Roinn Cumarsáide, Gníomhaithe ar son na hAeráide & Comhshaoil
Department of Communications, Climate Action & Environment

Geological Survey
Suirbhéireacht Gheolaíochta
Ireland | Éireann

Research Programme
- Short Calls, Final Report -

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Email	crowleyq@tcd.ie
Host Organisation name	Trinity College, Dublin
Project Title	An All-Ireland Geogenic Indoor Radon Map
Contract Number	2017-sc-08

Date: 03-12-2018

This report covers the period November 1st 2017 to October 31st 2018

2. (a) Project information:

<u>Final project report</u> (*<u>max</u>* ***<u>2500</u>*** *<u>words, excluding figures and headings</u>*):

(i) *<u>Progress</u>* of objectives and scientific/engineering targets beyond the state of the art & *<u>methods</u>* used

The project initially planned to extend the methodology of Elío et al (2017) to Northern Ireland, in order to produce a new probabilistic logistic regression indoor radon map for the entire island of Ireland. All the necessary geological data was agreed to be supplied through GSNI and BGS, however the indoor radon data (held by Public Health England) could not be accessed within the time-frame of the project. Figure 1 illustrates the publically available indoor radon data for Northern Ireland (supplied via the Northern Ireland Environment Agency) and the indoor radon data for the Republic of Ireland (supplied as point data by the EPA). Due to the spatial scale of Electoral Divisions for Northern Ireland, this map is of limited use. Given that a primary object of the project is to improve the spatial resolution of a probabilistic indoor radon map for the entire island of Ireland, it was not possible to do so with an approach of using the NIEA-EPA datasets.

The project has therefore investigated the use of Tellus radiometric data in the construction of an all-Ireland Radon Potential Map. Equivalent uranium (eU) from Tellus radiometric data were used to predict soil gas radon concentrations. A simplified GSI groundwater recharge map was used to estimate the sub-soil permeability (low, medium and high). Together these parameters have been used to define a Radon Potential Map (Fig. 4).

A Radon Potential Map was used as a means to divide the study area into four risk categories; Low Risk (<10), Moderate-Low (10-22.5), Moderate-High (22.5-35) and High (>35). Indoor radon measurements were not input as Radon Potential model parameters, so were used to validate the resultant map. The geometric mean of indoor radon measurements for each of these Radon Potential categories is 40.0, 52.5, 64.5 and 70.4 Bq/m^3. The probability of exceeding the national indoor reference level of 200 Bq/m^3 for each of these categories is 6.95, 8.94, 15.38 and 18.54 respectively. This demonstrates that Tellus data, in combination with sub-soil permeability can be used as effective predictor of Radon Potential.

