1 of 1

A STUDY OF RADON-222 CONCENTRATIONS IN NORTH CAROLINA GROUNDWATER

by

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JAMES PHILIP EVANS. A Study of Radon-222 Concentrations in North Carolina Groundwater (Under the direction of JAMES E. WATSON, JR.)

ABSTRACT

The groundwater of 400 North Carolina homes was sampled to ascertain the distribution and extent of ^{222}Rn in North Carolina groundwater. Arithmetic mean (AM) and geometric mean (GM) concentrations of $1,816 \text{ pCi L}^{-1}$ and 656 pCi L^{-1} were found for the state. These results indicate that two-thirds of N.C. homes served by groundwater exceed the EPA proposed 300 pCi L^{-1} maximum contaminant level (MCL). Only 2% of N.C. homes exceeded $10,000 \text{ pCi L}^{-1}$.

The Eastern region had the lowest radon concentrations by far, with a GM of 230 pCi L^{-1} . The Central region and Western region had GM's of 794 pCi L^{-1} and $1,032 \text{ pCi L}^{-1}$ respectively. The groundwater data approached a log normal distribution.

No consistent trends were noted in the relationship between indoor radon concentrations and groundwater radon concentrations. A correlation coefficient of 0.00921 revealed a very weak linear relationship.

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Special thanks go to my family for their support during this time. Most of all I thank my wife, Anne. Her love, patience, and understanding made my work not only possible, but most enjoyable. I wish to dedicate this work to my son Alex, who aspires to be a scientist. May he experience the wondrous nature of the universe about him, as I have and continue to do.

TABLE OF CONTENTS

LIST OF APPENDICES	vi
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
LIST OF ABBREVIATIONS	ix

CHAPTER

I. INTRODUCTION.....	1
Importance of Radon Studies	1
Sources of Radon.....	1
Radon Regulations	2
Survey Objectives	2
II. LITERATURE REVIEW	3
Radon - Airborne and Waterborne.....	3
N.C. Regional Geology	4
III. METHODS	6
Sampling Methodology	6
Sampling Instructions.....	7
Sample Analysis.....	7
Calibration Factors and Background Count Rates.....	8
Minimum Detectable Activity.....	9
IV. RESULTS.....	11
Weighting Factors	11
Statistics and Distribution of Data	11
Analysis of Paired Water Samples	21
Analysis of Paired Air and Water Data	21
V. DISCUSSION.....	31
VI. REFERENCES	34

LIST OF APPENDICES

I.	Principal Decays of the Uranium Series	37
II.	Mean Radon Concentrations and Number of Samples for N.C. Counties	39
III.	Homeowner Instruction Sheet for Obtaining Samples	43
IV.	Packard Tri-Carb 300 Liquid Scintillation Counter Program Settings.....	45
V.	Calibration Factors and Background Count Rates for LSC Analysis	47
VI.	Data for Air and Water Radon Analysis	50
VII.	Data for Paired Water Sample Analysis	61

LIST OF TABLES

Table 1:	Background and Calibration Factors	8
Table 2:	Groundwater Radon Survey Results	14

LIST OF FIGURES

Figure 1: North Carolina Groundwater Radon Survey Regions.....	5
Figure 2: North Carolina Groundwater Radon Survey Counties Sampled and Counties Not Sampled	12
Figure 3: North Carolina Groundwater Radon Survey Regions and Counties Not Sampled.....	13
Figure 4: Measures of Central Tendency	16
Figure 5: Proportion of Radon Concentrations Exceeding Specified Levels	17
Figure 6: N.C. Groundwater Radon Levels (0-10,000 pCi L ⁻¹).....	18
Figure 7: Natural Log N.C. Groundwater Radon Levels	19
Figure 8: Distribution of N.C. Groundwater Radon	20
Figure 9: N.C. Eastern Region Groundwater Radon Levels	22
Figure 10: N.C. Central Region Groundwater Radon Levels (0-10,000 pCi L ⁻¹).....	23
Figure 11: N.C. Western Region Groundwater Radon Levels (0-10,000 pCi L ⁻¹).....	24
Figure 12: N.C. County Mean Groundwater Radon Concentrations.....	25
Figure 13: Dual Samples - Pair Percent Differences	26
Figure 14: N.C. Groundwater Radon Concentrations vs. Indoor Radon Concentrations.....	27
Figure 15: N.C. Eastern Region Groundwater Radon Concentrations vs. Indoor Radon Concentrations.....	28
Figure 16: N.C. Central Region Groundwater Radon Concentrations vs. Indoor Radon Concentrations.....	29
Figure 17: N.C. Western Region Groundwater Radon Concentrations vs. Indoor Radon Concentrations.....	30

ABBREVIATIONS

a	probability of false signal detection
b	probability of false signal non-detection
λ	radiological decay constant for Radon-222 (1.8×10^{-1} days ⁻¹)
²¹⁴Po	Polonium-214
²¹⁸Po	Polonium-218
²²²Rn	Radon-222
²²⁶Ra	Radium-226
AM	arithmetic mean
ASD	arithmetic standard deviation
AVBKG	average background from 2 blank water samples
AVGCF	average of the 2 Radium standard calibration factors
B	background count rate
BKG-1	counts per minute for blank water sample #1
BKG-2	counts per minute for blank water sample #2
Bq L⁻¹	Becquerel per liter
CI	confidence interval
cpm	counts per minute
CPM-1	gross counts per minute for Radium standard #1
CPM-2	gross counts per minute for Radium standard #2
EPA	Environmental Protection Agency
GM	geometric mean
GSD	geometric standard deviation
k	value of standardized normal deviate (1.64 for $\alpha = 0.05$)
KeV	kilo electron volt
L	liter

L_c	decision limit
L_d	detection limit
LSC	Liquid Scintillation Counter
MCL	maximum contaminant level
MDA	minimum detectable activity
MED	median
ml	milliliter
N.C.	North Carolina
pCi	picocurie
pCi L⁻¹	picocuries per liter
RTI	Research Triangle Institute
t	elapsed time (from sample analysis)
V	sample volume (in milliliters)
X	net count rate (in counts per minute)
Y	calibration factor (in counts per minute / picocurie)

INTRODUCTION

Importance of Radon Studies

Concerns regarding indoor radon (^{222}Rn) have grown tremendously in the last few years. With the realization that radon comprises over half the average dose of radiation that people in the U.S. receive, many studies have been performed to ascertain the extent of radon in homes. Radon enters homes through two main pathways; first, it may seep from the soil or rock which lies under the home, and second, it may enter the home when water is used. Whenever faucets run, toilets flush, or clothes are washed, radon escapes from the incoming water. Some building materials (stone for example) also emit radon, but this is usually a small source and will not be addressed here.

Radon itself is not the problem. Radon is a partially water soluble, inert radioactive gas that is the progeny of ^{226}Ra . The problem lies with the progeny of the decayed radon atom, ^{218}Po and ^{214}Po , which are alpha-emitters (Appendix I lists the Uranium decay series). The radon progeny are charged particles which may attach themselves to other particles in the air. The particles with attached progeny as well as unattached progeny are then inhaled, thus increasing the risks of developing lung cancer.

Sources of Radon

High concentrations of radon in groundwater are associated with granitic rocks and/or uranium bearing minerals like carnotite or uraninite (Hess et al. 1985). Physical factors such as pressure, temperature, and porosity of the host rock or soil control the rate of emissivity (movement) of radon. The radon diffuses through microcrystalline rock fractures and enters surrounding interstitial groundwater. Once in the groundwater, radon transport is generally governed by the groundwater percolation rate instead of diffusion (Hess et al. 1985). The radon then enters a home via the use of water from a well and/or works its way to the surface under a home and seeps in.

Radon Regulations

The current action guide for radon in air is 4 pCi L⁻¹ which corresponds to an estimated lifetime cancer risk of 1.5×10^{-2} [1-5 in 100]. Radon in water is not currently regulated. However, the Environmental Protection Agency (EPA) has proposed a Maximum Contaminant Level (MCL) of 300 pCi L⁻¹ for public water systems. The MCL is primarily based on the inhalation risk of radon emitted by water. On average, 10,000 pCi L⁻¹ of radon in water contributes about 1 pCi L⁻¹ of radon to indoor air. At this rate, a 300 pCi L⁻¹ level would contribute about 0.03 pCi L⁻¹ of radon to home air. This level corresponds to an estimated lifetime cancer risk of approximately 2×10^{-4} [2 in 10,000]. The risk associated with the radon MCL is consistent with those of other drinking water contaminants (USEPA 1991). The EPA believes the aforementioned levels for radon in water and indoor radon will protect the public to the highest degree feasible, given current radon mitigation strategies (USEPA 1991).

Survey Objectives

The State of North Carolina and the EPA performed a survey to characterize indoor ²²²Rn levels for North Carolina during the period of February through April, 1990. The survey had two primary objectives; the first was to characterize the indoor radon distribution across the state, and the second was to identify areas with elevated indoor radon levels. Additionally, the information provided an estimation of mean indoor radon concentrations state wide and for geographical regions within the state (White et al. 1992). Barrier charcoal canisters were deployed for 48 hours using protocols recommended by the EPA (White, et al. 1992, USEPA 1986).

This report details a follow-up study (to the indoor radon survey) designed to investigate the distribution and extent of radon in North Carolina groundwater. The objectives of the groundwater radon survey are as follows:

- ◆ Examine the radon distribution in N.C. groundwater, state wide and by geographical region
- ◆ Estimate the mean concentrations of radon in N.C. groundwater
- ◆ Estimate the percentage of homes with radon concentrations above specified radon levels
- ◆ Study the relationship between groundwater radon concentrations and indoor radon concentrations.

LITERATURE REVIEW

Radon - Airborne and Waterborne

Groundwater accounts for less than 1% of the Earth's water. However, the amount of groundwater is 35 times greater than the volume of lakes and rivers on the Earth's surface (Flint and Skinner 1977). Out of nearly 60,000 public water supplies in the U.S., roughly 80% use groundwater sources. Of the groundwater supplies, over 90% serve 3,300 people or less (Hess et al. 1985). Estimates indicate that there are 13 million private wells in the U.S (Barron 1990).

There have been numerous studies performed on both indoor radon and groundwater radon in North Carolina. The aforementioned N.C. / EPA survey included nearly 1300 homes and found a mean indoor air concentration of 1.4 pCi L^{-1} for the state (White et al. 1992). Another study (Watson et al. 1988) revealed 63 counties (of 97 sampled) with no air measurement over 4 pCi L^{-1} . Additionally, mean concentrations of 0.5 pCi L^{-1} , 2.1 pCi L^{-1} , and 3.3 pCi L^{-1} were found for the Coastal Plain, Piedmont, and Mountains respectively. The highest concentrations were observed in the Mountains and western Piedmont.

