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MAPPING INDOOR RADON POTENTIAL USING GEOLOGY AND SOIL PERMEABILITY

William G. Alexander
Colorado Radon
Fort Collins, CO

Linda L. Devocelle
City of Fort Collins Natural Resources Department
Fort Collins, CO

ABSTRACT

The relative potential for elevated residential indoor radon has been mapped for the City of Fort Collins, Colorado. Using published geologic maps and soil permeability information, the study area was divided into geologic and soil permeability (geoperm) units. Evaluation of the data showed a relationship between residential basement indoor radon concentrations and geoperm units. Mean indoor radon concentrations for specific geoperm units ranged from 4.6 to 14.1 picocuries per liter (pCi/L). Using the corresponding indoor radon concentration data, geoperm units were classified into two categories, moderate and high, representing relative potential for elevated indoor radon concentrations. Color coding of mapped geoperm units, according to high or moderate potential for elevated indoor radon concentrations, has been accomplished to create an indoor radon potential map for the City of Fort Collins.

INTRODUCTION

Indoor radon represents a significant environmental health risk in the United States. Radon levels in the indoor environment are a function of site geologic characteristics, building construction, and domestic lifestyles. Identification of areas with geologic characteristics that contribute to high indoor radon levels can facilitate the incorporation of radon resistant features into building design, resulting in a significant reduction in indoor radon levels. This report documents a study in the Fort Collins urban growth area to evaluate the relationship between surficial geology, soil permeability, and indoor radon concentrations. The work was funded by the U.S. Environmental Protection Agency (EPA) under the State Radon Grants Program; the State of Colorado, under the Clean Air Colorado Program; and by the City of Fort Collins, Natural Resources Division.

BACKGROUND INFORMATION

This section discusses the physical properties of radon and mechanisms for its entry into the indoor environment, the health risk associated with radon, and the source of radon and geologic variables affecting source strength.

Properties of Radon and Mechanics of Entry

Radon is a radioactive gas resulting from the natural decay of uranium and is present in measurable quantities in virtually all soils. Radon has a half-life of 3.8 days and decays to radioactive solids commonly referred to as radon daughters. When radon and its daughters decay, potentially harmful alpha radiation is produced. Radon, being a gas, is mobile and can therefore migrate into indoor environments if a driving force and entry routes are present. Due to its relatively short half-life, the distance that radon can migrate before decay is limited. If the rate of migration is slow, the distance it can migrate will be less. The primary driving force causing radon to migrate from the ground into houses is the pressure differential existing between the subconstruction soil gas and the indoor air. Due to temperature differentials, combustion in gas furnaces and fireplaces, exhaust fans, and a number of other factors, the pressure in a house is usually less than the pressure in the underlying soil pore space. This causes soil gas, with high radon concentrations, to move into structures through cracks and openings in building foundations. During times of the year when houses are heated or air conditioned, the rate of fresh air exchange is limited since windows and doors are kept closed. This causes indoor radon concentrations to increase to levels that may represent a significant health risk.

Radon from soil gas is the main cause of elevated indoor radon levels in the majority of homes. Radon may be present in significant quantities in well water. Radon in water is released into the indoor air during showering, clothes washing, and dishwashing. Radon in water is not a problem in homes served by most public water supplies. In very rare instances building materials have been found to be a source of radon (EPA, 1992).

Health Risk

According to the EPA, radon is the second leading cause of lung cancer in the U.S. today. Only smoking causes more lung cancer deaths. The EPA estimates that between 7,000 and 30,000 deaths per year may be caused by indoor radon. In the U.S. these numbers far exceed those for other environmental pollutants or natural disasters.

Nearly one out of every 15 homes in the U.S. is estimated to have elevated radon levels (EPA, 1992). That number is likely to be much higher throughout most of Colorado. Maps recently published by the EPA showing radon potential in Colorado on a county by county basis, rate most counties in the highest of three categories (EPA, 1993). The EPA estimates that among non-smokers exposed to an average radon level of 4 pCi/L over a lifetime, two people in a thousand could get lung cancer (EPA, 1992). Residential indoor radon data for the City of Fort Collins, indicate a wide range of indoor radon concentrations, representing little or no health risk to significant health risk. The average basement radon level in Fort Collins measured in short-term tests using EPA testing protocols is roughly twice the EPA's recommended action level of 4 pCi/L.

Geologic Factors that Impact Indoor Radon Concentrations

As previously discussed, radon in the ground is usually the cause of elevated radon concentrations in homes. In order for an indoor radon problem to exist there must be a source of radon, and the radon must be able to move from the source into the house. The concentration of radon in the ground and it's rate of migration are determined in large part by geologic factors. Variables that control radon concentration and its rate of migration in the subsurface include composition and texture, permeability, and moisture content of the subsurface materials (Gundersen et al., 1988). These variables can and do vary significantly from neighborhood to neighborhood.

Composition. Rock types that may produce higher than average concentrations of radon include carbonaceous shale, glauconitic sandstone, fluvial sandstone, phosphatic rock and sediment, chalk, limestone and dolomite, glacial deposits, bauxite, lignite, coal, granite, gneiss, phyllite, schist, volcanic rocks, and rocks that have been faulted (Gundersen et al., 1992 and Tanner, 1986). Soils and sediment derived from these rock types may also produce higher than average concentrations of radon.

Texture and Permeability. Texture refers to soil or sediment grain size and distribution of grain sizes. Texture determines the permeability of soil or sediment. Permeability determines the distance that radon can migrate before decaying into other substances. The larger and the more uniform the grain size, the greater the permeability and the greater the distance that radon can migrate. The presence of a wide range of grain sizes in a soil or sediment decreases the pore space and the permeability of the material, and therefore limits the distance that radon can migrate.