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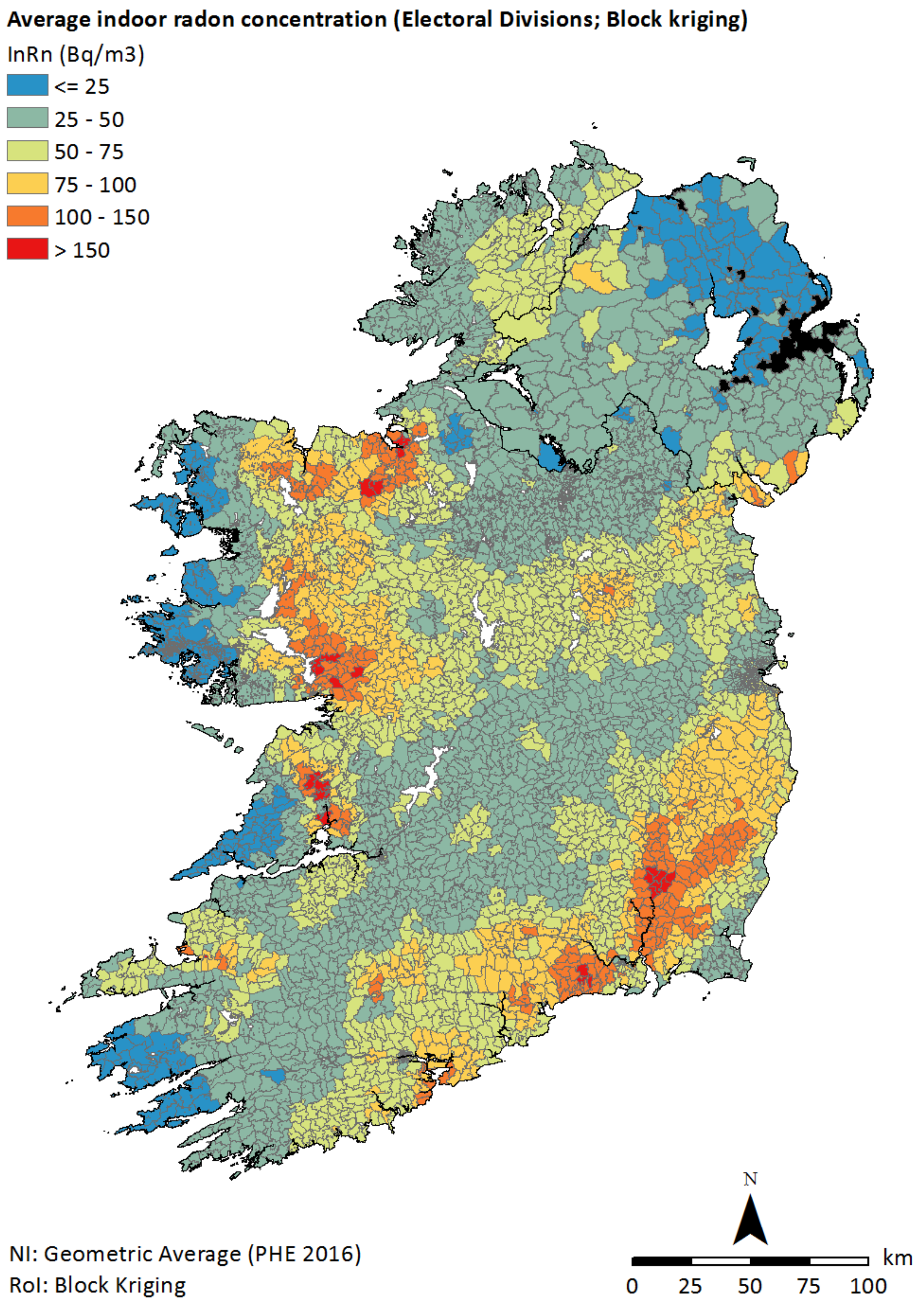

Figure 1. Average indoor radon data by electoral division for the island of Ireland. Note that due to the spatial scale of data for Northern Ireland (i.e. the relatively large Electoral Division), this map is of limited use for modelling of indoor radon.

$$C_{Rn} = \frac{C_{Ra} \cdot \varepsilon \cdot \rho}{n} \cdot \frac{1}{1 - S_F + S_F K_{w/Air}}$$

