Investigating Boston's Drinking Water Main Breaks

Introduction

In the next 20 years, Massachusetts is predicted to need $1.2 billion of investment to maintain and expand drinking water infrastructure.[1] The Boston Water and Sewer Commission (BWSC) provides drinking water to 590,000 people, but the service population nearly doubles each day due to commuters. The current BWSC Water Main Replacement Program's methodology for prioritizing pipe replacement is based on a pipe's age and material, soil conditions, break history, and consequence of failure among other variables.[2] This project explores clusters of several of these variables corresponding to the location of drinking water main breaks over time. This information can be used to conceptually understand, and potentially further inform, the capital investment planning decisions in Boston.

Data and Methods

The data for this analysis included: 1) point data of drinking water main breaks from 2000-2016; 2) population density, median income, and total number of households per Census Tract (2010-2015); and 3) BWSC infrastructure data aggregated by Census Tract.

Maps 1-3 were created using a space-time analysis tools in ArcMap. The first step was to create a space-time cube using point data of the location of water main breaks on a fishnet grid. Next, Maps 1 and 2 were created using the emerging hot spot analysis with a time step set 5-years and 7-years, respectively. Map 3 is displaying the result of a local outlier analysis for the 7-year time step.

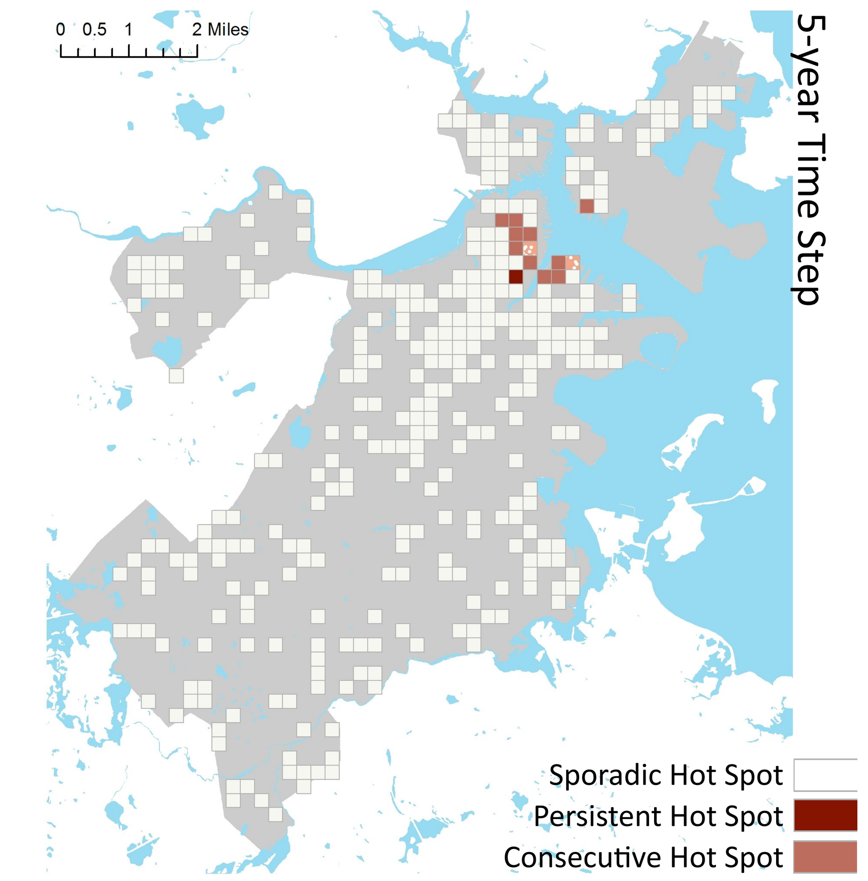
Maps 4-9 were created in GeoDa using bivariate local Moran's I. The weight's matrix for the analysis was created using first order queen contiguity. Each map tests a hypothesis considering the total number of breaks spatially joined to Census Tracts (CTs) as the dependent variables. The independent variables were chosen by data limitations as well as considering the social demand and cost on the drinking water system.

Discussion of Space-Time Analysis

A cluster of water main break hot spots emerges in downtown Boston when comparing Maps 1 and 2. Hot spots are considered areas where there is a trend of water main breaks. The amount of time necessary to see emerging patterns can be used to determine the amount of historical data needed to inform policy. Comparing areas that change depending on the time step can also inform where to prioritize investment, for example, in areas with persistent or consecutive hot-spots.

