Creating a Likelihood and Consequence Model to Analyse Rising Main Bursts

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Keywords: Geographical Information System (GIS), Risk Analysis, Spatial Analysis, Spatial Modelling, Data Interpretation, Data Visualisation.

Abstract: A model was created that analysed the likelihood and consequence of a sewage rising main bursting at any given time. Likelihood of failure was analysed through factor analysis using GIS data and historical rising main bursts data. Consequence was analysed through spatial analysis on GIS using multiple spatial joins, property density and a cost of tankering model that was created using data from GIS. This analysis created a likelihood and consequence score for each section of rising main to then create a combined overall risk score. These outputs were then used to develop a rising main planning tool in the data presentation programme Tableau to identify the high risk sites and target asset maintenance and rehab works. This paper will explain how the tool was created and the benefits of the final outputs.

1 INTRODUCTION

The waste water network is made up of various types of sewer pipes. One of these pipes is known as a rising main.

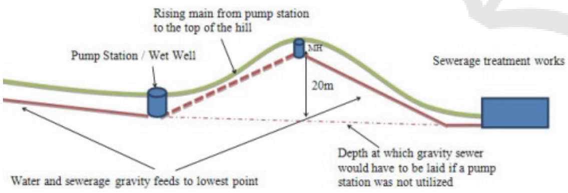

Figure 1: Rising main diagram (Sharkawi farm, 1999).

As shown from figure 1, gravity sewers take sewage from houses and connect them to a pumping station. This is then pumped up a rising main to the start of another length of gravity sewer. This process is then continued until the pipe reaches a sewage treatment works. Due to the increased pressure from the pumping station there is a risk that the rising main can burst.

Previously, 3 rising mains models have been created by the company:

- 2002/03 Spreadsheet Risk Model
- 2007/08 Probability of Failure x Rolling Ball model
- 20012/13 Updated Probability of Failure x Rolling Ball model

The most recent model is different to previous models because it has split the rising mains into smaller sections and observed other burst factors such as rising mains located under rail/roads, 'soft' land or 'urban' land to attempt to identify additional factors that could affect the likelihood of bursting. It also improves the consequence aspect of the risk model whereas previous models had less robust consequence models.

A sewage rising main bursting can cause a serious issue for the company. This is due to the cost of repair, cost of tankering and pollution and flooding fines. To address this issue investment is made into regular replacement of rising main pipes. To identify which areas need the greatest investment a model was created to identify the areas of rising main that pose the largest risk. Company datasets relating to the sewer network were regularly used throughout this project.

Spivey, R. and Valappil, S.
Creating a Likelihood and Consequence Model to Analyse Rising Main Bursts.
DOI: 10.5220/0006669601670172
In *Proceedings of the 4th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2018)*, pages 167-172
ISBN: 978-989-758-294-3

2 CREATING THE MODEL

2.1 Likelihood

To begin creating this model, historical burst data was obtained which contained a list of every recorded burst since 1994.

Burst data is updated regularly every time new bursts are recorded. Bursts are recorded by an eastings and northings coordinate system in a simple Excel spreadsheet. This is then plotted into GIS using the display X/Y feature. When each new burst point is plotted it is then saved as a shape file then spatially joined to sections of rising main. Based on the distance between the new burst points and the sections of rising main we can work out which section the new bursts is referring to.

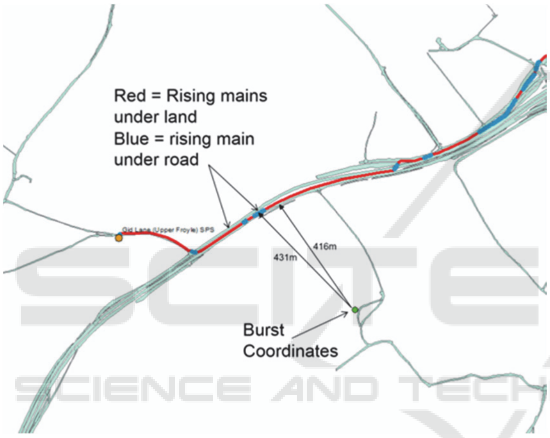

Figure 2: Diagram of burst identification issue.

