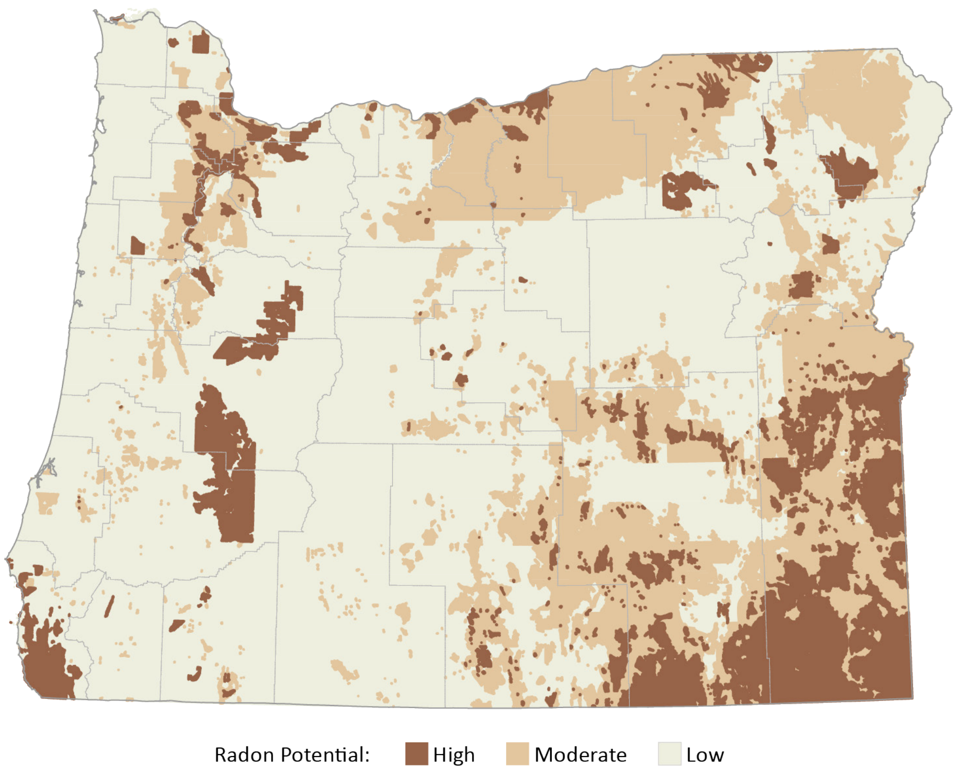
State of Oregon
Oregon Department of Geology and Mineral Industries
Brad Avy, State Geologist

OPEN-FILE REPORT O-18-01

RADON POTENTIAL IN OREGON

by Jon J. Franczyk[1], Clark A. Niewendorp[1], and Jason D. McClaughry[2]



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DISCLAIMER

Cover image: Map of radon potential in Oregon, showing areas of high, moderate, and low potential. See Sheet 1 for full-size map.

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GEOGRAPHIC INFORMATION SYSTEM (GIS) DATA

See the digital publication folder for files.
Geodatabase is Esri® version 10.5.1 format. The geodatabase contains embedded and the metadata is a separate .xml format file.

GEODATABASE

Radon_Potential_in_Oregon.gdb:
Feature class: *Radon_Data* (polygon)

Metadata in .xml file format:
Radon_Data.xml

ABSTRACT

Mapping the radon potential in Oregon is a research project initiated by the Oregon Department of Geology and Mineral Industries (DOGAMI) for the Oregon Geographic Information Council (OGIC), Natural Occurring Hazardous Materials (NOHM) element of the Hazard Framework Implementation Team. DOGAMI, in cooperation with the Oregon Health Authority (OHA), Radon Awareness Program, created the map of radon potential in Oregon at scale of 1:750,000. This project includes a spatial geodatabase with a resolution of 1:100,000 scale. DOGAMI identified areas of radon potential by the use of four data sources: (1) indoor radon measurements, (2) NURE equivalent uranium (eU) calculations (aeroradiometric data from the National Uranium Resource Evaluation [NURE] project), (3) locations of known uranium host rocks (Mineral Information Layer for Oregon, release 2 [MILO-2]), and (4) geologic polygons in OGDC-6 (Oregon Geologic Data Compilation, release 6, geodatabase). The DOGAMI map and geodatabase group geologic polygons into categories based on an estimation of ability of a particular rock/sediment type to generate radon. The approach maps variation in radon between and within geologic polygons and appears effective at differentiating Oregon's scattered high and moderate radon potential areas. Therefore, this map and geodatabase can serve as a regional guide for identification of areas needing further indoor radon testing, and, through that, as a basis for proactive decision making.

1.0 INTRODUCTION

Radon is a colorless and odorless gas, a radioactive byproduct of radium (**Figure 1-1**). This gas becomes a human health concern when radon makes its way from the ground into structures. If the gas builds up to high concentrations in indoor air, radon and its decay products can get trapped in the lungs through inhalation exposure. As the particles continue to decay, they release small bursts of energy (alpha emission) that can damage lung tissue. Long-term exposure to high radon levels may lead to lung cancer in some people. The only way to determine radon levels accurately in buildings is by making measurements of indoor air. All residences regardless of location should be tested for radon.

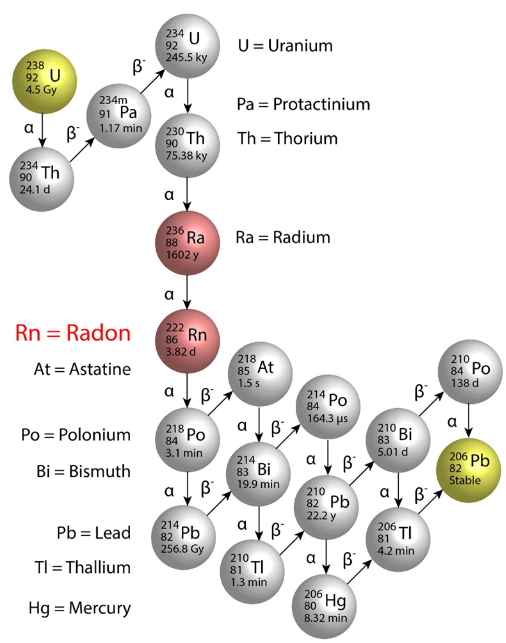


Figure 1-1. Uranium-238 radioactive chain diagram. The radioactive chain begins with uranium-238 (U-238, upper yellow sphere) and ends with stable lead-206 (Pb-208, lower yellow sphere). Radon (Rn = red lettering and sphere) is a colorless and odorless gas, a radioactive byproduct of radium (Ra = red lettering and sphere). As radon particles decay, they release small bursts of energy (α = alpha emission). Diagram modified from original image licensed under the Creative Commons Attribution (CC BY) 3.0 imported license (https://commons.wikimedia.org/wiki/File:Decay_chain(4n%2B2,_Uranium_series).svg)

