Analyzing a Water Line's Risk of Freezing Attributed to Slope Aspect and Soil Texture using Frozen Water Services and the Chi-Square Goodness-of-Fit Test

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Keywords: GIS (Geographic Information Systems), Soil, Frozen, Water Main, Frozen Water Service, Frost, Soil Texture, Slope Aspect

Abstract

An abnormally cold winter in 2013-2014 led to a record number of frozen water services in the city of Minnetonka. In March of 2014, a water main 8 feet beneath the surface froze. Using soil data from the Natural Resources Conservation Service Web Soil Survey and resources available to the city, a preventative maintenance plan was implemented comparing slope aspect and soil type to similar conditions found at the frozen water main. The aim of this project is to identify whether the criteria used in the preventative maintenance plan can be disproved with soil and slope data at reported frozen water service locations throughout the city. The chi-square goodness-of-fit test was employed to determine whether slope aspect and soil texture found at frozen water services are equally distributed. Additionally, soils were subdivided based on texture in the city and above water mains. Results show slope aspect to be equally distributed among frozen water services and identify soil textures at higher risk for freezing. These will be used to identify whether the city used soil and slope data adequately in an effort to prevent additional water mains from freezing.

Introduction

If you were to ask a child living in a city where their water comes from you may get the response, 'from the faucet.' In reality, there are hundreds of miles of pipe buried underground supplying water to homes and businesses throughout the nation. Losing water service can be an unexpected and inconvenience disruption. Water is normally shut off to repair a water valve, hydrant, main, or service line. A frozen service line is another reason for loss of service. In most cases, a water meter is not insulated and needs to be thawed from inside a residence or building. In other cases, the water service line freezes underground as frost surrounds it and turns the line to ice.

Frozen Ground, Soil Textures, and Water Utility Construction

Water freezes at or below 32 degrees Fahrenheit, depending on pressure. When water turns to ice, it expands. As the thickness of the ice increases, it acts as an insulator to the water below. Ice forms the same way in pores between soils. Soils at varying layers have varying temperatures. As frost penetrates deeper, the soil and water in the ground freeze. Layers on the top insulate those below until they freeze. In the same way, snow insulates soil as it accumulates over the winter. The more snow above the ground, the more

Reitter, Matthew T. 2014. Analyzing a Water Line's Risk of Freezing Attributed to Slope Aspect and Soil Texture using Frozen Water Services and the Chi-Square Goodness-of-Fit Test. Volume 16, Papers in Resource Analysis, 12 pp. Saint Mary's University of Minnesota. Minneapolis, MN. Retrieved (date) http://www.gis.smumn.edu

insulation it provides. Roadways are cleared of snow to provide safe travel and do not have the same insulation provided by snow allowing frost to penetrate deeper. Differing soil textures will have differing frost depths in similar conditions. Fine grained soils, like clay and silt, are more tightly packed. They are more resistant to freezing than looser soils, like sand and gravel, with more space for water to permeate (NSIDC, 2008).

Figure 1 displays the soil textural triangle with soil textures and particles making up the 12 categories. The presence of finer particles in soil, like clay and silt, make it more resistant to freezing. Coarser particles in soil make it more susceptible to freezing. Therefore, soils towards the bottom left corner of the triangle are more likely to freeze than those with characteristics found towards the top and right corners of the triangle.

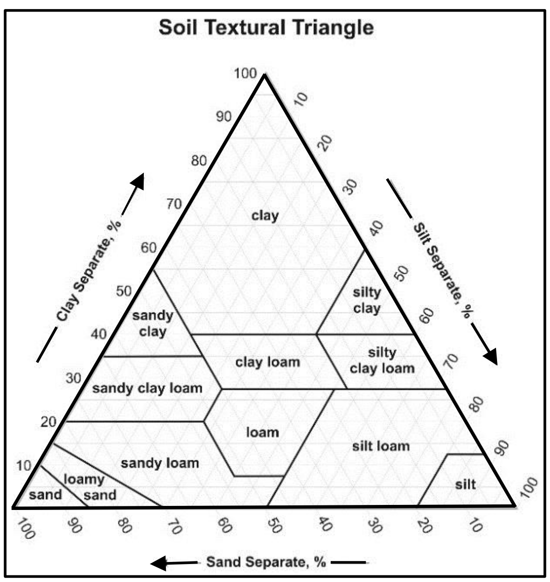

Figure 1. Soil textural triangle used to define a soil texture in the field based on the presence of clay, sand, and silt (Image Source: Thien, 1979).

