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AN ANALYSIS OF ENVIRONMENTAL AND ANTHROPOGENIC CONTROLS ON INDOOR RADON DISTRIBUTION IN GRAND FORKS, NORTH DAKOTA

by

Karen E. Butler
Bachelor of Science, University of Wisconsin-LaCrosse, 1992

A Thesis

Submitted to the Graduate Faculty

of the

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in partial fulfillment of the requirements

for the degree of

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This thesis, submitted by Karen E. Butler in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

Jon D. Hamer III
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This thesis meets the standards for appearance, conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Harvey Knull
Dean of the Graduate School
4-26-96

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Title	An Analysis of the Environmental and Anthropogenic Controls on Indoor Radon Distribution in Grand Forks, North Dakota
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Date April 25, 1996

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ABSTRACT

Indoor radon may be a potential health threat in a significant number of homes in Grand Forks, North Dakota. Ninety-three percent of the homes tested in 1988 to 1993 contained indoor radon levels greater than the Environmental Protection Agency's recommended action level of 4 picoCuries per liter. In addition, the average reading of indoor radon concentrations was 18.9 picoCuries per liter, well above the action level guidelines.

Several variables were examined through the use of regression analysis and a Geographic Information System in an attempt to characterize the controls on indoor radon levels in Grand Forks. The results of the analysis indicated no significant relationship with any of the variables tested: soil permeability, distance to surface water bodies, and house age. Bedrock and surficial geology are mainly homogeneous in nature and contain primarily shale, limestone, and sandstone which have been found to have high uranium concentrations. Therefore the bedrock and surficial geology play an important role in influencing high indoor radon levels. The outcome of the study led to the formulation of several alternative hypotheses for future studies. Studies investigating meteorological factors as well as building materials may prove to have a positive relationship with indoor radon levels in Grand Forks.

CHAPTER I

INTRODUCTION

1.1 Introduction

Radon is a product of the radioactive decay of uranium. It is a colorless, odorless, inert gas that occurs naturally in rock containing uranium, granite, shale, and phosphate. It is also found in soil, groundwater and outdoor air. Because radon is a gas, it is highly mobile in the environment and may reach soil and water to which people have access before it goes through radioactive decay (USEPA, 1986). Recent studies have shown that radon is present in almost all homes and buildings, sometimes in elevated concentrations (Brekke, 1987). An elevated (potentially hazardous) concentration is defined as being at or above the United States Environmental Protection Agency's (USEPA) suggested guidelines of 4 picoCuries per liter (pCi/l) (USEPA, 1986). According to the USEPA (1986), long term exposure to elevated levels of radon is associated with an increased risk of lung cancer, especially in uranium miners. It is estimated that between 5,000 and 20,000 people die each year from lung cancer due to radon exposure (USEPA, 1986).

1.2 Problem Statement

Radon test data from the University of North Dakota Radon Monitoring Facility indicates that the majority of homes tested for radon in Grand Forks, North Dakota have indoor radon levels greater than 4 pCi/l. This area exhibits great potential for high radon levels both in the ground and indoors, mainly due to the bedrock geology, the presence of radon in groundwater, and soil characteristics.

Grand Forks is located within the drainage system of the Red River of the North (Figure 1). It was once inundated by glacial Lake Agassiz and is now blanketed by lacustrine deposits. The oldest rocks below the surface in Grand Forks are Precambrian igneous and metamorphic rocks (Hansen and Kume, 1970). Ordovician rocks made up primarily of the Winnipeg Group, composed of shale, limestone, sandstone, and shaly limestone, unconformably overlie the Precambrian basement rocks (Hansen and Kume, 1970). Mesozoic rocks, including several formations of the Dakota, Colorado, and Montana Groups, overlie the Ordovician rocks (Hansen and Kume, 1970). Dark marine shales typically contain high levels of radium, and although sandstone is not usually enriched in radium, it can be the host rock for uranium deposits (Tanner, 1986).

The surficial geology of North Dakota, as described by Hansen and Kume (1970), is underlain by deposits of the Des Moines lobe. These flood deposits are comprised of mostly dark gray clay and silt, along with stratified olive-gray and yellowish-gray clay and silt, and may generate some of the highest radon levels in this area (Gunderson et al., 1992).

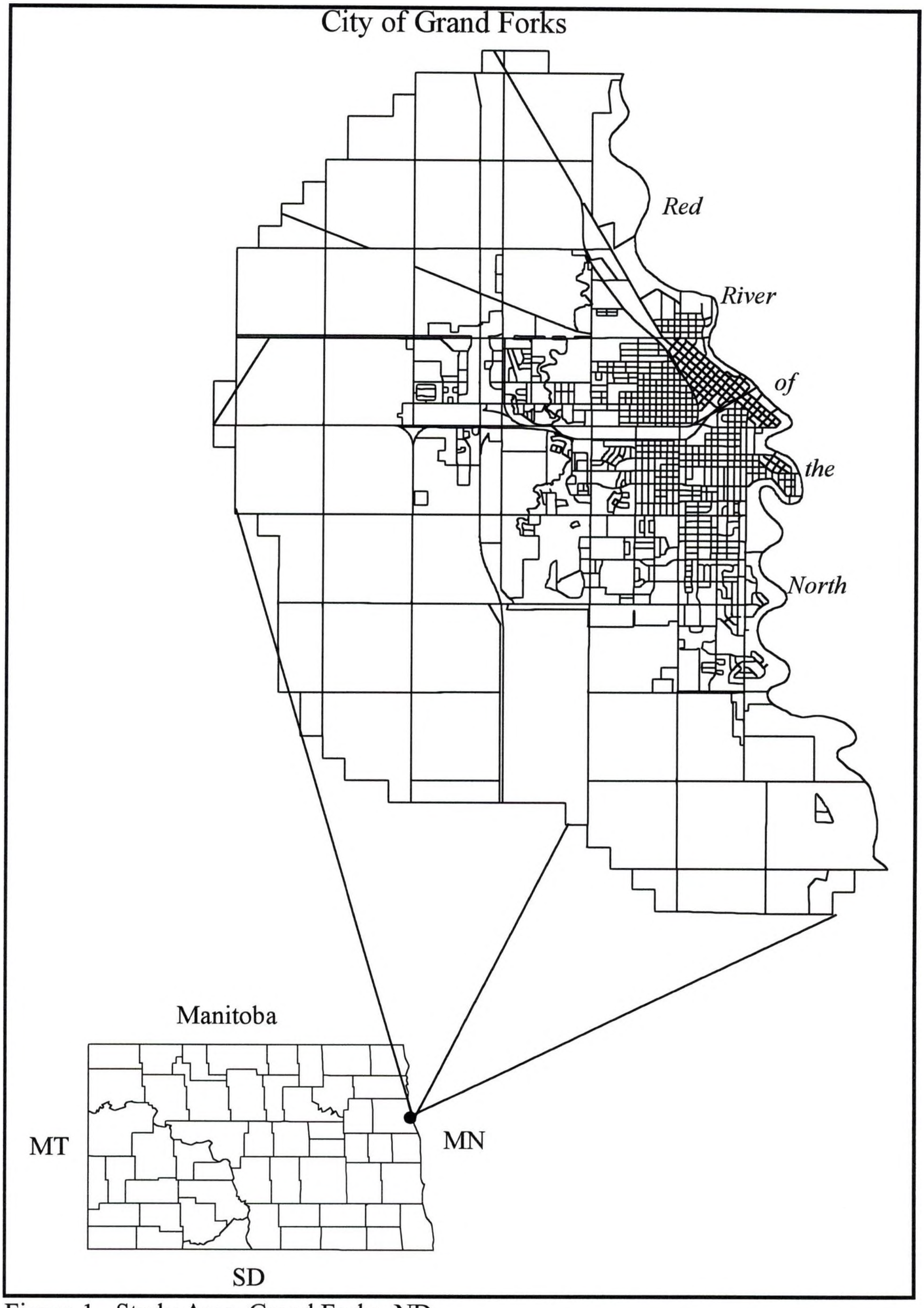

Figure 1. Study Area, Grand Forks, ND.

In a study of the distribution of radon in groundwater across the nation, Michel and Jordana (1988), discussed the aquifers of the Great Plains. They state that the aquifers of Grand Forks County are composed of unconsolidated sands from alluvial valley deposits. The uranium levels in the groundwater of Grand Forks County were found to be in the range of 1-5 pCi/l, radon levels were found to range from 100-500 pCi/l, and radium-228 levels were listed as high for Grand Forks County. In addition, the Red River Valley is a major discharge area for the northern Great Plains bedrock aquifer system (Downey, 1986). This can be seen in Downey's (1986) cross section from groundwater recharge area to discharge area. The cross section shows the gentle upward slope of the aquifers towards the Red River, showing the Red River Valley as the primary discharge area.

The soils of Grand Forks county are comprised primarily of poorly drained clay and silt, with relatively low permeability levels (USDA, 1981). The Colvin Silty Clay Loam are medium-textured soils formed in glacial lake plains. They are deep, level, poorly drained soils with moderately slow permeability (USDA, 1981). The Lamoure Silty Clay Loam are formed in medium-textured and moderately fine-textured alluvium. They are deep, level, poorly drained soils found on flood plains (USDA, 1981). The Overly Silty Clay Loam are deep, moderately well drained soils with moderately slow permeability found on glacial lake plains. They are formed in medium-textured and moderately fine-textured glacial lacustrine deposits (USDA, 1981). The Cashel Silty Clay Loam with 1-6% and 6-25% slopes are deep somewhat poorly drained soils found on flood plains and bottom land and are occasionally flooded by stream overflow. They are formed in fine-textured alluvium (USDA, 1981). The LaDelle Silt Loam are deep, moderately well drained, moderately permeable soils found on flood plains and stream terraces that are formed in medium-textured and moderately fine-textured alluvium (USDA, 1981). The Zell LaDelle Silt Loams (1-9%, 1-6%, and 1-15%) are deep, moderately well drained, moderately permeable soils found on glacial lake plains and in areas between beach ridges and are formed in medium-textured glaciolacustrine deposits (USDA, 1981). The Ojata Silty Clay Loam are deep, poorly drained, with moderate to slow permeability soils formed in medium- textured and moderately fine-textured glaciolacustrine deposits. They have very high saline contents and are found on glacial lake plains and in areas between beach ridges (USDA, 1981). The Bearden Silty Clay Loam are deep, somewhat poorly drained, moderately permeable soils found on glacial lake plains. They are formed in medium-textured glaciolacustrine deposits (USDA, 1981). The Bearden Silty Clay Loam-Saline and the Bearden-Parella Silty Clay Loam are deep, poorly drained, level soils located on swells and in swales and in shallow deposits on glacial lake plains (USDA, 1981). Soil permeability provides a mechanism through which radon transport may or may not be possible. Low soil permeability may limit the distance radon can travel, and radon will begin to decay immediately. High amounts of moisture in the soil can impede radon movement (Gunderson et al., 1992).

1.3 Objectives

The purpose of this study is to determine the spatial distribution of indoor radon levels in Grand Forks and to investigate their relationship with a select set of environmental and cultural parameters. The ability to determine which factors have the greatest influence on radon levels is very valuable not only to the residents of Grand Forks, but also for builders, city planners, and residents of other cities with a potential for high radon concentrations and possible health risks.

Specifically the objectives of this study are to determine:

1) the spatial location of varying levels of indoor radon, and

2) the relationship between indoor radon levels, and house age, distance to surface water, and soil permeability.

A Geographic Information System (GIS) will be used to discern and evaluate the spatial variation in radon levels throughout the city in conjunction with the variation of anthropogenic and environmental factors. Indoor radon values will be analyzed statistically to quantify their relationships to environmental controls and housing characteristics. This study will provide an end product displayed in both map form and written report revealing the relationship and spatial distribution of indoor radon levels and the aforementioned factors. The study will be conducted from a spatial perspective due to the tendency of radon levels to vary considerably from house to house. Most previous studies have focused on the geological factors that affect radon levels in larger U.S. cities and have focused only on the health risks associated with radon. This study will focus on a small urban environment located within an area naturally high in uranium decay.

1.4 Hypothesis

The results of some studies (Gunderson et al., 1992, and Bailey et al., 1988) indicate a positive relationship between soil permeability and indoor radon levels. These studies apparently indicate that radon migration in low-permeability soils may be limited, since radon will begin to decay immediately. Thus, this would indicate a strong relationship between variations in soil permeability and higher indoor radon levels in Grand Forks.

It is thought that older homes may have a greater percentage of cracks in the foundation, holes in the floors, and cracks in concrete walls and floor drains. Because radon can enter homes through cracks and penetrations through building foundations, floor drains, sumps, and joints (USEPA, 1987), it is hypothesized that older homes in Grand Forks would have the highest indoor radon concentrations.

It is expected that higher indoor radon concentrations are related to their proximity to the Red River and English Coulee. The aquifers of Grand Forks County were found to contain radon levels of 100-500 pCi/l (Michel and Jordana, 1988). In addition, the Red River Valley is a major discharge area for the northern Great Plains bedrock aquifer system (Downey, 1986). This means that a portion of the water in the Red River and its tributaries can be attributed to discharge from the Grand Forks aquifer; therefore, homes located along the Red River and English Coulee should have higher indoor radon levels than homes farther away from the river.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

The spatial distribution and concentration of radon has been the topic of extensive study all over the world. Such studies have examined radon in bedrock, soil, groundwater, and indoor air. Gates and Gunderson (1992) provided a brief history of radon studies. They found the first studies on radon concentrations were conducted for uranium exploration in the 1950s. Several years later, the USEPA (1986) determined that uranium miners, when exposed to high levels of radon, were at high risk for contracting lung cancer. When uranium exploration declined, and the levels of radon in homes exceeded the radon levels in uranium mines, environmental radon became the main focus of radon studies.

2.2 Radon and Radiation Physics

In order to begin to understand where radon comes from, a general understanding of radioactivity must be discussed. Natural radioactivity is exhibited by several elements, including radium and uranium (USEPA, 1986). The radiation produced is of three types: alpha, beta, and gamma (Okun, 1987). An alpha particle, consists of two protons and two neutrons and is emitted from the nucleus of a decaying atom (USEPA, 1986). The decaying atom decreases in atomic mass by four and decreases in atomic number by two (Okun, 1987). The beta particle is a high-speed electron of either positive or negative charge, which is ejected from the decaying nucleus, and the mass number of the decaying atom does not change, but the atomic number increases or decreases by one (Okun, 1987). Gamma decay is a radioactive process in which an atomic nucleus loses energy by emitting a gamma ray without change in its atomic or mass numbers (Okun,1987).

Radon has three main isotopes including Radon-222 (radium), Radon-220 (thorium), and Radon-219 (actinon) (Nero, 1988). Rn-222, formed in the radioactive decay chain of uranium-238, has a half-life of 3.8 days, which is long enough so that much of the Rn-222 formed within one meter of building under structures can reach indoor air (Nero, 1988). Produced by the decay of radium-224 as a step in the thorium-232 decay chain, Rn-220 has a half-life of 56 seconds, which substantially limits the distance Rn-220 can travel before it begins to decay, and therefore limits the amount that reaches air (Nero, 1988). Very little Rn-219 is present in air, because it is in the decay chain of uranium-235, which has a considerably lower abundance, and because Rn-219 has an extremely short half-life of 4 seconds (Nero, 1988). When radon gas and its progeny, a term used to refer collectively to the intermediate products in the radioactive decay chain, stay in soil and rock or are released to outside air and diluted, their release does not have the health hazards that they have when confined in indoor environments (USEPA, 1986).