High-risk areas of indoor radon can, however, be identified using different approaches: by measuring radon concentration in a sufficiently large sample of existing buildings, by studying the geological factors influencing indoor radon levels; or by a combination of indoor radon measurements and knowledge about geology and building characteristics (Miles and Appleton, 2005). To map radon potential, this study combined indoor radon measurements, geological factors, and knowledge about the geology. The four sources of data for the radon potential map, listed in order of importance, starting with most important source data (Sheet 1), are:

- Uranium host rock data (Mineral Information Layer for Oregon release 2 [MILO-2], Niewendorp and Geitgey, 2010);
- Indoor radon measurements shared by test kit manufacturers with OHA (Figure 1-2). Maps of indoor radon levels are a convenient method of identifying the areas at risk (Miles and Appleton, 2005). DOGAMI has a confidentiality understanding with OHA not to share individual results for radon testing data;
- Aeroradiometric data from the National Uranium Resource Evaluation project (NURE) (Hill and others, 2009);
- Statewide geologic mapping (Oregon Geology Data Compilation, release 6 [OGDC-6]; Smith and Rowe, 2010).

In 2015, the Oregon Geographic Information Council (OGIC) funded DOGAMI (Interagency Agreement 106099) to assess the radon potential statewide. Radon is part of the Natural Occurring Hazardous Materials (NOHM) element of the Hazard Framework Implementation Team. The deliverables for this project include:

- A statewide radon potential map and a related geodatabase with a feature class called Radon_Data;
- GILO (Geo-analytical Information Layer for Oregon), release 2;
- Metadata for each dataset;
- An open-file report (OFR) including a separate companion OFR describing a pilot project focused on local radon risk;
- An NOHM Data Standard and Stewardship Plan, Version 1.0, an OGIC endorsed standard that includes radon.

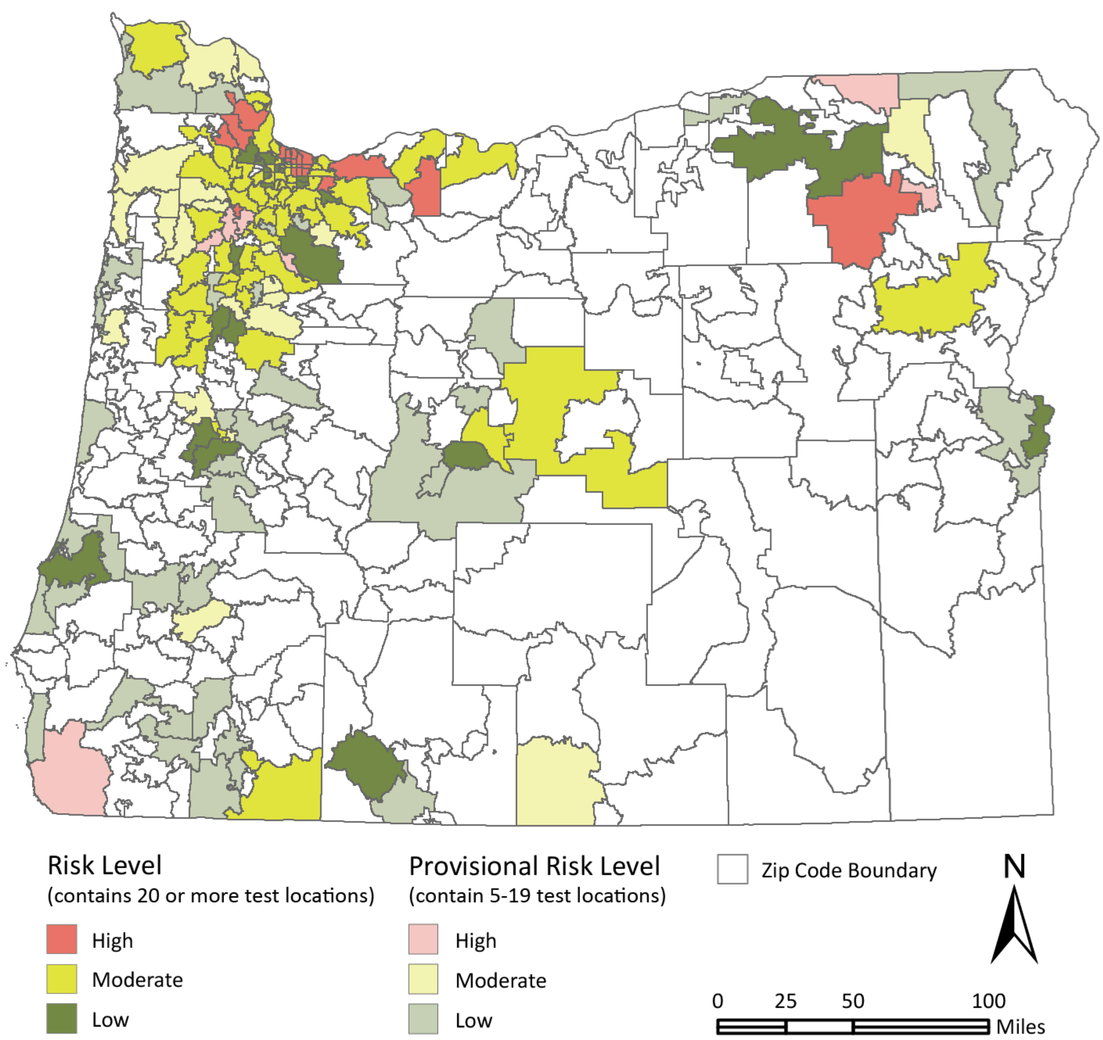
This report, geodatabase, and Sheet 1 fulfill the requirements for the first and part of the third deliverable.

1.1 Previous mapping

OHA has carried out radon mapping and it has an online interactive map of radon risk levels in Oregon (Burns and others, 1998; OHA, 2014) (http://geo.maps.arcgis.com/home/item.html?id=0c3757b6a8fb4dd1946633398112b003). The extent to which radon risk mapping has been conducted so far in Oregon is by ZIP code screening based on indoor radon gas measurements. Besides this, Otton (1993) compiled a county level map of Oregon's radon risk.

Figure 1-2 shows a map of radon risk compiled from OHA's summary of indoor radon test results by ZIP codes.

Figure 1-2. Map of radon health risk levels in Oregon by ZIP code (adapted from OHA, 2014; http://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/HEALTHYNEIGHBORHOODS/RADONGAS/Documents/final2015_summarytable.pdf). OHA's radon potential map, by design, does not show areas of high and moderate radon potential smaller than the ZIP code level. Test results that are equal to or exceed 4 pCi/L high risk level (red) is the level at which the U.S. Environmental Protection Agency recommends mitigation. Note that even radon levels below 4 pCi/L pose some risk because there is no safe level of radon. ZIP codes not assigned a radon risk are white. These ZIP codes have fewer than five locations with test kit results.



