ORNL/TM-13742

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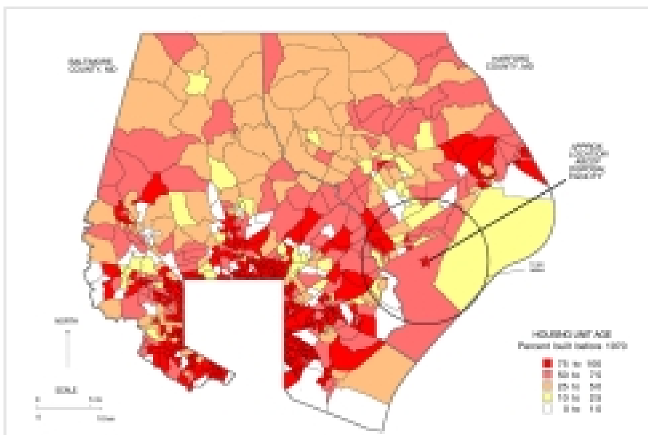

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OAK RIDGE NATIONAL LABORATORY
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TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS v

1. INTRODUCTION 1
2. PROTECTIVE MEASURES 2
3. BACKGROUND 5
4. METHODOLOGY 7
5. RESULTS 9
6. CONCLUSION 11
7. REFERENCES 12

APPENDIX A: MAPS SHOWING HOUSING STOCK AGE A-1

ACRONYMS AND ABBREVIATIONS

acph	air changes per hour
ASHRAE	American Society of Heating, Refrigeration, and Air-Conditioning Engineers
Btus	British Thermal Units
CSEPP	Chemical Stockpile Emergency Preparedness Program
DOE	Department of Energy
FEMA	Federal Emergency Management Agency
FmHA	Farmer’s Home Administration
GIS	Geographic Information System
HUD	U.S. Department of Housing and Urban Development
IRZ	immediate response zone
MPS	minimum property standards
NBS	National Bureau of Standards
NCSBCS	National Conference of States on Building Codes and Standards
ORNL	Oak Ridge National Laboratory
TIGER	Topologically Integrated Geographic Encoding and Referencing System
WAP	Low-Income Weatherization Assistance Program

1. INTRODUCTION

Determining an efficient screening method for analyzing groups of buildings in areas vulnerable to potential chemical releases has become a subject of interest to many researchers in the field of Emergency Planning. Although managers of hazardous installations have the primary responsibility for operating their facilities in a safe manner, public authorities are charged with establishing emergency preparedness plans that provide maximum protection to residents during critical events. Faced with a fast-moving or uncertain source term in a chemical or other hazardous release accident, authorities often order precautionary evacuations of the areas affected.

However, the effectiveness of ordering consecutive precautionary evacuations has been called into question as researchers argue the issue of "cry wolf" (Dow 1998). If a non-compliance situation should occur around hazardous facilities, the question then centers on whether residents would be protected from chemical releases in their own homes when refusing to follow an evacuation order. If authorities could be reasonably sure that most residents or those located in certain areas would likely be protected by sheltering-in-place, then emergency response efforts and resources for areas at risk could focus on those without residential protection. Or, authorities might consider providing certified protection (such as weatherization techniques) to improve structural shortcomings.

The purpose of this study was to develop a method for using surrogate measures to determine if reasonable protection could be afforded by structures in the vicinity of the eight military installations that have the potential to release a chemical warfare agent vapor in an accident. Although the event is highly unlikely to affect populations off-post, the consequences from a release of chemical warfare agent vapor would be significant. Knowing the existing residential housing conditions in certain locations could help emergency response personnel decide if sheltering was an adequate protection measure. In addition, it can provide a basis for estimating resources for decreasing air infiltration rates in older housing stock by using weatherization techniques. Thus an analysis of surrogate measures could benefit the public emergency sector overall.

The key factor in sheltering-in-place effectively centers on the level of protection offered by the structure. Rate of air infiltration into a structure determines the "leakiness". Buildings with low infiltration rates will afford residents higher levels of protection during a plume passage than those with high infiltration rates. The second issue is ensuring that residents leave the structure when the release is finished and vent the structure adequately before returning.

This paper suggests a methodology for using age of residential structures as a surrogate indicator to estimate air infiltration rates of buildings and to evaluate their effectiveness for use as in-place shelters. The method, developed at Oak Ridge National Laboratory (ORNL), uses data from the Census Bureau and a Geographic Information System (GIS) to map the number and percent of houses built before 1950 and before 1970, in communities surrounding the eight military facilities that store chemical warfare agents. Commercial buildings and institutions were not considered in this study, only buildings that fit the U.S. Census Bureau definition of residential housing units either occupied or vacant. Housing unit age is used as a surrogate indicator of air infiltration rates because research has shown that prior to the late 1960s, few building codes required weatherization measures in most private home construction. With the advent of the energy crisis in the early 1980s, building code standards changed and weatherization was required in new home construction to reduce air infiltration and thus decrease energy consumption.

This analysis was prepared for the Federal Emergency Management Agency (FEMA) in support of the Chemical Stockpile Emergency Preparedness Program (CSEPP). The CSEPP is a joint FEMA-Army program to ensure adequate preparedness in communities surrounding eight locations where the Army stores, and plans to destroy, its aging stockpile of unitary chemical warfare agents. As directed by Congress, a primary goal of the CSEPP is to promote the maximum protection of the public in surrounding areas until all agent and munitions are destroyed. Congress also mandated that the disposal facilities be dismantled after the munitions are destroyed.

2. PROTECTIVE MEASURES

Protective measures supported by CSEPP to reduce the public's exposure to hazardous airborne chemicals in the event of an accidental release include evacuation or taking shelter in buildings (i.e., in-place sheltering). Each measure provides a different level of protection depending on the type of potential accident and the type of agent stored at the installation.

Evacuation is the most common emergency countermeasure to a toxic chemical release and the one with which responders have the most experience. Evacuation consists of temporarily removing people from an area of actual or potential hazard to a safe area for a period of time. If there is enough time to complete an evacuation prior to a chemical plume's arrival, evacuation is generally the preferred alternative for most people living in areas likely to be affected by a chemical release. In some cases evacuation is inappropriate because certain special populations and institutions will not be able to evacuate quickly. Thus, some facilities, such as hospitals or schools have elected to over-pressurize their buildings, thus allowing those populations to remain safely within the facility at all times. Evacuation may not be advisable when the chemical plume is moving quickly through congested urban areas or in areas without multiple readily accessible evacuation routes. People in the process of evacuating could be overtaken by the toxic plume while in their vehicles. Vehicles generally offer far less protection than structures that can have the ventilation systems deactivated.

In-place sheltering is supported by the CSEPP for use in situations when some or all people in an area might not be able to complete an evacuation before being exposed. Generally, any building suitable for winter habitation will provide some protection from exposure if windows and doors are closed and heating, ventilation, and air conditioning systems are turned off. The degree of protection is largely a function of air exchange or air infiltration rates. Air exchange rates estimate the number of times per hour the volume of air inside a structure is exchanged with air from outside the structure. According to a study by the CSEPP Accident Planning Base Review Group (1996) housing stock in the U.S. varies from 0.2 to about 5 air changes per hour (acph). At 0.2 acph, it takes about 5 hours for the air to completely change over in a house. A tight house is considered to have an air exchange rate of less than 0.5, and the goal would be to achieve a rate of 0.25. The average for U.S. housing stock is about 0.7 acph, which results in a replacement time of 1 hour and 25 minutes. Older houses have significantly higher air exchange rates than modern houses. Also, the effectiveness of shelter-in-place can vary substantially with the nature of the chemical agent release, short-term release versus long-term release, and the type of shelter-in-place option chosen.

Four types of shelter-in-place are considered in the CSEPP: *normal, expedient, enhanced,* and *pressurized.* The different types of sheltering influence the degree of protection (or "safeness") afforded by in-place sheltering. Chester (1988) defined "protection factor" as the ratio of the dose from exposure a person would receive with no protection compared with the dose received if they were protected. Dose in this study refers to the amount of chemical warfare agent absorbed by a person's body at a specific time. Chemical substances affect people differently depending on the body weight and age of the individual. As shown by Chester (1988), the protection factor is dependent on both the number of air changes per hour and the plume passage time. As the toxic cloud passes by the structure, the protection factor increases as the number of air changes in the structure decreases.

Normal sheltering involves taking refuge in an existing, unmodified building to prevent or reduce exposure to a toxic chemical. Unmodified buildings have no additional measures to prevent leakage (e.g., additional weatherization). Normal sheltering requires people to close doors and windows and deactivate ventilation systems that replace indoor air with outdoor air. Exposure to chemical agents is partially blocked by reducing the amount of airborne agent infiltration into the structure's interior "protected" environment.

The problem with normal sheltering is that in most cases, as soon as the plume passes, the concentration of agent is higher in the protected environment (inside) than in the unprotected environment (outside). This means that the public must be notified once the plume has passed by so they can leave the shelter as well as ventilate the shelter to eliminate the agent concentration of the inside air. The protection factor associated with normal sheltering usually ranges from 1.3 to 10 (Chester 1988), depending on the time it takes the plume to pass by the shelter. Normal sheltering thus helps protect individuals from exposure when emergency actions are precautionary, concentrations of the chemical in the plume are low, or when cloud passage time is short (up to about 30 min.).

Expedient sheltering involves taking refuge in an interior room of an existing structure and reducing the room's infiltration rate before the plume arrives. In addition to closing windows and doors and deactivating ventilation systems, the process includes taping the seams of windows and doors, covering vents and other outlets with plastic sheeting, and laying wet towels across door thresholds. As in the case of normal sheltering, people who implement expedient sheltering must know when the toxic plume has passed by so they can vacate and ventilate the shelter.

Expedient sheltering can provide adequate protection when an airborne release results in a low to moderate concentration of agent in the plume or when exposure times are estimated to last between 1 to 3 hours (Rogers et al. 1990). Protection factors afforded by expedient sheltering are increased with the reduction of air infiltration rates into the structure and are greater than those associated with normal sheltering. If air infiltration can be reduced to 1 air change in 4 hours, the protection factor would range from approximately 2 to about 60 (Chester 1988).

Sorensen (1988) found that taping and sealing an average room can be accomplished in 10 to 15 min. According to Rogers (1990), limited trials found that expedient sheltering for two people in a single inside room could be completed on average in about 20 min.

Enhanced sheltering involves taking refuge in an existing building that has previously been adequately weatherized to reduce air infiltration rates. Enhanced sheltering requires that a building be modified in much the same way as for energy conservation. The process also involves the basic steps of closing windows and doors and deactivating ventilation systems. Enhanced sheltering further requires that public information systems notify the public to vacate and ventilate the shelter when the concentration of agent is estimated to be lower in the unprotected environment (outside) than in the protected environment (inside). If air infiltration can be reduced to 1 air change in 4 hours, the protection factor would range from approximately 2 to about 60 (Chester 1988). Enhanced sheltering provides protection from exposure concentrations are expected to be low to moderate, and cloud passage time is limited to 1 to 3 hours (Rogers et al. 1990).

Pressurized sheltering involves taking refuge in an existing building equipped with a specialized filtration/pressurization system. Like the other types of in-place sheltering, the process involves deactivating ventilation systems that replace indoor air with unfiltered outdoor air. In addition, pressurized sheltering requires activation of a pressurization system that uses filtered air to create positive pressure within the sealed shelter. The positive pressure prohibits the infiltration of contaminated air into the shelter because clean air is leaking out of the structure. Under conditions with moderate to large concentrations of agent being released with exposure times of 3 to 12 hours (i.e., slowly traveling plume of any size), pressurized sheltering can provide continuous and adequate protection (Rogers et al. 1990). This type of in-place sheltering provides maximum protection from toxic exposure in nearly all situations. Because no toxic air leaks into the shelter, it is not necessary for occupants to vacate or ventilate the shelter as soon as the plume passes. One problem with pressurized sheltering is limiting entrance and egress during the entire period of sheltering.

In preparing for possible implementation of in-place sheltering, emergency planners should evaluate structures in the area surrounding the chemical facility to estimate their "air-tightness", because the level of protection provided by non-pressurized shelter-in-place options is largely a function of air exchange or air infiltration rates within a structure (Birensvige 1983a,b; Chester 1988). The degree to which the outside air flows into the structure used as a shelter can be used to generally characterize the level of in-place protection (Rogers et al. 1990).

Several factors can influence the infiltration rate of a building:

- outdoor meteorological influences,
- building design,
- general climatic conditions of the region,
- adequate building codes that contribute to energy efficiency, and
- age of building.

Meteorological influences include wind speed and wind direction, indoor and outdoor temperature differences, and relative humidity. Other factors that affect infiltration include construction and design of the building, location of doors and windows in relation to wind direction, and the protective activities taken by the occupants before the plume arrives. These include closing doors and windows and deactivating ventilation systems (Birenzvige 1983b). Climatic conditions include whether the building is located in a cold or warm climate or whether topographical features (i.e., vegetation, ridges, valleys, etc.) create micro-climates that affect locations. Structural concerns include type and quality of construction (i.e., building standards and codes and how well they are enforced), type of building (i.e., residential vs office building), and the age of the building.

According to Rogers (1990), research indicates that the total cumulative exposure over time, or Ct, within a leaky (i.e., non-pressurized) structure will equal the cumulative exposure outside that structure if the structure is not ventilated and/or vacated after the plume has passed. Protection is maximized when protective sheltering is implemented before the plume's arrival and the shelter is vacated or ventilated immediately after the plume passes. If shelters remain sealed after the plume passes, they could seal chemical agent concentrations inside the structure and thereby increase occupant exposure.

3. BACKGROUND

Predicting the infiltration rates of particular residential housing stock is difficult without extensive field work. One surrogate measure to address air infiltration issues is the age of the residential housing unit. Unless they have been weatherized, older houses have significantly higher infiltration rates than modern energy-efficient houses. If structures are old and/or in poor condition, it is unlikely they would provide adequate protection from a chemical vapor release due to high air exchange rates. If information is known about the residential housing stock it may be feasible to recommend evacuation for some of the residents and shelter-in-place for other residents.

Prior to 1965, U.S. building codes did not include energy conservation standards. As in other areas of housing standards, local governments set the requirements for the construction of buildings in the interest of public health, safety, and general welfare. However, in the late 1960s and early 1970s energy conservation became an issue of national concern. Federal and state governments began working together to develop standards to include scope of code coverage, national code uniformity, energy efficiency, cost, and flexibility. In 1973, the National Conference of States on Building Codes and Standards (NCSBCS) requested the National Bureau of Standards (NBS) to develop criteria for energy conservation in buildings (Schweitzer 1978). After completion, the standards were forwarded to the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) to serve as a basis for a national energy conservation standard (NBS 1974). The result was ASHRAE 90-75, the "Energy Conservation in New Building Design" of 1975 (ASHRAE 1975). One of the performance standards established was for the exterior envelope of the building. A maximum acceptable "U" value was established for walls, floors, roofs and ceilings. The U value represents "thermal transmittance" and is the amount of heat, expressed in British Thermal Units (Btus), that will pass through a square foot of material per hour for each Fahrenheit degree difference between inside and outside temperature. By increasing the density of building materials, heat exchange is reduced. This need to reduce energy consumption in buildings resulted in more stringent weatherization requirements in new construction.

The Minimum Property Standards adopted by the U.S. Department of Housing and Urban Development (HUD) and the Farm Home Administration (FmHA) have also influenced energy conservation. By setting minimum standards, the requirements of these two agencies are binding nationwide upon the substantial number of buildings financed by HUD or FmHA. Of the energy codes and standards discussed, FmHA and HUD are by far the most stringent. With the completion of HUD's "Energy Conservation Performance Standards for New Buildings" in 1979, additional pressure was placed on state and local governments to adopt energy conservation measures. While state and federal governments were gaining influence in the codes field, local governments were losing their traditional dominance. The federal government has remained involved in seeking state of the art uniform solutions to the problem of reducing energy consumption in buildings. Soon after HUD's Minimum Property Standards incorporated energy efficiency requirements, a newly constructed house consumed much less energy than a house built prior to 1965 (Schweitzer 1978).

Concern for reducing air infiltration rates has also played a significant role in the U. S. Department of Energy's (DOE) Low-Income Weatherization Assistance Program (WAP). Grot and Clar (1981) examined over 200 dwellings occupied by low-income households in 14 cities across the U.S., representing all major climatic zones. Two types of measures were used: a tracer-gas decay technique (developed at the NBS) which uses air sample bags to measure natural air infiltration and a fan depressurization test that measures induced air exchange rates (as a measure of the tightness of a building's envelope). The latter method was used as a diagnostic tool to assist weatherization crews in analyzing the leakiness of buildings. The study was sponsored by the NBS Center for Building Technology to evaluate the effectiveness of weatherization. The goal was to provide data for determining the optimal level of weatherization for residences occupied by low-income families in various climatic zones in the United States. The results of the study demonstrated that building weatherization techniques can reduce air infiltration rates significantly.

Gettings (1988) reported on the results of a study done by the Wisconsin Energy Conservation Corporation on low-income, single-family buildings. The DOE-sponsored home study provided a wide range of initial air leakage rates. After initial analysis, a blower door was used to locate leaks and to measure a house's leakiness in air exchanges per hour. The study found that in addition to leakage around doors and windows, other characteristics of a house add significantly to its infiltration rate. These characteristics include the types of walls and ceilings, number of attic accesses, presence of fireplaces, and how electrical outlets are insulated. The study concludes that a 16% reduction in air leakage rates can be achieved by standard infiltration retrofit procedures.

4. METHODOLOGY

Based on the history of building codes and overall construction practices, homes constructed since the early- to mid-1970s are likely to have significantly lower infiltration rates than homes constructed earlier. This study aims to classify areas around the eight CSEPP locations according to the proportion of residences in each area that were constructed before 1950 and before 1970. This classification is expected to give an indication of which residential areas are likely to be suitable for in-place sheltering.

Data from the U.S. Bureau of the Census (U.S. Department of Commerce 1990) provide a starting point for analysis of structures through their enumeration of residential housing units by geographic area. The census defines housing units as living quarters in structures intended primarily for residential use but can also include structures intended for nonresidential use. Both occupied and vacant residential housing units are included in the housing unit inventory.

Under the Census Bureau definition, a housing unit may be either a house, an apartment, a mobile home or trailer, a group of rooms or a single room occupied as separate living quarters or, if vacant, intended for occupancy as separate living quarters. Separate living quarters are those in which the occupants live and eat separately from other persons in the building and which have direct access from outside the building or through a common hall. Recreational vehicles, boats, vans, tents, railroad cars, and the like are included only if they are occupied as someone's usual place of residence. If the living quarters contain nine or more persons unrelated to the householder or person in charge (a total of at least 10 unrelated persons), it is classified as group quarters and is not counted as a housing unit. The living quarters occupied by staff personnel within any group quarters are separate housing units if they satisfy the housing unit criteria of separateness and direct access; otherwise, they are considered group quarters (U.S. Department of Commerce 1990).

The Census also reports the year a housing unit (either occupied or vacant) was built. "Year" is defined as the actual year the structure was built, not remodeled, added to, or converted. It is the year all exterior windows, doors, and final usable floors were in place for the structure (U.S. Department of Commerce 1990).