The outlier analysis (Map 3) identifies a few areas to explore as investment priorities, such as areas where a high number of breaks is surrounded by other areas with a high number of breaks, as seen in downtown Boston. Further analysis could examine each type of outlier more thoroughly to help explain why these trends are occurring.

The orange boxes indicate hypothesized trends for downtown Boston.



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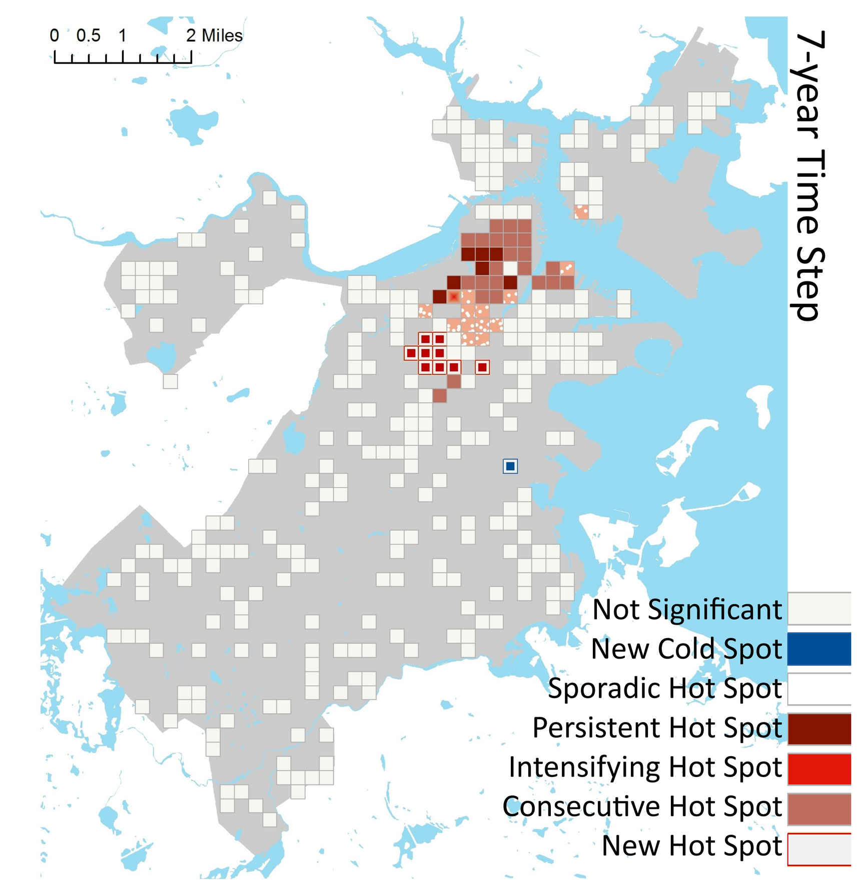

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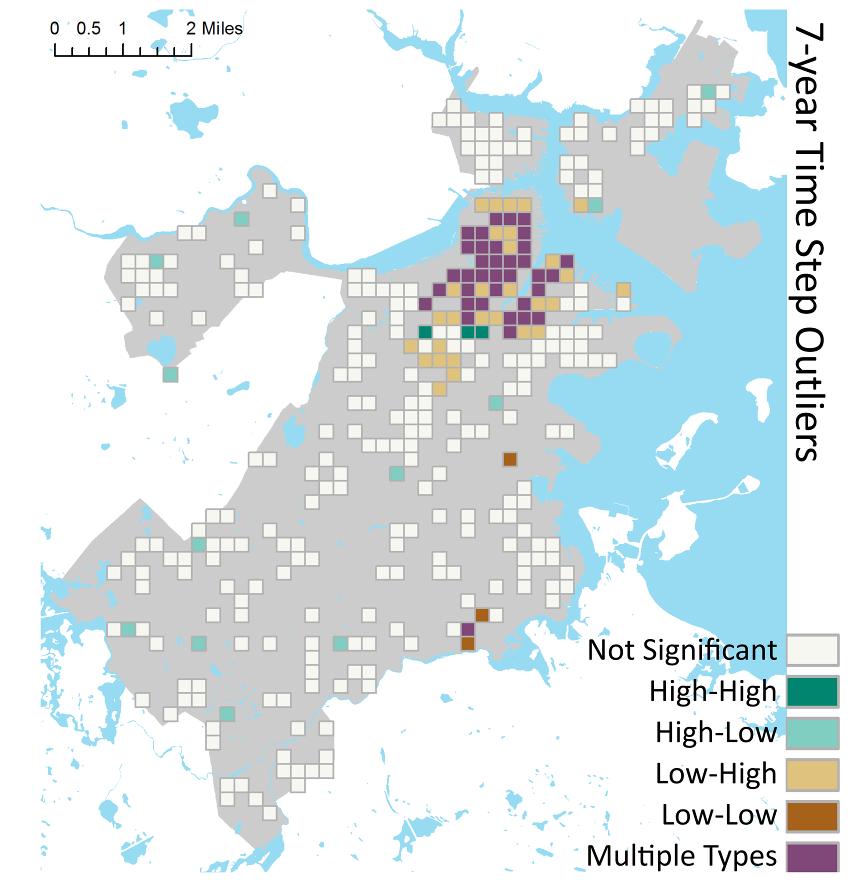

