# Geo-statistical Analysis for Pipe Inspection Prioritization

A case study on Watertown, Connecticut

A GIS Report by Devashri Karve and Tanay Kulkarni

## About

Every year millions of dollars are spent by water utilities globally to install, replace, and repair the drinking water network infrastructure. This linear pipeline infrastructure system is spread across the city following the roads, ensuring delivery of safe potable water to citizens.

Today, aging infrastructure is a major challenge that the United States of America is facing. The country planned to replace 12,000 miles of its water pipes in 2020 alone! It loses over 6 billion gallons of treated potable water every day and it is estimated to have a pipe break every two minutes! [2021 Report Card for America's Infrastructure]

The objective of this study is to understand how geospatial analysis can be used to understand the geo-statistical influence of various factors that affect pipes, and to estimate the priority for inspecting the pipes for repairs, replacements, or health-check in general. These factors include but cannot be limited to pipe age, material, length, diameter, number of breaks reported, bed soil in which the pipe is laid, groundwater table, etc. This study identifies pipe with higher inspection priority and criticality. A case of Watertown's drinking water infrastructure is studied and discussed here.

Watertown is a small town located in the Litchfield County of the Connecticut State of the United States of America. With around 6000 families residing consisting of about 21,000 people, the population density of Watertown in 2020 was approximately 750 people/square mile. [Wikipedia, US Census 2020]

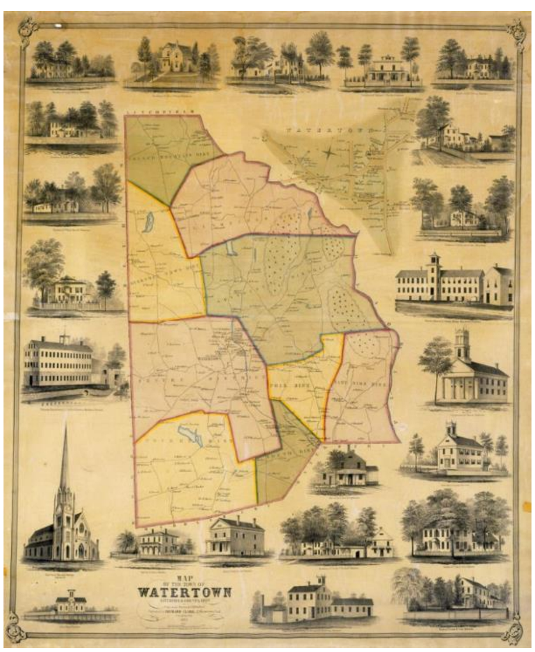
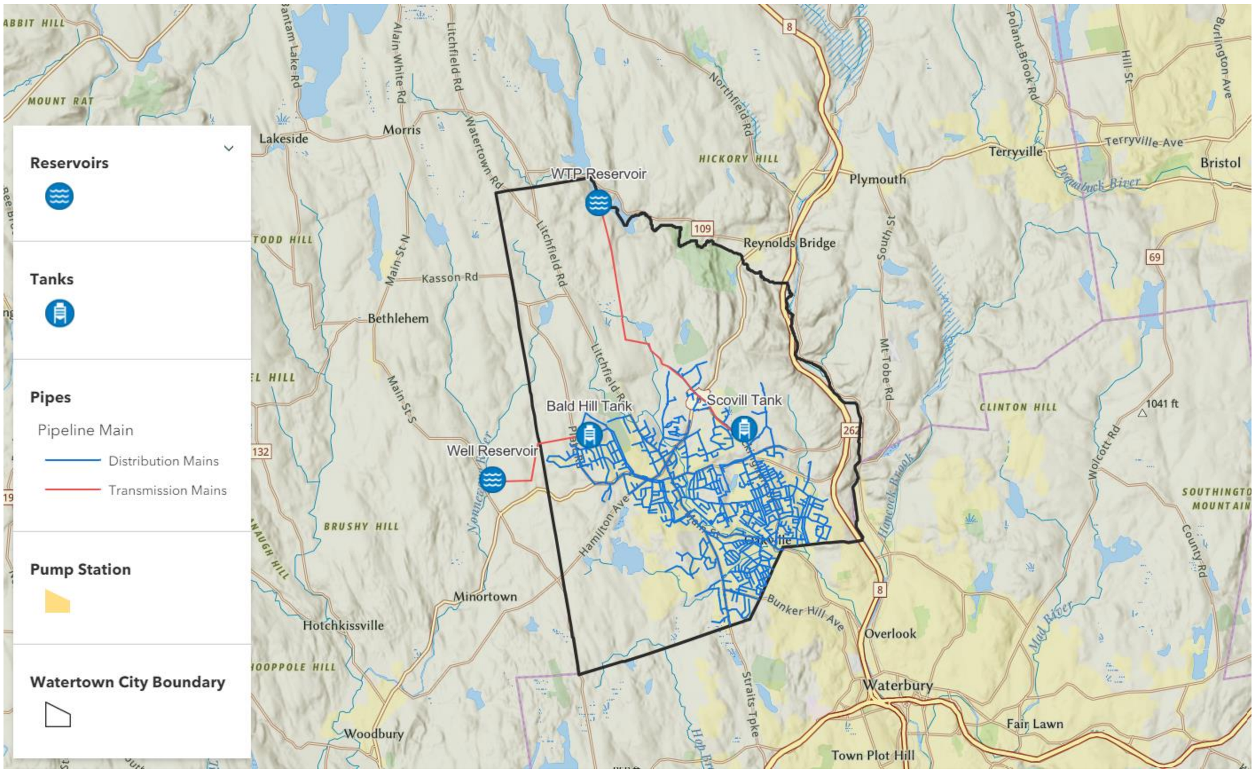



*Chart 1 Map of the Town of Watertown, Connecticut*

The Taft- a private boarding school, and the Watertown Historical Society, tops the list of notable places of the town! The town is bordered by the city of Waterbury of New Haven County to the southeast. The town has a total area of 30 square miles within which 29.5 square miles is land and remaining 0.5 square miles is surface water.

Here is a very peculiar map (Chart 1) of Watertown from the actual surveys of E. M. Woodford. The map was cartographed by Richard Clark in 1853. It is very interesting to note that the map shows buildings and even householders' names. On the periphery it includes the views of local buildings, districts, and even an inset map of Watertown! [Connecticut Historical Society's Museum & Library]

# The Scheme




*Map 1 Water Distribution Network Infrastructure, Watertown, CT*

## The Nonnewaug Falls Reservoir:

The Nonnewaug Falls Reservoir located on the west of Watertown, has a pumping station that pumps around 800 GPM (Gallons per minute) of water to the town.

