1988_55

REGIONAL NURE, GEOLOGY AND SOILS DATA AS PREDICTORS FOR INDOOR RADON

Joseph S. Cattafe, M.S., Colleen A. Ranney, M.P.H.
Keith E. Miller, Robert H. Andolsek
Camp Dresser & McKee Inc.
Edison, New Jersey 08818

ABSTRACT

For the New Jersey Statewide Scientific Study of Radon, environmental data was input into a geographical information system (GIS) to perform spatial analysis on geographic predictors of indoor radon. Geologic units were input at the 1:63,360 scale and soil association units were input at the 1:250,000 scale. A radon source potential map was developed by classifying geologic units as high, medium or low radon potential based upon average radium concentrations assigned to the units from aerial radiometric data obtained from the National Uranium Resource Evaluation (NURE). A radon transport potential map was similarly developed by classifying soil association units according to soil gas transport characteristics extrapolated from more detailed county soil surveys. A combined radon potential map was developed by intersecting these two maps and was compared to indoor radon concentrations measured in 6,000 homes in New Jersey. A positive correlation was found between indoor radon and radon potential as defined in this study.

INTRODUCTION

The New Jersey Department of Environmental Protection (NJDEP) began to assess the potential for a natural indoor radon problem in the state following the discovery of high radon levels in homes in neighboring northeastern Pennsylvania that were built over a geologic unit known as the "Reading Prong". The Reading Prong is a distinct lithologic and structural unit of pre-Cambrian granites and gneisses commonly associated with high uranium concentrations. The unit extends in a northeasterly direction out of Pennsylvania through northern New Jersey (New Jersey Highlands) and into New York State. A review of available geologic data conducted by the New Jersey Geological Survey demonstrated that New Jersey had significant potential for a radon problem and that the problem would not be confined to the Reading Prong region, but would likely include areas to the north and south as well.

In the fall of 1986, the NJDEP initiated a comprehensive project to characterize the nature and extent of the radon problem within the State of New Jersey. This project, the Statewide Scientific Study of Radon, was conducted by Camp Dresser & McKee Inc. (CDM) under the auspices of the Bureau of Environmental Radiation within NJDEP. A major component of this study was the sampling of over 6,000 dwellings across the state to obtain a geographically representative distribution of indoor radon concentrations in New Jersey. The second major data collection task of this study was to develop a statewide spatial data base, mapping environmental, meteorological and building characteristics thought to influence radon behavior. It was hoped that analysis of the combined data sets would result in a determination of whether environmental features such as geology or soils could be used to classify the natural potential of an area to have an indoor radon exposure problem. This paper presents the results of the spatial analysis conducted for this study.

METHODS

The mapping task for Statewide Scientific Study of Radon consisted of collecting and compiling data from several sources to facilitate a spatial analysis of the indoor radon exposure problem in New Jersey. The mapping data base was placed into a geographical information system (GIS) in order to take advantage of the powerful data manipulation capabilities of such systems. The GIS system used for this project was ARC/INFO which was run on CDM's VAX 8700.

The preparation of this spatial data base entailed the mapping of natural environmental features including:

- Geology
- Geologic provinces
- Soil associations
- Natural Uranium Resource Evaluation (NURE) radiologic data
- Hydrogeochemical Stream and Sediment Reconnaissance (HSSR) Data
- Hydrologic units

Political subdivisions (county and municipal boundaries) along with major roadways were also mapped. Finally, the locations of all the sampled houses and institutional facilities, and their valid radon and building characteristic data were placed into the GIS.

To perform the spatial analysis to determine radon potential, three of the above mapping coverages--geology, soil associations, and NURE radiologic data--were used as described below.

GEOLOGIC MAPPING

Geology was entered from 1:63,360 scale Geologic Atlas Series paper maps produced by the New Jersey Geological Survey (NJGS). The southern half of the state (Atlas Sheets 29 to 36) was manually digitized by CDM with all polygons entered into the GIS at the 1:63,360 scale. Sheets were edge-matched and border anomalies between sheets were corrected with guidance from the NJGS geologist. The geologic coverage for the northern half of the state was prepared by the Geographic and Statistical Analysis Unit of NJDEP's Office of Science and Research, using 1:63,360 scale maps of Atlas Sheets 21 to 28. Simplifications were made in this geologic coverage since more detailed maps at a 1:24,000 scale were entered for much of this area. No simplifications were made to the geology in the southern half of the state. The geologic coverages of northern and southern New Jersey were joined to produce one geologic map.