The commercial database package FoxPro© was used to extract a subset of the Census database Summary Tape File 3-A for purposes of the analysis discussed here. Fields of data were aggregated and summed to create the variables "number of housing units built prior to 1950" and "number of housing units built prior to 1970". These two variables were then divided by the total number of houses to determine the percent of housing units built prior to 1950 and prior to 1970. In the initial analysis, only counties in the area of potential hazard from the release of chemical weapon agents were examined. The results were then mapped (Appendix A). This method provides a quick and effective way to organize, analyze, and display vast amounts of spatially oriented data with Census variables. By graphically depicting the type of housing stock in certain areas, the methodology also aids decision-makers and stakeholders in synthesizing and comprehending the information.

The data used to generate the geographic features (i.e., county boundaries, block group polygons, and block group centroids) were taken from the Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) System. In its present form, the TIGER data is not graphically visible. Proprietary utility software developed at ORNL was used to import data directly from the Census TIGER/Line CD-ROM (U.S. Department of Commerce 1991). The data were then used to create MapInfo Exchange Format Files that can be directly imported into the MapInfo© GIS software for graphical display of the geographic objects.

The methodology allows MapInfo©, a commercially available geographic information system, to link the population and housing data to the geographic data generated from the Census TIGER/Line files. The calculations were done for each block group polygon in each county and were linked to the map polygons by the centroid. The centroid allows the data to be assigned to the appropriate polygon area. For comparative purposes, the number of housing units were calculated in potentially impacted areas within 15-km and/or 10-km radii for each site. When the CSEPP Immediate Response Zone (IRZ) boundary information was available, it was used as the bounding polygon instead of the radius circle.

To get an estimate of the number of residential housing units built prior to 1950 and 1970 falling inside the geographic area of interest, a proportional area method was used. In our analysis of the eight chemical agent stockpile sites, the latitude and longitude of the location of the proposed disposal facility was used as the central point of the radius circle. The GIS then estimated the proportion of the area of each census block group polygon falling within the radius circle or IRZ boundary. The resulting proportion was then applied to the number of residential housing units in that block group polygon to estimate the block group's contribution to the housing units inside the area of interest. The estimated total number of housing units within the area of interest was then obtained by summing the housing units of the block group polygons and the block group fragments contained in the radius circle. Once the data values were calculated, a thematic and a bivariate thematic map were created. Each polygon was shaded by ranges of percentages, where each range was represented by a different color. The number of housing units in each polygon was displayed by dots on the map, with each dot representing a number of residential housing units.

5. RESULTS

In this analysis we attempt to assess the potential of the residential housing stock for use as shelters to protect against a chemical vapor cloud. Age of the dwelling is one of the best indicators for making this assessment. Engineering inspections and an air-exchange test are more accurate measures of the protection offered by individual buildings. Older residential dwellings are more likely to have higher air exchange rates than newer dwellings. Age is not a predictor of the air exchange of any specific house but of a stock of dwellings. In addition, this analysis provides a rough estimate of the effort to increase the protection levels in dwellings in the IRZs at the CSEPP sites.

Table 1 summarizes the total number of residential housing units, those built before 1950, and those built before 1970, for each of the CSEPP sites. For 3 sites we use the 10-km radius because the IRZ is contained within this distance. For 4 sites we include the 15-km radius because the IRZ extends to this distance. For one site we use the IRZ boundary. Programmatically these are conservative estimates in that the actual IRZ areas are smaller than the radial circles we used in the analysis.

Our best estimates of the number of dwellings in the IRZ vicinities are as follows:

Total dwellings:	75,635
Built before 1970:	37,188 (49%)
Built before 1950:	13,630 (18%)

Overall almost 50% of the residential dwellings were built before 1970 and 18% were built before 1950. As many as 37,000 homes may require weatherproofing to achieve an air exchange rate that offers a reasonable amount of protection.

The percentage varies from site to site. The newest housing stocks are found in Umatilla and Aberdeen, while the oldest housing stocks are in Newport, Pueblo, Tooele, and Anniston. Anniston has the most dwellings built before 1970 and 1950 while Tooele has the fewest.

Table 1. Number of Housing Units in IRZ Counties around Chemical Activity Sites

Site	Total housing units	Built before 1950	% of total	Built before 1970	% of total
Aberdeen					
10 km radius	20,479	2,119	10%	7,904	39%
Anniston					
10 km radius	4,611	765	17%	2,489	54%
15 km radius	25,066	6,224	25%	15,141	60%
Blue Grass					
10 km radius	9,093	1,877	21%	4,659	51%
Newport					
10 km radius	1,357	723	53%	961	71%
Pine Bluff					
10 km radius	3,275	327	10%	1,211	37%
15 km radius	10,029	1,325	13%	4,827	48%
Pueblo					
10 km radius	165	63	22%	120	73%
15 km radius	725	206	28%	487	67%
Tooele					
within IRZ	385	137	36%	237	62%
Umatilla					
10 km radius	4,171	424	10%	1,405	34%
15 km radius	8,501	1,019	12%	2,972	35%
Total	75,635	13,630	18%	37,188	49%

The maps shown in Appendix A depict the number and the percent of pre-1950 and pre-1970 residential units in each Census block group around the eight CSEPP stockpile locations. The maps also give an indication of the age of the residential housing stock within each block group

polygon showing the age of the residential housing stock closest to the disposal facility location. It appears from the maps that there is a tendency for areas near the facilities to have the older homes.

In order to assess the programmatic impact of retrofitting residential housing, a basis for estimating cost is needed. Probably the best basis would be the data collected in DOE's WAP. Among the conservation measures carried out by this program, which provides weatherization services to low income persons, are ones to reduce air infiltration into the structure. Average costs of reducing air infiltration were calculated based on a study of almost 15,000 weatherized homes (Brown et al. 1993). According to this study it costs about $250 to caulk, weatherstrip, and seal a home. Based on this estimate it would cost a little over $9 million to implement an air infiltration reduction program in the pre-1970 residential housing stock and almost $3.5 million if just the pre-1950 stock were addressed.

6. CONCLUSION

The results indicate that readily available Census data and geographic information system software can be used to map the distribution of residential housing units according to age. The proportion of residences constructed before 1950 and 1970 can be described for specific areas of a community. Because evidence suggests that these housing units are likely to have higher air infiltration rates and would likely provide less protection than newer units, emergency planners can use the mapped information to evaluate how effective in-place sheltering might be for various neighborhoods in their communities. Planners could use this information to determine if certain locations would need special training or protective devices such as early warning systems.

While this information contributes to the planner’s professional decisions, it falls short of providing a tool that can produce a quantified estimate of the average air infiltration rate of residences in a specific area. Three steps would be needed to accomplish this important objective.

First, variables other than residential housing unit age should be incorporated into the analysis. For example, the number of commercial buildings and institutions would provide a better indication of potentially affected daytime populations. Additional data from the Census that might explain some of the variance in residential infiltration rates include household income, value of housing unit, type of housing (single-family, multi-family, mobile home), and the number of people per household. Data from other sources might also be useful, such as energy expenditure of the housing unit, climatic zone, average wind speed, and average difference between inside and outside temperatures.

As the second step in developing a tool to estimate air infiltration rates of potential shelters, empirical studies would need to be conducted to measure the infiltration rates of a diverse sample of residences in the Census block groups analyzed in the current study. Either the blower door method or the tracer gas decay method could be used to measure the air exchange rates of a randomly selected sample of residential units.

Finally, the data on potential predictor variables and the measurements of infiltration rates could be incorporated into a multivariate analysis to determine whether the average air infiltration rate of structures in an area can be successfully predicted and to identify the variables that are most important in making such a prediction. Coefficients might also be produced that would enable planners to perform a quantitative assessment of the suitability of the residential housing stock in a specific area to function as shelters in the event of a chemical agent release.

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APPENDIX A
MAPS SHOWING
RESIDENTIAL HOUSING STOCK AGE

(Maps included are examples.)

APPENDIX A

TABLE OF CONTENTS

Aberdeen Chemical Agent Disposal Facility (ABCDF), MD
Map 1a. Percent of houses built prior to 1950 .... A-4
Map 1b. Number and percent of houses built prior to 1950 .... A-5
Map 1c. Percent of houses built prior to 1970 .... A-6
Map 1d. Number and percent of houses built prior to 1970 .... A-7

Anniston Chemical Agent Disposal Facility (ANCDF), AL
Map 2a. Percent of houses built prior to 1950 .... A-8
Map 2b. Number and percent of houses built prior to 1950 .... A-9
Map 2c. Percent of houses built prior to 1970 .... A-10
Map 2d. Number and percent of houses built prior to 1970 .... A-11

Blue Grass Chemical Agent Disposal Facility (BGCDF), KY
Map 3a. Percent of houses built prior to 1950 .... A-12
Map 3b. Number and percent of houses built prior to 1950 .... A-13
Map 3c. Percent of houses built prior to 1970 .... A-14
Map 3d. Number and percent of houses built prior to 1970 .... A-15

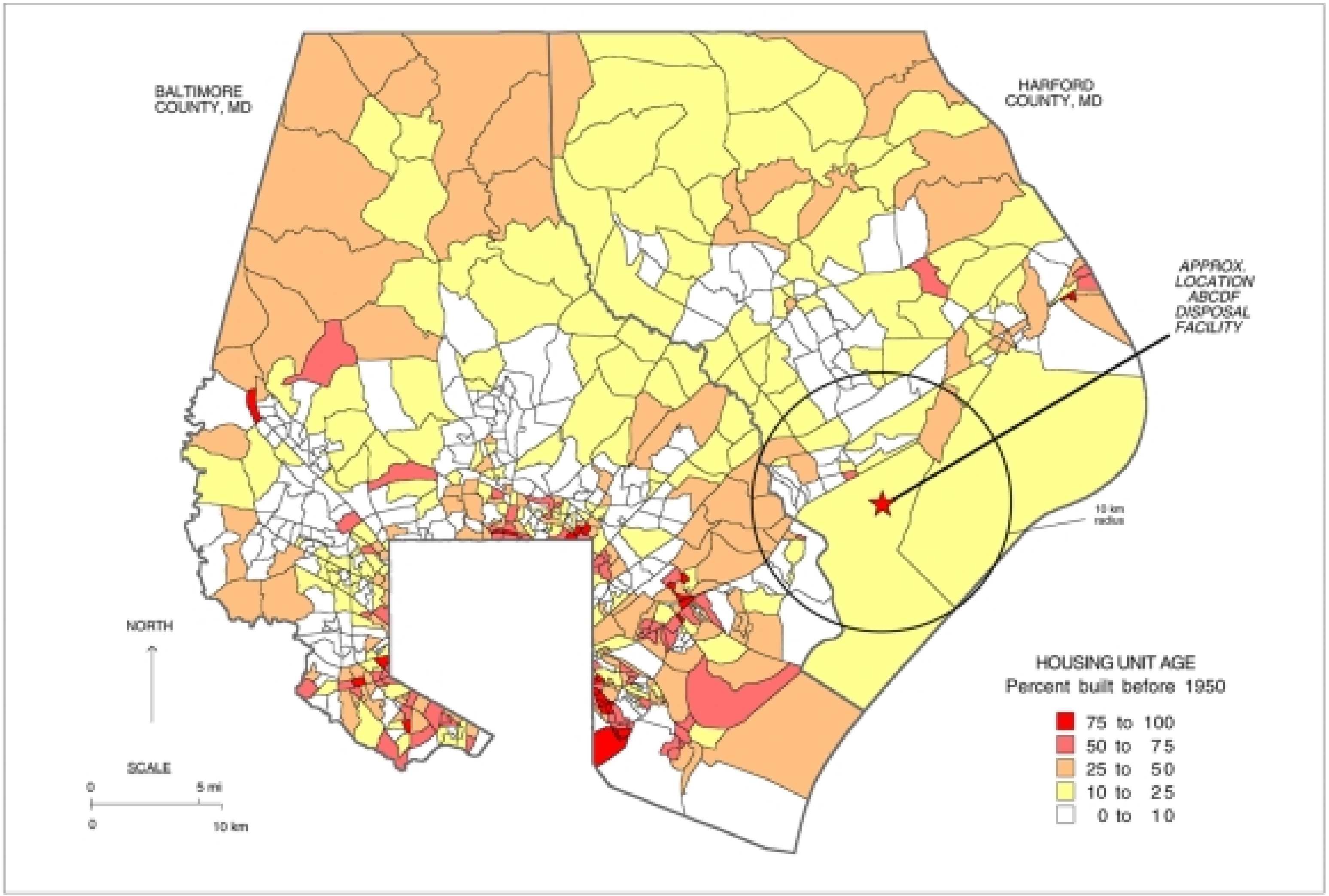
Newport Chemical Agent Disposal Facility (NECDF), IN
Map 4a. Percent of houses built prior to 195 .... A-16
Map 4b. Number and percent of houses built prior to 1950 .... A-17
Map 4c. Percent of houses built prior to 1970 .... A-18
Map 4d. Number and percent of houses built prior to 1970 .... A-19

Pine Bluff Chemical Agent Disposal Facility (PBCDF), AR
Map 5a. Percent of houses built prior to 1950 .... A-20
Map 5b. Number and percent of houses built prior to 1950 .... A-21
Map 5c. Percent of houses built prior to 1970 .... A-22
Map 5d. Number and percent of houses built prior to 1970 .... A-23

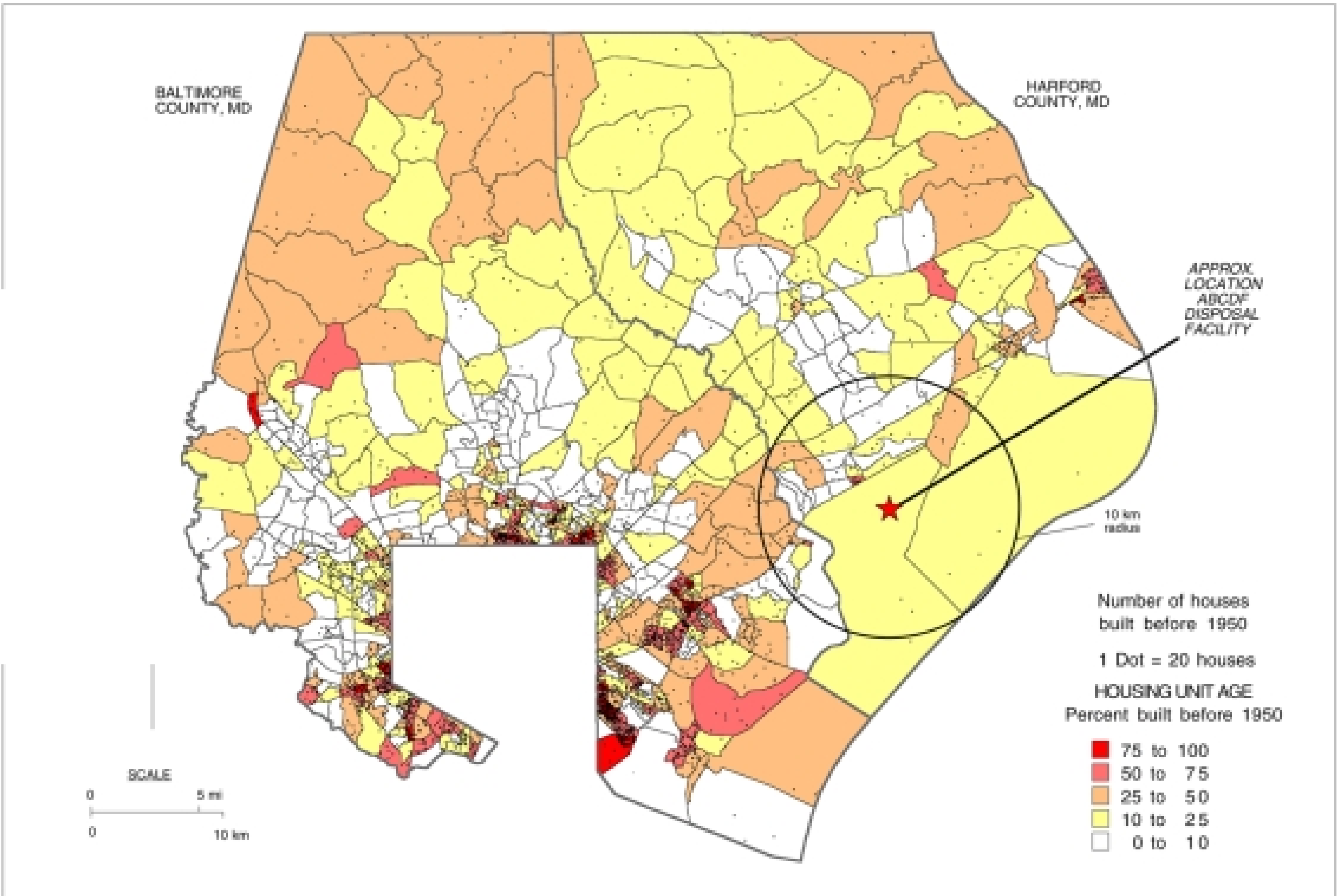
Pueblo Chemical Agent Disposal Facility (PUCDF), CO
Map 6a. Percent of houses built prior to 1950 .... A-24
Map 6b. Number and percent of houses built prior to 1950 .... A-25
Map 6c. Percent of houses built prior to 1970 .... A-26
Map 6d. Number and percent of houses built prior to 1970 .... A-27

Tooele Chemical Agent Disposal Facility (TOCDF), UT
Map 7a. Percent of houses built prior to 1950 .... A-28
Map 7b. Number and percent of houses built prior to 1950 .... A-20
Map 7c. Percent of houses built prior to 1970 .... A-30
Map 7d. Number and percent of houses built prior to 1970 .... A-31

