Microscale determinants of residential water use in greater Denver

ASU Urban Water Demand Roundtable, April 2019

By: Austin Troy, Gretel Folingstad, Bob Taylor, and Mehdi Heris
University of Colorado Denver
Importance of outdoor irrigation

- Water Loss, 76,000, 8%
- Outdoor Park & Commercial, 140,000, 14%
- Indoor Residential, 290,000, 30%
- Outdoor Residential, 240,000, 25%
- Indoor Non-Residential, 230,000, 23%

Total Municipal Water Diversions = 970,000 AF

Single Family Water Use

- Toilet 12%
- Shower 11%
- Clothes Washer 9%
- Faucet 8%
- Other 3%
- Dishwasher 1%
- Bathtub 1%
- Leak 5%
- Other 3%

Total Outdoor 50%

Source: 2011 Residential End Use Study

Yard irrigation is variable

Table ES.10 Summary of annual and outdoor water use for landscape group (n=838)

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample Size (n)</th>
<th>Average Annual Use (kgal)</th>
<th>Average Outdoor Use (kgal)</th>
<th>% Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clayton County</td>
<td>103</td>
<td>62</td>
<td>19.2</td>
<td>31%</td>
</tr>
<tr>
<td>Denver Water</td>
<td>95</td>
<td>125</td>
<td>77.0</td>
<td>62%</td>
</tr>
<tr>
<td>Ft. Collins</td>
<td>88</td>
<td>111</td>
<td>55.9</td>
<td>50%</td>
</tr>
<tr>
<td>Peel</td>
<td>69</td>
<td>87</td>
<td>24.1</td>
<td>28%</td>
</tr>
<tr>
<td>San Antonio</td>
<td>98</td>
<td>112</td>
<td>62.0</td>
<td>55%</td>
</tr>
<tr>
<td>Scottsdale</td>
<td>111</td>
<td>186</td>
<td>120.4</td>
<td>65%</td>
</tr>
<tr>
<td>Tacoma Water</td>
<td>107</td>
<td>73</td>
<td>27.0</td>
<td>37%</td>
</tr>
<tr>
<td>Toho</td>
<td>95</td>
<td>93</td>
<td>33.1</td>
<td>36%</td>
</tr>
<tr>
<td>Waterloo</td>
<td>72</td>
<td>58</td>
<td>13.0</td>
<td>22%</td>
</tr>
<tr>
<td>Total (9 sites)</td>
<td>838</td>
<td>100.8</td>
<td>50.5</td>
<td>50%</td>
</tr>
</tbody>
</table>

Source: Water Research Foundation 2016
Yard composition variability is key

Denver Water Study of 425 yards

- 18% of pervious area – no irrigation (sidewalks, rock, mulch etc.)
- 29% of pervious area – alternative landscape types (xeriscape, native, low-use) – 9 GPSF
- 53% of pervious area – bluegrass turf – 18 GPSF
Yard characteristics that may predict variability

1. Grass area and greenness
2. Tree canopy area
3. Tree size/age
4. Tree and building shade on growing space
5. Species grown

• HOA rules?
• Housing/subdivision age
Methods Overview

- Regress **annual water consumption** by parcel for Denver, Engelwood, Littleton against:
  - Total **lawn area**
  - Area of **non-irrigated lawn** (very low greenness)
  - Area of **slightly irrigated lawn** (low-medium greenness)
  - Area of **irrigated lawn** (high greenness)
  - Area of **tree canopy**
  - % of tree canopy accounted for by **low trees** (<6 m)
  - Mean hours of **shade** cast on lawn
  - Whether the property is from a **post-1950 subdivision**
  - Whether the property is part of **HOA**

- Did descriptive stats for HOAs

- Quadratic form regression for subdivision age, regression for NVDI

**Response data:** Denver Water consumption records filtered for private OO-SFH, lot coverage < 30%, July water use > 0, grass area >0= 53,852 observations
Tree height coded for each polygon from LiDAR.
Quantifying yard shade

- Modeled over the course of the day in July using LiDAR for each hour between 11 AM-6PM, then combined

- 3D models of buildings and trees, built in Quick Terrain Modeler

- Path of light relative to 3D objects modeled with ArcGIS hillshade tool, based on Solar Position Algorithm (NREL)

- Overlaid with grass, then average shade hours per grass pixel calculated by parcel
12 PM Shade Area = 728 m²/1hr
2 PM Shade Area = 3393 m²/3hr
4 PM Shade Area = 13613 m²/5hr
6 PM Shade Area = 25520 m²/7hr
Grass area