SOILS MAPPING

Early in the project it was determined that the most appropriate type of literature-based soils data that would contain information relating to radon transport through soils would be the soils series units developed by the United States Department of Agriculture's Soil Conservation Service (SCS). Soil series units are mapped at a scale of approximately 1:20,000 for most counties in New Jersey and the survey books also contain backup data on parameters such as permeability, moisture content and depth to water that are useful in evaluating soil gas transport potential. Since these data were not available for the entire state at the regional (1:250,000) scale, and since entering soil series mapping units at the more detailed scale of 1:20,000 was beyond the scope of this study, soil associations were mapped.

Soil associations are assigned to landscapes that are similar in their distinctive proportional pattern of soil types. In practice, their geographic assignment bears relationship to surface features like topography and proximity to rivers, lakes or oceans, etc. They usually consist of one or more major soil types and at least one minor soil type, and are named for the major types. An individual soil type in one association may also be in another association, but it will appear in a different pattern or proportion. Soil association maps are useful as general guidance in managing land use or general land planning activities, since the groupings of soil types share similar slope and drainage characteristics.

Soil associations were digitized from a 1:250,000 scale map produced by the State Soil scientist of the SCS. This statewide soil association map is an attempt to reconcile each of the individual soil association maps that had been prepared during the development of County Soil Surveys by the

SCS. The original county soil association maps had been prepared with little regard to the soils on the other side of the county border and often soil associations, and even soil types, were called different names across county borders.

NURE MAPPING

Digital data containing the aerial measurements of bismuth-214 collected during the National Airborne Radiometric Reconnaissance (NARR) flight of the National Uranium Resource Evaluation (NURE) program was obtained and evaluated for this study. The NARR data contained gamma spectrographic counts for selected radioisotopes taken along flight paths of either one quarter mile (for the detailed survey of the Reading Prong), or 3 mile or 6 mile spacing (see Figure 1). These counts can be used to estimate the concentration of radium-226 in the soil or rock within 0.5 meters of the ground surface.

Bismuth-214 (Bi-214), as a decay product within the uranium-238 chain can be used to estimate the concentration of radium-226 in the soil, assuming all radionuclides within the chain are in equilibrium. Since Bi-214 is a direct decay product of radon-222, a gas, there is a possibility that its concentration is not directly related to the radium-226 concentration at that location, but rather indicates a radium source at some distance. However, for the purposes of this study, the Bi-214 counts from the NURE study were taken to represent the concentration of radium-226 in the soil.

Using proprietary interpolating programs, a computerized grid of Bi-214 data from the regional (3 and 6 mile flight line spacing) survey was produced for the entire state at the 1:250,000 scale. Sufficient coverage into adjoining states was ensured so that the identification of all existing anomalous areas was possible. Since many areas of the state were not flown because of restricted air space, i.e. the areas around Philadelphia and Newark Airports and Fort Dix - McGuire Air Force Base (see Figure 1), boundary areas were defined so that interpolation would not simply cross through flight gaps. A grid interval of 1270 meters was used in the interpolation process. Prior to applying the interpolating algorithm, an anti-aliasing filter was imposed. The filter averages a sample point with the two samples before and after it along the flight line. This prevents potentially severe distortion of the resulting contour map should a single anomalous high sample be recorded. It also assures continuity of the data, should, for one reason or another, one sample be missing (i.e. not recorded due to equipment malfunction). Contouring of the same NURE data set without this anti-aliasing filter would produce slightly different anomaly maps. While applying the filter tends to dilute a high gamma reading, it prevents the problem of one anomalous reading being used to create a large surface area of elevated gamma as would happen with standard linear interpolation and contour programs. Since the intention of the radiometric mapping was to determine radon source strength at the regional scale, the use of the anti-aliasing filter was determined to be suited to this project.