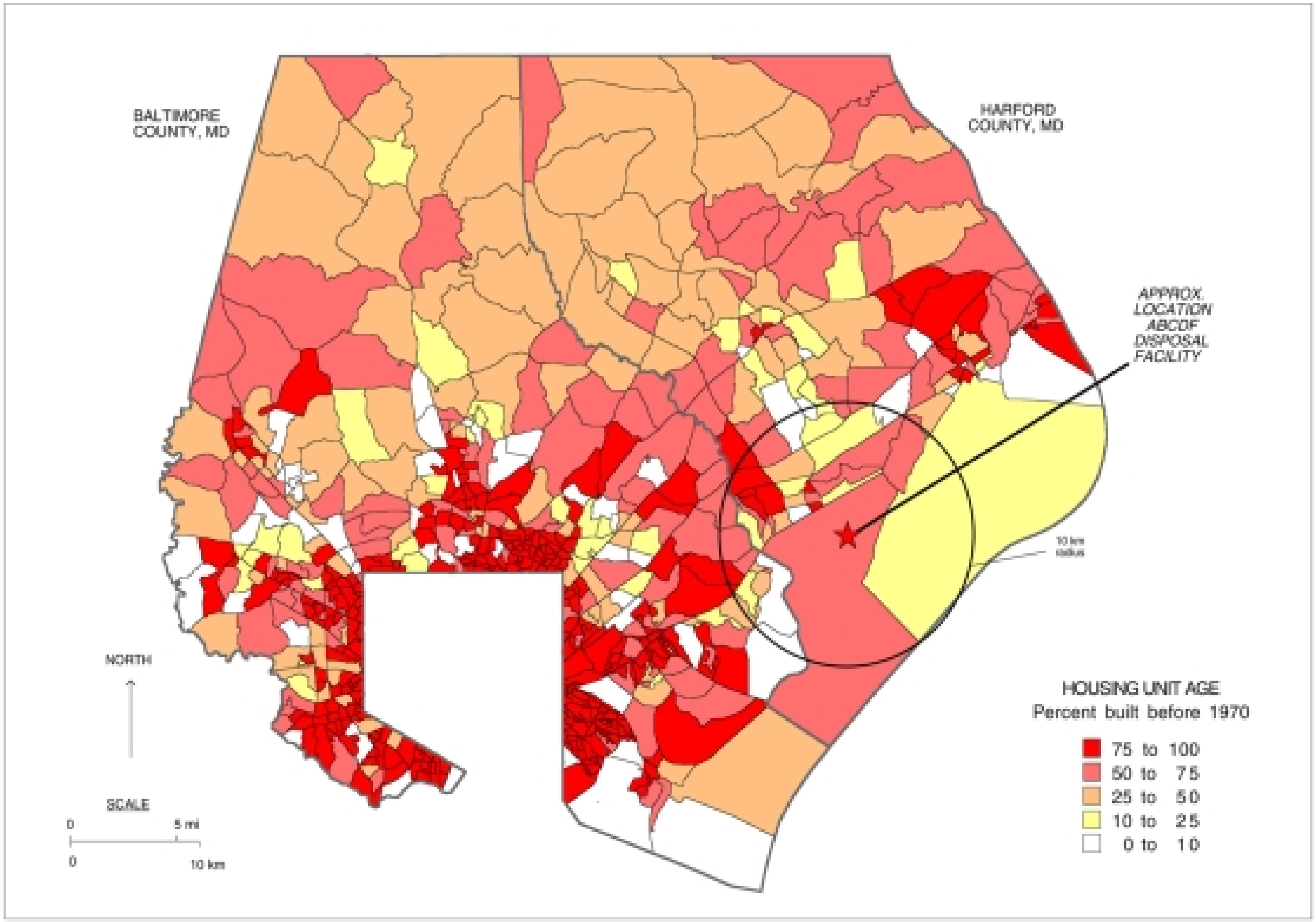
Umatilla Chemical Agent Disposal Facility (UMCDF), OR
Map 8a. Percent of houses built prior to 1950 .... A-32
Map 8b. Number and percent of houses built prior to 1950 .... A-33
Map 8c. Percent of houses built prior to 1970 .... A-34
Map 8d. Number and percent of houses built prior to 1970 .... A-35



Map 1a. Percent of housing units built prior to 1950 in area surrounding the Aberdeen Chemical Agent Disposal Facility (ABCDF), MD. (Source: US Census Bureau)
Map compiled by H. K. Hardee.



Map 1b. Number and percent of housing units built prior to 1950 in area surrounding the Aberdeen Chemical Agent Disposal Facility (ABCDF), MD. (Source: US Census Bureau) Map compiled by H. K. Hardee.



Map. 1c. Percent of housing units built prior to 1970 in area surrounding the Aberdeen Chemical Agent Disposal Facility (ABCDF), MD. (Source: US Census Bureau)
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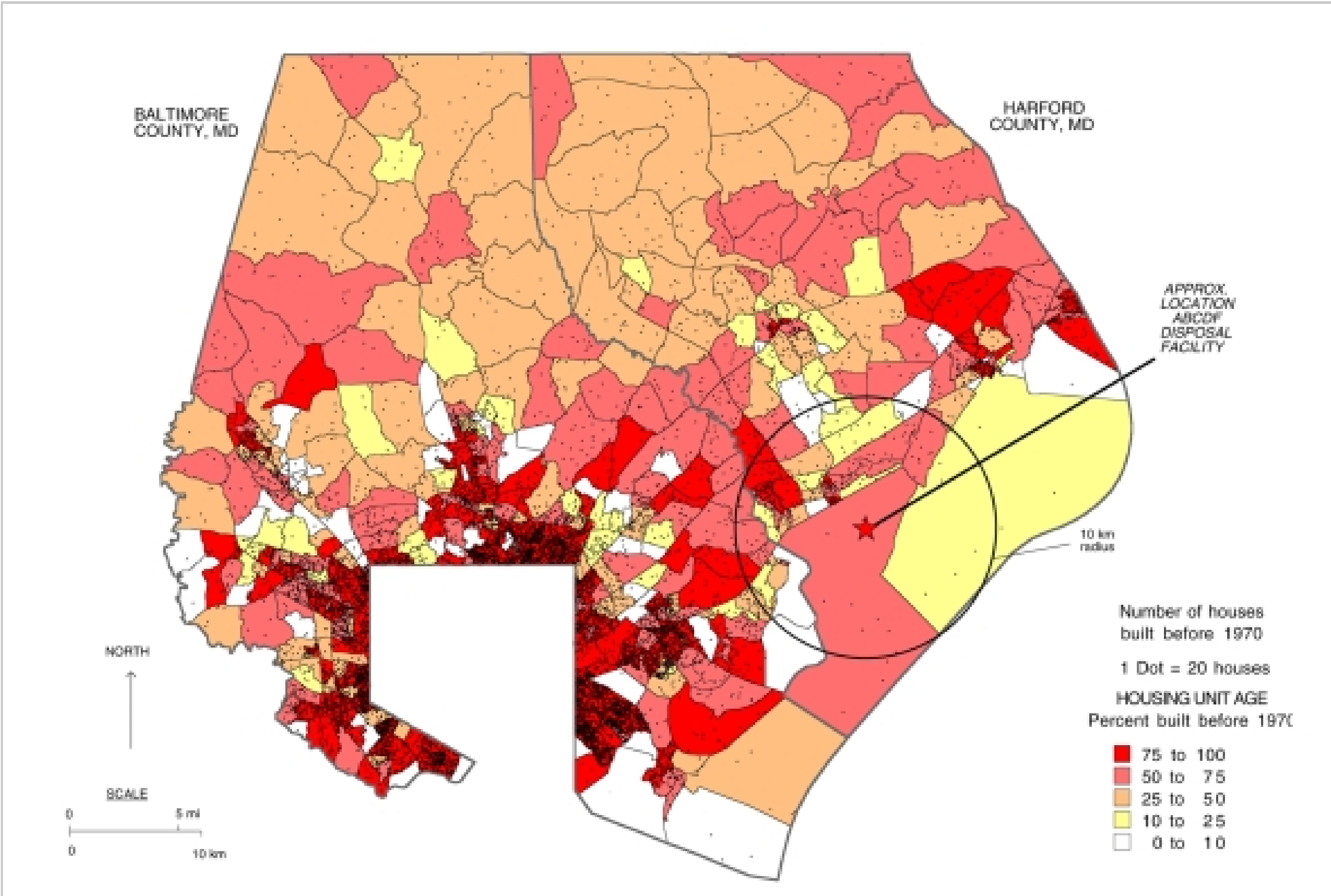
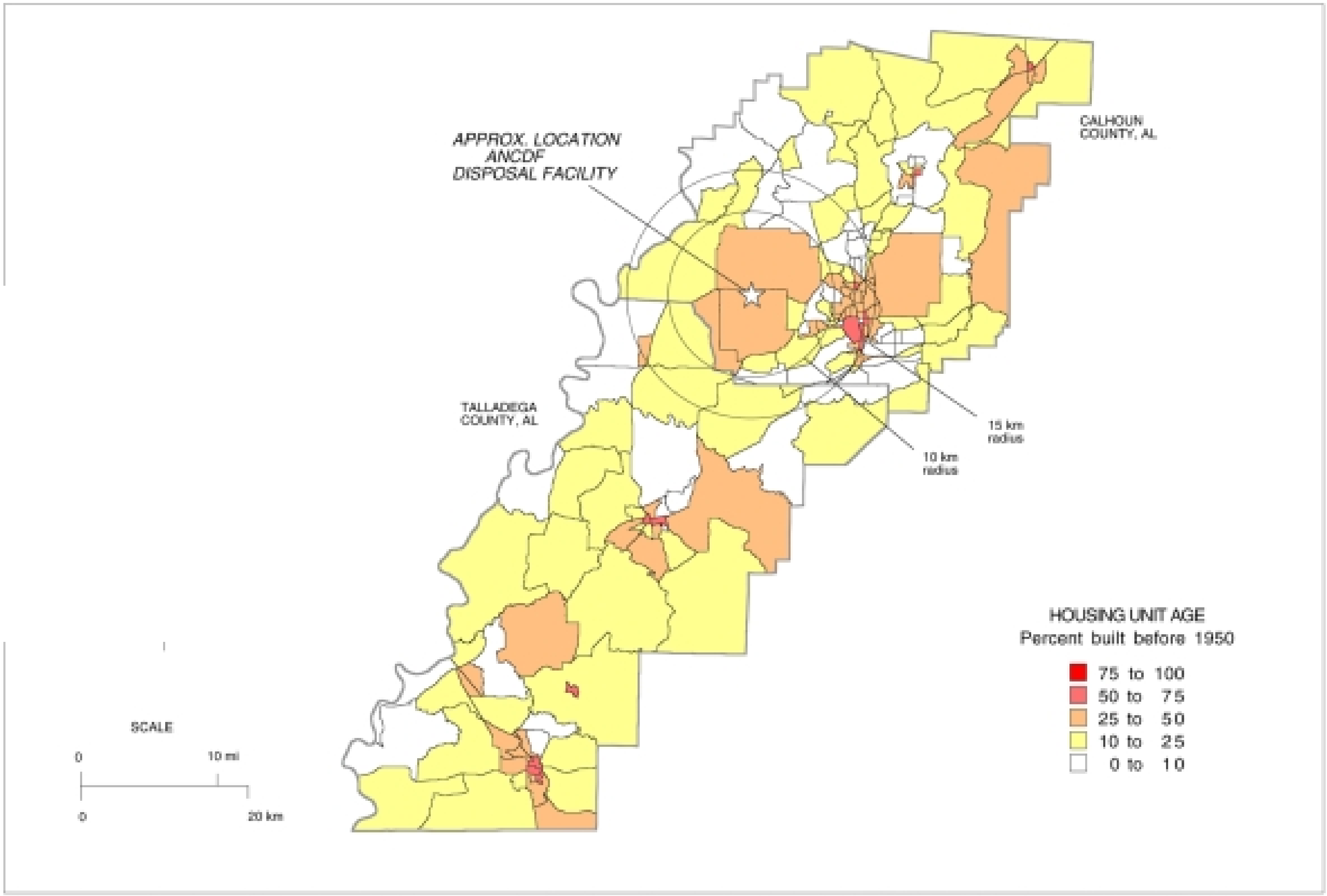
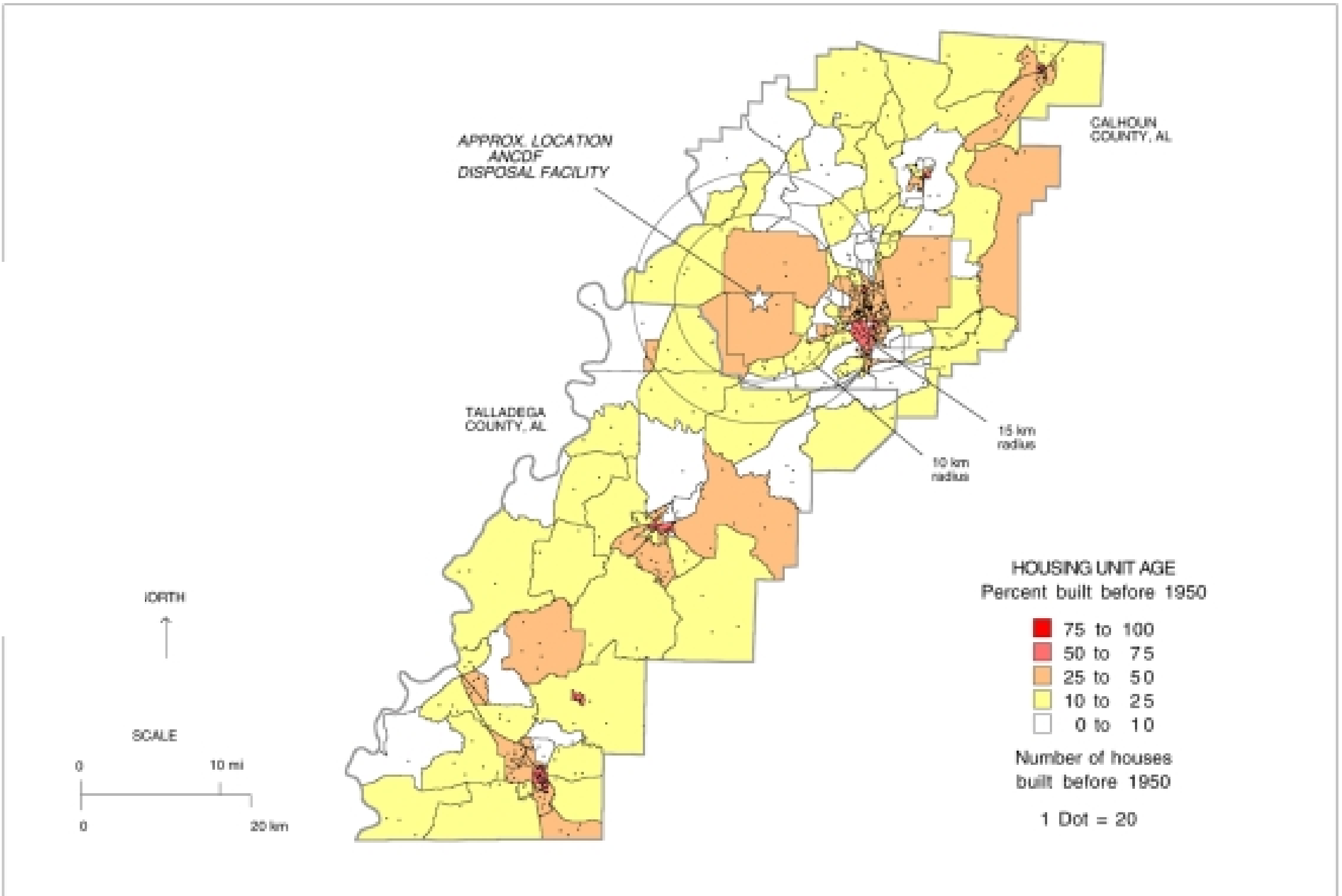


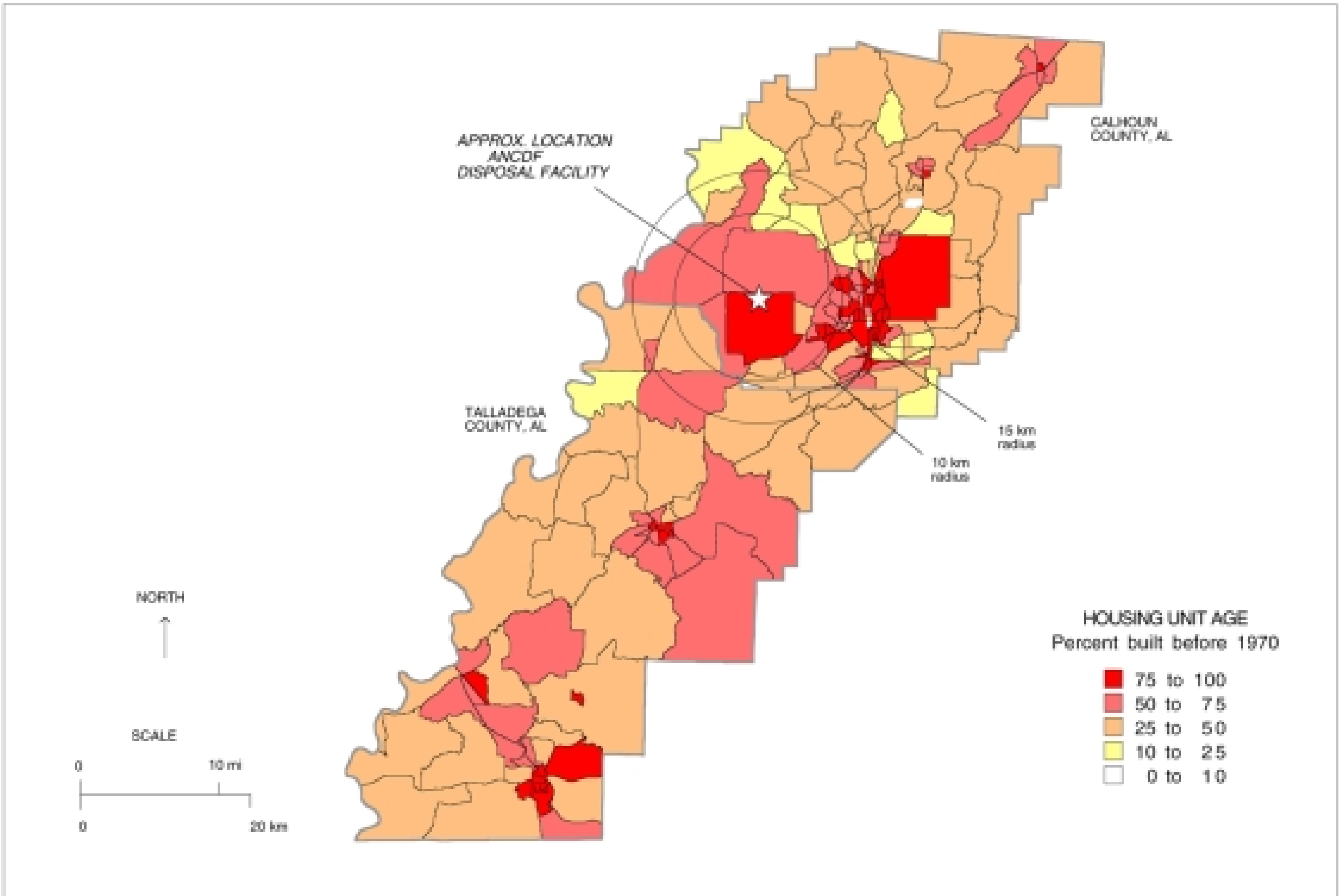
Map 1d. Number and percent of housing units built prior to 1970 in area surrounding the Aberdeen Chemical Agent Disposal Facility (ABCDF), MD. (Source: US Census Bureau) Map compiled by H. K. Hardee.



Map 2a. Percent of housing units built prior to 1950 in area surrounding the Anniston Chemical Agent Disposal Facility (ANCDF), AL. (Source: US Census Bureau)
Map compiled by H. K. Hardee.



Map 2b. Number and percent of housing units built prior to 1950 in area surrounding the Anniston Chemical Agent Disposal Facility (ANCDF), AL. (Source: US Census Bureau) Map compiled by H. K. Hardee.