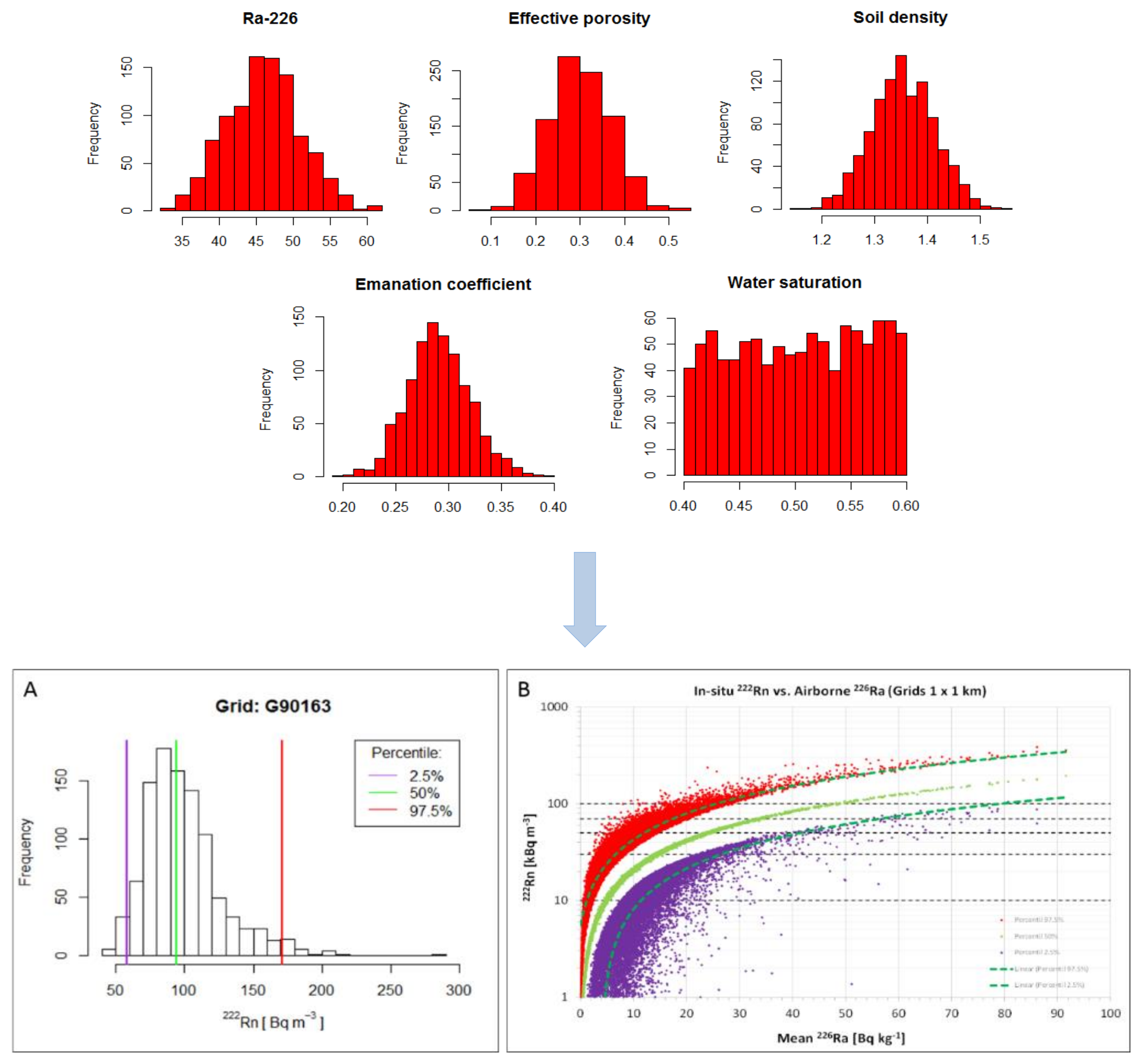

Figure 2. Transformation of radium (Ra) measurements from Tellus airborne data into soil gas radon predictions. Note that radium concentrations were calculated from effective uranium (eU) and that effective porosity, soil density, emanation coefficient and water saturation were input in the equation shown above in order to estimate soil radon concentrations.