SOURCE POTENTIAL MAPPING

A radon source potential map was developed based on the relative radon potential of geologic units as determined by their average radium (i.e. Bi-214) content from the NURE survey. A computer overlay was performed using the interpolated grid data to assign an average Bi-214 value to each geologic unit.

The radiometric assignments of the NURE data set were assumed to apply to both consolidated and unconsolidated material. The detector can only measure radiation emitted from the first foot or so below the ground surface. Therefore, high source material below this depth would go undetected if the overlying soils were of lower radioactivity. However, in most cases soils are derived from the underlying geologic unit. Even in glacially deposited soils, the major parent material is the nearby bedrock.

To assign a source potential category to each geologic unit, all units were ranked in order of mean Bi-214 concentration. Geologic units with mean concentrations falling in the lower third of the range were considered as having low radon potential, those with means in the second third were considered medium, etc.

TRANSPORT POTENTIAL MAPPING

Given the existence of a source, there is another primary environmental condition that must be satisfied before an indoor radon problem can occur--the soil must be sufficiently permeable for the radium decay product, radon, to be transported into a house.

The soil attributes determined to exert the most influence on radon transport through soils were permeability and depth to ground water. Other characteristics that were available, such as drainage classification and moisture content, were considered to be directly related to the depth to ground water classification. Permeability and depth to water characteristics of each of the major soil series within a soil association were obtained from the county soil surveys and were assigned transport values ranging from 1 to 3 based on assumed soil gas transport potential as shown below:

Rank	Permeability, in/hr	Depth to Ground Water, ft
1	0.06 - 0.6	0 - 2
2	0.6 - 6.0	2 - 6
3	6.0 - 20	>6

The transport rankings reflect conditions favorable for soil gas transport, e.g., as the permeability increases from one range to the next, the corresponding transport value increases. Likewise, a deep water table has a higher ranking than a shallow one because radon can diffuse more easily through unsaturated pore spaces.

The sum of the permeability and depth to ground water rankings for each each soil series was computed. The sum totals of each major soil series within an association were then averaged to come up with an average ranking for that association. A radon transport potential was then assigned to each soil association based on its average ranking value. All soil association units were then ranked according to their radon transport potential value and the entire range of values was divided into thirds to assign a transport potential category of high, medium or low to each soil association.

RESULTS

RADON SOURCE POTENTIAL

The statewide Bi-214 mean for the geology units based on the superimposed NURE survey results is 1.703 parts per million (ppm) with a standard deviation of 1.069 ppm. The average Bi-214 concentration for the geologic units ranged from 0.45 to 3.77 ppm. Some geologic units could not be assigned an average radium value since no grid data fell within their polygons. (Recall that the grid size for the regional data was 1270 meters and many geologic units entered at the 1:63,360 scale were less than 500 meters wide.)

The maximum Bi-214 measurement falling within a geologic unit was 7.56 ppm in Pre-Cambrian gneisses, amphibolites and granites (Pcg). However, the units with the highest mean concentrations were Cambro-Ordovician undifferentiated (COu), Hardyston Sandstone (Ch) and Triassic beds similar to the Lockatong Formation (Trba), with mean Bi-214 concentrations of 3.77, 3.32 and 3.17 ppm respectively. The geologic units with the lowest average concentrations were the Quaternary deposits tidal marsh and swamp (Qm), Cape May Formation (Qcm), and recent fill (Qf) with mean Bi-214 concentrations of 0.45, 0.63, and 0.54 ppm, respectively.

The geologic units were assigned source potential attributes (high, medium and low) based on their ranking; with mean values between 0.45 and 1.56 ppm considered low, mean values between 1.56 and 2.67 ppm classified as medium, and mean values greater than 2.67 ppm classified as high. The result of this classification was that 21 geologic units were assigned a low radon potential, 50 geologic units a medium radon potential, and 9 units a high potential. Figure 2 displays these results with geologic units shaded according to their source potential.

Table 1 presents a list identifying the geologic units that were assigned high radon source potential based on their high mean Bi-214 concentrations, along with the mean of the actual Level I samples placed over that formation.

The NURE report identified several formations in the Newark Quadrangle as environments either containing, or suspected of containing significant concentrations of uranium (1). The Lockatong, Epler and Hardyston formations, as well as the Pre-Cambrian rocks are four units identified in the report which are also classified as high source potential in this study.