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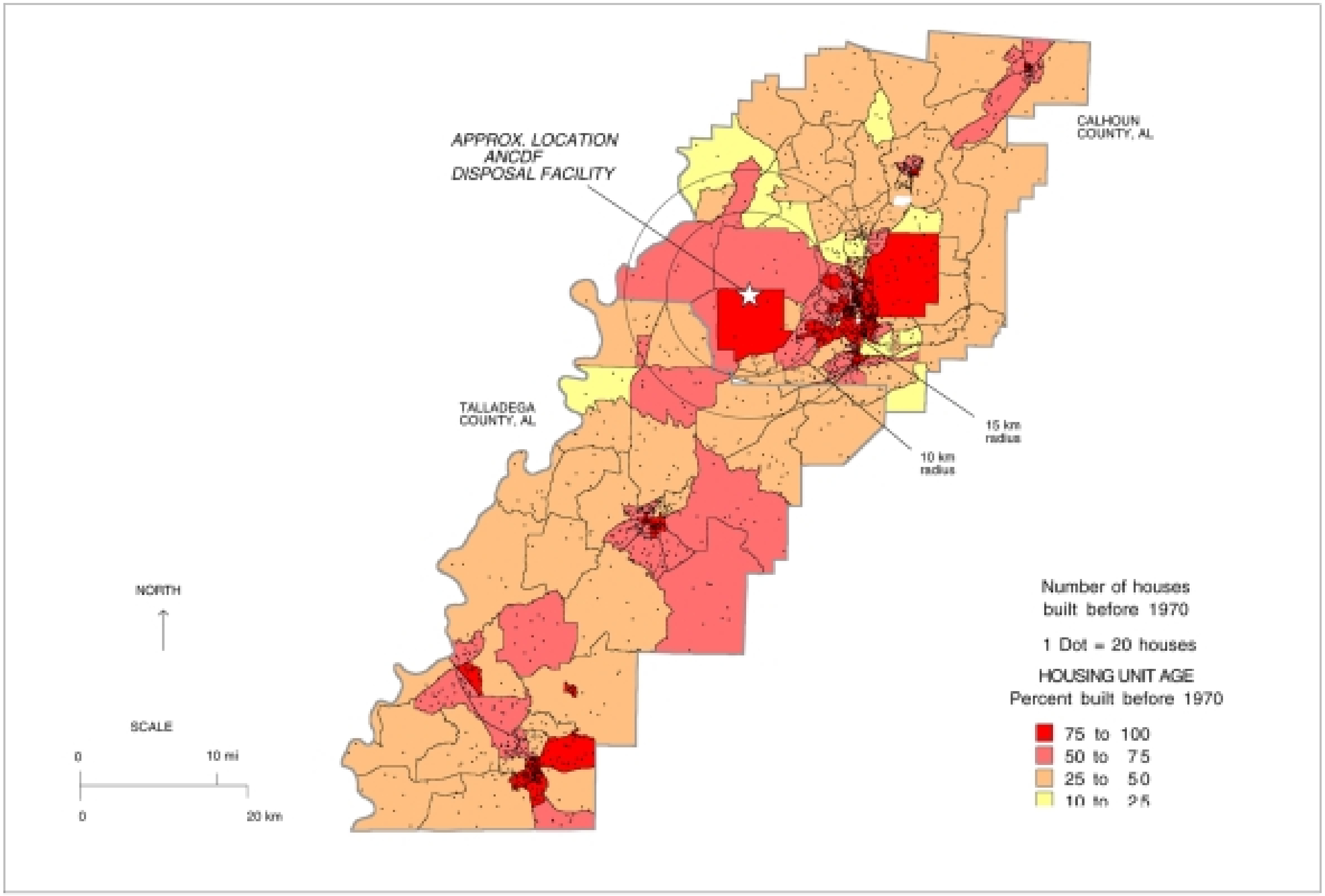

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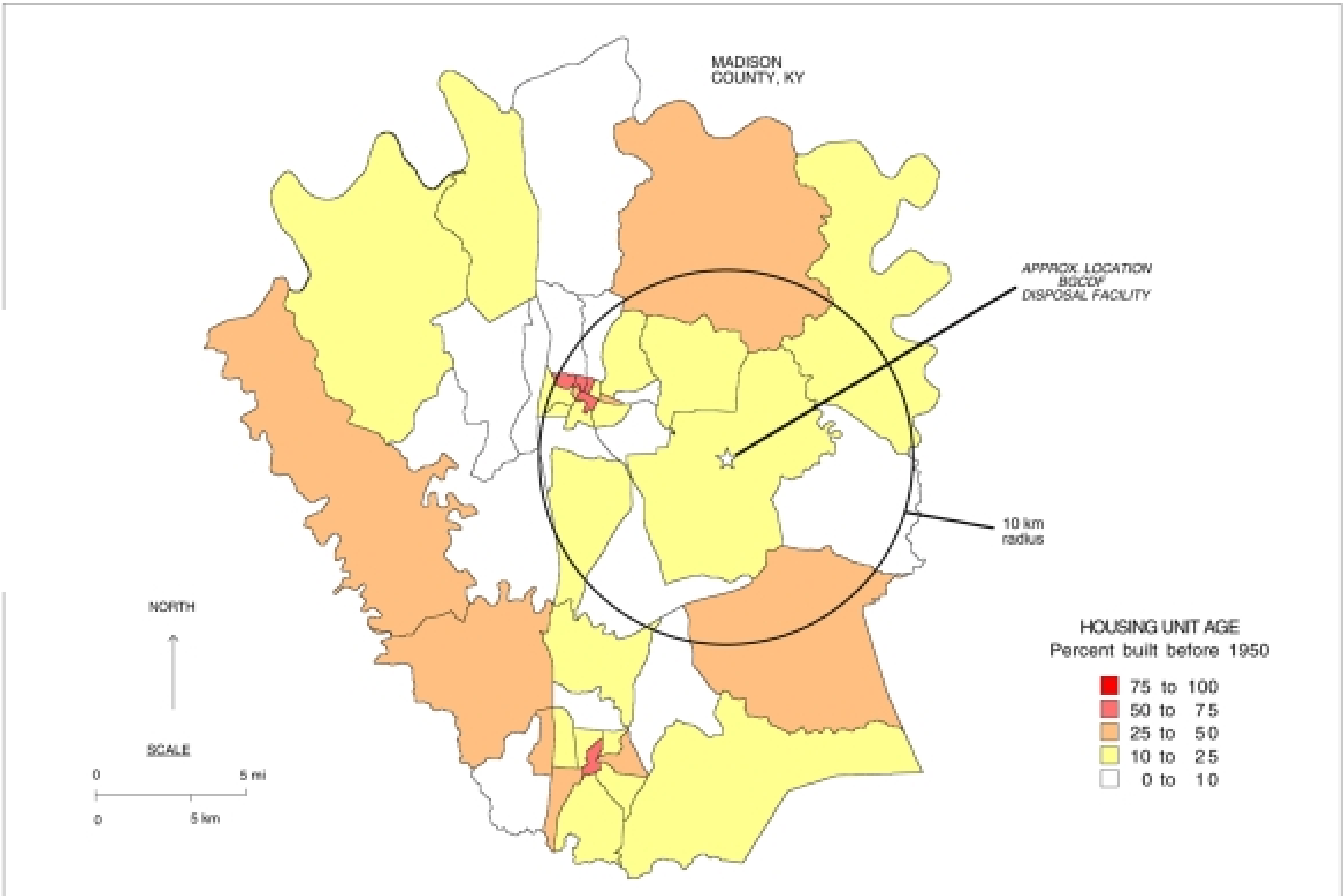

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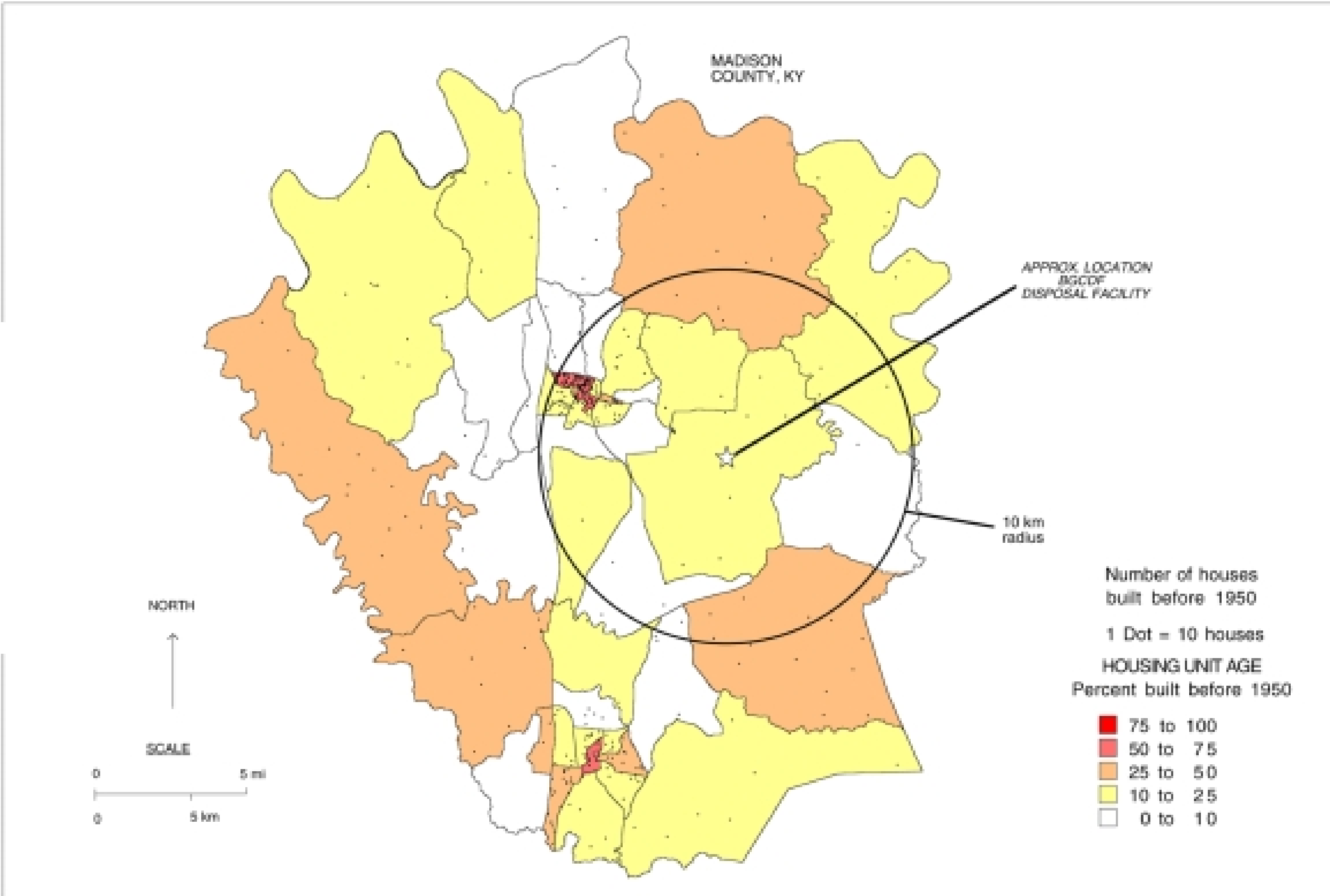

Map 3b. Number and percent of housing units built prior to 1950 in area surrounding the Blue Grass Chemical Agent Disposal Facility (BGCDF), KY. (Source: US Census Bureau)
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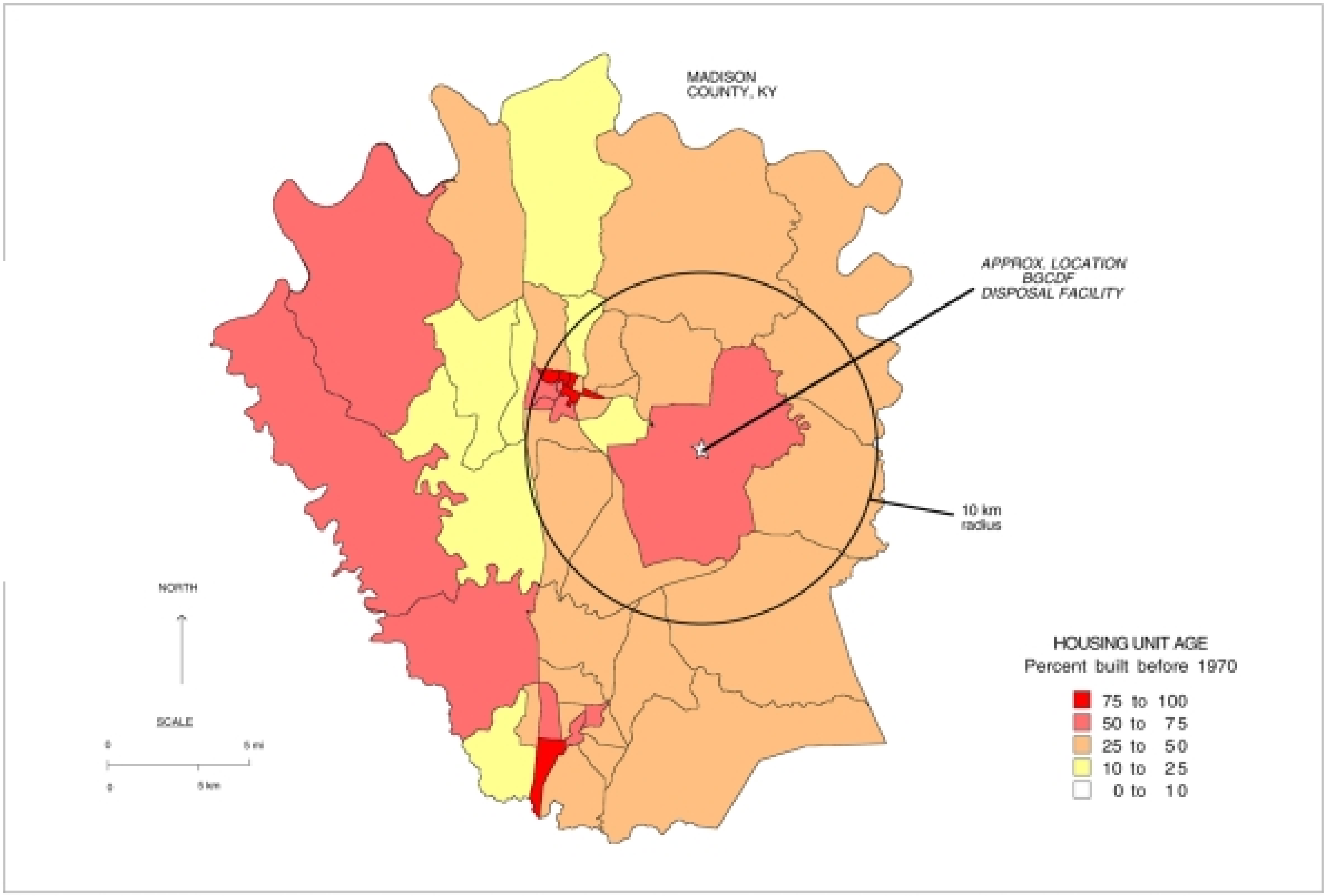

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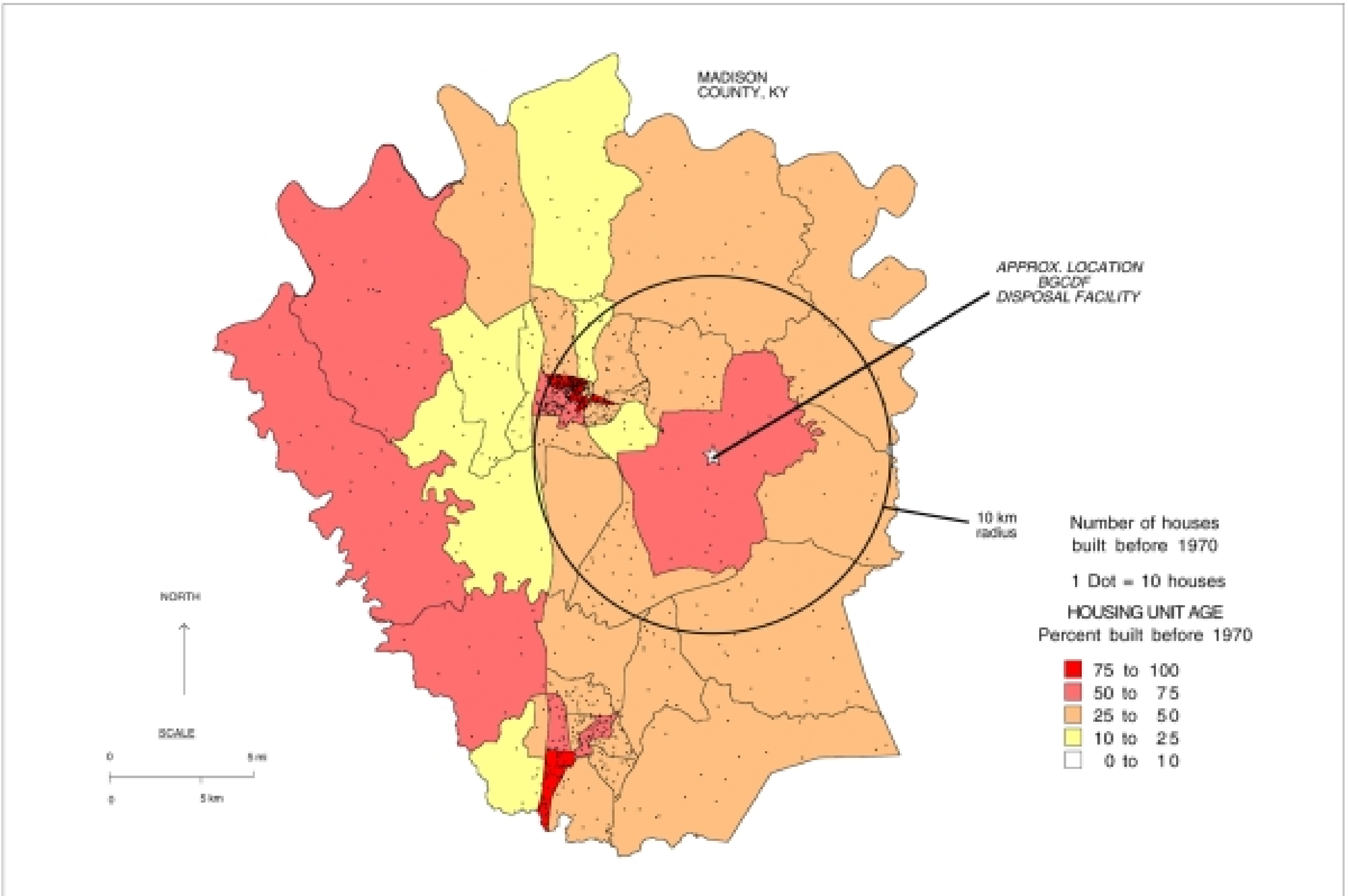