## The Wigwam Reservoir:

The Wigwam Reservoir pumping station at the north has a spillway with an elevation of 561' USGS, and pumps treated potable water to Watertown at a rate of 900 GPM.

## The Bald Hill Tank:

There are two elevated storage tanks in Watertown. The Bald Hill Tank has a storage capacity of 1.5 million Gallons and is stationed at 803' USGS ground elevation having a HGL at 821' USGS.

## The Scovill Tank:

The other tank in Watertown is the Scovill Tank of 1 million Gallons storage capacity. It has an Overflow Elevation at 999.5' USGS and a Ground Elevation: 875' USGS.

## The Pipes!

The pipes in water distribution infrastructure are analogous to blood veins in human body! The pipes are the most important and cost intensive element of the network infrastructure.

# Pipe statistics:

The Watertown water network has Ductile Iron, Cast Iron, Concrete, Steel, and PVC pipes of 4-inch, 6-inch, 8-inch, 10-inch, 12-inch, 14-inch, 16-inch diameters. The total number of pipe elements are 1219 summing up to a total length of 7042 ft.

Here are a few exploratory charts that reveals hidden insights about Watertown pipes:

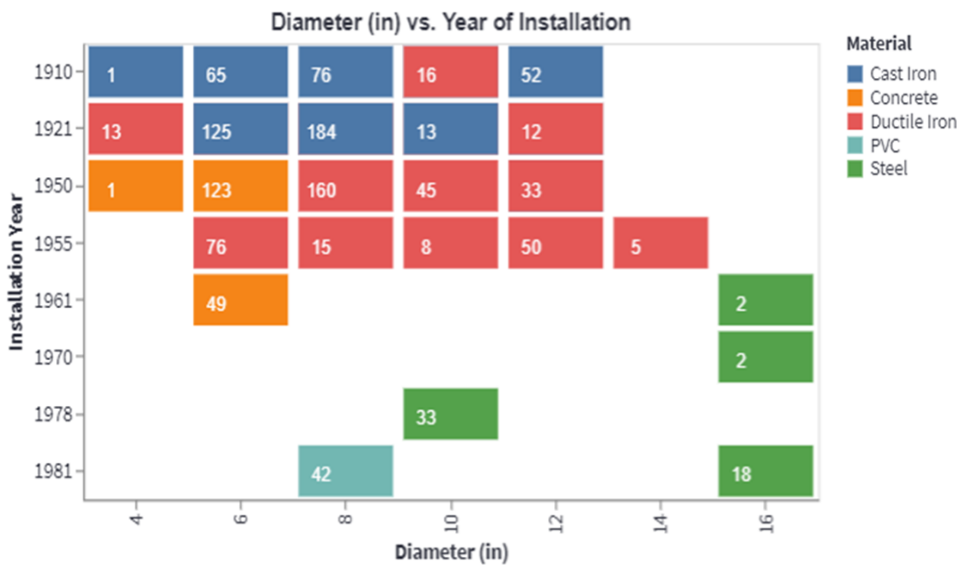



*Chart 2 Diameter (in) vs. Year of Installation, Watertown, CT*

Chart 1 shows Diameter-Material wise Age of pipes. It can be observed that maximum number of pipes are older than 70 years and are of Ductile Iron pipes!

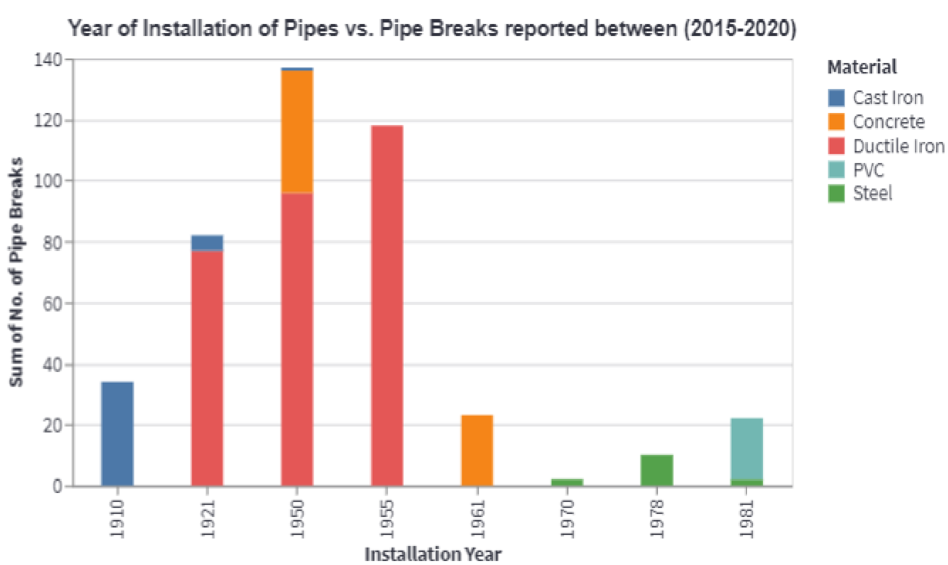



*Chart 3 Year of Installation vs. Pipe Breaks, Watertown, CT*

Chart 2 shows that these older ductile iron pipes have maximum records of breaks between 2015 and 2021.

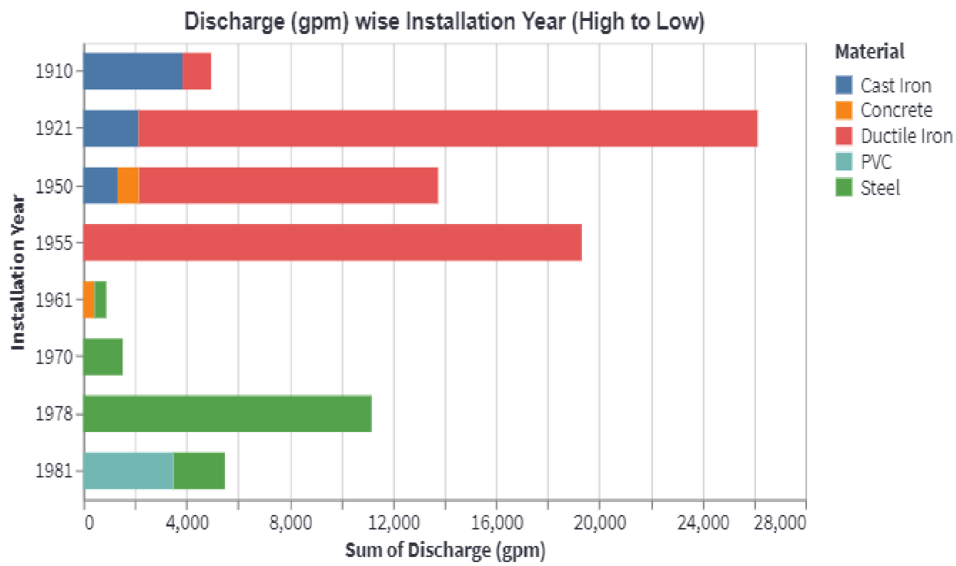



*Chart 4 Discharge (gpm) vs. Year of Installation, Watertown, CT*

Chart 3 shows that these older pipes carry maximum discharge in the network! Thus, should anything happen to these pipes, maximum number of customers would be effectively impacted!