Water mains and services are buried at a minimum depth, usually 7 – 8 feet, to prevent frost from damaging or freezing pipes. In most cases, sewer and water are constructed beneath roads within a right-of-way. This, among other reasons, makes it easier for a utility to locate valves used to shut off water lines and reduce damage to private property when making repairs (CEAM, 2013). Coincidentally, burying utilities beneath roads means frost is more likely to reach and impact pipes due to the lack of insulation at the surface.

City of Minnetonka Frozen Water Services Winter of 2013-2014

The winter of 2013-2014 was one of the coldest on record. There were 53 days with temperatures at or below zero. It tied as the 5th highest number of days at or below zero and was the 9th coldest winter on record in the Twin Cities metro area (MN DNR, 2014). Under normal circumstances, snow insulates the ground and prevents frost from penetrating deep into soils. Snow removal on streets, driveways, and sidewalks enables frost to penetrate deeper into the ground than areas insulated with snow cover. As a result of the cold temperatures and routine snow removal from pavement, there was an unusually high number frozen water services reported in the city from January to March of 2014.

On March 13th, the city began a repair on a water main suspected to be frozen. They noted it was on a north facing slope with sandy soil. After cutting into the pipe they discovered the water in several feet of the pipe was frozen solid, blocking the flow of water. In an effort to prevent additional frozen water mains, the city identified hydrants on dead end water mains to be fit with garden hose adaptors providing a continuous flow of water. To identify water mains at risk, a topology was created on the existing water distribution network identifying dangles (a line with an endpoint not covered by the endpoint of another line). Dangles provided locations of dead end water mains. Hydrants on dead ends were selected, buffered, and intersected with northern slope aspects (north, northwest, or northeast) and soil data matching the soil complex Malardi-Hawick, found at the frozen water main. This resulted in approximately 60 hydrants reviewed by city staff and narrowed down to 28 to be fitted with a garden hose adaptor used to continuously flow the water main. One of the first six hydrants to be fitted with a hose adaptor was found to be out of service because the water main was frozen. This led the city to believe the selection criteria was adequate for a preventative maintenance plan.

Hypothesis

This project explores the relationship between slope aspect and soil texture attributes in an attempt to identify common attributes found at frozen water services. These attributes will be compared to the selection criteria created by the city of Minnetonka to prevent dead end water mains from freezing. Results will be used to determine whether or not to reject the null hypothesis (H_0):

H_0: Water services with north facing slopes (north, northwest, or northeast) belonging to the soil complex Malardi-Hawick are more likely to have a frozen water service.

If disproved, the alternate hypothesis (H_A) will be concluded to be true:

H_A: Water services with north facing slopes belonging to the soil complex Malardi-Hawick are not more likely to have a frozen water service.

Since the Malrdi-Hawick complex is not a soil texture, it will be matched to the closest soil texture and reviewed for completeness in the sample to determine whether or not to reject H_0.

Methods

GIS Data Collection, Processing, and Reclassifying

Required data included frozen water service locations, soil type, slope aspect, and the city's water utility distribution dataset. The Hennepin County Soil Survey data was collected from the United States Department of Agriculture Natural Resources Conservation Service Web Soil Survey website. Remaining data was collected from the city of Minnetonka's enterprise GIS database and asset management database. Soil map units where broken further by complex name. The complex name was derived by removing slope percentages at the end of the map unit name.

Water service lines were digitized from the water main to the residence based on as-built drawings and service tie cards. The intersection of the water main, service line, slope aspect, and soil texture provided point attribute data with the assumption the surface was uninsulated, meaning snow had been removed from the surface. Finally, a summary of soil texture and slope aspect were created for total distances above water mains and areas within the city. These serve as the population to compare expected soil texture and slope aspect found at frozen water services. These processes were completed using ArcMap 10.1.

The soil map unit name did not provide a meaningful value for the analysis and needed to be reclassified into one of the 12 categories in the soil textural triangle: sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Categories above are ranked in order of coarsest to finest particle size. Figure 2 illustrates an example of a soil component from the Hennepin County Soil Survey. Soil map unit names were reclassified into soil textures through a manual process. The extent of the component was reviewed for all components found in the city. The percent of each component determined how much weight was placed on the typical profile. Values from the typical profile were reviewed and soil textures with the largest profile were selected to represent the map unit. Table 1 provides the component and typical profile for the Malard-Hawick Complex, 6 – 12 percent slopes. For this map unit, the two components with the greatest weight were Malardi and Hawick.

