This presentation premiered at WaterSmart Innovations

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Integrating environmental and social factors for understanding and improving irrigation efficiency in Orange County, CA

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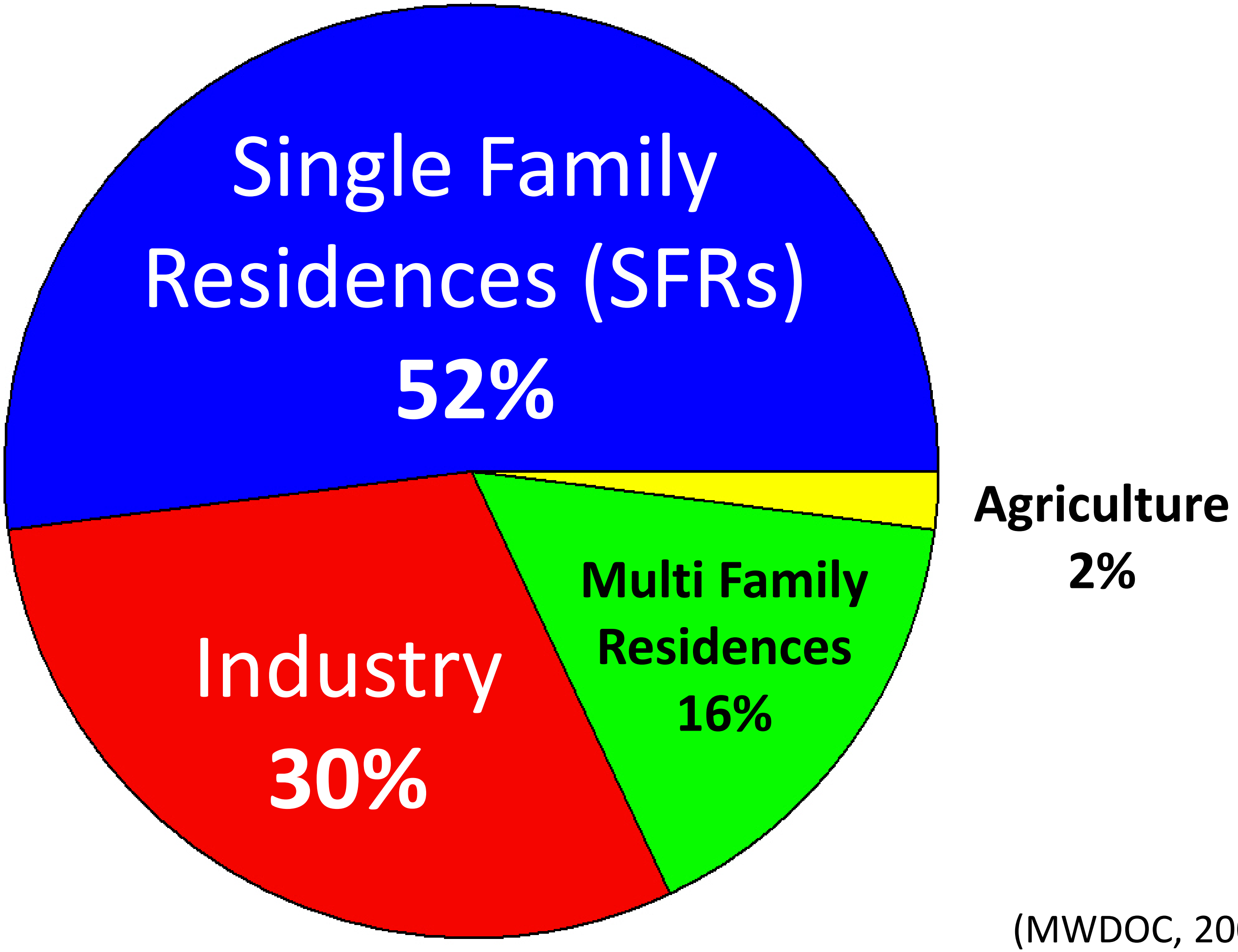
Orange County Water Use



(MWDOC, 2009)

Urban landscapes need a significant amount water

Milesi et al., 2005

Lawn is largest irrigated crop

- A dominant amount of SFR water use may be used for landscape irrigation- but this needs to be quantified.

Introduction

- A large proportion of irrigation may be applied in excess of plant irrigation demand.