Texture also determines the amount of material per unit volume that is in contact with soil or sediment pore space, and therefore able to contribute radon gas to the pore space. Larger grain sizes have less surface area per unit volume whereas smaller grain sizes have more surface area per unit volume available to contribute radon.

Moisture Content. The moisture content in rock or sediment pore space affects its permeability and emanating power. Emanating power refers to the fraction of the radon formed in rock or sediment that escapes from the solid material into the pore space. When radium decays, the resulting radon ion "recoils" as an alpha particle is given off. This recoil causes a significant percentage of resulting radon ions to "imbed" themselves into the adjacent rock or sediment. In dry material, only about one percent of radon ions escape into pore space. If moisture is present in the pore space, the coating of water on the rock or sediment "cushions" the collision between recoiling radon ions and the rock or sediment. This cushioning effect results in a smaller percentage of the recoiling radon ions becoming imbedded in the rock or sediment, and a greater percentage escaping into the pore space (Tanner, 1993). The average emanating power for 56 western soils studied was observed to be 22 percent by Rogers and Nielson (1988).

The emanating power of soils and sediment has been observed to increase with an increase in soil moisture content of up to 15 to 17 percent by weight. At greater moisture contents, the emanating power decreases (Damkjaer and Korsbech, 1985; Lindmark and Rosen, 1985). Excessive moisture in soils and sediment occupies pore space and reduces permeability. .

Characterization of the Radon Potential of Rocks and Soils

In recent years radon potential has been characterized in various parts of the United States on a county wide scale using geologic and soils maps combined with measurements of radon in soil gas and equivalent uranium (eU) in surface soils (Otton et al., 1988, Gundersen et al., 1988, and Schumann and Owen, 1988). Comparison of radon potential maps developed from these studies with measured indoor radon levels has yielded a fair correlation.

Geology. Geologic maps show the surface distribution of geologic formations. Geologic formations are rocks or unconsolidated sediment that are mappable as distinct units. Rocks or sediment included in a formation are generally formed within the same general time frame by similar processes and generally have similar composition and texture. Since composition and texture, in large part, control the concentration and mobility of radon in the subsurface, different geologic units have varying potential for causing elevated indoor radon concentrations. Published geologic maps are available for most areas.

Permeability. The U.S. Department of Agriculture Soil Conservation Service (SCS) has prepared soils surveys for many areas in the U.S. Maps included in these surveys show the distribution of specific soil series. The surveys commonly provide information on the permeability at various depths for each soil series. Permeability is directly correlated to the mobility of radon in the subsurface and therefore impacts the potential for elevated indoor radon concentrations.

Fort Collins Indoor Radon Potential Mapping Study

The remainder of this report documents a study to determine whether published geologic maps and soils surveys can be used to identify specific areas with greater potential for high indoor radon concentrations in the Fort Collins urban growth area (the study area). The study included evaluation of geology and soil permeabilities and comparison to measured indoor radon concentrations. Based on these evaluations a map was prepared showing the distribution of areas with varying degrees of potential for elevated indoor radon concentrations in the study area.

Methods of Investigation

The following sections describe the methods of investigation employed during the study. The discussion includes geologic mapping, subsurface soil permeability mapping, and indoor radon data evaluation.

Geologic Characterization

Fort Collins is situated at the western edge of the Denver Basin. The Denver Basin contains a sequence of sedimentary rocks and unconsolidated sediment ranging in age from Pennsylvanian (approximately 325 million years old) to Recent (modern day deposits). Sandstone, shale, chalk, and limestone of Cretaceous Age (66 to 144 million years old) are exposed at the land surface in the westernmost part of the study area. These layers dip to the east at an angle of 10 to 20 degrees and strike (trend) north and north-northwest. To the east, unconsolidated sediment of fluvial (deposited by streams or rivers) and eolian (windblown) deposits are present at the land surface. Bedrock throughout most of the study area is present at depths ranging from 0 to 50 feet (Hershey and Schneider, 1964). The unconsolidated sediment consists of clay, silt, sand, gravel, cobbles, and boulders. This sediment is derived (eroded) from sedimentary, metamorphic, and igneous rock units located west of the study area. The geologic units mapped in the study area include unconsolidated deposits of alluvium, pediment fan deposits, and loess and bedrock of the Pierre Shale, Niobrara Formation, Benton Shale, and the upper South Platte Formation.

Available geologic maps providing coverage of the study area were reviewed as part of the study. Evaluation of the maps indicated close agreement between location and outline of geologic units. The map showing the greatest level of detail was used to delineate geologic units in the study area. Some of the units shown on this map were combined, due to similarities in composition and mode of deposition. Specifically, all deposits along the Cache La Poudre River floodplain including floodplain and terrace deposits were classified as "alluvial deposits". Similarly, debris fan, alluvial fan, and pediment fan deposits were classified together as "pediment fan deposits". Table 1 summarizes the geologic units present in the study area. Figure 1 shows the distribution of the geologic units in the study area.

Permeability Mapping

The source of information used for preparing the permeability map of the study area was the SCS and the U.S. Forest Service *Soil Survey of Larimer County Area, Colorado* issued in 1980. The survey includes maps providing complete coverage of Larimer County. These maps show the distribution of specific soil series mapping units (SSMUs). The survey includes tables that list the permeability for each SSMU in inches per hour (in/hr) for various depths within the soil. In most cases the greatest depth evaluated for permeability was five feet below ground surface. Using these tables, the permeability for the greatest depth evaluated for a particular SSMU was assigned to that SSMU. Those SSMUs with permeabilities exceeding 6 in/hr were identified as having "rapid" permeability, those with permeabilities ranging from 0.6 to 6 in/hr had "moderate" permeability, and those with lower permeabilities were identified as having "slow" permeability. SSMUs on the SCS maps within the study area were color coded according to their respective permeabilities. Using overlay techniques, a map showing the permeability distribution in the study area was prepared. This map is shown in Figure 2.

