Geospatial and Regression Analysis to Assess Social and Demographic Disparities in Locations of Lead Water Pipes and Pavement Conditions of the National Highway System

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Presentation Overview

- Background/Context
- Social Vulnerability
- Geospatial Analysis
- Statistical Analysis
- Impact of Work

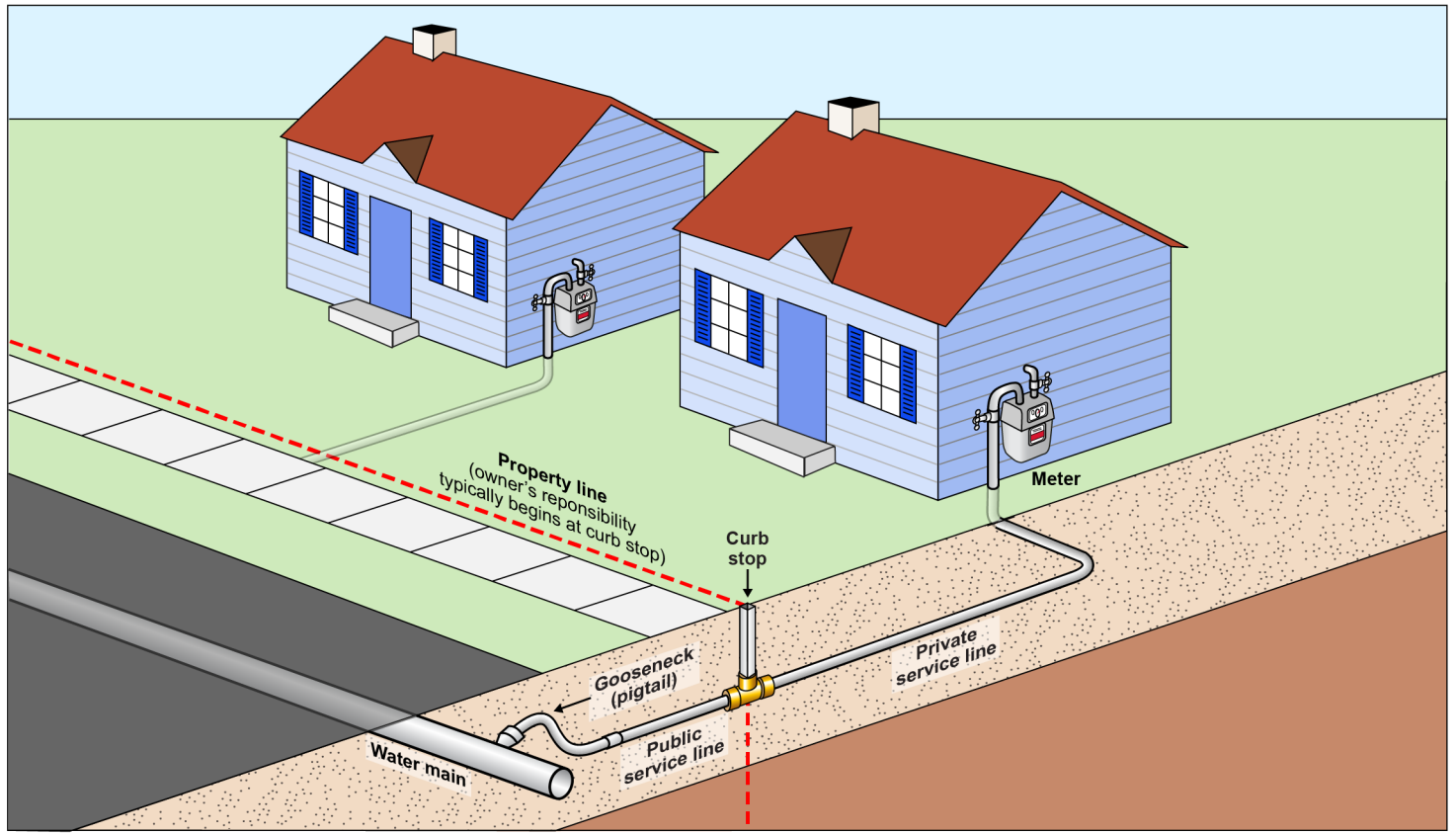
BACKGROUND/CONTEXT

Infrastructure ensures the economic vitality and quality of life in the country, from the water we drink to the roads that connect communities.

Drinking Water: GAO-21-78 EPA Lead Reduction Efforts

- In the late 1800s, lead pipe installation began; in the early 1900s lead toxicity concerns were documented, leading cities to shift away from lead pipes by 1920s
- However, an effective campaign by the lead industry promoted lead pipes, contributing to present-day challenges
- The Safe Drinking Water Act (SDWA) generally prohibited new lead pipes in 1986
- Flint, Michigan – health risks from lead – no safe amount of lead in drinking water
- Lead service lines (LSL) are throughout the U.S., but little information is known about their locations; new requirements for LSL inventories by 2024.