L2C—Malardi-Hawick complex, 6 to 12 percent slopes

Component Description

Malardi and similar soils

Extent: 60 to 90 percent of the unit
Geomorphic setting: Hills on stream terraces; hills on outwash plains
Position on the landform: Backslopes and summits
Slope range: 6 to 12 percent
Texture of the surface layer: Sandy loam
Depth to restrictive feature: Very deep (more than 60 inches)
Drainage class: Somewhat excessively drained
Parent material: Outwash
Flooding: None
Depth to wet soil moisture status: More than 6.7 feet all year
Ponding: None
Available water capacity to a depth of 60 inches: 4.3 inches
Content of organic matter in the upper 10 inches: 3 percent
Typical profile:
Ap—0 to 10 inches; sandy loam
Bt—10 to 15 inches; sandy loam
2Bt—15 to 29 inches; loamy coarse sand
2C—29 to 80 inches; gravelly sand

Figure 2. Sample of a map unit component description from the Hennepin County Soil Survey. Extent and typical profile were used to reclassify each map unit to soil texture (Image source: Steffen, 2001).

Reviewing these typical profiles led to the conclusion the soil texture was generally sand based on the profile from 29-80 inches of gravelly sand in the Malardi component (60-90%) and 11 to 80 inches of gravelly coarse sand in the Hawick component (10-30%). The most abundant soil texture by profile depth or cumulative depth in each of the components carried the most weight. As the extent of each component changes throughout a map unit, the results of the reclassification may contain errors. Additionally, components with multiple soil textures may not accurately represent the entire profile of the soil complex as a complexes profile and components vary from place to place.

Table 1. Example of the Malardi-Hawick complex 6 – 12 percent slopes used to classify soil textures for each map unit name and soil complex. For this soil map unit, sand was selected as the soil texture based on the profile from 29-80 inches of gravelly sand in the Malardi component (60-90%) and 11 to 80 inches of gravelly coarse sand in the Hawick component (10-30%).

Component Description Malardi-Hawick complex 6 – 12 percent slopes			
Component	% of the unit	Typical Profile	
		Inches	Soil Texture
Malardi	60 - 90	0 to 10	sandy loam
		10 to 15	sandy loam
		15 to 29	loamy coarse sand
		29 to 80	gravelly sand
Hawick	10 – 30	0 to 7	sandy loam
		7 to 11	gravelly loamy coarse sand
		11 to 80	gravelly coarse sand
Tomall	5 – 15	0 to 33	loam
		33 to 42	sandy loam
		42 to 47	loamy coarse sand
		47 to 80	gravelly loamy coarse sand
Crowfork	0 - 10	0 to 11	loamy sand
		11 to 20	loamy fine sand
		20 to 76	loamy sand
		76 to 80	sand

Three categories in the reclassification were not in the soil textural triangle. These include: unknown, muck, and water. Muck and water were not found at any of the frozen water services and did not receive any special attention. The unknown category consisted of several soil components descriptions referencing disturbances on the landscape making the soil difficult to classify. Some of examples include pits, mining, and urban development. These units require onsite investigation to determine soil properties and for the purposes of this project were classified as unknown.

Chi-Square Statistical Analysis

Using the chi-square goodness-of-fit test, frequencies of soil texture and slope aspect for points where frozen water services intersected water mains were tested to determine if they are equally distributed amongst frozen water services. The chi-square was also subdivided to test a predicted ratio from the distribution of soil textures present in the city as well as soil textures found above water mains. To perform these tests the chi-square statistic was calculated using the equation:

$$x^2 = \sum_{i=1}^{k} \frac{(f_i - f_e)^2}{f_e} \qquad v = k - 1$$

"Where f_i is the frequency observed in category i, f_e is the frequency expected in category i if H_0 is true, and the summation is performed over all k categories of data." Degrees of freedom (v) are equal to the number of categories minus one. A confidence level of 5 percent was used on the summation of the chi-square statistic (x^2) to determine the critical value of the chi-square distribution. If the critical value is greater than x^2, H_0 will not be rejected. If the critical value is less than x^2, H_0 will be rejected (Zar, 2010). These tests were completed using a combination of Microsoft Excel and IBM SPSS Statistics.

Results

Chi-Squared Goodness-of-Fit Statistical Analysis – Slope Aspect

To test if slope aspect at the surface of a frozen water service was equally distributed in the sample of frozen water services, the chi-square goodness-of-fit was used to test slope aspect frequency. The hypothesis for this test was:

H_0: Slope aspect is equally distributed among frozen water services.
H_A: Slope aspect is not equally distributed among frozen water services.