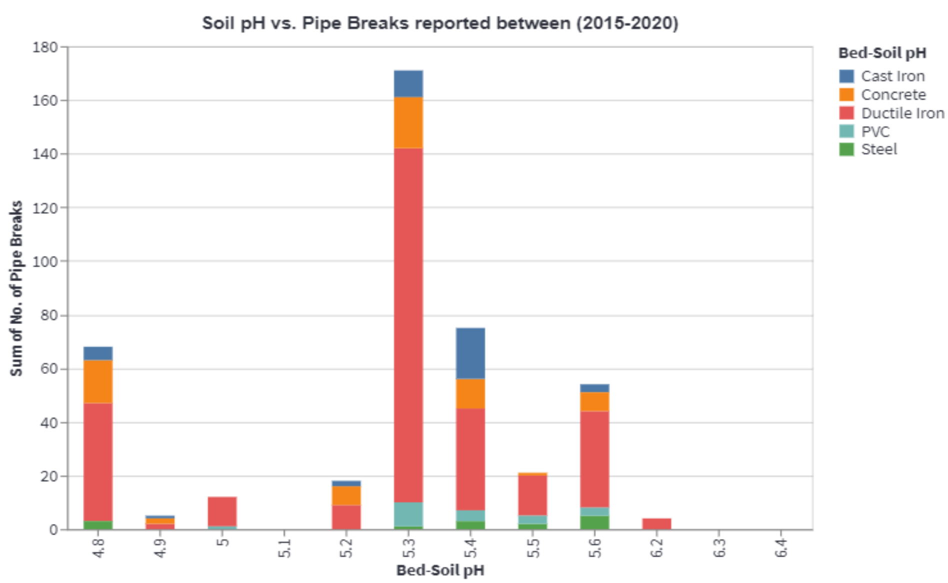



*Chart 5 Soil pH vs. Pipe Breaks, Watertown, CT*

Chart 4 shows how the bed-soil pH affects the corrosion rate of the pipe material. pH < 6 results in higher corrosion and the number of breaks reported are more in pipes with bed-soil pH less than 6!

## Zone Map


*Map 2 Zone Map of Watertown, CT*

The pipes are divided into seven distribution supply zones viz. Oakville High, Oakville Low, Northern, Town Hall, Fire District, Straits, and Supply Zones as shown in the map.

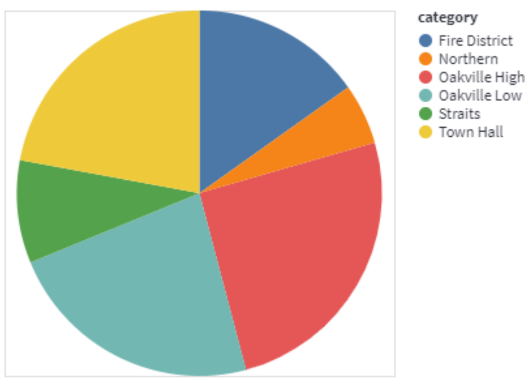



*Chart 6 Zonal Water Consumption, Watertown, CT (2019)*

The Oakville High, Oakville Low, and Town Hall zones have reported relatively larger annual consumption of water in 2019.

## Age Map

Major new-pipe installations happened in the years 1910, 1921, 1950, 1955, 1961, 1970, 1978, and 1981.


Maximum quantity of pipes was laid in 1950 and a majority of them were Ductile Iron pipes.

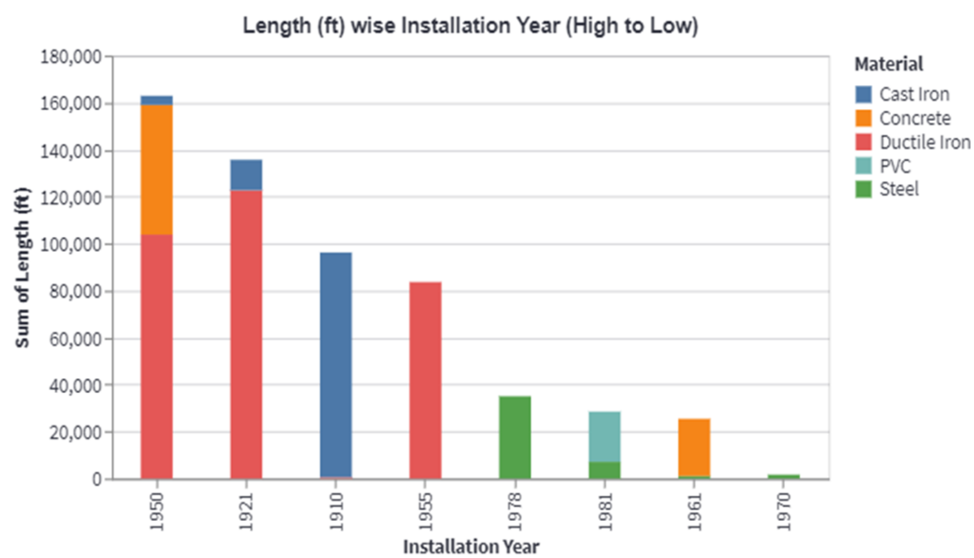
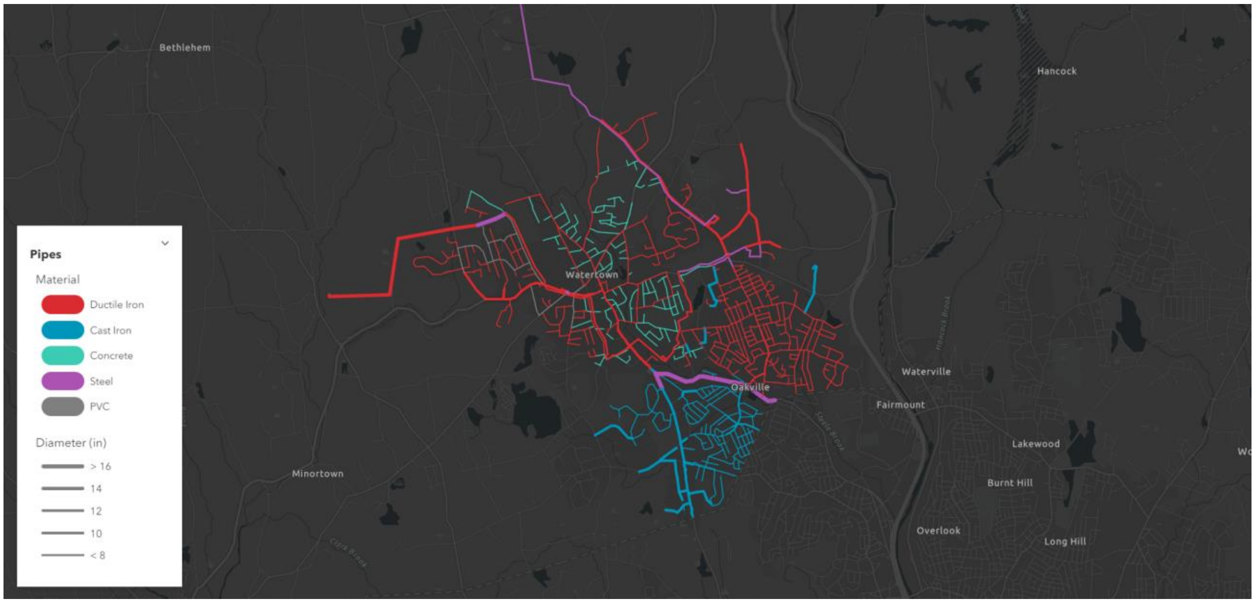