Typical Location of Water Main, Service Line and Other Pipes that Deliver Drinking Water to Homes

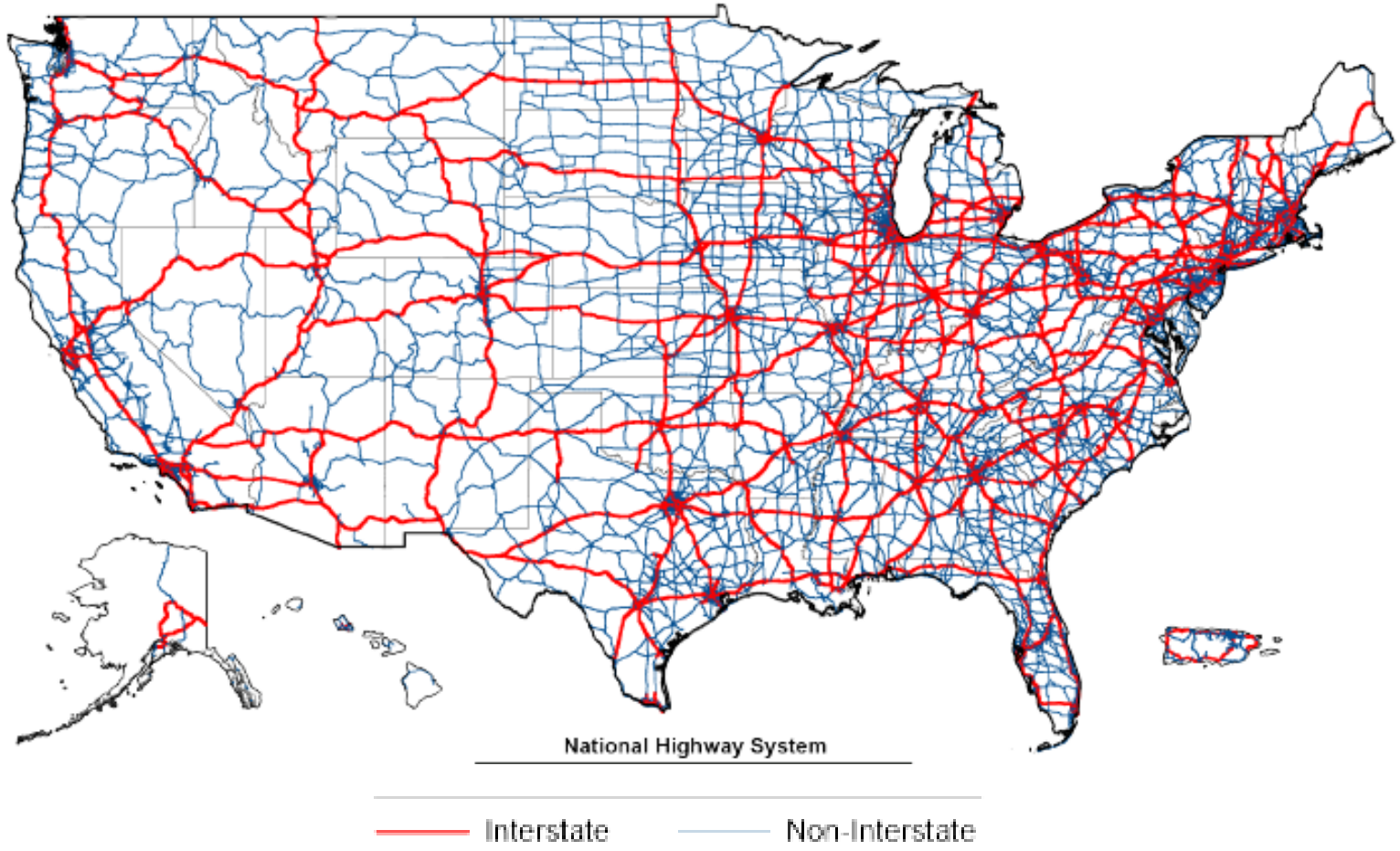


Source: GAO. | GAO-21-78

National Highways: GAO-22-104578 National Highways

- The National Highway System (NHS) is key to the nation's economy, defense, and mobility
- It comprises about 220,000 miles of roads and accounts for about 54% of all vehicle miles traveled
- It runs through a wide variety of landscapes and neighborhoods, including rural and major metropolitan areas, and urban cores
- Most pavement on the National Highway System is in good or fair condition

Map of the National Highway System



Illustrative Examples of National Highway System Pavement in “Good,” “Fair,” and “Poor” Condition, as Categorized by the Federal Highway Administration (FHWA)

Good

Fair

Poor

Source: Federal Highway Administration | GAO-22-104578

Note: FHWA categorizes pavement condition as good, fair, or poor, based on various metrics, including the extent to which the pavement surface has cracks, ruts, or faults.