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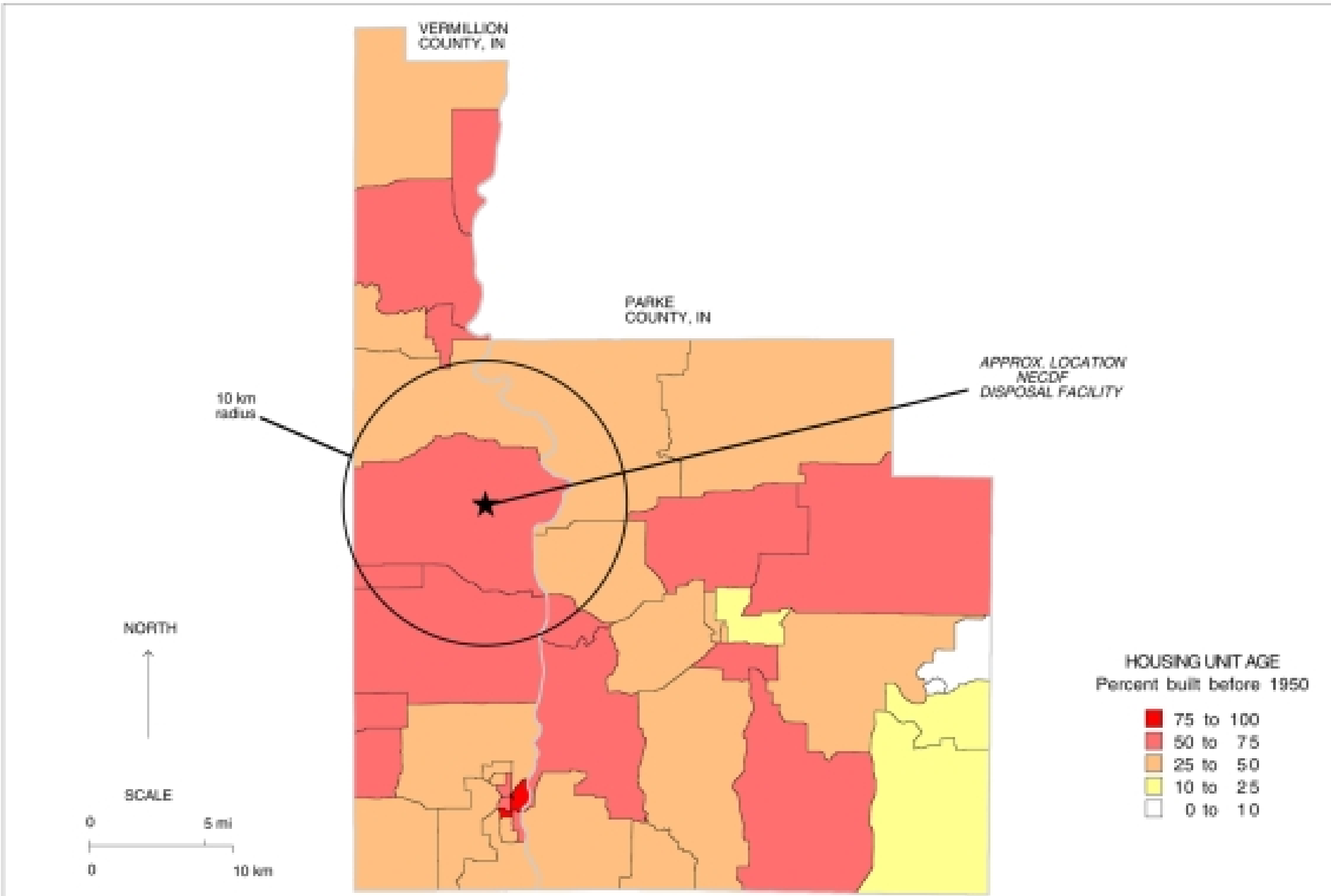

Map 4a. Percent of housing units built prior to 1950 in area surrounding the Newport Chemical Agent Disposal Facility (NECDF), IN. (Source: US Census Bureau)
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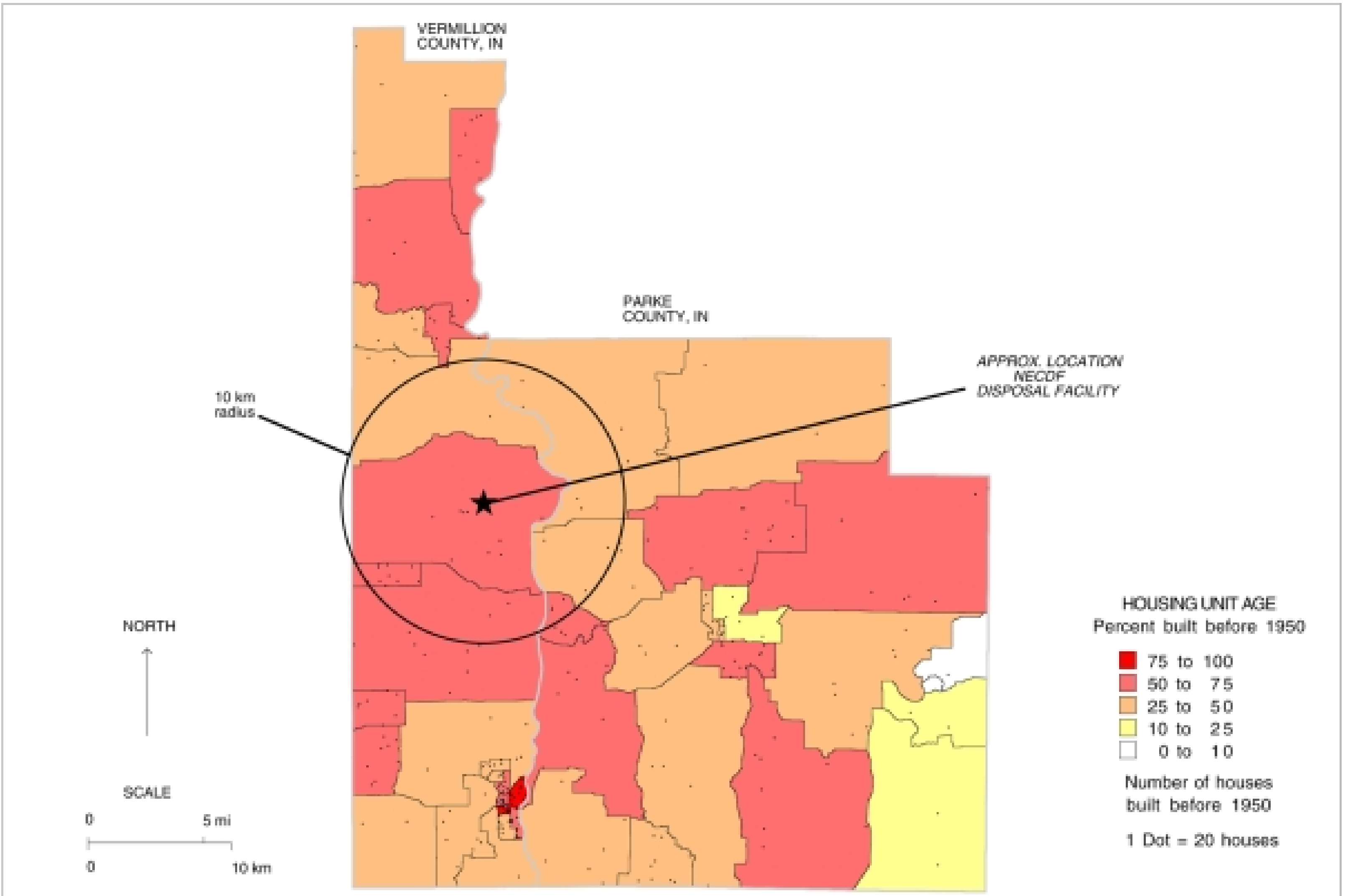
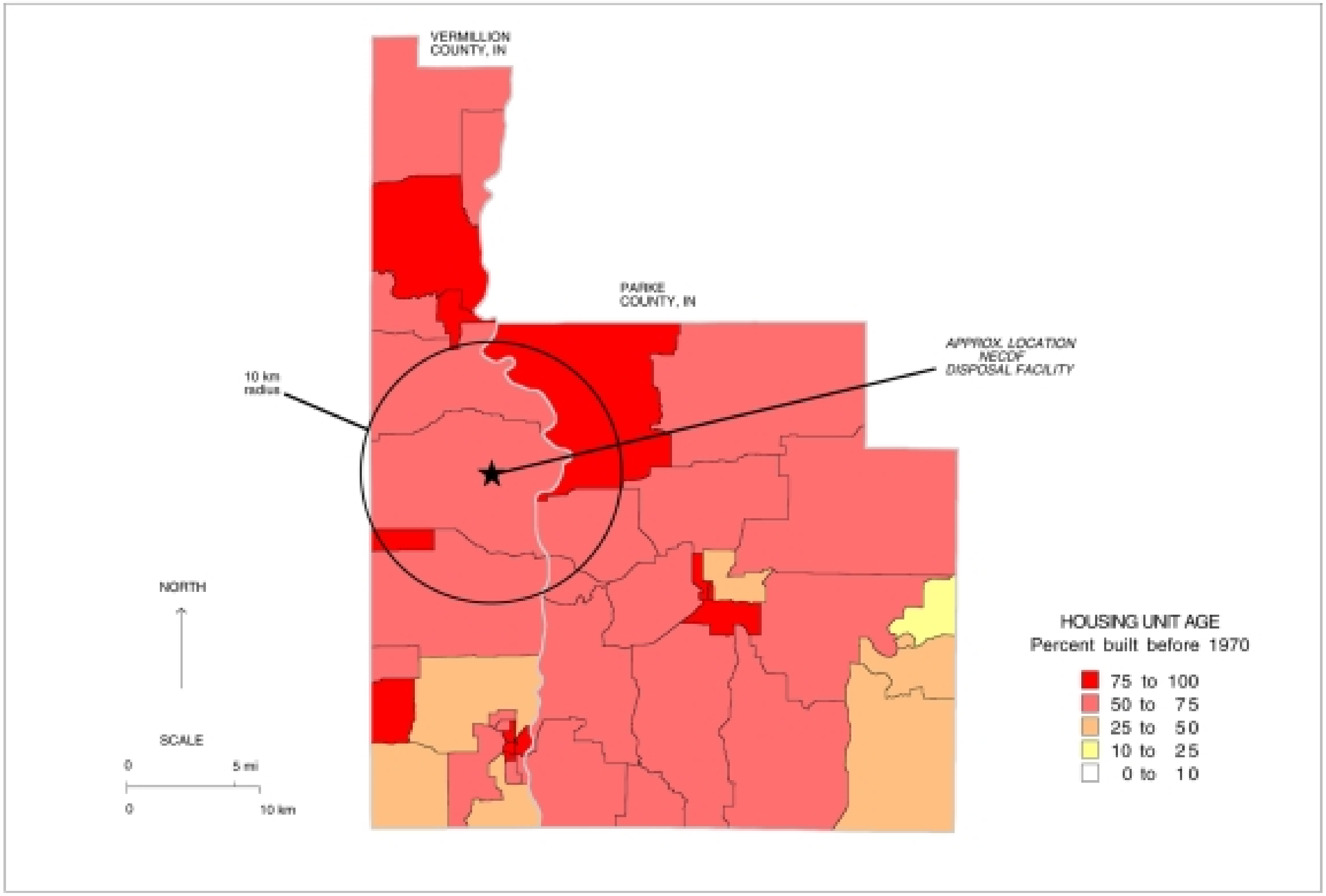
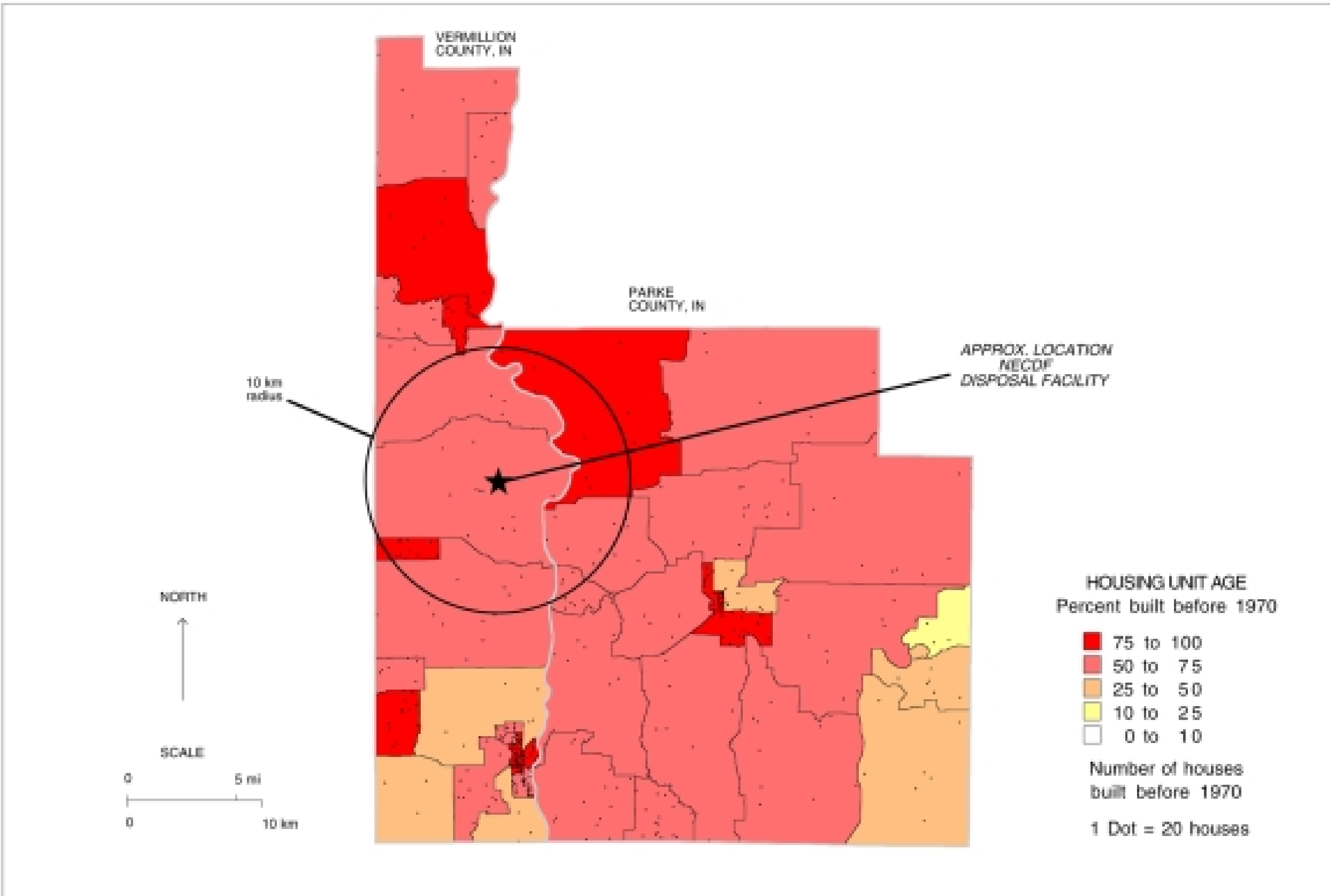


Map 4b. Number and percent of housing units built prior to 1950 in area surrounding the Newport Chemical Agent Disposal Facility (NECDF), IN. (Source: US Census Bureau) Map compiled by H. K. Hardee.



Map. 4c. Percent of housing units built prior to 1950 in area surrounding the Newport Chemical Agent Disposal Facility (NECDF), IN. (Source: US Census Bureau) Map compiled by H. K. Hardee.



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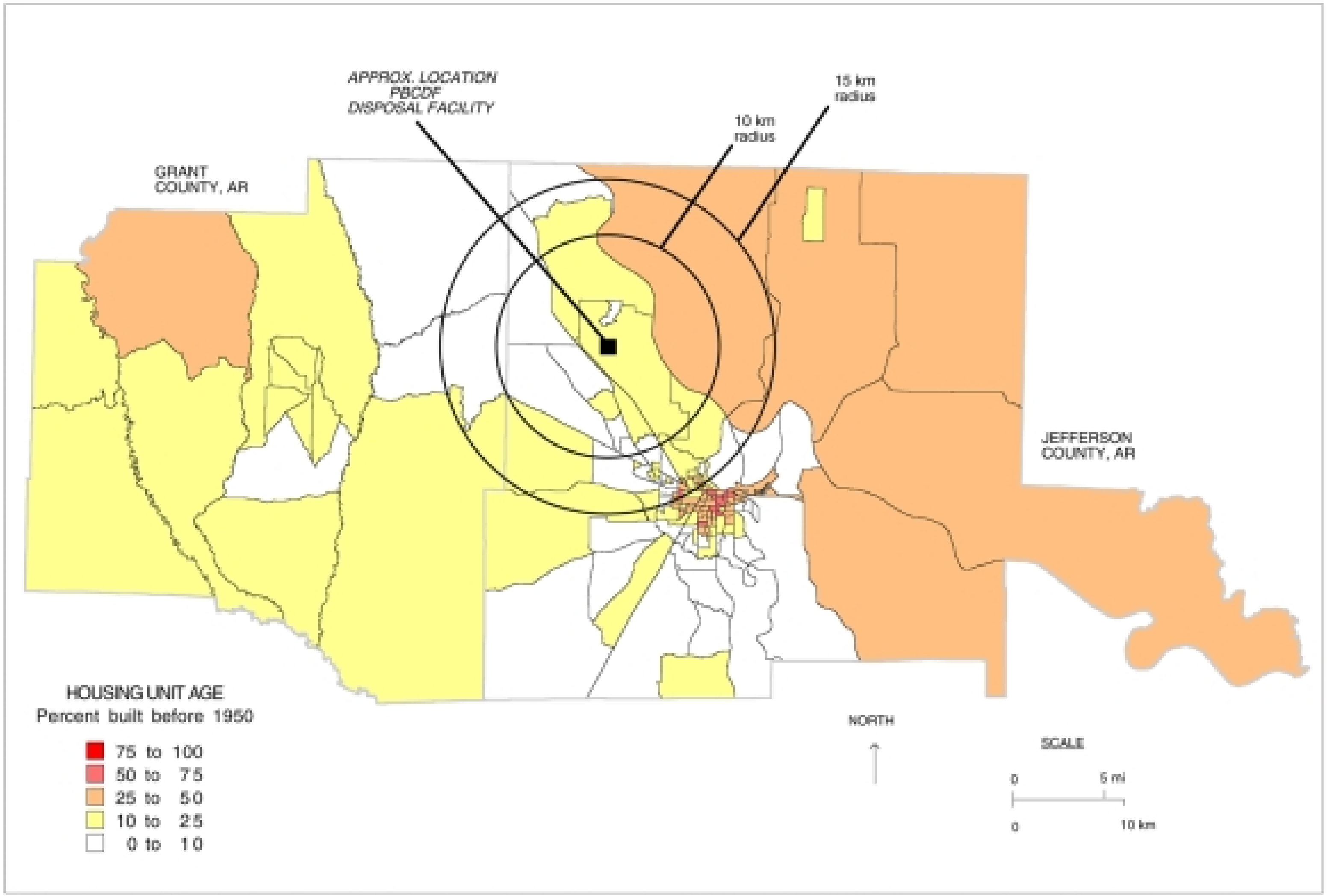