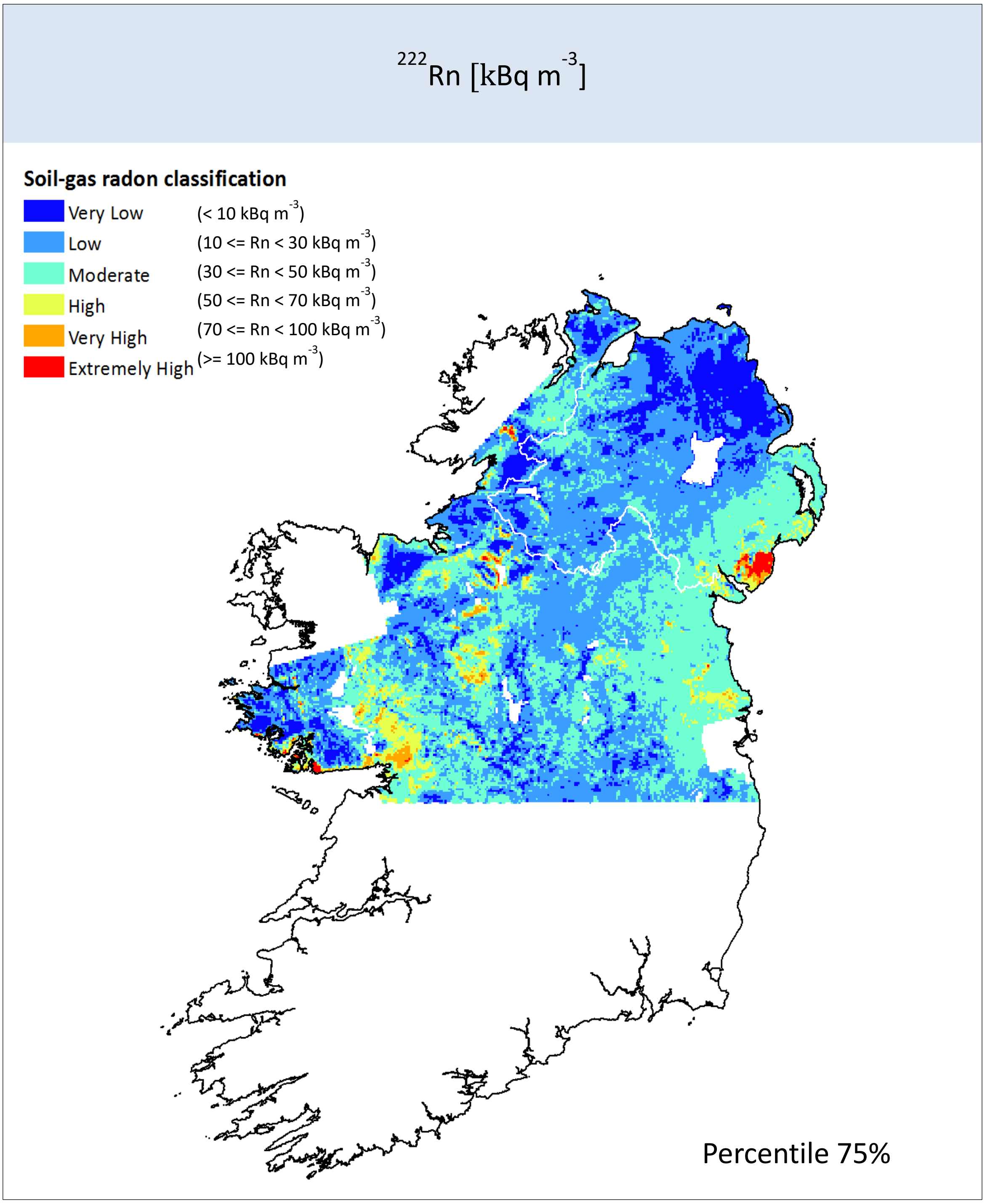

Figure 3. Estimation of radon soil gas concentrations, derived from the Tellus radiometric data.