*Chart 7 Length (ft) vs. Year of Installation*

From the map, it can be observed that Oakville High, Oakville Low, and Straits Zone have the oldest pipes.

## Pipe Material

The network has many Ductile Iron and Cast-Iron pipes; a few Concrete and Steel pipes; and very few PVC pipes, spread all across the town.




*Map 3 Pipe Material Map, Watertown, CT*

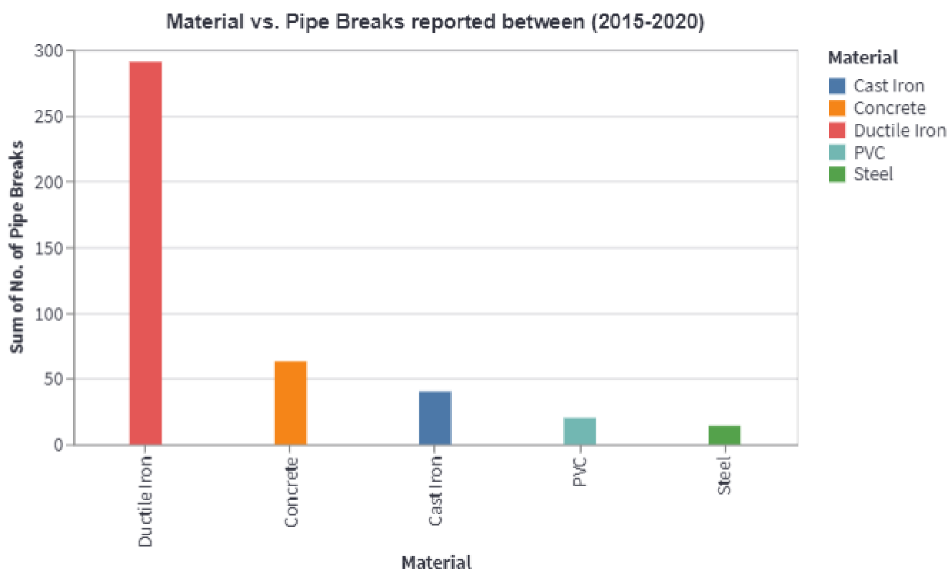
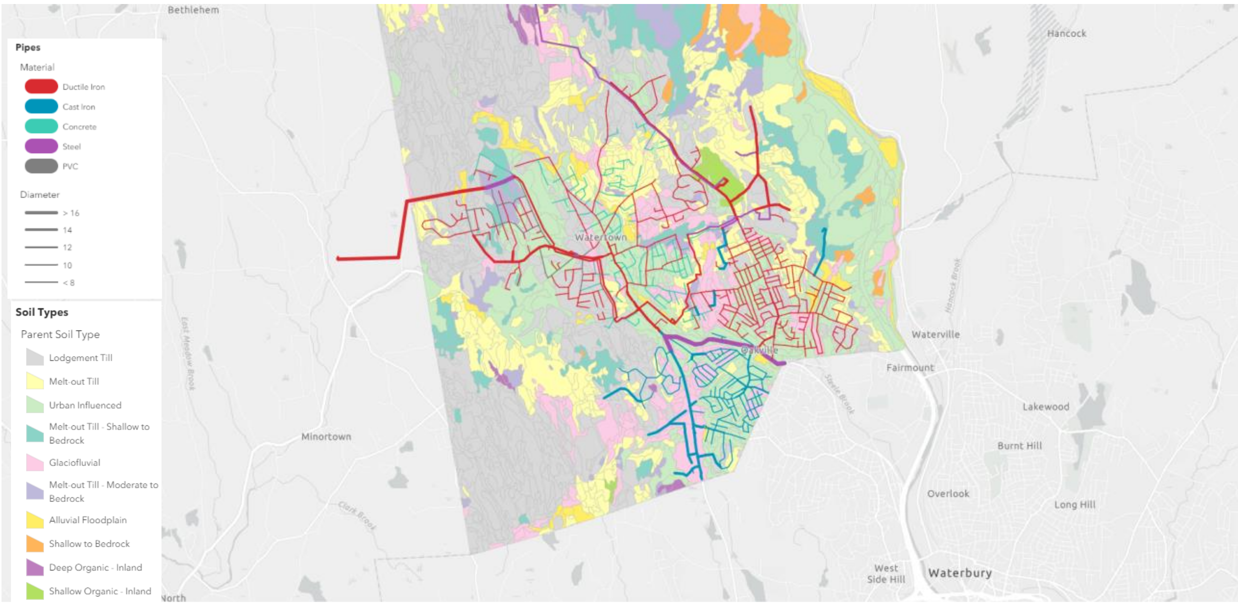



*Chart 8 Material vs. Pipe Breaks*

Maximum number of breaks between 2015 - 2021 were reported on Ductile Iron pipes followed by Concrete and Cast-Iron pipes.

