Identifying the Impact of Human Made Transformations of Historical Watercourses and Flood Risk

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Keywords: Geographical Information System, Lidar, Culvert, Watercourse, Digital Terrain Model, Sewer, Flood.

Abstract: In the past, many urban rivers were piped and buried either to simplify development, hide pollution or in an attempt to reduce flood risk and these factors define a culverted watercourse. A large amount of these watercourses are not mapped, and if they are, then their original nature is not clearly identifiable due to being recorded as part of the sewer network. Where these culverted watercourses are not mapped due to being lost to time and development, we expressed these to be so-called 'lost rivers'. There is a lack of awareness of the flood risk in catchments housing these rivers, and because many of them are incorrectly mapped as sewers, there is often confusion over their legal status and responsibility for their maintenance. To identify the culverted watercourses many datasets were used including LiDAR data (Ground Elevation Data), historical maps (earliest 1840's), asset data (Sewer network), and the river network. Automatic and manual identification of potential culverted watercourses were carried out and then the mapped assets are analysed with flooding data to understand the impacts. A GIS map has been created showing all potential lost rivers and sites of culverted watercourses in the North London area.

1 INTRODUCTION

London has a large legacy population of culverted and concealed watercourses, dating from the 19th and 20th centuries. Since these structures were built, changes to the governance of drainage have resulted in many assets being transferred between authorities and in the process, comprehensive records have not always survived. There is often uncertainty surrounding the legal status and responsibility for the maintenance of culverts. For example, many culverted watercourses in London were included on the map of public sewers, where their original status has become obscured over time. This can be a significant obstacle to the proper stewardship of the structures. In addition, the culverting of watercourses causes problems such as increasing upstream flood risk due to blockages, reduced ecological value within concrete channels and with reduced daylight and adverse effects on environmental features and wildlife. The issues are summarised as:

Inadequate maintenance and investment – the responsibility for drainage assets varies according to their legal status. For example responsibility for a watercourse normally rests with the owners of land through which it flows (riparian owners). Where a watercourse is incorrectly mapped or not mapped at all, owners may be unaware of their responsibilities. Different agencies often assume that others are responsible for such assets, and as a result appropriate maintenance regimes are not in place. Many of these assets are critical structures with a high impact of failure. They should be subject to regular inspection and have adequate investment plans for their maintenance and eventual replacement. More immediately, culverts often have grilles at their inlets and outlets which can become easily blocked, or debris causes a blockage within the culvert, potentially leading to flooding.

Poor understanding of flood risk – culverted sections of watercourse may drain large, upstream catchments that extend far beyond the urban area. Such a situation may not be clear from drainage records and if it is not appreciated, can lead to understatement of the flood risk as well as concealing potential upstream solutions to flooding. A recent study on drainage capacity relating to the surface water drainage system around the Mill Hill Circus junction in London by Transport for London (TfL) is a good example of this. During periods of medium to heavy rainfall, the Mill Hill Circus roundabout floods

Moran, T., Valappil, S. and Harding, D.
Identifying the Impact of Human Made Transformations of Historical Watercourses and Flood Risk.
DOI: 10.5220/0006672701730179
In *Proceedings of the 4th International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2018)*, pages 173-179
ISBN: 978-989-758-294-3

in three different areas. These flooded areas spread across lane 1, 2 and a footway (Transport for London, 2014).

Differing legislature and flood risk management – different asset types are governed by various pieces of legislation, which give design criteria for flood risk management and define stewardship responsibilities for agencies. Floods in urbanised areas have a greater impact due to the exclusion of rivers in those areas. The watercourses have been substituted by sewers which are not designed to convey intense rainfall as effectively as flood defences would be. Also, whilst rivers have a degree of protection against development with regard to flood risk, developers and property owners have right to connect to sewers, regardless of flood risk.