Research Objectives

Drinking Water

1. To what extent can neighborhood data on cities served by lead service lines be used to focus lead reduction efforts?

National Highways

1. To what extent does pavement condition vary on the National Highway System?

2. To what extent does FHWA assess National Highway System pavement condition within states, such as at the local level?

Drinking Water: Environmental Justice and Equity Criteria

- **Environmental justice (EJ)** is the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

- Executive Order 12898 directed federal agencies to make **EJ** part of their mission

- Environmental Protection Agency (EPA) **integrated EJ into its programs**, including achieving progress on national challenges like lead in drinking water

National Highways: Environmental Justice and Equity Criteria

- Department of Transportation's (DOT) strategic plan (2022-26): intention to deliver a safe, **equitable**, and reliable transportation system with strategic goals of safety and equity, citing the need to invest in **underserved communities** and to reduce inequities in transportation systems and disparities in safety outcomes.

- Executive Order 13985, January 2021, generally directs federal agencies to assess whether members of **underserved communities** face systemic barriers in accessing benefits and opportunities available under the agencies' policies and programs and whether agency action may be necessary **to advance equity** in their programs

SOCIAL VULNERABILITY

Drinking Water: Literature

- Worked with our GAO Librarian
- Searched 35 scholarly and peer-reviewed databases
- Timeframe: 2014-2019
- Keyword examples: synonyms of terms such as “community”, “characteristics”, “demographics”, “population”, “underserved”, “vulnerable”, “environmental racism” in close proximity with “lead” and “drinking water”

Note: a variation of this process undertaken for National Highways report

Drinking Water: Neighborhood Characteristics

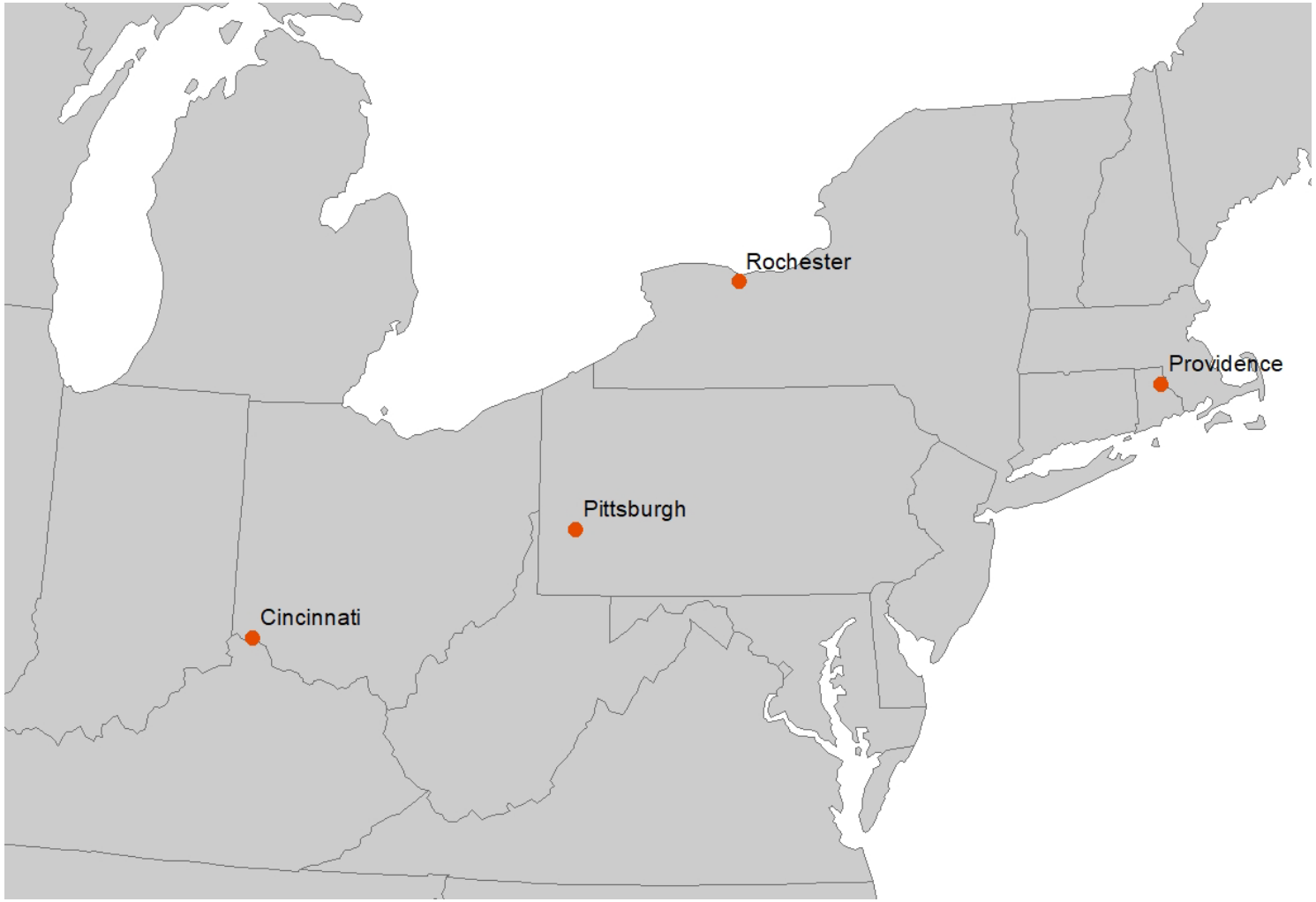
- **Housing:** Physical characteristics of the buildings within the neighborhoods
  - types of building
  - age of the infrastructure

