How does stream burial affect water runoff?

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Rationale

Over 75% of stream channels in the City of Pittsburgh are buried underground in pipes. Stream burial decreases the amount of time water spends in the watershed since pipes are smoother and straighter than natural channels so water passes through more quickly and can lead to flooding downstream. If we understand how stream burial affects runoff routing, we can better design stormwater infrastructure to slow down water, reduce floods, and prevent combined sewer overflows.

Overall Question

How does widespread burial of streams affect the relationship between rainfall and the flow volume in the stream?



Figure 1. Image on the left is a photo from April 28, 1922 of workers building a trench to bury a tributary of Nine Mile Run along Batavia street. No stream is visible in this location today as seen in the Google Street View image on the right. Image from Historic Pittsburgh - Pittsburgh City Photographer Collection (https://historicpittsburgh.org/collections/)

Approach

To learn more about the impact of stream burial on runoff response, we collaborated with Upstream Pittsburgh and Pittsburgh Parks Conservancy to measure storm responses in a watershed system that is largely buried. We measured streamflow in Nine Mile Run over 6.5 years (2014-2021) at a location where 98% of streams above this point are buried (Figure 1). The flow in the stream was compared with radar precipitation data from 3 Rivers Wet Weather (https://www.3riverswetweather.org/) to determine the timing of rainfall and high flows in the stream. Individual storms were selected, and characteristics of each event were measured: total rainfall volume, rainfall intensity, duration of rainfall, the maximum streamflow (also called discharge), duration of elevated streamflow, and the amount of time between when rainfall started and when flow started to increase in the stream (lag time).

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Definitions

A ***watershed*** is all the land that drains to a particular stream

Stream burial is the process of relocating a stream to pipes underground, often leaving little evidence on the landscape that a stream used to flow there. This was a common characteristic of suburban development in the early 20th century.

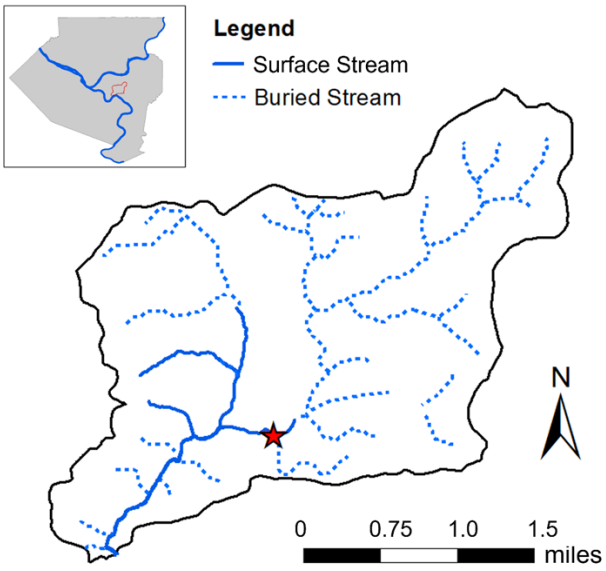


Figure 2. Map of Nine Mile Run. Buried streams are the dotted blue lines and streams still flowing on the surface are the solid blue lines. Streamflow was measured at the location of the red star. Inset map shows location of Nine Mile Run within Allegheny County.

Findings

Flow in buried streams increases very quickly after rainfall begins.

When it rains in a city, some of the rain infiltrates into lawns and gardens. However, rain that falls on impervious surfaces (roads, roofs, and parking lots) can't infiltrate and instead flows quickly into the storm sewer. Once this water is in the storm sewer pipes, it travels much faster than water flowing through soil and bedrock. Although both infiltrated water and storm pipes flow to and contribute water to the stream, the water from storm pipes increases the stream flow much faster than the water traveling through slow (soil/rock) flowpaths.

In a watershed like Nine Mile Run, where most of the stream channels are buried, a larger portion of the total rainfall flows through the fast piped flowpaths, resulting in increased streamflow (both volume and speed) very soon after rainfall. Flow through buried stream pipes is so fast that rain from distant parts of the watershed can reach the stream at almost the same time as flow from rain falling very close to the stream. We can visualize this if we plot streamflow over time. The shape of the graph of streamflow over time is very similar to the shape of the graph of rainfall over time. We can see each individual pulse of rainfall in the stream flow. This is because the rainfall flows directly to the stream through storm sewer pipes. Without the pipes, the streamflow pattern would be much smoother as the water travels slowly through soil or bedrock (Figure 3).

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Impervious surfaces are areas where rainfall can't infiltrate into the ground and becomes runoff instead. Examples are roads, parking lots, roofs, and sidewalks.

Runoff is the water that doesn't infiltrate into the ground but flows across the land surface

If we compare the time between the start of a rainstorm and the time stream flow increases (the lag time) in Nine Mile Run, this lag time is about 2.1 hours. However, in 70 storms we examined (13% of all of the storms analyzed) the lag time was 30 minutes or less due to high intensity summer thunderstorms when a large volume of rain occurred in a short period of time. This rapid connection between rain and streamflow in Nine Mile Run is one of fastest observed across the urban U.S.