Funding – funding for different types of drainage comes from multiple sources e.g. Sewerage investment is funded from customer bills, while land drainage comes from a combination of local taxes and levies and central government grants. If an asset is assigned to the wrong owner, they may not be able to access funds to maintain it. An example of a watercourse that encapsulates all of the issues is the Caterham Bourne, a chalk-fed river that flows from the North Downs, into South London. Much of its length is culverted and different culverts are variously mapped as ordinary watercourses, main rivers or as sewers (Surrey County Council, 2015). During a recent severe flood event, there was considerable dispute over responsibility for the different culverts, leading to delays in clearing blockages and the prolonging of the significant traffic disruption, caused by the flooding. In the subsequent investigation into the flooding, the different legal statuses of culverts meant the different agencies applied different thresholds of risk, since their origins are not clear. This is hampering the development of a coherent flood alleviation strategy and is an obstacle to identifying funding for investment.

Deculverting (or daylighting) these watercourses can instigate advantages including ecological benefits, reduced flood risks, recreation for local communities and a stimulus for regeneration. The evidence for these impacts are sparse, however these are the opportunities that present themselves when considering daylighting the watercourses.

2 METHODOLOGY

To identify the culverted watercourses many datasets will need to be used including LiDAR data, historical maps, asset data, and the river network. The potential culverts can then be drawn on GIS and plans can be put in place to ensure they receive the correct maintenance. This section outlines the datasets used and the mapping of the lost rivers through GIS.

2.1 GIS Asset Data

This dataset included:

- Gravity sewers
- Invert levels
- Manholes
- Operational sites
- Sewer end items

During analysis, gravity sewer coverage was the most useful with surface water sewers being identified as the most likely candidates for being culverts. Of these sewers, pipes with a large (>500mm) diameter were seen to have a higher probability.

The following sewer types were included in the analysis:

- Surface (S)
- Storm Overflow (SO)
- Other (O)

Sewer end types were also thought to be useful. The dataset was filtered to include only those that had notes in the watercourse attribute or which had “inlet”, “outfall” or “culvert” in the comments.

2.2 Historical Mapping

Datasets from around 1840 and 1935 were provided by the National Library of Scotland and were available at various scales; enabling identification of field boundaries. Rivers and watercourses were digitised from this mapping where they were present on the mapping but not on the EA main river network layer. Some smaller watercourses were also identified as the Ordinance Survey (OS) labelled them with flow direction.

2.3 EA Main River Network

This data was in the form of a shapefile showing the centroids of the main river channels as defined by the EA. The dataset shows both currently exposed watercourses and a number of culverted rivers. However, there did not seem like there was particular logic as to which of these covered watercourses were mapped, and the provenance of the data is unavailable.

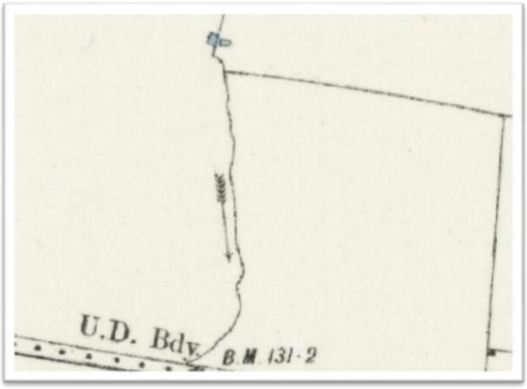

Figure 1: 1:10,500 mapping showing flow direction arrow.

2.4 EA Lidar Data

This dataset recently became open data, but the quality and resolution of the available data was variable. However, the 2m digital terrain model (DTM) data was selected to be utilised as it was adequate for picking out drainage channels and it also provided the most complete coverage.

The data is supplied in ESRI ASCII format (.asc files) in 10km by 10km tiles. These were converted in Quantum GIS (QGIS) to ERDAS IMAGINE format (.img files) and mosaicked to form a seamless dataset over the study area. This data was run through an automated drainage extraction routine in QGIS since the data is inherently noisy and a number of man-made features interfere with the natural drainage patterns (roads, railways etc.)

