Prioritising sewerage maintenance using inferred sewer age: a case study for Edinburgh

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ABSTRACT

The reported research project focuses on using a database which contains details of customer contacts and CCTV data for a key Scottish catchment to construct a GIS based sewer condition model. Given the nature of the asset registry, a key research challenge was estimating the age of individual lengths of pipe. Within this context, asset age was inferred using the estimated age of surface developments—this involved overlaying the network in a GIS with historical digital maps. The paper illustrates that inferred asset age can reliably be used to highlight assets which are more likely to fail.

Key words | asset management, blockage, collapse, flooding, GIS, sewer condition, sewer failure

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INTRODUCTION

In the UK, sewerage provision regulators categorise all sewerage derived flooding as being one of two types: those due to hydraulic overloading and those attributed to all other causes. Although the media tends to focus on hydraulic overloading problems (i.e. flooding caused by a lack of capacity and/or excessive rainfall), 84% of sewerage derived flooding incidents (>30,000 per year) in the UK fall into the latter of these categories and >90% of these are due to blockages. The remainder of the failures being due to collapses and plant failures (Arthur *et al.* 2009).

As part of a research project focused on using serviceability as a key performance indicator to prioritise sewerage asset maintenance (Arthur & Crow 2007; Arthur *et al.* 2008), Scottish Water supplied the project with a database which contains details of 162,000 anonymised customer contacts (asset failures) for the whole of Scotland and CCTV inspection data for key Scottish catchments. This data forms the basis of this feasibility study aimed at understanding the challenges associated with predicting failure likelihood using asset condition data.

At the outset, it was recognised that a substantial part of the proposed research would involve constructing a GIS based sewer condition model using the CCTV and complaints data. Given the nature of Scottish Water's asset registry at the time, a key research challenge in this was estimating the age of individual lengths of pipe. It is proposed that asset age will be inferred using the estimated age of surface developments–this will involve overlaying the network in a GIS with digitised historic catchment development maps available from the National Library of Scotland.

Once the condition model has been constructed, a correlation between asset failure rate and condition will be investigated. A feasibility study is required at this stage as;

1. there is uncertainty regarding the quality of data supplied by Scottish Water;
2. the process proposed for inferring catchment age involves some uncertainty; and
3. the extent to which failures are linked to anthropogenic factors is unclear.

The ultimate aim of the project is to augment a technique to enable asset managers to determine where undertaking jetting and other remedial actions is most viable and therefore enable them to proactively manage maintenance expenditure (Arthur *et al.* 2008). The focus is

doi: 10.2166/wst.2010.176

to produce a technique which can be deployed with little or no additional data collection beyond that which is already available to sewerage service providers.

METHOD

The key Scottish Water datasets and dated historic maps of Edinburgh (1450 to 1957) are the basis for the analysis in GIS. The maps were geo-referenced using recent Edinburgh data. The chronological growth of the city was then determined using the growth between different editions–termed "growth areas". Once the historical growth areas are established, the anonymised customer complaints and the CCTV-survey data were geographically analysed against the growth areas and statistical patterns determined.

Using this data, the growth of the City was analysed using two different sets of maps:

1. The first set was a thematic map published in 1919 that showed the growth of the City of Edinburgh since medieval times (Figure 1). Geo-referencing the map was difficult since folding and opening the original map has distorted it to a significant degree.
2. The maps of 1925, 1940 and 1957 are good quality OS maps which are well preserved and hence geo-referencing them was considerably easier than with the map of 1919. In all areas, the three more recent maps show a good fit with existing infrastructure data.

Digitised maps are by nature distorted, no matter how good the handling of the maps and the scanners are. Therefore, geo-referencing and digitising using scanned maps can only be an approximation of where the exact locations of objects are. However, the accuracy is considered sufficient for a preliminary study to show the potential of the proposed approach. As an example, Figure 2 shows the scale of the mismatch between the thematic map of 1919, the 1923 OS map and the most recent vector data of the road layout around in the New Town of Edinburgh. In some areas, the match of the three layers is good, in some areas the discrepancies between the maps and the vector data can be easily noted.

Once digitising of the 1919 map was completed, the three more accurate OS maps were loaded and geo-referenced.