# The Bed-Soil Factor




*Map 4 Bed-Soils Map, Watertown, CT*

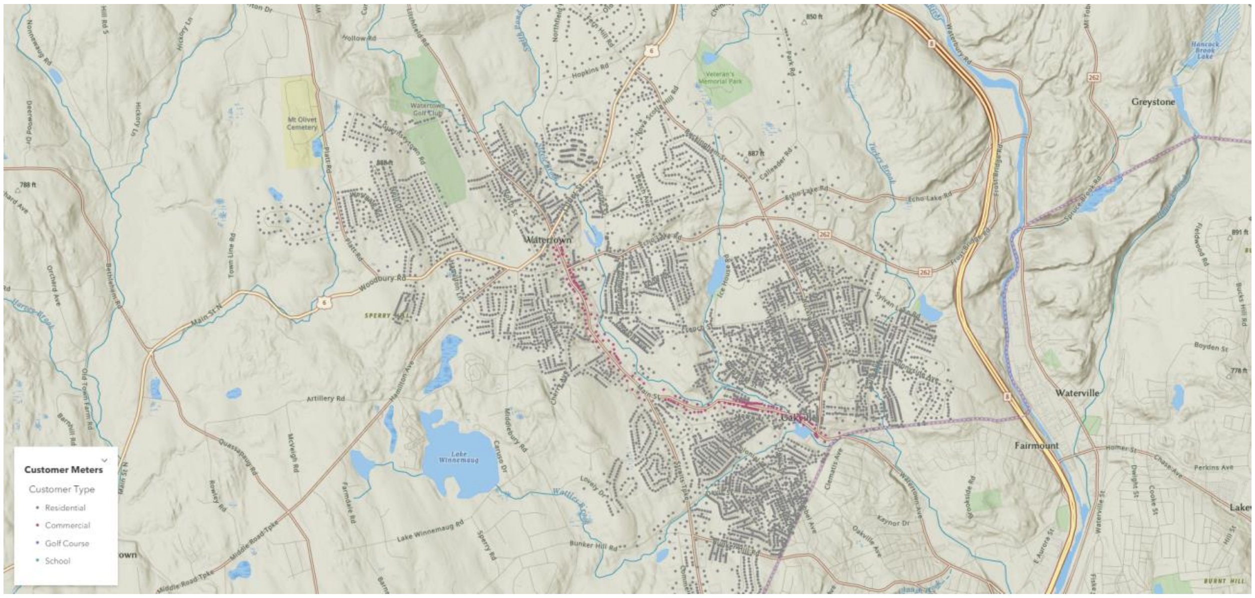
As per Soil Survey Geographic Database (SSURGO) Soils, Department of Energy & Environmental Protection, Wate rtown, CT has Lodgement Till, Melt-out Till, Urban Influenced, Melt-out Till - Shallow to Bedrock, Glaciofluvial, Melt-out Till - Moderate to Bedrock, Alluvial Floodplain, Shallow to Bedrock, Deep Organic - Inland, and Shallow Organic - Inland soil types.

# The Groundwater Factor


*Map 5 Groundwater Depth Map, Watertown, CT*

The map below shows depth of groundwater table from the ground surface in Watertown and the pipes closer to the groundwater table. Groundwater has a profound impact on the pipe condition, especially when the pipes are metallic.

## Customer Meters



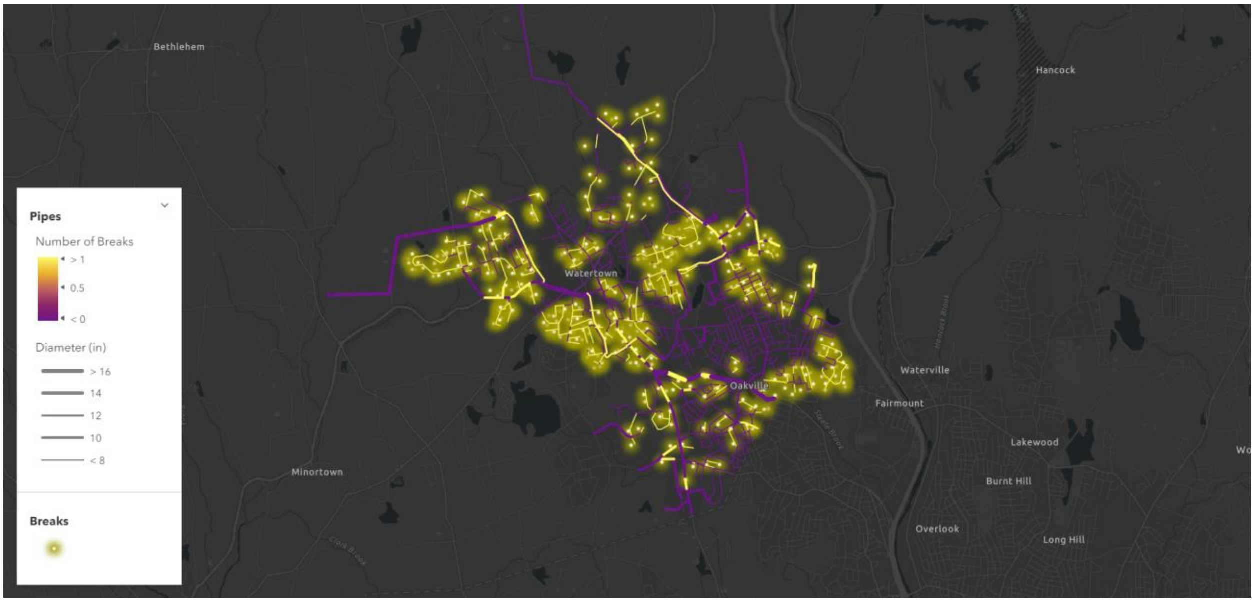

*Map  6 Customer Meter Map, Watertown, CT*

Water meters measures the total water consumption at the customer end. These meters are categorized based on the type of the customer.

Watertown has four major types of customers viz., residential, commercial, entertainment (golf course), and institutional (school). It is evident that residential meters constitute more than 95% of the 6610 number of total water meters in Watertown.