Sasser and Watson (1978) studied 225 N.C. groundwater supplies and reported roughly one-third of the supplies with radon concentrations in excess of 2000 pCi L^{-1} , with a maximum sample concentration of $46,600 \text{ pCi L}^{-1}$. Radon in N.C. groundwater has been investigated for its relationship to rock type and for the prediction of radon concentration (Loomis 1986, Rahlenbeck et al. 1991). It has been suggested that the radon concentration of water from private wells exceeds that of public utility water systems by a factor of 10 (Hess et al. 1985). However, another study by Loomis (1987) explored the inverse relationship between water-system size and ^{222}Rn concentration in N.C. public water supplies. Loomis suggests that the inverse relationship is a result of the differential distribution of water system sizes in areas of varying rock type (Loomis 1987).

Michel (1990) also suggests the relationship between water system size and aquifer composition.

It is commonly suggested that a water radon concentration of 10,000 pCi L⁻¹ will contribute an indoor concentration of 1 pCi L⁻¹ in a home (Hess et al. 1985, Lawrence et al. 1992). The degassing of radon from water may contribute significantly to indoor radon. Some factors that may affect the radon contribution are home air exchange rate, water usage rates, and home air volume (Lawrence et al. 1992, Hess et al. 1985). The EPA states that waterborne radon is responsible for about 5% of the indoor radon nationally (USEPA 1991).

N.C. Regional Geology

The geological features of North Carolina are indeed diverse and are beyond the scope of this text. However, certain generalities are helpful when describing an area and its rock type. High radon concentrations are associated with granitic rocks. The crystalline structure of granitic rocks contains fractures which facilitate the diffusion of radon into the surrounding air and/or groundwater.

The Coastal Plain is characterized by clastic sediment (sand, silt, sandstones, and shales) underlain by metamorphic rock. There are also some limestones and fossil containing sediments (chemical sediments). Highly complex metamorphic rocks and granitic rocks compose the Piedmont. The Mountains contain an abundance of granitic rocks and metamorphic rocks. The survey regions are divided as follows, Eastern region, Central region, and Western region. The Eastern region closely follows the Coastal Plain, while the Central region contains the eastern Piedmont, and the Western region contains the western Piedmont and the Mountains. See Figure 1 for a North Carolina map of counties and regions. Appendix II lists the counties in each region.

FIGURE 1: NORTH CAROLINA GROUNDWATER RADON SURVEY REGIONS

- ☐ EASTERN REGION
- ☐ CENTRAL REGION
- ☐ WESTERN REGION

METHODS

Sampling Methodology

The aforementioned North Carolina / EPA indoor radon survey was designed by the Research Triangle Institute (RTI). RTI has coordinated similar surveys with the EPA for 29 other states (White et al. 1992). The survey results apply to a population of occupied dwellings with:

- ◆ A listed telephone number
- ◆ A permanent foundation
- ◆ At least one floor at or below grade level (including crawl spaces).

The homeowners that participated in the N.C. / EPA indoor radon survey responded to a questionnaire, which included one question that asked the source of their drinking water. The homeowners who identified a well as the source of their drinking water were contacted by letter asking for their participation in the follow-up groundwater radon study. The points emphasized in the homeowner letter were:

- ◆ Their previous participation in the indoor radon survey
- ◆ Confidentiality of individual results
- ◆ Groundwater radon concentration results will be provided to them at no cost.

The indoor radon questionnaire identified 558 homes that obtained their drinking water from wells. Further investigation revealed that 57 homes were ineligible for the study. Survey ineligibility arose from two major areas; homes that were not obtaining water from a well and homeowners who could not be contacted by mail or telephone follow-up methods. Barring any objections, homeowners were mailed sample kits containing two sample vials (for duplicate samples), a set of sampling instructions, a pre-addressed return label with postage, and a reusable mailing container with packing material.

Homeowners from the 501 eligible homes returned 400 sample kits between November 1990 and August 1991. Attempts were made by follow-up letters and/or

phone calls to contact homeowners who did not respond. Roughly 50% of the follow-up letters and/or phone calls led to a successful sample return. Homeowner non-response accounted for the 101 sample kits that were not returned. (Note: all homeowners for the groundwater radon survey were respondents in the previous indoor air radon survey.)

Sampling Instructions

Each homeowner received an explicit set of instructions for obtaining the water samples. Appendix III contains a copy of the actual instruction sheet. In brief, the instructions were the following:

- ◆ Check the contents of your mailing tube.
- ◆ Turn the COLD water on all the way and let it run for five (5) minutes.
- ◆ After five (5) minutes turn the water flow down to a slow stream.
- ◆ Carefully fill each vial to the neck; try not to overfill the vials.
- ◆ Immediately put the cap on each vial. Make sure the caps are tight.
- ◆ Record time and date on instruction sheet.
- ◆ Carefully wrap vials in the packing material and place in the mailing tube.
- ◆ Place instructions in tube - make sure you recorded time and date above.
- ◆ Attach the return label to the tube.
- ◆ Mail immediately.

Sample Analysis

Twenty ml liquid scintillation counting vials served as sample vials. Each sample vial was filled with 10 ml of a non-hazardous mineral oil liquid scintillation fluid and weighed prior to homeowner distribution. The sample vials were re-weighed upon return to determine the mass, and hence volume of the water sample. An attempt was made to obtain duplicate samples from each homeowner, however, some vials broke or leaked during transit (see Results section). The results from all sample pairs were averaged for each home. When only an individual sample was available, it was also included in the analysis.

Sample counting was performed on a Packard Tri-Carb 300 liquid scintillation counter (LSC). The LSC was preprogrammed to count each sample for 50 minutes or until the percent deviation was down to 2 percent. The counting energy windows on the LSC were set for three ranges; 0 to 2000 KeV for channel A, 5 to 1850 KeV for channel

B, and 0 to 5 KeV for channel C. Counts from channel B were used in the actual calculation of radon concentrations. (Appendix IV lists the settings for the LSC.)

Liquid scintillation vials were Kimble 20 ml borosilicate glass vials with a cone-shaped lid liner (Fisher Scientific catalog no. 03-337-7). The liquid scintillation counting fluid was DuPont High Efficiency Mineral Oil Scintillator (NEN Research Products catalog no. NEF 957A).

Prior to counting, all samples, standards, and blanks were each shaken vigorously for approximately 10 seconds to mix the aqueous and oil phases. The agitation of the sample preferentially dissolves the radon into the scintillation fluid (Horton 1983). The vials then sat at least 4 hours before counting to allow equilibration of the radon progeny.

Calibration Factors and Background Count Rates

A quality assurance check was performed each time the LSC was used. Two blank (distilled water) samples were counted to establish the average background (cpm) and two standards (sealed aqueous Radium-226 samples) were counted to obtain the calibration factor (cpm pCi⁻¹). The calibration factor (standard net count rate / standard activity) relates sample activity to count rate by analyzing a sample of known activity in the same way that experimental samples are analyzed. The sample net count rate is then divided by the calibration factor to yield sample activity. Table 1 lists the maximum, minimum, mean and standard deviation for background count rates and calibration factors. Appendix V contains daily calibration factors and background count rates.

Table 1: Background and Calibration Factors

	MEAN	STDEV	MAX	MIN
BKG-1	30.96	1.18	33.00	28.04
BKG-2	30.50	1.06	33.16	28.48
AVBKG	30.73	0.93	32.61	28.48
CPM-1	7294.34	101.96	7496.12	7045.25
CPM-2	9444.86	133.66	9726.00	9067.29
AVGCF	10.03	0.12	10.24	9.67

BKG-1 Counts per minute for blank water sample #1 (cpm)

BKG-2 Counts per minute for blank water sample #2 (cpm)

AVBKG Average background from 2 blank water samples (cpm)

CPM-1 Gross counts per minute for 714 pCi L⁻¹ Radium standard #1 (cpm)
 CPM-2 Gross counts per minute for 952 pCi L⁻¹ Radium standard #2 (cpm)
 AVGCF Average of the 2 Radium standard calibration factors (cpm/pCi)

Radon concentrations in pCi L⁻¹ were then calculated from the LSC net count rates with the following relationship,

$$^{222}\text{Rn concentration (pCi L}^{-1}) = \frac{X}{Y} \frac{1000\text{ml/L}}{V} \exp(\lambda t)$$

where: X = Net Count Rate (cpm) [gross cpm minus background cpm]
 Y = Calibration Factor (cpm/pCi)
 V = Sample Volume (ml)
 λ = Radiological decay constant for ²²²Rn (0.18 days⁻¹)
 t = Time elapsed from sample collection to midpoint of count (days).

Minimum Detectable Activity

Counting time and background levels determine the minimum detectable activity (MDA). Various terms are used to describe the MDA, however, the meaning of such terms is subject to different interpretations. NCRP 58 (1985) suggests two terms for describing the MDA; the decision limit (L_c) and the detection limit (L_d). The decision limit is the net number of counts (total minus background) for reaching a decision of signal non-detection (when actual net counts are less than L_c), or signal detection (when actual net counts are larger than L_c). The detection limit is a signal level such that a signal at or above this level is likely to be detected. The proportion of false detection (a) and the proportion of false non-detection (b) are both 0.05, i.e., 95% confidence interval (C.I.). The formulae for L_c and L_d are as follows:

$$\begin{aligned} L_c &= k \sqrt{2} \sqrt{B} & L_d &= k^2 + 2L_c \\ L_c &= 2.32 \sqrt{B} & L_d &= 2.71 + 4.65 \sqrt{B} \end{aligned}$$

where: B = background counts
 k = 1.64, the value of the standardized normal deviate for the 95% C.I.

The mean number of counts for the background was 1537 counts (during a 50 minute period). A typical calculation for the L_c is as follows:

$$L_c = 2.32 \sqrt{B} = 2.32 \frac{\sqrt{1537} \text{ counts}}{50 \text{ minutes}} = 1.82 \text{ cpm}$$

To convert the L_c to a typical ^{222}Rn concentration, the following equation was used:

$$L_c (\text{pCi L}^{-1}) = \frac{1.82 \text{ cpm}}{10.03 \text{ cpm pCi}^{-1}} \cdot \frac{1000 \text{ ml / L}}{12.2 \text{ ml}} \exp (0.18 \text{ days}^{-1} \times 4.11 \text{ days}) = 31 \text{ pCi L}^{-1}$$

Assuming: Mean calibration factor of 10.03 cpm pCi⁻¹
Median sample volume of 12.2 ml
Median decay time of 4.11 days
 ^{222}Rn radiological decay constant of 0.18 days⁻¹

Results that were below the decision limit were included in calculations in order to avoid introduction of an unnecessary bias.