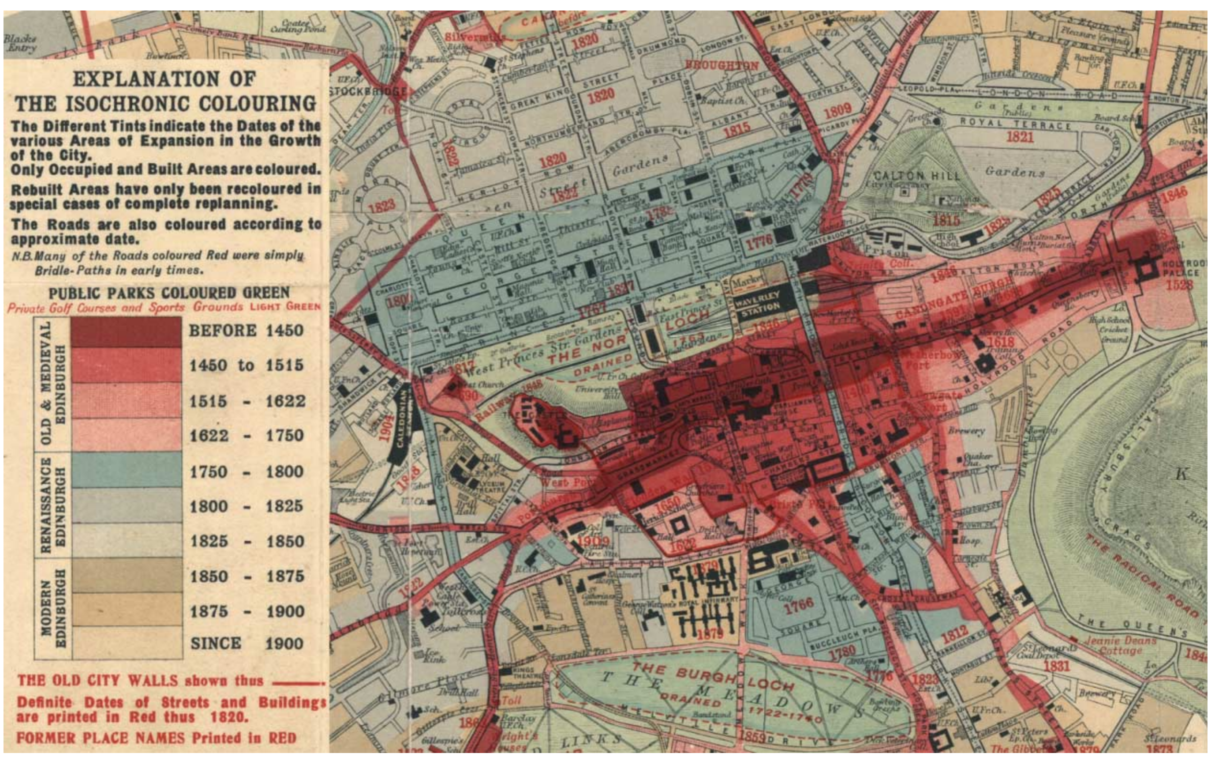


Figure 1 | An example area from the "Chronological Map of Edinburgh Showing Expansion of the City from Earliest Times to the Present"—1450–1919 (1919). Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from http://www.iwaponline.com/wst

Figure 2 | Match between 1919, 1925 and recent data.

The growth areas where then successively added to the previously digitised areas. Particularly notable is how little Edinburgh grew between the 1925 and the 1940 edition. A possible explanation is the fact that the 1940 edition was a war edition and thus little incentive existed to upgrade existing widely available maps. Furthermore, the great depression of 1928/9 to 1939 may also have contributed.

The more recent OS maps covered a larger area than the thematic growth map of 1919. Thus the digitised growth areas based on the OS maps outwith the boundary of the 1919 map may be inaccurate regarding their pre 1925 growth. The growth areas and the historic growth map extent are shown in Figure 3.

Sewer grades

The concept of sewer grades was first introduced in the Sewer Rehabilitation Manual (latest print edition–WRc 2000). The idea is to give a sewer an overall grade of how good (or bad) its condition is. The grades range from 1 to 5, the higher the number the worse the state of the sewer. Figure 4 shows the sewer grades.

In a second step, the anonymous customer complaints in the different growth areas were identified.