As shown from figure 2, allocating a burst to a specific section of rising can prove difficult at times as burst coordinates do not always match up exactly with sections of rising main. This can lead to a burst not being added to the model as the data is not specific enough be sure which section of rising main has burst. However, this is only the case for a small percentage of the burst data.

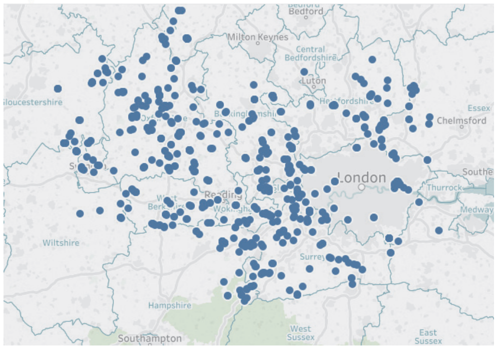

Figure 3: Burst map (Thames Water Utilities Ltd, 2017).

Figure 3 above shows the map of bursts from 1994 up until 2017 across the Thames Valley area.

Once we know what section of rising main that burst we can add this to the overall burst database which the model is based upon. This data enabled us to identify certain factors that contributed to a rising main bursting. These factors included:

1. Material
2. Age
3. Ground type
4. Diameter
5. Soil corrosivity

Information regarding material, age, ground type and diameter were accessible through the company records however soil corrosivity was identified from using the soil map from Cranfield University to show which areas of land are most corrosive.

Below shows the breakdowns of each factor based on the length in kilometres. Using historical burst data each category was given a burst rate of number of bursts per kilometre of pipe.

Material

- Plastic
- Iron
- Concrete
- Other
- Unknown

Diameter

- Small (225mm and below)
- Medium (226-600mm)
- Large (above 600m)
- Unknown

Age

- 1900 or earlier
- 1901-1959
- 1960 or later
- Unknown

Ground Type

- Traffic (rail or road)
- Soft land
- Urban land

Soil Corrosivity

- 0 (Very low corrosivity)
- 1 (Low corrosivity)
- 2 (Low-medium corrosivity)
- 3 (Medium corrosivity)
- 4 (High corrosivity)
- 6 (Very high corrosivity)

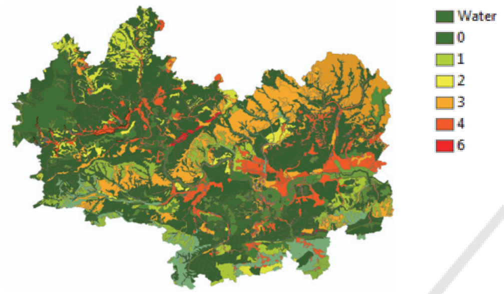

Figure 4: Soil corrosivity map (Cranfield University, 2017).

Figure 4 shows the areas of land that are most corrosive within the Thames Valley area. For the purposes of the model water was assumed to have a soil corrosivity of 0. GIS was used to create this map by adding soil data to GIS then colour coding based on soil corrosivity score.

Each category of burst was then given a burst rate score then matched up with the sections of rising main associated with each category. Some information for the rising mains is unknown due to a lack of information in some of the company records. Any category that had an unknown factor was taken out of final outputs as it is not an accurate measure. The category with the greatest bursts per km was other material, medium diameter, 1900 or earlier, soft ground type and soil corrosivity 6.

Category1	Bursts per KM per Year
1900 or earlier, medium diameter, ground type Soft, Other	0.075617683
1960 or later, small diameter, ground type Urban, Concrete	0.060026748
1960 or later, small diameter, ground type Traffic (rail/road), Concrete	0.047223450
1960 or later, medium diameter, ground type Traffic (rail/road), Concre..	0.040766417
1960 or later, small diameter, ground type Traffic (rail/road), Iron	0.040068794

Figure 5: Tableau table of burst rate categories.

The table above shows the top categories of bursts per km.

2.2 Consequence

Consequence was then added to the model through 3 factors including:

1. Distance to specific locations
2. Property density
3. Tankering cost

Specific locations were identified by the consequence to the business and society of flooding. Distances considered include:

- Hospitals
- Schools
- Roads (Motorways, A-Roads and B-Roads)
- Water
- Sites of Special Scientific Interest (SSSI's)
- Bio habitats
- Underground Stations
- Railways

The distances to each of these points of interest were analysed through spatial joins in GIS by combining shape files of rising main locations and spatial locations of all the areas listed above. Shape files of all these points of interest were created by obtaining easting and northing positions for each location and importing this data into GIS from Excel spreadsheets using these easting and northing positions.

