Optimal Outdoor Urban Irrigation Conservation Methodology

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Topics to Cover

- Urban water systems parcel level database
- Parcel level irrigation demand analysis
  - Determination of irrigators from potable system
  - Irrigable area distribution and trends
  - Application rate distribution and trends
- Predicted savings from outdoor conservation BMPs
  - Soil moisture sensors, irrigation audits, reuse
- Optimal outdoor BMP strategy
  - Nonlinear programming approach
- Incorporation into EZ Guide
  - Florida water conservation and planning online tool
Total Parcels: 8,807,768

Parcels Alachua: 99,305

Total Parcels GRU: 55,551

SFR parcels GRU: 30,910
Irrigable area mass balance

Direct IA data from parcel level database
Irrigable or pervious area \((PA)\)-GRU

\[ A_{irrigable} = PA = TA - (FS + AIA) \]

The time-series of the calculated data in the figure shows the decreasing trend in irrigable area.
Major Increase in Popularity of In-ground Irrigation Systems Since 1987 in Gainesville
Irrigable Area Distribution

- IA distribution appears lognormal
- Avg. IA (of irrigators) = 12.31ksf
- Std. dev. = 11.30 ksf

DeOreo and Mayer 2011 California SFR IA Data

Parcel Level Irrigation Demand Estimation

1. Hydrograph separation utilized to determine monthly outdoor usage for each SFR parcel
   - Total monthly usage from customer billing data
   - Indoor usage estimated from property appraisal data
   - Indoor usage consistent across country (Mayer et al. 1999, REUWS)

\[ \bar{Q}_{out} = \bar{Q}_{tot} - \bar{Q}_{in} \]

Where:
- \( \bar{Q}_{out} \) = single family residential outdoor usage (gal/mo)
- \( \bar{Q}_{in} \) = single family residential indoor usage (gal/mo)
- \( \bar{Q}_{tot} \) = single family residential total usage (gal/mo)
Parcel Level Irrigation Demand Estimation

2. Estimate application rate from calculated $Q_{out}$ and IA

$$\bar{Q}_{out} = k \times AR \times IA$$

Where:

- $AR = \text{average application rate for a given parcel (in. /yr.)}$
- $\bar{Q}_{out} = \text{average monthly outdoor usage (gal/mo)}$
- $IA = \text{irrigable area (1,000 ft}^2\text{)}$
- $k = \text{conversion factor}$

3. Determine which parcels irrigate from the potable system

- Irrigates from potable if: $1 \leq IA \leq 100$ and $1 \leq AR \leq 100$
- Removes outliers, and non-irrigators
• Avg AR (of irrigators) = 14.24 in./yr., std. dev. = 14.60 in./yr.
• Number of irrigators from potable = 16,303 of 30,903 total SFR (53%)
Predicted Savings From Outdoor Conservation BMPs

\[ \Delta Q_{out} = k \times IA \times (AR_i - AR_{min}) \]

Where:

- \( \Delta Q_{out} \) = change in total irrigation water use per parcel (gpad)
- \( AR_i \) = current irrigation application rate (in/yr)
- \( IA \) = irrigable area (sf)
- \( AR_{min} \) = minimum required irrigation application rate (in/yr)
- \( k \) = conversion factor

- Savings directly calculated as difference between current and “minimum required application rate (MAR)”
- MAR reflects a desired threshold application achieved with implementation of an outdoor BMP
- Assume IA remains constant
- Only reasonable to target SFR’s that irrigate above MAR
Joint distribution of AR vs. IA for GRU

Annual application rate vs. irrigable area for 16,303 GRU potable irrigators

- Application rate (lbs./yr.)
- Irrigable area (1,000 ft²)

Minimum application rate
Water Savings Production Function for Soil Moisture Sensors in GRU

<table>
<thead>
<tr>
<th>MAR, in./yr.</th>
<th>N</th>
<th>avg. IA, ksf</th>
<th>avg. AR above MAR, in./yr.</th>
<th>Maximum Savings Potential, gal./day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16,303</td>
<td>12.31</td>
<td>14.24</td>
<td>3,265,116</td>
</tr>
<tr>
<td>25</td>
<td>2,746</td>
<td>6.95</td>
<td>15.72</td>
<td>440,119</td>
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<tr>
<td>40</td>
<td>1,070</td>
<td>5.87</td>
<td>15.31</td>
<td>144,145</td>
</tr>
</tbody>
</table>

Comparison of savings potential for varying minimum application rates in GRU

- **1 in/yr min. application rate**
- **25 in/yr application rate**
- **40 in/yr min. application rate**
Consequences of Including Irrigators Below MAR