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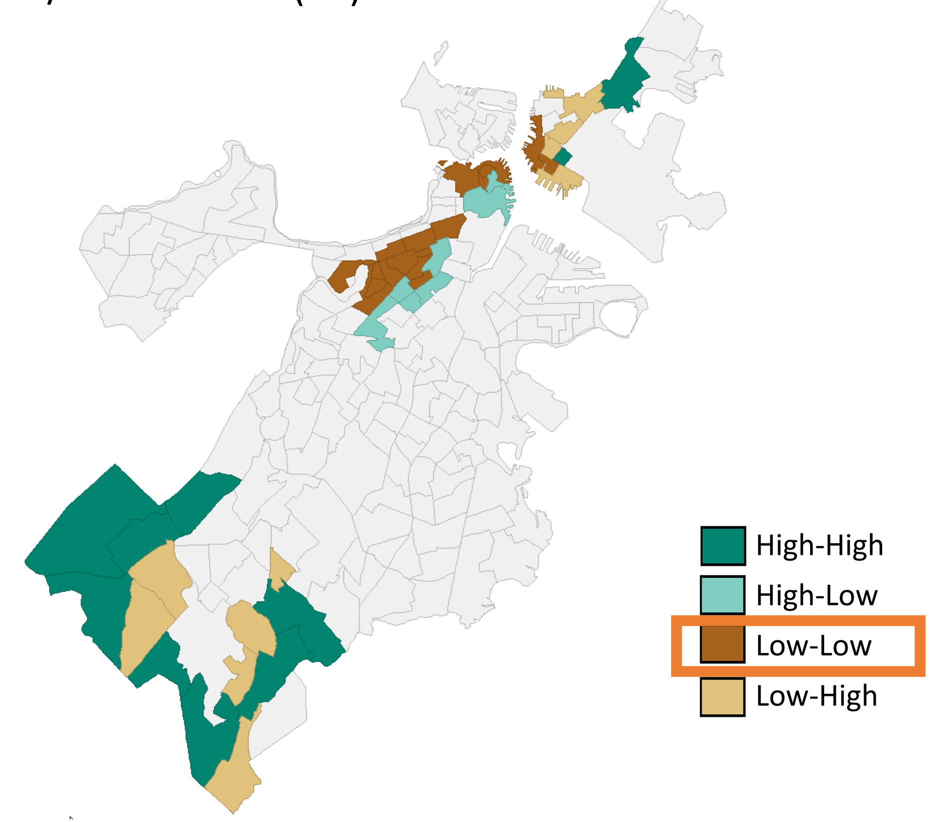
Why are there water main break hot-spots in downtown Boston?