However, it is important to note that not all customer complaints are relevant regarding potential sewer failures. In total there were 5,062 complaints for Edinburgh which related to 812 kilometres of network for the period from April 2003 to July 2006. The overwhelming majority (91%) of complaints concerned “sewer flooding” and “surcharging”

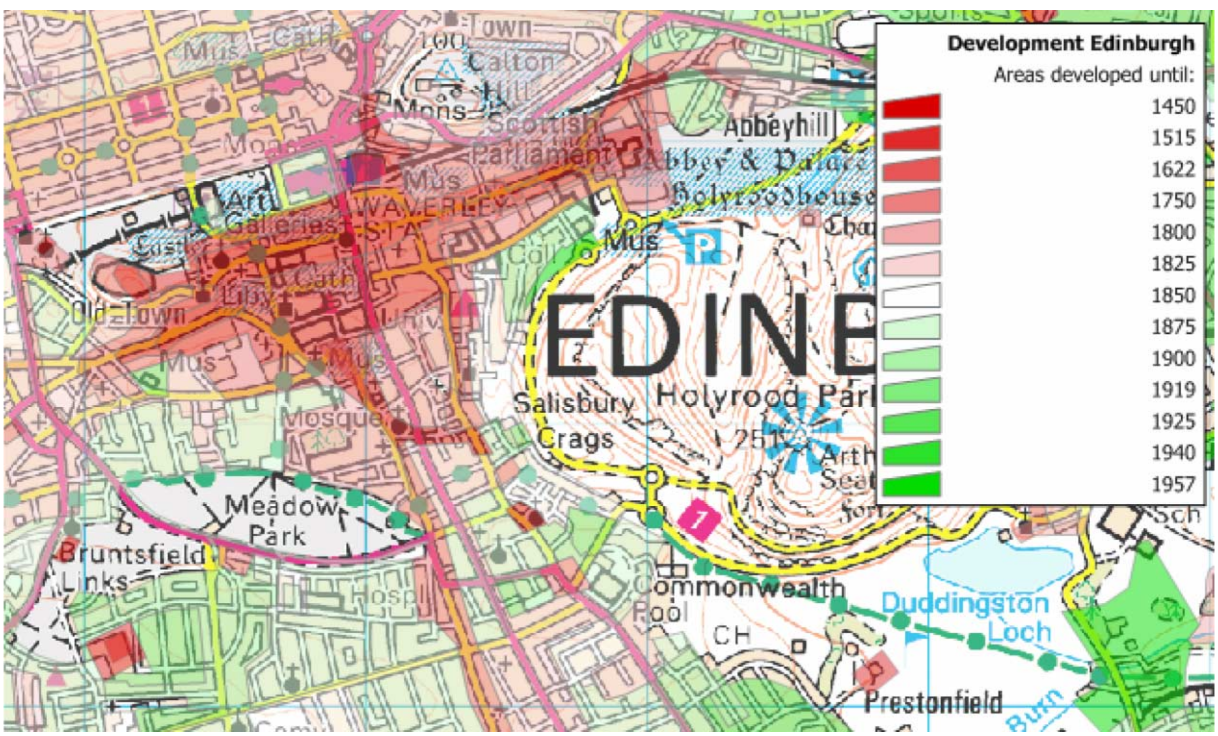


Figure 3 | Growth Areas of Edinburgh. Subscribers to the online version of *Water Science and Technology* can access the colour version of this figure from http://www.iwaponline.com/wst

Figure 4 | Example of Sewer Grade Mapping.

(as categorised by the operator on site)—these were the main focus of the project.

Research undertaken by the US Environmental Protection Agency in 1999 (EPA 1999) reported that the average expected number of complaints per mile of pipework per year was 4 (2.48/km). In the catchment studied in this work, there was found to be an average of 1.92 complaints per kilometre per year. While there may be cultural or management differences between the two populations, similarities between these performance data were found to be statistically significant (at the 5% level) and this was used as a basis to conclude that the catchment was not atypical. This conclusion was supported by data presented in the Sewerage Rehabilitation Manual (WRc 2000) which estimates the UK average blockage rate as being 0.1–2/km per year and other UK studies (Osborne 2003; Ashley *et al.* 2004; Arthur *et al.* 2008) have reported blockage rates of 0.2–0.62/km per year.

To determine whether the sewers in older areas are in a worse state than in more recently developed areas, the lengths of sewers of the different grades were set against the total length of sewers within a growth area. It is expected that the percentage of grade 5 sewers is higher in older areas than in newer ones. Table 1 summarises the lengths of the sewers that were surveyed and graded within the 1919 extent; the vast majority is grade 1, which is unproblematic.