Table 2 shows expected frequency, f_e, for eight categories equal to 22.25, x^2 equal to 10.3146, and a critical value of 14.067.

Table 2. Chi-square testing equal distribution of slope aspect for all frozen water services.

Chi Square Test for Slope Aspect			
H_0 : Slope aspect is equally distributed among frozen water services H_A: Slope aspect is not equally distributed among frozen water services			
Slope Aspect	$\boldsymbol{f_i}$	$\boldsymbol{f_e}$	$\boldsymbol{x^2}$
North	28	22.25	1.4860
West	28	22.25	1.4860
Northwest	26	22.25	0.6320
Northeast	25	22.25	0.3399
Southwest	23	22.25	0.0253
South	20	22.25	0.2275
East	14	22.25	3.0590
Southeast	14	22.25	3.0590
n = 178			**10.3147**
v = 8 - 1 = 7 $\quad x^2_{0.05,7} = 14.067$ $\boldsymbol{x^2 = 10.315} < 14.067$ Therefore do not reject H_0			

Since x^2 is less than the critical value, H_0 is not rejected. Slope aspect for the frozen water services may have come from an equal distribution of slope aspects according to the goodness-of-fit test.

Referencing the soil textural triangle sand, sandy loam, and loamy sand have the largest particle size which are more likely to freeze than particles on the other two corners of the triangle. Using these factors, the next test looks to identify whether soil textures have an equal distribution of slope aspect or whether frozen water services in other soil textures have an equal distribution of slope aspect. First, chi-square was tested against all frozen water services except those found in sand. The expected frequency, f_e, was 13.5, x^2 was 6.3704 with a critical value of 14.067, suggesting slopes were equally distributed for soil textures not equal to sand. This was performed two more times with similar results (table 3) for soil textures removing sand and loamy sand and removing sand, loamy sand, and sandy loam. H_0, was not rejected for all three cases suggesting slope aspect was equally distributed for soil textures not equal to sand, loamy sand, and sandy loam.

Table 3. Chi-square testing equal distribution of slope aspect excluding soil textures sand, loamy sand, and sandy loam.

Soil Textures	x^2	Critical Value $x^2_{0.05,7}$	H_0 Slope aspect is equally distributed
1	6.3704	14.067	Do Not Reject
2	8.8696	14.067	Do Not Reject
3	6.9697	14.067	Do Not Reject
1. Not Sand			
2. Not Sand or Loamy Sand			
3. Not Sand, Loamy Sand, or Sandy Loam			

The process was reversed to look only at soil textures sand, loamy sand, and sandy loam. For sand as well as sand and loamy sand, the hypothesis was not rejected at the 5 percent confidence level (table 4). When the confidence level was decreased to 10 percent, they were found to be statistically significant though only by a small margin. However the hypothesis, slope aspect is equally distributed for soil textures, was not rejected.

Table 4. Chi-square testing equal distribution of slope aspect for water services with soil textures sand, loamy sand, and sandy loam.

Soil Textures	x^2	Critical Value $x^2_{0.05,7}$	Critical Value $x^2_{0.10,7}$	H_0 Slope aspect is equally distributed $x^2_{0.05,7}$
1	**12.0571**	14.067	**12.017**	Do Not Reject
2	**12.9767**	14.067	**12.017**	Do Not Reject
3	11.0000	14.067	12.017	Do Not Reject
1. Only Sand				
2. Only Sand or Loamy Sand				
3. Only Sand, Loamy Sand, or Sandy Loam				

Results for slope aspect were supported by the summary from the population of slope aspect for the city and slope aspect above water mains. Figure 3 shows percentages for area and linear distances of slope aspect in the city and over water mains respectively.

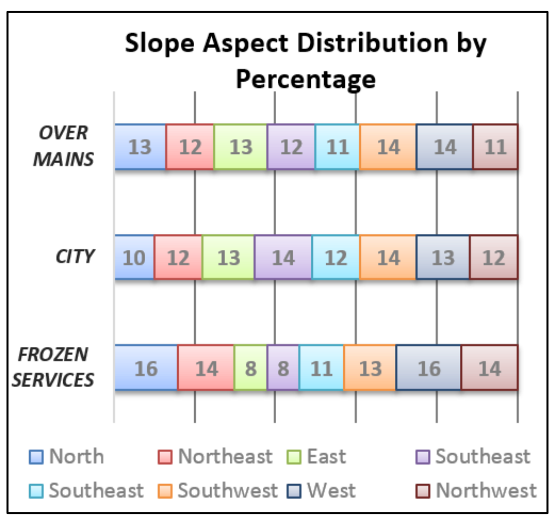

Figure 3. Slope aspect distribution by percentage over water mains, throughout the city, and for frozen water services. There are minor differences between the three groups.