- **Population:** Demographic characteristics of the people living in the neighborhoods
  - % families in poverty
  - % minority
  - % unemployed
  - % single, female-headed households
  - % without a vehicle
  - % children under 5 years old
  - % highest education level of high school

GEOSPATIAL ANALYSIS

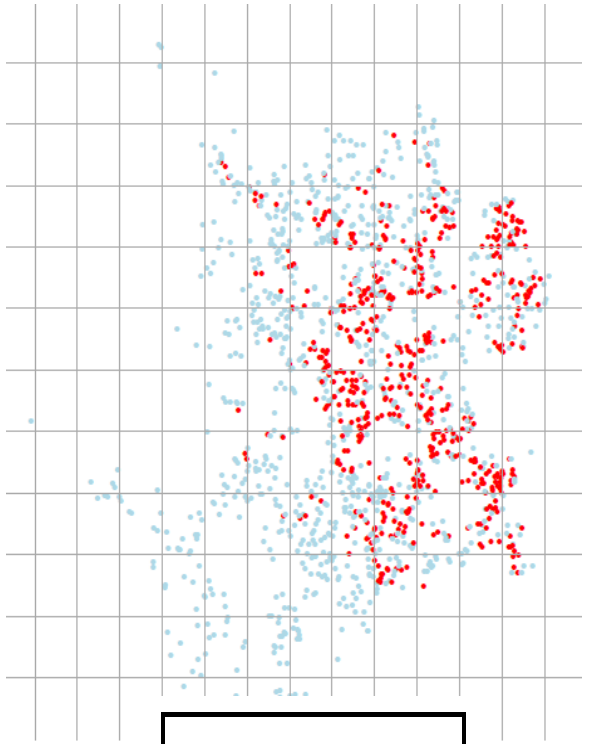
Drinking Water: Selected Water Systems

- Are among the largest water systems in the country
- With data on locations and material or pipes
- Were willing to share data with us within our reporting deadlines