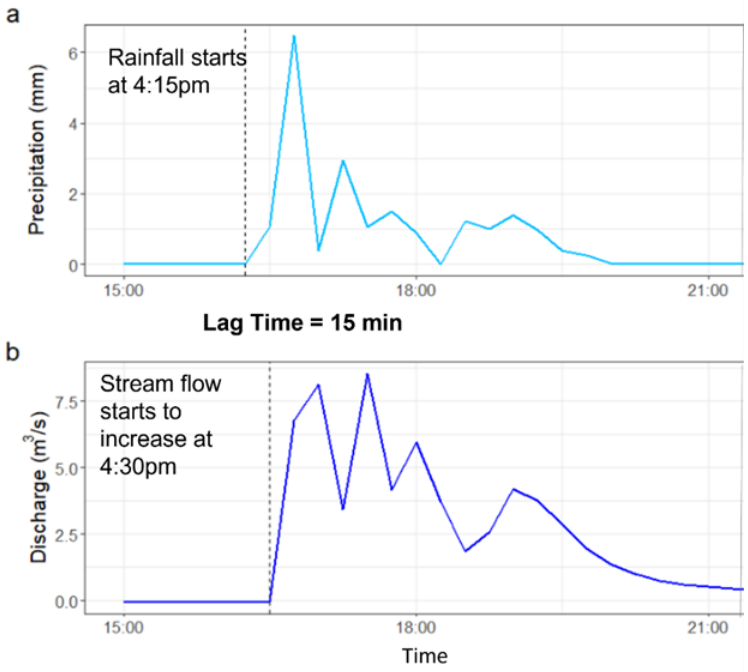


Figure 3. A storm event from July 10, 2017 shows the short lag time. The rain starts at 4:15pm and increased flow in Nine Mile Run starts at 4:30pm. In addition, the pattern of peaks in discharge almost matches the peaks in rain. This similarity is a result of the fast transport of water through sewer pipes.

Streams with upstream burial have higher peak flow for any given rainstorm.

Another result of faster stormwater transport is that water from different parts of the watershed reach the stream in a shorter period of time than it would if it traveled through rock and soil. This creates a larger total volume of water in the stream at the same time. Across all storms in our dataset, the median streamflow peak in Nine Mile Run was 3.6 m^3/s. To translate, that is the volume-equivalent of a mid-sized sedan full of stormwater passing a given location at every second. The largest storm in the record was approximately 81 m^3/s which translates to 2¼ school buses full of water passing through the stream every second. This incredibly large volume of water easily erodes stream banks and floods trails and roads near the stream.

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Discharge measures both the total amount of water in a stream as well as how fast it is flowing. It is expressed in units of volume per unit time (i.e., m^3/s or ft^3/s).

Lag time is the amount of time between the start of precipitation and the beginning of the increase in discharge



Figure 4. Two photos of Nine Mile Run taken from the same location during normal conditions (top) and during a storm (bottom).

Buried streams make combined sewer overflows worse, but there are solutions.

Buried streams in sewer networks result in stormwater filling the sewer systems. When the systems are combined (i.e., both sewage and stormwater flow in the same pipe system, https://www.pgh2o.com/sewer), this means the sewers are full and any sewage added to the system during a storm flows directly to the stream. According to our Nine Mile Run data, Pittsburgh experienced an average of 90 rainstorms a year from 2014 to 2020, and each of these could add raw sewage to rivers and streams, particularly given the upstream burial.

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Daylighting is the process of removing a stream from buried pipes and returning it to flow on the land surface.

Solving this problem can be done through separating streams from sewer systems (i.e., removing the soil over the stream and remaking, or "daylighting", the stream). Daylighting slows down the flow of water by reconnecting rainfall to the original soil and rock flowpaths of the watershed and thus reduce the potential for large floods downstream. Additionally, building stormwater infrastructure that slows down water before it enters the storm drain system is necessary to help Pittsburgh stop sewer overflows and comply with the EPA consent decree (https://www.alcosan.org/clean-water-plan).

Implications

- **Stream channel burial is a common issue in Pittsburgh and many other older U.S. cities. This has significant impacts on how water moves through the urban landscape.**
- **Buried streams create faster streamflow responses to rainfall. Sewer pipes increase the connection, and thus, speed up water transport between upland areas and streams.**
- **High peak flows endanger stream ecosystems as well as nearby infrastructure.**
- **Climate changes are predicted to increase the frequency of intense storms, making these issues of urban flooding and sewer overflows even worse. However, stormwater management solutions that slow down the flow of water and disconnect runoff from sewer system will make a difference.**

Stream burial in Pittsburgh speeds up watershed responses and results in extremely fast and high floods. This emphasizes the importance of stormwater management to increase the storage of water within the watershed before it gets to the stream.

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