Frozen services had slightly more with north, northeast, west and northwest slope aspect and slightly fewer in the east and southeast slope aspect. The differences between the values did not appear to be significant and were supported by the results of the chi-square goodness-of-fit test. Based on these findings, slope aspect was not explored in greater detail.

Chi-Squared Goodness-of-Fit Statistical Analysis – Soil Texture

Next the goodness-of-fit test was applied to soil texture with the following hypothesis:

H_0: Soil texture is equally distributed among frozen water services.
H_A: Soil texture is not equally distributed among frozen water services.

Table 5 shows expected frequency, f_e for six categories equal to 29.6667, x^2 equal to 108.1798, and a critical value of 11.070. Because x^2 is greater than the critical value H_0 was rejected, suggesting soil texture was not equally distributed among frozen water services. Soil texture was then subdivided to match areas of soil texture in the city and the lengths of soil texture above water mains based on the soil texture making up the top percentages for each sample.

Table 5. Chi-square testing equal distribution of soil texture for all frozen water services.

Chi Square for Soil Texture			
H_0 : Soil texture is equally distributed among frozen water services H_A: Soil texture is not equally distributed among frozen water services			
Soil Texture	f_i	f_e	x^2
Sand	70	29.6667	54.8352
Loam	49	29.6667	12.5993
Sandy Loam	26	29.6667	0.4532
Loamy Sand	16	29.6667	6.2959
Unknown	16	29.6667	6.2959
Clay Loam	1	29.6667	27.7004
n = 178			**108.1798**
v = 6 - 1 = 5 $x^2_{0.05,5} = 11.070$ $x^2 = \mathbf{108.1798} > 11.070$ Therefore reject H_0			

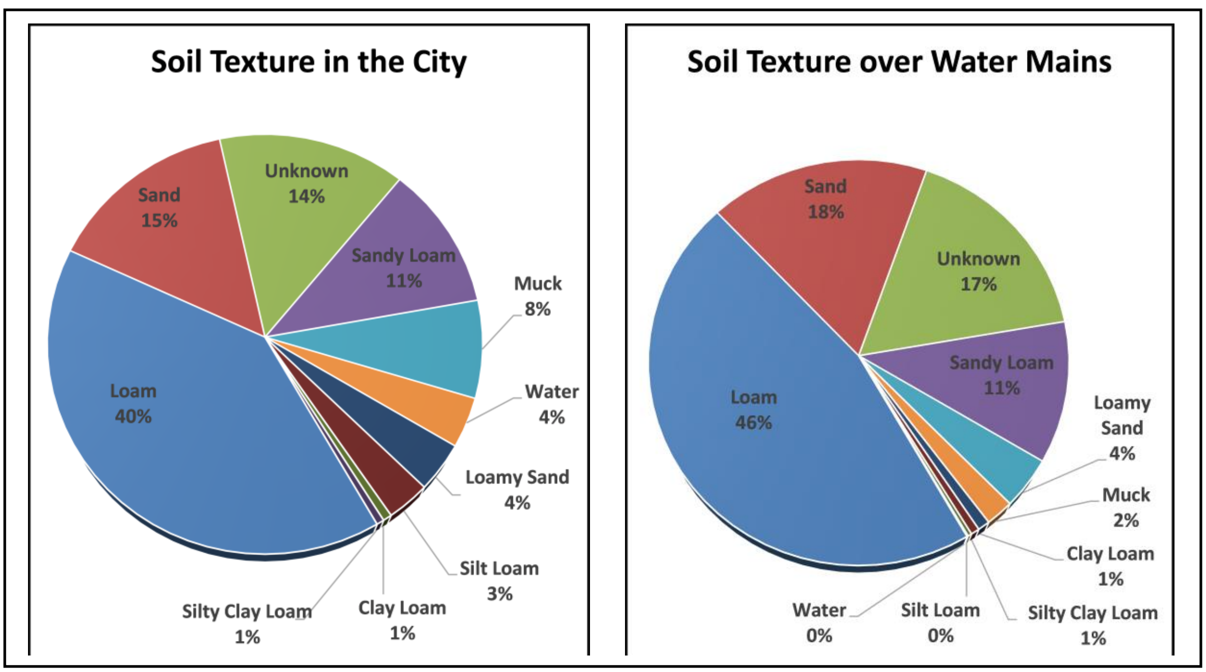

Figure 4. Break down of soil texture by percentage for areas in the city and soil textures over water mains.