In general, "rapid" permeability soils are developed on coarse grained alluvial deposits along the Cache La Poudre River and its tributaries and on coarse grained pediment fan deposits. Moderate and slow permeability areas include large areas of soils developed on loess deposits and portions of the pediment fan, alluvial deposits, and Pierre Shale.

Evaluation of Indoor Radon Data

Basement indoor radon data from radon screening tests conducted in 200 homes in the study area from 1987 through 1995 were evaluated. The measurements were made in accordance with EPA protocols for conducting short term screening tests using charcoal detectors and E-Perm devices. Using the geologic and soil permeability maps of the study area, the corresponding geologic unit and soil permeability were determined for each home tested. In order to maintain confidentiality, locations were noted by ten-acre parcel (quarter-quarter-quarter section, township, and range). A spreadsheet including basement indoor radon concentration, geologic unit, soil permeability, and location by ten-acre parcel was created for the indoor radon data.

The data were evaluated to determine the relationship, if any, between indoor radon concentrations and geology and soil permeability. The arithmetic mean, standard deviation, covariance, and range for the indoor radon concentrations were determined for the entire data set, for each geologic unit, and for each soil permeability. Within each mapped geologic unit, a full range of permeabilities was observed. Areas of specific permeabilities within specific geologic units were termed "geoperm units". Arithmetic mean, standard deviation, covariance, and range were also calculated for each geoperm unit. The results of this evaluation are presented and discussed in the next section.

RESULTS

This section presents the results of the evaluation of the indoor radon data used in this study with respect to geology and soil permeability. Using the sort and statistical functions available in the spreadsheet software, summary statistics including arithmetic mean, standard deviation, covariance, minimum, and maximum were calculated for the indoor radon measurements. These statistical values were determined for the entire data, each geologic unit, each soil permeability category, and each geoperm unit. These statistics are summarized in Table 2.

The mean radon concentration for the entire data set is 9.7 pCi/L. The standard deviation is 7.3, and the covarience is 0.8. The standard deviation is a measure of the variability of measured concentrations. Covariance is the standard deviation divided by the mean and is an expression of the variability as a fraction of the mean concentration.

Evaluation by Geologic Unit

When the data are sorted according to geologic unit, the relationship between geologic unit and indoor radon concentration is apparent. The mean concentrations for the geologic units represented range from 8.9 to 11.9 pCi/L. The standard deviations and covariances of the indoor radon data for two of the four geologic units are significantly less than that calculated for the entire data set (Table2). The "improved" statistics for these two geologic units, the Pierre Shale and the pediment fan deposits, indicate a relationship between geology and indoor radon. In general, higher indoor radon concentrations were measured in houses built on the Pierre Shale and lower concentrations were measured in houses built on the pediment fan deposits.

Evaluation by Soil Permeability

When the data are sorted by soil permeability, a significant difference is seen between indoor radon data from areas with moderate permeability and data from rapid and slow permeability areas (Table 2). The average indoor radon concentration in residences in moderate permeability areas was significantly less (7.7 pCi/L) than the average for the entire data set (9.7 pCi/L). The standard deviation and covariance for indoor radon concentrations in moderate permeability areas were also significantly less than for the entire data set. The average indoor radon concentrations for houses built in rapid and slow permeability areas were slightly higher than for the entire data set, 10.1 and 10.4 pCi/L, respectively.

Evaluation by Geoperm Unit

When the data are sorted by geoperm unit the mean indoor radon concentrations for the various units range from 4.6 to 14.1 pCi/L. Standard deviations and covariances are generally significantly less than observed for the entire data set, indicating a good relationship between geoperm units and indoor radon concentrations. In several cases, the number of measurements available for a particular geoperm unit is too small to allow for calculation of reliable statistical values. In general, the larger the number of samples (N), the more confidence can be placed in the statistics. Figure 3 graphically illustrates the mean and range of indoor radon concentrations for each geoperm unit along with the number of measurements for each unit. The basement indoor radon data suggest the following indoor radon risk ranking of geoperm units listed in order of decreasing risk.

Ø Pierre Shale, slow permeability (KpS)
Ø alluvium, slow permeability (alS)
Ø loess, slow permeability (loS)
Ø alluvium, moderate permeability (alM)
Ø pediment fan, rapid permeability (pfR)
Ø pediment fan, moderate permeability (pfM)
Ø Pierre Shale, moderate permeability (KpM)
Ø pediment fan, slow permeability (pfS)
Ø loess, moderate permeability (loM)
Ø alluvium, rapid permeability (alR)

In order to show how the data were distributed, frequency plots were created for the entire data set, each geologic unit, each soil permeability category, and each geoperm unit. The frequency plot for the entire data set is shown in Figure 4. The frequency plots for each geologic unit, soil permeability category, and geoperm units indicate that the largest number of measurements fall within the 5 to 10 pCi/L range. However, depending on the geologic unit, soil permeability, or geoperm unit being plotted, a significant number of measurements exceeding 10 pCi/L may be seen.

INTERPRETATION

This section provides an interpretation of the results of the investigation with respect to characterizing potential for elevated indoor radon concentrations in the Fort Collins area. The predictive relationship between geology and permeability (geoperm units) and measured basement indoor radon concentrations is evaluated. Based on the relationship between geoperm units and basement indoor radon concentrations, an indoor radon potential map of the Fort Collins urban growth area is presented and discussed.

Geology and Permeability Versus Indoor Radon

A good relationship between geoperm units and basement indoor radon concentrations in the Fort Collins area has been demonstrated. When sorted by geoperm unit, a reduction in standard deviation and covariance, compared to these values for the entire data set, was observed for eight out of the ten geoperm units with N values greater than 4. Composition and texture of the material on which a house is built determine the amount of radon available to migrate into the house and the ease with which it can migrate. Geologic units generally consist of rocks or sediment with similar composition and texture. Texture, in large part, determines permeability. Therefore it can be expected that houses built on a particular geoperm unit, an area of specific permeability within a geologic unit, will have an associated range of indoor radon concentrations. Other factors relating to construction characteristics such as the presence of openings in the slab and appliances or activities that decrease the pressure in the house relative to the subconstruction soil pore space will also contribute to variability in indoor radon concentrations.