2.0 MODEL STRUCTURE

Key products of this project are the Radon Potential in Oregon map (Sheet 1) and its geodatabase. Production of the radon potential map required the assessment and integration of spatial data on the basis of (1) whether the data were collected using direct measurements, e.g., MILO and indoor radon tests, and (2) indirect methods including an aerial NURE eU survey from which the concentration of equivalent uranium in rock and soil is calculated.

In **Table 2-1**, the first column lists the data sources used in this project with the most important on top (Chen, 2009): uranium occurrences, prospects, and mines followed by indoor radon measurements, NURE equivalent uranium (eU) survey, and then geologic (OGDC-6). However, in locations where a geologic polygon has a higher NURE rank than indoor radon, then the NURE rank supersedes the indoor radon rank. MILO-2's data supersedes all other sources of data (Hughes, 1994). **Table 2-1** also lists an index of radon hazard value/levels for each source of data. The geodatabase classification scheme of one (1), two (2), and three (3) corresponds to low, moderate, and high radon potential, respectively.

Table 2-1. Summary of radon hazard values and ranking system (modified from Gundersen and others, 1993).

	Radon Hazard Value/Level		
Data Source	**Low**	**Moderate**	**High**
Uranium occurrences, prospects, and mines	Supersedes all other factors	Supersedes all other factors	Supersedes all other factors
Indoor radon test kit measurements (average)	< 2 pCi/L‡	2–4 pCi/L‡	> 4 pCi/L‡
Aerial NURE equivalent uranium eU survey	< 1.5 ppm eU⁺	1.5–2.5 ppm eU⁺	> 2.5 ppm eU⁺
OGDC-6 geologic map unit polygons	Low* = geology or geology unlikely to contain uranium	Moderate* = (variable), geology may have uranium containing rocks	High* = geology contains uranium, or has rock types known to contain uranium

Data sources: uranium occurrences, prospects, and mines (Niewendorp and Geitgey, 2010); indoor radon (OHA, 2014), NURE eU survey (Hill and others, 2009); and OGDC-6 (Smith and Roe, 2015).

‡ Picocurie per liter of air.

⁺ Parts per million (ppm) equivalent uranium (eU).

* Definitions modified from Washington Department of Natural Resources (2015), radon hazard classification.

2.1 Data input and processing

The subsections below give a general description of data inputs and geoprocessing steps applied to arrive at a "High," "Moderate," and "Low" radon hazard level assignments. Simplified processing diagrams for each data factor (**Table 2-1**) summarize steps. See the appendix for a synopsis of the processing steps for the data in indoor radon, NURE eU, and OGDC-6. Toolbox functions in Esri® ArcMap® 10.5.1 and ArcGIS Pro® 2.0.0 performed geoprocessing of the data.

2.1.1 OGDC-6

Uranium and radium concentrations in surface rocks and soils are useful indicators of the potential for radon emissions from the ground. Radon potential is estimated for the rock types in OGDC-6 on the basis of the typical uranium content of the rock materials listed in **Table 2-2**. This type of data was used where no other data were available, e.g., along Oregon's southwest coastline. **Figure 2-1** illustrates the geoprocessing steps performed on the rock type data in OGDC-6 to derive radon hazard values for individual geologic unit polygons.

Table 2-2. Typical uranium content in different rock materials (adapted from Klepper and Wyant, 1957; Larson and Gottfried, 1960; NCRP, 1987).

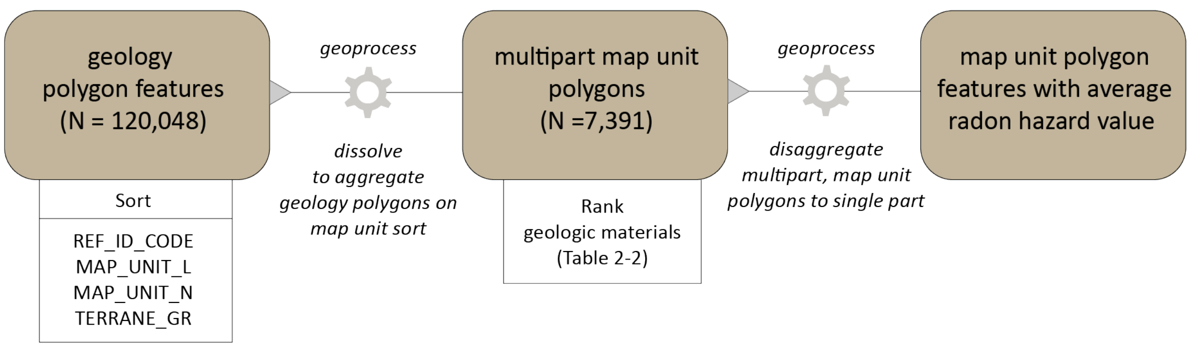
	Typical Uranium Content*		
Rock Category	**Percent**	**ppm****	**Rank**
Ultrabasic igneous rocks	0.001	1	Low (1)
Basic igneous rocks	0.001	1	Low (1)
Intermediate igneous rocks	0.002	2	Moderate (2)
Acidic (Felsic) igneous rocks	0.004	4	High (3)
Sedimentary rocks* (limestone, shale, mudstone, sandstone, siltstone, conglomerate)	0.001	1	Low (1)
Unconsolidated sediments	nd	nd	Low (1)
Metamorphic rocks	nd	nd	Low (1)

* Uranium content of these materials is variable and radon emanations vary.

** ppm is parts per million.

nd = no data reported.

Figure 2-1. Geodatabase processing steps to rank the ability of geologic rock types in OGDC-6 to generate radon.



2.1.2 Indoor radon data

Testing for indoor radon provides a gauge as to whether radon is an issue at a particular location. The Environmental Protection Agency's (EPA) threshold of radon action level in buildings is 4 piC/L or greater (U.S. EPA, 2016). The OHA sample set contains data for 15,913 indoor radon tests (**Figure 2-2**) in Oregon. For the mapping purpose of associating indoor radon tests with geologic polygons, the following protocol guided indoor radon data handling and processing:

- The threshold for consideration of risk level includes only those polygons that contained five or more tests. **Figure 2-3** illustrates the data processing steps performed on the Indoor radon data.
- We developed a reference grid (raster) with a square cell resolution of 15 feet (4.57 m), each cell named by a coordinate pair associated with its center. This raster grid scale was initially set up for the NURE eU data and then used here to support consistency.
- Zonal statistics applied to the raster dataset calculated an unweighted arithmetic average of the radon value from all of the cells within each of the geology polygons. To calculate the number of tests that fall within each polygon, we used ArcGIS Pro's tool resource called Summarize Within.

- Polygons with an unweighted arithmetic average that fell below 2.0 pCi/L were assigned a rank of 1. A rank of 2 was assigned if the average was 2.0 to 4.0 pCi/L. If the average was greater than 4.0 pCi/L, a rank of 3 was assigned (**Table 2-1**).

See the appendix for details of the indoor radon processing steps.

Figure 2-2. Map showing areas of indoor radon test coverage in Oregon.