Table 1 | Distribution of the sewer grades by inferred age

Grade	Graded length (m)	1850 Length (m)	1875 Length (m)	1900 Length (m)	1919 Length (m)	1925 Length (m)	1957 Length (m)
Grade 1	81,450	26,985	12,189	12,450	7,859	15,742	6,225
Grade 2	17,958	3,322	3,064	3,420	2,539	4,072	1,542
Grade 3	9,608	1,969	1,444	1,613	1,427	1,772	1,385
Grade 4	33,688	11,020	5,112	7,361	3,275	4,763	2,157
Grade 5	4,178	1,195	720	494	732	343	695
Total	146,882	44,491	22,529	25,338	15,832	26,692	12,004

Table 2 | Number of customer complaints within 100 m of graded sewers

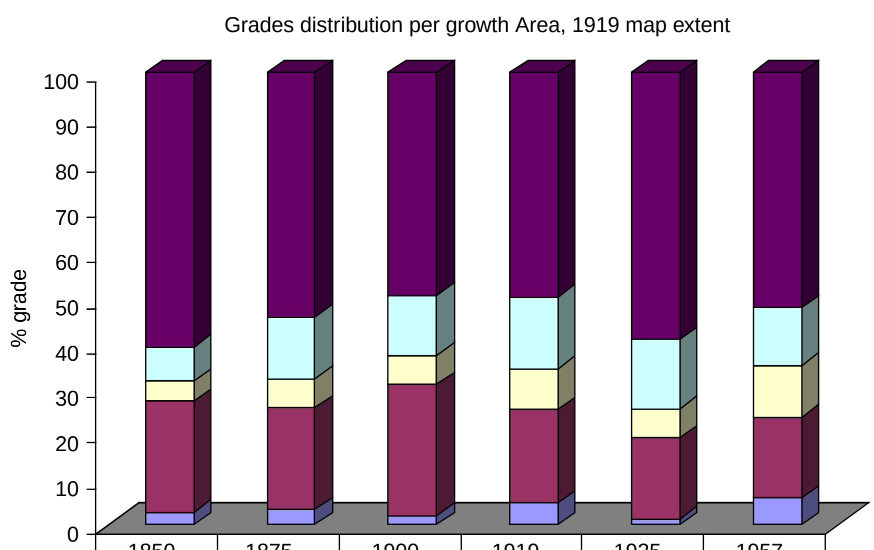
Grade	Length of all graded sewers	Number of customer complaints	% of all customer complaints (5062)	Complaints/km/Yr
5	2.8%	254	11.1%	19.72
4	22.9%	1,285	56.2%	12.37
3	6.5%	146	6.4%	4.93
2	12.2%	174	7.6%	3.14
1	55.5%	428	18.7%	1.70

However, a quarter of the sewers seem to be in the lowest condition grades (grade 4 and 5).

The 147 kilometres of surveyed and graded sewers reported in Table 2 represent only 18% of the sewer network. In other words, 82% of the network was not surveyed, graded or the records were not available. It is therefore important to note that this analysis depends strongly on the inspection strategy of Scottish Water and is therefore not as independent as the customer complaints analysis. In this case, the results should always be considered with this in mind. The sewers in areas with higher serviceability are automatically inspected more often and defects are more likely to be recorded. Furthermore, the analysis reported here takes no account of where sections of pipework have been replaced.

Although it is difficult to make comments on the sewer grades without knowing if the graded assets are representative of the wider network, an analysis of the distribution of the grades in the different growth areas is interesting. Although the grade 4 and 5 sewers peak around 1900 (Figure 5) and grade 1 sewers tend to be newer, there is actually very little variation in sewer grade (1850 average = 2.01; 1875 = 2.07; 1900 = 2.21; 1919 = 2.15; 1925 = 1.87; and, 1957 = 2.12). This observation suggests that sewers from the period between 1900 and 1919 are still “original” as their worst grades (3 to 5) seem to peak according to the data derived from the latest CCTV survey.

Table 2 shows a summary of the number of customer complaints within 100 m of sewers of various grades. Although grade 4 and 5 sewers make up 25.7% of the total length of graded sewers (which is 4.6% of all sewers!) –67.3% of customer complaints regarding sewer overflow



	1850	1875	1900	1919	1925	1957
Grade 1	60.65%	54.11%	49.14%	49.64%	58.98%	51.91%
Grade 2	7.47%	13.60%	13.50%	16.04%	15.25%	12.86%
Grade 3	4.42%	6.41%	6.37%	9.01%	6.64%	11.55%
Grade 4	24.77%	22.69%	29.05%	20.69%	17.84%	17.90%
Grade 5	2.69%	3.19%	1.95%	4.62%	1.29%	5.80%

Year developed

Figure 5 | Distribution of the Sewer Grades in the Growth Areas, 1919 Map Extent.