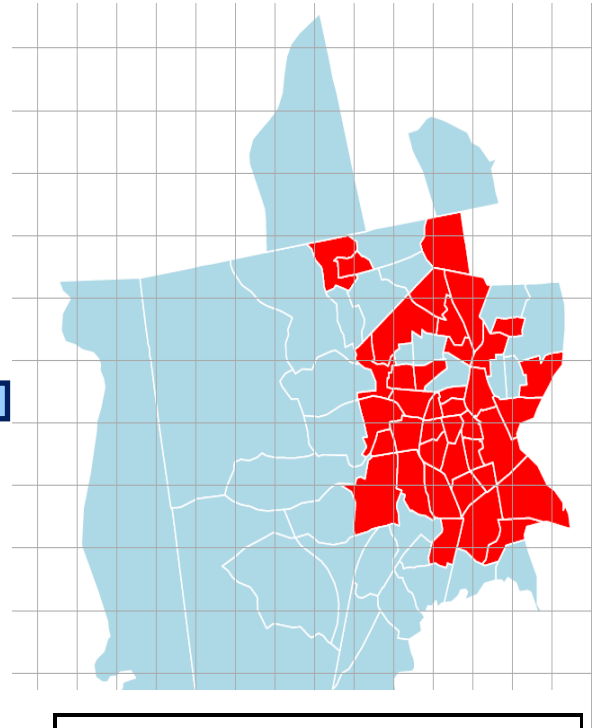


Drinking Water: Spatial Join of Lead Pipe Locations, High-poverty Tracts

Locations of lead pipes



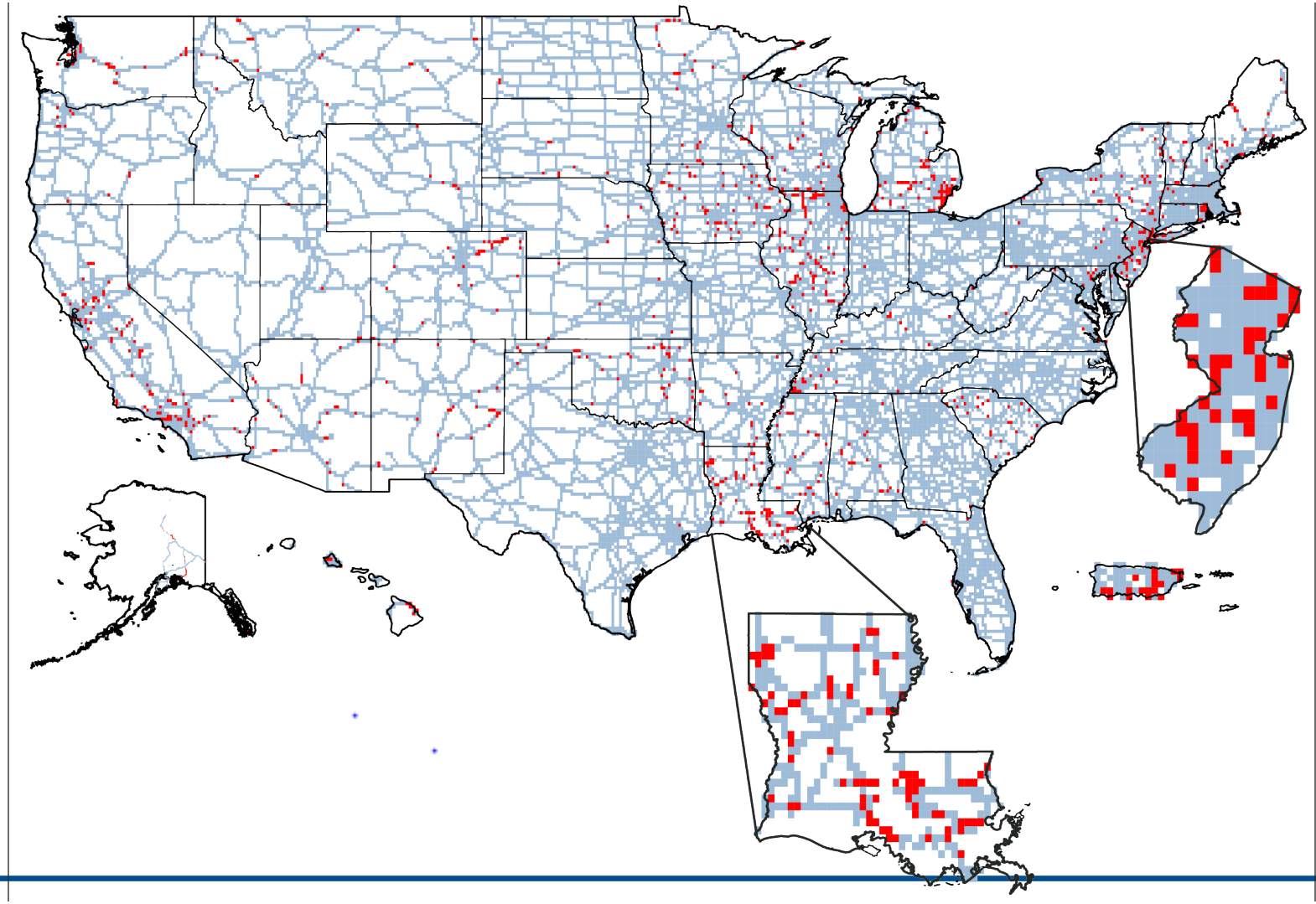
Locations of high-poverty tracts



Tabular data

Service line	Pipe material	Census tract	Estimated poverty
1	Lead	1	44.1%
2	Non-Lead	1	44.1%
3	Non-Lead	1	44.1%
4	Non-Lead	1	44.1%
5	Lead	2	23.8%
6	Lead	2	23.8%
...	...	...	...