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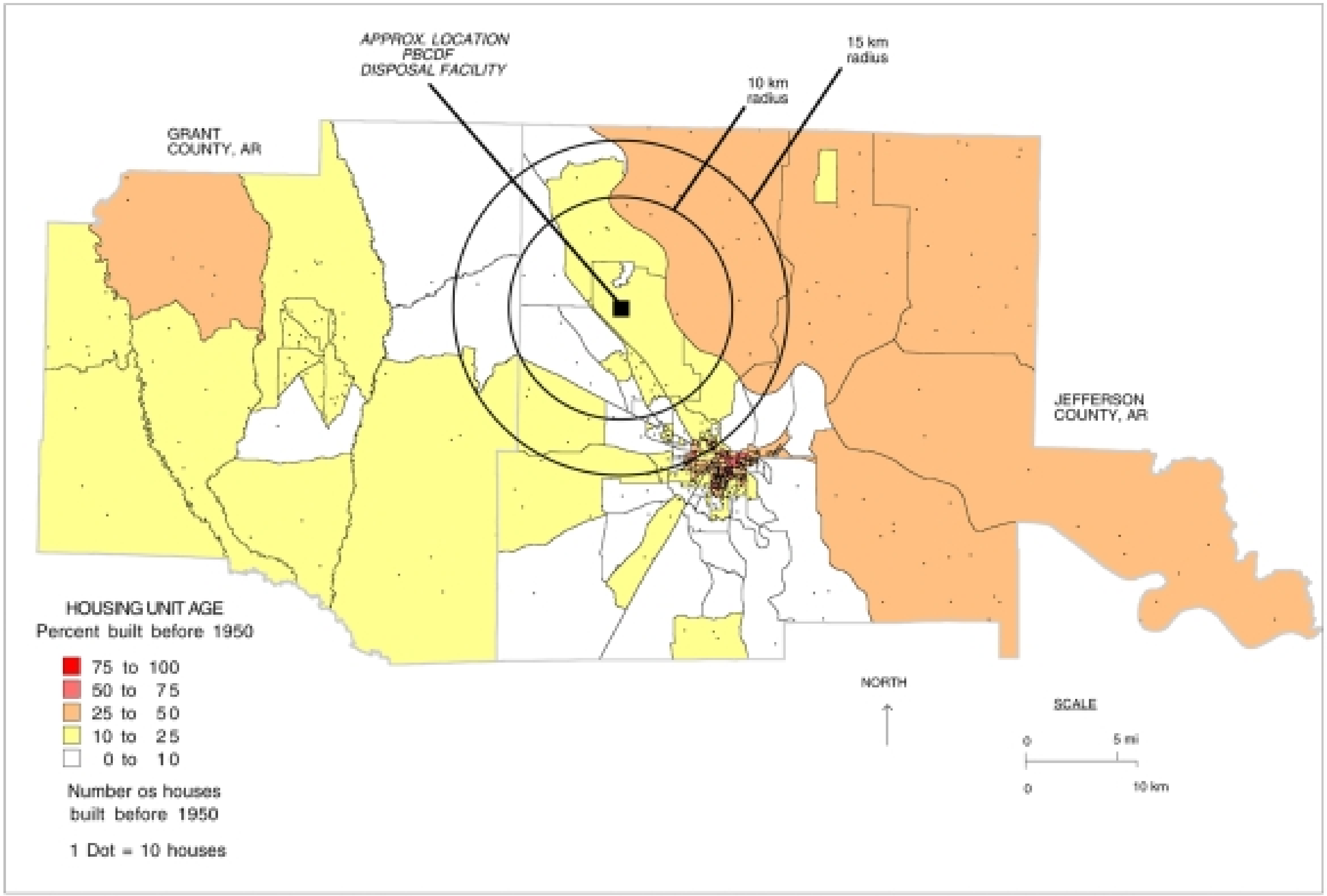
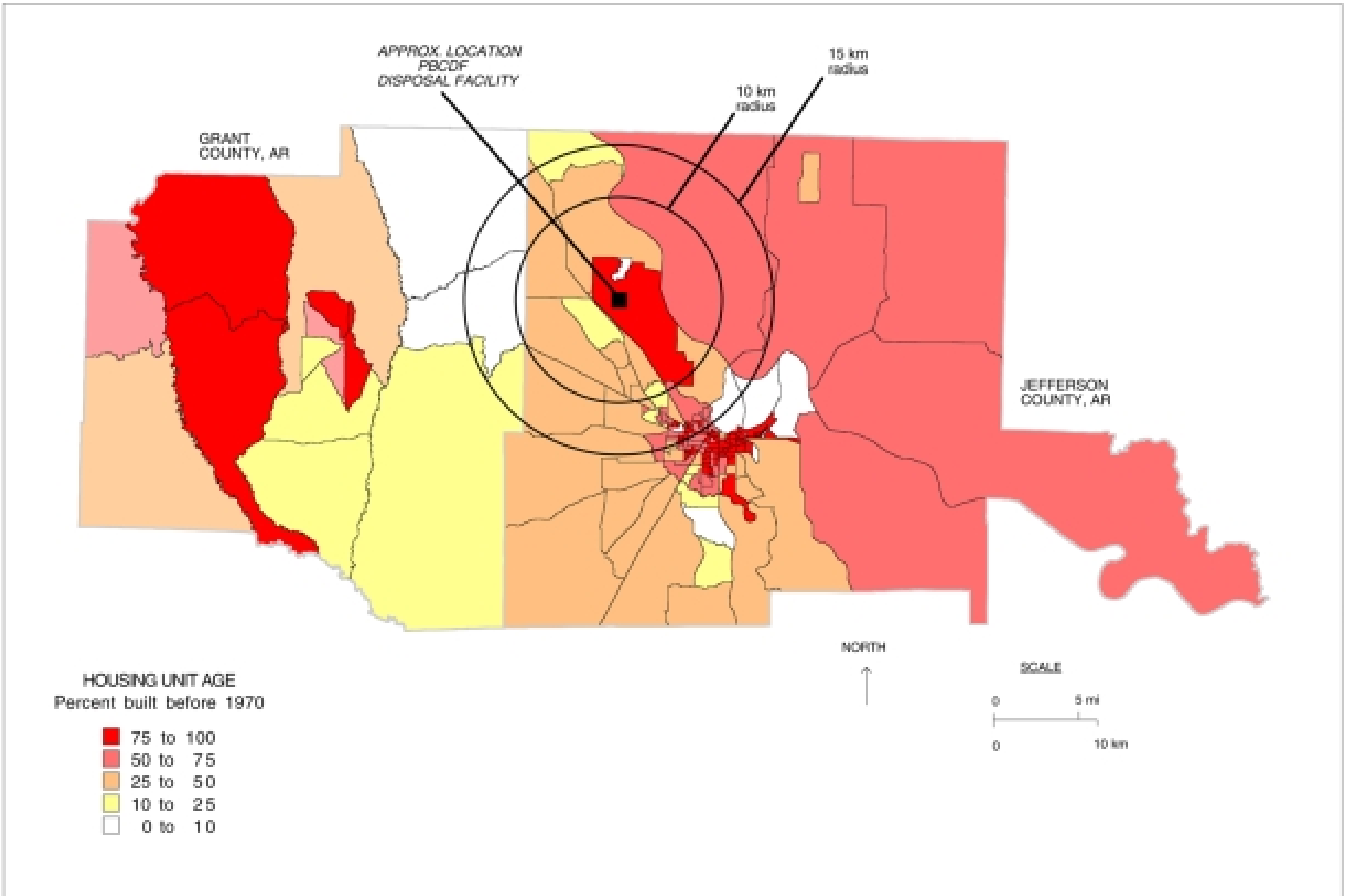


Map 5b. Number and percent of housing units built prior to 1950 in area surrounding the Pine Bluff Chemical Agent Disposal Facility (PBCDF), AR. (Source: US Census Bureau) Map compiled by H. K. Hardee.



Map 5c. Percent of housing units built prior to 1970 in area surrounding the Pine Bluff Chemical Agent Disposal Facility (PBCDF), AR. (Source: US Census Bureau)
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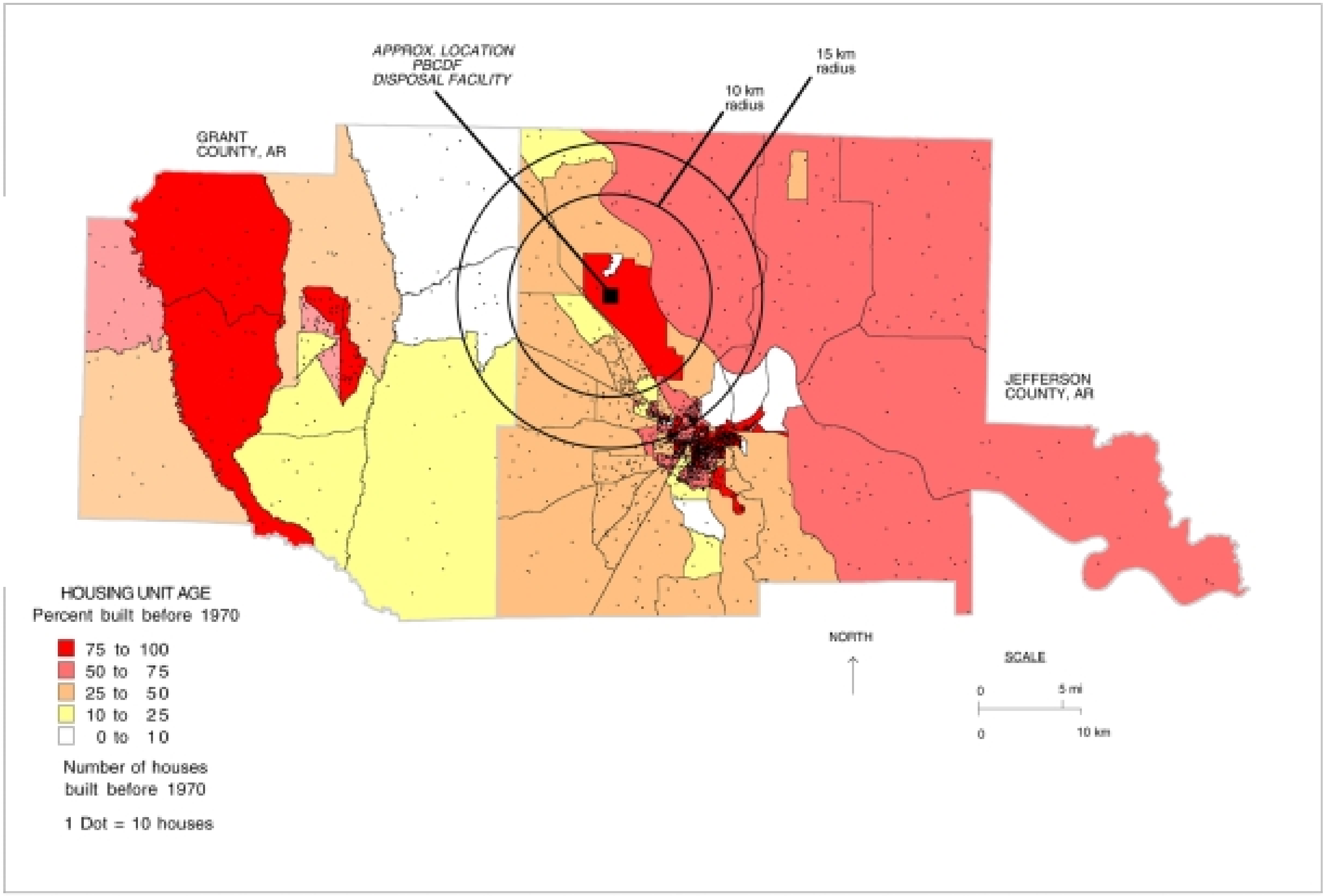

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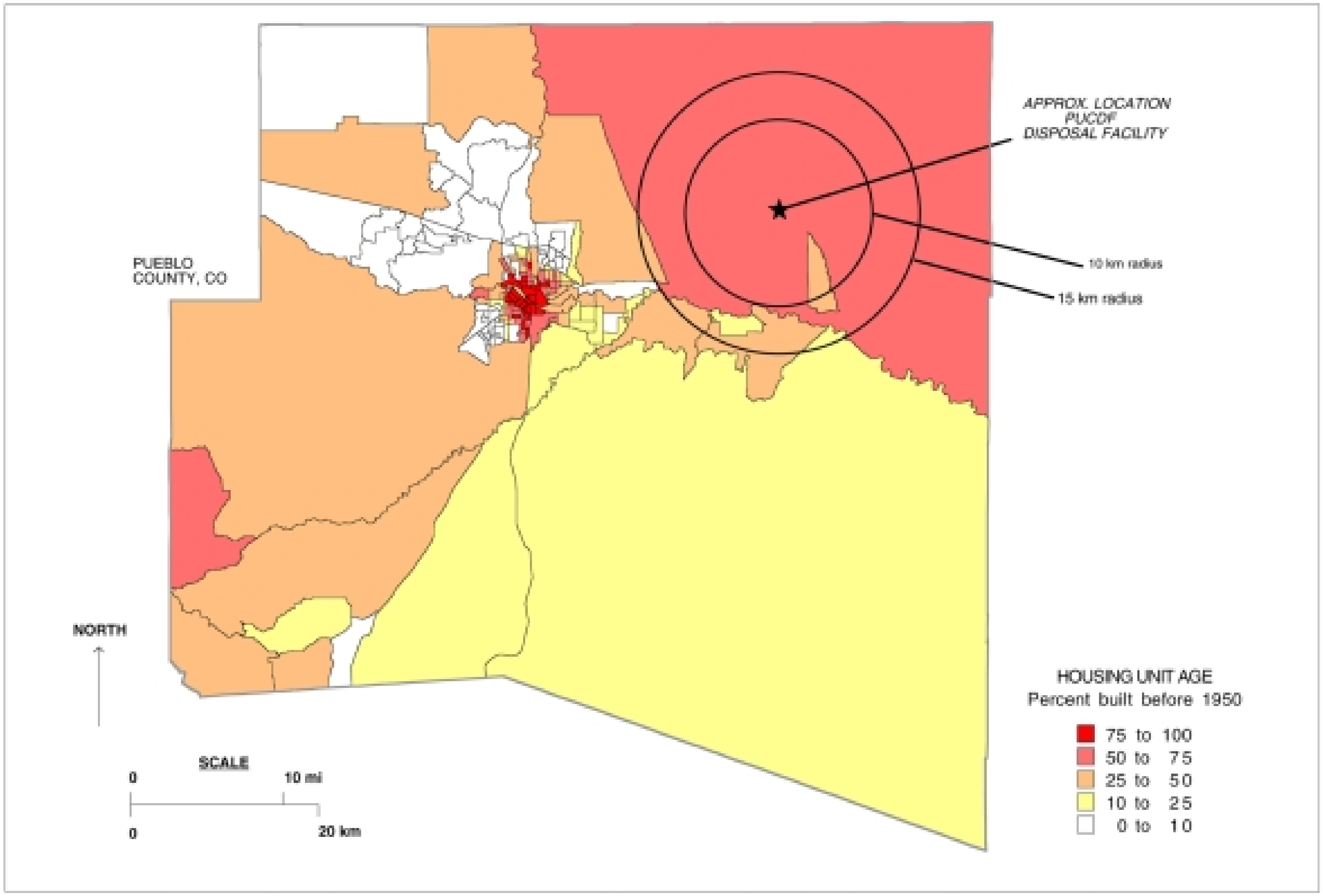

Map 6a. Percent of housing units built prior to 1950 in area surrounding the Pueblo Chemical Agent Disposal Facility (PUCDF), CO. (Source: US Census Bureau)
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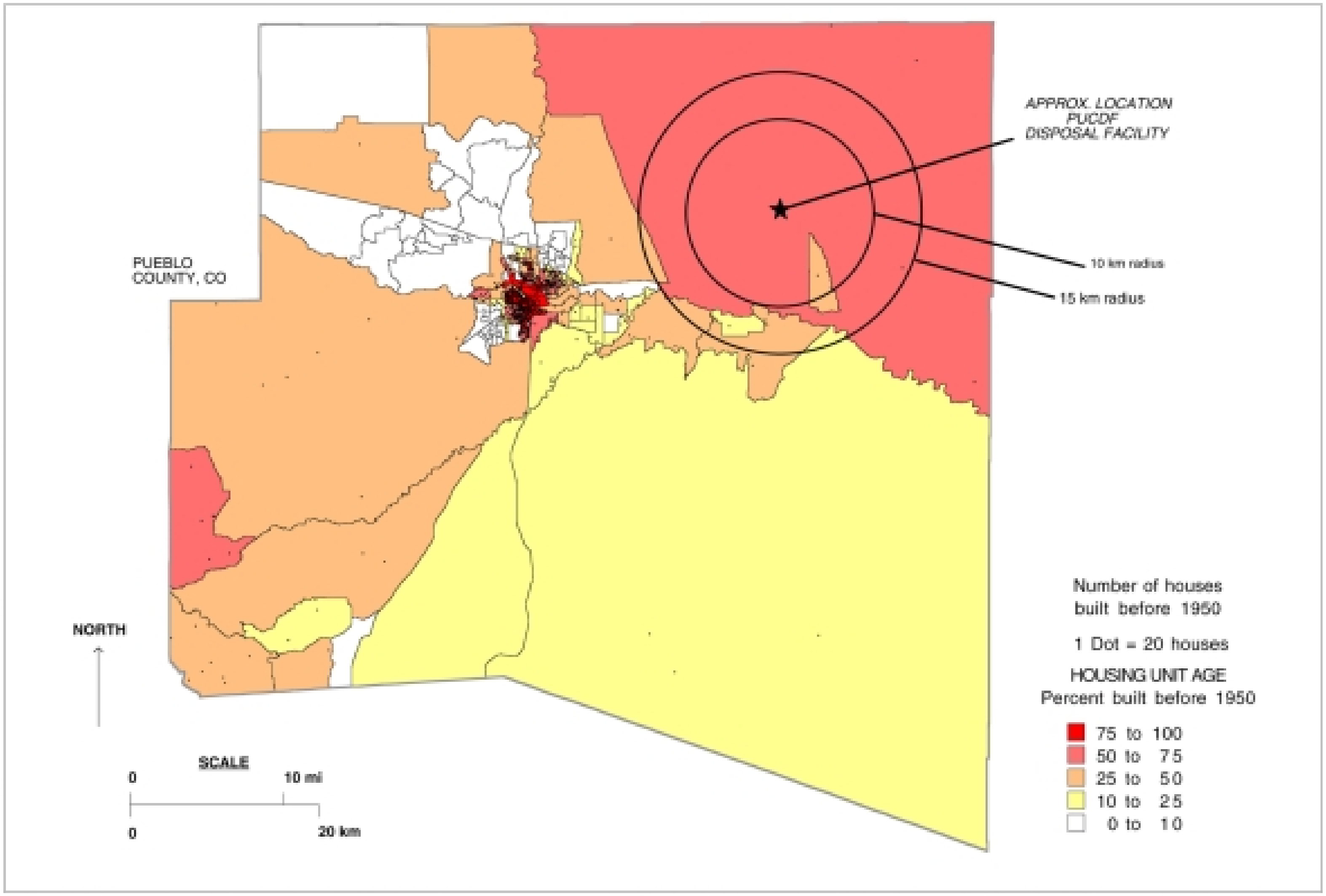