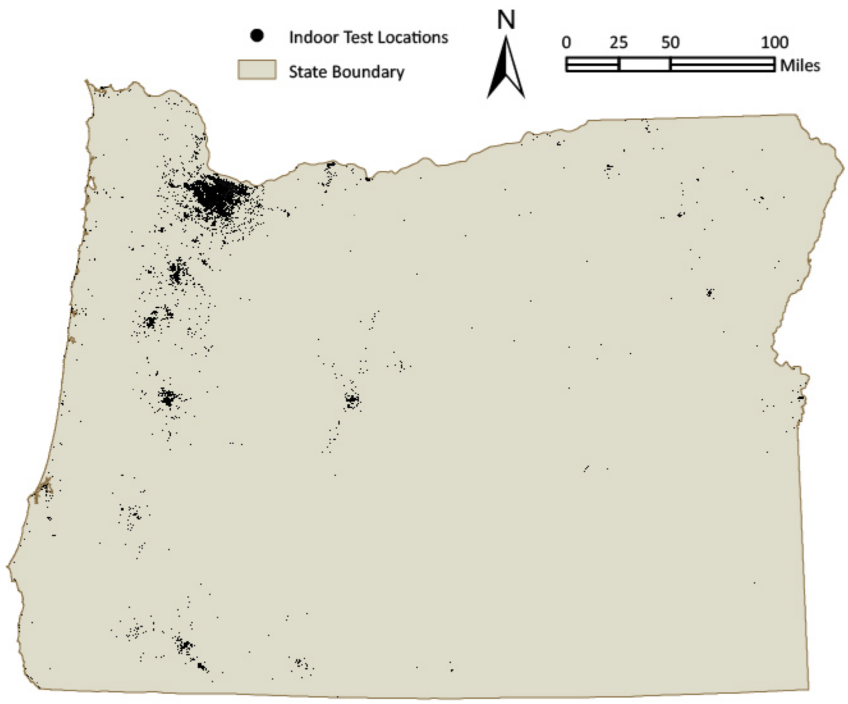
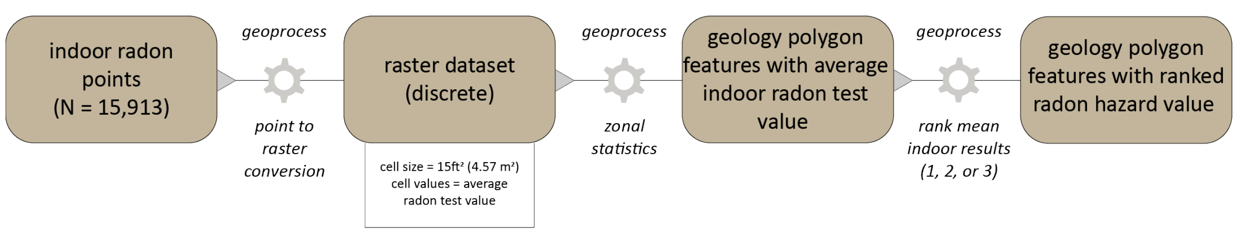


Figure 2-3. Data processing diagram for indoor radon.



2.1.3 NURE eU data

The NURE eU is equivalent uranium data collected along multiple, crisscrossing flight lines. (The "e" referred to means "equivalent" because the uranium content is calculated rather than measured directly using gamma ray data from bismuth 214, one of the uranium 238 daughter elements [Churchill, 2006]). The NURE eU information covers most of Oregon (**Figure 2-4**), although the spacing of measurements is variable and the coverage of the southwestern coastal region is missing. Spacing of the flight lines varied from ~3 km to ~10 km (~2 mi to ~6 mi). Each airborne measurement samples an area of several thousand square meters (Moed and others, 1984; Duval and other, 2005) and is an estimate of the surficial concentration of uranium eU in bedrock, soil, and surficial deposits to a depth of about 30 cm (~1.0 ft) (Moed and others, 1984; Duval and others, 1989a, 1989b, 2005). NURE eU data are substitutes for indoor radon measurements where indoor radon data are incomplete.

Figure 2-5 illustrates the NURE eU data processing steps. For mapping purposes of associating NURE eU data with geologic polygons, the following protocol guided NURE eU data handling and processing:

- Removed data with values less than the limits of the sensor (Hill and others, 2009).
- To simulate eU distribution between NURE flight lines, we used an inverse distance weighted interpolation (IDW) to create a continuous surface raster (Cattafe and others, 1988; Gundersen and others, 1993; Appleton and Miles, 2010; Drolet and others, 2014; and Kemski and others, 2001). We also tested kriging, but it turned out our data was not well distributed and discontinuities existed, thus informing our reason to use IDW instead of kriging.
- The square cell size of the raster surface is 15 ft (4.57 m), which achieved the resolution necessary to generate an average eU value within each geologic polygon except along the coast of southwest Oregon.
- Zonal statistics calculated an unweighted arithmetic mean of eU for the cells within each geology polygon.
- The mean values that fell below 1.5 ppm eU were assigned a rank of 1, values that were between 1.5 and 2.5 eU were assigned a rank of 2, and values greater than 2.5 were assigned a ranking of 3 (Gundersen and others, 1993; Churchill, 2012) (**Table 2-1**).

Figure 2-4. Coverage of flight lines for National Uranium Resource Evaluation (NURE) equivalent uranium (eU) measurements. The spacing of the flight lines varied from ~3 to ~10 km (~2 to~6 mi). Prior knowledge of the uranium content of the prevalent rocks of large regions influenced the density of the flight lines (Moed and others, 1984).