Indoor Radon Potential Categories Based on Geoperm Units

Based on the summary statistics for basement indoor radon concentrations in the data set (Table 2), geoperm units were divided into two categories representing different degrees of potential for elevated indoor radon concentrations. These categories are identified as Zone 1B and Zone 1C. This nomenclature follows the Zone 1 designation ascribed to Larimer County during recent radon potential mapping of the United States on a county scale by the EPA (EPA, 1993). Counties were classified as Zone 1, 2, or 3. Zone 1 counties were designated as having high radon potential (probable indoor radon average > 4 pCi/L), Zone 2 counties were designated as having moderate radon potential (probable indoor radon average 2-4 pCi/L), and Zone 3 counties were designated as having low radon potential (probable indoor radon average < 2 pCi/L. The letter designation used in this study (i.e. 1A, 1B, and 1C) ranks areas within Zone 1 according to decreasing potential for elevated indoor radon concentrations.

Table 3 lists the geoperm units included in the Zone 1B and Zone 1C categories and provides a statistical summary of each category. The average basement indoor radon concentration for geoperm units included in Zone 1B (using the data set for this study) is 11.0 pCi/L. The average concentration for Zone 1C is 6.7 pCi/L. A third category (Zone 1A) was created based on data obtained outside this study that shows extremely elevated indoor radon concentrations in a structure built on the Niobrara Formation. Since the concentrations observed in this structure are an order of magnitude greater than concentrations measured anywhere else in the study area, a separate category is warranted. The data set does not include measurements made in homes built on the Niobrara Formation. However, the highest concentrations of radon measured in soil gas during this study were in the Niobrara Formation.

Indoor Radon Potential Map of the Fort Collins Urban Growth Area

An indoor radon potential map was prepared for the Fort Collins Urban Growth Area using the indoor radon potential categories (Figure 5). The map shows the distribution of Zone 1A, Zone 1B, and Zone 1C geoperm units in the study area. Using a light table and map overlay techniques and the geologic and soil permeability maps prepared during this study, a map was prepared showing the distribution of permeability within mapped geologic units (geoperm units). Geoperm units were then color coded according to their indoor radon potential category (Zone 1A, Zone 1B, or Zone 1C).

The resulting map (Figure 5) indicates that slightly more than half of the study area falls within Zone 1B (average basement indoor radon concentration - 11 pCi/L), slightly less than half of the area falls within Zone 1C (average basement indoor radon concentration - 6.7 pCi/L), and less than 5 percent of the area falls within Zone 1A. Analysis of the indoor radon data set for this study indicates that 94 percent of the basement indoor radon measurements made in Zone 1B and 77 percent of the measurements made in Zone 1C exceeded the EPA's action level of 4 pCi/L.

CONCLUSIONS

This study has identified a distinct relationship between geoperm environment (geologic unit and permeability) and basement indoor radon concentrations. Once geoperm units have been characterized in terms of their potential for elevated indoor radon concentrations, published geologic maps and studies showing the areal distribution of soil permeability can be used to create indoor radon potential maps. Such a map has been created for the Fort Collins area

(Figure 5). The basement indoor radon data indicate that all geoperm settings in and around Fort Collins have potential for associated indoor radon concentrations exceeding EPA's action level of 4 pCi/L.

RECOMMENDATIONS

The Indoor Radon Potential Map of the Fort Collins Urban Growth Area (Figure 5) may be used in several ways. It may be used to emphasize the need for voluntary testing throughout the Fort Collins area. The map may also be used to convey to the public and municipal and county agencies, the relative magnitude of potential indoor radon risk at different locations in the Fort Collins area and to target efforts to encourage testing. Another use may be to identify currently undeveloped areas where radon resistant construction techniques should be required or encouraged.

In order to confirm and refine the model and map presented in this report, additional indoor radon measurements should be collected in geoperm environments where indoor radon data are limited. In particular, additional basement indoor radon measurements are needed in rapid permeability loess; slow, moderate, and rapid permeability Pierre Shale and Niobrara Chalk; slow, moderate, and rapid permeability alluvium; and moderate permeability pediment fan deposits. Increasing the number of basement indoor radon measurements will increase the confidence level for the estimated average concentrations for each geoperm unit.

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Figure 1. CITY OF FORT COLLINS
GEOLOGIC MAP

