1.0 0.6		1.44				0.0
Cottonwood Creek East	Fan	4	2.8	2.3	1.3	1.0	1.85	1.8	1.0	2.8	0.0
Deer Creek 1	Fan	4	5.9	5.4	1.9	1.4	1.65	3.65	1.4	5.9	50.0
Deer Creek 2	Fan	1	1.6				1.60	1.6	1.6	1.6	--
Ducor	Fan	0	No data				--	--	--	--	--
Frazier Creek	Fan	2	2.1	0.7			1.40	1.4	0.7	2.1	--
Kaweah 1	Sub-fan	2	7.5	1.7			4.60	4.6	1.7	7.5	--
Kaweah 2	Sub-fan	40	16.1 12.2 9.1 8.3 8.0 6.5 6.4 6.0 5.6 5.6	5.5 5.4 4.8 4.3 4.2 4.1 4.1 3.6 3.4 3.4	3.3 3.2 3.2 3.2 3.0 3.0 2.7 2.7 2.6 2.6	2.6 2.3 2.1 2.1 2.0 1.9 1.9 1.7 1.4 1.0	4.38	3.35	1.0	16.1	42.5

Kaweah 3	Sub-fan	241	17.3	4.6	3.0	1.9	3.74	3.0	0.6	17.3	34.0
			14.2	4.5	3.0	1.9					
			12.6	4.5	3.0	1.9					
			12.3	4.5	3.0	1.9					
			11.4	4.4	3.0	1.9					
			11.2	4.4	3.0	1.8					
			10.9	4.4	2.9	1.8					
			10.1	4.3	2.9	1.8					
			9.6	4.3	2.9	1.8					
			9.5	4.3	2.9	1.7					
			9.1	4.3	2.9	1.7					
			9.0	4.2	2.9	1.7					
			8.9	4.2	2.8	1.7					
			8.8	4.2	2.8	1.7					
			8.8	4.1	2.7	1.7					
			8.4	4.1	2.7	1.7					
			8.2	4.1	2.7	1.6					
			8.1	4.0	2.6	1.6					
			8.0	4.0	2.6	1.6					
			7.8	4.0	2.6	1.6					
			7.7	4.0	2.6	1.6					
			7.6	3.9	2.6	1.6					
			7.5	3.9	2.6	1.6					
			7.4	3.9	2.6	1.5					
			7.1	3.9	2.6	1.5					
			7.0	3.9	2.6	1.5					
			7.0	3.9	2.6	1.5					
			6.7	3.8	2.6	1.5					
			6.7	3.8	2.6	1.4					
			6.7	3.8	2.5	1.4					
			6.6	3.8	2.5	1.4					
			6.4	3.8	2.5	1.4					
			6.3	3.8	2.5	1.4					
			6.2	3.8	2.5	1.4					

			6.2	3.8	2.4	1.3					
			6.1	3.8	2.4	1.3					
			5.8	3.7	2.4	1.3					
			5.7	3.7	2.3	1.3					
			5.7	3.6	2.3	1.3					
			5.7	3.6	2.3	1.2					
			5.6	3.6	2.3	1.2					
			5.5	3.6	2.2	1.2					
			5.4	3.5	2.2	1.2					
			5.4	3.5	2.2	1.2					
			5.4	3.4	2.2	1.2					
			5.4	3.4	2.2	1.1					
			5.3	3.4	2.2	1.1					
			5.3	3.4	2.2	1.1					
			5.2	3.3	2.2	1.1					
			5.1	3.3	2.1	1.1					
			5.1	3.2	2.1	1.1					
			5.1	3.2	2.1	1.0					
			5.1	3.2	2.0	0.9					
			5.0	3.2	2.0	0.9					
			4.8	3.2	2.0	0.9					
			4.7	3.1	1.9	0.9					
			4.7	3.1	1.9	0.8					
			4.7	3.0	1.9	0.7					
			4.6	3.0	1.9	0.6					
			4.6	3.0	1.9	0.6					
			4.6								
Kaweah 4	Sub-fan	10	6.5	2.9	2.5	1.4	3.30	2.8	1.4	6.5	30.0
			5.2	2.8	2.2						
			4.9	2.8	1.8						
Kaweah 5	Sub-fan	27	13.6	3.5	2.1	1.3	3.20	2.3	0.5	13.6	22.2
			10.1	3.5	2.1	1.1					
			6.9	3.0	1.9	1.0					
			5.0	3.0	1.9	1.0					

			4.1	2.8	1.7	0.9					
			4.0	2.3	1.6	0.5					
			3.8	2.3	1.4						
Kings	Fan	0	No data				--	--	--	--	--
Long Creek	Fan	2	0.5	0.5			0.50	0.5	0.5	0.5	--
Rag Gulch	Fan	0	No data				--	--	--	--	--
Sand Creek	Fan	2	1.9	1.2			1.50	1.55	1.2	1.9	--
Travers Creek	Fan	8	3.1	1.5	1.4	0.8	1.56	1.45	0.7	3.1	--
Lower			2.2	1.5	1.3	0.7					
Travers Creek Upper	Fan	0	No data				--	--	--	--	--
Tule River	Fan	97	22.9	3.5	2.4	1.5	3.04	2.5	0.5	22.9	22.7
			15.4	3.5	2.4	1.5					
			8.1	3.4	2.4	1.4					
			7.0	3.3	2.4	1.4					
			6.1	3.2	2.2	1.4					
			5.9	3.1	2.1	1.4					
			5.8	3.0	2.0	1.3					
			5.6	3.0	1.9	1.3					
			5.4	3.0	1.9	1.3					
			5.3	3.0	1.9	1.3					
			5.0	2.9	1.8	1.2					
			4.9	2.8	1.8	1.2					
			4.7	2.8	1.8	1.1					
			4.7	2.7	1.8	1.1					
			4.7	2.7	1.8	1.1					
			4.5	2.7	1.8	1.0					
			4.5	2.7	1.8	0.9					
			4.4	2.7	1.7	0.9					
			4.4	2.7	1.7	0.9					
			4.2	2.6	1.6	0.8					
			4.2	2.6	1.6	0.8					
			4.2	2.5	1.6	0.5					
			3.9	2.5	1.6	0.5					