The Brunswick Formation, primarily deposited in an oxidizing environment, was not found by NURE investigators to contain anomalous radioactivity along exposed sections. However, within this sequence of predominantly red siltstones and sandstones are thin layers of interbedded dark grey pyritic shales (2). These shales may account for a certain degree of local anomalous radioactivity. Notably, the higher than expected average Bi-214 (2.72 ppm) for the Brunswick Formation is primarily due to the formation south of the Wisconsin Age terminal moraine, where the mean Bi-214 concentration was almost three times higher than that for the formation north of the moraine (2.89 ppm compared to 0.97 ppm). Most of the Brunswick north of the terminal moraine was not flown, due to the presence of the Newark Airport.

The Hardyston Sandstone was identified in the NURE report as having elevated uranium content associated with placer deposits. The uranium associated with the Kittatinny Limestone is due to secondary calcite precipitation into fractures in the parent rock.

The mapped area identified by the Cambrian-Ordovician Undifferentiated group consists of undifferentiable units of the Kittatinny Limestone, the Martinsburg Shale and the Jacksonburg Formation. The high mean Bi-214 value could be the result of Epler Formation, which has been lumped in with the Kittatinny for mapping purposes, and the black shales and siltstones of the Martinsburg Shale. Sufficient information is not currently available to accurately assess the radioactive potential of the Jacksonburg Formation.

The Inferred Pocono Island Formation will not be considered for analysis since there was only one data point within that polygon. The formation identified as Pocono Island has a mean Bi-214 value of 2.34 from twenty data points and falls into the medium source potential category.

As shown in Table 1, the ranking of the geologic formations by mean Bi-214 values does not always follow the ranking according to mean radon concentrations. There is obviously other factors influencing radon concentrations. Nevertheless, Bi-214 concentrations do seem to play a major role in controlling radon concentrations. Of the geologic units with 10 or more samples, the units with the highest radon concentrations, i.e. the Hardyston Sandstone (12.8 pCi/l), Kittatinny Limestone (9.3 pCi/l), Precambrian rock (8.3 pCi/l), and Martinsburg Shale (8.1 pCi/l), also had the highest Bi-214 values.

RADON TRANSPORT POTENTIAL

The range of soil transport rankings for the 39 soil associations was 1.5 to 6.0, based on the average ranking value of the individual soil series units. Soil associations with transport rankings between 1.5 and 3.0 were considered low potential; associations between 3.0 and 4.5 were considered medium potential; and those between 4.5 and 6.0 are considered high transport potential soils. These composite transport polygons have been shaded as to their transport potential in Figure 3.

In the Outer Coastal Plain (bottom half of the state in Figure 3), the radon transport potential rankings follow surface water drainage patterns very closely, with high transport assigned to drainage divides, and medium and low values along the streams and coast. In the northern portion of the state, the high transport potential soils are either associated with sand and gravel deposits of glacial or interglacial origin or with highly weathered soils found along the tops of hills and mountain ranges. For example, the slivers of high transport potential in the low potential area in the northeast part of the state are associated with stratified drift and much of the high potential soils in the north-central part of the state are found along the higher elevations of the Highlands. The northeast/ southwest trend of the soil units in this area further supports the notion that the categorization scheme follows the topography created by underlying bedrock formations.

OVERALL RADON POTENTIAL

To define the overall radon potential categories, radon transport and radon source potential rankings were combined according to our current understanding of their relative importance. Source potential was hypothesized to take priority over transport potential, since all previous analyses had shown source (i.e. NURE), to have the best single correlations with indoor radon. Transport was hypothesized to be more of an "on-off" phenomena. As evidence of this, previous analyses of radon values stratified by permeability rankings showed low radon at very low permeabilities but similar radon concentrations in soils with medium or high permeabilities. As a final statistical check, radon concentrations for the 5727 valid sampling points were stratified by the new radon transport and radon source map attributes, giving the following results:

Radon Source Potential	Radon Transport Potential	Mean Radon
H	H	6.5
	M	7.1
	L	2.0
M	H	3.9
	M	4.8
	L	2.3
L	H	2.4
	M	1.8
	L	1.5