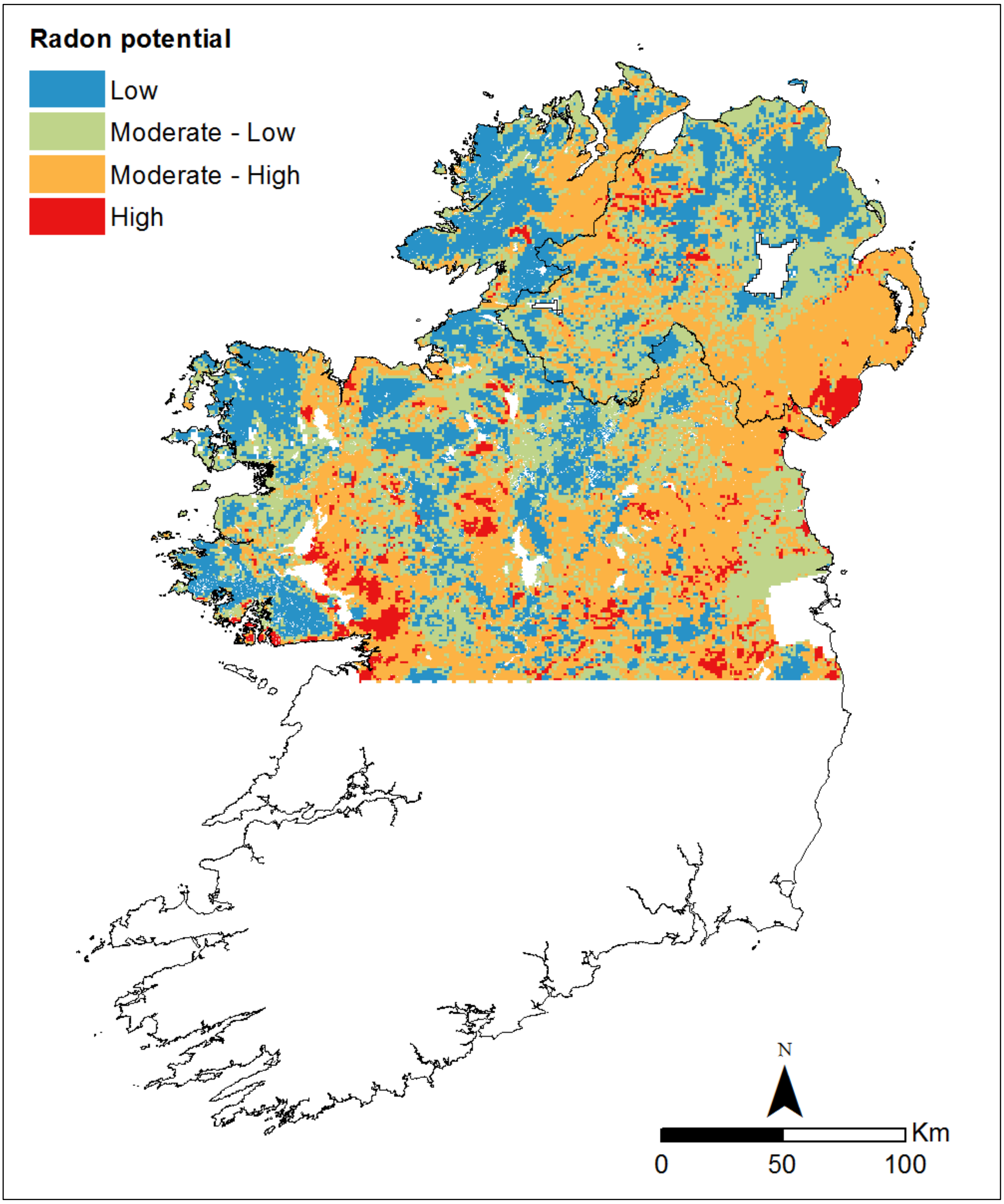

Figure 4. A seamless N-S Radon Potential (RP) map based on Tellus airborne radiometric data and subsoil permeability (the latter derived from the GSI Groundwater Recharge map data). Note that this map has been independently validated using indoor radon data (see table 1).

We have demonstrated that the methodology described in this study is useful for radon risk assessment at national scale, and that a radon potential map based on airborne radiometric data (i.e. eU) is therefore useful for delineating radon priority areas. The main advantage of this methodology over radon maps based on indoor radon measurements is that indoor radon measurements are not required. The methodology is therefore not affected by the sampling design or by large areas with few dwelling sampled, and may be applied in rural areas. Table 1 illustrates a validation of our approach using indoor radon data, as supplied by the EPA.

Table 1. Number of dwellings above the reference level in each RP classification

Radon Potential	Indoor Radon		Sampled dwellings			Binomial distribution		
	GM	GSD	≤ R.L.	> R.L	Total	Prob.	LCI	UCI
L	35.20	2.914	1,053	68	1,121	6.1%	4.7%	7.6%
M-L	44.26	2.718	3,964	312	4,276	7.3%	6.5%	8.1%
M-H	60.72	3.042	7,779	1,276	9,055	14.1%	13.4%	14.8%
H	74.38	3.258	1,721	451	2,172	20.8%	19.1%	22.5%
Total	**55.41**	**3.326**	**14,517**	**2,107**	**16,624**	**12.7%**	**12.2%**	**13.2%**

Reference Level (R.L.) = 200 Bq m-3; Probabilities (Prob.) in %; LCI and UCI are the 95% lower and upper confidence limit, respectively; L: Low, M-L: Moderate-Low, M-H: Moderate-High, H: High

In addition to developing a new methodology to produce an all-Ireland indoor risk map, we have validated the national map of Elío et al (2017), so that the same methodology can be applied to Northern Ireland, once the PHE NI indoor radon data is made available. The Environmental Protection Agency (EPA) supplied an additional ca. 7,000 indoor radon measurements, which we georeferenced and used to validate the Elío et al (2017) Indoor Radon Risk Map and the legislative EPA Indoor Radon Risk Map (First Interim report and Fig. 5). Given that the errors obtained with both maps are similar, the New Map (Elío et al, 2017) is preferable since the spatial resolution is improved considerably from 10 x 10 km to 1 x 1 km. The EPA is currently validating the map, with a view to replacing the Irish legislative map. Several meetings at the EPA were organized to assist with validation of the map.