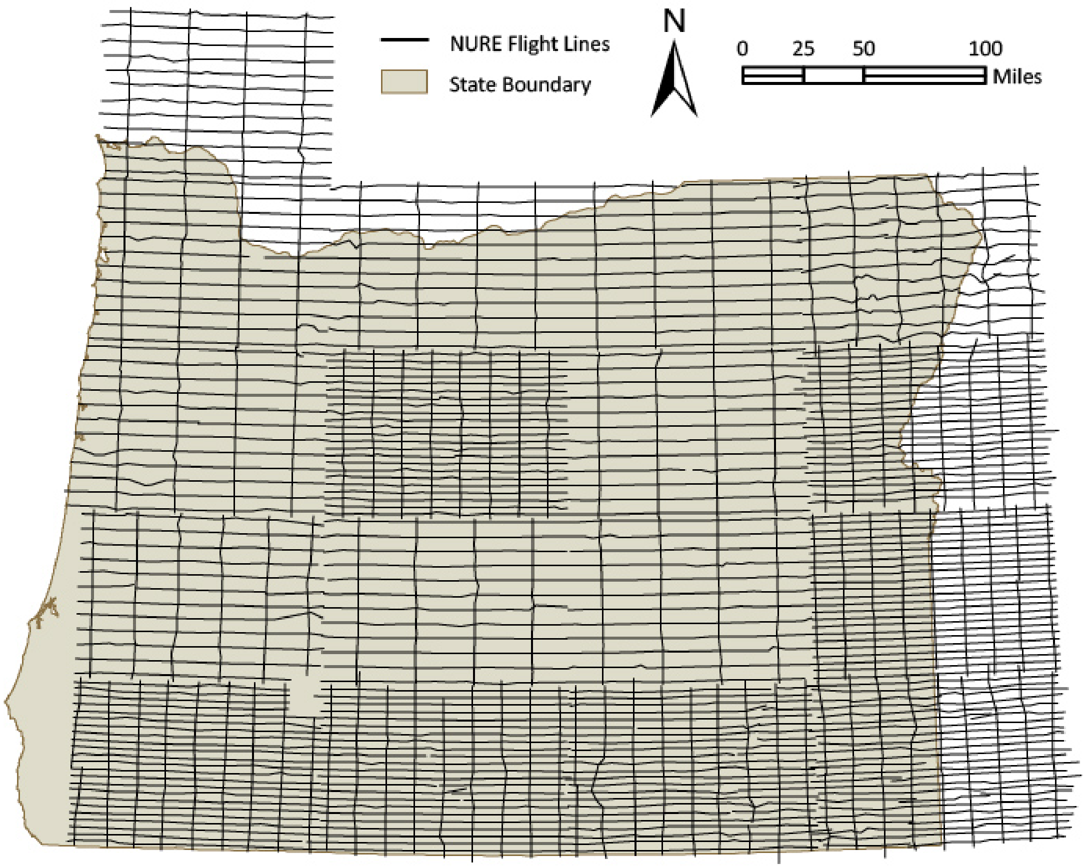
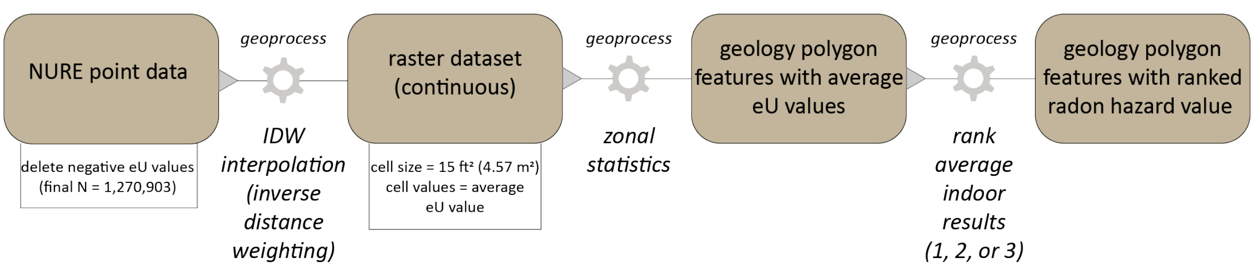


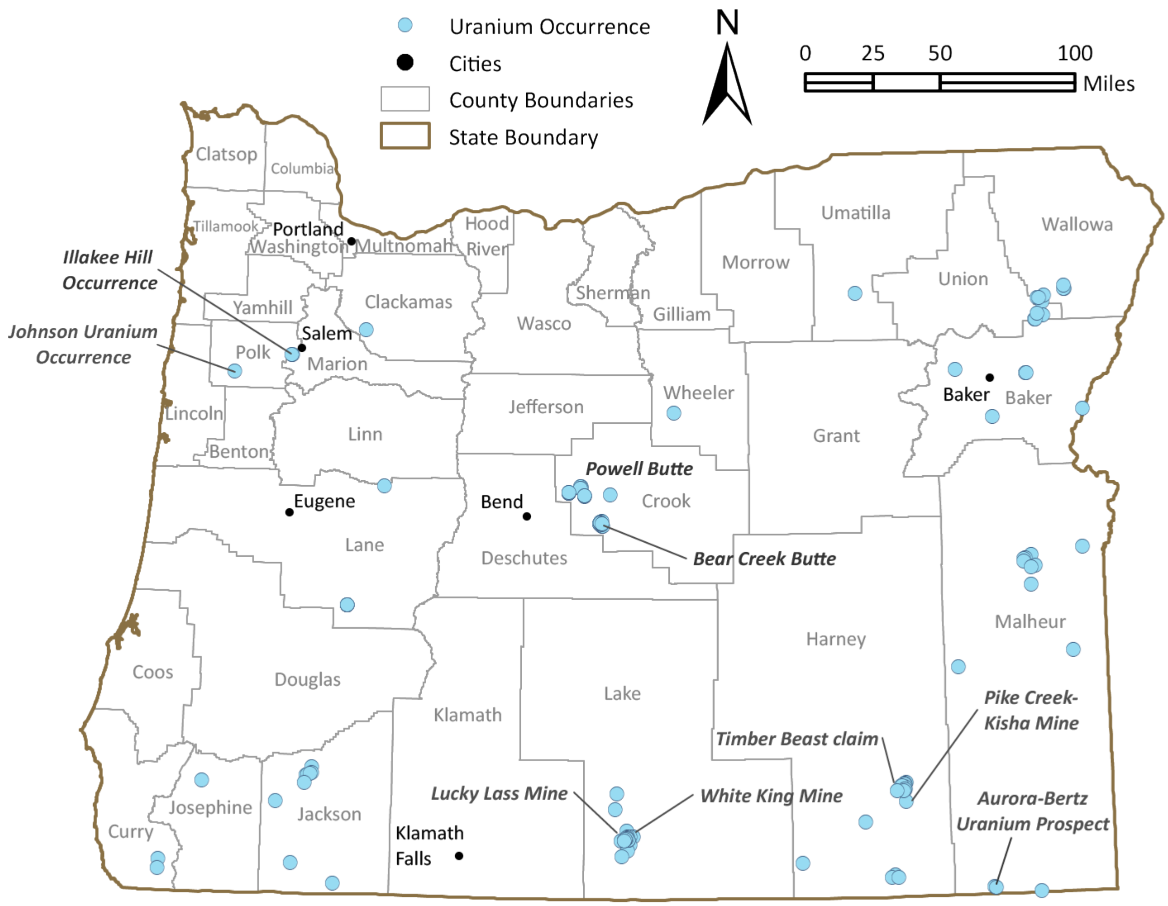
Figure 2-5. Data processing diagram for NURE (eU) data.



2.1.4 Uranium host rock data

Another uranium data source is MILO-2 (Niewendorp and Geitgey, 2010). Seventy-two OGDC-6 geologic polygons have host rocks with uranium bearing material. The polygons contain either a single uranium bearing site or a group of sites as shown in **Figure 2-6**. These polygons received a high radon potential classification because the polygons contain a mineral concentration.

Figure 2-6. Location of known uranium bearing materials in Oregon (MILO-2, Niewendorp and Geitgey, 2010). Labeled points are important mines, prospects, and occurrences.



3.0 DISCUSSION AND CONCLUSION

The most common methods used in producing radon risk maps have been described elsewhere (Miles and Appleton, 2005; Hahn and others, 2015) and will not be considered in this discussion. Instead, the focus of this discussion is to highlight some of the more important uncertainties and restrictions that have a bearing on the interpretation of the radon potential map and its use (see Sheet 1). In addition, the appendix has statements regarding the intended use and limitations.