Take average shade hourly value of each grass pixel.
Mean shade hours

- 0.00 - 0.01
- 0.02 - 0.09
- 0.10 - 0.23
- 0.24 - 0.42
- 0.43 - 0.58
- 0.59 - 1.68
- 1.69 - 1.77
- 1.78 - 1.99
HOAs
Year of subdivision
## Results: Water consumption

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>T stat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>-.096</td>
<td>-.075</td>
</tr>
<tr>
<td>MeanShadeHours*</td>
<td>-1.576a</td>
<td>-4.044*</td>
</tr>
<tr>
<td>TreeArea*</td>
<td>.022</td>
<td>9.389*</td>
</tr>
<tr>
<td>Grass-unirrigated</td>
<td>.000</td>
<td>-.068</td>
</tr>
<tr>
<td>Grass—semi-irrigated</td>
<td>-.005</td>
<td>-2.838*</td>
</tr>
<tr>
<td>Grass—irrigated</td>
<td>.069</td>
<td>26.713*</td>
</tr>
<tr>
<td>BuiltArea*</td>
<td>.316</td>
<td>60.804*</td>
</tr>
<tr>
<td>STORIES*</td>
<td>28.359</td>
<td>45.072*</td>
</tr>
<tr>
<td>PShortTree*</td>
<td>7.275</td>
<td>4.291*</td>
</tr>
<tr>
<td>After1950*</td>
<td>3.769</td>
<td>7.569*</td>
</tr>
<tr>
<td>HOA*</td>
<td>10.493</td>
<td>10.435*</td>
</tr>
</tbody>
</table>

Dependent Variable: TOTAL_QTY
R-squared= 0.267
* = significant at the 99% confidence level.
a. MeanShadeHours=-1.136 when only tree shade modeled
Interpretation of results

• Each additional 100 m$^2$ of irrigated grass (Grass3) is associated with 6000 additional gal of irrigation per year.

• Trees use irrigation, but less than grass. Each additional 100 m$^2$ of tree canopy is associated with 2,200 more gallons or irrigation.

• Shade cast by trees and buildings on lawns serves to at least partially offset the water use of trees: for each additional hour of average shade across all grass pixels, 1,576 fewer gallons of water are used (1,136 with only tree shade). Consistent with Litvak et al (2013).

• Shade also increases NDVI.

• If it were possible for a yard with 100 m$^2$ of tall trees to achieve a mean shading hours of 1.4 for lawn pixels, water savings from the shade would outweigh water use of trees.

• For each 10% increase in the proportion of trees that are short, there is a 726 gal increase in water use. i.e. old, mature trees use less proportionally. Consistent with Bijoor et al (2012).

• HOA status and subdivision year have impact irrigation directly and factors that drive irrigation.
HOA differences in Denver

<table>
<thead>
<tr>
<th>Category</th>
<th>No HOA</th>
<th>HOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parcel Area</td>
<td>900.00</td>
<td>1000.00</td>
</tr>
<tr>
<td>Irrig. grass area</td>
<td>500.00</td>
<td>500.00</td>
</tr>
<tr>
<td>Tree canopy area</td>
<td>300.00</td>
<td>300.00</td>
</tr>
<tr>
<td>Young tree area</td>
<td>100.00</td>
<td>100.00</td>
</tr>
</tbody>
</table>
HOA differences in Denver

Outdoor Irrigation (Gal)

No HOA

HOA

NDVI

No HOA

HOA

After 1950 (proportion)

No HOA

HOA
Subdivision age also drives grass area

Grass area (sq m) in relation to subdivision age

<table>
<thead>
<tr>
<th>Model</th>
<th>B</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>381.002</td>
<td>50.265</td>
<td>0.000</td>
</tr>
<tr>
<td>yrs_old</td>
<td>3.847</td>
<td>20.130</td>
<td>0.000</td>
</tr>
<tr>
<td>yrs_old2</td>
<td>-0.028</td>
<td>-26.290</td>
<td>0.000</td>
</tr>
</tbody>
</table>

a. Dependent Variable: AllGrass
Coefficients inform housing typology for UrbanSim-based predictive water consumption model.
Thanks/ Questions

Austin.troy@ucdenver.edu

Source: Eric Sonstroem (https://www.flickr.com/photos/sonstroem/)