Again, transport appeared to modify the source only when transport was classified as low. Notably, even when the source was high, the resulting radon concentration for the low transport potential polygons was similar to the radon concentration for low source potential units. With this further reinforcement of the working hypothesis, an overall radon potential ranking was assigned based on transport and source combinations shown below:

		Source		
		L	M	H
Transport	L	low	low	low
	M	low	med	high
	H	low	med	high

Transport and source potential polygons were intersected and the resulting intersecting polygons were assigned overall radon potential rankings. Accordingly, all polygons with low transport rankings were assigned low overall potential regardless of their source. After that, assignments followed the source potential rankings. The resulting polygons were then shaded according to their potential as shown in Figure 4.

As a final check, a mean radon value for each composite radon potential polygon was obtained and the results showed excellent correlation:

Overall Radon Potential	Mean Radon	Std. Dev.	Cases
High	6.79	12.65	2815
Medium	4.56	9.27	1853
Low	2.13	3.34	1059

Rather than display all radon concentrations on the composite map, radon samples greater than 20 pCi/l were displayed as shown by dots on Figure 4. The majority of the locations with radon greater than 20 pCi/l corresponded to areas classified as high overall potential. One sample with radon concentrations greater than 20 pCi/l was found in the low potential area in the northeastern portion of the state. Follow-up sampling at this home conducted by the NJDEP revealed that the radon in this home is due to industrial processing waste deposited beneath the home. Two other samples in the "low potential" area in the northwestern portion of the state are located in an area classified as high transport but low source potential. However, much of the geology in this area is considered incorrectly mapped and the NJGS is in the process of updating the geology on the Atlas sheets. It is possible that the area has been misclassified as to its source potential and that rocks of higher source potential actually underly this area.

CONCLUSION

The mapping data set collected during the New Jersey Statewide Scientific Study of Radon was utilized to develop a graphic analyses of the ability to use environmental information to predict the occurence of indoor radon problems. With the use of a GIS, a weighted combination of the geology and soil attributes was used to generate an overall radon potential overlay, with the composite map containing a three tier classification of radon potential.

As can be seen in Figure 4, the generalized radon potential map is a good first attempt at classifying the state of New Jersey according to areas of expected elevated radon occurrence. The major drawback of this scheme is that it does not take into account either house-specific features (substructure and heating system) or meteorology, both of which were found to have substantial effect on indoor radon concentrations during the study. However, since source was found to be the factor that plays the most dominant role in controlling indoor radon, the generalized ranking scheme shown in this map is appropriate as an initial attempt to characterize the radon problem in New Jersey.

The work described in this paper was not funded by the U.S. Environmental Protection Agency and therefore the contents do not necessarily reflect the views of the Agency and no official endorsement should be inferred.

REFERENCES

1. Popper, George H. P and Thomas S. Martin. National Uranium Resource Evaluation of the Newark Quadrangle, Pennsylvania and New Jersey. PGJ/F-123(82). Bendix Field Engineering Corp., Grand Junction Operations, Grand Junction, Colorado, March, 1982.

2. Van Houten, F.G. Late Triassic Part of Newark Supergroup, Delaware River Section, West Central New Jersey. In: Field Studies of New Jersey Geology and Guide to Field Trips. 52nd Annual meeting of the New York State Geological Association, Rutgers University, Newark, New Jersey, 1980.