2.3 Radon in Soil

According to the USEPA (1986), radon can be found in soils containing uranium, granite, shale, phosphate, and pitchblende; indoor radon levels may depend on the concentration of uranium in the underlying soil. There was some variability in the results of the soil-radon studies examined. Gunderson et al. (1992) found that the concentration of radon in soil may be dependent on soil permeability and moisture content. They state the distance radon may travel in soil can be limited in low-permeability soils, because radon will begin to decay immediately. In addition, high amounts of moisture in the soil can block pore spaces and impede radon movement. A study of indoor radon concentrations in northern Virginia and southern Maryland revealed that soils of low permeability and low soil radon levels yielded indoor radon levels less than 5 pCi/1, and soil of high permeability and high soil radon levels were associated with homes that had indoor radon levels of more than 15 pCi/1 (Bailey et al. 1988).

The results of a study of soil-gas in Fairfax County, VA, by Mose et al. (1988), indicated no relationship between indoor radon levels and soil permeability. This contradicts the results of some of the previous studies examined, indicating the diversity in the results of the studies. The findings, however, did indicate a relationship with outdoor air temperature and indoor radon levels. Generally, as the air temperature decreased, indoor radon levels increased. They speculated that in colder climates, where homes are better insulated and windows are not opened as much, indoor radon levels will be higher. In addition, where rainfall caps the soil and prevents the escape of radon into the atmosphere, indoor radon values may be higher. When pores fill up with water, the gas permeability is gradually reduced, and as the top layer of soil becomes saturated, a cap that prevents the vertical mixing of soil-gas radon with the atmosphere is formed (Asher-Bolinder et al., 1991).

Mose et al.'s (1988) study of radon soil-gas in Fairfax County, VA brings up several interesting points in comparison with the study area in this thesis. First, Grand Forks, ND has a particularly cold climate and cold temperatures below freezing may last for 4 months out of the year. Second, just as the authors predict that rainfall may cap the soil, chilling or freezing of the soil, or snow cover can cause radon to accumulate in the upper soil layers (Tanner, 1964). When this happens, more radon is available to filter into homes (Mushrush and Mose, 1989).

In a study of soil-gas radon in Grand Forks County, North Dakota Solie (1995) noted,

> Water with high dissolved solids has the ability to leach radium ions from sediment and keep ions in the solution... Areas of elevated radium-226 concentrations are present in the eastern portion of the county. These areas generally coincide with areas of the lake plain that have been salinized by the discharge of high dissolved solids groundwater from the Dakota Formation and deeper Ordovician aquifers. The overlap of saline soils and elevated radium-226 soils suggest the properties are related... Radium-226 may be present in the saline water when it leaves the aquifer. Radium may also be leached from the sediment overlying the aquifer as the bedrock groundwater slowly discharges to the surface. The water is taken up by evapotranspiration; the dissolved solids and radium are then concentrated in the soil. (p.96-97)

Reimer et al. (1991) found that soil-gas samples collected along a traverse in Prince Georges County, MD revealed radon concentrations of up to 2,500 pCi/1. Further, they discovered that higher levels of soil-gas radon occurred in some of the

Tertiary sediments, and lower concentrations of radon soil-gas occurred in the Cretaceous and Quaternary sediments. They concluded that the controlling factors for the radon soil-gas concentrations were due to geologic sources.

The previous studies of radon in soil indicate that soil characteristics alone can not adequately predict indoor radon levels. A number of other factors must be examined in order to accurately predict which geographic areas will have high indoor radon levels. Soil analysis does, however, provide a rapid, initial means to discern the distribution and concentrations of radon soil-gas levels.

2.4 Geology and Groundwater

Bedrock needs to be examined in addition to soil, because much of the soil is a derivative of its parent material (i.e., bedrock). Thus, some radon in the soil may be due to the underlying bedrock. "Geologic information is critical to the understanding of radon occurrence and mobility," (Hall et al., 1988 p.26). Tanner (1986) lists the type of rocks that may contain high levels of radium as granites, many gneisses, rocks containing phosphate, and dark marine shales. Also, during the process of recrystallization, limestones and dolomites expel uranium and radium from the newly formed crystals and concentrate them in the pores and along surfaces that fracture easily. Radon can be picked up and carried by air or water that moves along the fractures. In order to predict radon occurrence and mobility, the uranium concentrations in the bedrock, the type of unconsolidated deposits that overly the bedrock, and how groundwater is incorporated in the bedrock and soil must all be discerned (Hall et al., 1988).

Tanner (1986) provided a great deal of insight into the various means for the controls of radon movement in the ground. He states,

> Radium in rock and soil contributes to radon in soil air only if the radium is very close to the surfaces of the rock and soil grains. In many rocks only a few percent of the radium disintegrations produce radon that can get into the pore spaces.... Once radon is in the rock or soil pores, the amount of water in the ground is very important. If the pores are filled with water, radon can only move a few inches before it decays; if only a small amount of water is present, radon may move a hundred times farther. The distance the radon can move tends to be greater in fractured rocks and coarse soils and gravels, and much less in fine-grained soils like silt and clay, which also hold more water. (Tanner, p.2)

Studies on the occurrence of radon in groundwater directly link the occurrence of radon in groundwater to geologic controls (Michel and Jordana, 1988). One such study examined radon in groundwater in Illinois and found the highest concentrations occurred in areas where the Cambrian and Ordovician bedrock were overlain by shale deposits (Gilekson and Cowart, 1988).

Another study by Szabo and Zapecza (1991), presented the findings on the geologic factors which control the occurrence of radon in groundwater of the Newark basin, New Jersey. Two hundred sixty groundwater samples were taken and analyzed for gross alpha- and beta-particle activity. Results of the analyses show that alpha-particle activities range from 1 to 124 pCi/l, and uranium concentrations range from 71 to 15,900 pCi/l. The elevated concentrations of uranium, radium-226, and radon-222 in the groundwater were found to be controlled by the uranium and radium-226 content in the surrounding bedrock.

Lico and Rowe (1991), studied the controls of radon-222 in the groundwater of Carson Valley, NV. In a total of 30 groundwater samples, radon-222 levels ranged from

100 to 10,000 pCi/l. They found several factors that contributed to the occurrence of radon-222 in groundwater. It was thought that Cretaceous granitic rocks containing high concentrations of uranium may release radon-222 to the groundwater. They expected that the fault on the eastern side of the Carson Range served as a conduit for groundwater containing radon-222, and groundwater containing elevated concentrations of radon-222 may flow from fractured bedrock into the alluvial-fan aquifer. Geology was the major contributor to elevated levels of radon-222 in the groundwater of Carson Valley.

2.5 Structural and Surficial Geology

One study by Littleton and Smith (1994) hypothesized that a spatial relationship exists between radon occurrence and geological faults in a focused area of Massachusetts. They used Geographic Information System (GIS) technology to display and manipulate the data. The GIS was crucial to the creation, manipulation, and analysis of large spatial data sets (13,870 records), that included the location of the radon level in latitude and longitude, the address, city, state, and zip code of the radon point, and the radon reading. The radon attributes were very important, because they provided information used to contour radon values on the digital map created. Once the spatial data sets were created, questions about the relationship between radon level and geological faults could be asked and answered both statistically and visually. The visual analysis indicated that the initial hypothesis is supported, and the potential relationship between radon and geologic faults exits. The statistical analysis was expected to reveal that radon levels increased as distance to the fault decreased. The statistical analysis of the radon-fault relationship involved creating a series of buffers around the faults. The buffering of faults grouped the radon points by their nearness to the fault. The results of the statistical correlation analysis did not support the hypothesis, and no significant relationship was found to exist between radon level and distance to geologic fault.

Thomas and Scull (1988) analyzed radon levels in Hartford, Connecticut. Data collected included 300 well-water radon samples and 2000 indoor radon samples. Spatial and statistical analysis were done by correlating radon data with data taken from digital maps of surficial geology and bedrock geology. Upon completion of the study, the results were used to predict the potential for high radon levels in different areas of the state.

2.6 Home Construction

According to the USEPA (1987), radon can enter homes through exposed soil in crawl spaces, through cracks and penetrations through building foundations and sump holes. However, a driving force, in addition to entry points, must exist for radon to enter a building from the soil (Peake and Schumann, 1991). A driving force is caused when there is negative pressure inside a home relative to the soil (Gunderson et al., 1992).

> A lower pressure inside a home may result from: heated air rising which causes a stack effect, wind blowing past a home, which causes a down-wind draft or Venturi effect, air being used by fireplaces and wood stoves, which causes a vacuum effect, or air being vented to the outside by clothes dryers and exhaust fans in bathrooms, kitchens, or attics, which also cause a vacuum effect. (USEPA, 1987 p.1)

Gunderson et al. (1992) also found that homes with basements tend to have higher indoor radon levels than homes without basements. This is because homes with basements have a driving force and more entry points than homes without basements. This contradicts the results from Brookin's (1988 and 1990) studies which researched the indoor radon problem in Albuquerque, New Mexico. He found that indoor radon levels may be attributed to the degree of insulation and solar heating systems. Further, no clear relationship exists between indoor radon levels and the year the house was built or the building material used. He suggested that these relationships be examined further.

A case study of Kentucky by Peake and Schumann (1991) provided an example of the characterization of geologic radon potential. The initial indoor radon data was available through the 1986-87 EPA/State indoor radon survey. Indoor radon data from the counties of Kentucky was combined and grouped by house type (basement versus nonbasement) for comparison with geologic and soil data. Soil data was obtained from the Soil Conservation Service Soil Survey, and geologic data was obtained from various geologic maps. Soil permeability ranged from 0.6 to 6.0 inches per hour, and geology was primarily shale and limestone. Correlation analysis, between indoor radon levels and soil permeability, bedrock type, and house construction, revealed that indoor radon levels are controlled by both geologic and house construction factors. The authors surmise that geology can be used for estimating indoor radon potential, but house construction may determine how geology will influence indoor radon levels.

Lanctot et al. (1992) conducted a study on the influence of several factors, including bedrock and house construction, on indoor radon levels in Maine. Five hundred forty seven water samples and five hundred thirty nine indoor air samples were collected from homes with drilled wells. Logistic regression was performed to examine the relationship between indoor radon levels and house construction, draftiness of the house, heating source, basement construction, and the type of bedrock underlying the house. The results of the analysis indicated that woodframe homes were 10 times more likely than mobile homes to have indoor radon levels greater than 4 pCi/l, brick or stone houses were 108 times more likely to have high indoor radon levels, homes built over sands and gravels were 12 times more likely to have high indoor radon than homes built over clay, and high indoor radon levels were more likely to occur in winter than in summer.

CHAPTER III

METHODOLOGY

3.1 Data

This study investigates the spatial distribution of indoor radon levels and their relationships with soil permeability, bedrock geology, distance to surface water bodies, and house age. Data for the study was obtained from the Soil Conservation Service Soil Survey of Grand Forks County, North Dakota (1981), North Dakota Geological Survey miscellaneous map 21 (1982), North Dakota Geological Survey Bulletin (1970), United States Geological Society topographic maps, the University of North Dakota Radon Monitoring Facility, and the Grand Forks Department of City Planning.

3.1.1 Radon

Radon data collected from the University of North Dakota (UND) Radon Monitoring Facility database includes local housing address, radon level, and collection date. Five hundred fifty-five samples were placed in homes in accordance with homeowner demand. These samples were obtained through the use of charcoal canisters. The canisters were placed in the lowest livable level of each home, such as the basement, and exposed to indoor air for a period of three to seven days. Radon samples were analyzed in the UND Radon Monitoring Facility, and the results from the analysis were used to build the indoor radon level database. While the homeowners were instructed to put the canisters in the lowest level of the home, some homeowners tested the basement as well as other areas in the home. This was to obtain an accurate level of radon in the most populated area of the home. If this occurred, the samples were averaged to obtain the overall indoor radon level for each home. In addition, if more than one sample was collected for the same house during the same year, but on different days, the results of the samples were averaged to get a total indoor radon level for that year. In cases where all years of the study (1988 to 1993) were used for analysis, such as indoor radon vs. soil permeability and indoor radon vs. distance to surface water bodies, if more than one sample was collected at the same location in subsequent years, the first sample collected was the one used for analysis. Also to aid in determining which homes, tested in subsequent years, may have used radon reduction methods before re-testing, a t-test was performed. The results of the t-test will reveal whether or not the indoor radon levels, in homes sampled in subsequent years, decreased.

3.1.2 Soil Permeability

Soil permeability (inches/hour) has been defined as the rate of flow of a liquid or gas through the pore spaces (Nazaroff, Moed, and Sextro, 1988). Soil permeability is a very important criterion because most radon is not released from the soil surrounding a building but from the rocks beneath the soil. It is necessary for the radon to have a conduit that allows the movement of the radon from the source through the soil. Soil permeability is a good measure of this conductivity (Burkhart and Huber, 1993). Since the range of soil permeability values can vary greatly from one location to the next, the distance radon may migrate through the soil will vary greatly; this, in turn may influence the variability of indoor radon concentrations.

Soil data for Grand Forks was obtained from the Soil Survey of Grand Forks County (1981). The Soil Survey provided data on soil associations, which include major and minor types of relief and drainage. Data on soil type and permeability was also provided, and permeability for each soil type was determined using Table 14, Physical and Chemical Properties of the Soils. Four horizons were listed for each soil type. Each horizon listed had a corresponding permeability range. The lowest permeability range within each soil type was then averaged to establish a mean permeability for each soil type. For example, if the lowest range for a particular soil type was 0.6-2.0 inches/hour, then the average permeability for that soil type is 1.3 inches per hour. Table 1 lists the permeability, measured in inches per hour, for each soil type.

TABLE 1

SOIL TYPE AND PERMEABILITY GRAND FORKS, ND

Soil Type	*Soil Permeability (in/hr)*
Bearden Silty Clay Loam	0.4
Bearden Silty Clay Loam - Saline	1.1
Bearden-Parella Silty Clay Loams	0.4
Cashel Silty Clay Loam	0.4
Cashel Silty Clay Loam (6-25% Slopes)	0.33
Colvin Silty Clay Loam	0.4
LaDelle Silt Loam (0-3% Slopes)	1.3
Zell-LaDelle Silt Loams (1-15% Slopes)	1.3
Lamoure Silty Clay Loam	1.3
Ojata Silty Clay Loam	0.33
Overly Silty Clay Loam	0.33

Plate numbers 25, 34, 52, 61, and 70, at a scale of 1:20,000, from the Soil Survey were used to produce a map, in State Plane coordinates, that displayed the location of the various soil types in Grand Forks. Soil permeability levels were also used to create a map, using the aforementioned plates, that displayed the permeability levels for each soil type in Grand Forks. Soil permeabilities were also added as an attribute to the GIS database and were correlated with indoor radon levels, using Statistical Analysis System software (SAS, 1980). A linear regression analysis was selected as the best method to use.

3.1.3 Surface Water Bodies

The 7.5 minute series US Geological Survey Grand Forks topographic quadrangle was used to obtain the location of surface water bodies in Grand Forks. Information was digitized from this map and brought into a GIS for analysis. A coverage entitled Surface Water Bodies was created. Distance from each radon point to the surface water bodies was calculated, added to the feature attribute table, and used for the regression analysis.

3.1.4 Housing Data

Housing data was obtained from the Grand Forks Department of City Planning and consisted of house age, address, and property parcel identification number. The Grand Forks Department of City Planning also prepared a property parcel and city street map which was used to link the housing data and radon levels to individual homes in Grand Forks.

3.2 Database Construction and Spatial Analysis

Surfer for Windows (Golden Software, 1990) was used to perform an interpolation routine on the location of radon points and their value, which graphically displayed the spatial distributions of radon levels, thus making it easier to view any patterns that may occur. One contour map was produced for each year the data was collected except 1993, due to insufficient data.

The GIS phase was organized into a series of steps, each one of which was built upon the previous one. The first step was to digitize the maps that were not in digital format. The maps that needed to be digitized consisted of soil type and surface water bodies. The property parcel and city street maps were digitized by the Department of City Planning and exported into PC Arc/Info (ESRI, 1994). The remaining maps were digitized using PC Arc/Info's Arc Digitizing System. Once the maps were digitized, any digitizing errors that occurred were corrected, edited, and polygon topology was created.