RESULTS

As previously explained in the Methods section, 57 of the 558 homes initially identified were determined to be ineligible for the study. Of the 501 remaining homes, samples were collected from 400. An attempt was made to obtain duplicate samples, and of the 400 homes surveyed, 364 provided duplicate samples. For the remaining 36 homes single samples were obtained due to broken or leaky sample vials. When duplicates were available, sample concentrations were determined by averaging the concentrations of each sample pair. Concentrations from duplicate and single samples were included in the groundwater radon analysis. There were 389 water samples that had a corresponding indoor radon concentration (from the N.C. / EPA survey).

Weighting Factors

Each home was assigned a discrete weight adjustment factor by RTI in the indoor radon survey (Bergsten et al. 1989). The weighting factors account for unequal probabilities of selection and are used to generate unbiased population estimates from the sample data. The western region of the state was sampled most heavily (277 samples), followed by the central (80 samples) and eastern (43 samples) regions. The weighted statistics are valid for an estimation of groundwater radon concentrations for North Carolina homes (served by groundwater) with a listed telephone number, a permanent foundation, and at least one floor at or below grade (including homes built over a crawl space). Non-weighted measures would reflect statistics for the samples only.

Statistics and Distribution of Data

Figures 2 and 3 show maps of the counties sampled and survey regions with counties sampled, respectively. Table 2 shows the statistics for the residential water samples. All statistics are calculated for North Carolina as a whole, and for three geographic regions; Eastern, Central, and Western. The arithmetic mean (AM) concentration for the state is $1,816 \text{ pCi L}^{-1}$, however the median (MED) and geometric

**FIGURE 2: NORTH CAROLINA GROUNDWATER RADON SURVEY COUNTIES
SAMPLED AND COUNTIES NOT SAMPLED**

☐ SAMPLED

☐ NOT SAMPLED

FIGURE 3: NORTH CAROLINA GROUNDWATER RADON SURVEY REGIONS AND COUNTIES NOT SAMPLED

- ☐ EASTERN REGION
- ☐ CENTRAL REGION
- ☐ WESTERN REGION
- ☐ NOT SAMPLED

Table 2 - Groundwater Radon Survey Results (pCi L⁻¹)

Region Sampled	State	Eastern	Central	Western
Number of Homes Sampled	400	43	80	277
Minimum Concentration	9	67	9	21
Maximum Concentration	59,088	1,715	19,558	59,088
Arithmetic Mean (AM)	1,816	318	2,252	2,262
Arithmetic Standard Deviation (ASD)	± 4,127	± 446	± 4,415	± 5,005
Median (MED) {50th percentile}	591	211	848	1,189
Geometric Mean (GM)	656	230	794	1,032
Geometric Standard Deviation (GSD)	x + 5.2	x + 2.5	x + 4.4	x + 4.1
% Homes > 300 pCi L⁻¹	67%	30%	75%	83%
% Homes > 1,000 pCi L⁻¹	37%	5%	38%	56%
% Homes > 5,000 pCi L⁻¹	9%	0%	13%	10%
% Homes > 10,000 pCi L⁻¹	2%	0%	4%	2%

mean (GM) are 591 pCi L⁻¹ and 656 pCi L⁻¹ respectively. The difference in the measures of central tendency helps illustrate the distribution of the data. Figure 4 depicts the measures of central tendency listed in Table 2. Clearly, the Eastern region has considerably lower concentrations than those of either the Central or Western regions. The Western and Central regions have similar arithmetic means of 2,262 pCi L⁻¹ and 2,252 pCi L⁻¹ respectively. However, their geometric means are 1,032 pCi L⁻¹ and 794 pCi L⁻¹ respectively. Additionally, their respective medians are 1,189 pCi L⁻¹ and 848 pCi L⁻¹. The AM is much more sensitive to extreme values than are the MED or GM.

A few very high concentrations tended to increase the AM. Figure 5 compares proportions of various radon concentrations for the state and regions (see bottom of Table 2 for values). A large number of homes have water radon concentrations in excess of the proposed EPA maximum contaminant level (MCL) of 300 pCi L⁻¹; 30% in the Eastern region, 75% in the Central region, and 83% in the Western Region. The combined regional figures revealed 67% of the state's homes in excess of the 300 pCi L⁻¹ MCL. Ninety-five percent of the Eastern region homes had levels below 1,000 pCi L⁻¹, with none above 2,000 pCi L⁻¹. The rest of the state presents a different picture though. The Central and Western regions have considerably higher radon concentrations than the Eastern region. The highest radon concentration (59,088 pCi L⁻¹) was found in the Western region, while the highest Central region concentration was 19,558 pCi L⁻¹. The Western region had a higher proportion of homes with greater than 1,000 pCi L⁻¹ than did the Central region. Yet, the Central region had a higher proportion of homes exceeding the 5,000 pCi L⁻¹ and 10,000 pCi L⁻¹ categories than did the Western region. State wide, 98% of the homes had concentrations below 10,000 pCi L⁻¹.

Figures 6 and 7 portray the distribution of the groundwater radon concentrations for the state. The radon concentrations are plotted in frequency distributions showing the respective proportion of homes per interval. Figure 6 clearly indicates that the data are not normally distributed. The data are strongly skewed in the positive direction. Figure 7 is similar to Figure 6 with the exception of the logarithmic axis for radon concentration. However, for this case the frequency distribution approaches that of a normal curve. Lastly, Figure 8 depicts the cumulative percent versus log concentration for the groundwater radon data. Other studies have indicated the log normal distribution for their data (Hess et al. 1985, Longtin 1990). The middle area of the curve approximates a log normal distribution.

FIGURE 4: MEASURES OF CENTRAL TENDENCY

FIGURE 5: PROPORTION OF RADON CONCENTRATIONS EXCEEDING SPECIFIED LEVELS

FIGURE 6: N.C. GROUNDWATER RADON LEVELS (0-10,000 pCi/L)

FIGURE 7: NATURAL LOG N.C. GROUNDWATER RADON LEVELS

FIGURE 8: DISTRIBUTION OF N. C. GROUNDWATER RADON

Figures 9 - 11 show regional frequency distributions of groundwater radon concentrations that appear similar in shape to the state wide frequency distribution (Figure 6). A larger number of samples would increase statistical power and probably produce regional frequency distributions which more closely approximate log normal distributions. Figure 12 shows a map of N.C. counties with their number of samples (in parentheses) and mean radon concentrations in pCi L⁻¹. The highest levels are in the Western and Central regions. Further sampling is needed to gain enough statistical power to get viable mean concentration estimates for the counties. Appendix VI lists the data for the groundwater radon and indoor air radon concentrations.

Analysis of Paired Water Samples

Of the 400 homes sampled, 364 dual samples were obtained. (Appendix VII contains the concentrations for the individual vials.) All dual samples were analyzed for percent difference, and Figure 12 shows the frequency distribution for the analysis. Over 75% of the pairs had percent differences of 10% or less and 90% had percent differences of 20% or less. Potential sources of error within paired samples include leakage of radon from one (or both) of the vials and/or overfilling of a vial by the homeowner. Leakage of radon from the vials appeared minimal after several sequential LSC runs of the same samples.

Analysis of Paired Air and Water Data

The residential water radon data were paired to the corresponding home air radon data yielding 389 pairs of data. (Some indoor measurements were not present in the NC / RTI information.) There are a few negative readings for the indoor radon levels. The negative measurements were included in the analysis to avoid introduction of bias. The scatter plot of air radon concentrations versus water radon concentrations for N.C. are shown on Figure 14. Linear regression analysis found a correlation coefficient of 0.00921, indicating a very weak linear relationship. The regional plots (Figures 15-17) are very similar in appearance to the state wide plot. Without a log axis for the concentration, the data markers produce an unintelligible blot on the scatter plots.

FIGURE 9: N.C. EASTERN REGION GROUNDWATER RADON LEVELS

**FIGURE 10: N.C. CENTRAL REGION GROUNDWATER RADON
LEVELS (0-10,000 pCi/L)**

**FIGURE 11: N.C. WESTERN REGION GROUNDWATER RADON
LEVELS (0-10,000 pCi/L)**

FIGURE 12: NORTH CAROLINA COUNTY MEAN GROUNDWATER RADON CONCENTRATIONS

FIGURE 13: DUAL SAMPLES - PAIR PERCENT DIFFERENCES

**FIGURE 14: N.C. GROUNDWATER RADON CONCENTRATIONS VS.
INDOOR RADON CONCENTRATIONS**

FIGURE 15: N.C. EASTERN REGION GROUNDWATER RADON CONCENTRATIONS VS. INDOOR RADON CONCENTRATIONS

FIGURE 16: N.C. CENTRAL REGION GROUNDWATER RADON CONCENTRATIONS VS. INDOOR RADON CONCENTRATIONS

**FIGURE 17: N.C. WESTERN REGION GROUNDWATER RADON
CONCENTRATIONS VS INDOOR RADON CONCENTRATIONS**

DISCUSSION

The wells of 400 North Carolina homes were sampled to ascertain the distribution and extent of ^{222}Rn in North Carolina groundwater. Arithmetic and geometric mean concentrations of $1,816 \text{ pCi L}^{-1}$ and 656 pCi L^{-1} were found for the state. These results indicate that two-thirds of N.C. homes (served by groundwater) exceed the EPA proposed 300 pCi L^{-1} maximum contaminant level (MCL). Only 2% of N.C. homes exceeded $10,000 \text{ pCi L}^{-1}$. The distribution of the groundwater data approaches a log normal distribution.

The Eastern region had the lowest concentrations by far. About 30% of the homes surpassed the 300 pCi L^{-1} level but none of the samples exceeded $2,000 \text{ pCi L}^{-1}$. The arithmetic and geometric means were 318 pCi L^{-1} and 230 pCi L^{-1} respectively. The low radon concentrations are typical of the Eastern region. The coastal plain (Eastern region) is comprised of clastic sediments underlain by metamorphic rocks. Other states on the east coast show similar findings for their coastal plain regions (Michel 1990, Longtin 1990).

About 75% of the Central region homes exceed the 300 pCi L^{-1} MCL. The arithmetic mean of $2,252 \text{ pCi L}^{-1}$ is a sharp contrast to the Eastern result. However, the geometric mean is only 794 pCi L^{-1} . All Central region samples were below $20,000 \text{ pCi L}^{-1}$. The arithmetic mean for the Western region is $2,262 \text{ pCi L}^{-1}$. This is almost identical to that of the Central region. However, the geometric mean of $1,189 \text{ pCi L}^{-1}$ is considerably higher than the 794 pCi L^{-1} result for the Central region. Over 80% of the homes exceed 300 pCi L^{-1} for the Western region. The elevated readings for the Central and Western regions are consistent with those of other studies which found elevated air and groundwater radon concentrations in the Mountain and Piedmont areas (Watson et al. 1988, Longtin 1990, Sasser and Watson 1978, Dillon et al. 1991).

The highest measured groundwater radon concentrations generally came from the western piedmont and the mountainous areas - this is concordant with the area geology.

The mountains and piedmont are comprised of crystalline granitic rocks and a variety of complex metamorphic rocks.