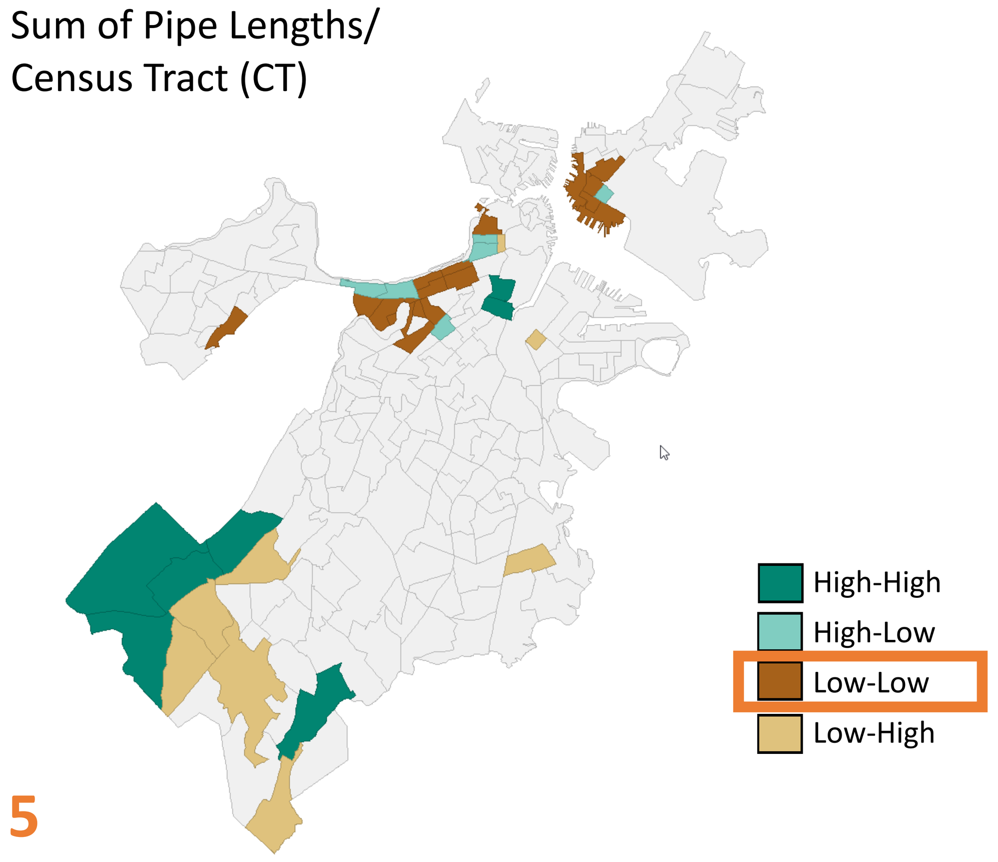
Total Number of Breaks - Acres/Census Tract (CT)



4

Hypothesis: There will be less breaks in smaller CTs. This hypothesis holds true for some of the downtown CTs. Yet, there is a comparable amount of small CTs with a high number of breaks.

Total Number of Breaks - Sum of Pipe Lengths/ Census Tract (CT)



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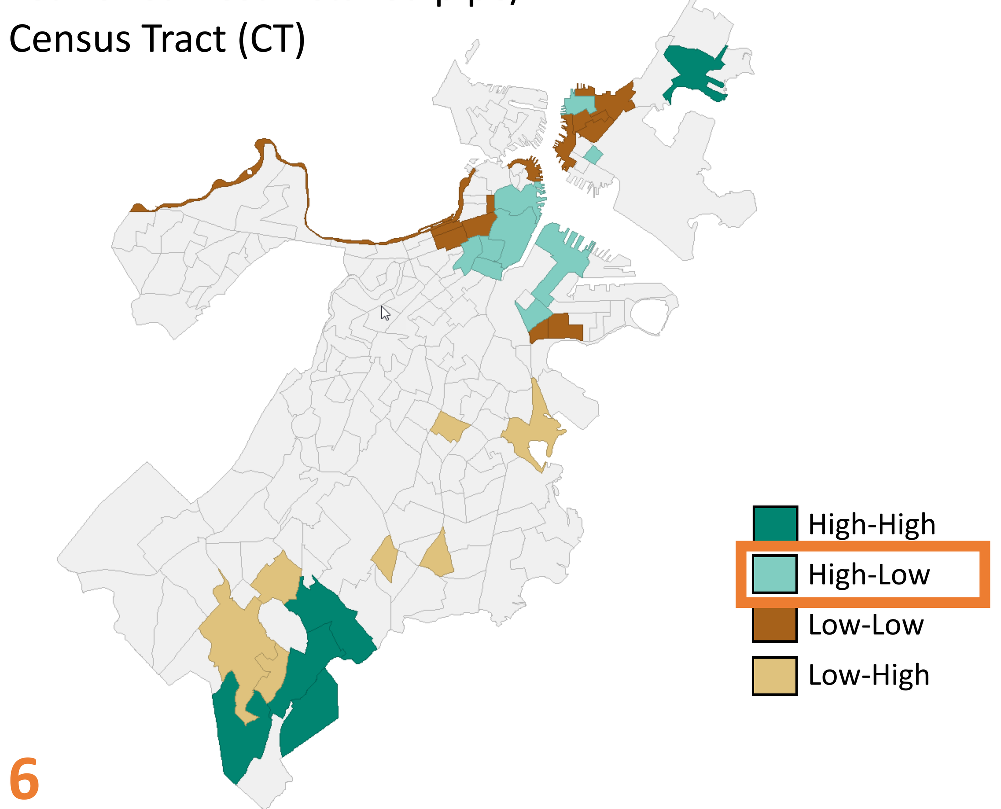
Hypothesis: There will be more breaks in CTs with more pipes (feet). There is a small cluster where this holds true in the downtown area, but the trend is not consistent.