With all coverages in the same coordinate system, the next step was to create the feature attribute tables. Feature attribute tables were created by linking the soil type labels and permeability levels to the soil coverage, and house address, house age, and radon level data to the property parcel coverage. Once the feature attribute tables were arranged, the property parcel map was converted to a point coverage containing only points instead of property parcel polygons, and included in the point attribute table were house age and radon level. This was done to maintain homeowner privacy. Once overlain with the city street coverage, only the block location of each point was identified.

After the database was prepared, spatial analysis was performed. An overlay of the soil coverage and point coverage showed what kind of relationship existed between soil type and indoor radon levels and which soil type corresponded with which radon level. Distance from each radon point to the Red River and English Coulee were determined through use of a spatial query. A special command built into the GIS performed this function automatically by examining the Surface Water Bodies Coverage and the Radon Points coverage and then calculating the distance from each radon point internally. The results were automatically added to the feature attribute table.

The final step in the GIS phase was to create final map displays of the results. A final map of the point coverage and city street map for each year was created, a map which displayed soil permeability ranges for the city was produced, and a map that revealed the spatial distribution of house age was created.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Soil Permeability

Soil permeability levels in Grand Forks, ranged from 0.33 to 1.3 inches per hour. Figure 2 shows the spatial distribution of permeability levels for the City of Grand Forks and some outlying areas. Data was included for some portions beyond the city limits to ensure accuracy for the entire city, and because the city limits were indistinguishable on the soil map. The majority of Grand Forks had soil permeability values between the range of 0.4 and 1.1 inches per hour. Appendix A shows the soil permeabilities and corresponding indoor radon levels for the years 1988 to 1993 (477 observations). It was expected that higher indoor radon levels would occur in the area where the permeability is 1.3 inches per hour, which runs along the river. This was the highest permeability value for Grand Forks, and previous studies (Bailey et al., 1988, and Gunderson et al., 1992) had determined that areas of greater soil permeability yielded higher indoor radon levels. However, a permeability value of 1.3 inches per hour is not considered a high permeability value (highly permeable soils have permeabilities greater then 14.0 inches/hour (Peake and Schumann, 1991), and therefore in accordance with the aforementioned studies, indoor radon levels in Grand Forks should be low (<4pCi/l).

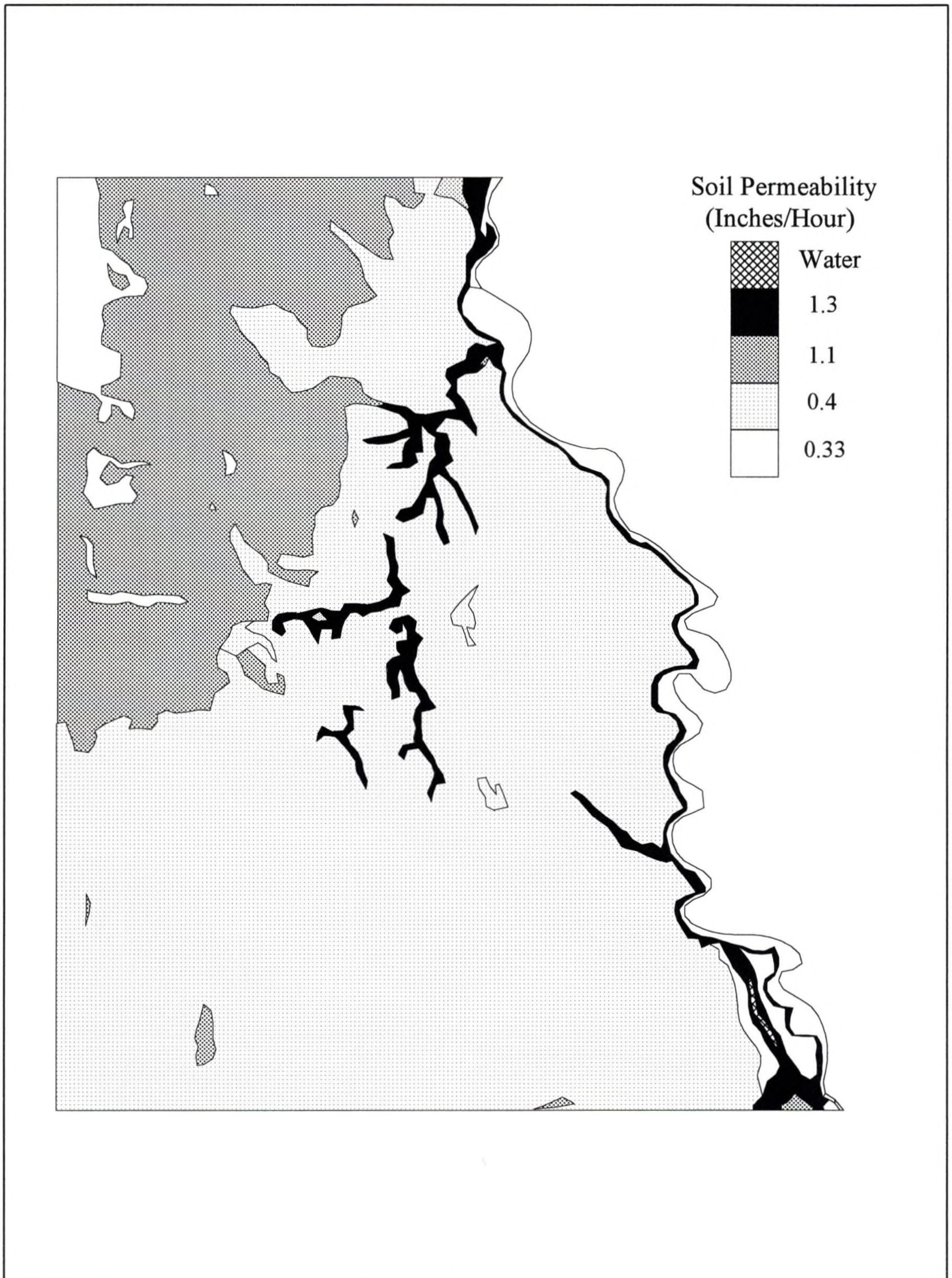

Figure 2. Soil Permeabilities, Grand Forks, ND

Linear regression analysis indicated an r-square of 1 percent which was significant at the 0.01 level. Thus, soil permeability accounted for only 1 percent of the total variation in radon levels in Grand Forks. This result contradicts previous studies, which found low soil permeability yields low indoor radon levels. Based on the regression analysis, soil permeability was discounted as a possible control of the high indoor radon levels in the City of Grand Forks. Because the permeabilities were low (<1.4 inches per hour) and because the results of the regression analysis only accounted for 1% of the total variation, it was determined that the elevated levels of indoor radon concentration were due to other variables.

4.2 Distance to Surface Water Bodies

An r-square of .18 percent significant at the .34 level suggests that distance to surface water bodies is not a factor in explaining the variation in indoor radon levels.

4.3 House Age

Figure 3 indicates the spatial distribution of house construction date for 1988 to 1993. The distribution of house age appears to have a clustered pattern. The majority of newer homes are located in the western and southern portions of the city, while older homes are located primarily along the river.

Radon levels were compared to housing construction date to determine the relationship that existed between the two variables. A regression analysis performed with housing construction date as the indepent variable and radon level as the dependent variable

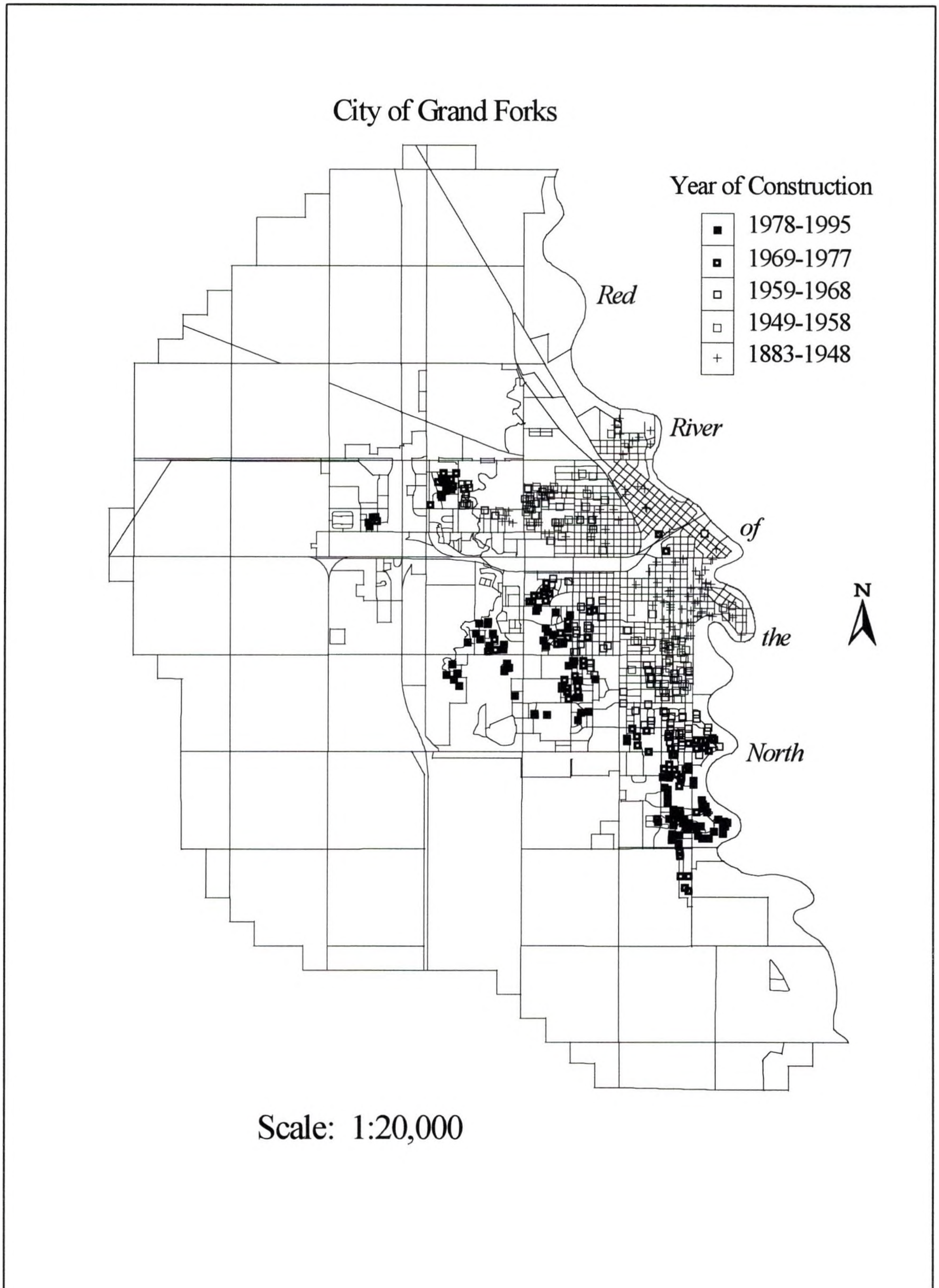

Figure 3. Housing Construction Date for Grand Forks, ND.

resulted in an r-square of only 0.03, indicating that only 3 percent of the variance in indoor radon levels could be explained by variation in housing construction date and was significant at the .69 level.

4.4 Radon Levels

The radon levels collected by the UND Radon Monitoring Facility ranged from 0.40 to 326.1 pCi/l. Because the samples were placed in the home in accordance with homeowner demand, it was believed that an accurate representation of indoor radon levels of Grand Forks was achieved. However, upon examining the spatial distribution of the houses sampled, it was discovered that the central portion of the city had very few, if any, high indoor radon values. In fact, very few indoor radon samples were collected from this area. Figures 4 through 9 show a post plot of the indoor radon samples for the years 1988 to 1993. Upon examination of the maps, it became apparent that some areas of the city had not been sampled, or had relatively few homes samples. This was just one of the limitations encountered with the data set. However, certain restrictions applied to the number of samples collected. First, the samples were placed in accordance with homeowner demand, limiting the number of samples and the areas sampled. Second, due to the requirements of having to report any levels of radon found in the home, many homeowners may have chosen not to have their homes tested, thus limiting the actual number of samples.

Another problem that may have affected the accuracy of the distribution of radon levels can be attributed to lack of information about homes that were tested for indoor radon more than one time. There was no way of knowing whether a home that had significant

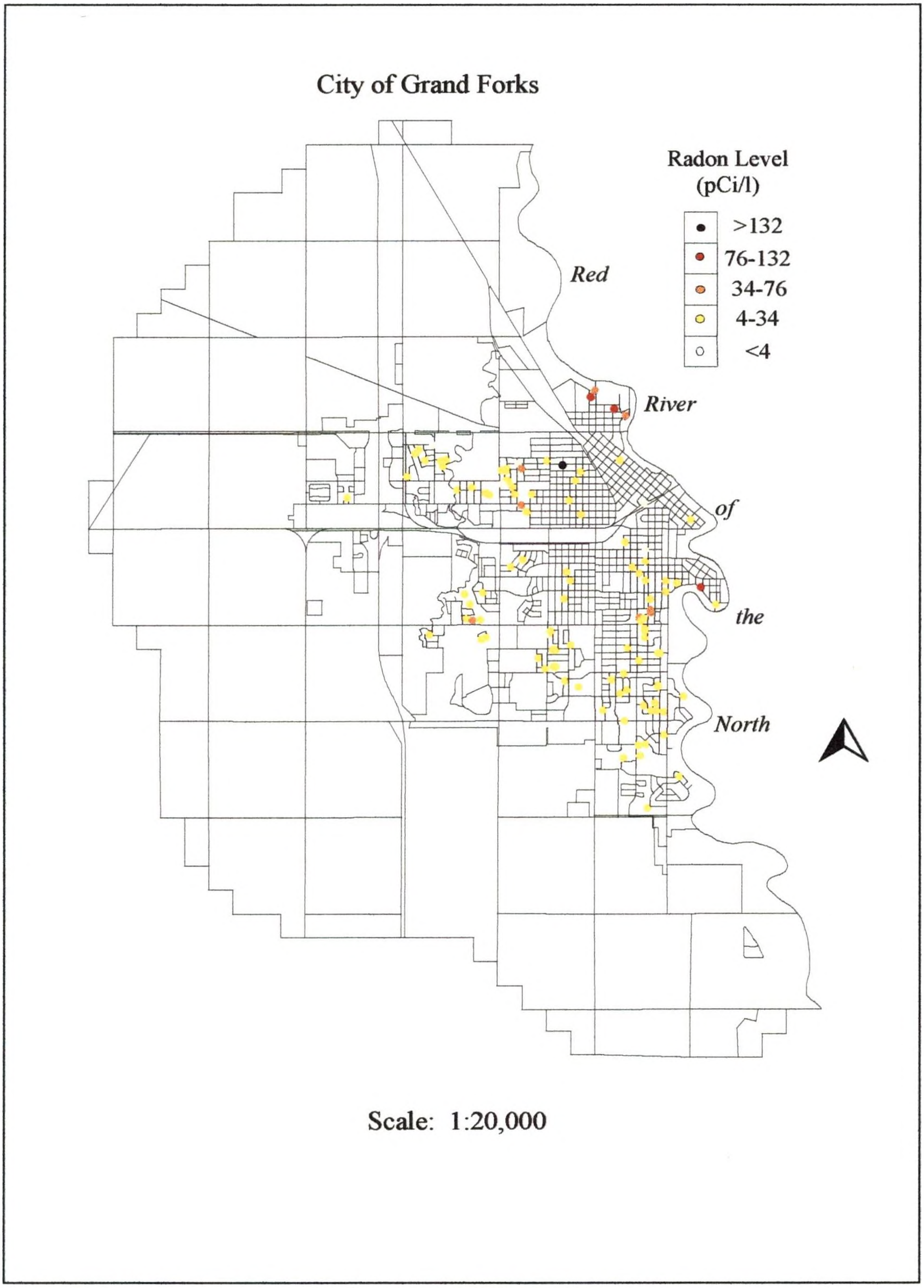

Figure 4. Indoor Radon Levels for Grand Forks, ND, 1988.