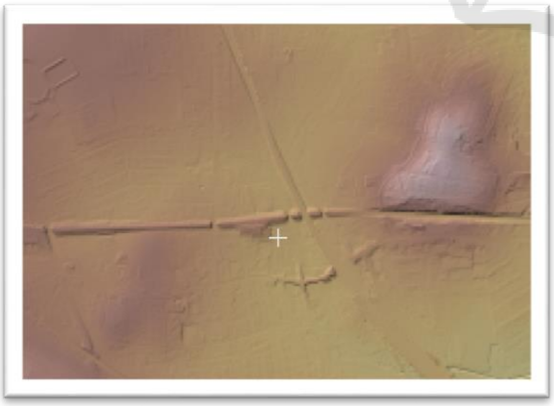

Figure 2: Cuttings and embankments in the EA DTM.

However, this is true of all DTM products. The full resolution 2m DTM was found to give a dense network of drainage, far too detailed for the purpose.

Figure 3: Detailed drainage from 2m DTM overlain on 1900 1:10,500 mapping.

3 GIS ANALYSIS

It was decided to reduce the scale of the DTM to 10m resolution and use thinning and cleaning techniques to produce the final drainage output from the EA LiDAR data.
The 2m DTM was resampled to 10m, then the dataset was run through the r.watershed routine in QGIS. The parameters applied to the dataset include:

- Minimum size of exterior watershed basin: 100
- Maximum length of surface flow: 0
- Convergence factor for MFD: 5
- Beautify flat areas – selected

The process produced a raster output with pixels of varying value tracing the drainage pathways. This was then run through a thinning routing (r.thin in QGIS) that removed excess pixels from the drainage, outputting a single pixel path for the drainage. The raster dataset was then converted to shapefile by the r.to.vect routine in QGIS.

This still resulted in a fairly complex drainage pattern, so in order to simplify it a little more a cleaning routine was run to remove dangling vectors under 100m in length. It was then run through the v.clean routine in QGIS using rmdangle as the cleaning tool and 100 as the threshold. A considerably simplified drainage output was the result of this process.

It was clear that the watercourses digitised from the 1900 historical mapping were the primary indicator of potential lost rivers. A number of large diameter surface water sewers were observed closely following the course of the original watercourses and these became high confidence targets.

3.1 Buffer Zones

As the sewers did not exactly follow the original watercourses, it was necessary to add a buffer zone around the line of the watercourses. A buffer of 50 meters was used for the historical rivers and EA river network in order to include those sewers that run parallel to the original watercourse. This figure was derived from trial and error so as to include known targets.

As the EA LiDAR drainage was less well defined, two buffer zones of 30m and 100m were used; the first to capture high probability targets and the second to capture lower probability targets.

3.2 Sewer end Items

Sewer end items that include a watercourse name or “inlet, “outfall” or “culvert in the comments were felt to be indicative of natural drainage. These were filtered from the original dataset, buffered to 10m to ensure intersection with the sewer network and then used to select output vectors from the 100m buffered EA LiDAR drainage dataset.

3.3 Lost Rivers Model

The model was constructed in ERDAS IMAGINE Spatial Modeller (Sterling Geo, 2016).

3.3.1 Examples

The following demonstrates some of the features found in this investigation.

Firstly, here is the OpenStreetMap (OSM) data over an area in West London, where there is no trace of surface watercourses:

Figure 4: OSM of an area with no surface watercourses.

And this is what the same area looked like around 1900:

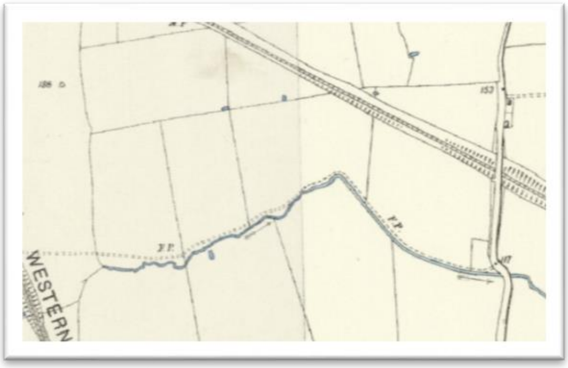

Figure 5: OS 1:10,500 Historical Mapping.