Table 2 shows that 4% of homes in the Central region exceed $10,000 \text{ pCi L}^{-1}$, but only 2% exceed $10,000 \text{ pCi L}^{-1}$ in the Western region. However, the Western region has a higher median and a higher geometric mean than the Central Region. More intensive sampling of the Central region would increase the statistical power of the analysis and should help identify the similarity (or lack thereof) between the statistics of the Western and Central regions. Moreover, further data from the Eastern region would help provide a more complete analysis for the state. Figure 12 indicates a lack of data in many counties. Further studies could also identify potential "hot spots".

Generally, the risk from radon in groundwater is associated with the inhaled dose from the radon emitted to air (USEPA 1991). The EPA proposed MCL of 300 pCi L^{-1} is primarily based on the contribution of radon from water to indoor air, hence the inhalation pathway. However, the ingestion of radon laden water may contribute to increased risk to the stomach, intestines, and other organs (Crawford-Brown 1990). It is unclear how much risk may be attributed to ingestion, but the pathway should not be ignored.

The number of North Carolinians who live in homes served by groundwater is estimated to be 3.8 million (personal communication with Thomas Dickey, Groundwater Section, N.C. Division of Environmental Management). The state AM and GM of $1,816 \text{ pCi L}^{-1}$ and 656 pCi L^{-1} respectively would equate to continuous inhalation exposures of about 0.18 pCi L^{-1} and 0.07 pCi L^{-1} . These inhalation exposures correspond to estimated lifetime cancer risks of 12×10^{-4} (12 in 10,000) and 5×10^{-4} (5 in 10,000) respectively (USEPA 1991). Until further studies of the indoor radon/groundwater radon relationship and radon ingestion pathways are performed, it will be difficult to ascertain the amount of risk associated with a particular concentration of radon in water.

Regarding possible correlation between groundwater radon and indoor radon, no consistent trends were observed. Linear regression analysis showed a very weak linear relationship with a correlation coefficient of 0.00921. The potential temporal, spatial, and structural variations within a home contribute many unknowns to the analysis. In order to get a more accurate view of the air/water radon relationship, a carefully designed, long term analysis needs to be performed. If homes are known to have high groundwater radon concentrations (i.e., $10,000 \text{ pCi L}^{-1}$ or more), the contribution to indoor air contributions

may be significant enough to study. Air and water radon measurements would need to be taken at multiple locations within each home. The measurements should be both instantaneous and integrated over time. Home resident living patterns, such as the amount of time home, water use time, and water consumption rate should be analyzed. Air exchange rates would have to be calculated or at least allowed for. The weather (both long and short term) should also be factored into the analysis. Some work has been performed regarding spatial and temporal variations, and great fluctuations in radon measurements have been noted (Steck 1992, Borak, et al. 1989, Cohen 1986, Lawrence, et al. 1992).

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APPENDIX I

PRINCIPAL DECAYS OF THE URANIUM SERIES

PRINCIPAL DECAYS OF THE URANIUM SERIES*

Nuclide	Half-Life	Energy (MeV)		
		Alpha	Beta	Gamma
U-238	4.51x10 ⁹ y	4.198 (77%) 4.149 (23%)		
Th-234	24.10 d		0.193 0.103	0.092 (4%) 0.063 (3%)
Pa-234m	1.175 m		2.31	1.0 (1.5%) 0.76 (0.36%) I.T.
Pa-234	6.66 h		0.5	
U-234	2.48x10 ⁵ y	4.773 (72%) 4.721 (27%)		
Th-230	7.7x10 ⁴ y	4.688 (76%) 4.621 (23%)		0.068 (0.59%)
Ra-226	1,622 y	4.785 (94%) 4.602 (6%)		
Rn-222	3.82 d	5.486 (100%)		
Po-218	3.05 m	6.003 (100%)		0.186 (3%)
Pb-214	26.8 m		0.65	0.352 (37%) 0.295 (19%) 0.242 (7%)
Bi-214	19.9 m	5.05 (4%)		1.765 (16%) 1.120 (15%) 0.6093 (46%)
Po-214	1.6x10 ⁻⁴ s	7.687 (100%)		
Tl-210	1.32 m		1.96	2.36 (100%) 0.78 (100%) 0.30 (100%)
Pb-210	22.3 y		0.017	0.047 (4.5%)
Bi-210	5.01 d		1.17	
Po-210	138 d	5.297 (100%)		
Pb-206	Stable			

*Only the most prominent energies are listed.

APPENDIX II

MEAN RADON CONCENTRATIONS AND NUMBER OF SAMPLES FOR N.C. COUNTIES

EASTERN REGION

COUNTY SAMPLED	MEAN (pCi/L)	# SAMPLES
BEAUFORT	272	5
BERTIE	748	1
BRUNSWICK	350	3
CAMDEN	255	1
CARTERET	328	4
COLUMBUS	282	2
CUMBERLAND	119	3
CURRITUCK	283	1
DARE	179	2
DUPLIN	118	1
EDGECOMBE	201	1
HERTFORD	975	1
NEW HANOVER	747	3
NORTHAMPTON	172	1
PASQUOTANK	175	1
PENDER	124	2
PITT	347	4
ROBESON	81	1
SAMPSON	290	4
WAYNE	243	1
WILSON	377	1

NOT SAMPLED
BLADEN
CHOWAN
CRAVEN
GATES
GREENE
HOKE
HYDE
JONES
LENOIR
MARTIN
ONSLOW
PAMLICO
PERQUIMANS
SCOTLAND
TYRELL
WASHINGTON

CENTRAL REGION

COUNTY SAMPLED	MEAN (pCi/L)	# SAMPLES
ALAMANCE	278	2
ANSON	3337	1
CABARRUS	432	3
CHATHAM	2435	2
DAVIDSON	2113	1
FORSYTH	173	3
FRANKLIN	5154	3
GRANVILLE	171	2
GUILFORD	2366	7
HARNETT	174	2
JOHNSTON	1243	4
LEE	210	1
MECKLENBURG	1394	7
MONTGOMERY	399	2
MOORE	278	2
NASH	6309	5
ORANGE	179	1
PERSON	963	1
RANDOLPH	1132	3
RICHMOND	1252	1
ROCKINGHAM	1690	2
ROWAN	601	4
STANLY	1241	2
UNION	2830	3
VANCE	354	2
WAKE	5078	12

NOT SAMPLED
CASWELL
DURHAM
HALIFAX
WARREN

WESTERN REGION

COUNTY SAMPLED	MEAN (pCi/L)	# SAMPLES
ALEXANDER	2075	7
ALLEGHANY	1091	3
ASHE	1459	5
AVERY	783	2
BUNCOMBE	1479	21
BURKE	862	8
CALDWELL	1634	8
CATAWBA	798	18
CHEROKEE	1318	2
CLAY	1850	6
CLEVELAND	8261	10
DAVIE	818	3
GASTON	2138	29
GRAHAM	1981	4
HAYWOOD	793	8
HENDERSON	4950	16
IREDELL	1927	18
JACKSON	1727	7
LINCOLN	3309	13
MACON	1493	8
MADISON	341	5
MCDOWELL	2656	10
MITCHELL	5885	2
POLK	680	4
RUTHERFORD	952	7
STOKES	988	4
SURRY	2072	17
TRANSYLVANIA	5425	5
WATAUGA	5489	8
WILKES	2350	8
YADKIN	1425	5
YANCEY	733	4

NOT SAMPLED

SWAIN

APPENDIX III

HOMEOWNER INSTRUCTION SHEET FOR OBTAINING WATER SAMPLES

INSTRUCTIONS

1. Preparation

- ◆ Check the contents of the mailing tube. **DO NOT THROW AWAY THE TUBE.**
You should have the following items:
 - Reusable mailing tube
 - Reusable packing material
 - Return address label and postage
 - 2 glass vials with plastic caps (note: the liquid in the vials is mineral oil and is not hazardous).
- ◆ You also need a pencil or pen and a clock.
- ◆ Choose a faucet in your house that does not have an aerator or any other attachments. If this is not possible, then remove the aerator or attachment from a faucet.

2. Taking the samples

- ◆ Turn the COLD water on all the way and let it run for five (5) minutes.
- ◆ After five (5) minutes turn the water flow down to a slow stream.
- ◆ Carefully fill each vial to the neck; try not to overfill the vials.
- ◆ Immediately put the cap on each vial. Make sure the caps are tight.
- ◆ Record the date and time below

Date _____
 Month/Day/Year
Time _____ AM PM (circle one)

ID # _____ *

3. Returning the samples

- ◆ Carefully wrap the vials in the packing material and place them in the mailing tube.
- ◆ Place these instructions in the tube (be sure you recorded the date and time above)
- ◆ Attach the return label to the tube.
- ◆ Mail immediately. Any delay will cause the samples to go bad.

* Note to the reader: the ID # was filled in before mailing the instructions to each homeowner.

APPENDIX IV

PACKARD TRI-CARB 300

LIQUID SCINTILLATION COUNTER PROGRAM SETTINGS

LSC Program Settings

Terminators: Minutes = 50, % Deviation = 2

Radionuclide = Manual

Windows: *
A: LL = 0 KeV UL = 2000 KeV
B: LL = 5 KeV UL = 1850 KeV
C: LL = 0 KeV UL = 5 KeV

QIP = Yes

AEC = No

SCR = A/B

Vials / Std = 1, # Vials / Sample = 1, # Counts / Vial = 1

BKG = Manual: A = 0, B = 0, C = 0

Divide Factor K = 1

Data Mode = CPM

- * The "B" window is the counting window used for obtaining the gross cpm for radon concentration calculations.