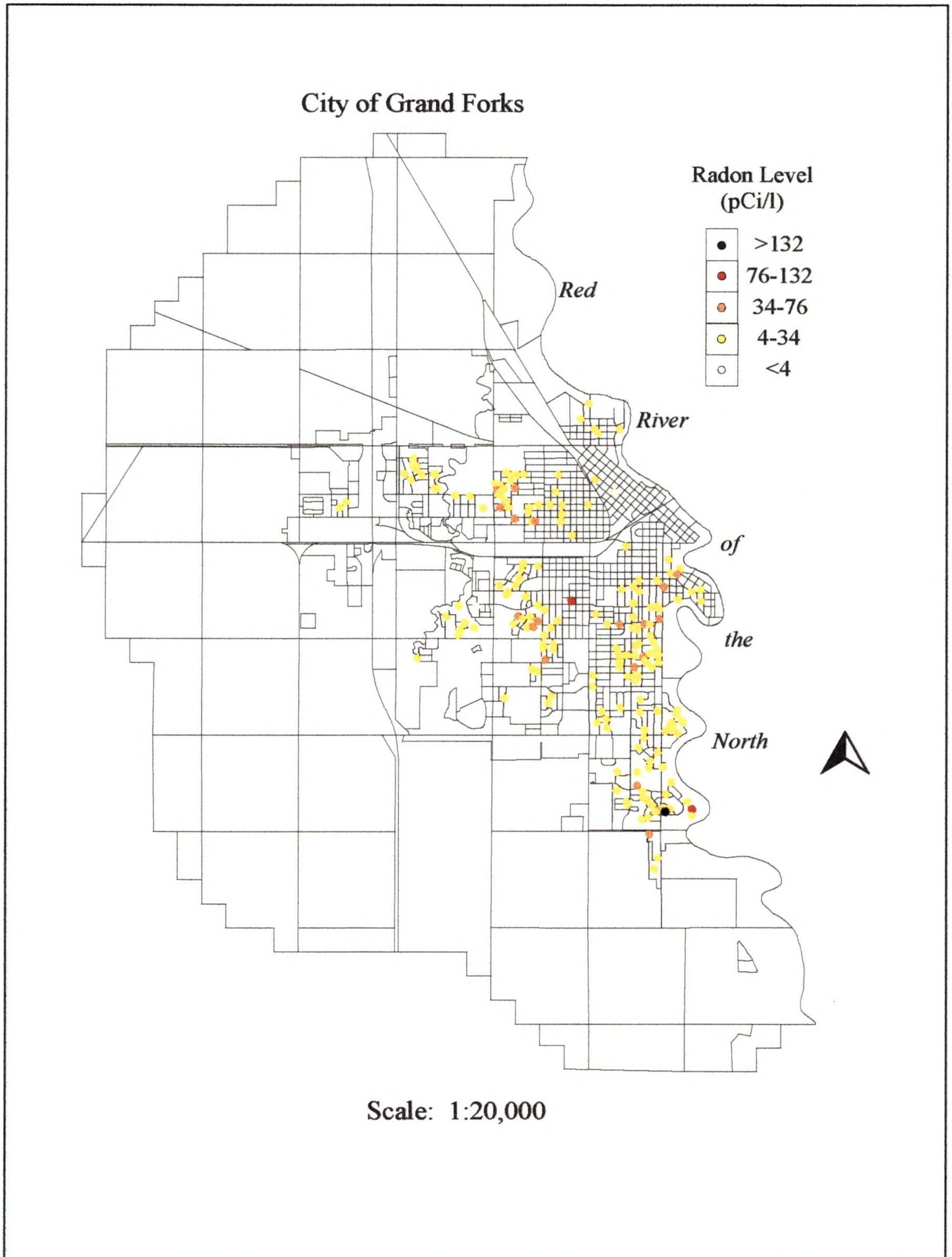

Figure 5. Indoor Radon Levels for Grand Forks, ND, 1989.

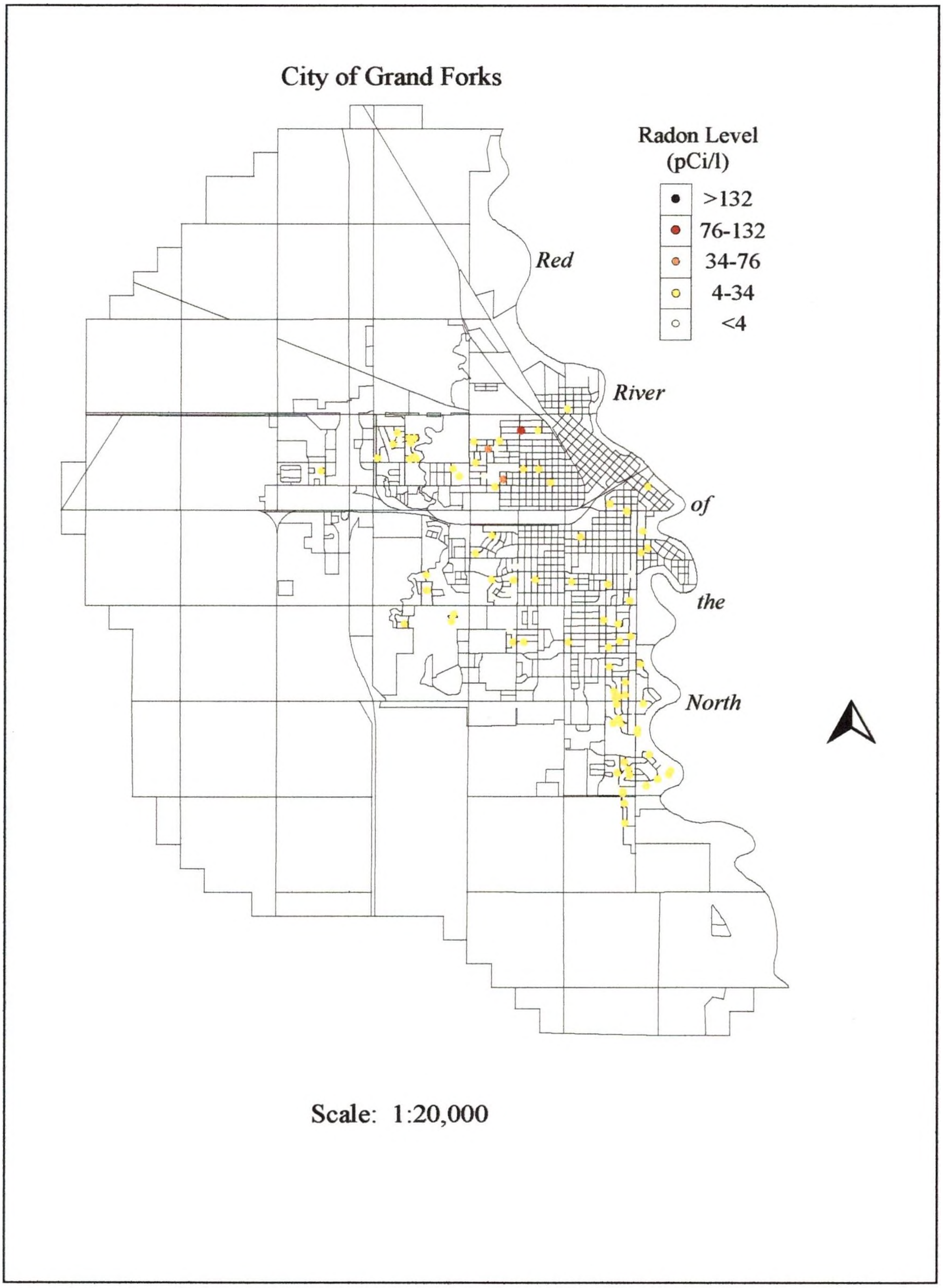

Figure 6. Indoor Radon Levels for Grand Forks, ND, 1990.

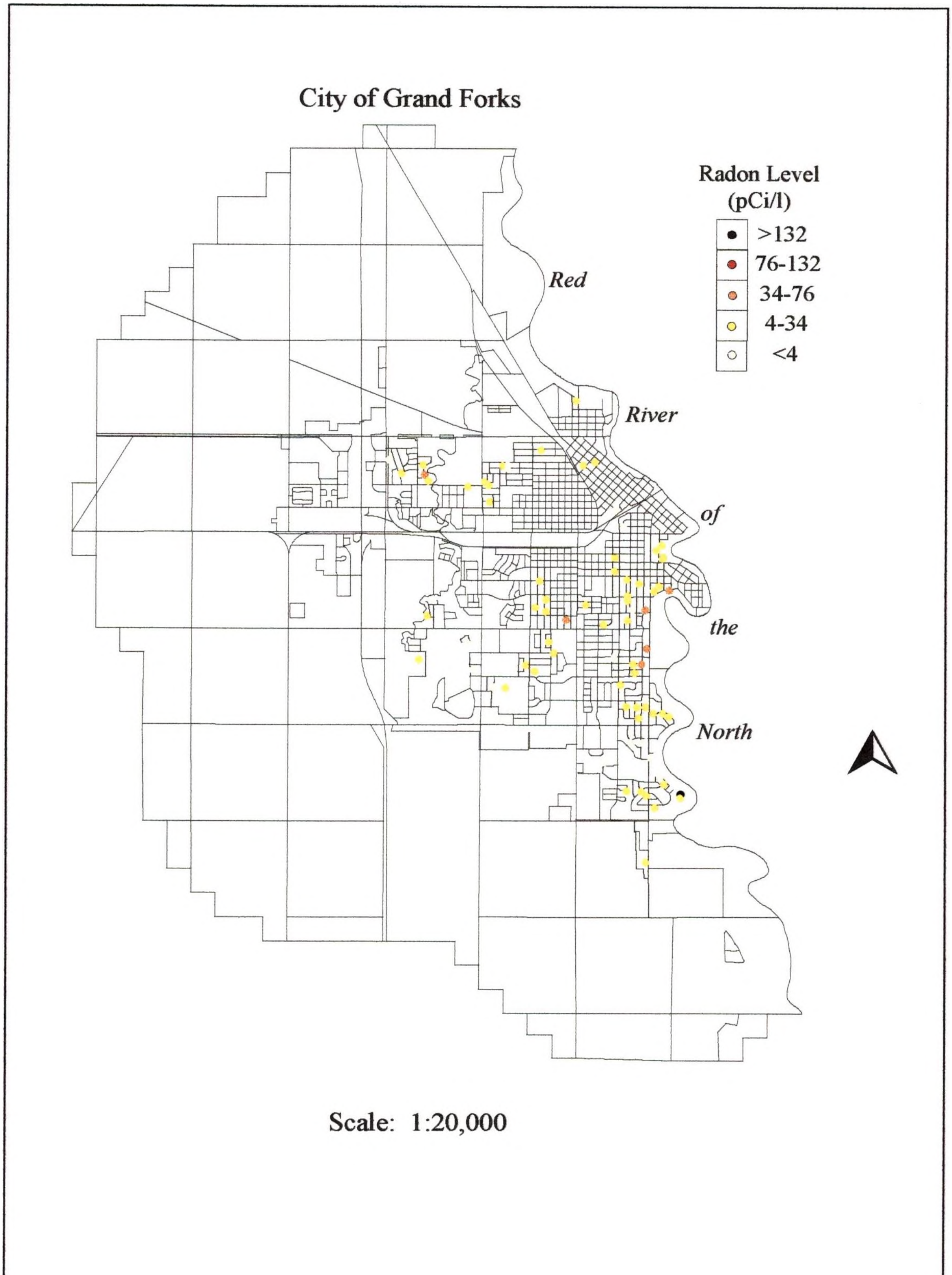

Figure 7. Indoor Radon Levels for Grand Forks, ND, 1991.

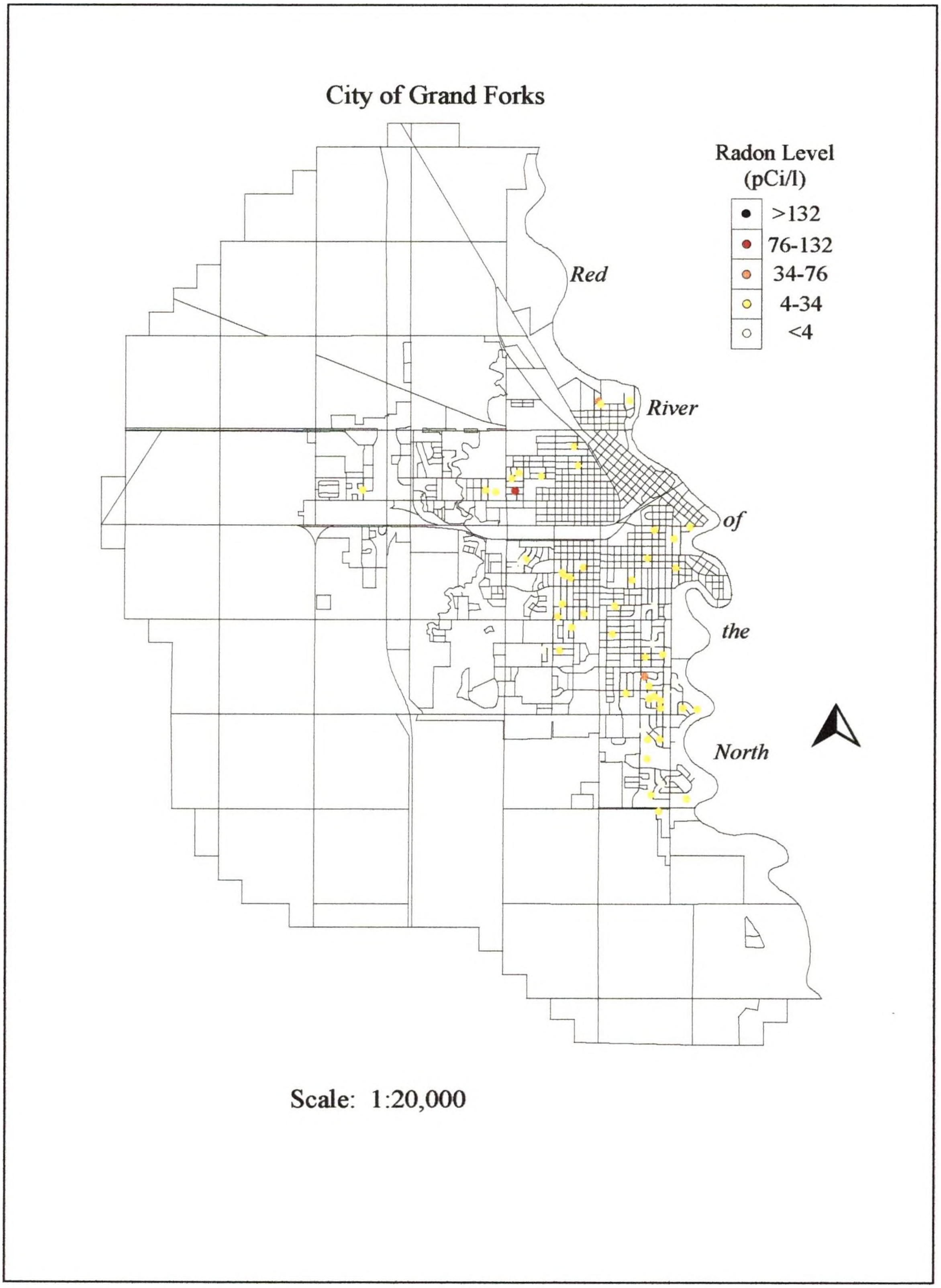

Figure 8. Indoor Radon Levels for Grand Forks, ND, 1992.