			3.8 3.8	2.5	1.5	0.5					
Very Old Fan 1	Fan	0	No data				--	--	--	--	--
Very Old Fan 2	Fan	0	No data				--	--	--	--	--
Very Old Fan 3	Fan	0	No data				--	--	--	--	--
Vestal	Fan	0	No data				--	--	--	--	--
White River	Fan	0	No data				--	--	--	--	--
Sierra Nevada	Homes in granitic and metamorphic rock areas	40	33.0 13.7 10.6 6.5 4.4 4.0 3.7 3.6 3.3 3.2	3.0 2.8 2.7 2.7 2.7 2.5 2.5 2.4 2.1 2.1	2.1 2.1 2.0 2.0 1.9 1.8 1.7 1.7 1.6 1.6	1.5 1.3 1.3 1.2 1.0 1.0 0.9 0.9 0.7 0.7	3.51	2.1	0.7	33.0	15.0

2016 RADON POTENTIAL IN WESTERN TULARE COUNTY, CALIFORNIA 61

APPENDIX G

Tulare County NURE Uranium data for Soil, Sediment and Talus Samples by Surficial Geologic Unit*

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)	Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
--	Basin Deposits-within Kaweah River and Tule River Fans	14	7.6 5.8 5.4 5.0 6.2 5.8 5.3 4.4 6.2 5.7 5.0 5.8 5.5 5.0	5.62	5.6	4.4	7.6	92.86
--	Basin Deposits-outside of Kaweah River and Tule River Fans	33	6.4 4.2 3.4 2.0 6.2 4.1 3.2 1.9 5.3 4.0 3.0 1.9 5.2 4.0 3.0 1.6 4.8 3.9 3.0 1.5 4.7 3.9 2.3 1.4 4.7 3.9 2.2 1.4 4.4 3.5 2.1 1.2 4.3	3.41	3.5	1.2	6.4	12.12
--	Basin Deposits-all	47	7.6 5.3 4.1 2.3 6.4 5.2 4.0 2.2 6.2 5.0 4.0 2.1 6.2 5.0 3.9 2.0 6.2 5.0 3.9 1.9 5.8 4.8 3.9 1.9 5.8 4.7 3.5 1.6 5.8 4.7 3.4 1.2 5.7 4.4 3.2 1.4 5.5 4.4 3.0 1.4 5.4 4.3 3.0 1.2 5.3 4.2 3.0			1.2	7.6	36.17

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
--	Foothill Alluvium and colluvium with small bedrock outcrops	11	3.6 3.1 2.7	2.6 2.3 2.1	2.1 2.1 2.1	1.5 1.1	2.30	2.1	1.1	3.6	0.00
--	Foothill Bedrock-metamorphic rocks and westernmost Sierra Nevada granitic rocks	29	5.2 4.1 4.0 4.0 3.6 3.6 3.4 3.0	3.0 2.9 2.7 2.6 2.6 2.6 2.4	2.4 2.4 2.4 2.2 2.2 2.1 2.0	2.0 1.9 1.8 1.5 1.4 1.1 0.6	2.61	2.4	0.6	5.2	3.45
COe	Cottonwood Creek East Fan	6	4.9 4.4	4.4 3.4	2.3 2.3		3.62	3.9	2.3	4.9	0.00
COw	Cottonwood Creek West Fan	1	2.7				2.70	2.7	2.7	2.7	--
DE1	Deer Creek 1 Fan	13	4.9 4.8 4.7 4.2	4.1 3.8 3.8	3.6 3.5 3.4	3.1 2.9 2.1	3.76	3.8	2.1	4.9	0.00
DE2	Deer Creek 2 Fan	18	4.7 4.4 4.2 4.0 3.9	3.3 3.2 3.0 2.7 2.7	2.5 2.1 2.0 2.0 1.9	1.7 1.7 1.5	2.86	2.7	1.5	4.7	0.00
DU	Ducor Fan	19	3.6 3.5 3.1 2.9 2.6	2.4 2.4 2.2 2.2 2.1	2.1 2.1 2.0 2.0 1.9	1.9 1.9 1.7 1.5	2.32	2.1	1.5	3.6	0.00

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
FR	Frazier Creek Fan	18	3.3 3.3 3.1 3.0 3.0	2.9 2.8 2.7 2.6 2.6	2.5 2.4 2.3 2.3 2.3	2.2 2.2 1.8	2.63	2.6	1.8	3.3	0.00
KA1	Kaweah River 1 Fan	9	4.5 3.8 3.7	3.5 3.3	3.3 2.9	2.7 1.5	3.24	3.3	1.5	4.5	0.00
KA2	Kaweah River 2 Fan	7	7.8 6.3	6.2 5.5	5.3 5.3	2.8	5.60	5.5	2.8	7.8	85.71
KA3	Kaweah River 3 Fan	43	10.0 8.4 8.1 7.4 7.2 7.0 7.0 7.0 6.8 6.6 6.5	6.4 6.4 6.3 6.2 5.8 5.7 5.7 5.7 5.7 5.6 5.5	5.5 5.5 5.4 5.4 5.4 5.4 5.3 5.3 5.2 5.1 5.1	5.1 5.0 4.8 4.8 4.7 4.5 4.2 4.1 4.0 1.6	5.78	5.5	1.6	10.0	81.40
KA4	Kaweah River 4 Fan	11	11.4 7.7 6.2	6.0 5.5 5.3	5.3 5.2 5.0	4.4 4.2	6.02	5.3	4.2	11.4	81.82
KA5	Kaweah River 5 Fan	9	5.3 4.1 4.0	3.7 3.5	3.4 3.1	2.9 2.6	3.62	3.5	2.6	5.3	11.11
KI	Kings River Fan	5	5.9 5.4	5.2	5.2	4.8	5.30	5.2	4.8	5.9	80.00

