A century of stream burial in Michigan (USA) cities

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1. Introduction

Stream burial is an undesirable outcome of human development, and typically follows a predictable transition from natural land uses to agriculture to urbanization (Julian, Wilgruber, de Beurs, Mayer, & Jawarneh, 2015). Urban stream burial occurs when stream channels are rerouted into underground pipes and ditches or completely eliminated from the stream network (Elmore & Kaushal, 2008; Leopold, Huppman, & Miller, 2005; Meyer & Wallace, 2001; Napieralski & Carvalhaes, 2016; Veliz & Richards, 2005). Many heavily industrialized, or densely populated urban areas, have essentially buried a majority of the original stream network. For example, the River Thames (London, UK) has more than 20 major, subterranean rivers (see Barton, 1992), while, in the USA, the cities of Detroit (Michigan, USA) (Napieralski et al., 2015; Napieralski & Carvalhaes, 2016), Baltimore (Maryland, USA) (Elmore & Kaushal, 2008), Greater Oklahoma City (OK, USA) (Julian et al., 2015), and Cincinnati (Ohio, USA) (Roy, Dybas, Fritz, & Lubbers, 2009) have a documented history of stream burial caused by rapid urbanization.

Stream burial deteriorates watershed health because it influences aquatic ecosystem structure and function (Kaushal & Belt, 2012; Paul & Meyer, 2001; Roy et al., 2009; Veliz & Richards, 2005; Walsh et al., 2005; Wenger et al., 2009) by decreasing hydrologic connectivity; increasing flashiness, flood frequency, and intensity (Leopold et al., 2005); and decreasing nitrate uptake and carbon production at the watershed scale (Pennino, Kaushal, Beaulieu, Mayer, & Arango, 2014). The urban watershed continuum framework (Kaushal & Belt, 2012) describes how an urban watershed changes during different urbanization stages, which constantly modifies hydrologic flowpaths (engineered and natural) in urban areas. In particular, it conveys the frequency of stream modification and burial, such as a replacement of first order streams by storm drains, ditches, gutters, or pipes. Cities experiencing rapid development frequently show a sequence of stream modification (crooked and disconnected channels caused by agriculture and low density development) to stream burial (substantial portions of the stream networks devoid of surface channels) (Julian et al., 2015; Napieralski et al., 2015).

Mapping buried streams in cities can be a challenging process, as most topographic records of surface channels have been modified or even erased. In most circumstances, surface channels were replaced with subsurface conveyance structures, creating a hyper-efficient, three-dimensional complex of surface and subsurface flowpaths. It is not uncommon to have the subsurface network align with parts of the historic stream network. Additionally, accurate and consistently constructed maps of rivers that predate urbanization are rare. For example, the spatiotemporal pattern of stream burial in London (UK) is quite convoluted and based on a wide range of historical records, including street and place names and written records (Barton,
1992; Talling, 2011). Topographic maps are some of the most reliable sources of historical data, but in the USA, they only extend back to the late 1880s (and typically at a relatively coarse scale, such as 1:62,500). Aerial photos have also been used to digitize old stream channels (e.g. Napieralski et al., 2015), but are limited to the mid-twentieth century. Now, with high-resolution digital elevation models (DEM), frequently derived from LiDAR, it is possible to identify abandoned or buried channels as subtle scars in the urban landscape (see Napieralski et al., 2015 as an example), although this may have limitations in such heavily modified urban areas. Consequently, maps of buried streams in urban areas usually reflect only the most recent land use change and, in many situations, this involved rapid development of housing and expansion of commercial and industrial land.

This map was a by-product of a project focused on mapping the impact of urbanization on urban stream networks, with a particular focus on identifying and mapping riverless urban areas (i.e. urban stream deserts) that have a history of stream burial (Napieralski et al., 2015; Napieralski & Carvalhaes, 2016). However, the urban stream desert concept uses gaps in the modern stream network data to assume stream burial has occurred. This map extends that work by concentrating on mapping and comparing modern and historic stream networks in Michigan’s seven largest cities (defined as >100,000 people). Stream flowlines were mapped from the earliest available topographic maps (1902–1929) and the distribution and patterns were compared against flowlines from the United States Geological Survey (USGS) National Hydrography Dataset (NHD), which contains stream/river and artificial path vector features at a maximum scale of 1:24,000 (data accessed in 2015). The map illustrates the degrading impact urbanization has on the stream network when short-term economic progress is prioritized over long-term environmental sustainability.

2. Study area

Michigan is located within the northern Midwest of the USA, surrounded by the Great Lakes, and is the 10th most populated state in the USA, according to the US Census in 2010. As of 2010, Michigan’s seven major cities had a population of >100,000: Detroit (713,777), Grand Rapids (188,040), Warren (134,056), Sterling Heights (129,699), Lansing (114,297), Ann Arbor (113,934), and Flint (102,434) (Table 1). Most of the cities expanded in the 1930s and 1940s due, in part, to the growth of industry, especially automobile manufacturing. Several cities, such as Detroit and Flint, exhibited an already heavily modified stream network at the turn of the twentieth century, while changes in exurbs outside these cities since that time best demonstrated the transition from natural land uses to agriculture (i.e. angular channels and increased dependence on canals and ditches) to urbanization.

