Water yield change with urban development in the Denver metropolitan area

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Projected growth in Colorado is focused in the Denver area.

Shifting growth patterns

Colorado is expected to gain 3 million new residents between 2015 and 2050, 84 percent of which will settle along the Front Range. But Larimer, Weld and El Paso counties are expected to claim a larger share of the state population in the future.

Sources: Colorado Division of Local Affairs; State Demography Office
Urbanization changes:

• Water use

  Nicholas Guthro’s presentation next will discuss water use patterns

• How much flow there is in streams
The questions addressed today are:

What are the tap water contributions to urban baseflow in the Denver, Colorado area?

How does the streamflow response to rainfall events change with impervious surface cover in the Denver, Colorado area?
I want to acknowledge here that historical population changes have come at a dire cost.

The land that this research focuses on is located on Nunt'zi (Ute), Hinono'eino' (Arapaho), and Tsistsistas (Cheyenne) traditional homelands.
The questions addressed today are:

What are the tap water contributions to urban baseflow in the Denver, Colorado area?

Noelle Fillo
2020 CSU MS Graduate
Now at WEST Consultants, Phoenix

Fillo, Bhaskar, and Jefferson (2021) Water Resources Research

Abdullah Al Fatta
PhD student at CSU
Urban watersheds flowed more often.

*Based on analysis of 5-to-15 minute streamflow, limited to April to September, 2013-2020.*
Urban streams had more streamflow.
Lawn irrigation return flows (LIRFs) can increase baseflow.

Surface runoff into the storm sewer system, which then drains into the stream

Infiltration of irrigation and subsequent discharge from the subsurface into the stream

Surface runoff directly into the stream
Lawn irrigation return flows (LIRFs) can increase baseflow.

Surface runoff from the lawn irrigation system directly into the storm sewer system, which then drains into the stream.
Lawn irrigation return flows (LIRFs) can increase baseflow.

Surface runoff into the storm sewer system, which then drains into the stream.

Infiltration of irrigation and subsequent discharge from the subsurface into the stream.

Surface runoff directly into the stream.
Denver’s tap water is imported from higher elevations and is isotopically distinct from locally-derived water.

Surface Water in the Rocky Mountains
Mean Elevation: 2622 m – 3556 m above sea level

Surface Water in the Denver Metropolitan Area
Mean Elevation: 1676 m above sea level

Our first step to answering our research questions was to characterize the Denver metropolitan area.

<table>
<thead>
<tr>
<th>Grassland Streams</th>
<th>Area (km(^2))</th>
<th>Imperviousness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWOM</td>
<td>3.7</td>
<td>1</td>
</tr>
<tr>
<td>WOM</td>
<td>7.5</td>
<td>5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Urban Streams</th>
<th>Area (km(^2))</th>
<th>Imperviousness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>63.3</td>
<td>44</td>
</tr>
<tr>
<td>Low</td>
<td>3.9</td>
<td>22</td>
</tr>
</tbody>
</table>
We sampled baseflow, taps, and precipitation in the summers of 2019, 2021, and 2022.

Streams sampled approx. biweekly

Composite precipitation sampled monthly

Tap samples collected from each water provider in each watershed where baseflow was sampled.
Two end-member mixing analysis was used to solve for tap and precipitation proportions of urban baseflow.

\[ \delta_{\text{precipitation}} \times \text{Proportion}_{\text{precipitation}} + \delta_{\text{tap}} \times \text{Proportion}_{\text{tap}} = \delta_{\text{stream}} \]  

(3)

\[ \text{Proportion}_{\text{precipitation}} + \text{Proportion}_{\text{tap}} = 1 \]  

(4)
The LIRF contributions to baseflow were separated implicitly using reported water infrastructure losses.
~ \(\frac{3}{4}\) of urban baseflow is from leaking pipes, and
~ \(\frac{1}{2}\) of urban baseflow is from lawn irrigation return flow.
Tap contributions are a large part of why streamflow is higher in urban streams.
The questions addressed today are:

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How does the streamflow response to rainfall events change with impervious surface cover in the Denver, Colorado area?

Stacy Wilson
2021 CSU MS Graduate
Now at Wright Water Engineers, Denver

Wilson, Bhaskar, Choat, Kampf, Green, Hopkins (2022), Hydrological Processes
We identified 3,644 paired rainfall-streamflow events using instantaneous streamflow + a semi-automated process.
In semi-arid Denver, CO, USA urbanization...

- increased the responsiveness of these watersheds to even small rain events, resulting in more streamflow events occurring in watersheds with more impervious surfaces
- increased peak streamflow and shortened streamflow event duration

- reduced the time that streams are dry
- does not have a clear effect on total runoff, runoff ratio, or time to peak
How do these changes compare to other studies?

↓ zero flow
↓ precipitation threshold
↑ streamflow events
↑ peak flow
↓ streamflow event duration
↔ runoff depth, time to peak

Agrees with Phoenix (McPhillips et al., 2019)
Agrees with Phoenix and Tucson
Opposite of Tucson (Gallo et al., 2013)
Agrees with Tucson (Gallo et al., 2013)
The higher stormflow in urban streams also contributes to higher streamflow.
In summary:

An isotope mixing analysis estimated that tap water contributed a mean of 80% of urban baseflow on specific days in late summer.

Urbanized watersheds in Denver have higher peak flow and shorter streamflow responses compared to their less developed counterparts.

Ongoing work is looking at:

- How to predict these changes to streamflow based on watershed properties
- Monitoring streamflow in a rangeland watershed as it urbanizes
- How changes to water management such as rainwater harvesting would affect flow and use

Ask Santiago Ramírez Núñez and Junwon Lee about this at their posters this afternoon!