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)	Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
LO	Long Creek Fan	9	2.9 2.4 2.2 1.7 2.6 2.3 2.0 1.6 2.5	2.24	2.3	1.6	2.9	0.00
Q1	Very Old Fan 1	9	3.2 2.5 2.1 0.6 2.5 2.1 1.4 0.6 2.5	1.94	2.1	0.6	3.2	0.00
Q2	Very Old Fan 2	1	1.9	1.90	1.9	1.9	1.9	--
Q3	Very Old Fan 3	4	4.0 2.6 2.2 1.9	2.68	2.4	1.9	4.0	0.00
RA	Rag Gulch Fan	7	3.5 2.6 2.1 1.5 2.7 2.4 2.0	2.40	2.4	1.5	3.5	0.00
SA	Sand Creek Fan	7	2.5 2.1 1.9 1.6 2.1 2.0 1.9	2.01	2.0	1.6	2.5	0.00
SE	Seville Fan	3	2.5 1.9 1.3	1.90	1.9	1.3	2.5	0.00
TRl	Travers Creek Lower Fan	5	4.8 4.3 2.4 2.4 4.4	3.66	4.3	2.4	4.8	0.00
TRu	Travers Creek Upper Fan	2	2.7 2.2	2.45	2.45	2.2	2.7	0.00
TU	Tule River Fan	38	7.5 4.9 4.2 3.7 6.3 4.8 4.2 3.7 5.4 4.7 4.2 3.7 5.4 4.7 4.1 3.6 5.4 4.7 4.0 3.2 5.4 4.6 4.0 3.2 5.1 4.4 3.9 3.2 5.1 4.4 3.8 2.6 5.1 4.3 3.8 2.3 4.9 4.3	4.39	4.3	2.3	7.5	23.67

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
--	Tule Lake Sediments	36	6.2	3.1	2.7	1.9	2.67	2.7	1.1	6.2	2.78
			4.1	3.1	2.6	1.7					
			4.0	3.1	2.6	1.6					
			4.0	3.0	2.5	1.5					
			4.0	2.9	2.5	1.5					
			3.5	2.9	2.0	1.4					
			3.5	2.9	1.9	1.4					
			3.2	2.9	1.9	1.2					
			3.1	2.7	1.9	1.1					
VE	Vestal Fan	2	2.0	1.2			1.60	1.6	1.2	2.0	0.00
WH	White River Fan	23	6.2	3.0	2.4	1.5	2.59	2.6	0.5	6.2	4.35
			4.1	3.0	2.2	1.4					
			4.0	2.9	2.1	1.4					
			3.6	2.9	2.0	1.0					
			3.5	2.7	1.6	0.5					
			3.4	2.6	1.5						

Unit Symbol Figure 1	Unit Name	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
--	Sierra Nevada Granitic and Metamorphic Rock Areas (East of western Tulare County Radon Map Coverage and west of the Kern River watershed)	120	28.8	7.5	4.2	2.8	5.54	4.25	1.2	28.8	38.33
			20.5	7.5	4.2	2.8					
			17.1	7.48	4.2	2.71					
			16.74	7.41	4.1	2.7					
			12.4	6.9	4.1	2.7					
			11.8	6.5	4.1	2.6					
			11.8	6.2	4.09	2.6					
			10.7	6.2	4.0	2.6					
			10.3	6.2	3.95	2.5					
			10.3	6.0	3.9	2.5					
			10.2	5.7	3.85	2.5					
			10.1	5.3	3.8	2.5					
			10.1	5.12	3.8	2.5					
			9.6	5.1	3.6	2.4					
			9.5	5.1	3.5	2.4					
			9.4	5.0	3.5	2.3					
			9.2	4.9	3.5	2.3					
			9.1	4.85	3.5	2.2					
			8.7	4.79	3.4	2.2					
			8.6	4.7	3.3	2.1					
			8.6	4.68	3.3	2.1					
			8.5	4.6	3.2	2.1					
			8.44	4.5	3.2	2.0					
			8.2	4.5	3.12	2.0					
			8.1	4.5	3.1	2.0					
			8.1	4.5	3.1	1.92					
			8.0	4.4	3.1	1.80					
			7.9	4.4	3.0	1.56					
			7.79	4.3	2.97	1.35					
			7.5	4.3	2.86	1.2					

*NURE data are from the Bakersfield and Fresno 1X2 degree quadrangles.

APPENDIX H

Tulare County NURE Uranium Data for Soil and Sediment Samples in western Sierra Nevada Watersheds*

Watershed Name	N	NURE U Data (ppm)				Mean (ppm)	Median (ppm)	Low (ppm)	High (ppm)	% ≥ 5.0 ppm
Cottonwood Creek-upper	9	3.5	2.6	2.2	1.9	2.60	2.60	1.80	3.50	0.00
		3.4	2.6	2.1	1.8					
		3.3								
Deer Creek-upper	12	5.1	4.2	2.6	2.1	3.20	3.05	1.20	5.10	8.33
		4.4	4.1	2.5	2.0					
		4.2	3.5	2.5	1.2					
Kaweah River	39	17.1	6.5	4.4	3.1	5.74	4.50	2.30	17.10	43.29
		12.4	6.2	4.3	3.0					
		11.9	6.0	4.3	2.8					
		10.7	5.7	4.0	2.8					
		10.3	5.3	3.9	2.7					
		10.0	5.1	3.8	2.7					
		10.0	5.0	3.6	2.5					
		8.6	4.7	3.5	2.3					
		8.6	4.6	3.4	2.3					
		7.9	4.5	3.1						
Kings River (within Fresno Quad)	111	20.5	7.0	3.8	1.9	4.89	3.90	0.50	20.50	38.74
		15.7	6.8	3.8	1.9					
		15.2	6.7	3.8	1.8					
		12.7	6.6	3.7	1.8					
		11.8	6.6	3.7	1.8					
		11.3	6.6	3.5	1.8					
		11.1	6.5	3.4	1.8					
		11.0	6.4	3.3	1.8					
		9.8	6.3	3.0	1.8					
		9.5	5.7	2.9	1.7					
		9.4	5.6	2.9	1.6					