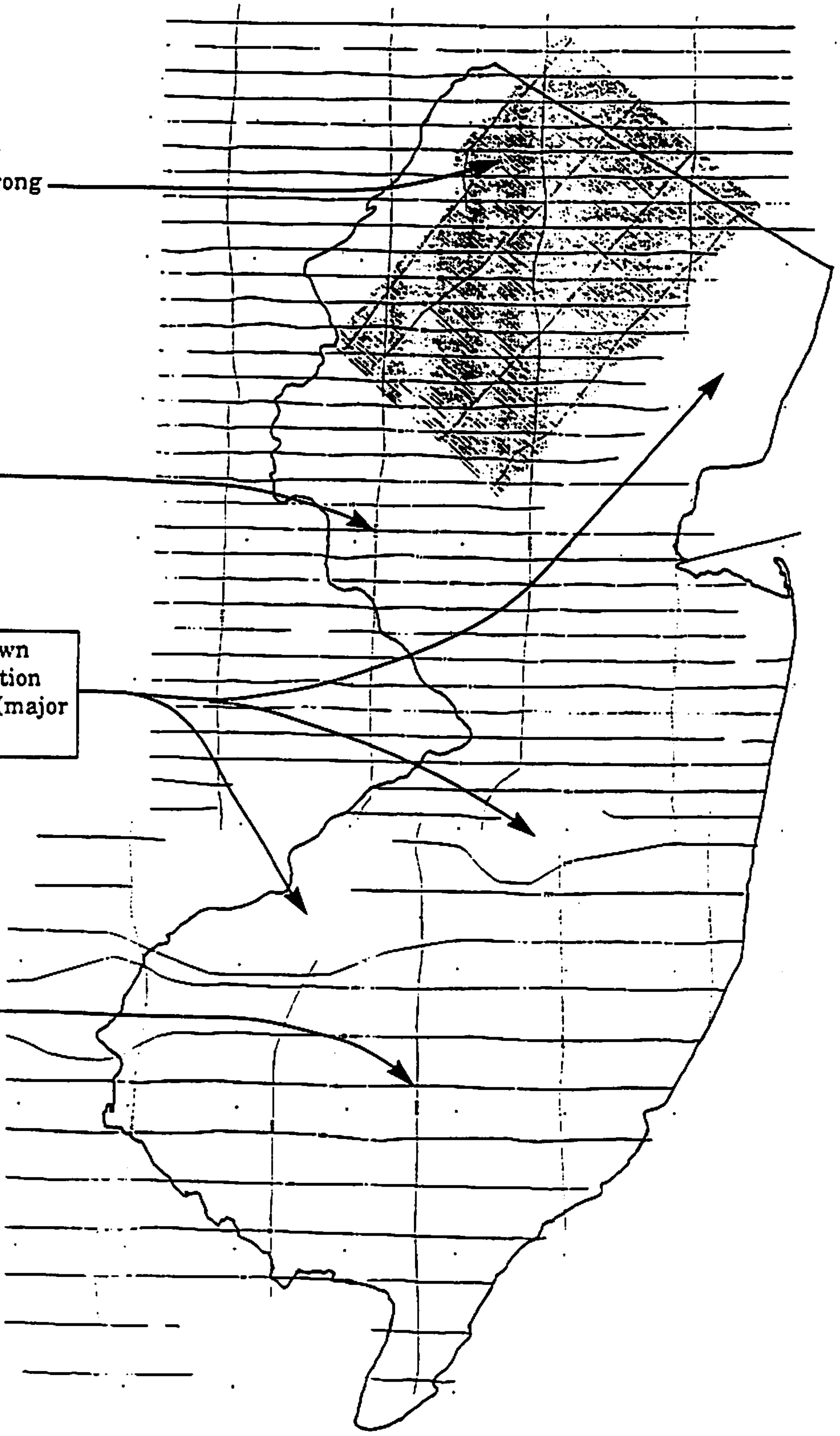
TABLE 1

NURE AND RADON MEANS FOR GEOLOGIC FORMATIONS CLASSIFIED AS HIGH SOURCE POTENTIAL

(ranked low to high)

Geology	Age	Map symbol	Bi-214 mean	Radon mean
Brunswick Formation	Triassic	Trb	2.72	3.5
Gneisses, Amphibolites and Granites	pre-Cambrian	Pcg	2.76	8.3
Lockatong Formation	Triassic	Trl	2.76	6.2
Pocono Island Inferred	Silurian	Spi	2.85	NA
Jacksonburg Formation	Ordovician	Ojb	2.91	4.8
Kittatinny Limestone (including Ontelaunee, Epler, Rickenback, Allentown and Leithsville Members)	Cambro-Ordovician	COk	3.02	9.3
Rock Similar to Lockatong	Triassic	Trba	3.17	4.45
Hardyston Formation	Cambrian	Ch	3.32	12.8
Cambrian-Ordovician Undifferentiated*	Cambro-Ordovician	COu	3.77	4.7

*There is an area of uncertainty on the overlay where COk, Omb, and Ojb run together. There is apparently a lack of discrimination between these units.