3.1 Non-geologic factors

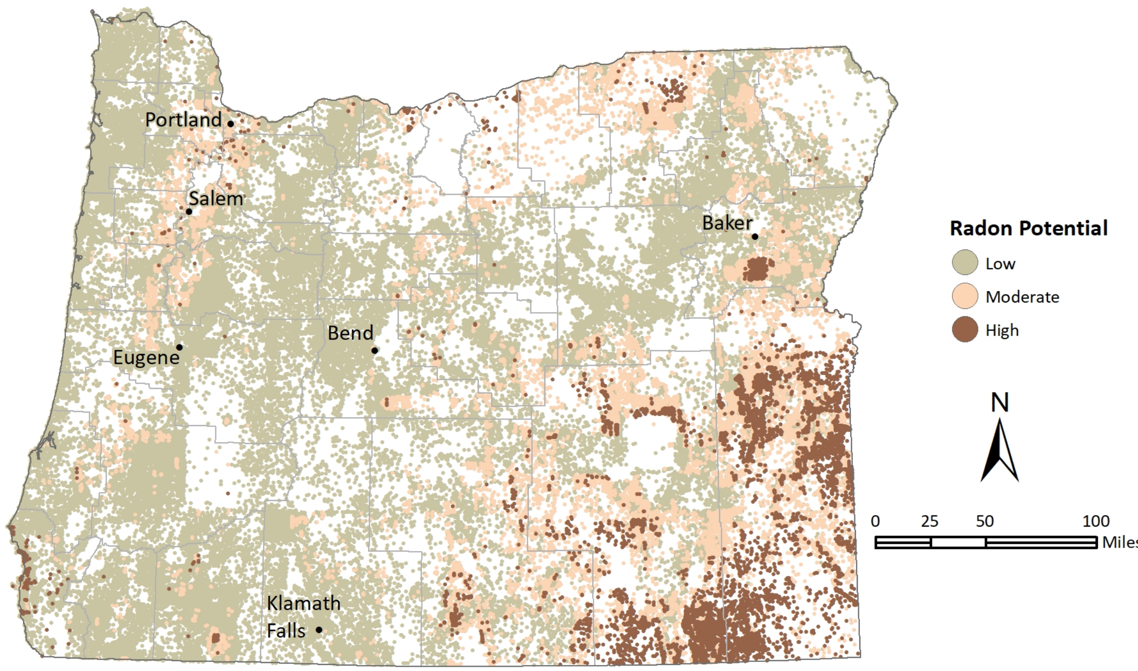
While it is not the purpose of this project to evaluate non-geologic factors affecting indoor radon levels, a number of these factors are worth mentioning. Studies have shown that non-geologic factors that affect radon levels include specific building conditions (e.g., depth of foundation, type of foundation, basement, age of construction, ventilation, mitigation) and the way the building is used. Radon levels in enclosed spaces can also fluctuate with rains, winds, and other natural forces. Wintertime results in higher indoor radon concentrations, as this time is accompanied by low-pressure systems (David Dreher and Curtis Cude, OHA, written commun., 2017). Another seasonal issue is soil saturation caused by rain or the presence of ice or snow on the soil surface. Each of these conditions reduces local permeability at the perimeter of the building and forces more radon toward the structure itself. Further, there are the shortcomings of the testing, for example:

- Non-professionals (aka homeowners) who may/may not have been following the kit manufacturer's directions;
- Building type is supposed to be limited to single family residential, but it is largely unknown whether that is true;
- The reliability of address information is unknown. OHA assumes that the address provided is where the test was performed, but the address may actually be a return address that a radon measurement contractor or landlord entered in order to ensure that they received the results.

3.2 Geology

The 342 maps in the OGDC-6 compilation have a range of scales from 1:24,000 to 1:500,000, which creates significant variations in the level of detail in the geology being portrayed across the state. Polygons along the borders of maps with different scales frequently do not match up or simply do not appear on the small-scale (large area) maps. Geologic units portrayed on those maps consists of multiple geologic formations that may differ significantly from each other in lithology, chemistry, physical properties such as permeability for radon gas migration. As a result, the areas mapped at smaller scales are far less reliable for the determination of radon potential (**Figure 3-1**) (Churchill, 2012).

Figure 3-1. A map of the centroids for the geologic polygons in OGDC-6 used for this study. The centroid color corresponds to radon potential of that geologic polygon. Tightly clustered centroids indicate areas of more detailed mapping (e.g., 1:24,000 scale), while the white parts depict areas covered by small scale (less detailed) mapping. In addition, the clusters of centroid or lack clusters of might be viewed as a proxy, albeit indirect, for gauging the reliability of OGDC-6 source material for the prediction of the local radon potential.



3.3 Indoor radon

OHA's data include both short-term (2–90 day) and long-term (91–365 day) test results. From Churchill's (2012) comparison of the consistency between short-term and long-term test data, which found that the data were comparable, we assume that including both types is inconsequential to the outcome of the analysis. Similarly, the fact that the results come from a variety of test kit types, such as activated charcoal and alpha rack, should not have considerable influence on the analysis. The factor associated with the indoor measurements that is likely to have the greatest effect on the reliability of the radon potential maps is the number of tests per geologic polygon. We used a sample population of five tests per polygon as the threshold for inclusion. That is the same level used by Gundersen and others (1993), but other studies have used higher threshold values (Churchill, 2012; Appleton, 2005).

3.4 NURE eU

NURE eU information is a stand-in geologic factor where indoor radon test data were incomplete. In the early 1970s, the NURE program itself was an attempt to locate uranium resources. The utility of the NURE data was expanded to assess geologic units for radon potential. NURE eU data also comes with their own set of uncertainties that could influence the assessment of radon potential. Weather, vegetation cover, and terrain influenced data collection, along with the physical characteristics of rock and soil (Moed and others, 1984). In addition, our spot checks of the eU data accuracy found disagreement at overlapping points where some flight lines crossed and where some points overlapped along segments of some flight lines. This disagreement was 10 percent for the former and in some cases 20 percent for the latter.

3.5 Soils

When a newly formed radon atom migrates into the soil pore space, transport of the radon atom through the soil depends on permeability, which varies with soil grain size and shape and moisture content (Hughes, 1994). Analytical soil datasets containing direct permeability tests at specific sites and other predictors of radon potential in soil such as soil gas (radon) data, measurements of radon emanation, and gamma spectrometric measurements were not readily available for this project.

DOGAMI turned to the Oregon SSURGO (Soil Survey Geographic Database) and STATSGO (State Soil Geographic Data Base) Soils Compilation, U.S. Department of Agriculture, Natural Resource Conservation Service (NRCS, 2015). The proxy for permeability in SSURGO is soil drainage type and saturated hydraulic conductivity information in STATSGO (Muckel, 2004). The statewide coverage of SSURGO is incomplete; where missing, the data were supplemented by STATSGO. The result was seven generalized drainage classes covering different parts of the state that did not affect assessment.