APPENDIX V

CALIBRATION FACTORS AND BACKGROUND COUNT RATES FOR LSC ANALYSIS

AVERAGE BACKGROUND AND CALIBRATION FACTORS

DATE	BKG-1	BKG-2	AVBKG	CPM-1	CPM-2	AVGCF
11-30-90	31.50	30.70	31.10	7205.93	9334.62	9.91
12-03-90	31.88	32.72	32.30	7058.39	9279.05	9.78
12-06-90	30.52	31.34	30.93	7045.25	9081.31	9.67
12-10-90	32.78	32.44	32.61	7170.37	9339.42	9.89
12-13-90	29.74	29.86	29.80	7239.85	9324.04	9.93
12-19-90	31.26	31.02	31.14	7203.70	9321.15	9.90
12-21-90	31.12	33.16	32.14	7462.60	9550.98	10.20
1-03-91	31.86	32.62	32.24	7474.61	9375.96	10.12
1-10-91	30.14	31.20	30.67	7370.99	9536.31	10.13
1-17-91	31.88	31.10	31.49	7305.30	9490.29	10.06
1-22-91	29.56	30.52	30.04	7301.50	9335.24	9.98
1-25-91	32.76	31.26	32.01	7348.48	9508.74	10.10
1-30-91	29.96	30.48	30.22	7058.39	9067.29	9.87
1-31-91	31.42	29.66	30.54	7239.55	9269.52	9.90
2-03-91	30.90	30.38	30.64	7334.85	9561.76	10.12
2-04-91	30.86	30.20	30.53	7256.72	9420.39	9.99
2-05-91	32.98	30.10	31.54	7383.21	9516.67	10.13
2-07-91	31.50	28.90	30.20	7261.19	9560.78	10.07
2-09-91	30.82	29.62	30.22	7493.80	9431.07	10.16
2-11-91	32.50	31.10	31.80	7252.35	9532.35	10.05
2-14-91	31.16	30.70	30.93	7397.71	9524.51	10.14
2-15-91	33.00	31.64	32.32	7227.61	9191.51	9.85
2-19-91	30.92	30.34	30.63	7355.30	9510.78	10.11
2-20-91	30.70	30.02	30.36	7421.37	9431.07	10.11
2-22-91	31.08	30.30	30.69	7384.85	9375.96	10.06
2-25-91	32.14	30.86	31.50	7423.26	9639.60	10.22
2-26-91	31.64	31.60	31.62	7244.03	9630.69	10.09
2-27-91	31.88	31.46	31.67	7307.52	9406.80	10.02
3-01-91	30.68	32.74	31.71	7255.97	9582.35	10.08
3-04-91	32.38	32.56	32.47	7231.34	9552.94	10.04
3-06-91	32.54	31.96	32.25	7261.94	9444.66	10.01
3-10-91	32.28	29.78	31.03	7292.48	9427.18	10.02
3-12-91	31.56	30.18	30.87	7280.60	9726.00	10.17
3-14-91	31.06	29.80	30.43	7332.58	9515.69	10.10
3-15-91	30.58	30.26	30.42	7327.07	9385.58	10.02
3-18-91	32.16	30.58	31.37	7351.51	9643.56	10.17
3-20-91	30.44	30.66	30.55	7428.24	9643.56	10.17
3-22-91	29.80	30.32	30.06	7423.66	9670.30	10.24

AVERAGE BACKGROUND AND CALIBRATION FACTORS

DATE	BKG-1	BKG-2	AVBKG	CPM-1	CPM-2	AVGCF
3-25-91	30.04	29.62	29.83	7283.58	9529.41	10.07
3-27-91	30.80	30.68	30.74	7194.07	9291.43	9.88
3-31-91	31.54	29.36	30.45	7358.33	9547.06	10.13
4-01-91	30.42	30.82	30.62	7443.08	9464.08	10.15
4-02-91	31.10	29.46	30.28	7360.61	9527.45	10.12
4-03-91	29.86	29.46	29.66	7324.06	9516.63	10.09
4-04-91	31.00	28.72	29.86	7318.04	9488.35	10.07
4-05-91	30.96	29.06	30.01	7290.22	9360.22	9.98
4-08-91	30.62	31.10	30.86	7310.53	9422.33	10.03
4-10-91	32.46	30.54	31.50	7208.21	9403.85	9.95
4-12-91	31.56	30.98	31.27	7400.76	9592.16	10.18
4-16-91	30.76	30.02	30.39	7318.94	9527.18	10.09
4-18-91	31.42	29.56	30.49	7230.60	9396.12	9.96
4-22-91	31.62	29.82	30.72	7243.28	9565.35	10.06
4-24-91	32.00	29.74	30.87	7272.18	9395.19	9.99
4-26-91	29.80	29.02	29.41	7306.77	9521.57	10.08
5-03-91	31.16	29.26	30.21	7266.92	9245.71	9.91
5-03-91	31.16	31.48	31.32	7496.12	9194.34	10.04
5-10-91	29.24	29.24	29.24	7356.06	9547.06	10.13
6-06-91	28.42	28.54	28.48	7234.33	9466.99	10.00
6-14-91	29.04	30.88	29.96	7290.22	9352.96	9.98
7-03-91	28.04	29.36	28.70	7143.38	9334.62	9.87
8-04-91	28.62	29.72	29.17	7141.48	9348.64	9.88
8-11-91	28.80	31.18	29.99	7217.91	9519.74	10.02
8-14-91	28.18	30.00	29.09	7119.12	9434.32	9.91

DATE Date of sample analysis (month-day-year)

BKG-1 Counts per minute for blank water sample #1 (cpm)

BKG-2 Counts per minute for blank water sample #2 (cpm)

AVBKG Average background from 2 blank water samples (cpm)

CPM-1 Gross counts per minute for 714 pCi L⁻¹ Radium standard #1 (cpm)

CPM-2 Gross counts per minute for 952 pCi L⁻¹ Radium standard #2 (cpm)

AVGCF Average of the 2 Radium standard calibration factors (cpm/pCi)

APPENDIX VI

DATA FOR AIR AND WATER RADON ANALYSIS

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
E	0.6	71	NC00609	BEAUFORT
E		76	NC00561	BEAUFORT
E	0.0	93	NC01491	BEAUFORT
E	0.1	109	NC01252	BEAUFORT
E	0.5	1011	NC00921	BEAUFORT
E		748	NC00722	BERTIE
E	0.5	224	NC00463	BRUNSWICK
E	0.0	327	NC00377	BRUNSWICK
E	0.7	498	NC00212	BRUNSWICK
E	0.0	255	NC01026	CAMDEN
E	0.2	141	NC00648	CARTERET
E	-0.1	197	NC00385	CARTERET
E	0.5	318	NC00587	CARTERET
E	0.0	657	NC01293	CARTERET
E	0.7	269	NC01356	COLUMBUS
E	-0.1	295	NC00250	COLUMBUS
E	0.5	67	NC01175	CUMBERLAND
E	0.1	80	NC01435	CUMBERLAND
E	0.9	211	NC00822	CUMBERLAND
E	0.2	283	NC00596	CURRITUCK
E	-0.3	168	NC00883	DARE
E	0.1	191	NC00741	DARE
E	0.4	118	NC01487	DUPLIN
E		201	NC00169	EDGECOMBE
E	0.8	975	NC00708	HERTFORD
E	0.3	214	NC00379	NEW HANOVER
E	-0.5	312	NC00172	NEW HANOVER
E	0.2	1715	NC00600	NEW HANOVER
E	1.2	172	NC01365	NORTHAMPTON
E	0.2	175	NC00829	PASQUOTANK
E	0.3	94	NC00844	PENDER
E	0.1	154	NC01350	PENDER
E	0.0	133	NC00527	PITT
E	4.1	166	NC00740	PITT
E	0.7	534	NC00643	PITT
E	0.0	558	NC00233	PITT
E	-0.2	81	NC01415	ROBESON
E	0.3	113	NC01170	SAMPSON
E	1.0	249	NC00695	SAMPSON
E	0.5	263	NC00282	SAMPSON
E	0.8	534	NC01401	SAMPSON

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
E	0.2	243	NC00276	WAYNE
E	-0.5	377	NC01168	WILSON
C	0.3	118	NC00854	ALAMANCE
C	1.1	437	NC00880	ALAMANCE
C	0.3	3337	NC00166	ANSON
C		9	NC01374	CABARRUS
C	0.0	270	NC01283	CABARRUS
C	0.3	705	NC00359	CABARRUS
C	1.2	744	NC01450	CABARRUS
C	0.9	146	NC00605	CHATHAM
C	0.9	4759	NC00275	CHATHAM
C	2.0	2113	NC00227	DAVIDSON
C	21.5	62	NC01447	FORSYTH
C		100	NC01406	FORSYTH
C	0.7	230	NC00473	FORSYTH
C	3.1	301	NC00196	FORSYTH
C	0.0	2908	NC01342	FRANKLIN
C	0.8	3359	NC00625	FRANKLIN
C	0.8	9197	NC00604	FRANKLIN
C	-0.1	55	NC00583	GRANVILLE
C	0.4	287	NC00261	GRANVILLE
C	0.6	148	NC01148	GUILFORD
C	0.4	261	NC00957	GUILFORD
C	0.3	460	NC01407	GUILFORD
C	0.7	477	NC00914	GUILFORD
C	0.4	497	NC00213	GUILFORD
C	0.8	1612	NC01477	GUILFORD
C	2.7	13106	NC00206	GUILFORD
C	0.7	164	NC01464	HARNETT
C	0.6	184	NC00808	HARNETT
C	-0.2	140	NC01219	JOHNSTON
C	0.0	169	NC00554	JOHNSTON
C	-0.1	217	NC01152	JOHNSTON
C	0.1	4444	NC01360	JOHNSTON
C	0.3	210	NC01257	LEE
C	0.1	443	NC01444	MECKLENBURG
C	1.0	906	NC00636	MECKLENBURG
C	2.0	995	NC00959	MECKLENBURG
C	0.5	997	NC01154	MECKLENBURG
C	0.5	1569	NC00353	MECKLENBURG
C	0.9	1695	NC00387	MECKLENBURG

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
C	0.8	3153	NC01195	MECKLENBURG
C	-0.1	328	NC01094	MONTGOMERY
C	0.3	469	NC00887	MONTGOMERY
C	0.0	179	NC01340	MOORE
C	1.0	377	NC00271	MOORE
C	-0.1	859	NC00507	NASH
C	0.7	1145	NC01194	NASH
C	0.6	3910	NC01029	NASH
C	0.4	6075	NC01198	NASH
C	0.8	19558	NC00444	NASH
C	0.6	179	NC00922	ORANGE
C	0.0	963	NC01329	PERSON
C	0.5	459	NC00933	RANDOLPH
C		941	NC00809	RANDOLPH
C	1.2	1117	NC01521	RANDOLPH
C	0.7	2012	NC00623	RANDOLPH
C	0.3	1252	NC00901	RICHMOND
C	0.2	943	NC01353	ROCKINGHAM
C	1.5	2438	NC00602	ROCKINGHAM
C	0.8	394	NC01404	ROWAN
C	-0.2	563	NC00248	ROWAN
C	-0.2	602	NC00913	ROWAN
C	0.5	843	NC01220	ROWAN
C	2.0	1148	NC00909	STANLY
C	0.9	1333	NC00634	STANLY
C	0.0	518	NC00394	UNION
C	0.2	983	NC00162	UNION
C	0.0	6988	NC01310	UNION
C	0.6	354	NC00916	VANCE
C	1.3	21	NC00963	WAKE
C	0.6	436	NC00168	WAKE
C	0.2	570	NC01047	WAKE
C	0.5	853	NC00223	WAKE
C	1.3	934	NC01341	WAKE
C	1.4	1121	NC01177	WAKE
C	-0.4	3615	NC01355	WAKE
C	1.6	7265	NC01402	WAKE
C	1.6	8164	NC00795	WAKE
C		9119	NC00897	WAKE
C	1.6	9391	NC00770	WAKE
C	3.3	12451	NC00254	WAKE