Figure 6: Rising main map (Thames Water Utilities Ltd, 2017).

Figure 6 shows a map of rising mains and their location across the Thames Valley area. To analyse distances to various points of interest other spatial data is added to the map then spatially joined from the rising main data. For example Figure 7 shows the rising main data combined with motorway data across the Thames Valley area.

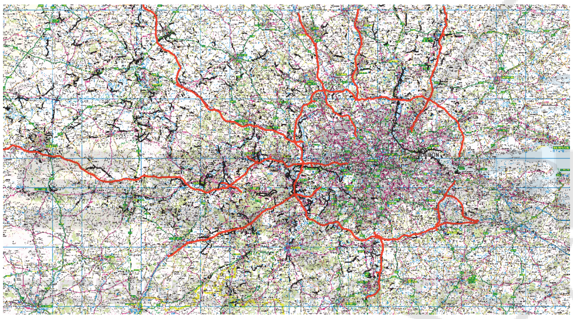

Figure 7: Map of rising mains and motorways (Thames Water Utilities Ltd, 2017).

After the distance to each of these points of interest had been analysed for each section of rising main they were combined into an overall distance ratio by taking an average of all the distances. This allows the model to take into account sections of rising main that are close to more than one point of interest rather than just how close it is to an individual location.

After spatial distance data had been analysed we then looked at the property density that each section of rising main falls into. To add this we combined a square kilometre grid across the whole of the Thames Valley area with property data. This allowed us to create a count of properties per each square kilometre. Rising main location data was then added to this grid count to analyse which property grid square each section of rising main was in. This allowed us to allocate a number of properties per section of rising main.

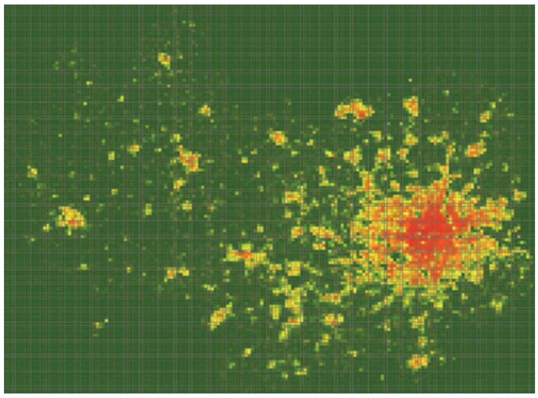

Figure 8: Property density heat map.

Figure 8 shows a heat map of property density across the Thames Valley area. The colour scale ranges from green to red with red being highest number of properties. As expected the highest number of properties are located in and around the London area.

After property density had been considered we added tankering cost to the consequence model. Tankering is the process of providing tankers to the location of the burst in order for the waste water to fill into the tankers rather than flood across the burst area.

In order to add this, a separate model was created to analyse tankering cost. This model was created by combining 5 separate factors to create a tankering cost per section of rising main. These factors include:

1. Distance from pumping stations to tanker depots
2. Distance from pumping stations to sewage treatment works
3. Flow data in the rising mains
4. Diameter of rising main
5. Length of rising main

Flow data, diameter and length were accessible through company records however the distances were created by spatially joining locations of pumping stations to tanker depots and sewage treatment works in GIS.

At this point in the model intervention data was added to the outputs. Intervention data is data regarding what lengths of rising main have been recently replaced. This is then removed from the outputs as it is assumed that if the pipe has recently been replaced then it reduces the risk of bursting again.

The 3 consequence factors were then combined to create an overall consequence of failure score for each section of rising main. Likelihood and consequence scores were rated between 0 and 10 with 10 being the highest and 0 the lowest. By taking the average of these scores an overall risk score was created in order to rank each section of rising main on its risk priority.