National Highways: High Concentrations of Pavement in Poor Condition

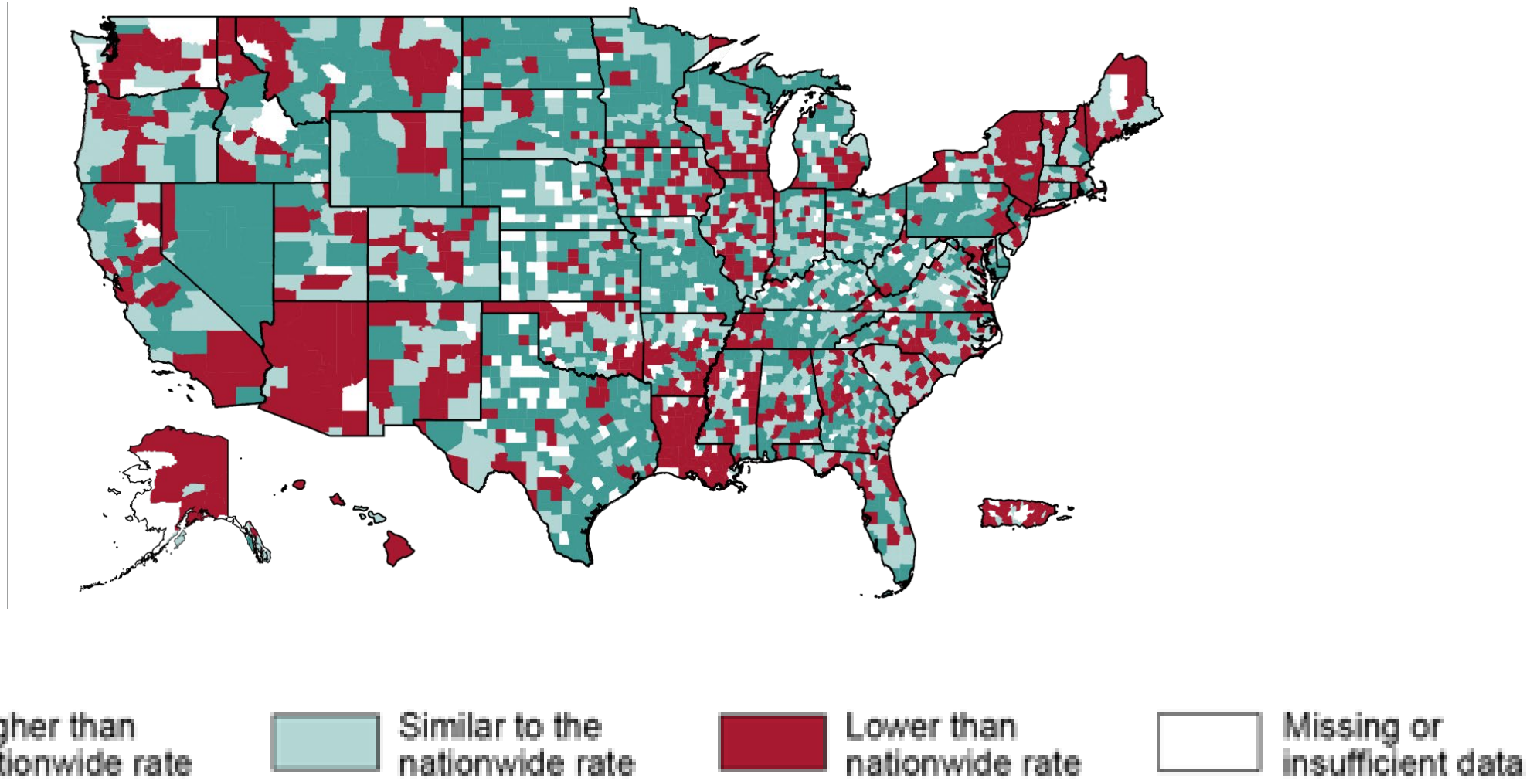


<=10 percent of lane miles in poor condition

> 10 percent of lane miles in poor condition

Source: GAO analysis of Federal Highway Administration and U.S. Census Bureau data. | GAO-22-104578

National Highways: County Rates of Good Pavement Condition Compared to Nationwide Rate



Source: GAO analysis of Federal Highway Administration and U.S. Census Bureau data. | GAO-22-104578

STATISTICAL ANALYSIS

Regression Model

Outcomes: Lead Pipes? Good Roads?

Binary (Yes/No) and nested within census tracts that contain the demographic characteristics

- ✓ Hierarchical (mixed model) generalized linear model with logit link
- ✓ Random effect for each census tracts