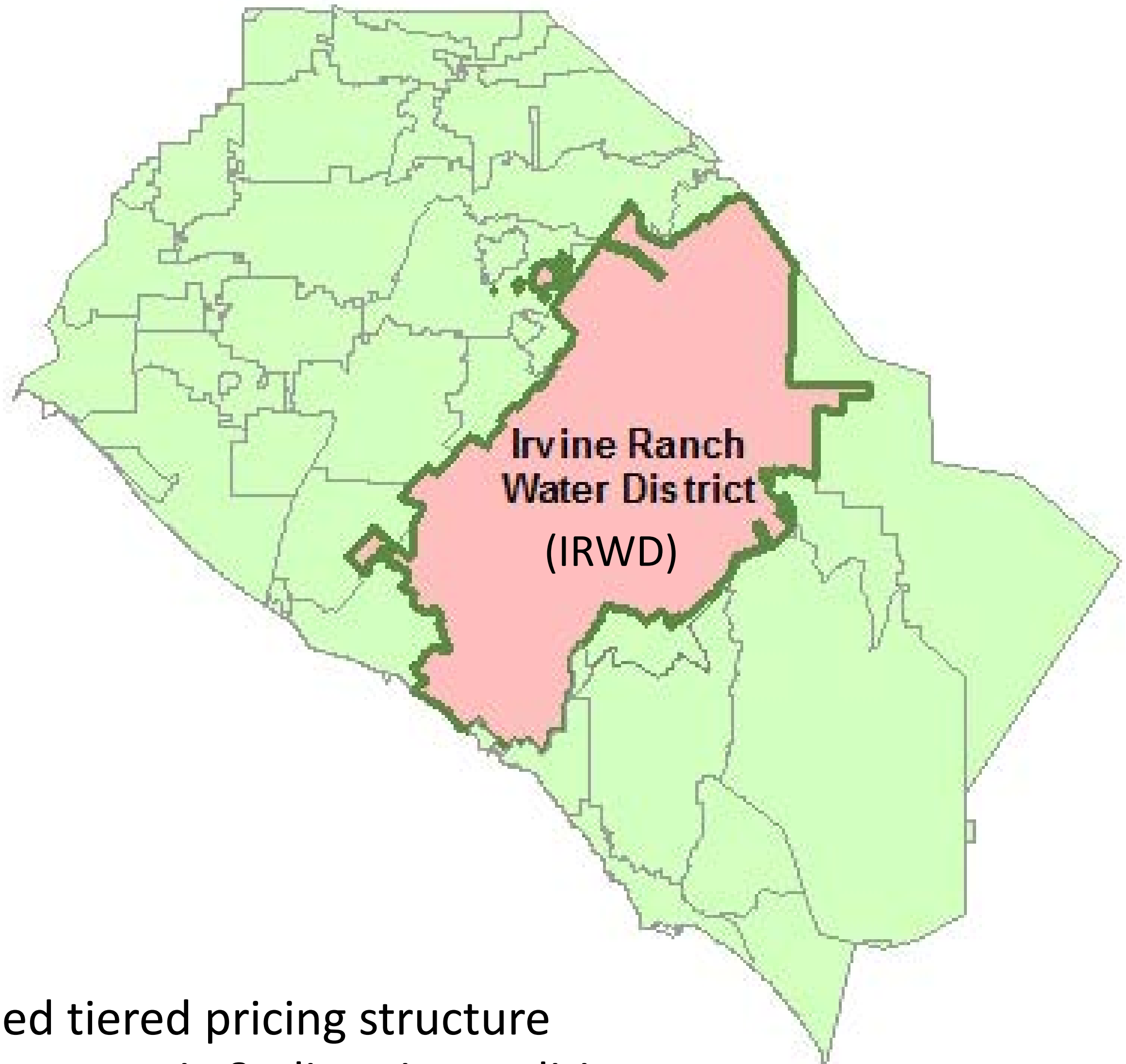
- To target conservation efforts, we need to know how much, where, and why over-irrigation is occurring.

- This requires data mining and analysis of a large amount of billing data.

Research Questions for this Study

- What is the outdoor water use for single family residences (SFRs)? What are the trends over time?
- Are landscapes being over-irrigated? What are the trends?
- Do people adjust watering based on climate (air temperature and precipitation) or income?
- Where are the areas of high water use?