Figure 4 displays the breakdown of all soil texture in the city by percentage. Categories from the frozen water services were subdivided into categories of soil texture in the city to determine if the ratio from frozen water services fit the ratio of soil texture in the city. For this test, results from soil texture in the city were estimated to be a ratio of 4:2:1:1 for loam, sand, unknown, and sandy loam. The ratio was determined by dividing each soil texture percentage by 10 and rounding to the nearest whole number. This was tested for goodness-of-fit by subdividing frozen water services for the above ratio. Results from the test are displayed in Table 6.

Table 6. Subdividing frozen water services to match ratio of soil texture found in the city.

Subdividing Soil Texture based on ratio of Soil Texture in the City				
H_0 : Frozen water services came from a population with a ratio of 4:2:1:1 for soil textures loam, sand, unknown, and sandy loam H_A: Frozen water services did not come from a population with a ratio of 4:2:1:1 for soil textures loam, sand, unknown, and sandy loam				
Soil Texture	f_i	f_e	***Ratio***	x^2
Loam	49	80.5	4	12.3261
Sand	70	40.25	2	21.9891
Unknown	16	20.125	1	0.8455
Sandy Loam	26	20.125	1	1.7151
n = 161				**36.8758**
v = 4 - 1 = 3		$x^2_{0.05,3}$ = 7.815		
x^2 = **36.8758** > 7.815				
Therefore reject H_0				

Expected observations were 80.5, 40.25, 20.125, and 20.125 for loam, sand, unknown, and sandy loam respectively. These values were determined by dividing the total number of observations by the sum of the ratio, eight. They were multiplied by the ratio to predict expected values. For this test, H_0 was rejected because x^2, 36.8758 was greater than the critical value of 7.815 suggesting frozen water services did not have the same ratio as soil texture found in the city.

The ratio of soil texture over water mains was tested similarly. Figure 4 displays the breakdown of soil texture over water mains by percentage. A ratio of 5:2:2:1 for soil textures loam, sand, unknown, and sandy loam was hypothesized and tested against results from frozen water services. The ratio was determined by dividing soil texture percentages by 10 and rounding to the nearest whole number. The expected observations for these soil textures was 80.5, 32.2, 32.2, and 16.1 respectively. These values were determined by dividing the total number of observations by the sum of the ratio, ten. This value was multiplied by the ratio to predict the expected value. H_0 was rejected because x^2, 70.9379 was greater than the critical value of 7.815 suggesting frozen water services did not have the same ratio as soil texture above water mains. Results can be viewed in Table 7.

Table 7. Subdividing frozen water services to match the ratio of soil texture over water mains.

Subdividing Soil Texture based on ratio of Soil Texture over Water Mains				
H_0 : Frozen water services came from a population with a ratio of 5:2:2:1 for soil textures loam, sand, unknown, and sandy loam H_A: Frozen water services did not come from a population with a ratio of 5:2:2:1 for soil textures loam, sand, unknown, and sandy loam				
Soil Texture	f_i	f_e	***Ratio***	x^2
Loam	49	80.5	5	12.3261
Sand	70	32.2	2	44.3739
Unknown	16	32.2	2	8.1503
Sandy Loam	26	16.1	1	6.0876
n = 161				**70.9379**
v = 4 - 1 = 3		$x^2_{0.05,3}$ = 7.815		
x^2 = **70.9379** > 7.815				
Therefore reject H_0				

A reexamination of x^2 in table 5 reveals sand, loam, loamy sand, unknown, and clay loam to provide significant contributions to x^2 as they are all more than half the critical value. The next step was to subdivide values into expected ratios based on the chi-statistic values for each soil texture. A ratio of 8:6:3:2:2 was used for the soil textures sand, loam, sandy loam, loamy sand, and unknown based on the number of observations for each texture divided by the total number of observations times 100. These values were multiplied by 2 and divided by ten to create the ratio in order to distinguish between loamy sand, unknown, and clay loam. Results of the subdivision of chi-square are displayed in Table 8.

Table 8. Subdividing soil texture to match results from goodness-of-fit test for equal distribution.