Model Outputs: Express qualitatively (higher/lower) and quantitatively

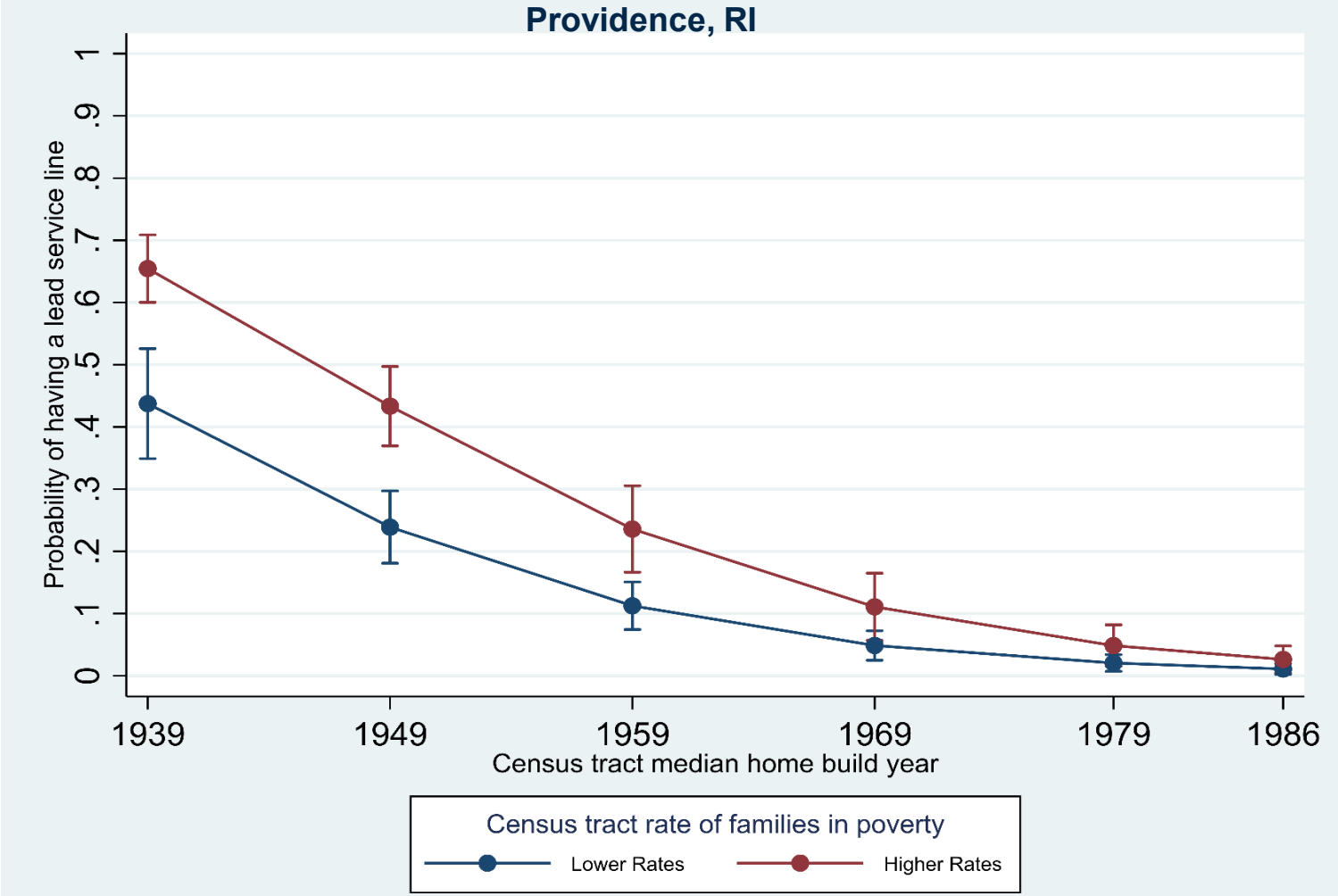
- ✓ Coefficients as probabilities
- ✓ Association, not causation

Drinking Water: Findings

Through a statistical model, we found households in neighborhoods with:

- Older homes are more likely to have lead service lines
- Higher % of families in poverty are more likely to have a lead service line, even after accounting for the median home age of the area

Drinking Water: Probability of a Home Having a Lead Line, by Home Age and Poverty Rates



A house in a census tract that is otherwise typical, but with % of families in poverty:

"Above Average"

vs

"Below Average"

Source: GAO analysis of water system geospatial lead data and American Community Survey 5-year (2015 – 2017) estimates | GAO-21-78

National Highways: Sources of Data

- 2019 Performance Measure Rule 2 (**PM2**) Pavement Metric Data on road pavement conditions and Highway Performance Monitoring System (**HPMS**) data on road characteristics and traffic, obtained from FHWA.

- Publicly available data
  - Community characteristics: Census' 2015-2019 **ACS**
  - Climate data: Modern-Era Retrospective Analysis for Research and Applications, Version 2 (**MERRA-2**) climate data from the National Aeronautics and Space Administration (**NASA**)
  - Population density: 2010 Rural-Urban Commuting Area (**RUCA**) Codes related to population density from the US Department of Agriculture's (**USDA**) Economic Research Services (**ERS**).