Participating Agency



> 50,000 SFRs
> 180 sq. mi.
Allocation-based tiered pricing structure
Range of socioeconomic & climatic conditions

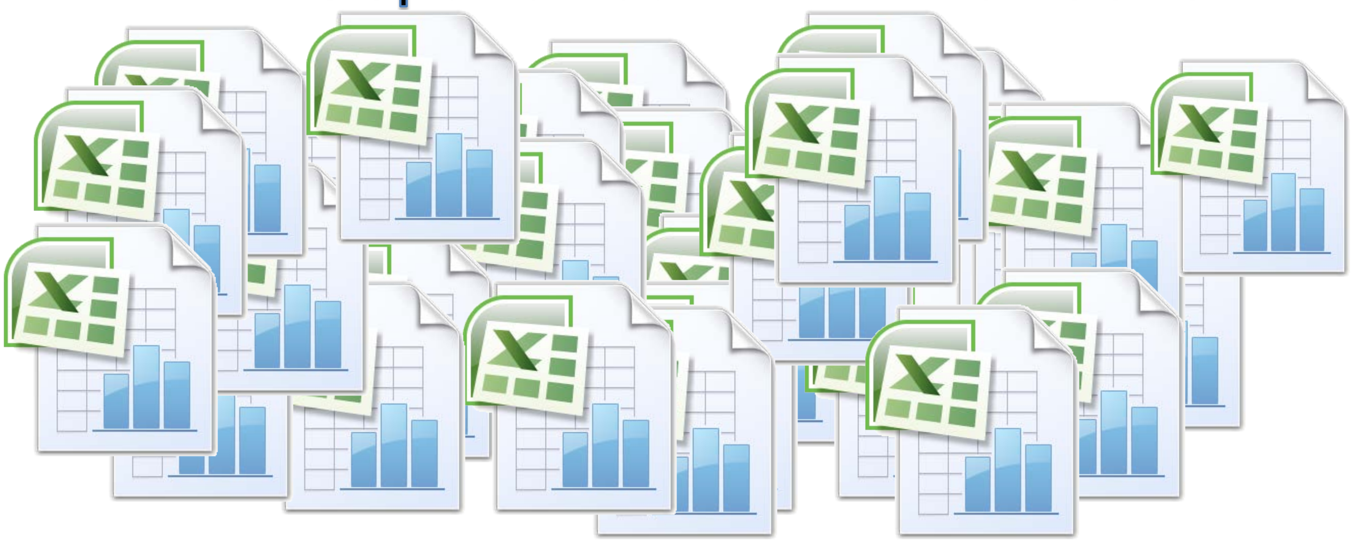
IRWD Billing Data

< About 3 Million Rows >

Account Sequence Number	TENANT NO.	SVC STR NO	SVC STR NAME	SERVICE CITY CODE	CCF_Usage	ACCOUNT NO	BILL TYPE CODE	BILL PER FROM	BILL PER TO	CUR YR DAYS	OUTDOOR ACRES ET	Creation date	DESCRIPTION
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20061226	20070125	30	0.03	20070126	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20070125	20070226	32	0.03	20070227	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	7	10000782093	REG	20070226	20070327	29	0.03	20070328	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20070327	20070425	29	0.03	20070426	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20070425	20070524	29	0.03	20070525	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20070524	20070625	32	0.03	20070626	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	7	10000782093	REG	20070625	20070725	30	0.03	20070726	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	7	10000782093	REG	20070725	20070823	29	0.03	20070827	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	6	10000782093	REG	20070823	20070924	32	0.03	20070925	5/8" DISC
782	9	24492	APPLEWOOD LN	TU	5	10000782093	REG	20070924	20071024	30	0.03	20071025	5/8" DISC

⋮ (3,138,886 rows !)