Table 3 | Customer complaints regarding sewer flooding/surcharging

Sewer age		Area (m^2 & %)		Complaints		Complaints per km^2
Up to	1450	238,974	0.6%	85	2.5%	355.7
1450	1515	800,825	2.0%	150	4.5%	187.3
1515	1622	396,987	1.0%	20	0.6%	50.3
1622	1750	1,727,950	4.3%	178	5.3%	103.0
1750	1800	1,063,053	2.6%	159	4.7%	149.6
1800	1825	3,416,564	8.5%	380	11.3%	111.2
1825	1850	2,852,800	7.1%	236	7.0%	82.7
1850	1875	5,389,357	13.4%	490	14.6%	90.9
1875	1900	7,121,344	17.7%	731	21.8%	102.6
1900	1919	4,298,937	10.7%	268	8.0%	62.3
1919	1925	8,134,027	20.2%	438	13.0%	53.8
1925	1940	189,716	0.5%	2	0.1%	10.5
1940	1957	4,627,622	11.5%	221	6.6%	47.8

Table 4 | Customer complaints regarding sewer backup, no overflow

Period		Area (m^2 & %)		Complaints		Complaints per km^2
Up to	1450	238,974	0.6%	22	1.7%	92.0
1450	1515	800,825	2.0%	58	4.5%	72.4
1515	1622	396,987	1.0%	17	1.3%	42.8
1622	1750	1,727,950	4.3%	61	4.7%	35.3
1750	1800	1,063,053	2.6%	70	5.4%	65.8
1800	1825	3,416,564	8.5%	159	12.3%	46.5
1825	1850	2,852,800	7.1%	93	7.2%	32.6
1850	1875	5,389,357	13.4%	217	16.8%	40.2
1875	1900	7,121,344	17.7%	261	20.3%	36.6
1900	1919	4,298,937	10.7%	90	7.0%	20.9
1919	1925	8,134,027	20.2%	166	12.9%	20.4
1925	1940	189,716	0.5%	2	0.2%	10.5
1940	1957	4,627,622	11.5%	72	5.6%	15.6

and backup fall within 100 m of these sewers. This result suggests, as would be expected that, there is a strong link between customer complaints regarding surcharge and backup and the sewer grades. This observation suggests that the methodology Scottish Water uses to highlight assets for inspection is robust.

Sewer flooding per growth area

In Table 3, the number of complaints per square kilometre and growth area are summarised and Figure 6 shows the number of complaints per square kilometre in all areas. As would be expected, the number of complaints is fewer in areas which were developed in more recent times.

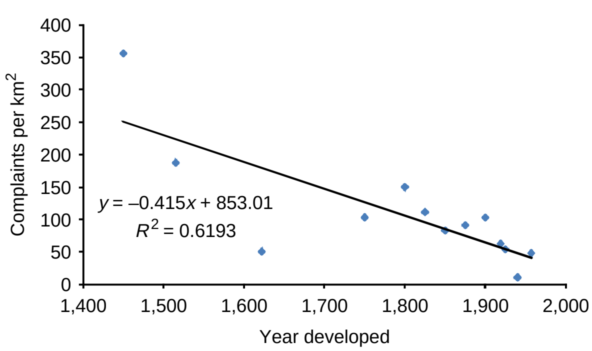


Figure 6 | Sewer Flooding/Surcharging Complaints per km^2 against Time, Map Extent.

Sewer backup, no overflow per growth area

Table 4 and Figure 7 shows the number of complaints per square kilometre in all areas. As expected, the number of complaints is fewer in areas which were developed in more recent times.

Although the results presented in Figures 6 and 7 are encouraging, displaying the growth areas before 1850 as distinct growth areas is problematic as the first sewers were not built until the mid 19th century:

> 1761 – But how can it be suffered that all manner of filth should still be thrown even into this street continually. How long shall the capital city of Scotland, yea, and the chief street of it, stink worse than a common *sewer*?

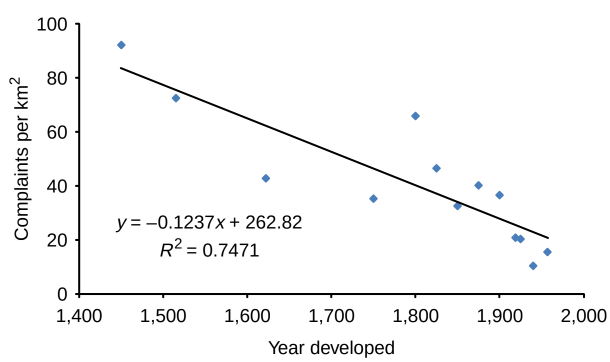


Figure 7 | Sewer Backup, No Overflow Complaints per km^2 against Time.