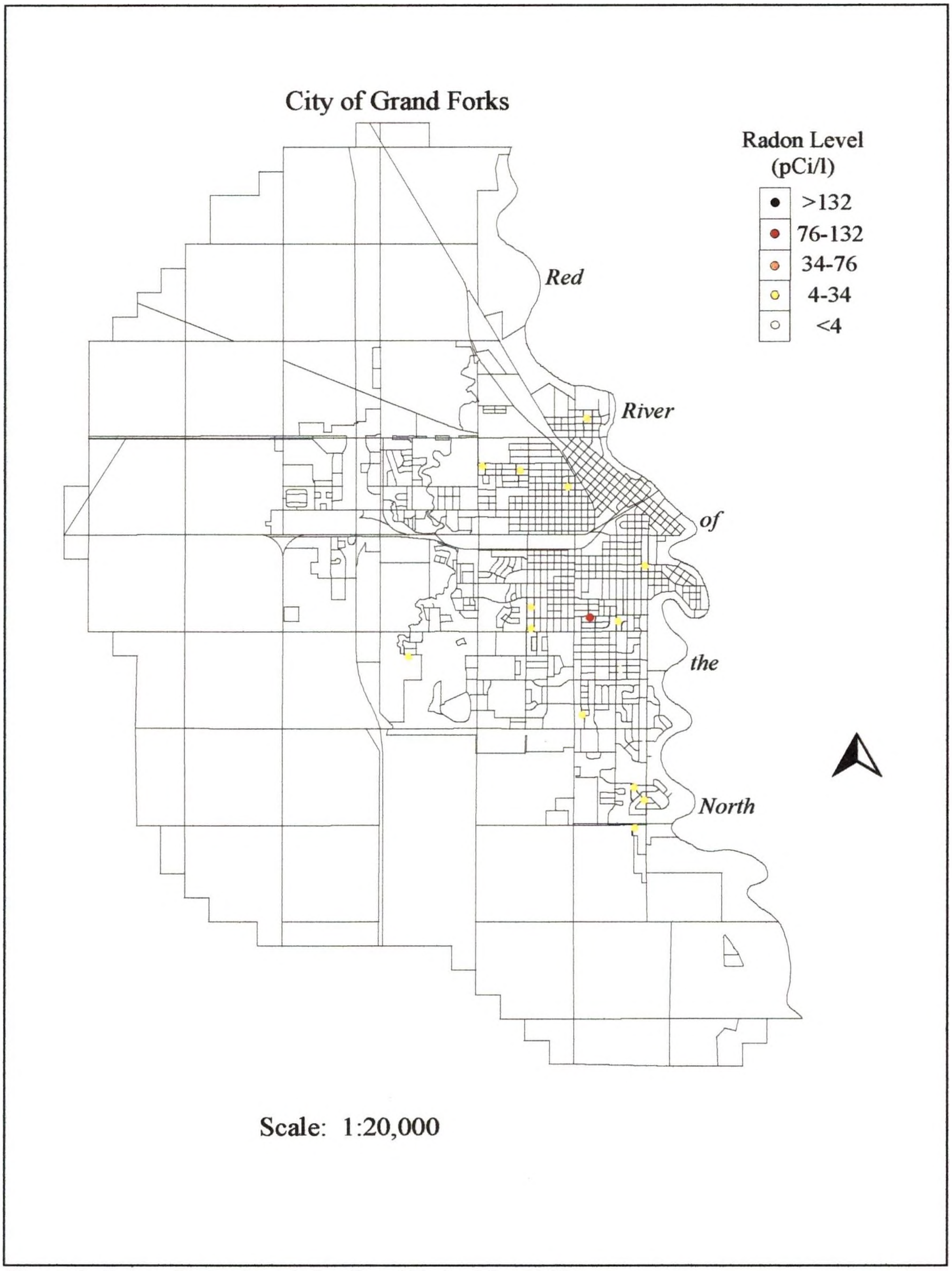

Figure 9. Indoor Radon Levels for Grand Forks, ND, 1993.

levels of indoor radon when tested one year was repaired to lower the radon concentration and then tested again. To help ascertain whether homes tested in more than one year used radon reduction methods after the first findings, a t-test was performed. The results of the analysis revealed a probability of .0028 and a t-score of -3.153, which showed a significant decrease in radon level after the first test for subsequent years tested. These findings indicate a strong possibility that homes tested in more than one year used some type of radon reduction methods. In addition, there was no way to determine whether or not a home had been tested and action taken to reduce radon levels prior to having been tested by the UND Radon Monitoring Facility.

To aid in revealing the spatial distribution of indoor radon levels, contour maps for the years 1988 to 1992 were created. The year 1993 was not included as a contour map, because of the small sample size for that year. Figures 10 through 14 display areas of low (<4 pCi/l), extremely high (>132 pCi/l), and indoor radon concentrations in between. Radon levels for 1988 ranged from 0 to >220 pCi/l, and the majority of samples collected ranged from 0 to 40 pCi/l. The contour map for 1989 showed the range of radon levels at 0 to 80 pCi/l. Most of the radon samples were in the higher (20 to >80 pCi/l) range. Radon levels for 1990 ranged from 0 to >70 pCi/l, and the majority of samples were above 5 pCi/l. The year 1991 had a wide range of radon levels, 0 to >170 pCi/l. The highest levels were concentrated along the eastern portion of the city. Radon levels for 1992 showed a distribution of 0 to >110 pCi/l. The majority of radon levels above 10 pCi/l occurred in the northern half of the city. Higher radon levels consistently occurred in the northeastern half of the city for each study year.

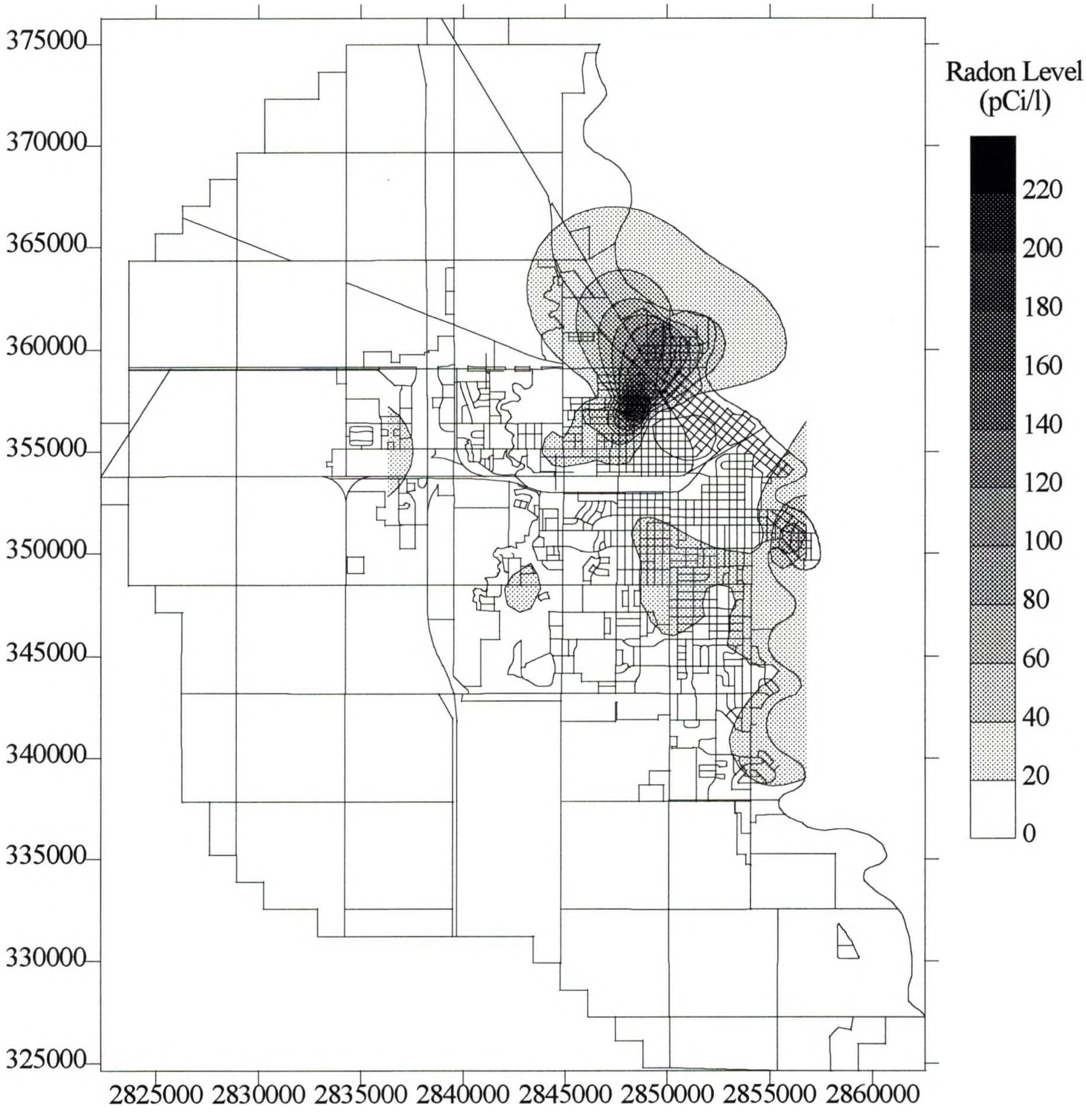

Figure 10. Radon Level Contour Map of Grand Forks, 1988.

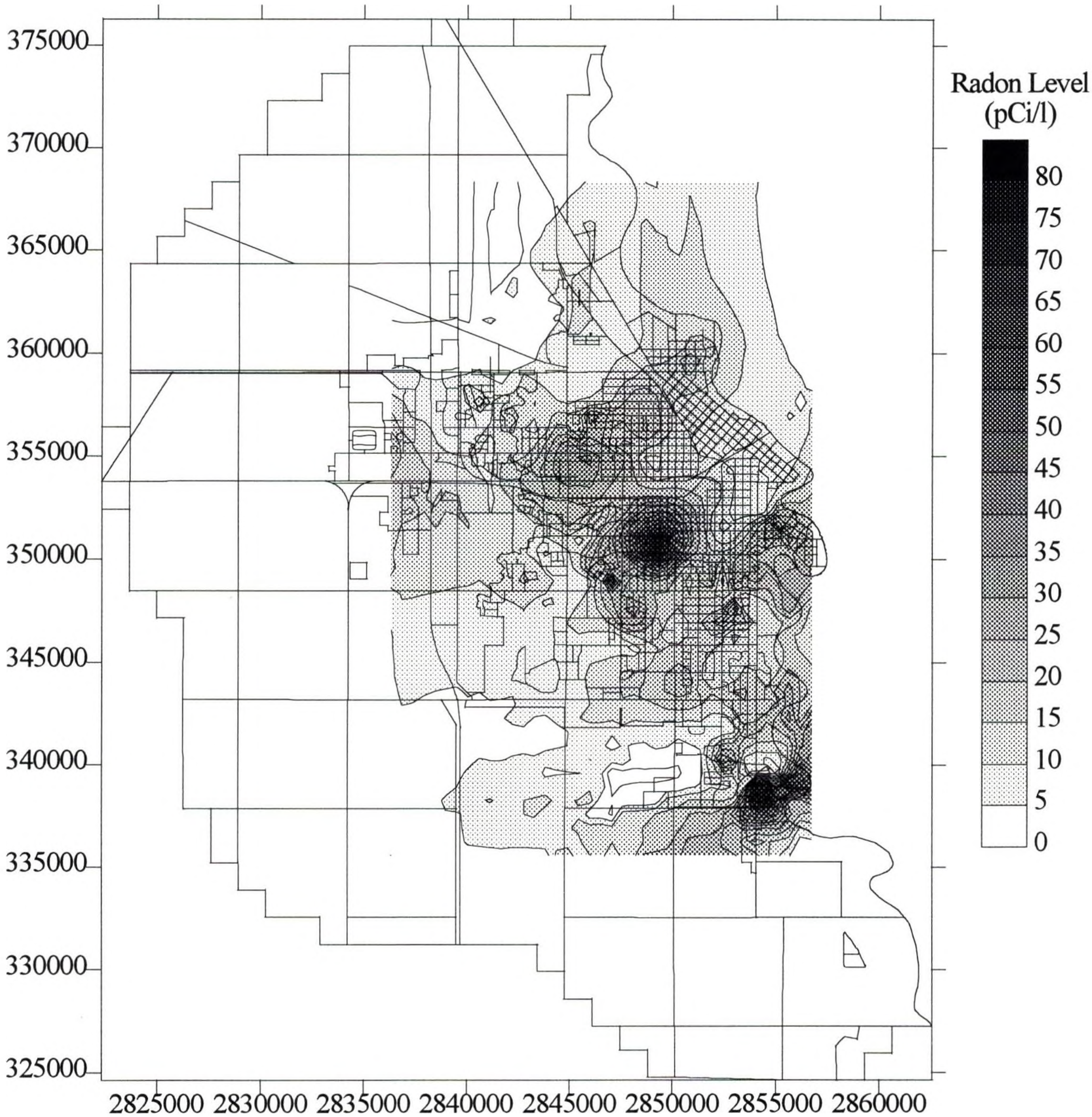

Figure 11. Radon Level Contour Map of Grand Forks, 1989.

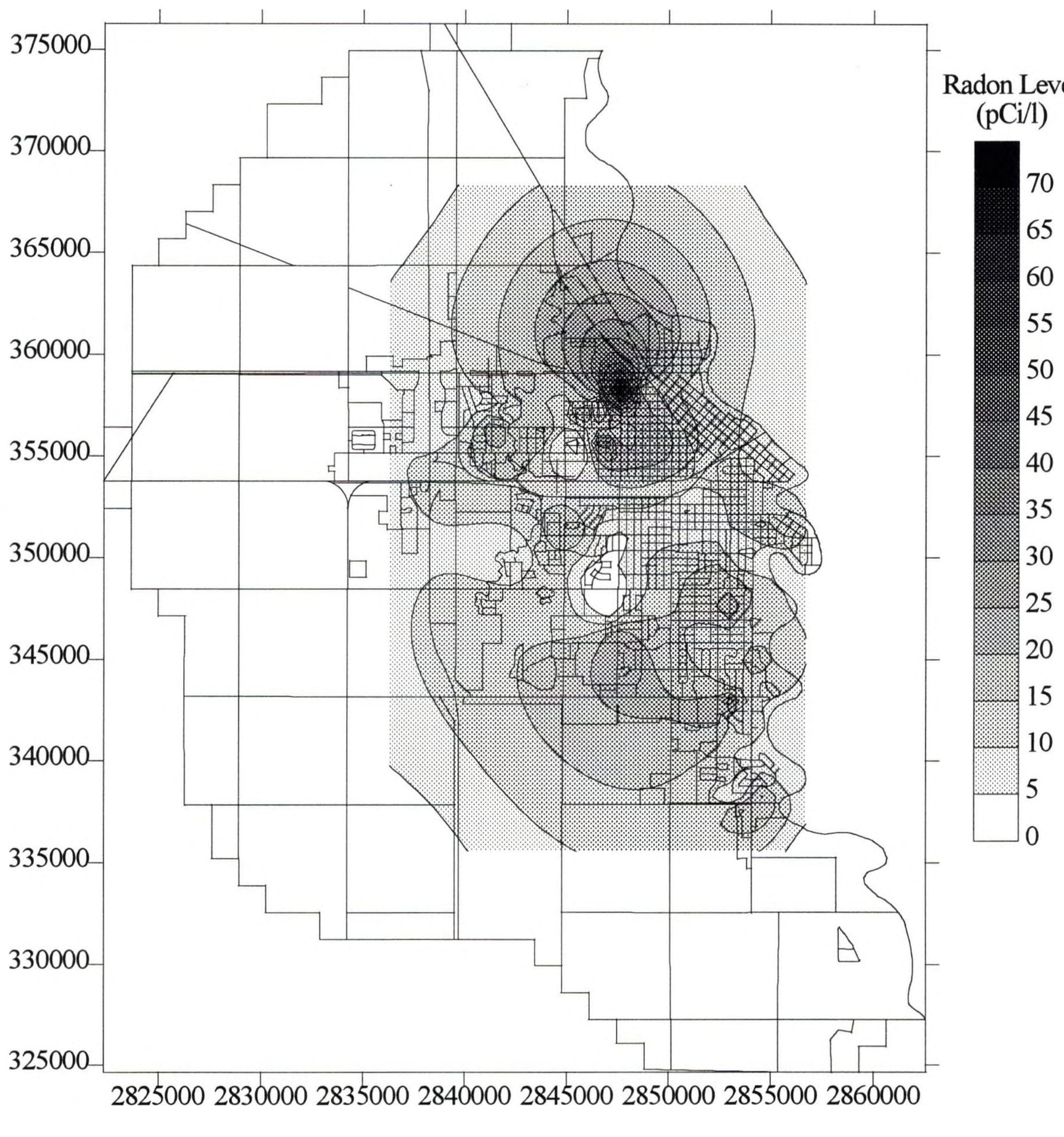

Figure 12. Radon Level Contour Map of Grand Forks, 1990.