3. Results

All seven cities displayed a pattern of stream modification and burial over the twentieth century (Main Map), although some of the older cities, including Detroit and Flint, were already developing and disrupting the stream network in the early 1900s. Detroit is the most extreme with 58% impervious surface coverage (ISC) and 86% of its river network lost over the last 100 years, followed by Warren with 59% ISC and 67% stream loss (Figure 1). Ann Arbor buried 60% of its streams since 1902 but, unlike the other cities with high stream burial rates, it has a low ISC (33%), perhaps due to a ‘greenbelt’ policy allowing the city government to purchase development rights on agricultural land parcels adjacent to the city, minimizing intensive development.

4. Conclusion

The map in this study illustrates several key observations:

- Michigan’s seven largest cities were all built along a major river, emphasizing the value streams have on the growth of agricultural and urban areas. Originally, the stream network was valued for irrigation, transportation, and freshwater, but with post-industrial development, it shifted to support productivity and profitability, which led to stream degradation and loss.
- Many stream networks are angular, especially in Detroit and Warren. As cities urbanized, the stream network that remains was modified to fit urbanization patterns, which includes a rectangular system of roads and urban infrastructure (e.g. property lines and railways). Frequently, this process of stream modification is a precursor to burial, as channels are moved to demark property or operate as ditches and canals, before being removed to provide space for development (Main Map). The end product may be well-defined expansive riverless urban areas (i.e. urban stream deserts).
- Cities with higher ISC percentage usually had higher rates of stream burial. The only exception is Ann Arbor (i.e. Tree Town), where the city has made a conscious effort to counteract rapid urban sprawl, including a ‘greenbelt’ plan that gave the city government permission to purchase development rights on adjacent agricultural parcels to prevent development. However, the relationship between ISC percentage and stream burial might be stronger in the
most intensely developed urban areas that reached city-status well before government policy was enacted to protect surface water features.

- There was a connection between the depopulation of Detroit and the systematic removal of streams in adjacent communities. As Detroit lost a substantial percent of its population in the mid-twentieth century, Warren benefited and increased in population from 830 residents (1900) to 134,000 in 2010. However, depopulation continued and led to the rapid development of Sterling Heights, which is the youngest of the three cities, and has the least amount of ISC percentage and stream burial.

- Comparing historic datasets against contemporary datasets likely underestimated stream loss. The historic USGS topographic maps were completed at a scale of 1:62,500 and stream features were more generalized (and/or small stream orders not mapped at all) than the USGS NHD dataset. As a result, data from the historic datasets will have relatively less detail than current flowline data. In some situations, there are modern streams where there were no historic streams and this can be attributed to either generalization or channel modification that result in drainage ditches or canals associated with urbanization.

Urban stream burial dominates the urban landscape in the Michigan cities, which is likely also true for cities within the Great Lakes basin and beyond. Digitizing historic stream channels is one approach to mapping a history of change in perception and management of urban surface waters, but the overall impact of urbanization on the urban stream network is unclear due to mapping inconsistencies (e.g. spatiotemporal resolution and survey technique). It is clear from this study, however, that as percentage ISC increases, urban stream burial increases, which reduces access to valuable ecosystem services.

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| Table 1. Summary and comparison of population density, urbanization, and historic and present-day stream network within the seven cities in Michigan |
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| **Population (2010)** | **Area (km²)** | **Population density (ppl/km²)** | **Percent ISC** | **Percent developed land use** | **Length of historic channels (km)** | **Length of NHD channels (km)** | **Percent rivers buried** |
| Detroit | 713777 | 370.4 | 1927 | 58 | 96 | 343 | 49 | 86 |
| Grand Rapids | 188040 | 117.7 | 1597 | 44 | 90 | 98 | 61 | 48 |
| Warren | 134056 | 89 | 1506 | 59 | 99 | 103 | 34 | 67 |
| Sterling Heights | 129699 | 95.1 | 1364 | 45 | 95 | 145 | 112 | 23 |
| Lansing | 114297 | 103 | 1110 | 37 | 85 | 96 | 54 | 44 |
| Ann Arbor | 113934 | 74.3 | 1533 | 33 | 88 | 114 | 46 | 60 |
| Flint | 102434 | 88.3 | 1160 | 45 | 94 | 67 | 51 | 24 |

Figure 1. The urban stream network in Detroit, MI, experienced heavy modification as a precursor to burial. In this example, historic river channels are nearly parallel to modern road patterns, which tend to be angular. The channels were likely modified to be drainage ditches along major roads before burial.
Disclosure statement

No potential conflict of interest was reported by the authors.

Software

All maps were completed using Esri ArcGIS 10.3. All components of the map layouts were produced using Esri ArcGIS 10.3.

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