## Pipe Breaks

Out of 6610 total number of customers, 428 reported breaks on water mains between 2015 and 2021. These breaks are geographically mapped at the customer meter locations and associated to the nearest pipe. The map below that shows where and on which date the breaks were reported between 2015 and 2021.

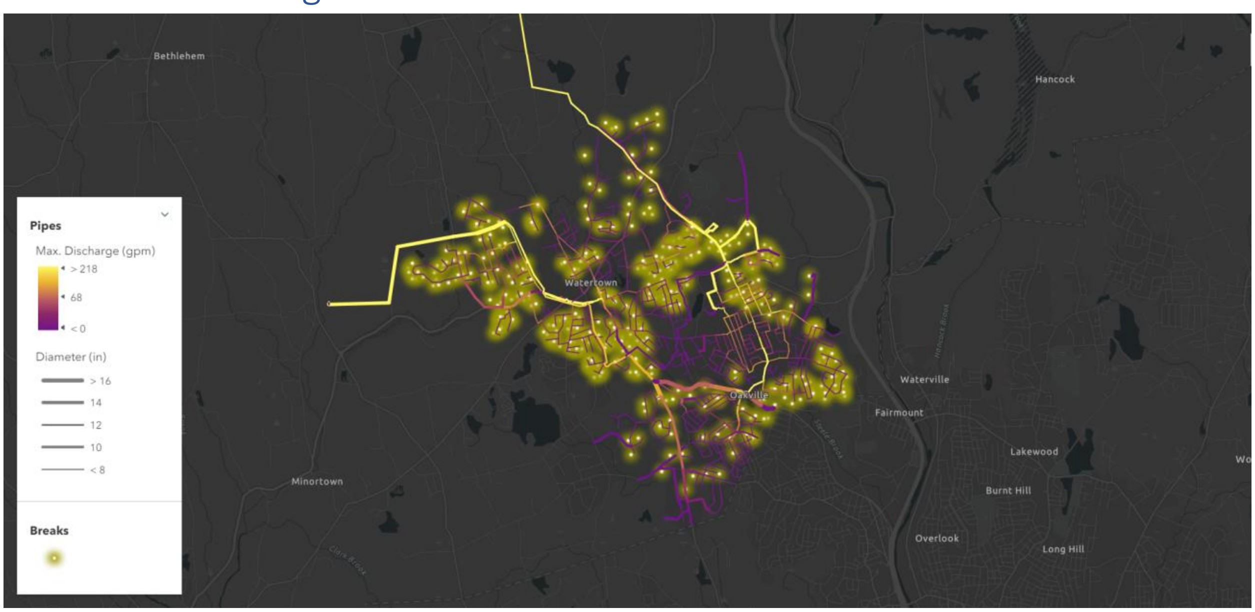



*Map 7 Pipe-Break Map, Watertown, CT*

## Geospatial Correlation

The sequence of maps below shows the geospatial correlation between different feature attributes and the reported number of breaks.

## Breaks ⇆ Discharge

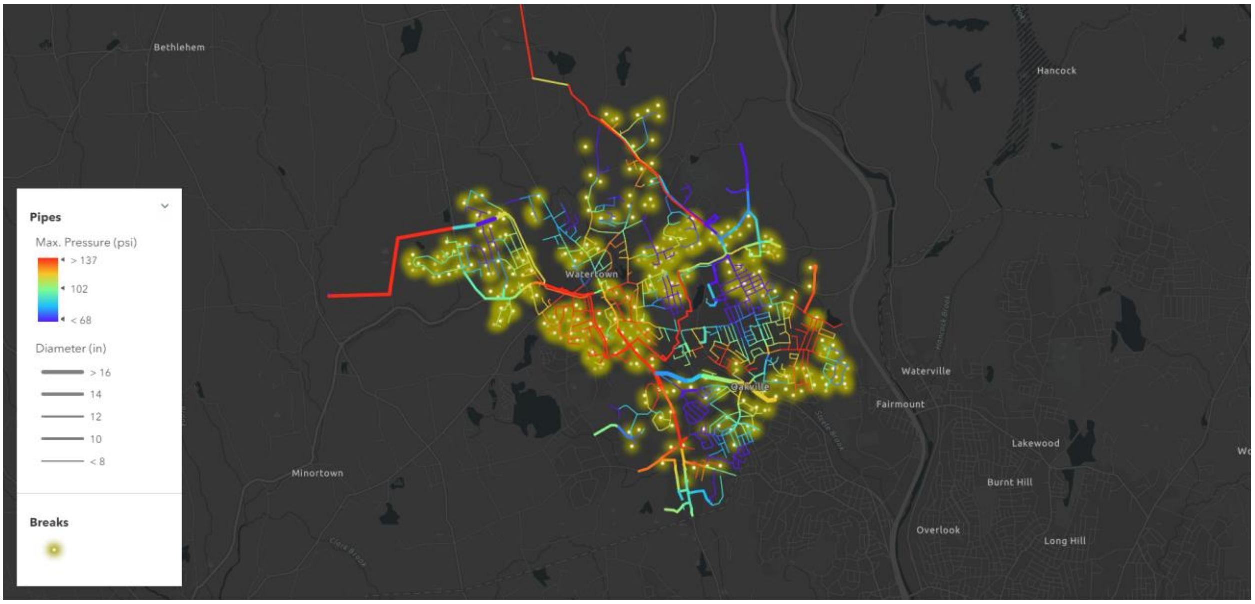



*Map 8 Discharge-Break Map, Watertown, CT*

This map shows that there is a strong "negative" correlation between discharge and number of breaks reported. That means, a greater number of breaks were reported on pipes with lower discharges.

These are mainly the tertiary distribution pipes of smaller diameters to which the customer meters are laterally connected to.

## Breaks ⇆ Pressure




*Map 9 Pressure-Break Map, Watertown, CT*

This map shows that there is a strong "positive" correlation between pressure and number of breaks on pipes. That means higher the pressure on smaller diameter pipes (insight from previous map) a greater number of breaks there will be.