Flight lines at
1/4 mile spacing
over Reading Prong

Flight lines at
3 mile spacing

Areas not flown
due to congestion
of air space (major
airports).

Flight lines at
6 mile spacing

Figure 1. Flight line locations of NURE aerial radiometric data in New Jersey.

FIGURE 2 RADON SOURCE POTENTIAL

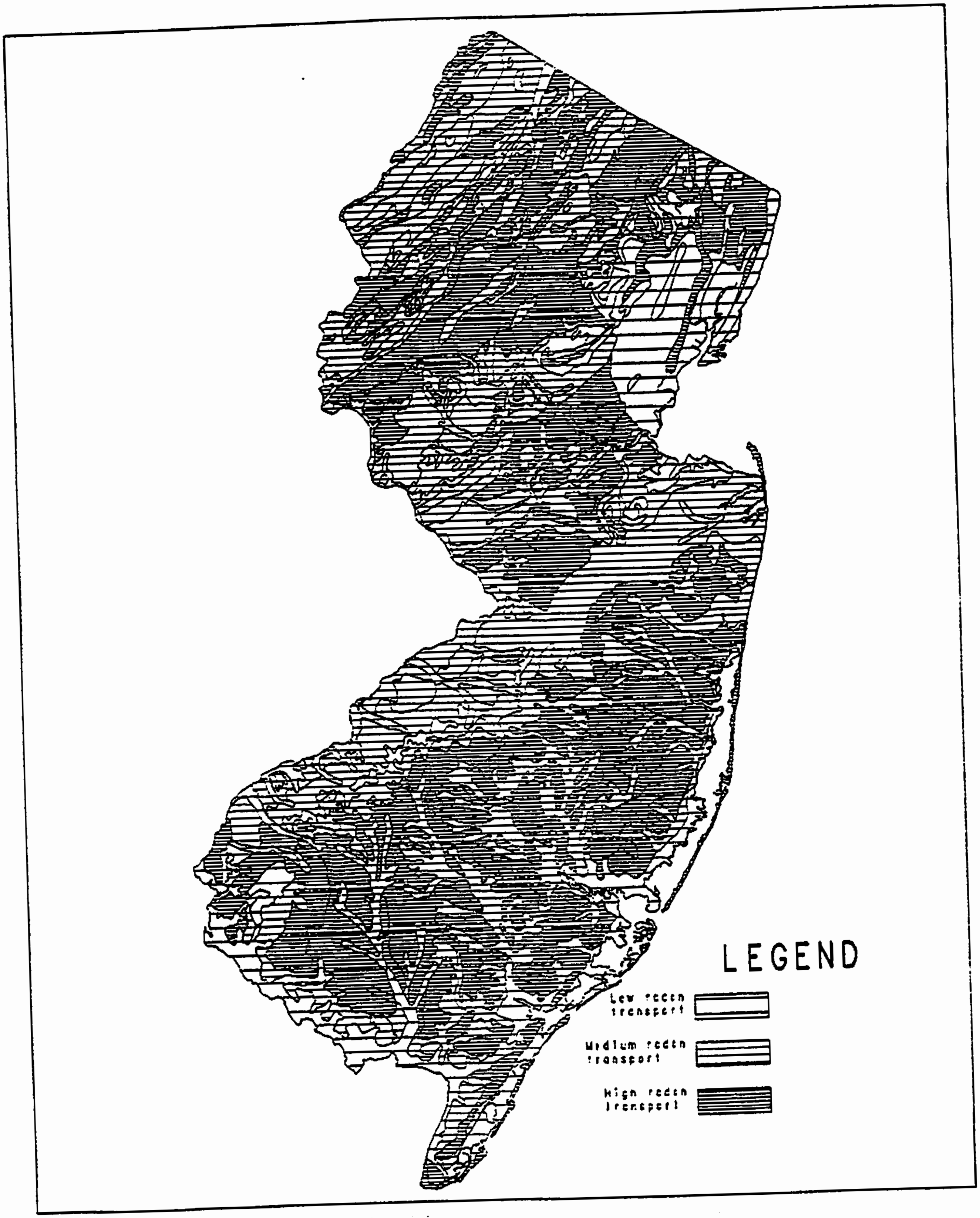


FIGURE 3 RADON TRANSPORT POTENTIAL

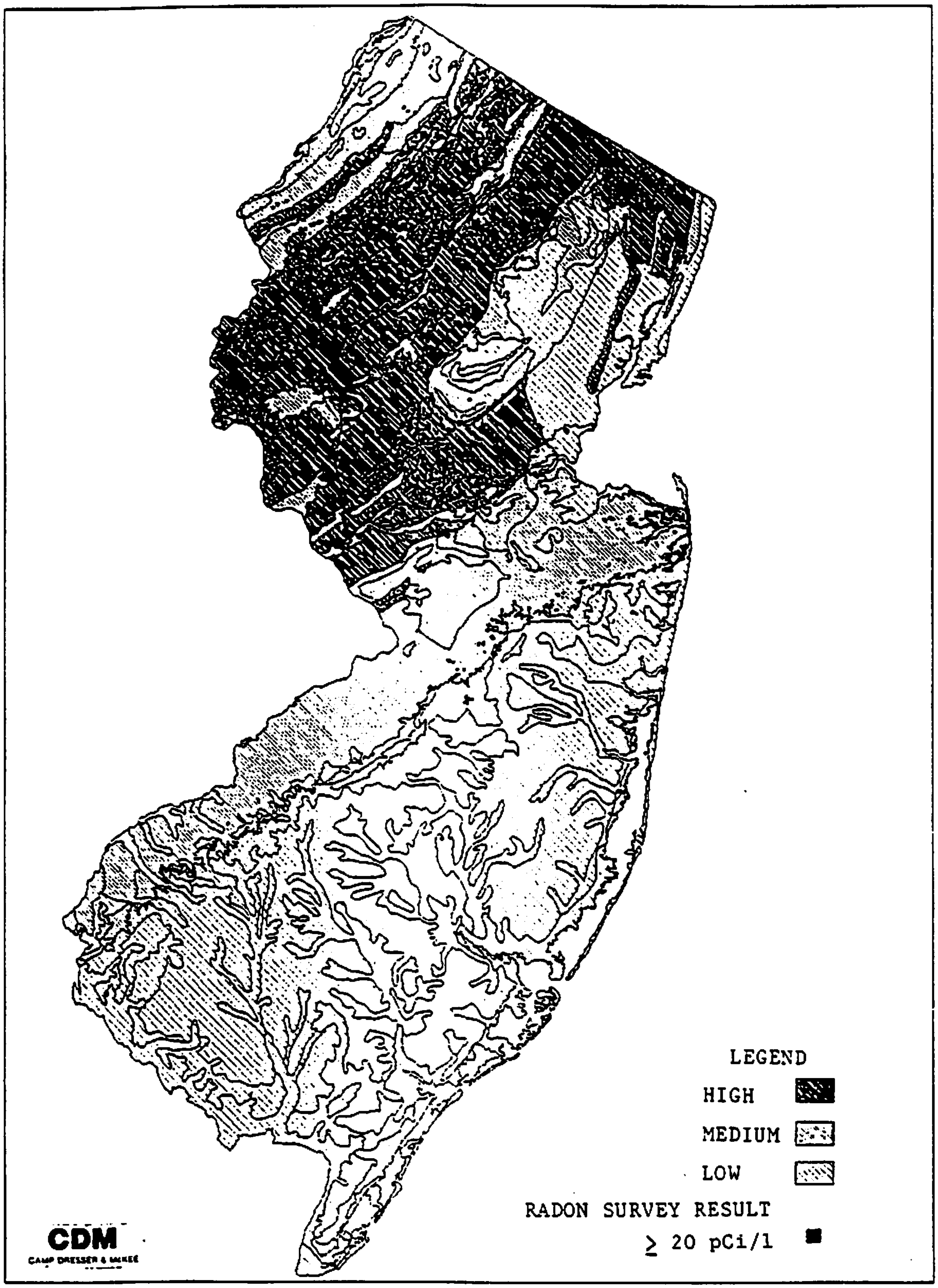


FIGURE 4 OVERALL RADON POTENTIAL