Subdividing Soil Texture based on ratio from Goodness-of-Fit Test				
H_0: Frozen water services came from a population with a ratio of 8:6:3:2:2 for soil textures sand, loam, sandy loam, loamy sand, and unknown. H_A: Frozen water services did not come from a population with a ratio of 8:6:3:2:2 for soil textures sand, loam, sandy loam, loamy sand, and unknown.				
Soil Texture	f_i	f_e	***Ratio***	x^2
Sand	70	67.43	8	0.0981
Loam	49	50.57	6	0.0488
Sandy Loam	26	25.29	3	0.0202
Loamy Sand	16	16.86	2	0.0436
Unknown	16	16.86	2	0.0436
n = 177				**0.2542**
v = 5 - 1 = 4		$x^2_{0.05,4} = 9.488$		
$\mathbf{x^2 = 0.2542} < 9.488$				
Therefore do not reject H_0				

The expected frequency, f_e, for the five categories was calculated as the total observations, n=177, divided by the sum of the ratios, 21 and multiplied by each ratio value. H_0 was not rejected because x^2, 0.2542 was less than the critical value of 9.488 suggesting a frozen water service's soil texture may have come from a population with a distribution of 8:6:3:2:2 for sand, loam, sandy loam, loamy sand, and unknown.

Map of Frozen Services over Soil Texture

The 82 map unit names were reclassified to match one of the 12 soil textural triangle soil classes from the soil survey along with three others: water, muck, and unknown. This data was overlaid with locations of the frozen water services and cartographically dispersed to better display clusters in Figure 5. Soil textures found on the bottom left corner of the soil textural triangle (sand, loamy sand, and sandy loam) appear to coincide with frozen water service clusters. Unknown soil types cluster near commercial developments, schools, highways, and interstate ramps as well as historic gravel pits. The map serves as a starting point to investigate outliers for given soil texture or identify common variables for the clusters on the western edge in loam or the cluster on the northeastern corner in an unknown soil texture.

Discussion

The first goodness-of-fit test found slope aspect from frozen water services to be equally distributed. The results of x^2 did not reject the hypotheses suggesting slope aspect was equally distributed in the sample data and may not be a factor contributing to a frozen water service. The goodness-of-fit test for soil texture revealed they were not equally distributed. Further tests subdividing the ratio of soil texture in the city and above water mains suggests the sample did not come from either population. Instead, results point to the conclusion sand, loam, sandy loam, loamy sand, and unknown textures were more likely to freeze with a ratio of 8:6:3:2:2. These results were partially supported by the first three soil textures found on the bottom left corner of the soil textural triangle. The amount of loam found in the city may be attributed to its greater frequency among frozen water services compared to soil textures with higher potential for freezing such as sandy loam and loamy sand. Figure 5 also displays spatial relationships of soil textures and provides a point of beginning to investigate spatial outliers for additional variables. These results may be used to build a freeze potential risk model for water services or mains based solely on soil texture.

Further Research

When slope aspect was tested for goodness-of-fit for categories more likely to freeze (sand – sandy loam) at the 10% confidence level, H_0 was rejected by a small margin. One explanation may be the slope aspect used for the project was generalized to match the slope aspect used by the city in the original analysis. There may be benefit in creating and using a slope aspect at a larger scale and assign