Total # of Breaks Year of earliest installed pipe/ Census Tract (CT)



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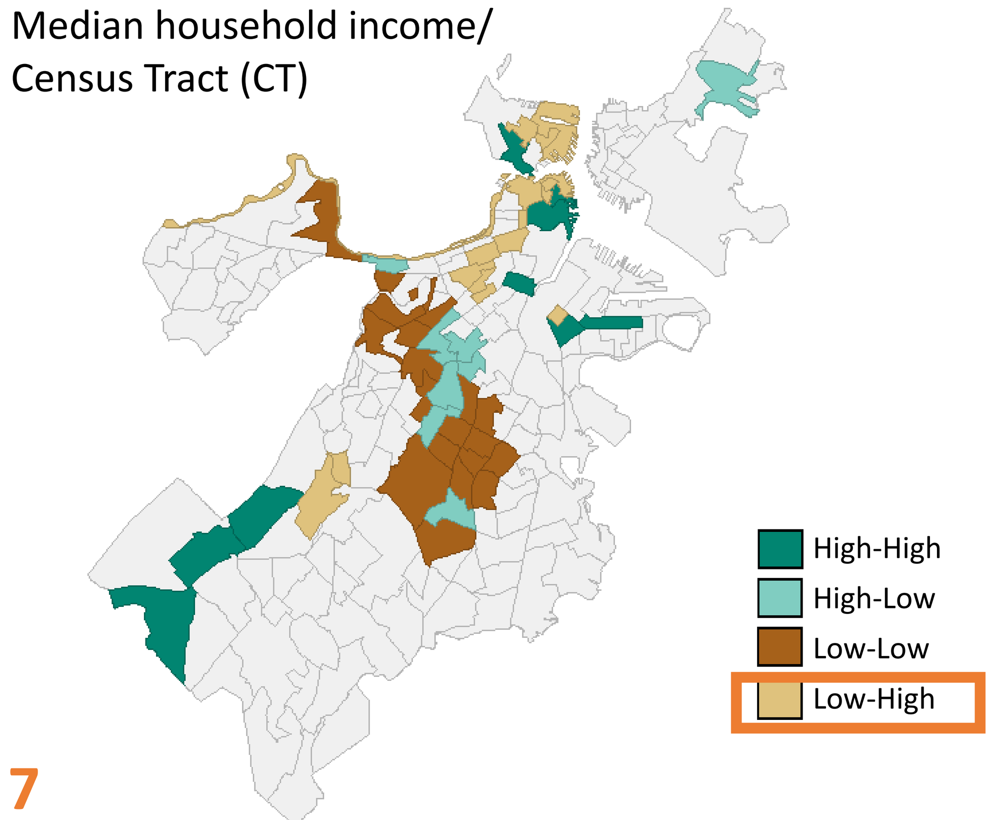
Hypothesis: There will be more breaks in CTs with older pipes ("low" installation years). This holds true for most of the downtown with only a few exceptions.