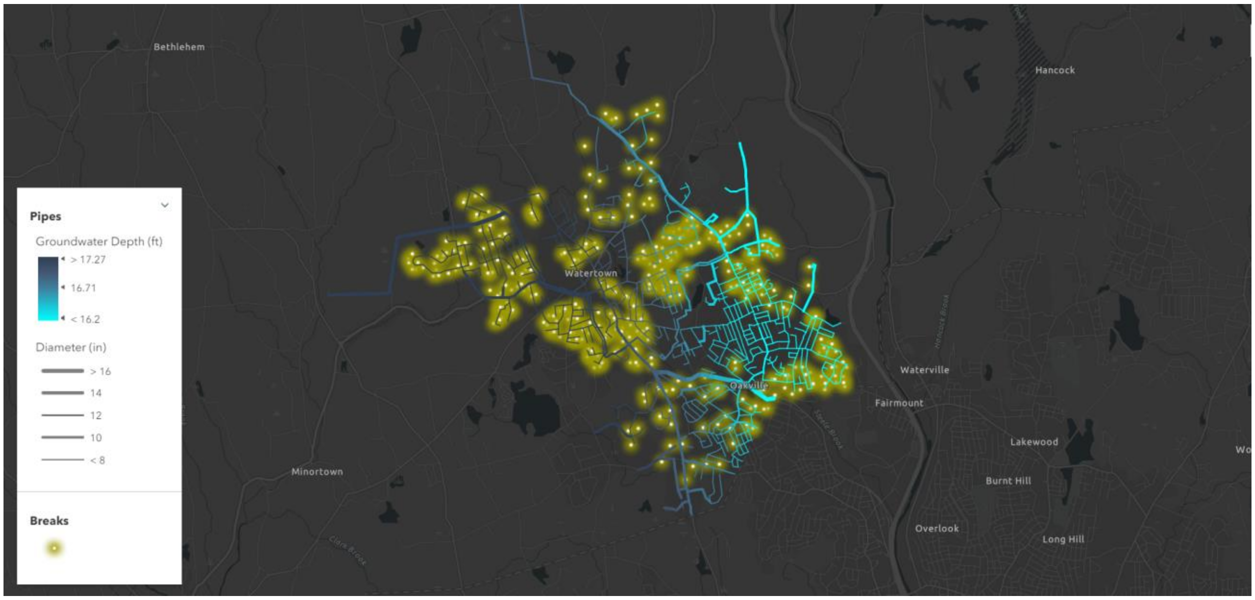
This explains why most of the utilities worldwide focus on pressure management strategies to reduce breakages and ruptures that eventually increase the Non-Revenue Water (NRW).

## Breaks ⇆ Bed-Soil pH


*Map 10 Soil pH-Break Map, Watertown, CT*

This map shows a strong "negative" correlation between bed-soil pH and number of pipe breaks. This indicates that a greater number of breaks were observed on pipes that were laid in soils with lower pH values (approx. less than pH of 5.3).

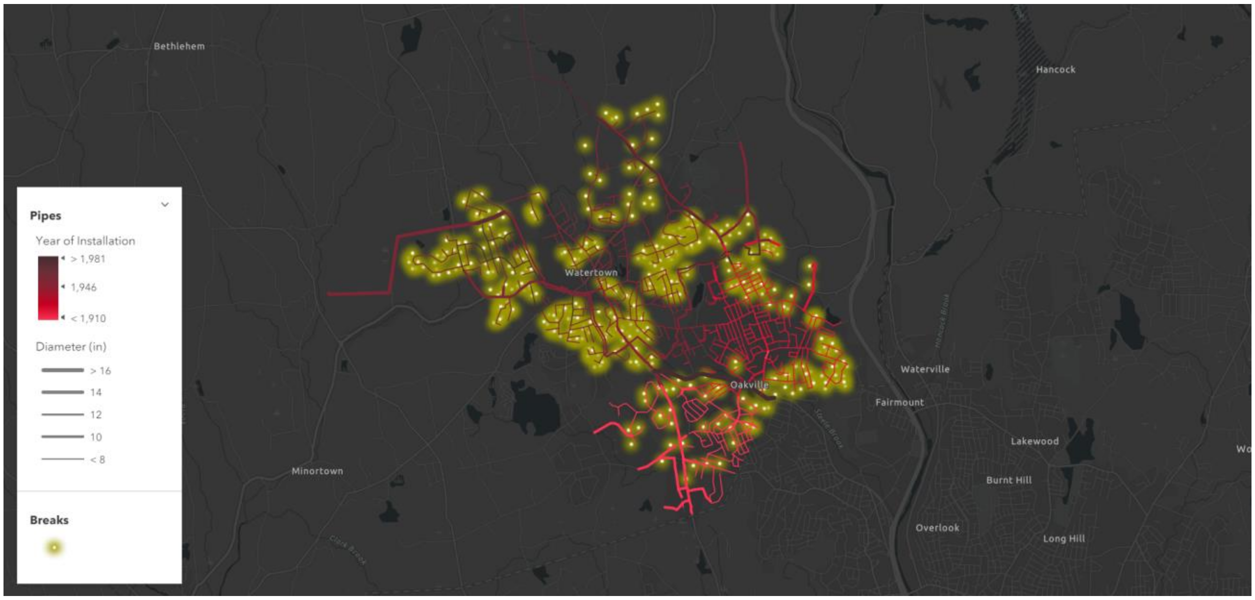
## Breaks ⇆ Groundwater Depth




*Map 11 Groundwater-Break Map, Watertown, CT*

Ironically, map shows that there is no visible correlation between number of breaks and depth of groundwater table.