3.6 Summary

There is a good relationship between geology and indoor radon concentrations. **Figure 3-1** provides an illustrative example of this relationship. Notably, the areal distribution of high levels of indoor radon measurements corresponds to the coarse-grained Missoula Flood deposits. In this regard, the purpose of the study was to map variations in radon between and within geologic polygons in order to differentiate scattered high and moderate radon potential areas. **Figure 3-2** illustrates the difference in detail between the ZIP code level mapping and the results of this study (Sheet 1). However, there can be many sources of uncertainty and bias in the data underlying the radon potential map and in the processing methods used. Nevertheless, this work is a starting place for the future and a step toward further characterizing Oregon's radon potential.

Figure 3-2. Indoor radon measurement locations and underlying geology in the Portland metro area. Color of dot represent radon test values and shows variations in values over different Missoula Flood deposits in the Portland area. There is a close correlation between test results > 4.0 pCi/L (dark red circles) and coarse Missoula Flood deposit type (red). This example also shows that a wide spectrum of radon readings can occur in the various types of deposits such as in the case of the fine-grained Missoula Flood deposits.

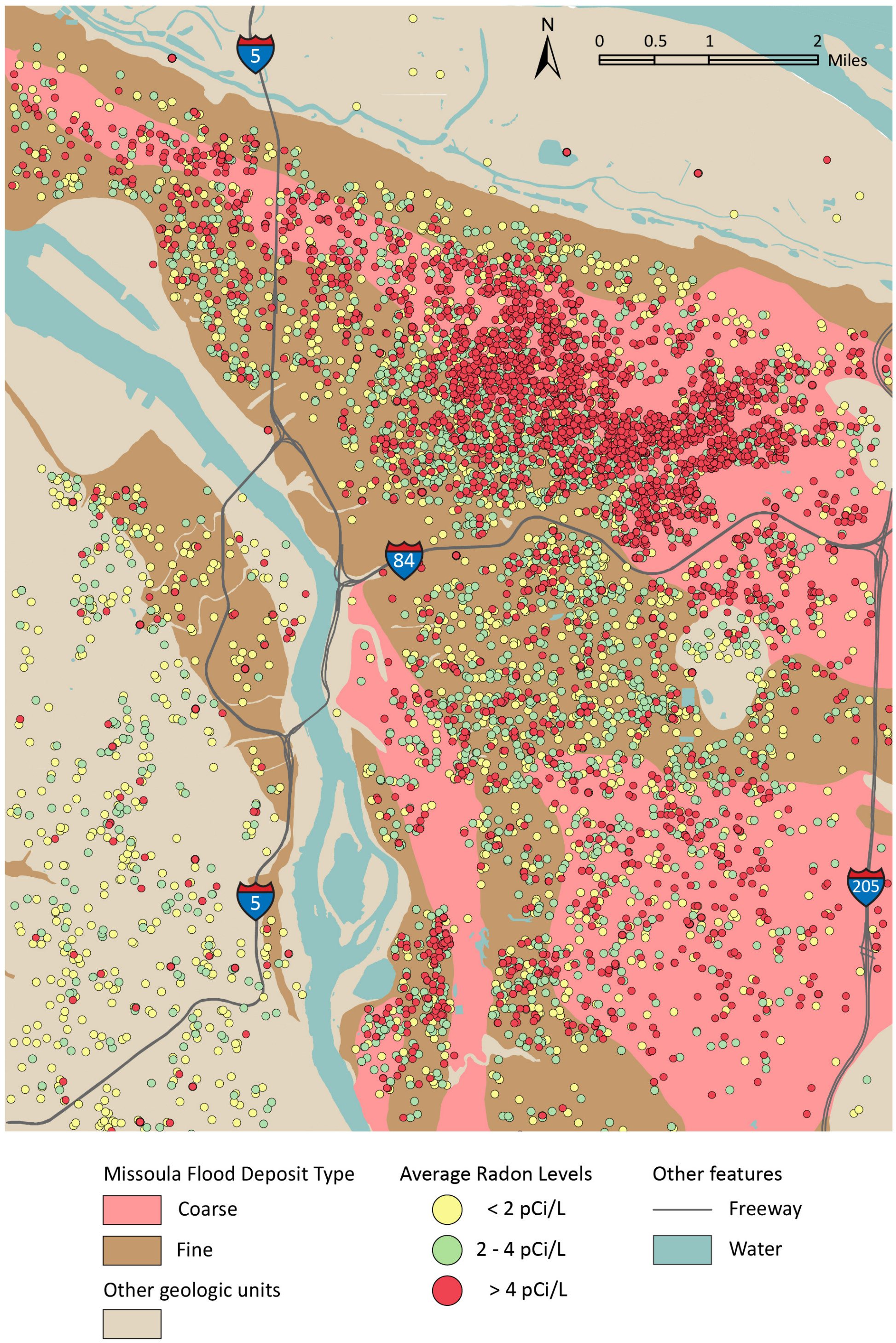
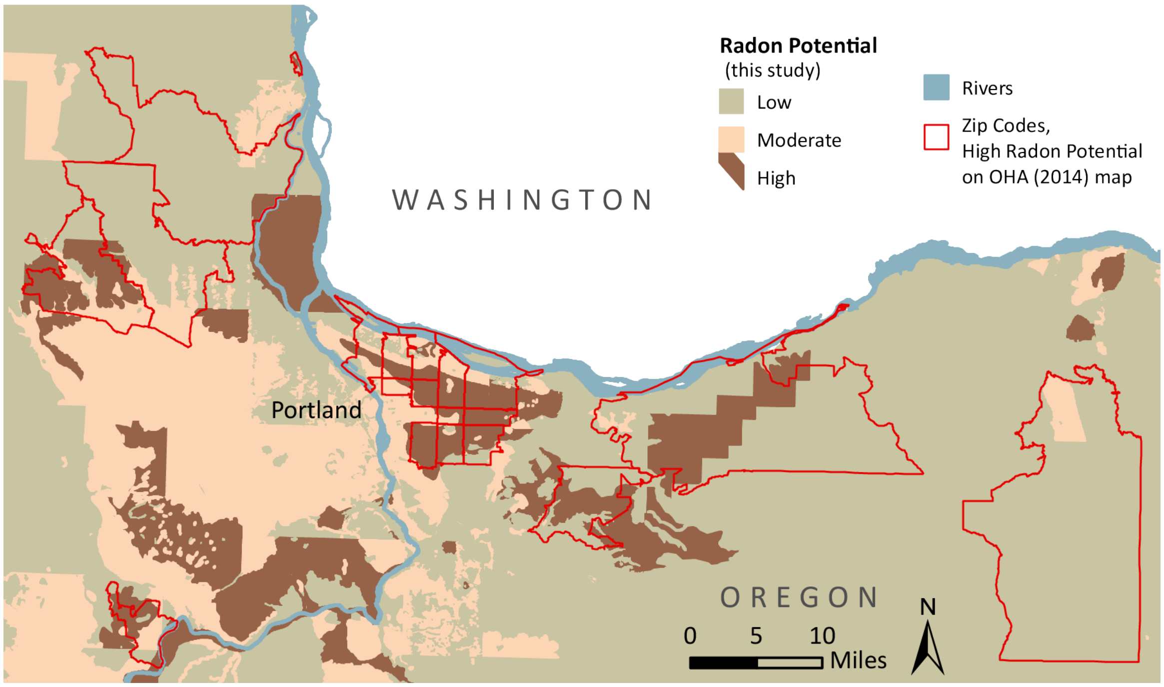