		9.3	5.6	2.8	1.5					
		9.3	5.5	2.8	1.5					
		8.9	5.4	2.7	1.5					
		8.7	5.0	2.6	1.5					
		8.5	4.8	2.6	1.5					
		8.5	4.8	2.5	1.3					
		8.5	4.7	2.4	1.3					
		8.3	4.6	2.4	1.0					
		8.2	4.5	2.3	1.0					
		8.2	4.5	2.3	0.9					
		8.0	4.4	2.3	0.9					
		7.9	4.2	2.3	0.9					
		7.8	4.1	2.3	0.9					
		7.6	4.0	2.2	0.9					
		7.5	4.0	2.1	0.6					
		7.5	4.0	2.1	0.5					
		7.1	3.9	2.0						
Kings River (within Mariposa Quad)	95	29.3	9.5	7.1	5.9	8.33	7.20	3.20	29.30	90.53
		20.4	9.3	7.0	5.9					
		18.7	8.8	7.0	5.7					
		18.3	8.7	6.8	5.7					
		17.1	8.7	6.7	5.6					
		16.4	8.6	6.7	5.5					
		13.7	8.6	6.6	5.5					
		13.4	8.5	6.6	5.5					
		13.1	8.4	6.6	5.4					
		12.7	8.4	6.6	5.3					
		12.5	8.2	6.6	5.1					
		12.3	8.1	6.6	5.1					
		12.1	8.0	6.6	5.1					
		11.5	8.0	6.5	5.0					
		11.3	7.9	6.5	4.9					
		10.9	7.9	6.4	4.9					
		10.8	7.9	6.2	4.8					

		10.6	7.8	6.2	4.7					
		10.4	7.8	6.2	4.4					
		10.4	7.5	6.2	4.0					
		10.1	7.5	6.1	3.7					
		9.9	7.4	6.1	3.6					
		9.8	7.3	6.0	3.2					
		9.6	7.2	6.0						
Kings River (all)	206	29.3	8.3	6.2	3.4	6.48	6.20	0.50	29.30	62.62
		20.5	8.2	6.1	3.3					
		20.4	8.2	6.1	3.2					
		18.7	8.2	6.0	3.0					
		18.3	8.1	6.0	2.9					
		17.1	8.0	5.9	2.9					
		16.4	8.0	5.9	2.8					
		15.7	8.0	5.7	2.8					
		15.2	7.9	5.7	2.7					
		13.7	7.9	5.7	2.6					
		13.4	7.9	5.6	2.6					
		13.1	7.9	5.6	2.5					
		12.7	7.8	5.6	2.4					
		12.7	7.8	5.5	2.4					
		12.5	7.8	5.5	2.3					
		12.3	7.6	5.5	2.3					
		12.1	7.5	5.5	2.3					
		11.8	7.5	5.4	2.3					
		11.5	7.5	5.4	2.3					
		11.3	7.5	5.3	2.2					
		11.3	7.4	5.1	2.1					
		11.1	7.3	5.1	2.1					
		11.0	7.2	5.1	2.0					
		10.9	7.1	5.0	1.9					
		10.8	7.1	5.0	1.9					
		10.6	7.0	4.9	1.8					
		10.4	7.0	4.9	1.8					

		10.4	7.0	4.8	1.8					
		10.1	6.8	4.8	1.8					
		9.9	6.8	4.8	1.8					
		9.8	6.7	4.7	1.8					
		9.8	6.7	4.7	1.8					
		9.6	6.7	4.6	1.7					
		9.5	6.6	4.5	1.6					
		9.5	6.6	4.5	1.5					
		9.4	6.6	4.4	1.5					
		9.3	6.6	4.4	1.5					
		9.3	6.6	4.2	1.5					
		9.3	6.6	4.1	1.5					
		8.9	6.6	4.0	1.3					
		8.8	6.6	4.0	1.3					
		8.7	6.6	4.0	1.0					
		8.7	6.6	4.0	1.0					
		8.7	6.5	3.9	0.9					
		8.6	6.5	3.8	0.9					
		8.6	6.5	3.8	0.9					
		8.5	6.4	3.8	0.9					
		8.5	6.4	3.7	0.9					
		8.5	6.3	3.7	0.6					
		8.5	6.2	3.7	0.5					
		8.4	6.2	3.6						
		8.4	6.2	3.5						
Long Creek	2	2.2	1.8			2.00	2.00	1.80	2.20	0.00
Sand Creek	5	3.0	2.0	1.6	1.2	2.08	2.00	1.20	3.00	0.00
		2.6								
Travers-upper	4	2.4	2.3	2.0	1.1	1.95	2.15	1.10	2.40	0.00
Tule River (Foothills part)	9	3.6	3.1	2.6	2.1	2.77	3.00	1.50	3.60	0.00
		3.4	3.0	2.4	1.5					
		3.2								

Tule River (Sierra Nevada part)	38	28.0 16.74 11.8 10.3 9.85 9.5 9.2 9.1 8.44 8.0	7.79 7.48 7.41 6.9 5.5 5.12 4.9 4.85 4.79 4.68	4.5 4.5 4.5 4.1 4.1 4.09 3.98 3.85 3.8	3.5 3.12 3.1 2.97 2.86 2.71 1.92 1.56 1.35	6.34	4.74	1.35	28.00	42.11
Tule River (all)	47	28.0 16.74 11.8 10.3 9.85 9.5 9.2 9.1 8.44 8.0 7.79 7.48	7.41 6.9 5.5 5.12 4.9 4.85 4.79 4.68 4.5 4.5 4.5 4.1	4.1 4.09 3.98 3.85 3.8 3.6 3.5 3.4 3.2 3.12 3.1 3.1	3.0 2.97 2.86 2.71 2.6 2.4 2.1 1.92 1.56 1.5 1.35	5.65	4.10	1.30	28.00	34.04
White River-upper	24	7.5 6.2 6.2 4.1 4.0 3.6	3.2 2.6 2.6 2.5 2.4 2.4	2.4 2.2 2.2 2.1 2.1 2.0	2.0 2.0 1.9 1.9 1.4 0.6	2.92	2.40	0.60	7.50	12.50
Yokohl Creek (part of Kaweah River watershed)	10	10.2 3.6 3.2	3.0 2.9 2.7	2.6 2.6	2.5 2.4	3.57	2.80	2.40	10.20	10.00