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	0.8	121	NC01323	ALEXANDER
W	3.3	343	NC01338	ALEXANDER
W		926	NC00320	ALEXANDER
W	0.7	1239	NC01307	ALEXANDER
W	0.4	1621	NC01223	ALEXANDER
W	8.9	4680	NC00716	ALEXANDER
W	1.5	5592	NC00265	ALEXANDER
W	0.0	953	NC00615	ALLEGHANY
W	1.4	1024	NC00628	ALLEGHANY
W	1.8	1296	NC01439	ALLEGHANY
W	0.9	71	NC00549	ASHE
W	4.2	106	NC00858	ASHE
W	2.9	1777	NC00299	ASHE
W	13.5	2620	NC01458	ASHE
W	1.4	2721	NC00932	ASHE
W	0.6	264	NC01063	AVERY
W	4.6	1302	NC00830	AVERY
W	0.7	106	NC01071	BUNCOMBE
W	0.8	134	NC00448	BUNCOMBE
W	0.0	175	NC01216	BUNCOMBE
W	1.0	321	NC01358	BUNCOMBE
W	4.3	365	NC00351	BUNCOMBE
W	1.4	458	NC01137	BUNCOMBE
W	0.5	759	NC00286	BUNCOMBE
W	10.4	833	NC00763	BUNCOMBE
W	0.5	866	NC00295	BUNCOMBE
W	1.0	886	NC00390	BUNCOMBE
W	4.0	1186	NC01298	BUNCOMBE
W	5.3	1377	NC00729	BUNCOMBE
W	4.0	1496	NC00274	BUNCOMBE
W	2.6	1506	NC00810	BUNCOMBE
W	0.9	1606	NC01091	BUNCOMBE
W	1.1	1783	NC00429	BUNCOMBE
W	1.1	1825	NC01418	BUNCOMBE
W	2.5	2183	NC00289	BUNCOMBE
W	0.5	2324	NC01256	BUNCOMBE
W	4.0	3062	NC01388	BUNCOMBE
W	3.6	7806	NC00252	BUNCOMBE
W	3.1	44	NC01233	BURKE
W	4.0	131	NC00518	BURKE
W	2.4	484	NC00360	BURKE

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	2.8	598	NC01058	BURKE
W	0.5	677	NC00398	BURKE
W	2.9	1113	NC01037	BURKE
W	-0.2	1404	NC00926	BURKE
W	4.1	2442	NC00792	BURKE
W	1.8	286	NC01243	CALDWELL
W	0.9	404	NC00430	CALDWELL
W	4.2	784	NC00943	CALDWELL
W	1.2	1669	NC01271	CALDWELL
W	2.2	1855	NC01019	CALDWELL
W	1.0	1923	NC00713	CALDWELL
W		2555	NC00530	CALDWELL
W	1.4	3595	NC00776	CALDWELL
W	0.3	31	NC01492	CATAWBA
W	0.4	104	NC01376	CATAWBA
W	0.1	125	NC00466	CATAWBA
W	2.1	157	NC00482	CATAWBA
W		209	NC00774	CATAWBA
W	0.6	216	NC00985	CATAWBA
W	1.0	237	NC00243	CATAWBA
W	1.1	292	NC00982	CATAWBA
W	0.7	361	NC00580	CATAWBA
W	0.8	388	NC00974	CATAWBA
W	3.0	515	NC00903	CATAWBA
W	1.2	591	NC00967	CATAWBA
W	0.5	813	NC00268	CATAWBA
W	3.6	866	NC00734	CATAWBA
W	0.0	907	NC00471	CATAWBA
W	2.3	1207	NC00902	CATAWBA
W	2.4	1236	NC00746	CATAWBA
W	1.2	2828	NC01345	CATAWBA
W	1.4	4089	NC00305	CATAWBA
W	1.0	646	NC00635	CHEROKEE
W	1.3	1990	NC01392	CHEROKEE
W	0.6	360	NC01333	CLAY
W	0.7	710	NC01316	CLAY
W	1.2	1744	NC00504	CLAY
W	5.4	1890	NC00814	CLAY
W	0.8	2298	NC00535	CLAY
W	3.6	4095	NC01172	CLAY
W	0.2	207	NC00245	CLEVELAND

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	1.5	243	NC00408	CLEVELAND
W	1.3	856	NC00956	CLEVELAND
W	1.1	1120	NC00754	CLEVELAND
W	2.6	1690	NC01061	CLEVELAND
W	0.5	1831	NC00908	CLEVELAND
W	1.9	4912	NC01111	CLEVELAND
W	10.7	5000	NC01253	CLEVELAND
W	4.4	7662	NC00461	CLEVELAND
W	5.5	59088	NC00552	CLEVELAND
W	0.2	103	NC00270	DAVIE
W	3.4	496	NC00936	DAVIE
W	0.4	1854	NC00357	DAVIE
W	-1.6	21	NC00696	GASTON
W	0.1	39	NC01332	GASTON
W	0.4	90	NC01135	GASTON
W	0.1	94	NC00610	GASTON
W	3.8	203	NC01150	GASTON
W	0.4	251	NC00395	GASTON
W	1.2	268	NC00437	GASTON
W	1.1	472	NC01160	GASTON
W	1.3	614	NC01527	GASTON
W	0.5	617	NC00419	GASTON
W	1.7	630	NC00501	GASTON
W	0.1	745	NC00812	GASTON
W	1.4	1164	NC01001	GASTON
W	4.4	1181	NC00509	GASTON
W	0.6	1366	NC00949	GASTON
W	0.0	1422	NC01382	GASTON
W	0.4	1425	NC01380	GASTON
W	0.2	1489	NC00231	GASTON
W	2.8	1538	NC00869	GASTON
W	0.9	1787	NC01347	GASTON
W	0.9	1835	NC01324	GASTON
W	0.1	1853	NC00575	GASTON
W	1.2	1923	NC01541	GASTON
W	2.1	3628	NC00396	GASTON
W	1.3	4296	NC01496	GASTON
W	1.9	4830	NC00924	GASTON
W	0.0	5850	NC01052	GASTON
W	1.3	8487	NC01452	GASTON
W	4.0	13872	NC00413	GASTON

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	0.5	1182	NC00698	GRAHAM
W	-0.4	1191	NC00178	GRAHAM
W	8.8	2180	NC00445	GRAHAM
W	2.2	3372	NC01279	GRAHAM
W	-0.2	65	NC01207	HAYWOOD
W	0.8	489	NC00731	HAYWOOD
W	10.5	502	NC00738	HAYWOOD
W	1.3	747	NC00321	HAYWOOD
W	3.7	811	NC00800	HAYWOOD
W	0.7	940	NC00550	HAYWOOD
W	1.4	1189	NC00464	HAYWOOD
W	1.6	1520	NC00262	HAYWOOD
W	0.1	120	NC00717	HENDERSON
W	1.3	165	NC00639	HENDERSON
W	0.4	766	NC01086	HENDERSON
W	1.7	1248	NC01385	HENDERSON
W	3.9	1581	NC00955	HENDERSON
W	6.8	1990	NC00656	HENDERSON
W	5.5	2516	NC00777	HENDERSON
W	0.9	2629	NC00893	HENDERSON
W	3.2	3971	NC01064	HENDERSON
W	1.8	4557	NC01461	HENDERSON
W	331.8	6064	NC01274	HENDERSON
W	15.0	6151	NC00739	HENDERSON
W	3.3	7089	NC00663	HENDERSON
W	3.9	8637	NC00691	HENDERSON
W	3.5	10587	NC01542	HENDERSON
W	5.9	21122	NC00892	HENDERSON
W	2.3	202	NC01305	IREDELL
W	0.3	235	NC00526	IREDELL
W	-0.8	304	NC01308	IREDELL
W	0.8	430	NC01000	IREDELL
W	0.3	595	NC00499	IREDELL
W	0.6	814	NC00782	IREDELL
W	-0.2	832	NC01269	IREDELL
W	2.9	1077	NC01197	IREDELL
W	0.5	1225	NC00674	IREDELL
W	1.4	1745	NC01109	IREDELL
W	3.6	2003	NC01368	IREDELL
W	1.7	2188	NC00928	IREDELL
W	0.9	2374	NC00401	IREDELL

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	2.9	3439	NC00450	IREDELL
W	2.1	4212	NC00659	IREDELL
W	0.8	4228	NC01239	IREDELL
W	0.4	4365	NC01547	IREDELL
W	3.8	4425	NC01433	IREDELL
W	3.7	150	NC01400	JACKSON
W	0.6	211	NC00200	JACKSON
W	0.8	445	NC00548	JACKSON
W	0.0	1008	NC01098	JACKSON
W	0.2	3090	NC00645	JACKSON
W	5.4	3552	NC00307	JACKSON
W	3.0	3634	NC01145	JACKSON
W	0.9	46	NC01004	LINCOLN
W	0.3	105	NC00224	LINCOLN
W	0.3	293	NC01129	LINCOLN
W	0.5	315	NC00888	LINCOLN
W	5.0	379	NC00226	LINCOLN
W	0.1	1214	NC01476	LINCOLN
W	9.3	1301	NC01427	LINCOLN
W	3.8	1364	NC00361	LINCOLN
W	1.9	1453	NC01078	LINCOLN
W	6.1	1741	NC01428	LINCOLN
W	6.2	4815	NC01199	LINCOLN
W	0.9	5639	NC01484	LINCOLN
W	18.8	24357	NC01255	LINCOLN
W	1.1	236	NC01072	MACON
W	4.9	398	NC01474	MACON
W	-0.2	550	NC01459	MACON
W	3.7	575	NC01089	MACON
W	1.2	1167	NC00404	MACON
W	2.0	1610	NC01050	MACON
W	4.3	1616	NC00930	MACON
W	1.0	5789	NC00208	MACON
W	1.7	130	NC01228	MADISON
W	1.2	181	NC00891	MADISON
W	0.0	289	NC00964	MADISON
W	1.7	511	NC00454	MADISON
W	2.0	592	NC01520	MADISON
W	4.0	354	NC01143	MCDOWELL
W	2.5	1119	NC00533	MCDOWELL
W	7.4	1228	NC01317	MCDOWELL