Now, the digitised drainage (blue line), the EA river buffer (green shading) and the drainage extracted from the EA LiDAR (green line) can be overlaid.

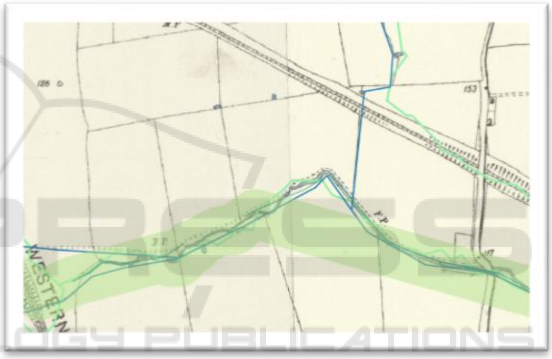

Figure 6: Overlay showing extracted drainage.

It is clear that the EA LiDAR drainage follows the river quite well, but the railway interferes with the drainage path. The EA main river network is mostly good, but it cuts a corner on the 1900 river path.

This matches up to the filtered sewer network in the following way:

Figure 7: Overlay of drainage buffers and sewer network.

The large (>300 diameter) sewers (thick red line) in this instance provide a close match to the digitised drainage network, with the smaller diameter sewers not relevant.

Figure 8: Target high probability sewers over OSM.

Figure 9: Sewer end targets in yellow.

In other areas, a high concentration of sewer end targets (figure 9 in yellow) may also be an indicator of former watercourses.

3.4 Output

The following seven shapefiles were produced:

Table 1: Shapefiles in order of probability of being a culverted sewer.

Group	Diameter of sewer	Data used
P7	>300mm	Within 50m of the digitised rivers from historical mapping.
P6	>300mm	Within 50m of the EA Main River Network.
P5	<300mm	Within 50m of the digitised rivers from historical mapping.
P4	>300mm	Within 30m of the drainage network extracted from EA LiDAR DTM.
P3	<300mm	Within 50m of the EA Main River Network.
P2	>300mm	Within 100m of the drainage network extracted from EA LiDAR DTM that also intersect with the filtered sewer end outfall/inlet/culvert/watercourse points.
P1	>300mm	Within 100m of the drainage network extracted from EA LiDAR DTM.

These criteria proved to be too broad and identified over 1023km of pipes as culverted watercourses, out of the 5245km of pipe in the trial area of North London. Therefore, we decided to use the digitised rivers from historical mapping along with the EA main river network to perform further analysis. Also included was the whole gravity sewer network in the trial area, filtered so only surface (S) and surface overflow (SO) with diameter over 300mm were considered. These pipes were then classified as “highly likely”, “possible” and “not likely” to be a culverted sewer in the following way:

Figure 10: Example of highly likely culverted watercourses.

A sewer (green) connecting two watercourses (blue) or following closely to the digitised lost river (pink) were classed as “highly likely” if the diameter is greater than 600mm, or “possible” if between 300mm and 600mm.

In addition, when an Ordinance Survey (OS) watercourse ends but the EA river network continues, the sewers connected to this have been classed as possible. See figure 11 for a “possible” watercourse shown in orange:

Figure 11: Example of a possible culverted watercourse.

All other surface and storm overflow sewers greater than 300mm are classed as “not likely”. Since some of these watercourses were not all connected but had the same GISID, it was necessary to categorise the lost rivers by a letter (describing its likelihood due to positioning) and a number (detailing the rivers connected ID). The details of the categories are as follows:

Table 2: Category description.

Category	Probability of being a culverted sewer	Sewer description (After Manual Checking)
A	Possible	Between two watercourses and likely.
B	Highly Likely	Between two watercourses and highly likely.
C	Possible	Follows the path of a lost river and likely.
D	Highly Likely	Follows the path of a lost river and highly likely.
E	Possible	End of EA river network and likely.
F	Highly Likely	End of EA river network and highly likely.
(none)	Not Likely	None of the above.