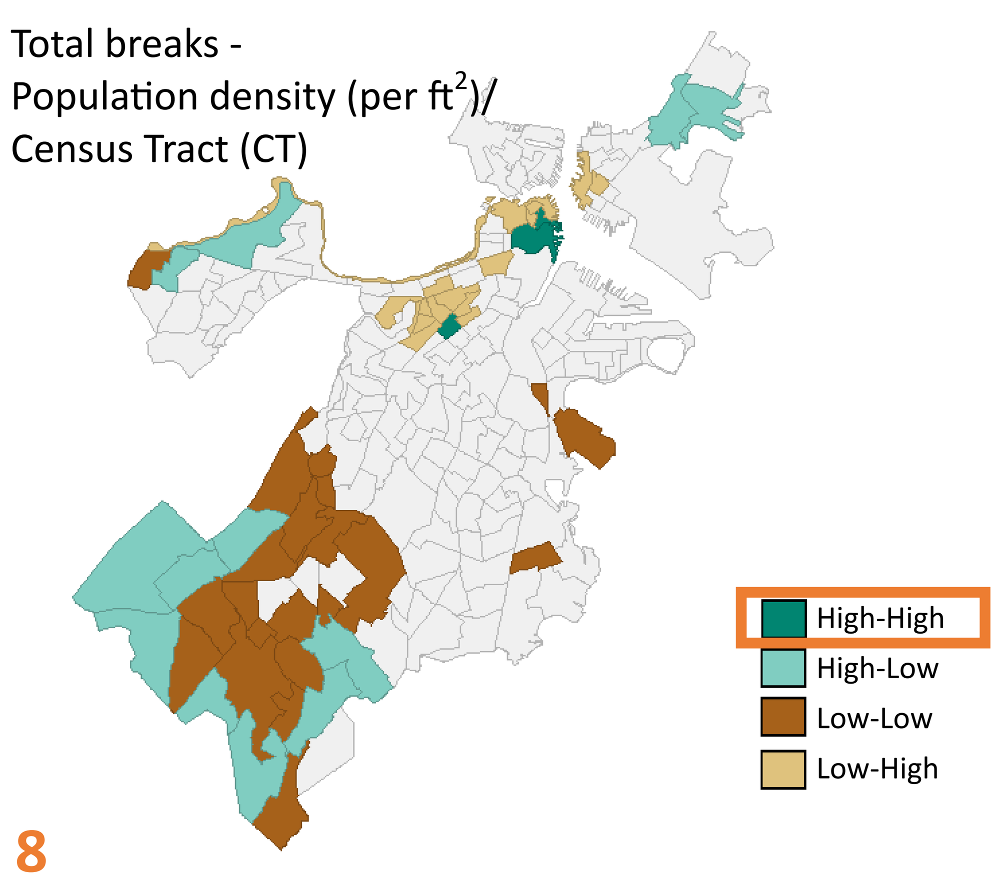
Total breaks - Median household income/ Census Tract (CT)



7

Hypothesis: There will be less breaks in CTs with higher median incomes. There is a larger cluster supporting the hypothesis downtown, but this does not hold true for all of downtown.

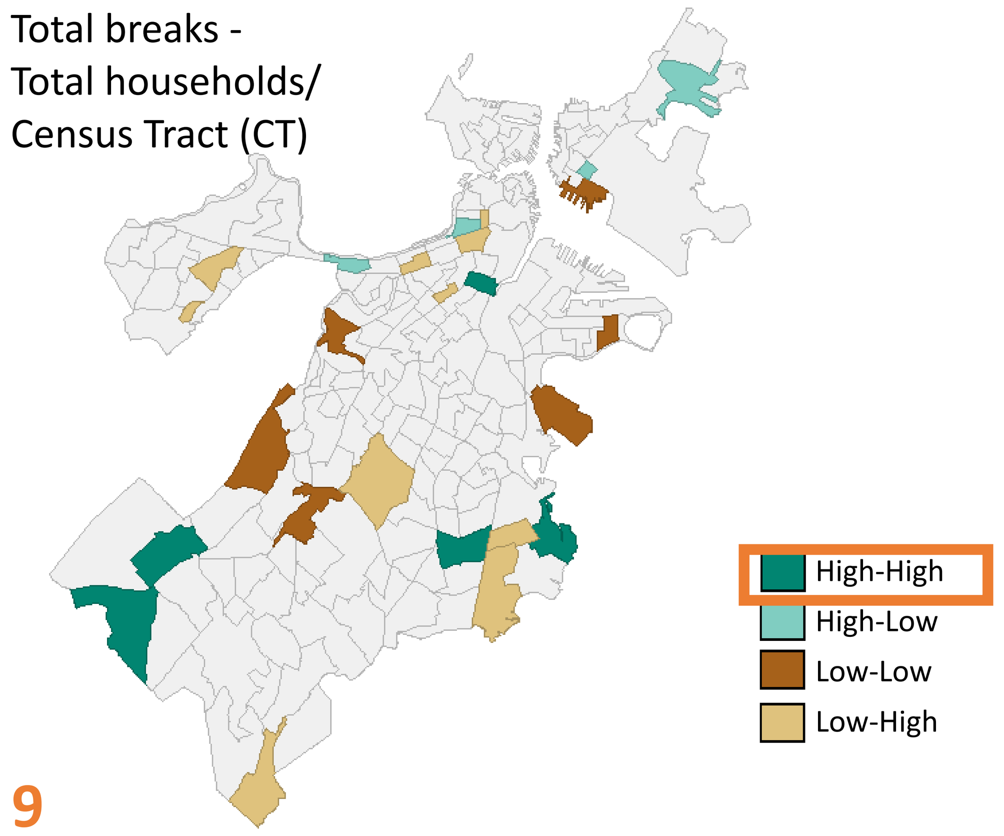
Total breaks - Population density (per ft^2)/ Census Tract (CT)