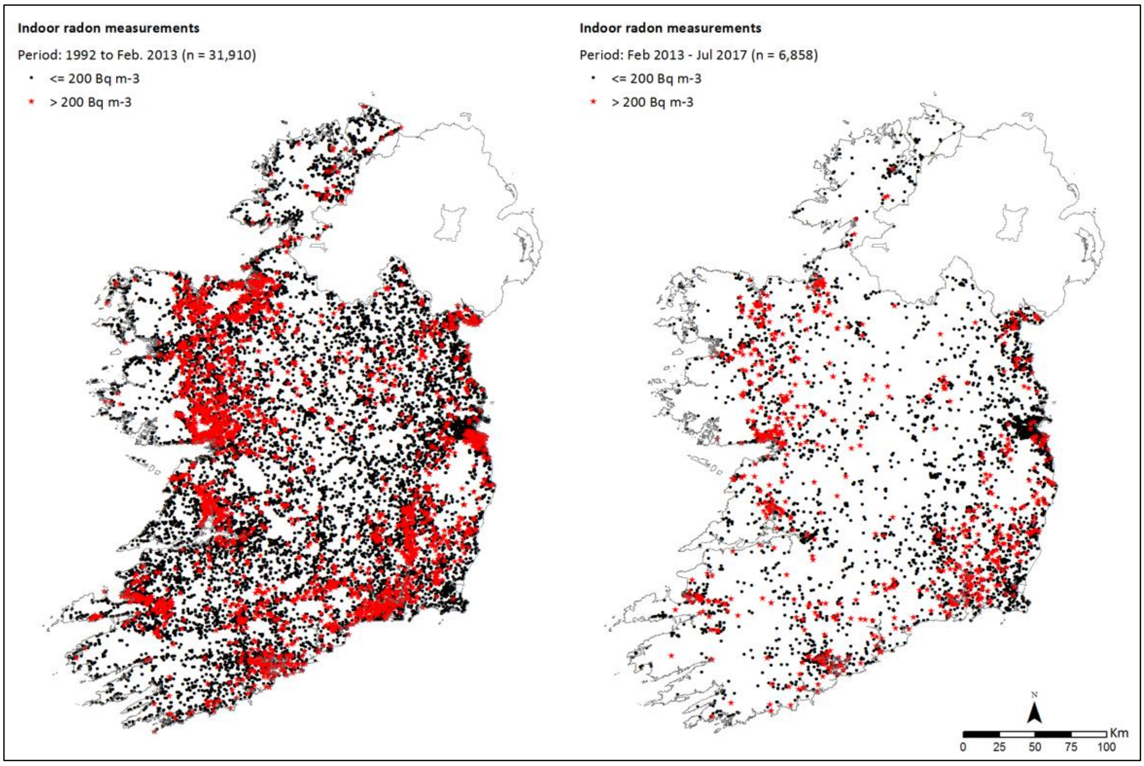

Figure 5. Indoor radon measurements from old survey (January 1992 – February 2013) and the new survey (February 2013 – July 2017).

Finally, implementation of the EURATOM Basis Safety Standards (EU Directive 2013/59/Euratom) in Ireland will require that all workplaces in High Risk Areas (HRAs) must test for indoor radon, and remediate if necessary. However, the definition of HRAs is based on measurements carried out in dwellings while it is well know that indoor radon behaviour differs between dwellings and workplaces. A radon map which does not depend of building characteristics (i.e. Radon Potential Map) may be therefore more appropriate for assessing the radon risk in workplaces. This hypothesis should be tested in further investigations, but knowing the legal implication of radon maps in Irish workplaces it could be a major contribution of the Tellus programme in the National Radon Control Strategy.