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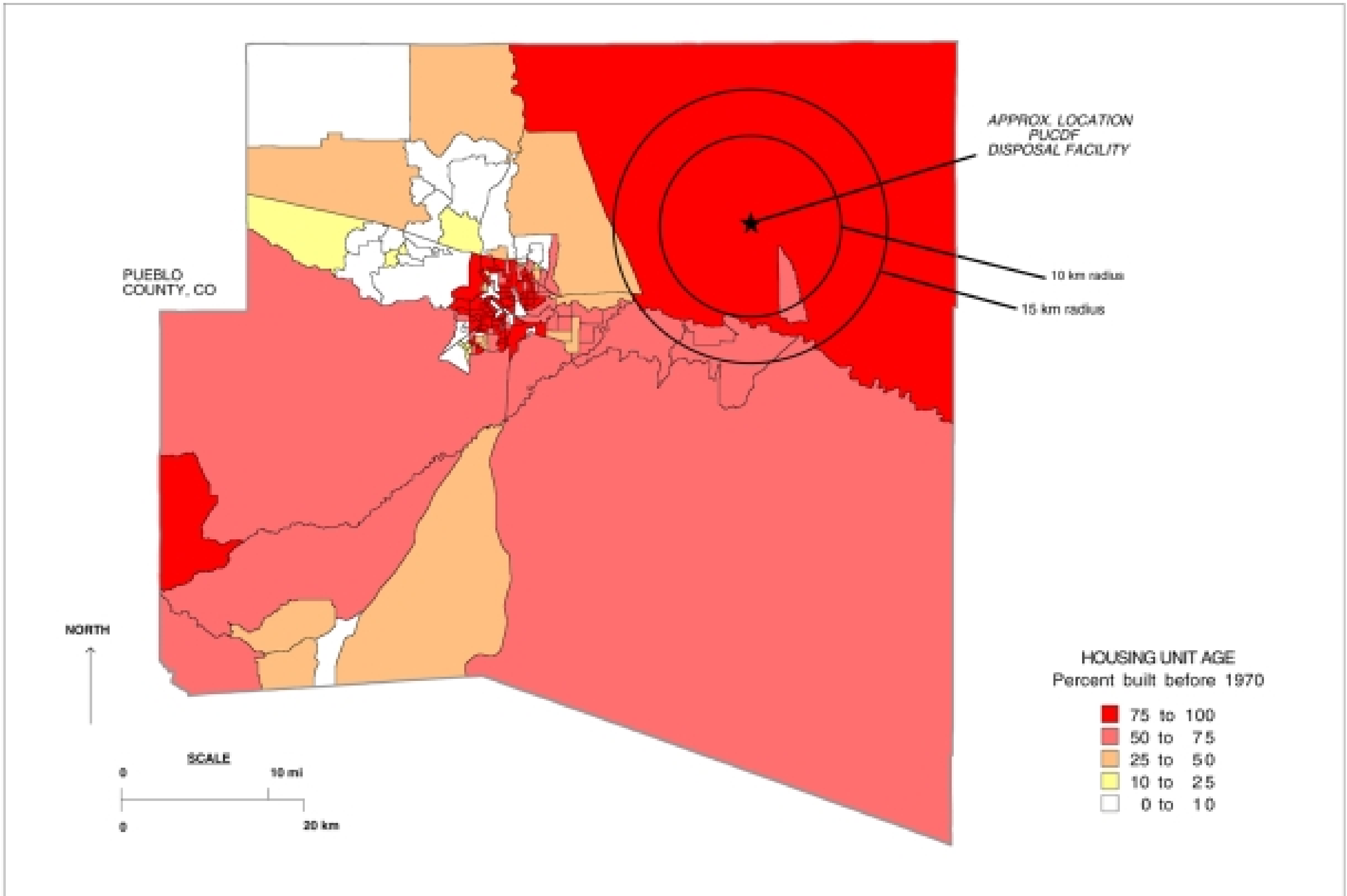

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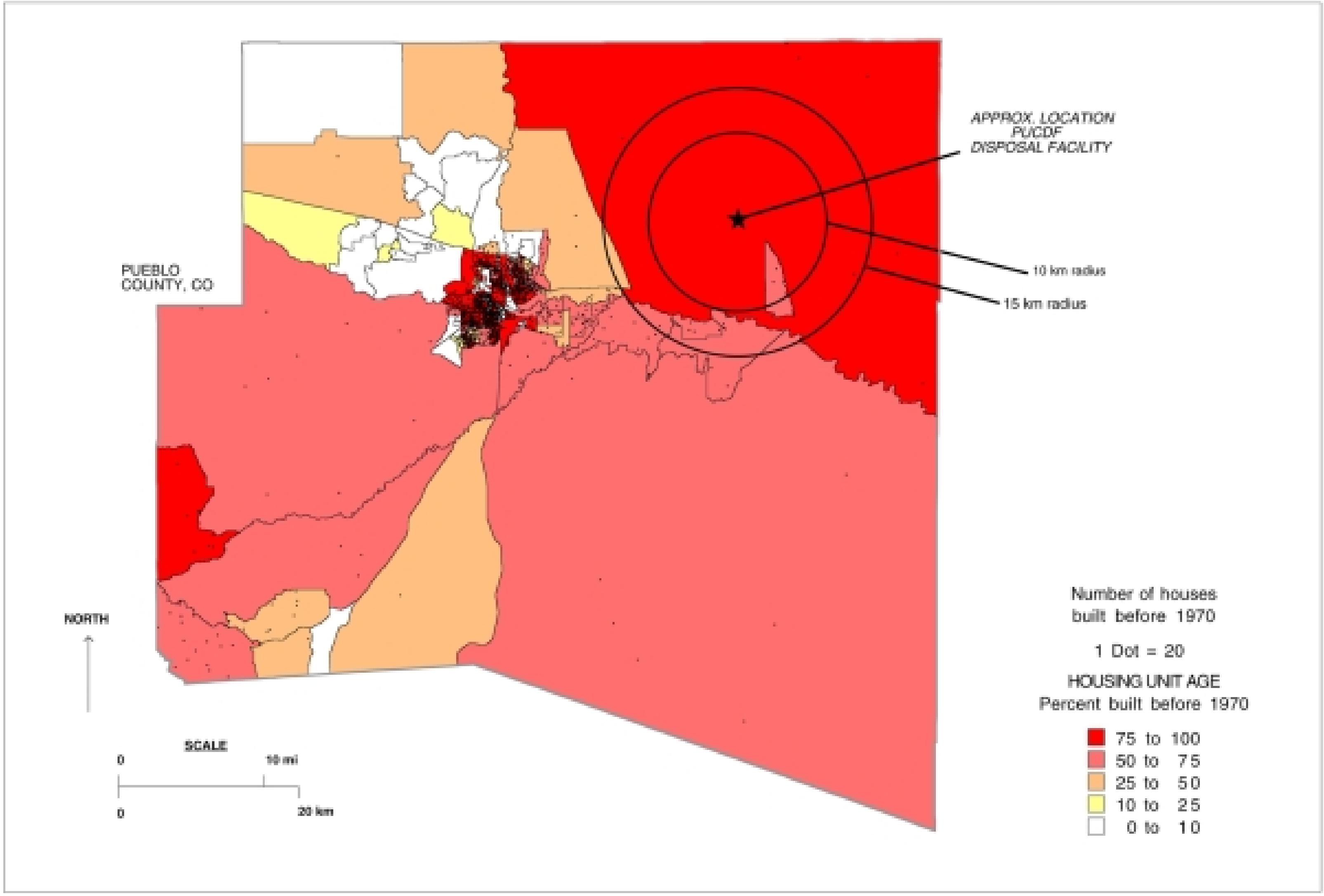

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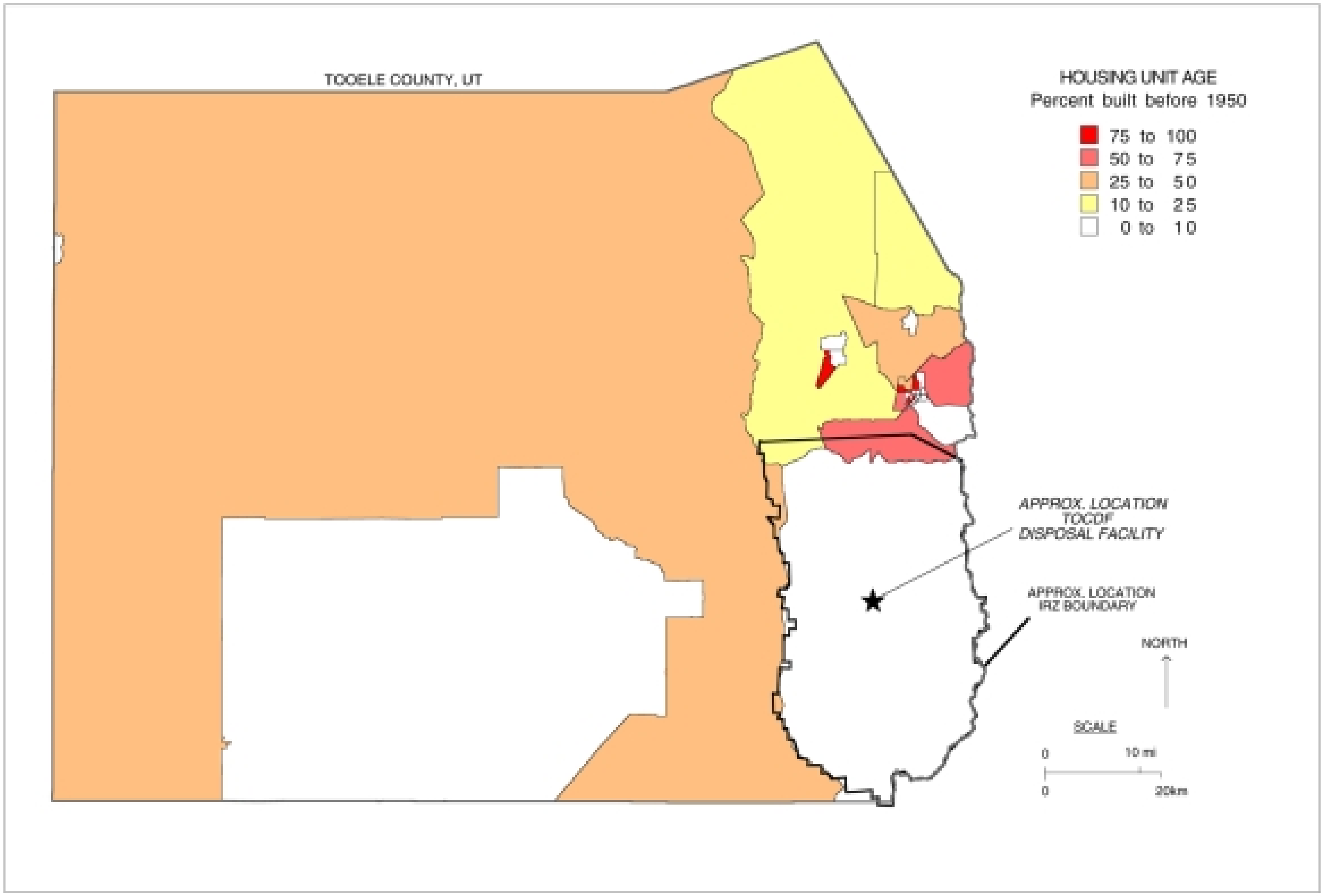
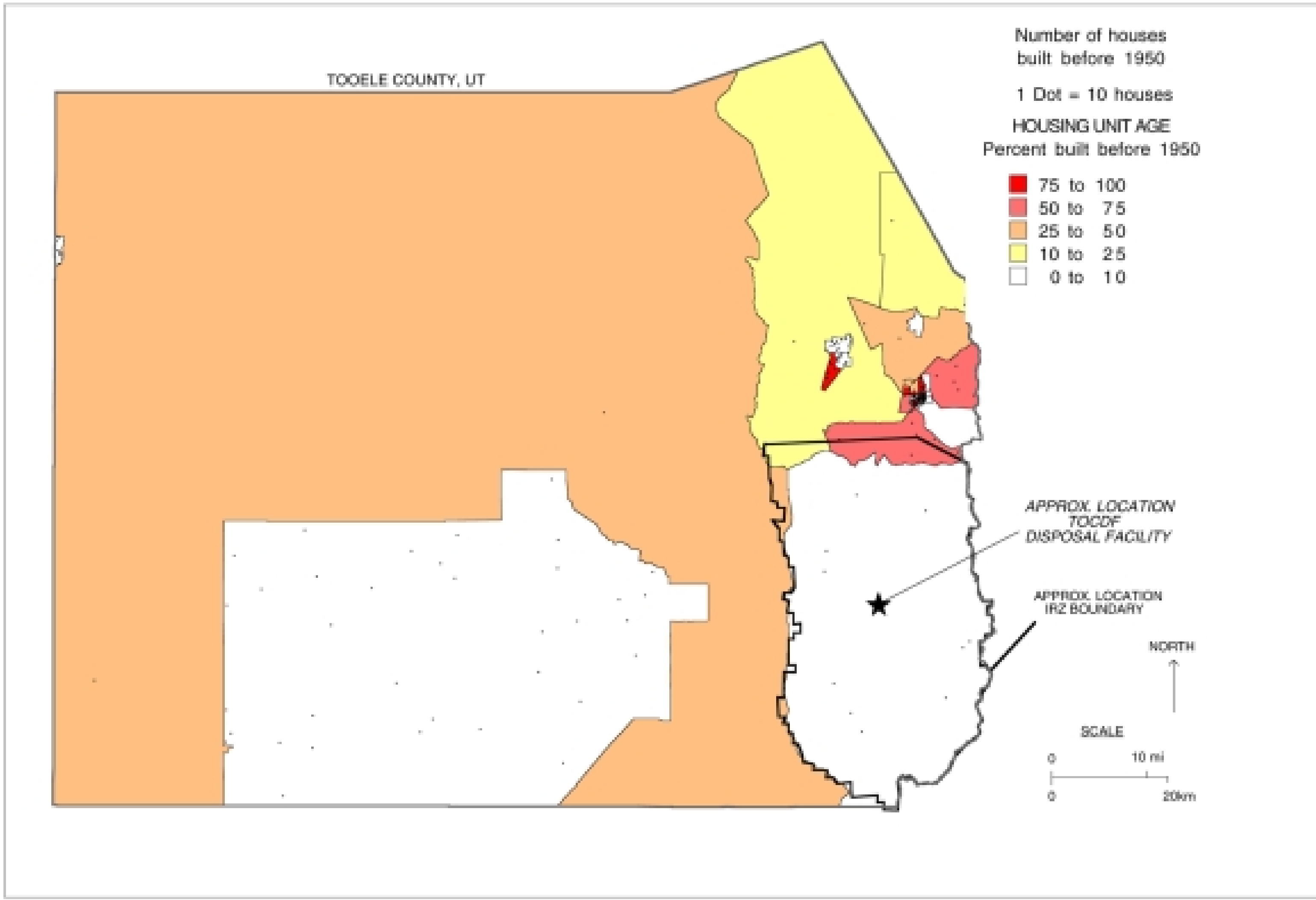
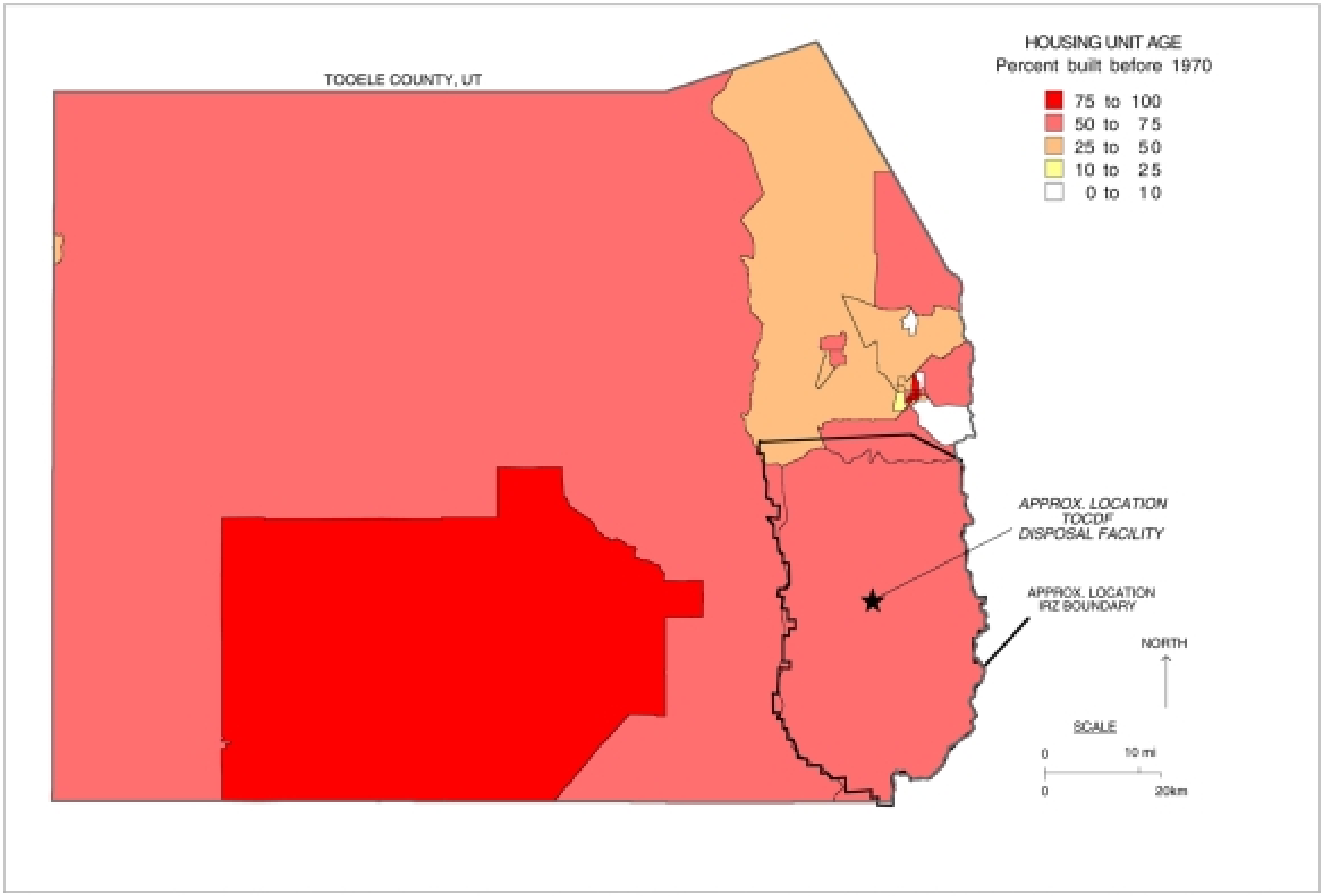


Map 7a. Percent of housing units built prior to 1950 within the IRZ surrounding the Tooele Chemical Agent Disposal Facility (TOCDF), UT. (Source: US Census Bureau)
Map compiled by H. K. Hardee.