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	2.7	1316	NC01304	MCDOWELL
W	1.7	1828	NC01169	MCDOWELL
W	0.9	2231	NC00712	MCDOWELL
W	5.3	3036	NC00544	MCDOWELL
W	2.7	3236	NC00446	MCDOWELL
W	0.7	5897	NC01296	MCDOWELL
W	7.0	6314	NC01155	MCDOWELL
W	1.6	4325	NC01326	MITCHELL
W	3.5	7445	NC01278	MITCHELL
W	0.9	351	NC00191	POLK
W	0.8	425	NC00714	POLK
W	1.5	831	NC00724	POLK
W	17.3	1113	NC01375	POLK
W	1.0	189	NC01112	RUTHERFORD
W	0.2	594	NC00780	RUTHERFORD
W	0.8	741	NC00672	RUTHERFORD
W	0.8	831	NC00941	RUTHERFORD
W	0.6	1052	NC01437	RUTHERFORD
W	3.2	1523	NC00388	RUTHERFORD
W	4.6	1734	NC00409	RUTHERFORD
W	3.6	491	NC00779	STOKES
W	1.0	510	NC00154	STOKES
W	0.2	543	NC00671	STOKES
W	0.4	2408	NC00264	STOKES
W	0.4	179	NC00828	SURRY
W	1.5	206	NC00498	SURRY
W	0.9	337	NC00783	SURRY
W	2.3	561	NC00294	SURRY
W	1.2	708	NC00209	SURRY
W	6.7	953	NC00997	SURRY
W		992	NC01488	SURRY
W	1.8	1071	NC01191	SURRY
W	0.7	1603	NC00217	SURRY
W	2.8	1678	NC00534	SURRY
W	3.1	1892	NC01526	SURRY
W	0.6	2007	NC01371	SURRY
W	0.1	2021	NC01025	SURRY
W	2.1	2377	NC00996	SURRY
W	2.4	2409	NC01066	SURRY
W	0.3	3199	NC00766	SURRY
W	0.4	6917	NC00757	SURRY

REGION	AIR pCi/L	H2O pCi/L	HOUSE ID	COUNTY
W	9.5	8192	NC00288	SURRY
W	2.3	2510	NC00453	TRANSYLVANIA
W	8.2	2846	NC00415	TRANSYLVANIA
W	15.4	4685	NC00425	TRANSYLVANIA
W	5.5	6693	NC00995	TRANSYLVANIA
W	1.8	10391	NC01146	TRANSYLVANIA
W	0.5	70	NC00621	WATAUGA
W	1.3	728	NC01206	WATAUGA
W	0.4	1278	NC01036	WATAUGA
W	2.3	1416	NC00977	WATAUGA
W	14.0	5839	NC01006	WATAUGA
W	3.1	5914	NC00994	WATAUGA
W	9.0	8483	NC01093	WATAUGA
W	7.1	20183	NC01403	WATAUGA
W	7.3	1146	NC01193	WILKES
W	1.3	1307	NC01142	WILKES
W	1.6	1317	NC00953	WILKES
W	4.0	1481	NC00331	WILKES
W	1.2	2167	NC01328	WILKES
W	1.4	2189	NC01159	WILKES
W	0.2	4437	NC01113	WILKES
W	1.2	4754	NC00838	WILKES
W	1.7	403	NC00938	YADKIN
W	1.9	501	NC00805	YADKIN
W	0.6	548	NC00251	YADKIN
W	0.6	578	NC00786	YADKIN
W	0.8	5097	NC00753	YADKIN
W	0.1	122	NC01330	YANCEY
W	0.6	198	NC01513	YANCEY
W	3.4	1283	NC00381	YANCEY
W	4.9	1329	NC01018	YANCEY

Concentrations rounded to nearest 10th pCi L⁻¹ and nearest pCi L⁻¹ for air and water respectively.

APPENDIX VII

DATA FOR PAIRED WATER SAMPLE ANALYSIS

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
E	NC00609	71	81	62	20	27.4
E	NC00561	76	84	68	16	21.1
E	NC01415	81	79	84	5	6.6
E	NC01491	93	80	107	27	28.7
E	NC00844	94	89	99	10	10.3
E	NC01252	109	101	116	15	13.7
E	NC01170	113	81	146	65	57.0
E	NC01487	118	133	103	30	25.4
E	NC00527	133	141	124	17	12.9
E	NC00648	141	141	141	0	0.3
E	NC01350	154	149	159	10	6.5
E	NC00740	166	174	157	16	9.8
E	NC00883	168	177	160	17	10.3
E	NC01365	172	174	169	6	3.3
E	NC00829	175	165	186	20	11.4
E	NC00741	191	194	187	7	3.6
E	NC00385	197	201	192	9	4.4
E	NC00169	201	193	209	16	7.9
E	NC00822	211	188	235	47	22.4
E	NC00379	214	204	224	20	9.4
E	NC00463	224	190	257	67	30.2
E	NC00276	243	296	191	105	43.2
E	NC00695	249	225	273	48	19.3
E	NC01026	255	267	243	24	9.5
E	NC00282	263	416	111	304	115.6
E	NC01356	269	265	273	8	3.2
E	NC00596	283	291	275	16	5.5
E	NC00250	295	293	296	3	0.9
E	NC00172	312	301	323	22	6.9
E	NC00587	318	396	240	156	49.1
E	NC01168	377	393	361	31	8.3
E	NC00643	534	537	530	6	1.1
E	NC01401	534	542	527	14	2.7
E	NC00233	558	587	528	58	10.4
E	NC01293	657	676	639	36	5.5
E	NC00708	975	949	1001	52	5.3
E	NC00921	1011	1020	1002	18	1.8
E	NC00600	1715	1735	1694	41	2.4
C	NC01374	9	10	8	1	15
C	NC00963	21	4	37	33	161.6
C	NC00583	55	40	70	30	54.9
C	NC01447	62	67	57	10	15.6

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
C	NC01406	100	77	123	46	46.0
C	NC00854	118	142	94	48	40.2
C	NC01219	140	145	135	10	6.8
C	NC00605	146	156	137	19	12.8
C	NC01464	164	169	158	12	7.1
C	NC00554	169	167	172	6	3.5
C	NC00922	179	178	180	1	0.8
C	NC00808	184	174	194	19	10.4
C	NC01257	210	236	183	52	25.1
C	NC01152	217	198	235	36	16.7
C	NC00473	230	249	211	38	16.3
C	NC00957	261	282	240	41	15.8
C	NC01283	270	280	261	19	7.0
C	NC00261	287	355	218	137	47.8
C	NC00196	301	268	334	66	21.8
C	NC01094	328	321	335	14	4.3
C	NC00916	354	338	370	32	9.0
C	NC01404	394	394	395	1	0.2
C	NC00168	436	452	420	32	7.4
C	NC00880	437	457	417	41	9.3
C	NC01444	443	459	426	33	7.4
C	NC00933	459	424	494	70	15.4
C	NC01407	460	515	405	110	24.0
C	NC00887	469	471	467	4	0.9
C	NC00394	518	536	500	36	7.0
C	NC00248	563	553	574	21	3.8
C	NC01047	570	596	544	52	9.1
C	NC00913	602	587	617	30	5.0
C	NC00359	705	740	670	70	9.9
C	NC00722	748	717	778	61	8.2
C	NC01220	843	814	872	58	6.9
C	NC00223	853	861	844	17	2.0
C	NC00507	859	894	825	69	8.1
C	NC00636	906	892	919	27	3.0
C	NC01341	934	938	930	7	0.8
C	NC00809	941	919	964	44	4.7
C	NC00162	983	964	1001	38	3.8
C	NC00959	995	993	997	4	0.4
C	NC01154	997	1020	973	48	4.8
C	NC01521	1117	1181	1053	128	11.4
C	NC01177	1121	1140	1101	39	3.5
C	NC01194	1145	1179	1111	68	6.0

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
C	NC00909	1148	1133	1163	30	2.6
C	NC00901	1252	1252	1253	2	0.1
C	NC00634	1333	1368	1297	71	5.3
C	NC00353	1569	1568	1571	2	0.2
C	NC01477	1612	1510	1715	205	12.7
C	NC00387	1695	1728	1663	65	3.9
C	NC00623	2012	2039	1986	53	2.6
C	NC00227	2113	2109	2117	8	0.4
C	NC00602	2438	2465	2410	55	2.2
C	NC01342	2908	2937	2879	58	2.0
C	NC01195	3153	3106	3201	94	3.0
C	NC00166	3337	3278	3396	118	3.5
C	NC00625	3359	3358	3360	2	0.1
C	NC01355	3615	3633	3598	34	0.9
C	NC01029	3910	3910	3909	1	0.0
C	NC00275	4759	4795	4723	72	1.5
C	NC01198	6075	6138	6013	125	2.1
C	NC01310	6988	6994	6982	11	0.2
C	NC01402	7265	7182	7349	167	2.3
C	NC00795	8164	8325	8003	322	3.9
C	NC00897	9119	9007	9231	224	2.5
C	NC00770	9391	9352	9429	77	0.8
C	NC00206	13106	12937	13276	339	2.6
C	NC00254	19451	19450	19453	3	0.0
C	NC00444	19558	19664	19452	212	1.1
W	NC00696	21	22	21	1	5.4
W	NC01332	39	52	26	26	65.8
W	NC01004	46	53	40	13	28.4
W	NC01207	65	63	67	4	6.7
W	NC00621	70	68	73	5	7.3
W	NC00549	71	79	63	16	22.2
W	NC01135	90	92	88	3	3.8
W	NC00610	94	98	90	8	8.9
W	NC00270	103	97	109	12	11.6
W	NC01376	104	99	110	11	10.3
W	NC00224	105	125	85	40	37.9
W	NC00858	106	100	111	11	10.1
W	NC01071	106	123	89	34	31.6
W	NC00717	120	128	113	15	12.4
W	NC01323	121	142	101	41	34.0
W	NC00466	125	120	130	10	8.2
W	NC01228	130	145	115	29	22.5

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC00518	131	157	105	52	39.6
W	NC00448	134	152	117	35	26.0
W	NC00482	157	150	164	14	9.0
W	NC01216	175	161	189	29	16.4
W	NC00828	179	187	172	15	8.3
W	NC00891	181	190	171	19	10.8
W	NC01112	189	176	201	25	13.3
W	NC01513	198	192	204	11	5.6
W	NC01305	202	193	210	17	8.5
W	NC01150	203	241	165	76	37.4
W	NC00498	206	208	205	3	1.6
W	NC00245	207	241	172	69	33.6
W	NC00774	209	207	210	3	1.4
W	NC00200	211	207	215	8	3.7
W	NC00985	216	213	218	4	2.1
W	NC00526	235	273	197	76	32.2
W	NC01072	236	203	268	65	27.6
W	NC00243	237	247	228	19	8.2
W	NC00408	243	236	251	15	6.3
W	NC00395	251	240	263	23	9.2
W	NC01063	264	280	247	33	12.5
W	NC01243	286	272	300	28	9.7
W	NC00964	289	279	299	20	6.8
W	NC00982	292	280	303	23	8.0
W	NC01129	293	297	288	9	3.2
W	NC01308	304	332	276	56	18.3
W	NC00888	315	312	317	5	1.6
W	NC01358	321	299	343	44	13.7
W	NC00783	337	343	330	12	3.7
W	NC01338	343	320	367	47	13.6
W	NC00191	351	360	341	19	5.5
W	NC01143	354	347	361	14	4.1
W	NC01333	360	371	349	22	6.0
W	NC00580	361	407	315	91	25.3
W	NC00351	365	354	377	23	6.3
W	NC00226	379	356	402	46	12.2
W	NC00974	388	385	391	6	1.6
W	NC01474	398	396	400	4	0.9
W	NC00938	403	406	401	6	1.4
W	NC00430	404	403	405	2	0.4
W	NC00714	425	416	435	19	4.5
W	NC01000	430	409	452	43	10.0