*NURE data are from the Bakersfield, Fresno and Mariposa 1X2 Degree Quadrangles

APPENDIX I

Fresno and Bakersfield 1X2 Degree Quadrangle NURE Airborne Radiometric Survey Equivalent Uranium (eU) Data for western Tulare County Surficial Geologic Units and Sierra Nevada Foothill Bedrock

Geologic Unit Reference	Geologic Unit Name	N	N ≥ 5.0 ppm eU	% ≥ 5.0 ppm eU	Low ppm eU	High ppm eU	Median ppm eU
COe	Cottonwood Creek East	462	120	26.0	0.3	8.2	3.5
COw	Cottonwood Creek West	7	3	42.9	4.2	7.3	4.9
DE1	Deer Creek 1	646	2	0.3	0.5	5.3	2.7
DE2	Deer Creek 2	734	6	0.8	1.1	5.5	2.8
DU	Ducor	1,062	7	0.7	0.8	5.6	2.8
FR	Frazier Creek	1,029	59	5.7	0.3	7.4	2.6
KA1	Kaweah 1	438	9	2.1	0.3	6.2	2.8
KA2	Kaweah 2	203	23	11.3	1.4	7.6	3.7
KA3	Kaweah 3	2,032	273	13.4	0.6	9.8	3.7
KA4	Kaweah 4	618	64	10.4	1.2	8.3	3.5
KA5	Kaweah 5	470	90	19.2	0.7	9.0	3.8
KI	Kings River	359	81	22.6	1.2	7.1	4.1
LO	Long Creek	484	60	12.4	0.8	7.0	2.6
Q1	Very Old Fan 1 (Qvof 1)	555	1	0.2	0.9	5.0	2.7
Q2	Very Old Fan 2 (Qvof 2)	0	--	--	--	--	--
Q3	Very Old Fan 3 (Qvof 3)	193	9	4.7	1.1	6.5	3.5
RA	Rag Gulch	492	1	0.2	0.7	5.0	2.4
SA	Sand Creek	404	14	3.5	0.7	6.7	2.4
SE	Seville	111	0	0.0	0.9	4.5	2.6
TRl	Travers Creek Lower	111	4	3.6	1.3	6.0	3.5
TRu	Travers Creek Upper	94	33	35.1	2.7	7.0	4.6
--	Tulare Lake	1,840	43	2.3	0.1	6.7	3.2
TU	Tule River	2,012	31	1.5	0.5	7.2	3.1
VE	Vestal	45	0	0	1.7	4.6	3.1
WH	White River	1,074	13	1.2	0.4	5.8	2.9
--	Basin Alluvium (all)	2,173	82	3.8	0.4	7.7	3.0
--	Sierra Nevada Foothill Bedrock	5,483	437	8.0	<0.6	9.0	2.5

APPENDIX J

Tulare County NRCS Soil Units and Indoor-Radon Measurements

Permeability (saturated hydraulic conductivity class) abbreviations: VR = very rapid; R = rapid; MR = moderately rapid; M = moderate; MS = moderately slow; S = slow; and VS = very slow or impermeable.

Shrink-Swell abbreviations: S = severe, M = moderate, and L = low

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
NRCS Survey CA660, Tulare County, California, Central Part												
101	Akers-Akers, saline-Sodic, complex, 0-2 percent slopes *Akers component 60%, Akers saline-sodic component 25%; on fan remnants, valleys*	0-16”=M 16-60”=MS	C	Granitic rock sources	L	>60”	28	9	32.1	2.9	0.6	14.2

Soil Unit	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Hydrologic Soil Group**	**Parent Material**	**SH-SW**	**Depth to Bed Rock (inches)**	**N**	**N ≥ 4 pCi/L**	**% N ≥ 4 pCi/L**	**Median**	**Min pCi/L**	**Max pCi/L**
108	Colpien loam, 0-2 percent slopes *Colpien component = 85%; on fan remnants, valleys*	0-6”=M 6-60”=MS 60-65”=MS to R	C	Granitic rock sources	M	>60”	33	15	45.5	3.9	1.1	12.6
110	Delhi loamy sand, 0-2 percent slopes *Delhi component = 85%; on dunes, valleys, sand sheets, flood plains, alluvial fans*	0-60”=R	A	Granite	L	>60”	1	0	0	2.2	2.2	2.2
114	Exeter loam, 0-2 percent slopes *Exeter component = 85%; on fan remnants, valleys*	0-26”=MR 26-28”=MS 28-46”=VS 46-72”=MR	C	Granitic rock sources	M	20-40” to duripan	7	1	14.3	1.9	1.2	7.5

Soil Unit	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Hydrologic Soil Group**	**Parent Material**	**SH-SW**	**Depth to Bed Rock (inches)**	**N**	**N ≥ 4 pCi/L**	**% N ≥ 4 pCi/L**	**Median**	**Min pCi/L**	**Max pCi/L**
116	Flamen loam, 0-2 percent slopes *Flamen component = 85%; fan remnants, valleys*	0-43”=M 43-72”=S	B	Granitic rock sources	M	40-60” to duripan	27	7	25.9	2.8	0.5	13.6
122	Grangeville sandy loam, drained, 0-2 percent slopes *Grangeville component = 90%; on valleys, flood plains, alluvial fans*	0-67”=MR	A	Granitic rock sources	L	>60”	38	15	39.5	3.35	1.4	9.6
124	Hanford sandy loam, 0-2 percent slopes *Hanford component = 85%; on flood plains, alluvial fans, valleys*	0-30”=MR 30-60”=R	A	Granitic rock sources	L	>60”	3	0	0	1.4	0.8	2.0

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
130	Nord fine sandy loam, 0-2 percent slopes *Nord component = 85%; on flood plains, alluvial fans, valleys*	0-38"=M 38-50"=MR 50-72"=M	B	Mixed rock sources	L	>60"	79	22	27.9	2.7	0.7	17.3
135	San Joaquin loam, 0-2 percent slopes *San Joaquin component = 85%; on fan remnants, valleys*	0-10"=M 10-15"=MS 15-39"=VS	D	Mixed rock sources	M	20-40" to duripan	2	1	50.0	8.05	0.7	15.4
137	Tagus loam, 0-2 percent slopes *Tagus component = 85%; on fan remnants, valleys*	0-17"=MR 17-40"=R 40-63"=MR	B	Granitic rock sources	L	>60"	149	50	33.6	3.0	0.6	16.1