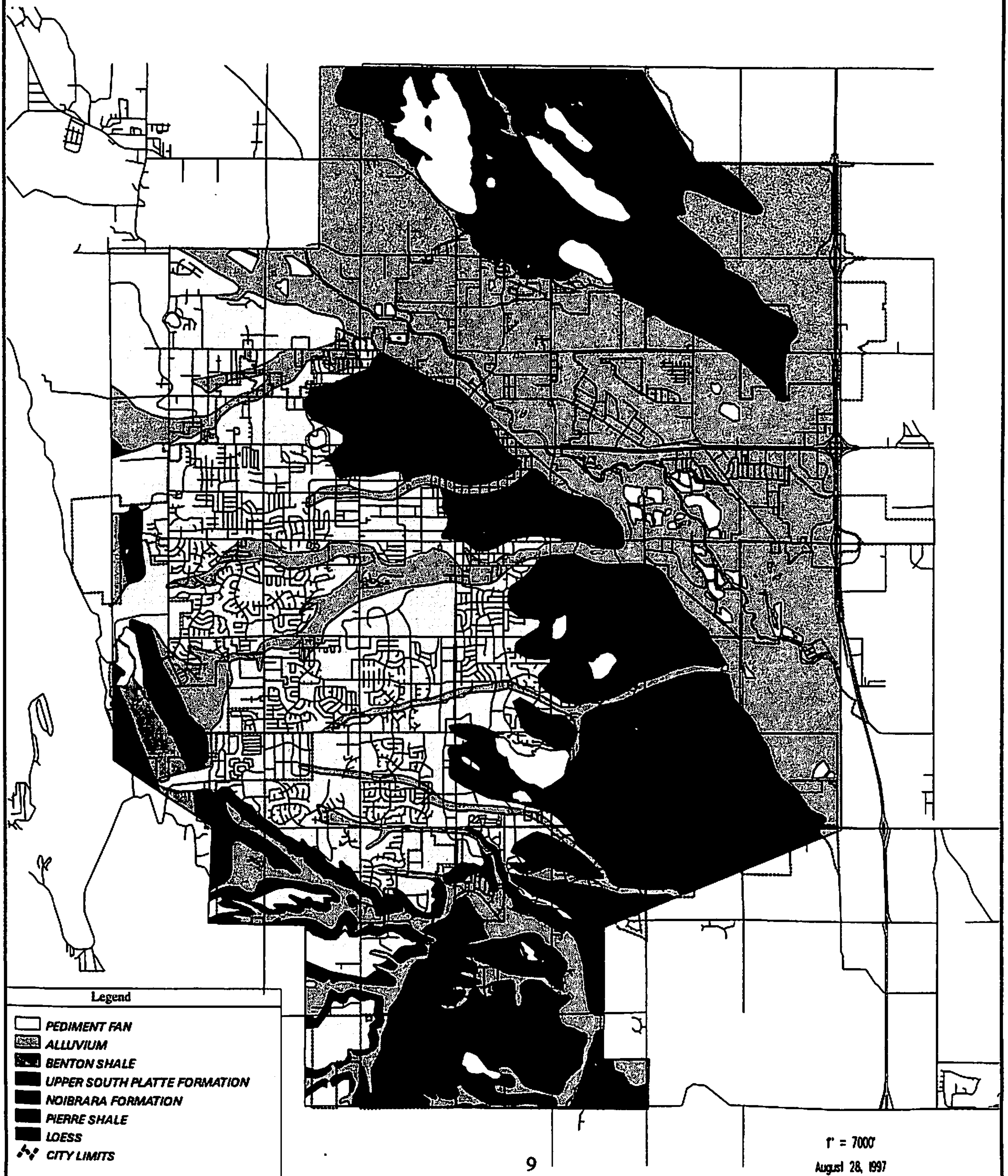


Figure 2. CITY OF FORT COLLINS
SOIL PERMEABILITY MAP

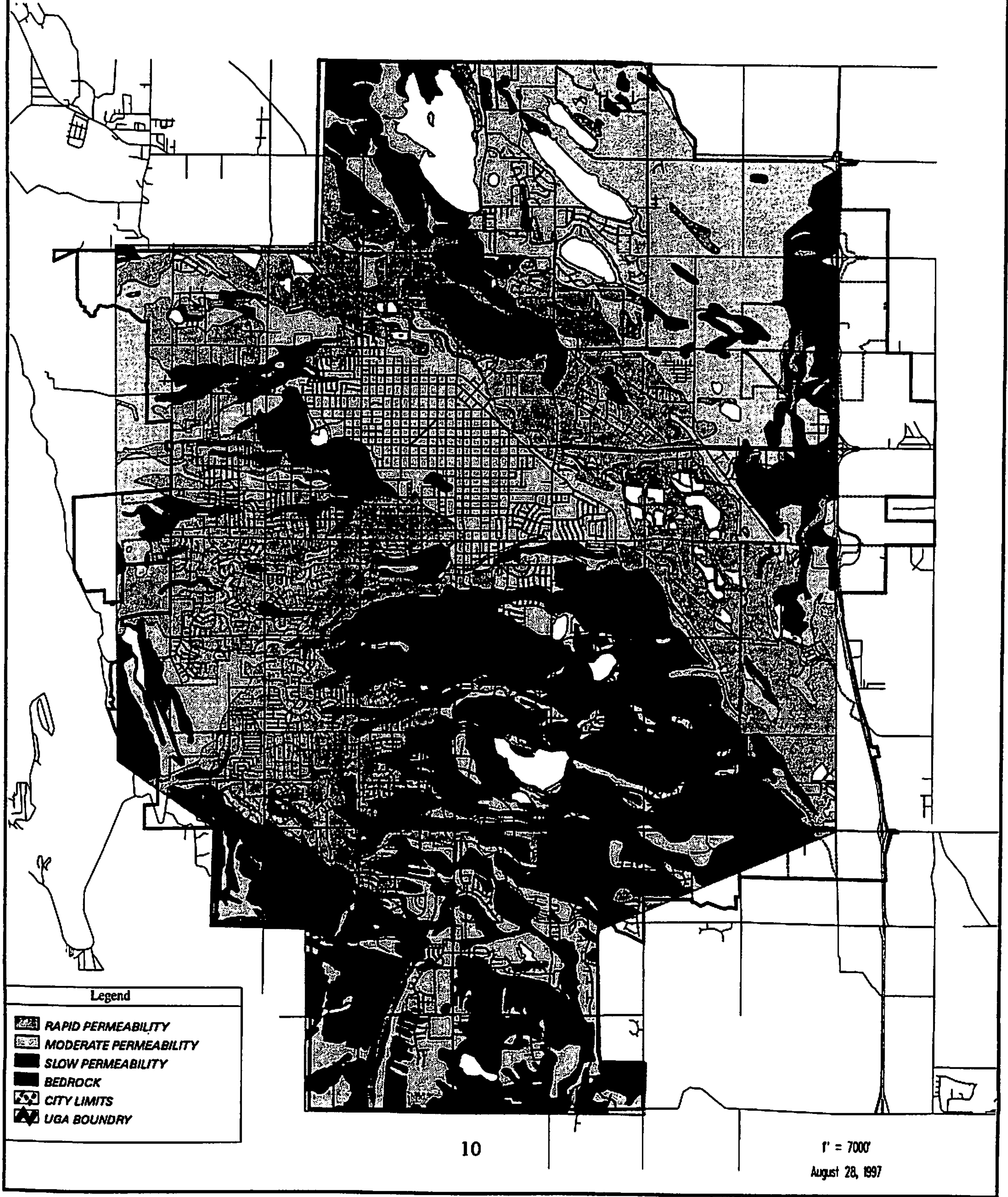