(ii) Implementation

The PI (Q.Crowley) started work on this project in November 2017. Initial meetings between TCD, GSNI, BGS, and PHE were organized to discuss the provision of the indoor radon measurements carried out in Northern Ireland. There was an initial agreement to have the data aggregated by grids of 1x1 km. Unfortunately these data were never provided, so it was not possible to produce an all-Ireland radon risk map as per the methodology used in Elío et al (2017). However, despite this drawback, an entirely new methodology for developing a radon potential map has been successfully developed and validated. Rather than rely on the provision of indoor radon data, the new methodology utilises (equivalent) uranium concentration from the Tellus radiometric dataset. When Tellus airborne survey has been completed and covers the entire island island of Ireland, an all-Ireland Radon Potential map will be calculated.

(iii) Outputs

a) New indoor radon measurements geocoded (N = 6,858).

b) A written report explaining the validation of the Elio et al (2017) and the EPA legislative map has been completed. This report was presented to the EPA, who are now in the process of consulting internally within the EPA in order to adopt the New Map as the legislative map.

c) A Radon Potential map of half of the island (area covered by Tellus airborne surveys).

d) An oral presentation incorporating some of this research was given at the IGRM in UCC.

e) Oral presentations incorporating some of this research were given at 3 international conferences (i.e. 12th Conference on Geostatistics for Environmental Applications; VI. Terrestrial Radioisotopes in Environment International Conference on Environmental Protection; and the EGU General Assembly, Austria).

f) A research manuscript was submitted to “Environmental Earth Science”, and two more are in progress. One to describe the methodology carried out to produce the Radon Potential map, and another to analyse the uranium distribution in the topsoil using a compositional data approach (the latter an invited contribution from the GeoEnv2018 conference in Belfast).

Task No.	Deliverable description	Planned delivery (as per proposal)	Date of delivery
1	Indoor radon dataset	Jan 2018	April 2018
2	All-Ireland Radon Risk Map	April 2018	Radon Potential Map completed March 2018
3	Correlation indoor radon data and airborne radiometric data	June 2018	Completed with existing Tellus data

Publications to date:

Journal Papers:

- Elío J., Crowley Q., Scanlon R., Hodgson J., Long S. *In Review*. Rapid radon potential classification using soil-gas radon measurements in the Cooley Peninsula (County Louth, Ireland), Environmental Earth Science.

- Elío J., Crowley Q., Scanlon R., Hodgson J., Long S. *In Progress*. Radon Potential maps base on airborne radiometric surveys: a case study of Tellus programme (Ireland).

- Elío J., Crowley Q., Scanlon R., Hodgson J., Long S. *In Progress*. Geostatistics of compositional data, a cross-validation exercise with topsoil uranium concentrations from Tellus programme, Ireland.

Conference Publications:

- Elío J., Crowley Q., Scanlon R., Hodgson J., Gallagher V., Long S. (2018) Correlation between topsoil geochemistry and indoor radon concentration, 12th Conference on Geostatistics for Environmental Applications – geoENV2018 (Northern Ireland).

- Bossew P., Cinelli G., Tollefsen T., Gruber V., De Cort M., García-Talavera M., Elío J. (2018). From the European Indoor Radon Concentration Map to a European Indoor Radon Dose Map, VI. Terrestrial Radioisotopes in Environment International Conference on Environmental Protection, University of Pannonia, Veszprém (Hungary).

- Elío J., Crowley Q., Scanlon R., Hodgson J., Long S., Zgaga L., Bossew P., (2018) Utilizing multiple approaches for the definition of radon priority areas, EGU General Assembly 2018 (Austria).

- Hodgson J., Bossew P., Elío J., Crowley Q. (2018) Airborne gamma spectrometry as predictor of indoor radon concentration and radon priority areas, EGU General Assembly 2018 (Austria).

- Crowley Q., Elío J., Lehne R., Militzer A., Ciotoli G., McKinley J., Cinelli G., Bossew P. (2018) Tectonically enhanced geogenic radon, EGU General Assembly 2018 (Austria).

Report:

- Elío J., Crowley Q. (2018). *Validation of Indoor Radon Risk Maps of Ireland*. Trinity College Dublin. Unpublished Report.

4. Data/outputs submitted with final report *(please list the documents, presentations, datasets etc. submitted with this report)*

All documents have previously been submitted.