National Highways: Variables Included in Our Model

Community Characteristics

- Race/Ethnicity ACS
- Families in Poverty ACS
- Rural Urban Codes RUCA

Traffic, Climate, Other Characteristics

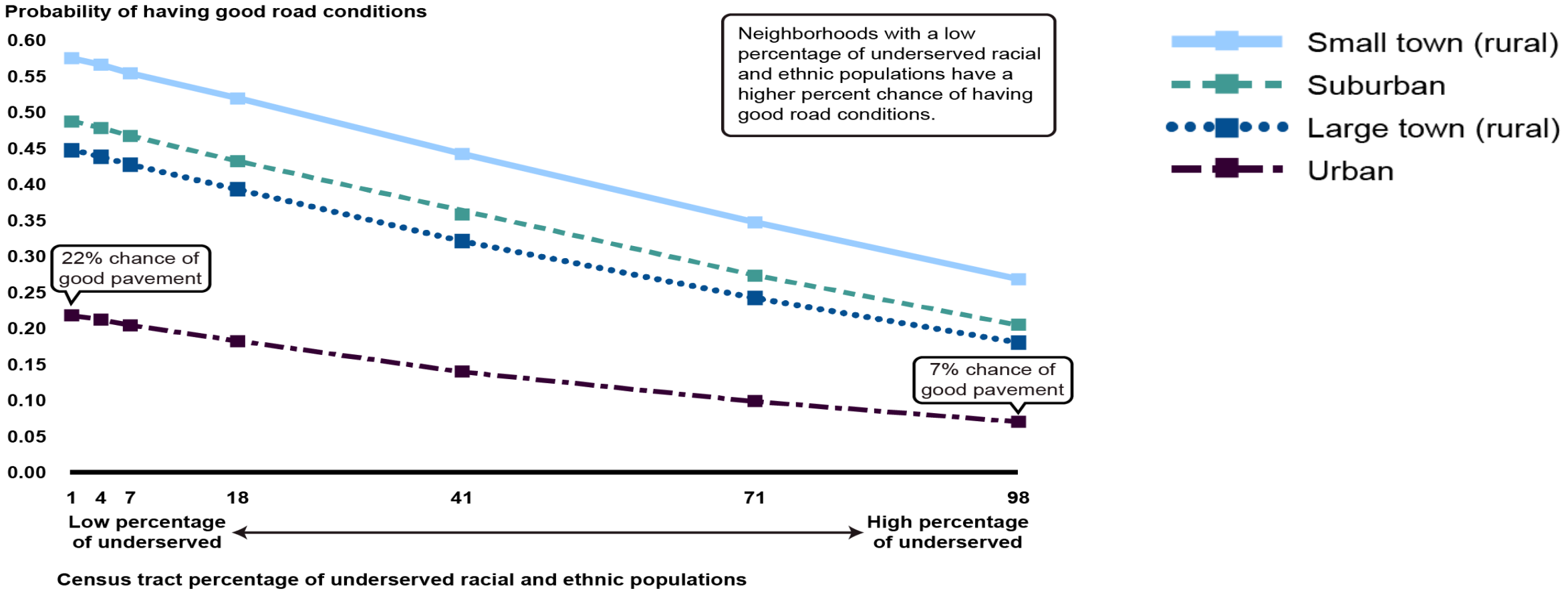
- Average Daily Traffic HPMS
  - Annual
  - Single Unit
  - Combo Unit
- Interstate PM2
- Climate MERRA-2

National Highways: Findings

Through a statistical model, we found pavement is less likely to be in good condition in:

- Communities with higher percentages of underserved racial and ethnic populations
- Communities with higher % of family in poverty
- Urban areas

National Highways: Probability of Pavement in Good Condition by Race/Ethnicity, Population Density



Source: GAO analysis of Federal Highway Administration, U.S. Census Bureau, National Aeronautics and Space Administration, and U.S. Department of Agriculture data | GAO-22-104578

IMPACT OF WORK

- **Recommendations**

1. **EPA should** incorporate the use of ACS data and geospatial lead data into its Federal Action Plan to Reduce Childhood Lead Exposures.

2. **EPA should** develop guidance for water systems that explains methods for using ACS and geospatial data to I.D. where to focus lead reduction efforts.

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1. **FHWA should** analyze pavement condition data, such as Highway Performance Monitoring System data, to examine the concentration of poor pavement in specific areas within states and differences in pavement condition by community or other characteristics, which could include race and ethnicity, poverty, or population density.

2. **FHWA should,** based on the rec 1, identify potential strategies to help states detect and address issues that could contribute to concentrations in poor pavement and differences in pavement condition by community or other characteristics, which could include race and ethnicity, poverty, or population density.

- **Agency follow-up with GAO**

- **Interest by outside groups**

GAO Staff Acknowledgments

GAO-21-78 EPA Lead Reduction Efforts

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GAO-22-104578 National Highways

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