Figure 3. Indoor Radon Concentration vs Geoperm Unit

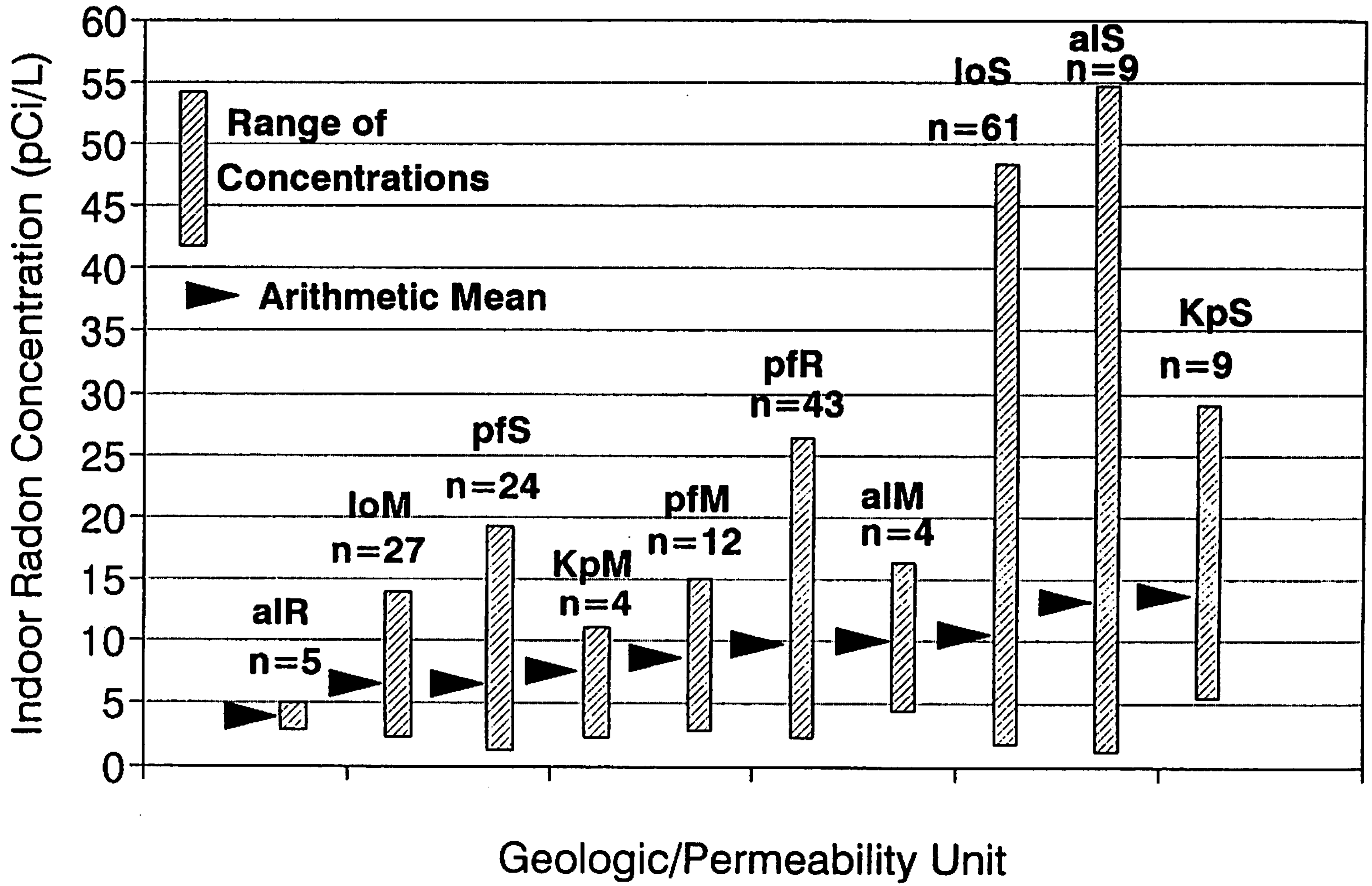


Figure 4. Basement Radon Levels
Fort Collins (1987-1995)