Figure 3-3. A portion of this study's radon potential mapping with an overlay of ZIP codes (red lines) which were assigned high radon potentials (OHA, 2014). This example also shows the distribution of radon potential between and within geologic polygons and the level of detail of high and moderate radon potential areas within those ZIP codes. The area the map covers is the northern part of the Willamette Valley encompassing the Portland metro area.



4.0 ACKNOWLEDGMENTS

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6.0 APPENDIX: GEOPROCESSING STEPS

Below is a synopsis of the geoprocessing steps on the data for indoor radon test, NURE eU, and OGDC-6. Statements of intended uses and limitations follow the synopsis. Intermediate products are not part of the final geodatabase.

Indoor radon test data (blue, dataset or table; green, attribute field; and red, Toolbox functions in Esri ArcMap 10.5.1 or Esri ArcGIS Pro 2.0.0)

1. Create high resolution raster from the indoor radon test data (Indoor_fc) using the Point to Raster tool. The tool inputs include Value = Radon, Cell size = 15, and Cell assignment type = "MEAN". Named the output raster Indoor_15ft_MEAN.img.
2. Determine the number of test points from Indoor_fc that fall within each Oregon Geologic Data Compilation (OGDC_fc) polygon using Summarize Within tool (ArcGIS PRO only). The tool inputs include Input Polygons = OGDC_fc, Input Summary Features = Indoor_fc, Output Feature Class = OGDC_fc_SumWin, Summary Fields include Field = Radon, Summary Fields, Statistic = "MEAN". The output feature class will have a "COUNT" value in the attribute table. This step determines the average indoor test value for each polygon that contains greater than or equal to five (5) test points.
3. Use Zonal Statistics as Table tool to create a table that has the arithmetic mean of Indoor radon point measurements for each polygon in OGDC_fc. The tool inputs include Input raster or feature zone data = ODGC_fc_SumWin, Zone field = PRIM_KEY, Input value raster = Indoor_15ft_Mean.img, Output table = OGDC_Indoor_ZonalStats, Statistics type = "MEAN". The output table location is the File Geodatabase. Join OGDC_indoor_ZonalStats table to the attribute table of OGDC_fc. Use the PRIM_KEY field as the primary key in the join.
4. Create a new field in OGDC_fc and call it Indoor_Count. Join the OGDC_fc_SumWin table to the OGDC_fc feature class and copy the values from the COUNT Field to the Indoor_Count field. OGDC_fc should now have the indoor test point count and mean test value per polygon.
5. Calculate the Indoor radon measurement rank: Create a new field called Indoor_Rank in OGDC_fc. Use the Indoor_MEAN field and, according to the radon potential matrix table (Table 2-1), calculate the radon potential rank for each polygon. The new rank values populate the Indoor_Rank field.
6. Use zonal statistics on indoor raster. For each Map Name aggregation (dissolve), determine MEAN indoor air value. The idea is to apply an average indoor air value to each rock type for that terrain region. This is the same method for the NURE analysis.

NURE eU data (blue, dataset or table; green, attribute field; and red, Toolbox functions in Esri ArcMap 10.5.1 or ArcGIS Pro 2.0.0)

1. Remove all negative values and one outlier from the NURE, point feature class dataset (NURE_fc).
2. Create high-resolution raster from NURE_fc using the IDW (Inverse Distance Weighting) tool. The tool inputs include Input point features = NURE_fc, Z value field = App_U, Output cell size = 15. Name the output raster NURE_15ft_MEAN.img.
3. Use Zonal Statistics as Table tool to create a table that has the arithmetic mean of NURE point measurements for each polygon in OGDC_fc. The tool inputs include Input raster or feature zone data = OGDC_fc, Zone field = PRIM_KEY, Input value raster = NURE_15ft_Mean.img, Output table

= OGDC_NURE_ZonalStats, Statistics type = "MEAN". The output table location is the File Geodatabase.

4. Join the OGDC_NURE_ZonalStats table to the attribute table of OGDC_fc. Use the PRIM_KEY as the primary key in the join = average eU value for each geology polygon. Save as new feature class called OGDC_fc_tablejoin.
5. Create a new field called NURE_Rank in OGDC_fc_tablejoin. Use the field representing the average eU values and, according to the radon potential matrix table (Table 2-1), calculate the radon potential rank for each polygon. The new rank values populate the NURE_Rank field.

OGDC-6 data (Toolbox functions in Esri ArcMap 10.5.1)
OGDC-6 is a compilation of 342 "source" maps (Smith and Roe, 2015). A source map contains a collection of one or many individual geology polygons that make a map unit. The label for each geologic polygon (a map unit label) shows the map unit the label stands for. Of the 120,048 geologic polygons in OGDC-6, there are 7,391 map units. A dissolving step aggregated the geologic polygons into polygons of their map unit. The result is that each geologic polygon shares the same rank of that map unit.

Intended uses and limitations of the data
The resolution of the Radon_Data feature class data in the geodatabase is 1:100,000 scale, while Sheet 1 is 1:750,000 scale. The intended use of both is at those scales; the information was meant not to predict indoor radon test results but to help agencies target their radon program activities and resources. It is the user's responsibility to examine the actual data and understand how the data apply to radon potential. The use of Sheet 1 and Radon_Data feature class data also requires knowledge of local conditions and the application of professional judgment and common sense. Other limitations that apply to both include:

- They do not show or predict absolute indoor radon levels in buildings. Those levels are estimates in terms of an average indoor radon potential for the area of the geologic polygon. Other factors that are not trivial contribute to elevated indoor radon hazard potential in specific buildings, measures of which are beyond the scope of this study.
- A radon hazard level may only cover a fraction of the geologic polygon's area. The user should evaluate an area with caution and should always examine the actual data to gain a better perspective.
- Localized areas of higher or lower radon potential are likely to exist within any given geology polygon, but their identification is not possible because of scale, sparse data, or a combination of both.
- Hazard classifications on Sheet 1 are approximate and so are the underlying mapped boundaries (i.e., geology polygons).
- The sample set of indoor radon tests is relatively small with spatial variations in sample sizes. Both introduce varying degrees of uncertainty. Therefore, more widespread and focused radon testing along with detailed geologic mapping would inform future radon potential maps.