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
138	Tujungo loamy sand, 0-2 percent slopes *Tujungo component = 85%; on flood plains, valleys*	0-70”=R	A	Granite	L	>60”	2	1	50.0	4.4	1.8	7.0
143	Yettem sandy loam, 0-2 percent slopes *Yettem component = 85%; on flood plains, alluvial fans, valleys*	0-63”=MR	A	Granitic rock sources	L	>60”	6	0	0	2.45	1.5	2.8
NRCS Survey CA660, Tulare County, California, Central Part												
104	Auberry-Rock outcrop complex, 9-50 percent slopes *Auberry component = 50%; on foothills, hills*	0-16”=MR 16-22”=M 22-43”=MS 43-56”=MR 56-60”=rock	C	Residuum weathered from quartz diorite	L	40-60”	1	0	0	0.9	0.9	0.9

Soil Unit	**Soil Unit Name**	**Permeability by Soil Sub-unit**	**Hydrologic Soil Group**	**Parent Material**	**SH-SW**	**Depth to Bed Rock (inches)**	**N**	**N ≥ 4 pCi/L**	**% N ≥ 4 pCi/L**	**Median**	**Min pCi/L**	**Max pCi/L**
105	Blasingame sandy loam, 9-15 percent slopes *Blasingame component = 80%; on foothills, hills*	0-7”=MR 7-36”=MS 36-60”=rock	C	Residuum weathered from quartz diorite	M	20-40”	1	0	0	2.1	2.1	2.1
106	Blasingame sandy loam, 15-30 percent slopes *Blasingame component = 80%; on foothills, hills*	0-7”=MR 7-36”=MS 36-60”=VS to S	C	Quartz diorite	M	20-40”	7	1	14.3	1.5	0.9	6.5
107	Blasingame sandy loam, 30-50 percent slopes *Blasingame component = 80%; on foothills, hills*	0-7”=MR 7-36”=MS 36-60”=rock	C	Residuum weathered from quartz diorite	M	20-40”	3	1	33.3	2.1	0.7	4.0

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
108	Blasingame-Rock outcrop complex, 9-50 percent slopes *Blasingame component = 50%; on foothills, hills*	0-7”=MR 7-36”=MS 36-60”=rock	C	Residuum weathered from quartz diorite	M	20-40”	8	1	12.5	1.9	1.0	13.7
110	Centerville clay, 0-2 percent slopes *Centerville component=80 %; on alluvial fans, dissected terraces, valleys*	0-37”=S 37-60”=rock	D	Alluvium derived from granitoid	H	20-40”	2	2	100.0	5.65	5.4	5.9
111	Centerville clay, 2-9 percent slopes *Centerville component = 85%; on alluvial fans, dissected terraces, valleys*	0-37”=S 37-60”=rock	D	Alluvium derived from granitoid	H	20-40”	1	0	0	0.7	0.7	0.7

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
113	Cibo clay, 15 to 30 percent slopes *Cibo component = 80%; on hills, foothills*	0-35”=S 35-45”=rock	D	Residuum weathered from gabbro	H	20-40”	5	0	0	1.4	1.0	1.8
116	Cieneba-Rock outcrop complex, 15-75 percent slopes *Cieneba component = 55%; on ridges, foothills, hills*	0-16”=MR 16-60”=rock	D	Residuum weathered from granitoid	L	10-20”	1	0	0	2.5	2.5	2.5
124	Exeter loam, 0-2 percent slopes *Exeter component = 75%; on terraces, valleys*	0-14”=M 14-30”=MS 30-43”=duripan 34-60”=MR	D	Alluvium derived from granitoid	M	20-40” to duripan	3	0	0	0.5	0.5	2.1
125	Exeter loam, 2-9 percent slopes *Exeter component = 85%; on terraces, valleys*	0-14”=M 14-30”=MS 30-43”=duripan 34-60”=MR	C	Alluvium derived from granitoid	M	20-40” to duripan	1	1	100.0	4.4	4.4	4.4

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
131	Grangeville silt loam, drained *Grangeville component = 90%; on alluvial fans, valleys*	0-14”=M 14-64”=MR	B	Alluvium derived from granitoid	L	> 60”	1	0	0	1.9	1.9	1.9
132	Greenfield sandy loam, 0-2 percent slopes *Greenfield component = 85%, on alluvial fan; valleys*	0-70”=MR	A	Alluvium derived from granitoid	L	> 60”	1	0	0	1.9	1.9	1.9
142	Las Posas loam, 15-30 percent slopes *Las Posas component = 80%; on hills, foothills*	0-9”=M 9-32”=S 32-60”=rock	D	Residuum weathered from gabbro	H	20-40”	1	0	0	3.2	3.2	3.2

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
143	Las Posas loam, 30-50 percent slopes *Las Posas component = 80%; on hills, foothills*	0-9”=M 9-32”=S 32-60”=rock	D	Residuum weathered from gabbro	H	20-40”	1	0	0	1.9	1.9	1.9
146	Pits	--	--	--	--	--	1	0	0	0.5	0.5	0.5
148	Porterville clay, 2-9 percent slopes *Porterville component = 85%, on alluvial fans, valleys*	0-72”=slow	C	Alluvium derived from igneous rock	H	> 60”	11	2	18.2	1.8	0.5	4.7
151	Riverwash	--	--	--	--	--	1	0	0	1.8	1.8	1.8
152	Rock outcrop	--	--	--	--	--	1	0	0	0.6	0.6	0.6
153	San Emigdio loam *San Emigdio component = 90%; on alluvial fans, valleys*	0-66”=MR	A	Alluvium derived from granitoid and/or alluvium derived from sedimentary rock	L	>60”	28	8	28.6	2.65	0.5	22.9