8

Hypothesis: There will be more breaks in CTs with higher population density (person/sq ft). The same area with high median incomes and a low number breaks, also has high density, largely dismissing this hypothesis for downtown.

Total breaks - Total households/ Census Tract (CT)



9

Hypothesis: There will be more breaks in CTs with more households. There result of this map looks sporadic. There does not appear to be a trend in the downtown area.

Discussion of Independent Variable Clusters and Regression

The spatial cluster analysis provides an initial investigation of where infrastructure investment efforts could be concentrated. In addition, it provides locations where there would likely be high social costs after a water main break and where redundancy investment should be confirmed or updated.

The most apparent cluster in the downtown area is a high number of total breaks clustered with the earliest years of pipe installation (light blue on Map 6). However, the regression results of the non-spatial relationship was not statistically supported (see Table 1 for p-values). Likewise, the non-spatial relationship between the total number of acres and median income per CT was not significant. Map 9, displaying total number of breaks and total households, appeared to have the most random distribution throughout all of Boston. Surprisingly, the non-spatial relationship of these variables had an indirect and

Table 1. OLS Regression Results

Map	Variable	Coefficient	p-value
4	Acres	0.00023	0.88501
5	Total Length of Pipe	0.00019	0.00000
6	Earliest Installed Pipe	-0.02146	0.28070
7	Median Income	-0.00001	0.41704
8	Population Density	169.59500	0.00131
9	Total Households	-0.00143	0.00960

statistically significant relationship. The number of acres, population density, and median household income had some clusters supporting the hypothesis, but of these three, only population density was found to have a statistically significant relationship. Population density had the largest coefficient and would have a substantially greater impact per unit than other variables. However, this is still quiet small and unlikely for Boston. The model predicts that for every 1 person added per square foot of space (over 164,000 people/ square mile), there will be 169 more breaks. Despite the numbers, the importance of this finding is the impact human activity may have on pipe breakage and how investment should consider the social cost of breaks in investment planning. The increase of breaks as median income decreased and population density increased could suggest that these variables do not hold a very strong weight in the current investment priorities. Lastly, the R-squared was 0.458, meaning the model explained 45% of the variance of total breaks.

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Sources: Boston Water and Sewer Commission. 2017. Aggregated Pipe Data by Census Tract.

Joshua Eaton via Carto. BWSC 2000-2016 Water Main Breaks. Confirmed by Nicole Kieser of BWSC.

MassDEP. 2010. Hydrography.

US Census Bureau. 2016. Tiger Shapefiles.

Mass GIS. 2009. Town Boundaries.

US Census Bureau. 2010-2015. Median Household Income and Population by Census Tract. American Community Survey 5-year estimates.

[1]American Water Works Association. Massachusetts Infrastructure Overview.

[2]Vitale, H. 2017-2019 Boston Water and Sewer Commission Capital Improvement Program.

Projected Coordinate System: NAD 1983 State Plane Massachusetts Mainland FIPS 2001 (Meter)