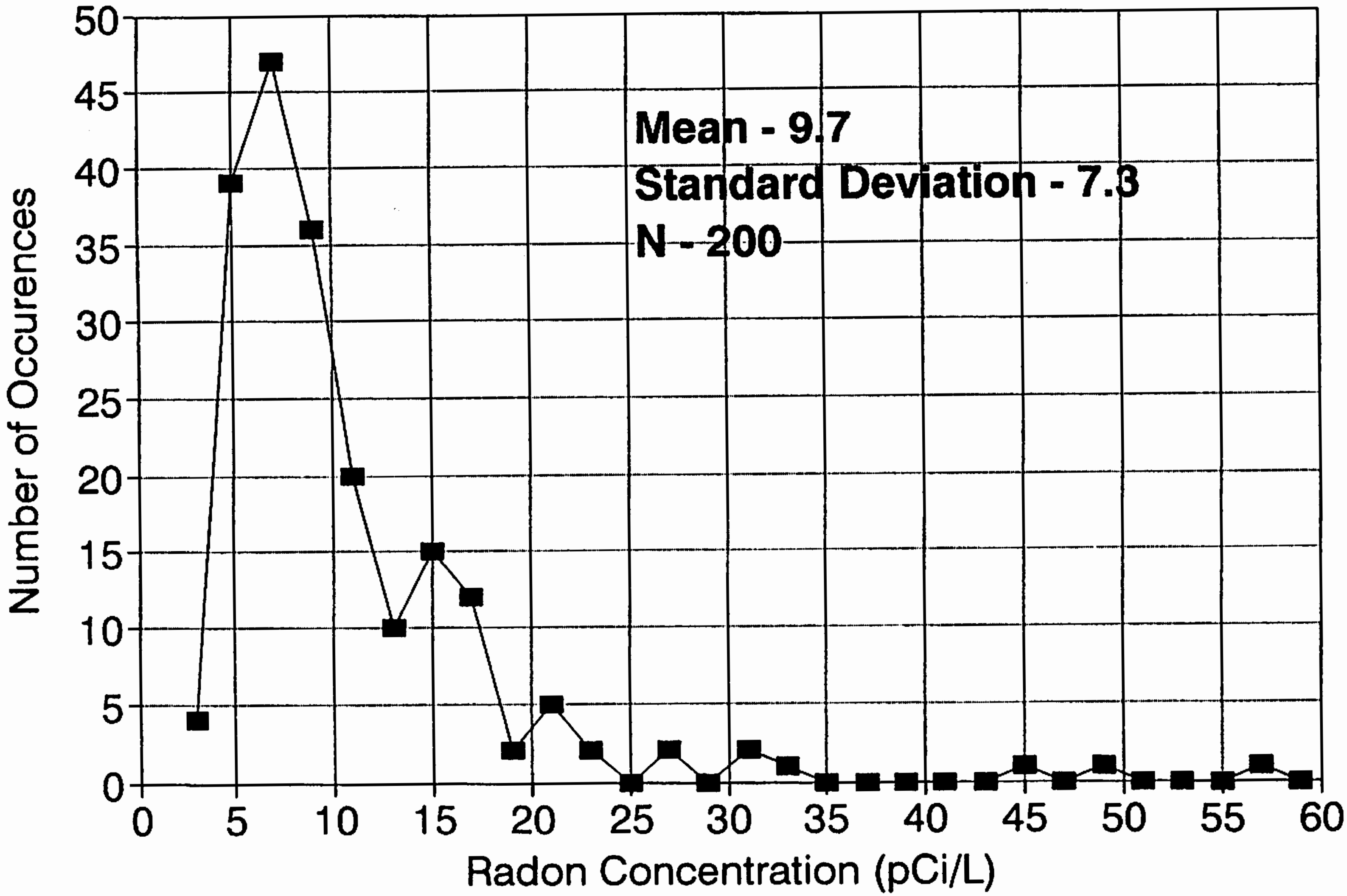
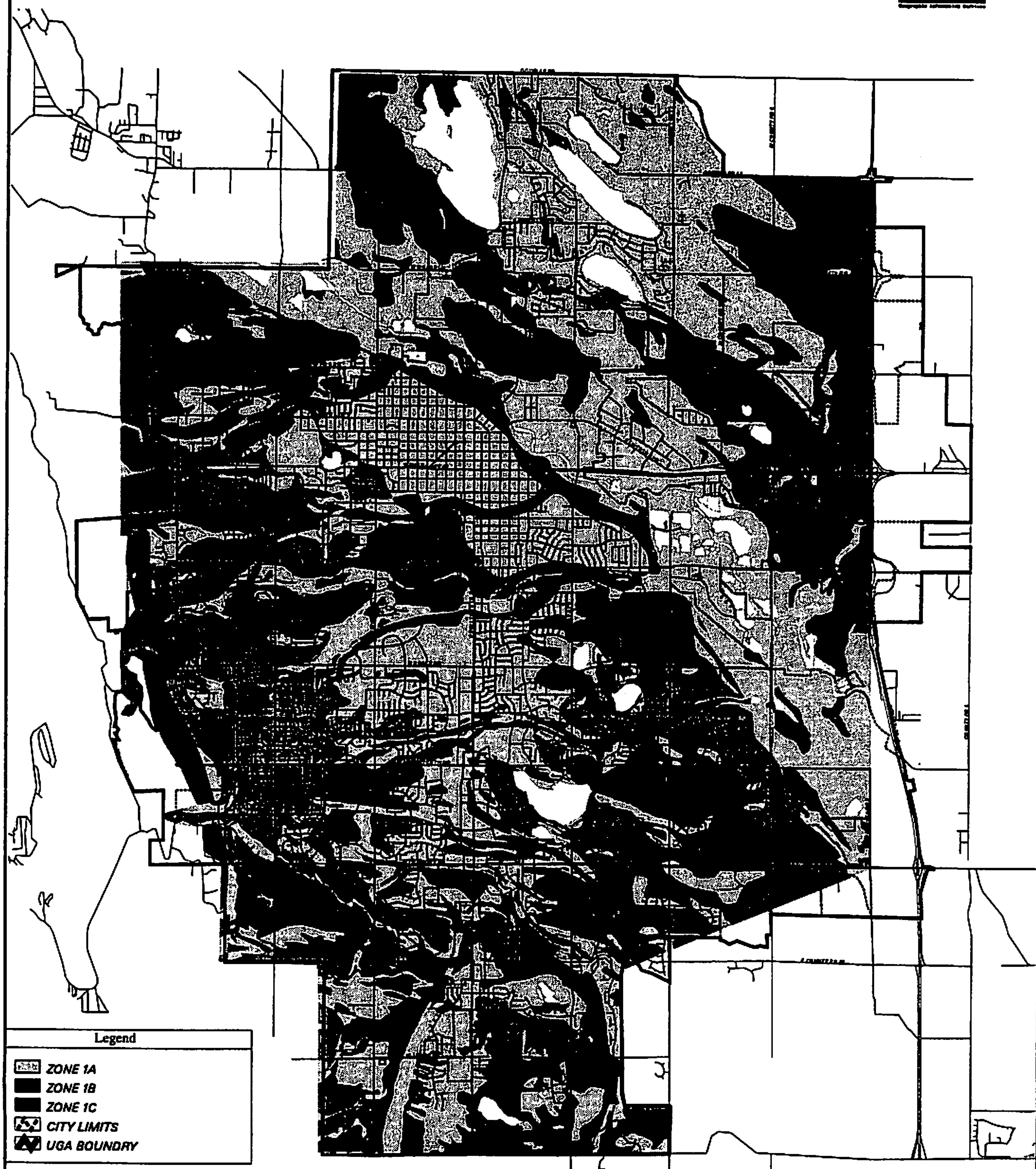