4 FLOOD RISK

Analysis was carried out to identify areas of culverted sewer flooding using 70 years of surface water flooding data and 16 years of hydraulic flooding data.

4.1 Results

The rate of “highly likely” watercourses flooding is much greater than the rate of “possible” and “not likely” watercourses flooding.

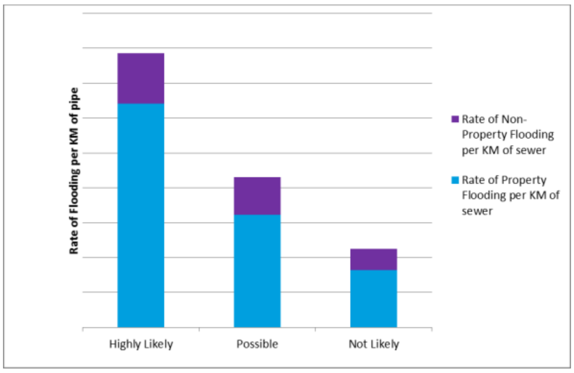

Figure 12: Rate of flooding per kilometre of pipe.

Figure 13 shows a site where “highly likely” culverted watercourses (green) have the same flooding patterns (beige) as water features (blue).

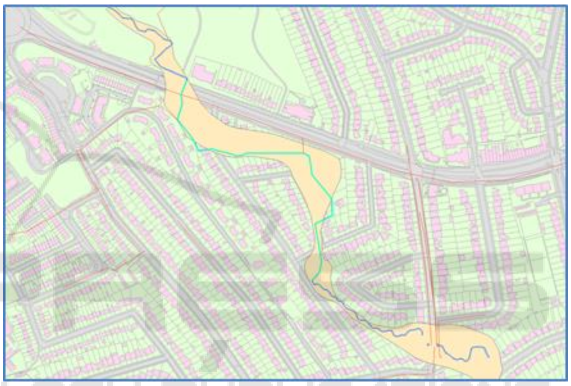

Figure 13: Similarities in flooding patterns between culverted watercourses and water features.

Figure 14 shows an area with hydraulic sewer flooding (brown points circled in red) due to culverted watercourses (green):

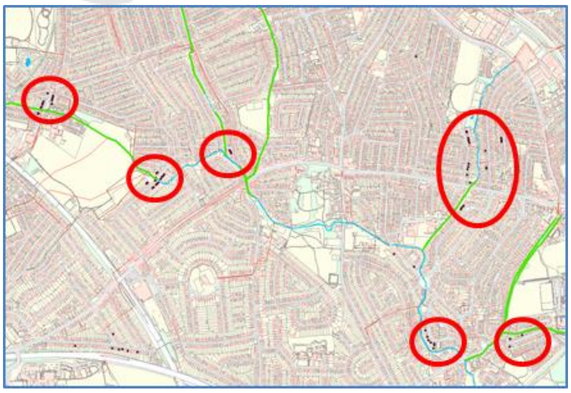

Figure 14: Example of hydraulic flooding due to watercourses.

5 CONCLUSIONS

Through spatial modelling and analysis we have produced a lost river map in North London and identified 83 “highly likely” culverted watercourse sites, 12 of these were found to have had hydraulic sewer flooding in the last 8 years. In addition, 47 “possible” culverted sewer sites were found, 5 of which had hydraulic sewer flooding in the last 8 years.

There are some obvious examples of where pipes have been culverted and have the same flooding patterns as rivers. There is also evidence to suggest that culverted watercourses are flooding at a higher rate than non-culverted watercourses. Further work has been planned to complete the lost river mapping and identification of culverted sewers across the London area to aid future investigations into the flooding risk of other culverts.

More field trials are required to evaluate the asset characteristics and structural conditions of these assets. At those sites, engagement with all relevant agencies will occur to explore the issues and options surrounding the ownership of the assets and responsibility for their stewardship. Observations from this exercise will be incorporated into a draft template for establishing stewardship regimes at similar, high-risk sites.

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