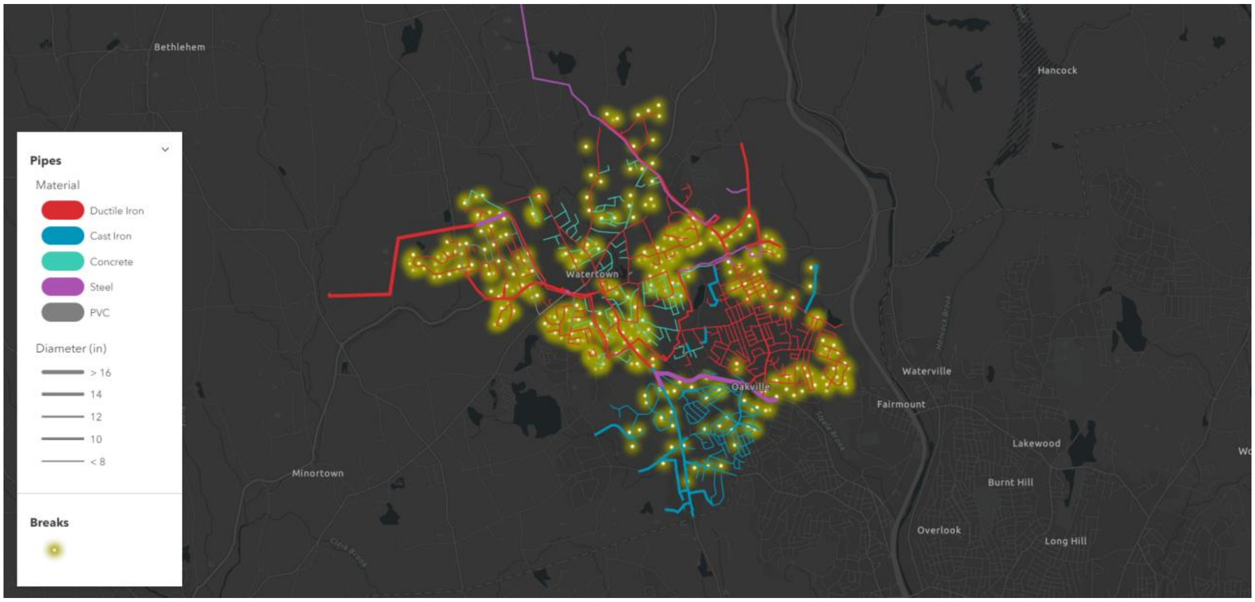
## Breaks ⇆ Year of Installation




*Map 12 Year of Installation - Break Map, Watertown, CT*

This map shows that pipes installed between 1946 and 1981 have a greater number of breaks reported as compared to the pipes that were installed before 1946.

## Breaks ⇆ Material




*Map 13 Material-Break Map, Watertown, CT*

This map shows that there is a strong correlation between pipe material and breaks. Majority of the pipe breaks occurred on Ductile Iron pipes.

## Pipe Inspection Priority

K-Means Clustering algorithm is applied to the data for classification of pipes into three number of clusters (0, 1, 2; shown below) based diameter, material, length, installation year, bed-soil pH, groundwater depth, pressure, and discharge.

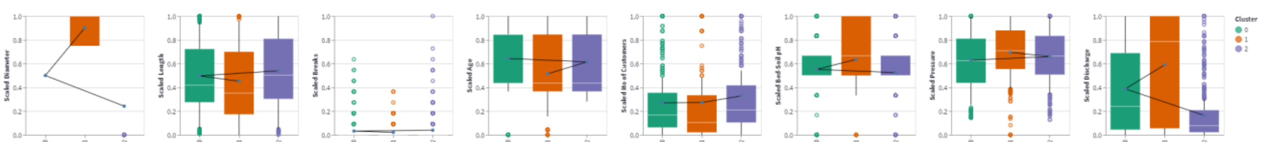
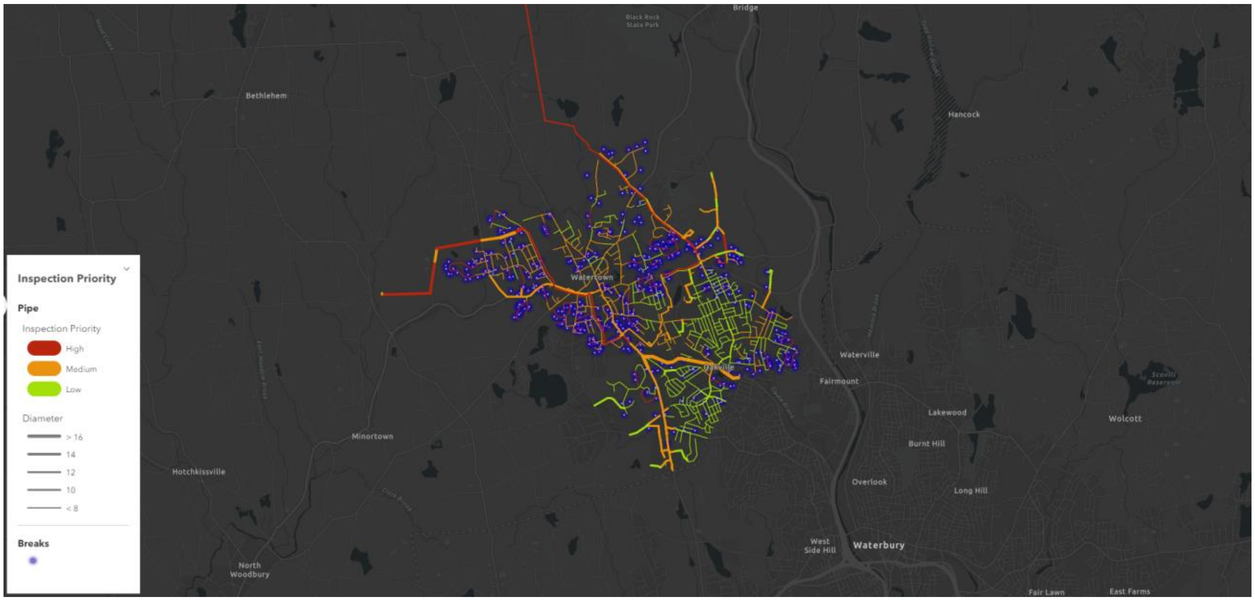


*Chart 9 Pipe Clusters, Watertown, CT*

Upon careful observation of the above figure, cluster 2 has comparatively lowest diameters, highest length, highest breaks, medium age, highest number of customers, lowest bed-soil pH, medium pressures, and lowest discharges. Therefore, should these pipes fail, there would be largest system wide impact affecting the overall resilience of the system.




*Map 14 Pipe Inspection Priority Map, Watertown, CT*

Thus, from inspection priority perspective it can be derived that, pipes of cluster 2 (Inspection Priority: High) tops the list followed by pipes in cluster 0 (Inspection Priority: Medium) and then cluster 1 (Inspection Priority: Low).

## Conclusion

In conclusion, it is seen that this geo-statistical analysis helps in precisely prioritizing the pipeline inspection schedules. The intersection of roles of GIS and Machine Learning result in much wiser insight from the data model and are encouraged to be explored even further. Maps with inspection priority can assist the utility to understand the overall health of pipelines with respect to other geo-hydro-physical parameters discussed above.


## Acknowledgements:

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## Sources and References:


1. Watertown Water Dataset: Bentley Systems Inc. ( www.bentley.com )
2. Connecticut's Department of Energy & Environmental Protection (DEEP): Geographic Information Systems Open Data Website ( link ): Soil Survey Geographic Database (SSURGO) Soils
3. U.S. Geological Survey ( link ): Groundwater table data, Connecticut
4. Drinking Water: Infrastructure Report Card, ASCE ( link )