Figure 5. CITY OF FORT COLLINS INDOOR RADON POTENTIAL



1" = 7000'

August 29, 1997

Table 1. Geologic Units in the Fort Collins Area.

Geologic Unit	Depositional Environment	Lithology	Age
Alluvium	fluvial, includes current floodplain surfaces and older stream terraces	clay, silt, sand, gravel, cobbles, and boulders	Pleistocene through Holocene (1.6 million years to Recent)
Pediment Fan	alluvial fan, pediment surface deposits, and debris flows	clay, silt, sand, gravel, cobbles, and boulders	Pleistocene through Holocene (1.6 million years to Recent)
Loess	eolian (windblown)	clay, silt, and very fine sand	Holocene (Recent)
Pierre Shale	marine	dark-gray shale, sandy shale, and thin olive-gray, fine grained, well cemented, fossiliferous sandstones	Upper Cretaceous (66 to 98 million years old)
Niobrara Formation	marine	grayish-orange to grayish-yellow, chalky shale and limestone	Upper Cretaceous (66 to 98 million years old)
Benton Shale	marine	dark-gray to black, fissile shale with interbeds of fossiliferous, chalky limestone and bentonite	Upper Cretaceous (66 to 98 million years old)
Upper South Platte Formation	coastal marine	light to dark-gray, well-sorted, fine grained sandstone, siltstone, and gray, carbonaceous shale	Lower Cretaceous (98 to 144 million years old)

* Ages presented for geologic units in this section were obtained from the Geotime computer program (Rockware, Inc., 1996).

Table 2. Summary Statistics for Basement Indoor Radon Data

DATA SET	N	ARITHMETIC MEAN (pCi/L)	STANDARD DEVIATION (pCi/L)	MINIMUM (pCi/L)	MAXIMUM (pCi/L)	COVARIANCE
ALL DATA	200	9.7	7.3	2.1	55.3	0.8
Kp	14	11.9	6.4	3.2	29.6	0.5
al	18	10.3	11.8	2.3	55.3	1.1
lo	89	9.9	8.0	2.8	49.0	0.8
pf	79	8.9	4.8	2.1	27.0	0.5
SLOW PERM	103	10.4	8.4	2.1	55.3	0.8
RAPID PERM	50	10.1	7.0	3.3	44.9	0.7
MOD PERM	47	7.7	3.8	3.2	17.0	0.5
loR	1	44.9	*	44.9	44.9	*
KpS	9	14.1	6.7	6.2	29.6	0.5
alS	9	13.5	15.5	2.3	55.3	1.1
loS	61	10.8	8.0	2.8	49.0	0.7
alM	4	10.2	4.4	5.6	17.0	0.4
pfR	43	10.0	5.0	3.3	27.0	0.5
pfM	12	8.9	4.4	3.8	15.4	0.5
KpM	4	7.8	3.2	3.2	11.7	0.4
KpR	1	7.7	*	7.7	7.7	*
loM	27	6.8	3.2	3.3	14.6	0.5
pfS	24	6.8	3.8	2.1	19.7	0.6
alR	5	4.6	0.7	3.6	5.5	0.2

EXPLANATION OF ABBREVIATIONS

loR = loess, rapid permeability
KpS = Pierre Shale, slow permeability
alS = alluvium, slow permeability
loS = loess, slow permeability
alM = alluvium, moderate permeability
pfR = pediment fan, rapid permeability
pfM = pediment fan, moderate permeability
KpM = Pierre Shale, moderate permeability
KpR = Pierre Shale, rapid permeability
loM = loess, moderate permeability
pfS = pediment fan, slow permeability
alR = alluvium, rapid permeability

* Standard deviation and covariance not calculated if N < 3

Table 3. Summary Statistics for Indoor Radon Potential Categories

CATEGORY	N	MEAN INDOOR RADON (pCi/L)	STANDARD DEVIATION (pCi/L)	MINIMUM (pCi/L)	MAXIMUM (pCi/L)	COVARIANCE
ALL DATA	200	9.7	7.3	2.1	55.3	0.8
Zone 1B	139	11.0	8.1	2.3	55.3	0.7
Zone 1C	61	6.7	3.4	2.1	19.7	0.5

EXPLANATION OF ABBREVIATIONS

Zone 1B Geoperm Units

loR = loess, rapid permeability
KpS = Pierre Shale, slow permeability
alS = alluvium, slow permeability
loS = loess, slow permeability
alM = alluvium, moderate permeability
pfR = pediment fan, rapid permeability
pfM = pediment fan, moderate permeability

Zone 1C Geoperm Units

KpM = Pierre Shale, moderate permeability
KpR = Pierre Shale, rapid permeability
loM = loess, moderate permeability
pfS = pediment fan, slow permeability
alR = alluvium, rapid permeability