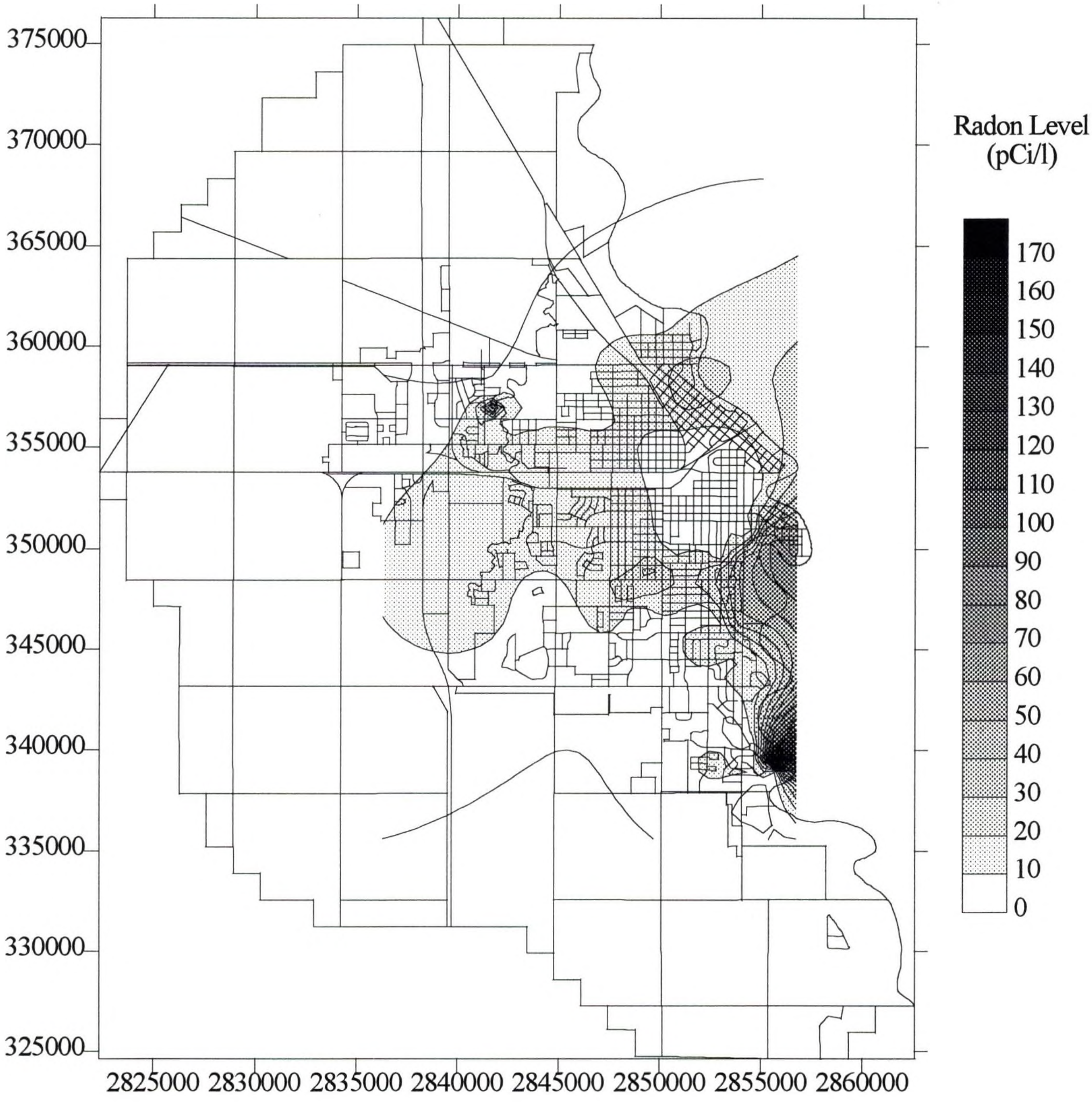

Figure 13. Radon Level Contour Map of Grand Forks, 1991.

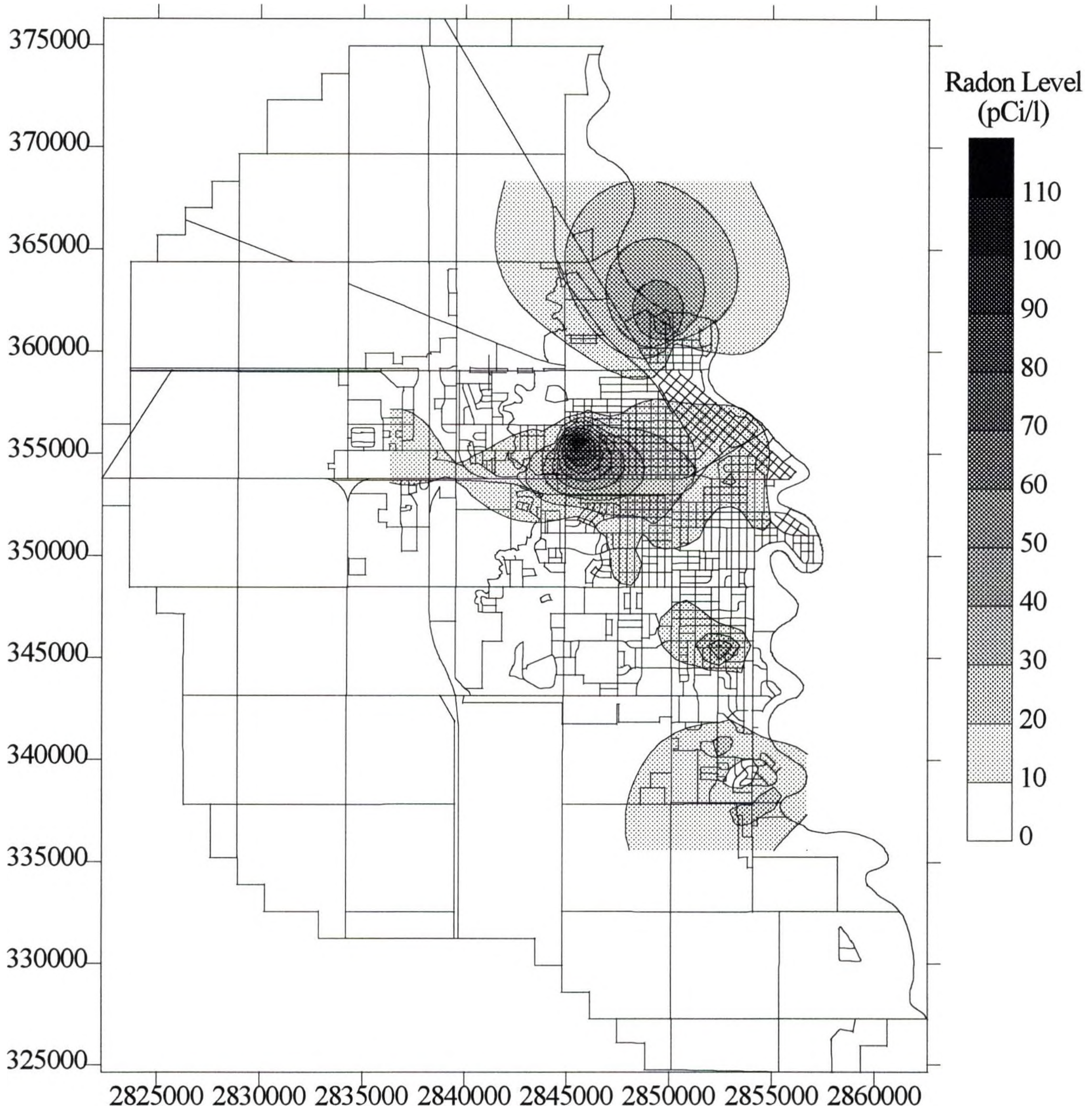

Figure 14. Radon Level Contour Map of Grand Forks, 1992.

CHAPTER V

SUMMARY

This study investigated the possible controls on indoor radon levels in Grand Forks. The results of the analysis indicated no significant relationship with any of the variables examined: soil permeability, distance to surface water bodies, and housing construction date. Soil permeability levels for Grand Forks are low, at less than 1.4 inches per hour, and the results of the regression analysis indicated no significant relationship between indoor radon level and soil permeability. This was not the expected outcome, as Grand Forks has high indoor radon concentrations, and studies revealed soils with low permeability yield low indoor radon concentrations. Distance to surface water bodies was expected to have the most significant relationship with indoor radon concentration, because of the regional and local groundwater flow, but proved to have no relationship at all with indoor radon concentration. House age was another factor investigated in this study, and it also showed no significant relationship with indoor radon concentration. Statistical analysis and visual examination of the data from this study suggest that none of these individual factors controls indoor radon concentration.

None of the variables investigated had a statistically significant impact on indoor radon levels. However, several alternative hypotheses could be formulated. The first concerns building materials. In several previous studies by Brookins (1988, 1990), Peake and Schumann (1991), and Lanctot et al. (1992), it was noted that building materials, such as woodframe homes and homes made of stone or brick, or even the degree of insulation in a home, can influence the concentration of indoor radon. Although house age was not found to correlate with indoor radon in Grand Forks, building materials may warrant further investigation.

A second possible control on indoor radon levels may be meteorological in nature. This was brought up in two of the studies that were reviewed. Both Mose et al. (1991), and Holloway (1993) found atmospheric pressure, temperature, and precipitation to have a strong influence on indoor radon concentrations. One suggestion for a future study is to compare meteorological records with indoor radon concentrations and the date the sample was collected with indoor radon concentrations.

Examination of bedrock (Bluemle, 1982) and surficial geology maps (scale: 1:1,000,000) revealed that both exhibited little variation throughout the study area. Tanner (1986) determined, however, that the type of bedrock in Grand Forks, containing mostly shale, limestone, and some sandstone play an important role in influencing high indoor radon levels. However, because of their homogeneous lack of spatial variability, no analysis was performed on bedrock and surficial geology for this study. The radon and uranium concentrations emitted from the bedrock and surficial geology may have little variation throughout the city, but further studies of radon levels emitted from bedrock at an appropriate scale (1:24,000) may reveal more variability than previously indicated. Core samples taken directly from the bedrock would give a more accurate representation of the distribution of radon concentrations in the bedrock.

Further studies are needed, because of the high occurrence of indoor radon levels in Grand Forks. The controls of indoor radon need to be determined. The mean reading of indoor radon concentrations in Grand Forks for the years studied was 18.9 pCi/l, well above the USEPA guidelines. Four hundred ninety-six homes were tested in Grand Forks through the years 1988 to 1993. It was determined that 93% of the homes tested for the first time by the UND Radon Monitoring Facility were above the USEPA guidelines of 4 pCi/l. There are a significant amount of homes in Grand Forks within the "danger zone". Once the major controls on indoor radon levels in Grand Forks have been determined, a prevention and/or reduction standard can be adopted to significantly reduce indoor radon concentration.

APPENDIX A

RADON LEVEL VS. SOIL PERMEABILITY FOR YEARS 1988 TO 1993

Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)
326.10	0.40	18.60	0.40	12.20	0.40	2.69	0.40
132.40	0.40	18.60	0.40	12.19	1.30	1.83	0.40
90.97	0.33	18.40	1.30	11.80	0.40	1.60	0.40
76.40	0.40	18.40	0.40	11.80	0.40	163.85	0.40
69.50	0.40	18.40	0.40	11.60	0.40	113.90	0.40
60.90	0.40	18.40	0.40	11.31	1.30	95.10	0.40
60.57	0.40	18.10	0.40	11.20	0.40	57.70	0.40
56.10	0.40	17.90	0.40	11.12	0.40	57.40	0.40
42.50	0.40	17.80	0.40	10.70	0.40	51.20	0.33
41.60	0.40	17.80	0.40	10.60	0.40	50.70	0.40
39.90	0.40	17.70	0.40	10.20	0.40	47.10	0.40
38.90	0.40	17.50	0.40	10.20	0.40	46.70	0.40
33.90	0.40	17.30	1.30	9.50	0.40	43.00	1.30
32.79	0.40	16.50	0.40	9.50	0.40	39.50	0.40
31.30	0.40	16.40	0.40	9.20	0.40	39.10	0.40
31.14	0.40	16.10	0.40	9.00	0.40	39.00	0.40
30.80	0.40	16.10	0.40	8.85	0.40	38.70	0.40
27.30	0.40	16.01	0.40	8.82	0.40	38.10	0.40
26.80	0.40	15.90	0.40	8.82	0.40	37.70	0.40
26.80	0.40	15.90	0.40	8.70	0.40	36.40	0.40
25.50	0.40	15.90	0.40	8.58	0.40	36.10	0.40
24.10	0.40	15.80	0.40	7.71	0.40	35.55	0.40
23.30	0.40	15.30	1.30	7.52	0.40	34.00	0.40
22.90	0.40	15.00	0.40	7.50	0.40	32.60	0.40
22.50	0.33	14.84	0.40	7.49	0.40	32.30	0.40
22.30	0.40	14.70	0.40	7.35	0.40	31.30	0.40
21.30	0.40	14.60	0.40	7.06	0.40	31.20	0.40
21.30	0.40	14.20	0.40	6.55	0.40	31.00	1.30
20.90	0.40	14.20	0.40	5.45	0.40	30.50	0.40
20.60	0.40	14.10	0.40	4.55	0.40	29.80	0.40

Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)
28.40	0.40	13.51	0.40	3.18	0.40	6.20	0.40
28.30	0.40	19.70	1.30	13.80	0.40	9.90	0.40
28.00	0.40	19.50	0.40	13.70	0.33	9.90	0.40
28.00	0.33	19.40	0.40	13.70	0.40	9.80	0.40
27.80	0.40	19.20	0.40	13.60	0.40	9.73	0.40
27.20	0.40	19.00	0.40	13.60	1.30	9.70	0.40
26.43	0.40	19.00	0.40	13.60	0.40	9.50	0.40
25.70	0.40	19.00	0.40	13.60	0.40	9.20	0.40
25.30	0.40	18.50	0.40	13.50	0.40	9.20	0.40
25.10	0.40	18.40	0.40	13.50	0.40	9.00	0.40
24.90	0.33	18.30	0.40	13.20	0.40	9.00	0.40
24.80	0.40	18.20	0.40	13.00	1.30	8.50	0.40
24.70	0.40	17.80	0.40	13.00	0.40	8.50	0.40
24.50	0.40	17.50	0.40	12.90	0.40	8.30	0.40
24.20	0.40	17.50	0.40	12.90	0.40	8.30	0.40
24.20	0.40	17.20	0.40	12.70	1.30	8.20	0.40
24.10	0.40	17.10	0.40	12.70	0.40	8.10	1.30
23.90	0.40	16.90	0.40	12.70	0.40	8.05	0.40
23.70	0.40	16.90	0.40	12.60	0.40	7.70	1.30
23.60	0.40	16.80	1.30	12.55	0.40	7.60	0.40
23.50	0.40	16.60	0.40	12.40	0.40	7.50	0.40
23.40	0.40	16.60	0.40	12.10	0.40	7.30	0.40
23.40	0.40	16.50	0.40	12.00	0.40	7.10	0.40
23.30	0.40	16.40	0.40	12.00	0.40	6.90	0.40
23.10	1.30	16.40	0.40	11.90	0.40	6.90	0.40
22.70	0.33	16.30	0.40	11.80	0.40	6.90	0.40
22.60	0.33	16.23	0.40	11.80	0.40	6.80	0.40
22.50	0.40	15.90	0.40	11.65	0.40	6.80	0.40
22.50	0.33	15.90	0.40	11.50	0.40	6.70	0.40
22.30	0.40	15.80	0.40	11.30	0.40	6.30	0.40
22.00	1.30	15.70	0.40	11.10	0.40	6.30	0.40
22.00	0.40	15.60	0.40	11.00	0.40	5.40	0.40
21.90	0.40	15.40	0.40	10.90	0.40	5.10	0.40
21.85	0.40	15.40	0.40	10.80	0.40	5.10	0.40
21.80	0.40	15.20	0.40	10.70	0.40	5.00	0.40
21.70	0.40	15.00	0.40	10.50	0.40	4.90	0.40
20.30	0.40	14.60	0.40	10.50	0.40	4.80	1.30

Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)	Radon (pCi/l)	Permeability (Inches/Hr)
10.20	1.30	3.90	0.40	19.70	0.40	14.00	0.40
27.10	0.40	11.00	0.40	68.20	0.40	17.90	0.40
80.80	0.40	10.90	0.40	15.30	0.40	36.40	0.40
43.20	0.40	10.70	0.40	7.70	0.40	31.50	0.40
35.80	0.40	10.45	0.40	10.30	0.40	4.95	0.40
30.90	0.40	10.10	0.40	7.60	0.40	20.40	0.40
30.70	0.40	10.10	0.40	8.10	0.40	10.20	0.40
25.60	0.40	10.05	0.40	12.58	0.33	8.00	0.40
24.70	0.40	9.50	0.40	17.80	0.40	27.60	0.40
23.00	0.40	9.40	0.40	17.00	0.40	2.60	0.40
23.00	0.40	9.40	0.40	0.40	0.40	10.85	0.40
22.30	0.40	9.00	0.40	21.80	0.40	48.00	0.40
21.60	0.40	8.80	0.40	4.90	0.40	5.80	0.40
20.30	0.40	8.50	0.40	12.40	0.40	13.40	0.40
20.20	0.40	8.10	0.40	8.70	1.30	3.60	0.40
18.95	0.40	8.00	0.40	7.40	0.40	7.20	0.40
18.90	0.40	7.60	0.40	12.30	0.40	15.30	0.40
18.90	0.40	7.40	1.30	4.35	0.40	50.13	0.40
18.50	0.40	7.20	1.30	12.70	0.40	2.90	0.40
16.90	0.40	7.10	0.40	3.30	0.40	10.10	0.40
16.80	0.40	6.90	0.40	20.10	0.40	12.00	0.40
15.70	0.40	6.90	0.40	2.70	0.40	24.50	0.40
15.60	0.40	6.87	0.40	11.00	0.40	56.30	0.40
15.20	0.40	6.50	0.40	18.10	0.40	0.50	0.40
15.10	0.40	6.40	0.40	19.20	0.40	5.80	0.40
15.10	0.40	6.20	0.40	8.00	0.40	3.50	0.40
14.90	0.40	5.10	0.40	4.50	0.40	8.60	0.40
14.60	0.40	4.30	0.40	8.90	0.40	4.50	0.40
14.40	0.40	4.10	0.40	2.10	0.40	15.90	0.40
14.40	0.40	3.50	0.40	70.84	1.30	8.75	0.40
14.30	0.40	1.80	0.40	8.10	0.40	3.20	0.40
14.10	0.40	1.30	0.40	5.90	0.40	9.30	0.40
14.00	0.40	19.00	0.40	8.30	0.40	7.20	0.40
13.20	0.40	31.60	0.40	9.30	0.40	20.80	0.40
13.10	0.40	10.80	0.40	11.90	0.40	11.70	0.40
13.00	0.40	12.70	0.40	7.60	0.40	6.00	0.40
12.85	0.40	2.45	0.40	18.50	0.40	4.80	0.33

Radon (pCi/l)	Permeability (Inches/Hr)
3.60	0.40
19.50	0.40
6.00	0.40
17.00	0.40
6.30	0.40
16.30	0.40
14.90	1.30
8.63	0.40
4.00	0.40
23.80	1.30
23.10	0.40
7.60	0.40
19.00	0.40
11.10	0.40
6.10	0.40
6.50	0.40
13.40	0.40
11.85	0.40
50.00	1.30
15.10	0.40
3.80	0.40
4.10	0.40
14.30	0.40
11.80	0.40
26.40	0.40
19.20	0.40
13.60	0.40
3.53	0.40
28.40	0.40
19.80	0.40
14.60	0.40
19.70	0.40
10.30	0.40
10.30	0.40
4.60	0.40
8.20	0.40

Radon (pCi/l)	Permeability (Inches/Hr)
20.50	0.40
20.20	0.40
19.60	0.40
19.20	1.30
20.10	0.40
29.30	0.40
29.20	0.40
29.10	0.40
28.60	0.40
4.80	0.40
14.00	0.40
13.91	0.40
13.90	0.40
13.65	0.40
14.60	0.40
4.30	0.40
4.30	0.40
4.00	0.40
3.75	0.40
10.40	0.40
11.90	0.40
16.60	1.30
1.50	0.40
2.90	0.40
0.50	0.40

APPENDIX B

RADON LEVEL VS. DISTANCE TO SURFACE WATER BODIES FOR YEARS 1988-1993

Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)
31.6	1229.8	18.1	7000.2	8.3	3377.7	18.4	1678.1	6	825.79
10.3	1995.6	4.5	6475.6	17.5	3428.2	21.3	6552.8	6.4	672
12.7	1899.9	9.5	6417.5	22.3	3299.6	16.8	1488	3.6	683.7
13.65	3164.7	23.1	6558.6	28.4	3317.8	12.2	2582.7	7.5	1222.5
13.4	3417.6	18.6	6544.6	18.95	3115.2	10.3	2626.3	10.9	828.54
9.4	1715.5	8.3	6548	17.8	3170.8	15.9	1840.8	16.4	1658.3
13.91	1247.5	4.95	5767.8	3.6	2971.6	10.1	1862.6	28	1388.6
12.4	1058.4	22.9	6250.3	18.4	2755.8	21.8	2221.2	163.9	1467.7
6.3	826.52	15.1	1715.1	13.5	2691.3	3.75	2424.9	11	696.61
13.1	861.64	11.85	1477.3	22.3	2753.5	17.1	3208.2	4	1222.5
24.7	3695	8.82	1678.9	34	2548.3	11.8	3528	113.9	697.38
326.1	3874.7	15.4	1737.3	10.2	2527.6	19.6	927.41	7.2	696.01
26.43	4228.1	68.2	2096.9	16.5	2374.4	8.5	1721.7	14.9	774.2
7.1	519.03	13.6	2214.5	6.9	2186.9	9.9	1730.1	237.9	748.68
11	2386.6	22.5	2330.1	9.4	2391.8	48	1580.1	7.4	713.13
8.7	599.69	30.7	2240.3	12.9	2331	13.8	1445	9.2	376.31
12.3	661.62	11.31	1889	16.8	1876.6	16.6	1803.3	21.6	931.81
6.3	2024.9	20.9	1950.1	50.13	1446	13.6	1774.2	23.8	635.46
7.6	2546.8	13.2	2472	12	1684.2	31.14	1537.4	17.3	2328.8
6.6	1456.3	13.6	714.39	6.5	1367.1	30.8	1624.1	18.2	2165
61.7	1279.7	57.4	7008.2	12.1	3855.2	3.2	2182.4	26.4	2254.2
7.3	935.6	24.2	6722.5	6.2	4020.6	28.6	1968	51.2	2345.1
132.4	1001.2	19.7	6854.9	15	4974.9	11.3	2112.2	12.19	2356.6
9	1525.9	0.5	6994.6	2.6	5052.6	7.1	2139.9	16.6	2042
42.5	604.95	19.5	6675.4	17.7	5090.9	50.7	2309.7	6.9	2102.2
12.9	3172.9	27.8	6912.8	18.9	4881.7	20.2	2443.1	8.5	2092.6
7.6	3015.7	6.2	7008.5	2.9	6406.2	12.4	2468.1	3.5	2513.7
9.8	4988	37.7	7142.3	13	5024.9	4.3	2494.8	8.85	2500.4

Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)
16.1	4533.3	1.1	6953.5	16.23	1155.8	23	2042.9	10.2	6343.5
27.2	4275.3	5.8	8359.8	14	1203.9	28.4	2548.3	33.9	4666.2
25.6	4117.4	9.2	7903.5	24.5	845.52	14	2381.1	10.6	4488
11.9	7143.3	0.5	7843.6	16.3	605.54	11.9	4847.9	8.1	4387.3
18.5	7145.9	13.51	3206.2	6	924.6	8.8	4836	23	4420.2
32.3	7273.4	14.4	3746	14.6	1167.8	43.2	6104.6	8.1	3988.6
10.2	7241.6	6.9	3719.7	5.1	1231.7	31	6058.9	19	3924.3
12.55	7366.3	13.4	4040.9	7.2	1127.3	18.5	5916.2	9.9	3313.2
24.8	6947.9	15.3	4447.9	11.7	811.46	31.3	6090.3	17.8	4158
6.8	4572.6	31.3	6163.4	20.8	1454.4	46.7	2035	19.2	6387.2
19.2	6853.2	41.6	1878	23.7	862.01	17	5565.4	9.7	1183.8
8.3	4646.6	9.3	2069.3	23.3	2305.8	14.1	2534.7	11.2	1023.5
10.85	4492.1	12.7	2411.4	31.5	2179.4	9.3	2485.6	8.1	1019.5
15.7	3710.7	17.5	4601.9	5	2520.7	8.75	2483.7	1.8	1122.1
30.5	3654.4	15.3	4648.1	38.9	2554.8	9.73	2312.1	10.45	768.02
12.7	3576.3	23.4	4674	11.12	2523.2	16.4	2276.5	1.83	926.8
4.8	480.35	28.6	4679.2	16.6	2416.3	15.9	2171	6.7	265.71
19.8	4419.2	22	4267.7	0.4	2544.5	15.7	2307.8	10.7	697.69
7.6	4354.2	7.49	3237.3	12.58	2033.4	24.2	2133	23.6	764.86
19.7	1417.9	19.2	740.25	24.9	2495.6	4.5	3561.6	28.3	611.88
13.7	1574.8	9.5	979.96	10.05	2230.6	15.6	4152.3	24.1	488.87
128	5708.4	7.4	3173.4	15.2	2091.1	19.7	4065.1	19.2	428.32
35.55	5579	4.1	4322.6	27.3	2482.8	10.1	811.36	6.1	1067.4
20.6	6023.6	4.35	2678.7	11.9	2869.9	11.8	2103.6	5.1	962.89
20.6	6023.6	14.6	3224	4.9	551.91	21.3	1067.8	7.52	380.9
17.9	2511.5	4	2733.8	16.01	4648.3	20.1	1019.4	4.55	718.26
20.4	3531.9	3.9	1691.6	8	5489.6	3.8	1179.5	1.4	266.47
39	3183.3	7.1	2893.8	13.6	5514.7	9.4	1777.2	5.4	545.82
23.9	470.53	13	2519.1	2.45	5731.5	8.2	1371.6	6.87	817.86
38.1	1374.4	5.1	2451.7	17.2	5803.2	25.1	1370	20.1	5918.7
16.9	1363.1	12.6	3646.8	10.5	5753.8	9	1619.5	95.1	5812.9
8.1	760.38	22	3534.6	11	5316.8	13.7	1504.9	29.2	7511.2
2.1	784.83	8.5	3580.3	11.1	4918.4	16.5	1982.8	21.8	7525.2
8	769.7	26.8	3627.1	10.8	4938.7	20.2	2054.6	17.8	7543.6
9	710.9	60.9	3911.9	18.3	5690.5	0.5	2334.8	15.8	7559.7
15.1	1199.1	15	3555.3	1.5	5799.6	7.3	3270	43	7405.9

Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)	Radon (pCi/l)	Distance (Feet)
21.85	351.71	4.3	2853.6	35.8	5794.5	17	2652.8	18.6	5778.2
70.84	258.82	7.5	4257.6	6.5	4939.7	9.5	2194.9	23.1	2032.8
9	763.68	12	4153.9	56.1	5956.6	14.3	2352.7	14.84	7422.6
90.97	400.98	4.1	6902.7	47.1	6048.1	12	2209.6	16.8	3241.8
29.3	646.96	15.9	6511.7	15.3	5581.6	21.7	2255.9	3.18	5723
22.5	309.22	16.9	7104.2	8.82	5153.2	6.9	2003.4	17.5	3349.3
10.8	2317.7	7.71	3691.6	6.55	5184	19.5	1946.8	6.8	1009.6
14.2	2250	23.5	919.88	19	5201.8	6.3	2001.3	39.9	6191.4
22.5	2446	3.5	751.85	13.5	5481.5	38.7	1893.6	10.7	2669.1
15.4	3246.4	18.9	702.44	16.1	4917.3	4.3	2048.3	11.8	717.42
8.9	3110.5	18.4	521.73	39.1	5118.8	29.8	1909.2	4.8	5097.7
11.6	999.27	13	1690.2	7.7	5100.1	14.4	2083.6	7.7	5175.7
14.6	958.93	18.5	1646.1	4.9	5369.9	22.7	2184.3	80.8	4219.3
36.4	980.11	60.57	397.97	10.3	5521.3	10.4	2186	19	6316.8
50	1107.7	25.7	1418	14.6	1852.5	14.3	2649.2	1.3	6220.7
16.9	1104.5	11.65	1672.2	11.2	1988.1	8.63	2550.1	4.6	5952.9
29.1	1444.4	20.6	1344.5	14	2004.4	8.05	2508.3	39.5	6014.6
2.9	1798.9	15.3	591.18	15.2	1901.3	16.3	1937.3	13.9	3170.8
15.9	1808.1	76.4	1147.6	17.8	1995.8	8.2	617.54	14.7	4615.8
5.9	2090	23.3	2265.1	14.1	2610.1	32.79	806.03	24.7	4035.6
13.2	1552.2	18.1	3955.4	69.5	1847.4	6.9	7723.5	15.9	3622.8
25.5	5467	14.6	6807.5	28	840.24	1.1	7927.8	15.9	4907.8
7.35	5362.7	25.3	6002.3	11.5	5396.9	15.8	8007.8	13.6	7585
7.6	5311.3	19.4	5896.2	7.06	3120.5	13.7	8011.3	20.3	6171.3
1.6	5244.5	16.4	5744.5	31.2	7016	5.45	3362.7	36.1	6000.5
24.1	5815.4	12.7	5423.9	27.6	6661.7	15.6	1435.8	5.8	6270
23.4	5763.1	8.58	5572.8	8	6595.2	57.7	804	3.53	2130
24.5	2451.5	10.9	5590.3	20.5	6385.4	10.2	2813.4	36.4	5511.2
10.7	2394.7	11.8	4916.4	9.5	7126.3	1.3	5767.9	30.9	2098.2
56.3	2335.1	21.9	4675	8.7	7261	4.8	3485.9	19	1979.8
12.7	2062	2.7	4850.9	7.2	7158.7	22.6	6954.1	12.85	6420.6
18.4	1494.6	3.3	5160.1	20.3	7097.2	18.4	3589.6		
26.8	1475	11.1	5556.4	14.2	7029.8	15.1	6924		
8.6	2202	32.6	1717.3	9.2	7138.7	22.3	7701.3		
17.9	3257.9	14.9	3288.3	10.1	7172.6	10.5	4869.8		
11.8	3251.9	19	3849.6	2.69	7801.4	7.6	5839.3		