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
154	San Joaquin loam, 0-2 percent slopes *San Joaquin component = 75%, on terraces, valleys*	0-13”=M 13-20”=MS 20-25”=VS 25-56”=duripan 56-76”=S	C	Alluvium derived from acid igneous rock	M	20-40 “ to duripan	12	2	16.7	1.6	0.7	5.6
155	San Joaquin loam, 2-9 percent slopes *San Joaquin component = 80%, on terraces, valleys*	0-13”=M 13-20”=MS 20-25”=VS 25-56”=duripan 56-76”=S	C	Alluvium derived from acid igneous rock	M	20-40 “ to duripan	7	0	0	1.3	1.0	2.8
164	Tujunga sand *Tujunga component = 90%; on alluvial fans, valleys*	0-60”=R	A	Alluvium derived from granitoid	L	> 60”	6	1	16.7	2.25	0.8	5.3

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
165	Vista coarse sandy loam, 9 to 15 percent slopes *Vista component makes up 85%; on hillslopes, foothills*	0-27”=MR 27-60”=rock	B	Residuum weathered from quartz-diorite	L	20-40”	1	0	0	2.0	2.0	2.0
166	Vista coarse sandy loam, 15-30 percent slopes *Vista component makes up 85%; on hillslopes, foothills*	0-27”=MR 27-60”=rock	B	Residuum weathered from quartz-diorite	L	20-40”	2	0	0	2.6	2.5	2.7
168	Vista-Rock outcrop complex, 9-50 percent slopes *Vista component makes up 55%; on hillslopes, foothills*	0-27”=MR 27-60”=rock	B	Residuum weathered from quartz-diorite	L	20-40”	2	0	0	3.15	2.7	3.6

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
173	Wyman loam, 2-5 percent slopes *Wyman component = 85%; on alluvial fans, valleys*	0-30”=M 30-69”=MS 69-75”=R	C	Alluvium derived from igneous rock	M	> 60 “	6	1	16.7	2.4	1.3	10.6
176	Yettem sandy loam, 0-2 percent slopes *Yettem component = 85%; on alluvial fans, valleys*	0-70”=MR	A	Alluvium derived from granitoid	L	> 60”	5	0	0	1.8	1.7	3.4
177	Yettem sandy loam, 2-5 percent slopes *Yettem component = 85%; on alluvial fans, valleys*	0-70”=MR	A	Alluvium derived from granitoid	L	>60”	1	0	0	1.7	1.7	1.7

Soil Unit	Soil Unit Name	Permeability by Soil Sub-unit	Hydrologic Soil Group	Parent Material	SH-SW	Depth to Bed Rock (inches)	N	N ≥ 4 pCi/L	% N ≥ 4 pCi/L	Median	Min pCi/L	Max pCi/L
NRCS Survey CA760—Sequoia National Forest Parts of Fresno, Kern and Tulare Counties, California												
622	Dome-Chaix-Rock outcrop association, steep *Dome component = 35%, Chaix component = 30%; on mountains*	Dome 0-50”=MR 50-54”=VS to S Chaix 0-25”=MR 25-30”=VS-S	A-B-D	Residuum weathered from granite	L	50” Dome 25” Chaix	1	1	100	33.0	33.0	33.0
672	Dome-Chaix association, moderately steep *Dome component = 45%, Chaix component = 25%; on mountains*	Dome 0-50”=MR 50-54”=VS to S Chaix 0-25”=MR 25-30”=VS-S	A-B	Residuum weathered from granite	L	50” Dome 25” Chaix	1	0	0	2.1	2.1	2.1

APPENDIX K

Descriptive Statistics and Statistical Comparison of Indoor Radon Measurements (non-transformed) by western Tulare County Radon Potential Zone and the Sierra Nevada-Three Rivers Area

	Western Tulare County Area Only					**Sierra Nevada Data**	**All Tulare Co. Data**
	All Indoor Radon Data	**High Zone Radon Data**	**Low Zone Radon Data**	**Unkn Zone Radon Data**			
Size	467	420	41	6		31	498
Mean	3.428	3.604	1.551	3.967		4.032	3.466
Sec. Dev.[1]	2.654	2.076	0.718	2.618		6.025	2.969
Std. Error[2]	0.123	0.132	0.112	1.069		1.082	0.133
C.I. of Mean[3]	0.241	0.260	0.227	2.748		2.210	0.261
Range	22.4	22.4	3.2	6.1		32.3	32.5
Maximum	22.9	22.9	3.7	7.5		33.0	33.0
Minimum	0.5	0.5	0.5	1.4		0.7	0.5
Median	2.7	2.9	1.5	3.65		2.5	2.7
25%	1.7	1.8	1.050	1.625		1.7	1.7
75%	4.3	4.4	2.0	6.3		3.3	4.2
Skewness	2.558	2.525	0.865	0.283		4.113	3.775
Kurtosis	10.350	10.011	0.869	-2.345		18.786	25.187
K-S Dist.[4]	0.149	0.141	0.114	0.285		0.347	0.159
K-S Prob.[5]	<0.001	<0.001	0.196	0.134		<0.001	<0.001
SWilk W[6]	0.782	0.786	0.950	0.854		0.469	0.702
SWilk Prob[7]	<0.001	<0.001	0.069	0.169		<0.001	<0.001
Sum	1601.1	1513.7	63.6	23.8		125.0	1726.1
Sum of Squares	8771.47	8523.53	119.26	128.68		1593.04	10364.51

[1]Standard Deviation
[2]Standard Error of the Mean
[3]Confidence Interval for the Mean
[4]K-S Distance (The Kolmogorov-Smirnov distance)
[5]K-S Probability (The Kolmogorov-Smirnov probability)
[6]Shapiro-Wilk W (The Shapiro-Wilk W-statistic)
[7]Shapiro-Wilk Probability

APPENDIX L

Descriptive Statistics and Statistical Comparison of Indoor Radon Measurements (Ln-transformed) by western Tulare County Radon Potential Zone and the Sierra Nevada-Three Rivers Area