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC00548	445	428	463	35	7.9
W	NC01137	458	480	436	44	9.6
W	NC01160	472	504	441	63	13.4
W	NC00360	484	454	514	60	12.3
W	NC00731	489	498	480	18	3.8
W	NC00779	491	494	488	6	1.1
W	NC00936	496	557	435	123	24.7
W	NC00805	501	517	485	32	6.4
W	NC00738	502	503	501	2	0.5
W	NC00154	510	486	535	50	9.7
W	NC00454	511	516	507	9	1.8
W	NC00671	543	568	518	50	9.2
W	NC00251	548	537	558	21	3.8
W	NC01459	550	574	526	48	8.7
W	NC00294	561	513	609	96	17.0
W	NC01089	575	538	611	73	12.8
W	NC00786	578	598	558	40	7.0
W	NC00967	591	562	620	58	9.9
W	NC00499	595	634	555	79	13.2
W	NC01058	598	554	643	88	14.8
W	NC01527	614	651	577	74	12.0
W	NC00501	630	594	666	73	11.5
W	NC00635	646	590	702	112	17.3
W	NC00398	677	681	673	9	1.3
W	NC00209	708	735	682	54	7.6
W	NC01316	710	703	718	15	2.1
W	NC01206	728	745	711	33	4.6
W	NC00672	741	762	721	41	5.6
W	NC00812	745	755	735	20	2.6
W	NC00321	747	754	740	14	1.8
W	NC00286	759	755	762	6	0.8
W	NC01086	766	765	767	2	0.3
W	NC00943	784	812	756	57	7.2
W	NC00800	811	812	811	0	0.1
W	NC00268	813	784	842	58	7.1
W	NC00782	814	808	819	11	1.4
W	NC00724	831	837	825	11	1.4
W	NC00941	831	813	848	35	4.2
W	NC01269	832	823	841	18	2.2
W	NC00763	833	783	882	100	12.0
W	NC00956	856	810	902	92	10.7
W	NC00734	866	849	883	34	3.9

REGION	HOUSE ID	H2O pCl/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC00295	866	840	892	52	6.0
W	NC00390	886	900	872	27	3.1
W	NC00471	907	915	899	16	1.8
W	NC00320	926	927	926	0	0.0
W	NC00550	940	858	1022	164	17.5
W	NC00615	953	963	943	21	2.2
W	NC00997	953	915	992	77	8.0
W	NC01488	992	998	986	12	1.2
W	NC00628	1024	1065	983	82	8.0
W	NC01437	1052	1010	1094	84	8.0
W	NC01191	1071	1164	978	186	17.3
W	NC01197	1077	1108	1046	63	5.8
W	NC01037	1113	1120	1105	15	1.4
W	NC01375	1113	1100	1126	27	2.4
W	NC00533	1119	1148	1089	59	5.3
W	NC01193	1146	1171	1121	51	4.4
W	NC01001	1164	1196	1133	63	5.4
W	NC00404	1167	1189	1144	45	3.9
W	NC00509	1181	1162	1199	37	3.2
W	NC00698	1182	1198	1166	32	2.7
W	NC01298	1186	1178	1193	16	1.3
W	NC00178	1191	1111	1270	159	13.3
W	NC00674	1225	1193	1258	65	5.3
W	NC01317	1228	1220	1235	14	1.2
W	NC00746	1236	1257	1214	43	3.5
W	NC01307	1239	1264	1213	51	4.1
W	NC01385	1248	53	2444	2392	191.6
W	NC01036	1278	1267	1290	23	1.8
W	NC00381	1283	1297	1269	28	2.2
W	NC01439	1296	1288	1305	17	1.3
W	NC01427	1301	1303	1300	3	0.2
W	NC00830	1302	1382	1223	159	12.2
W	NC01142	1307	1327	1288	39	3.0
W	NC01304	1316	1265	1366	101	7.7
W	NC00953	1317	1283	1352	68	5.2
W	NC01018	1329	1368	1290	78	5.9
W	NC00361	1364	1396	1332	64	4.7
W	NC00949	1366	1362	1371	9	0.7
W	NC00729	1377	1409	1344	65	4.7
W	NC00926	1404	1422	1387	35	2.5
W	NC00977	1416	1458	1375	83	5.9
W	NC01382	1422	1439	1405	34	2.4

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC01380	1425	1426	1423	3	0.2
W	NC01078	1453	1412	1495	83	5.7
W	NC00331	1481	1519	1443	76	5.1
W	NC00231	1489	1454	1523	69	4.7
W	NC00274	1496	1431	1560	129	8.6
W	NC00810	1506	1520	1491	29	2.0
W	NC00262	1520	1513	1529	16	1.1
W	NC00388	1523	1471	1576	104	6.8
W	NC00869	1538	1605	1470	134	8.7
W	NC00955	1581	1553	1609	56	3.5
W	NC00217	1603	1610	1596	14	0.9
W	NC01091	1606	1594	1618	24	1.5
W	NC01050	1610	1645	1576	68	4.2
W	NC00930	1616	1654	1578	76	4.7
W	NC01223	1621	1589	1653	63	3.9
W	NC00534	1678	1664	1691	27	1.6
W	NC01061	1690	1751	1628	122	7.2
W	NC00409	1734	1845	1623	223	12.8
W	NC01428	1741	1808	1674	133	7.7
W	NC00504	1744	1796	1692	104	6.0
W	NC01109	1745	1756	1733	23	1.3
W	NC00299	1777	1809	1745	65	3.6
W	NC00429	1783	1796	1770	26	1.5
W	NC01347	1787	1781	1794	13	0.7
W	NC01418	1825	1878	1772	106	5.8
W	NC01169	1828	1813	1844	31	1.7
W	NC00908	1831	1817	1845	28	1.5
W	NC01324	1835	1845	1824	21	1.1
W	NC00575	1853	1860	1846	14	0.7
W	NC00814	1890	1877	1902	24	1.3
W	NC01526	1892	1968	1816	152	8.0
W	NC01541	1923	1768	2078	310	16.1
W	NC00713	1923	1787	2060	274	14.2
W	NC01392	1990	2050	1931	119	6.0
W	NC00656	1990	2094	1886	208	10.5
W	NC01368	2003	1971	2035	64	3.2
W	NC01371	2007	2016	1999	16	0.8
W	NC01025	2021	2000	2043	42	2.1
W	NC01328	2167	2264	2070	193	8.9
W	NC00289	2183	2165	2200	35	1.6
W	NC00928	2188	2206	2170	37	1.7
W	NC01159	2189	2267	2110	157	7.2

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC00712	2231	2248	2214	34	1.5
W	NC00535	2298	2349	2158	191	8.5
W	NC01256	2324	2468	2179	289	12.4
W	NC00401	2374	2360	2387	27	1.1
W	NC00996	2377	2440	2315	125	5.3
W	NC00264	2408	2393	2424	31	1.3
W	NC01066	2409	2403	2414	11	0.5
W	NC00792	2442	2536	2347	189	7.7
W	NC00453	2510	2511	2509	2	0.1
W	NC00777	2516	2537	2494	43	1.7
W	NC00530	2555	2616	2494	122	4.8
W	NC01458	2620	2625	2615	10	0.4
W	NC00893	2629	2582	2677	94	3.6
W	NC00932	2721	2747	2695	53	1.9
W	NC01345	2828	2818	2838	20	0.7
W	NC00415	2846	2875	2817	58	2.0
W	NC00544	3036	3118	2954	164	5.4
W	NC01388	3062	3140	2984	156	5.1
W	NC00645	3090	3122	3058	64	2.1
W	NC00766	3199	3121	3277	156	4.9
W	NC00446	3236	3263	3209	55	1.7
W	NC01279	3372	3537	3207	330	9.8
W	NC00450	3439	3414	3464	50	1.4
W	NC00307	3552	3597	3507	90	2.5
W	NC00776	3595	3694	3495	200	5.6
W	NC00396	3628	3908	3349	559	15.4
W	NC01145	3634	3429	3838	409	11.3
W	NC01064	3971	4004	3940	64	1.6
W	NC00305	4089	4026	4152	126	3.1
W	NC01172	4095	4111	4080	30	0.7
W	NC00659	4212	4277	4148	129	3.1
W	NC01239	4228	4221	4236	14	0.3
W	NC01496	4296	4215	4377	162	3.8
W	NC01326	4325	4333	4318	15	0.3
W	NC01547	4365	4316	4414	98	2.2
W	NC01433	4425	4432	4418	14	0.3
W	NC01113	4437	4392	4482	90	2.0
W	NC01461	4557	4575	4539	36	0.8
W	NC00716	4680	4560	4801	241	5.2
W	NC00425	4685	4643	4728	85	1.8
W	NC00838	4754	4782	4726	55	1.2
W	NC01199	4815	4848	4782	67	1.4

REGION	HOUSE ID	H2O pCi/L	VIAL 1	VIAL 2	ABS DIFF	% DIFF
W	NC00924	4830	4844	4816	28	0.6
W	NC01111	4912	4956	4867	90	1.8
W	NC01253	5000	5010	4990	20	0.4
W	NC00753	5097	5079	5115	36	0.7
W	NC01484	5639	5627	5650	23	0.4
W	NC00208	5789	5583	5994	410	7.1
W	NC01006	5839	5832	5846	14	0.2
W	NC01052	5850	6270	5429	841	14.4
W	NC01296	5897	5939	5856	83	1.4
W	NC00994	5914	5886	5942	56	1.0
W	NC01274	6064	6017	6110	94	1.6
W	NC00739	6151	6305	5997	309	5.0
W	NC01155	6314	6399	6230	170	2.7
W	NC00995	6693	6685	6702	17	0.3
W	NC00757	6917	7015	6819	196	2.8
W	NC00663	7089	7107	7071	37	0.5
W	NC01278	7445	7409	7481	71	1.0
W	NC00461	7662	7099	8225	1126	14.7
W	NC00288	8192	8179	8205	26	0.3
W	NC01093	8483	8242	8724	482	5.7
W	NC01452	8487	8257	8717	459	5.4
W	NC00691	8637	8538	8737	200	2.3
W	NC01146	10391	10509	10272	236	2.3
W	NC01542	10587	10776	10397	379	3.6
W	NC00413	13872	14193	13551	642	4.6
W	NC00892	21122	21098	21146	48	0.2
W	NC01255	24357	23860	24855	996	4.1
W	NC00552	59088	58843	59333	490	0.8

Concentrations rounded to nearest pCi L⁻¹ for water samples.