Table 5 | Customer complaints by inferred sewer age

Period		Area (m^2 & %)		Network (m & %)		Complaints sewer flooding/ surcharging per km	Complaints sewer backup, no overflow per km
Up to	1850	10,497,154	28.4%	201,696	24.8%	6.0	2.4
1850	1875	5,443,080	14.7%	102,042	12.6%	4.8	2.1
1875	1900	7,205,861	19.5%	145,489	17.9%	5.0	1.8
1900	1919	4,343,670	11.8%	77,485	9.5%	3.4	1.1
1919	1925	5,230,793	14.2%	170,220	21.0%	1.6	0.6
1925	1940	191,604	0.5%	1,823	0.2%	1.1	1.1
1940	1957	4,010,618	10.9%	113,495	14.0%	1.5	0.4

> 1841 – " Description of the new *Sewer* in the Valley of the Cowgate, *Edinburgh*."–By George Smith. …describes the mode of constructing the first *sewer*, which begins at the south back of the Canongate, passes along the Cowgate, and through the Grassmarket.

Based on this, in all further analysis, the growth areas before 1850 were incorporated in one growth area that was developed up to 1850 whereas all other growth areas remained distinct.

Complaints per network kilometre

Another interesting analysis is the number of complaints per network kilometre [km′] in the different chronological growth areas within the 1919 map extent. This analysis takes into account the total respective network lengths. Consider the following example: A growth area may be large, includes a short network and contains few complaints. The analysis gives a very low complaints-to-area ratio. However, if we consider the short length of the network within the area, the complaints-to-network length looks different.

Table 5 summarise the key data for the normalised customer complaints analysis. They show clearly that while some areas are larger, the total network length within them is smaller. This analysis is therefore much more accurately describing the performance of the network regarding sewer flooding or surcharging.

Figure 8 shows that the correlation between network length and customer complaints is better than the relationship between growth area and customer complaints for flooding and backing up. This is logical since it is primarily the network length that has an influence on possible sewer incidents rather than the total area within which a sewer network is placed.

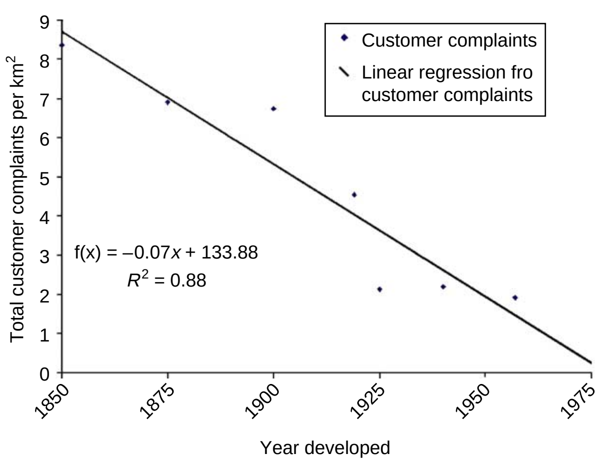


Figure 8 | Sewer Flooding/Surcharging Complaints per km from 1850 Map Extent.

CONCLUSIONS

The results show that sewers which serve older parts of the city are significantly more likely to fail. Specifically, the results presented indicate that sewers which serve parts of the city constructed in ~1850 are far more likely (>600%) to fail (or at least generate customer complaints) when compared to post-WW2 developments. Although this result may be partly due to the age of the network, it is clear that factors such as maintenance strategy, population density, urban density and network dentricity may also play a significant role. This study also shows that it is relatively easy to gain significant results with regards to the behaviour of sewer systems by analysing readily available data.

The next step for the project team must be to develop an approach which adds depth to this key result, by developing techniques which tell asset mangers which older assets are most likely to fail and, more importantly, why these assets in particular are vulnerable. As well as investigating further how sewer grade and age can be used to predict failure likelihood, the role of population density will also be consider. Furthermore, to better understand the uncertainty associated with customer complaints data, factors such as level of social deprivation will be used to better understand which residents are most likely to complain when a problem occurs.

ACKNOWLEDGEMENTS

The reported research was funded by KTTBE and was undertaken with support from Scottish Water and the SAWA Interreg IVB project.

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