	Western Tulare County Area					Sierra Nevada Data	All Tulare Co. Data
	All Indoor Radon Data	High Zone Radon Data	Low Zone Radon Data	Unkn Zone Radon Data			
Size	467	420	41	6		31	498
Mean	1.000	1.063	0.332	1.164		0.965	0.998
Sec. Dev.[1]	0.677	0.658	0.482	0.739		0.797	0.684
Std. Error[2]	0.0313	0.0321	0.0753	0.302		0.143	0.0307
C.I. of Mean[3]	0.0616	0.0631	0.152	0.775		0.292	0.0603
Range	3.824	3.824	2.001	1.678		3.853	4.190
Maximum	3.131	3.131	1.308	2.015		3.497	3.497
Minimum	-0.693	-0.693	-0.693	0.336		-0.357	-0.693
Median	0.993	1.065	0.405	1.164		0.916	0.993
25%	0.531	0.588	0.0477	0.482		0.531	0.531
75%	1.459	1.482	0.692	1.835		1.194	1.435
Skewness	0.0613	0.0451	-0.319	0.0163		1.290	0.168
Kurtosis	-0.0224	0.0749	-0.255	-2.861		2.705	0.207
K-S Dist.[4]	0.0358	0.0349	0.0858	0.260		0.161	0.0341
K-S Prob.[5]	0.158	0.247	0.580	0.225		0.040	0.177
SWilk W[6]	0.997	0.997	0.979	0.847		0.902	0.996
SWilk Prob[7]	0.620	0.774	0.646	0.150		0.008	0.249
Sum	467.205	446.624	13.596	6.985		29.906	497.110
Sum of Squares	681.143	656.467	13.815	10.861		47.896	729.039

[1]Standard Deviation
[2]Standard Error of the Mean
[3]Confidence Interval for the Mean
[4]K-S Distance (The Kolmogorov-Smirnov distance)
[5]K-S Probability (The Kolmogorov-Smirnov probability)
[6]Shapiro-Wilk W (The Shapiro-Wilk W-statistic)
[7]Shapiro-Wilk Probability

APPENDIX M

Results of the Shapiro-Wilk Normality Test for Untransformed and Ln-Transformed Indoor-Radon Data, by Radon Potential Zone

Data	n	W-Statistic*	P	Result
All western Tulare-Untransformed	467	0.782	<0.001	Failed
All western Tulare-Ln Transformed	467	0.997	0.620	Passed
High Zone-Untransformed	420	0.786	<0.001	Failed
High Zone-Ln Transformed	420	0.997	0.774	Passed
Low Zone-Untransformed	41	0.950	0.069	Passed
Low Zone-Ln Transformed	41	0.979	0.646	Passed
Unknown Zone-Untransformed	6	0.854	0.169	Passed
Unknown Zone-Ln Transformed	6	0.847	0.150	Passed
Sierra Nevada-Three Rivers Area-Untransformed	31	0.469	<0.001	Failed
Sierra Nevada-Three Rivers Area-Ln Transformed	31	0.902	0.008	Failed
All Tulare County Rn Data	498	0.702	<0.001	Failed
Ln All Tulare County Rn Data	498	0.996	0.249	Passed

*Shapiro-Wilk Statistic (W)—tests the null hypothesis that the data were sampled from a normal distribution. Small values of W indicate a departure from normality (SigmaPlot®12 Statistics User's Guide part 2, Systat Software, Inc., p.23)

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

A test that passes indicates that the data matches the pattern expected if the data were drawn from a population with a normal distribution.

APPENDIX N

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data between High, Low and Unknown Radon Potential Zones (Untransformed Data) for western Tulare County

Mann-Whitney Rank Sum Test					
Group	*n*	*Missing*	*Median*	*25%*	*75%*
High Zone	420	0	2.9	1.8	4.4
Low Zone	41	0	1.5	1.05	2.0
Result	Mann-Whitney U Statistic = 3165.5 T = 4026.5 n(small) = 41 n(big) = 420 (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)				
Group	*n*	*Missing*	*Median*	*25%*	*75%*
High Zone	420	0	2.9	1.8	4.4
Unknown Zone	6	0	3.65	1.625	6.3
Result	Mann-Whitney U Statistic = 1155.5 T = 1385.5 n(small) = 6 n(big) = 420 (P = 0.728) 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 = 0.728)				
Group	*n*	*Missing*	*Median*	*25%*	*75%*
Low Zone	41	0	1.5	1.05	2.0
Unknown Zone	6	0	3.65	1.625	6.3
Result	Mann-Whitney U Statistic = 47.0 T = 220.0 n(small) = 6 n(big) = 41 (P = 0.016) 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 = <0.016)				

APPENDIX O

Mann-Whitney Rank Sum Test Comparisons of Indoor-Radon Data (untransformed) from the High and Low Radon Potential Zones in western Tulare County and Sierra Nevada Radon Data

<table>
<tr><th colspan="6">Mann-Whitney Rank Sum Test</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Group</td><td>n</td><td>Missing</td><td>Median</td><td>25%</td><td>75%</td></tr>
<tr><td>High Zone western Tulare Co Rn Data</td><td>420</td><td>0</td><td>2.9</td><td>1.8</td><td>4.4</td></tr>
<tr><td>Sierra Nevada Rn Data</td><td>31</td><td>0</td><td>2.5</td><td>1.7</td><td>3.3</td></tr>
<tr><td>Result</td><td colspan="5">Mann-Whitney U Statistic= 5503.000

T = 5999.000 n(small)= 31 n(big)= 420 (P = 0.151)

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; <u>there is not a statistically significant difference</u> (P = 0.151)</td></tr>
<tr><td>Group</td><td>n</td><td>Missing</td><td>Median</td><td>25%</td><td>75%</td></tr>
<tr><td>Low Zone western Tulare County Rn Data</td><td>41</td><td>0</td><td>1.5</td><td>1.05</td><td>2.0</td></tr>
<tr><td>Sierra Nevada Rn Data</td><td>31</td><td>0</td><td>2.5</td><td>1.7</td><td>3.3</td></tr>
<tr><td>Result</td><td colspan="5">Mann-Whitney U Statistic= 298.500

T = 1468.500 n(small)= 31 n(big)= 41 (P = <0.001)

The difference in the median values between the two groups is greater than would be expected by chance; <u>there is a statistically significant difference</u> (P= 0.001)</td></tr>
</table>