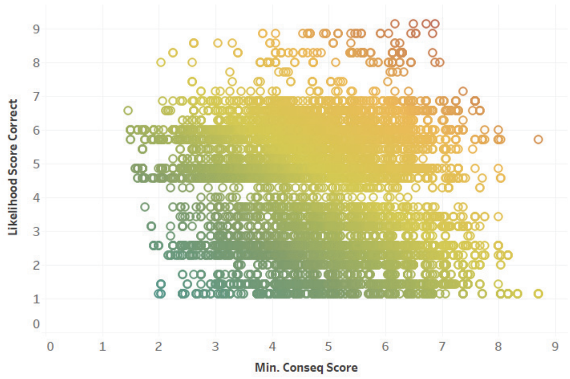

Figure 9: Likelihood consequence plot.

Figure 9 shows the overall plot of the likelihood and consequence scores for each section of rising main. To identify the top sites that need attention the top 10 sections of rising main with the highest risk score were observed.

When observing the highest risk sections we observed sites that have a consequence score over 5.5 and a likelihood score of over 5. The sum of the length of rising main that were incorporated in this category came to 7km. Hence, if 7km of rising main were replaced it would remove all of the high risk sections from the model. 7km may seem like a large amount of pipe however the overall length of rising main that was incorporated in the model is 2109km. Therefore, only 0.33% falls in the high risk area of this risk plot.

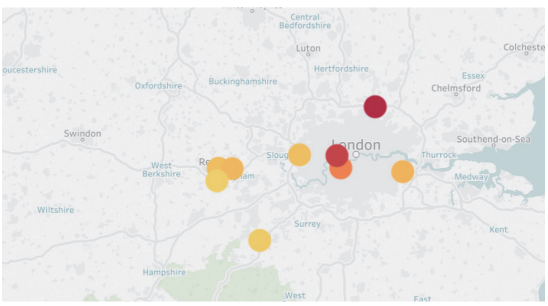

Figure 10: Map of high risk sites.

Figure 10 shows the locations of the sites that based on the model created have the greatest risk score.

3 PLANNING TOOL

After this model had been created it was then adapted into a user friendly planning tool. This was created within the data visualisation programme Tableau. Tableau was chosen for this planning tool as it allows spatial and other data files to be combined into one, user-friendly, interactive dashboard. The planning tool contains data relating to each section of rising main. For example, the region that the rising main falls within and the contact details of the operational staff member responsible for the rising main section. The region was identified through spatially joining the rising main file to the operational regional boundary file in GIS. This is very useful as if there is an issue with a certain section of rising main the member of staff responsible can be quickly contacted in order to resolve this issue.

The planning tool will be used by many members of staff across the business. Therefore, the planning tool will need to be user friendly in order for staff members from a non-analytical background to use it effectively. This is achieved through easy access information dashboards that can be filtered through drop down menus relevant to the maps or graphs. Updating the model is also extremely user friendly. New bursts data is added to the original burst spreadsheet and Tableau will update all of the models and dashboards based on this new data. This allows for the model to stay updated therefore reducing the need for a new model to be created when the current data set is outdated. The planning tool will be distributed across the business in the form of a packaged workbook file in Tableau reader. This allows access for all staff across the business without them being able to edit the original file. Due to this only one Tableau server license is needed to share this tool with the rest of the business.

4 CONCLUSIONS

To conclude, this paper has shown how GIS spatial analysis and modelling is used by the water industry to analyse the impact of a rising main bursting. This model will provide a direction for rising main replacement investment. It allows the business to efficiently replace the minimum amount of rising main pipe based on how detrimental a burst would be in that section, therefore maximising the operational cost saving.

Without the use of the tools within GIS this model would have been a lot more difficult to create. Simple tools on GIS such as spatial joining were influential in the making of this model. The outputs from this project include a list of all rising main sections with its associated risk score and a user friendly planning tool to be used across the business.

This model has areas for improvement using further applications in GIS and other programmes. The model could be improved by adding in lidar data to the consequence modelling in order to analyse the heights of all the sites listed within the distance factor of consequence. This will give a better insight into the flow of the flooding out of a burst rising main. For example, if a school is downhill from a rising main burst it is more likely to flood towards the school compared to if the school was higher than the burst. This model will be further improved by adding in a more detailed likelihood model based on further analysis that looks to identify which likelihood factors are greater linked to a burst. This is likely to be modelled within the statistical programme R using logistical regression.

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