Map 7b. Number and percent of housing units built prior to 1950 within the IRZ surrounding the Tooele Chemical Agent Disposal Facility (TOCDF), UT. (Source: US Census Bureau) Map compiled by H. K. Hardee.



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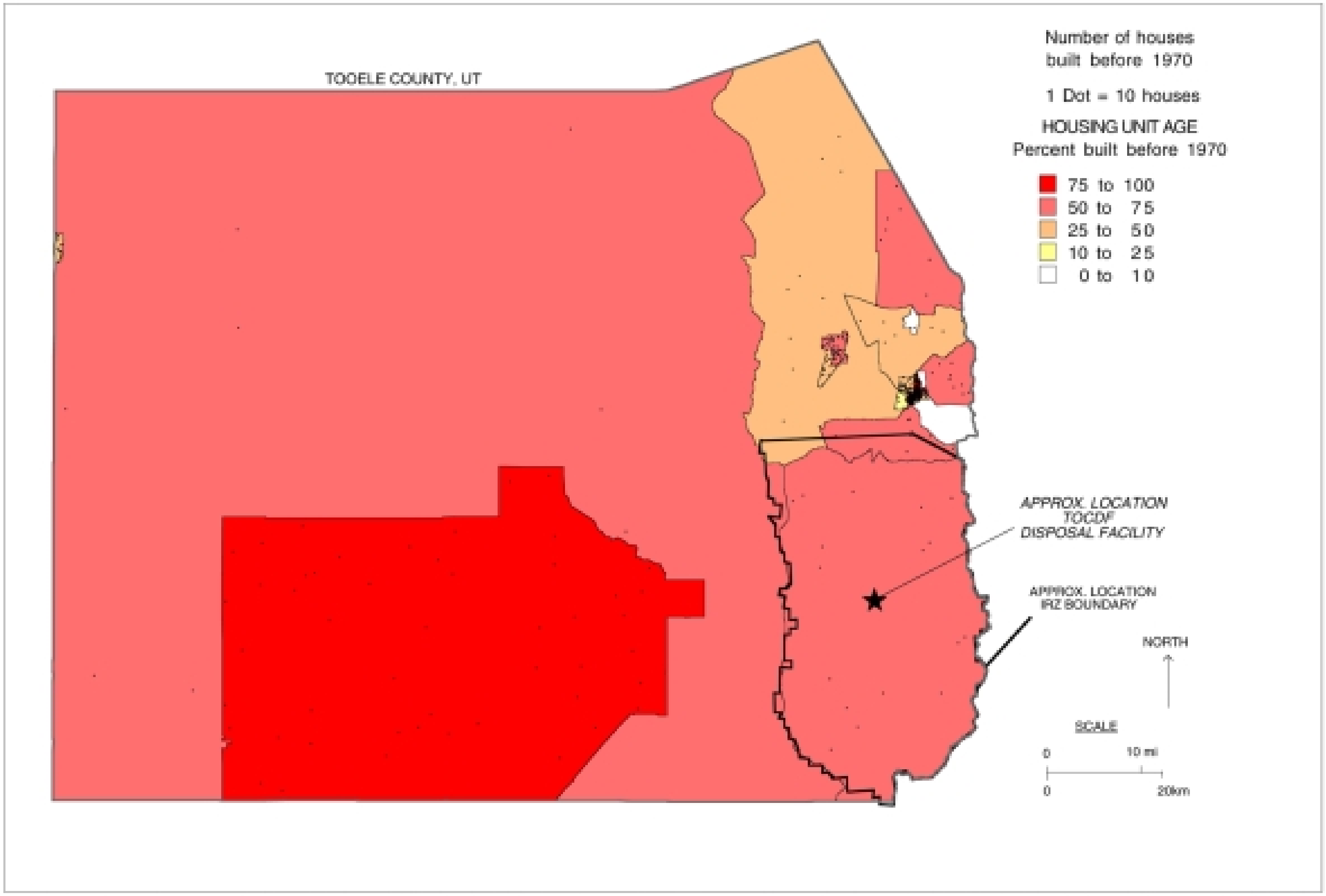

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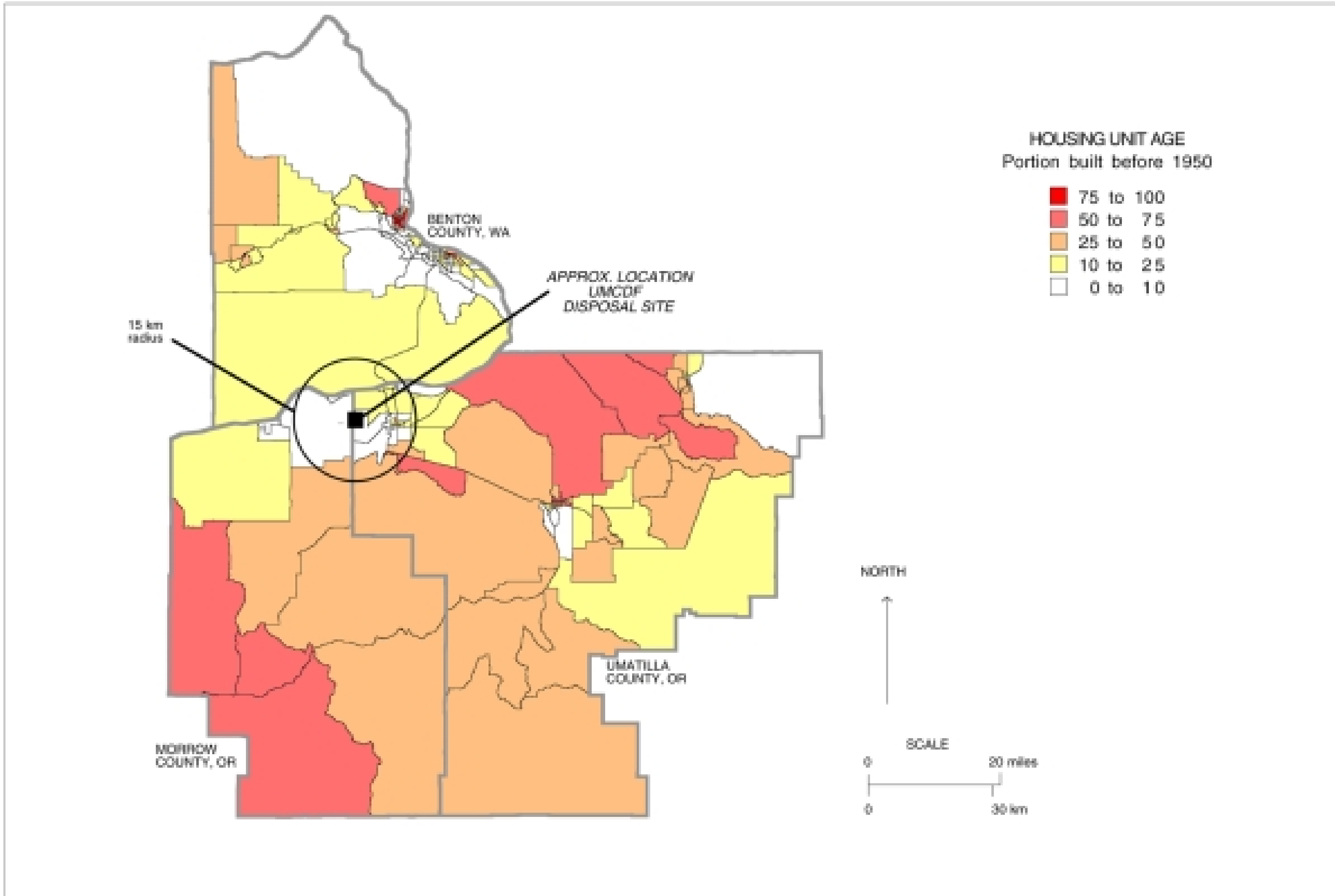

Map 8a. Percent of housing units built prior to 1950 in area surrounding the Umatilla Chemical Agent Disposal Facility (UMCDF), OR. (Source: US Census Bureau)
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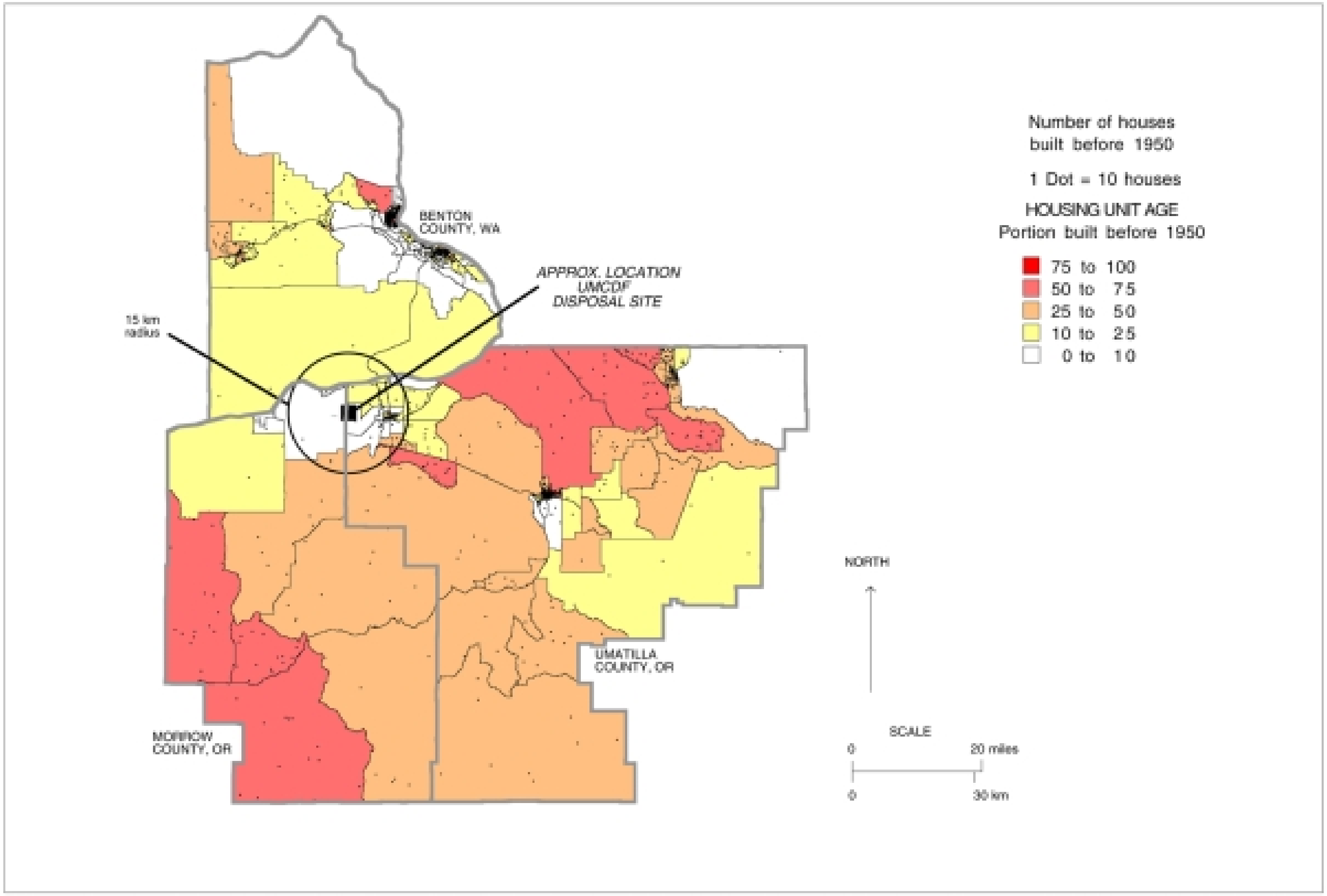

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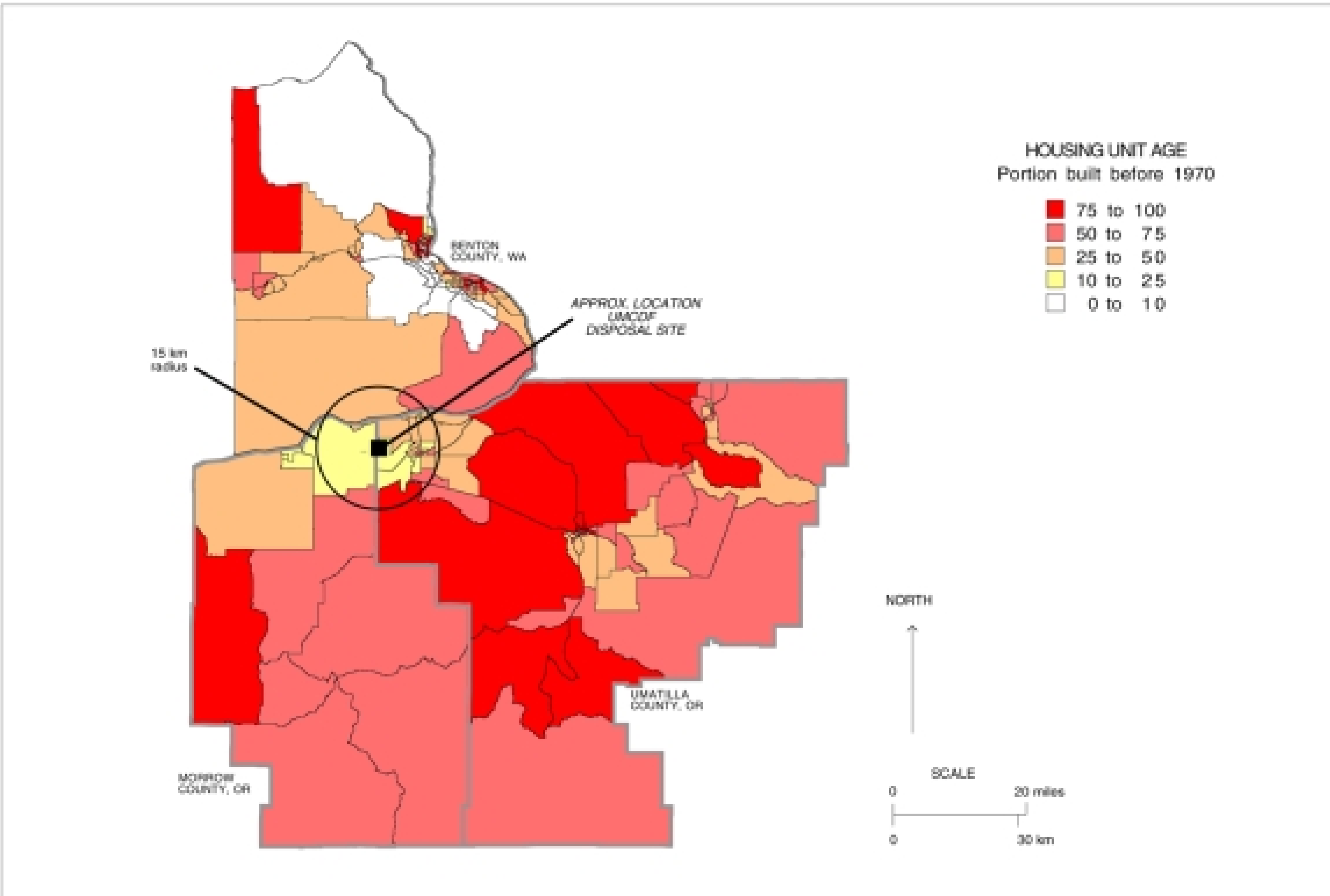

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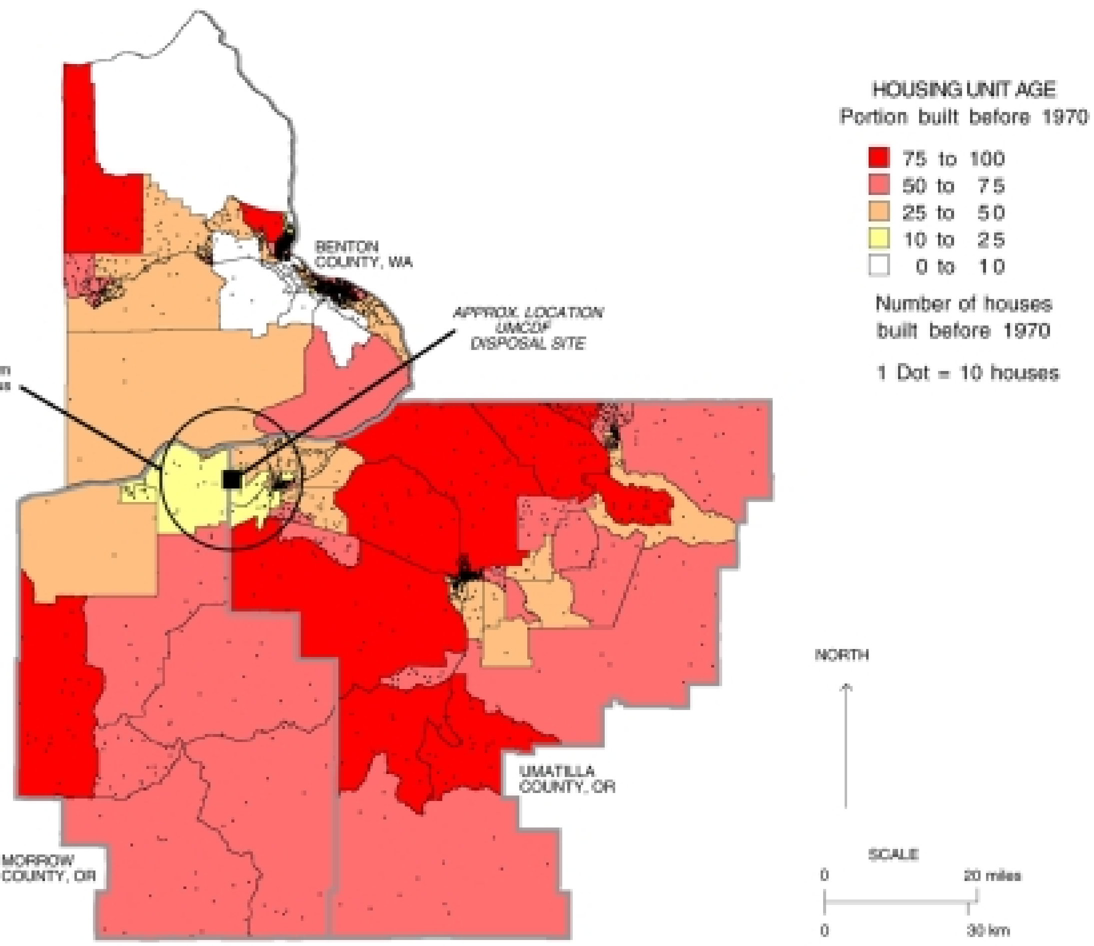

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