Cumulative savings for a minimum application rate of 25 in/yr
Optimal Mix of Outdoor BMPs can be Found Using Nonlinear Programming

The least cost mix of soil moisture sensor retrofits, irrigation audits, and reuse to achieve a desired reduction in water use (gal/day) can be found by solving following the nonlinear program:

Minimize \( Z = c_1 x_1 + c_2 x_2 + c_3 x_3 \)

Subject to:

\[
y = \sum_{i=1}^{3} y_{\text{max},i} \cdot (1 - e^{-k_i x_i})
\]

\( x_i \leq x_{\text{max},i} \)

\( y \geq Q \)

\( x \geq 0 \)

Where:

\( Z \) = total costs, $/day

\( y \) = quantity of water saved, gal/day

\( Q \) = water savings target, gal/day

\( c \) = unit cost of bmp, $/account/day

\( x \) = number of accounts to retrofit with an upper bound of \( x_{\text{max}} \)
Recent Application of Methodology

- Applied to a 6 county planning region in Central Florida (CFWI)
- An estimated 50% (304,214 of 610,536) of SFR parcels irrigate from potable system
- MAR for reuse assumed to be 0 in/yr
- MAR for irrigation audits and soil moisture sensors requested to be set at 40 in/yr
  - Audits assumed to reduce demand by 0.25*ΔAR
- Assumed 10% of irrigators (30,214) could be hooked up to reuse

Parameters for the outdoor BMP optimization

<table>
<thead>
<tr>
<th>BMP</th>
<th>c_i</th>
<th>ymax_i</th>
<th>k_i</th>
<th>xmax_i</th>
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</thead>
<tbody>
<tr>
<td>Soil moisture sensors (x1)</td>
<td>0.22</td>
<td>3,494,087</td>
<td>2.241E-4</td>
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<td>Irrigation audits (x2)</td>
<td>0.06</td>
<td>873,522</td>
<td>2.241E-4</td>
<td>28,119</td>
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<td>Reuse (x3)</td>
<td>0.36</td>
<td>5,493,904</td>
<td>1.9401E-4</td>
<td>30,421</td>
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<td>Total</td>
<td>n/a</td>
<td>9,861,513</td>
<td>n/a</td>
<td>86,659</td>
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</table>
Least costly combination of the three outdoor BMPs to meet a specified target savings for CFWI.

<table>
<thead>
<tr>
<th>Target conservation savings, Q (MGD)</th>
<th>Total cost ($/d)</th>
<th>Accounts to retrofit</th>
<th>Total accounts</th>
<th>Marginal cost ($/kgal)*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Soil moisture sensors</td>
<td>Irrigation audits</td>
<td>Reuse</td>
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<tr>
<td>0.5</td>
<td>$151</td>
<td>623</td>
<td>235</td>
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<td>1</td>
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<td>3</td>
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<td>5</td>
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<td>8</td>
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<td>8.3</td>
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<td>9</td>
<td>$7,558</td>
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<td>9.83</td>
<td>$17,829</td>
<td>26,119</td>
<td>25,807</td>
<td>29,263</td>
</tr>
</tbody>
</table>

#Marginal cost is the shadow price (dual variable) with the respect to the specified minimum amount of water.
Total and Marginal Cost Curves for CFWI Outdoor BMPs

**Total cost curve for CFWI outdoor BMPs**

- Equation: \( y = 193.38e^{0.4289x} \)
- \( R^2 = 0.9712 \)

- **X-axis:** Cumulative water saved (MGD)
- **Y-axis:** Total cost ($/day)

**Marginal cost curve for CFWI outdoor BMPs**

- **X-axis:** Cumulative water saved (MGD)
- **Y-axis:** Marginal cost ($/mgal/day)
Ongoing Methodology Enhancements

- Reuse market potential and cost per account highly variable and utility specific
- Depends on existing reuse network and reclaimed water treatment plant locations

Combining with other BMPs

Legend
- Irrigation Selection Group
- Toilet Selection Group
- State roads
- Interstate highways
- Service Area Boundary
- FDOR Parcels

Reuse service areas
Summary And Conclusions

- Outdoor water usage can be estimated at the parcel level using property appraisal and customer billing data.
- Trending toward smaller irrigable area with increasing percentage of in-ground sprinklers.
- Need to focus outdoor BMPs on only those homes which “over irrigate.”
- Optimal mix of outdoor BMPs can be found using nonlinear programming.
  - Can be extended to BMPs from other sectors.
- Reuse opportunities depend on current infrastructure.
- Incorporation into EZ Guide planning tool.