APPENDIX C

RADON LEVEL VS. YEAR HOUSE WAS BUILT FOR YEARS 1988 TO 1993

Radon (pCi/l)	Year	Radon (pCi/l)	Year	Radon (pCi/l)	Year	Radon (pCi/l)	Year	Radon (pCi/l)	Year
31.6	1902	27.2	1963	27.8	1976	34	1957	19.8	1956
10.3	1909	25.6	1930	6.2	1978	10.2	1957	7.6	1958
12.7	1908	11.9	1963	37.7	1975	16.5	1958	19.7	1958
13.65	1951	18.5	1962	19	1978	6.9	1957	13.7	1955
13.4	1950	32.3	1963	1.3	1977	9.4	1957	18.4	1971
9.4	1930	10.2	1963	4.6	1987	12.9	1957	21.3	1959
13.91	1923	12.55	1967	39.5	1980	16.8	1957	16.8	1913
12.4	1913	24.8	1962	7.6	1977	50.13	1955	12.2	1906
6.3	1920	15.1	1961	31.3	1986	12	1957	10.3	1922
13.1	1890	19.2	1966	1.1	1987	6.5	1957	15.9	1922
24.7	1957	18.1	1962	5.8	1987	12.1	1957	10.1	1893
326.1	1953	4.5	1974	9.2	1984	6.2	1955	21.8	1890
26.43	1952	9.5	1965	0.5	1984	15	1984	3.75	1898
7.1	1925	23.1	1968	13.51	1985	2.6	1986	17.1	1937
11	1888	18.6	1963	14.4	1987	17.7	1985	11.8	1939
8.7	1929	8.3	1963	6.9	1986	18.9	1985	19.6	1938
12.3	1922	4.95	1958	13.4	1991	2.9	1989	8.5	1951
6.3	1975	22.9	1972	15.3	1994	13	1989	9.9	1958
7.6	1973	15.1	1962	69.5	1955	20.3	1949	48	1955
6.6	1947	11.85	1961	41.6	1954	36.1	1947	13.8	1953
61.7	1948	8.82	1962	8.3	1964	5.8	1985	16.6	1955
7.3	1962	15.4	1963	10.85	1956	3.53	1891	13.6	1954
132.4	1946	68.2	1962	15.7	1961	20.8	1968	31.14	1954
9	1948	13.6	1961	30.5	1958	16.23	1969	30.8	1954
42.5	1890	22.5	1962	12.7	1959	14	1965	3.2	1959
12.9	1923	30.7	1962	8.3	1958	24.5	1968	28.6	1956
7.6	1904	11.31	1967	17.5	1957	16.3	1969	11.3	1954
9.8	1948	20.9	1966	22.3	1958	6	1967	7.1	1956
14.7	1923	13.2	1963	28.4	1958	14.6	1966	50.7	1965

Radon (pCi/l)	Year
7.7	1977
14.2	1929
22.5	1938
15.4	1936
8.9	1954
11.6	1938
14.6	1883
36.4	1940
50	1934
16.9	1937
29.1	1935
2.9	1935
15.9	1930
5.9	1928
9.3	1927
12.7	1946
17.5	1965
15.3	1969
23.4	1969
28.6	1969
22	1974
19.2	1984
9.5	1904
7.4	1926
4.1	1928
4.35	1915
14.6	1929
4	1910
3.9	1913
7.1	1977
13	1977
5.1	1988
12.6	1976
22	1976
8.5	1977
26.8	1978
16.4	1966

Radon (pCi/l)	Year
15	1976
17.5	1977
10.2	1978
4.3	1978
7.5	1977
12	1985
4.1	1977
15.9	1978
16.9	1987
7.71	0
23.5	1955
3.5	1963
18.9	1963
18.4	1966
13	1907
18.5	1924
60.57	1937
25.7	1927
11.65	1918
20.6	1920
15.3	1941
76.4	1941
23.3	1956
23.3	1956
31.5	1948
5	1950
38.9	1950
11.12	1952
16.6	1957
0.4	1975
12.58	1976
24.9	1977
10.05	1978
15.2	1979
27.3	1977
11.9	1975
22.3	1956

Radon (pCi/l)	Year
8	1955
13.6	1955
2.45	1954
17.2	1954
10.5	1957
11	1955
11.1	1954
10.8	1963
18.3	1957
1.5	1955
3.18	1960
1.3	1954
35.8	1910
6.5	1899
56.1	1954
47.1	1954
15.3	1958
8.82	1956
6.55	1955
19	1957
13.5	1952
16.1	1959
39.1	1954
7.7	1914
4.9	1953
10.3	1955
14.6	1964
11.2	1963
14	1964
15.2	1964
17.8	1963
14.1	1968
14.1	1965
9.3	1963
8.75	1961
9.73	1961
19.5	1976

Radon (pCi/l)	Year
15.7	1968
24.2	1963
4.5	1969
15.6	1969
19.7	1969
10.1	1966
11.8	1971
21.3	1971
20.1	1972
3.8	1974
9.4	1971
8.2	1969
25.1	1969
9	1975
13.7	1975
16.5	1975
20.2	1975
0.5	1975
7.3	1977
16.8	1976
17	1986
9.5	1988
14.3	1977
12	1977
21.7	1976
6.9	1978
19.5	1976
6.3	1977
38.7	1979
4.3	1978
29.8	1985
14.4	1979
22.7	1979
10.4	1988
14.3	1986
8.63	1987
10.8	1918

Radon (pCi/l)	Year
4.8	1978
23.1	1969
46.7	1971
23	1969
28.4	1970
14	1972
11.9	1962
8.8	1945
43.2	1948
31	1919
18.5	1950
31.3	1963
11.5	1951
17	1950
128	1952
35.55	1949
20.6	1924
20.6	1924
17.9	1984
20.4	1954
39	1949
23.9	1935
38.1	1911
16.9	1930
8.1	1925
2.1	1922
8	1926
9	1927
15.1	1916
6.8	1909
57.7	1922
21.85	1893
70.84	1931
9	1948
90.97	1954
29.3	1940
22.5	1933

Radon (pCi/l)	Year
23	1940
8.1	1957
19	1959
9.9	1958
17.8	1940
7.06	1914
9.7	1968
11.2	1969
8.1	1969
1.8	1969
10.45	1972
1.83	1973
6.7	1972
10.7	1969
23.6	1969
28.3	1972
24.1	1972
19.2	1972
6.1	1974
5.1	1974
7.52	1972
4.55	1973
6.87	1964
20.1	1961
95.1	1958
29.2	1969
21.8	1970
17.8	1972
15.8	1972
43	1970
14.84	1969
22.6	1969
31.2	1969
27.6	1963
8	1963
18.4	1965

Radon (pCi/l)	Year
9.5	1970
8.7	1970
7.2	1972
20.3	1976
14.2	1978
9.2	1978
10.1	1978
2.69	1985
13.6	1974
22.3	1976
6.9	1974
1.1	1973
15.8	1977
13.7	1974
5.45	1970
15.6	1950
32.6	1952
13.2	1952
14.9	1956
19	1955
80.8	1951
25.5	1950
7.35	1951
7.6	1948
1.6	1950
24.1	1948
23.4	1949
24.5	1961
10.7	1962
56.3	1963
12.7	1963
18.4	1960
26.8	1959
8.6	1962
17.9	1959
11.8	1964

Radon (pCi/l)	Year
25.3	1966
19.4	1966
16.4	1970
12.7	1974
8.58	1975
10.9	1974
11.8	1975
21.9	1972
2.7	1973
3.3	1972
11.1	1974
16.3	1978
8.2	1984
14.9	1984
237.9	1985
7.4	1985
9.2	1984
21.6	1989
23.8	1988
17.3	1980
18.2	1979
26.4	1985
51.2	1986
12.19	1977
16.6	1977
6.9	1988
8.5	1988
3.5	1985
8.85	1985
36.4	1964
30.9	1975
19	1974
12.85	1941
39.9	1934
19.2	1951
10.2	1949

Radon (pCi/l)	Year
6	1977
6.4	1987
3.6	1989
7.5	1976
10.9	1983
113.9	1981
7.2	1990
28	1978
11	1985
4	1989
16.1	1964
60.9	1976
8.1	1927
16.01	1955
20.5	1964
15.9	1965
6.8	1937
0.5	1976
13.5	1955
23.7	1970
11.8	1979
4.8	1965
4.9	1888
32.79	1977
14.6	1963
8.05	1987
16.4	1986
163.9	1988
10.6	1909
12.4	1952
20.2	1951
4.3	1953
10.7	1954
7.2	1968
5.1	1966
11.7	1966

Radon (pCi/l)	Year
33.9	1913
17.8	1955
18.95	1955
3.6	1959
18.4	1959
13.6	1967
24.2	1976
19.7	1977
24.7	1904
15.9	1953
10.5	1946
28	1968
57.4	1977
15.9	1946
18.1	1967
13.9	1964

APPENDIX D

RADON LEVELS FOR YEARS 1988 TO 1993

1988 Radon Level PCi/l	1988 Radon Level (pCi/l)	1988 Radon Level (pCi/l)	1988 Radon Level (pCi/l)	1989 Radon Level (pCi/l)	1989 Radon Level (pCi/l)
1.60	11.80	18.40	60.90	1.10	9.00
1.83	11.80	18.40	69.50	3.29	9.00
2.69	12.19	18.40	76.40	3.90	9.20
3.18	12.20	18.60	90.97	4.10	9.20
3.53	13.51	18.60	132.40	4.60	9.35
3.75	13.60	19.00	326.10	4.80	9.50
4.00	13.65	19.20	60.57	4.80	9.70
4.30	13.90	19.20	11.60	4.80	9.73
4.30	13.91	19.60	18.40	4.90	9.80
4.55	14.00	20.20	56.10	5.00	9.90
5.45	14.10	20.50	18.10	5.10	9.90
6.55	14.20	20.60	11.31	5.10	10.20
7.06	14.20	20.90	39.90	5.40	10.30
7.35	14.60	21.30	41.60	5.90	10.30
7.49	14.70	21.30	42.50	6.30	10.40
7.50	14.84	22.30	17.80	6.30	10.50
7.52	15.00	22.50	17.80	6.70	10.50
7.71	15.30	22.90	17.90	6.80	10.70
8.58	15.80	23.30	10.70	6.80	10.80
8.70	15.90	24.10	11.12	6.90	10.90
8.82	15.90	25.50	11.20	6.90	11.00
8.82	15.90	26.80	33.90	6.90	11.10
8.85	16.01	26.80	38.90	7.10	11.30
9.00	16.10	27.30	17.50	7.30	11.40
9.20	16.10	30.80	17.70	7.50	11.50
9.50	16.40	31.14	10.20	7.50	11.65
9.50	16.50	31.30	10.60	7.60	11.80
10.20	17.30	32.79		7.70	11.80

1989 Radon Level PCi/l	1989 Radon Level (pCi/l)	1989 Radon Level (pCi/l)	1989 Radon Level (pCi/l)	1990 Radon Level (pCi/l)	1990 Radon Level (pCi/l)
16.23	12.70	22.30	31.00	0.50	10.90
16.30	12.70	22.50	31.20	0.60	11.00
16.40	12.70	22.50	31.30	1.10	11.10
16.40	12.90	22.60	32.30	1.10	11.80
16.50	12.90	22.70	32.60	1.30	11.85
16.60	13.00	23.10	34.00	1.30	11.90
16.60	13.00	23.30	35.55	1.80	12.30
16.65	13.20	23.40	36.10	2.60	12.85
16.80	13.40	23.40	36.40	3.50	12.97
16.90	13.50	23.50	36.90	4.10	13.00
16.90	13.50	23.60	37.45	4.30	13.10
17.10	13.60	23.70	37.70	5.10	13.20
17.20	13.60	23.90	38.10	6.10	13.30
17.50	13.60	24.10	38.70	6.20	14.00
17.50	13.60	24.20	39.00	6.40	14.10
17.80	13.70	24.20	39.10	6.50	14.30
18.20	13.70	24.50	39.50	6.50	14.40
18.30	13.80	24.70	43.00	6.87	14.40
18.40	14.00	24.80	46.70	6.90	14.60
18.50	14.30	24.90	47.10	6.90	14.90
19.00	14.60	25.10	50.70	7.10	15.10
19.00	14.60	25.30	51.20	7.20	15.10
19.00	14.60	25.70	57.40	7.40	15.20
19.20	14.67	26.43	57.70	7.60	15.20
19.40	15.00	27.20	95.10	8.00	15.50
19.50	15.20	27.50	113.90	8.10	15.60
19.70	15.30	27.80	163.85	8.50	15.70
19.70	15.40	28.00	22.00	8.58	16.80
19.70	15.40	28.00	30.50	8.80	16.90
19.80	15.60	28.05	8.50	9.00	18.50
20.10	15.70	28.30	12.60	9.16	18.90
20.10	15.80	28.40	16.00	9.40	18.90
20.30	15.90	28.40	8.50	9.40	18.95
21.70	15.90	28.60	12.55	9.50	19.60
21.80	22.00	29.10	8.05	10.05	20.20
21.85	29.80	29.20	8.10	10.10	20.30

1990 Radon Level (pCi/l)	1991 Radon Level PCi/l	1991 Radon Level (pCi/l)	1991 Radon Level (pCi/l)	1992 Radon Level (pCi/l)	1992 Radon Level (pCi/l)
23.00	8.20	0.40	70.84	0.40	12.58
23.00	8.30	0.40	237.87	0.50	12.70
24.70	8.30	0.50	8.10	0.60	13.40
25.60	8.70	0.70	50.13	0.80	15.10
26.25	8.75	1.00	68.20	1.40	15.30
30.70	9.30	1.40	8.10	2.70	15.30
30.90	9.40	1.50	50.00	3.20	15.90
35.80	9.50	2.10	8.00	3.30	16.60
43.20	10.10	2.45		3.30	17.05
80.80	10.20	2.60		3.50	17.80
10.70	11.00	2.90		3.55	19.20
22.80	11.40	2.90		4.35	20.10
10.45	11.63	2.90		4.50	21.80
22.30	11.70	3.00		4.50	23.10
	12.00	3.50		4.80	23.80
	12.30	3.60		4.95	26.40
	12.70	3.60		5.17	56.30
	13.70	3.80		6.00	61.70
	14.20	4.00		6.20	128.00
	14.90	4.27		6.60	11.87
	15.30	4.52		7.10	12.40
	16.30	4.90		7.20	11.50
	17.00	5.80		7.20	
	17.00	5.80		7.30	
	17.90	5.80		8.00	
	18.10	5.90		8.10	
	18.50	6.00		8.20	
	19.00	6.10		8.60	
	20.40	6.30		8.63	
	20.80	7.20		8.90	
	24.50	7.20		9.30	
	27.60	7.30		9.35	
	31.50	7.40		10.20	
	31.60	7.60		10.30	
	36.40	7.60		10.85	
	48.00	7.70		11.20	

1993 Radon Level (pCi/l)
1.60
6.50
7.60
10.80
11.90
13.40
16.00
16.00
16.40
16.80
19.50
20.60
27.10
28.60
77.50

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