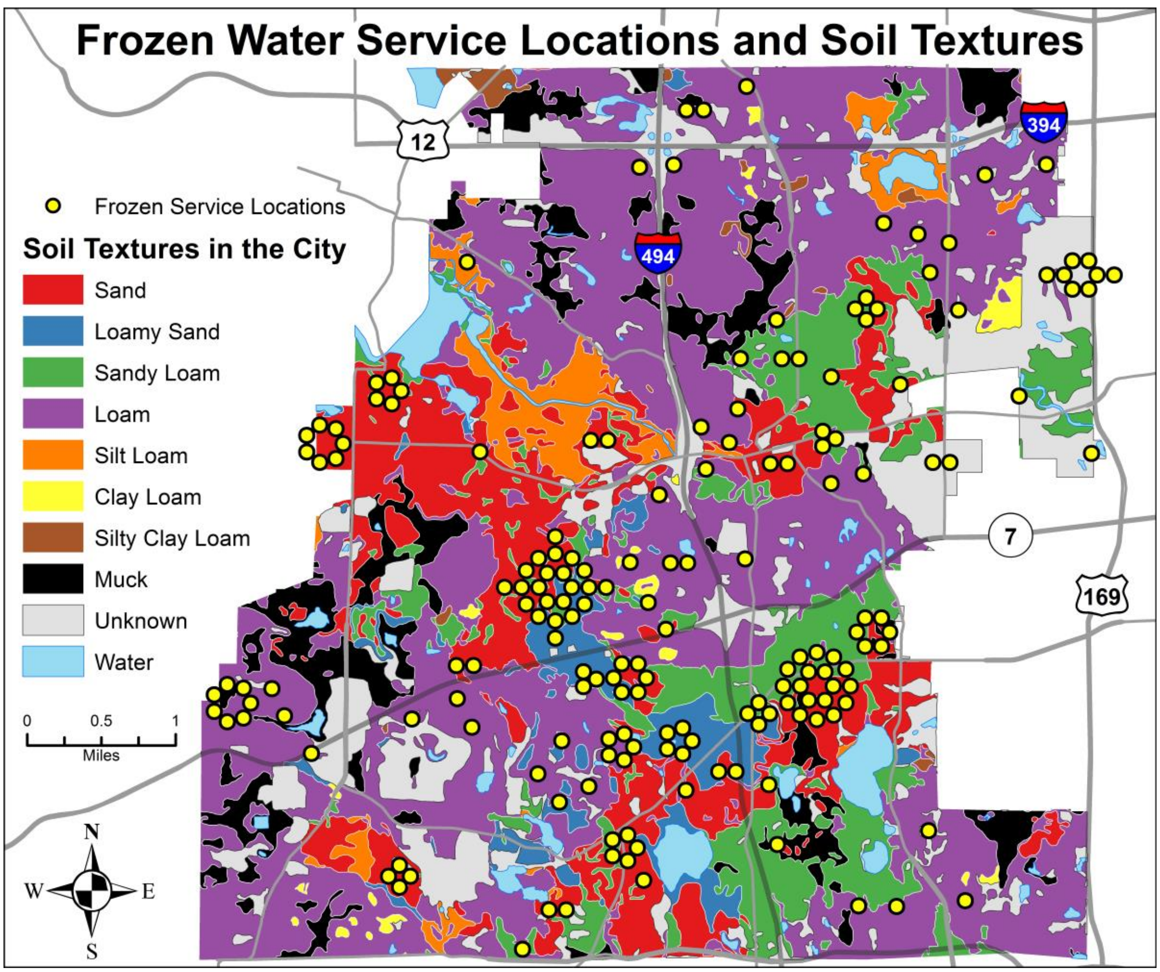

Figure 5. Soil texture map from reclassified soil map unit names including locations of frozen water services. Locations of frozen water services have been dispersed into rings to display clusters. There appears to be clusters of frozen services around coarser soil textures sand, loamy sand, & sandy loam. Unknown soil types appear near the Interstate 394 and 494 corridors and near commercialized locations among others.

slope percentages for each surface. The presence of large trees providing shade throughout the day may be another factor to be examined relating to slope aspect and the amount of radiant heat available at the surface. Additionally, soil texture classifications were estimated based on the sum of the whole. It may be beneficial for a qualified soil scientist to assign a value to each soil texture and calculate the soil texture's risk for freezing based on the profiles making up each individual component. A reclassification of soil textures and slope aspect might yield slightly different or more conclusive results at a higher confidence level.

There are several factors that can contribute to a frozen water service that have not been addressed in this project. For this project, it was assumed all water services were at or below a minimum depth of 7.5 feet and the water service froze at the water main. In reality, the service may freeze at any point along the water line and the soil texture at the location may differ from the soil texture found at the main. Additionally, the presence of large underground storm sewers or gas mains may allow sub-zero temperatures to begin freezing the ground several feet below the surface. This variable may make a service in a soil texture at lower risk more susceptible to freezing than it might normally be.

Conclusions

The goal of this project was to determine if the city's preventative maintenance plan could be disproved or invalidated. Coincidently, the choice of soil complex Malardi-Hawaick was one of two soil complexes classified as sandy in the city and was far more ubiquitous than the other, Eden Prairie sandy loam. However, slope aspect may not have been a valid selection. Results from the goodness-of-fit test for soil textures confirmed the soil complex, Malardi-Hawick, to be a reasonable selection based on the amount of time and resources the city had to take action. The hypothesis for this project was rejected based on the results from the goodness-of-fit test. Since slope aspect was found to be equally distributed, it would have been better to only select dead end water mains in the soil complex Malardi-Hawick for the preventative maintenance plan.

Acknowledgements

I would like to thank my advisor, Mr. John Ebert as well as Dr. David McConville for their guidance and advice during this project and their encouragement throughout my learning experience at Saint Mary's University. I also owe a great debt of gratitude to my family for their love, support, and patience throughout my life and in pursuit of higher education.

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