< Separated in 49 Sheets >

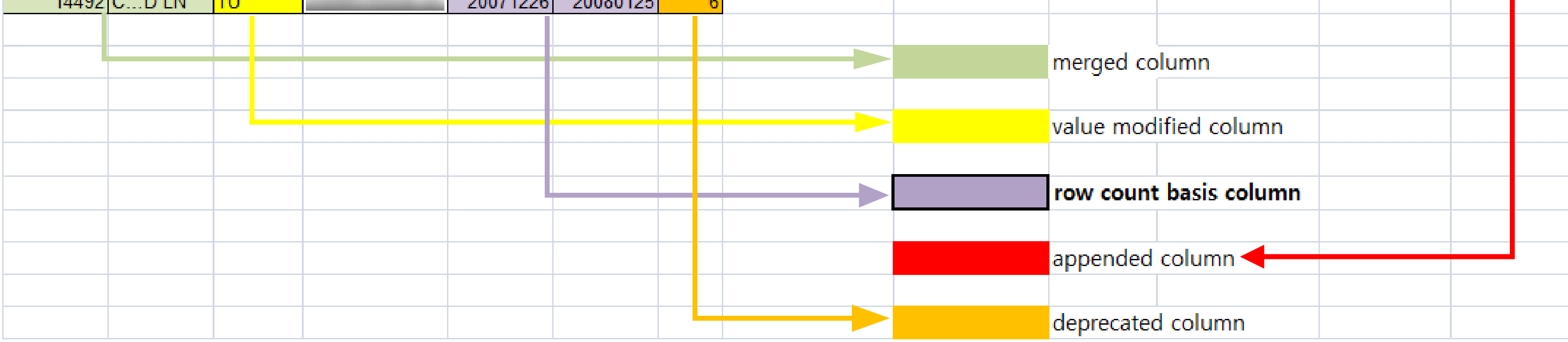


Refining the data

< Row / Col Rearrangement into Monthly Format>

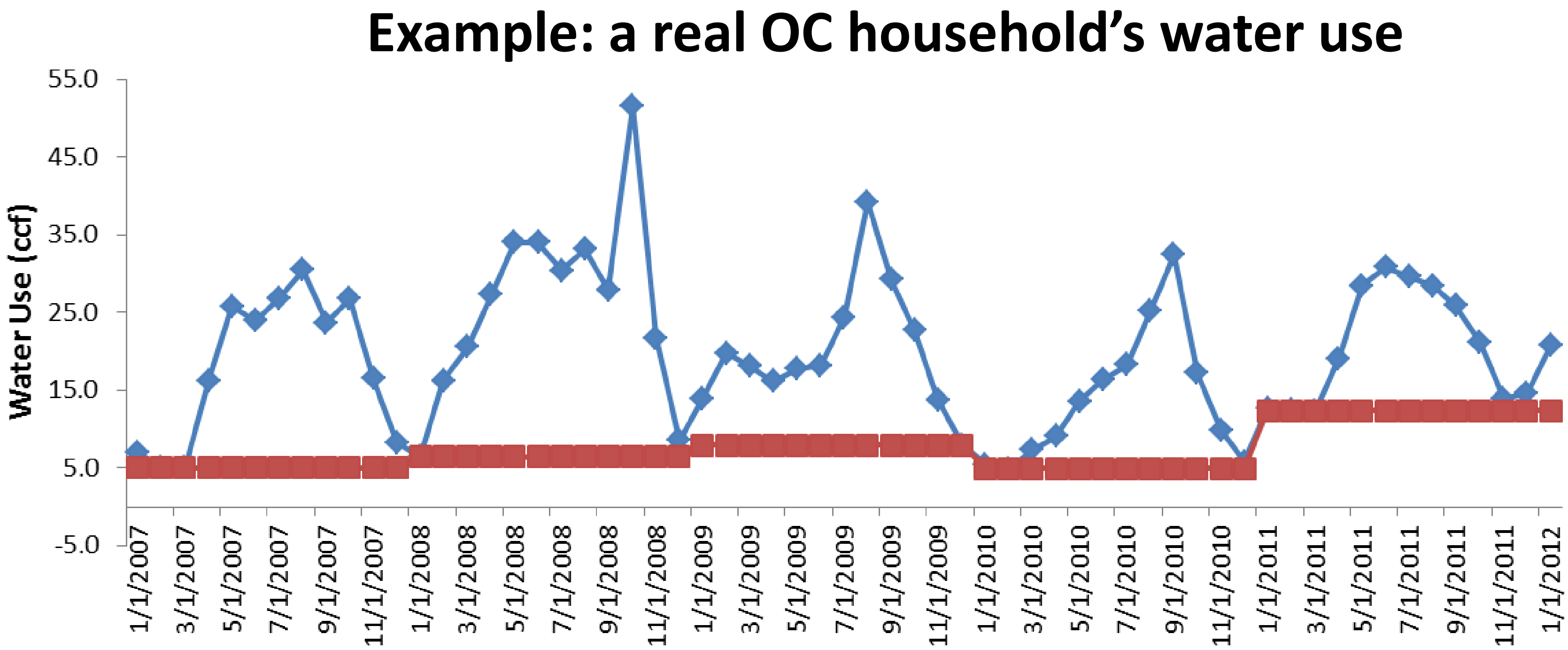
SVC STR NO	SVC STR NAME	SERVICE CITY CODE	ACCOUNT NO	BILL PER FROM	BILL PER TO	CCF_ Usage
14492	C...D LN	TU	[illegible]	20061226	20070125	5
14492	C...D LN	TU	[illegible]	20070125	20070226	5
14492	C...D LN	TU	[illegible]	20070226	20070327	7
14492	C...D LN	TU	[illegible]	20070327	20070425	5
14492	C...D LN	TU	[illegible]	20070425	20070524	5
14492	C...D LN	TU	[illegible]	20070524	20070625	5
14492	C...D LN	TU	[illegible]	20070625	20070725	7
14492	C...D LN	TU	[illegible]	20070725	20070823	7
14492	C...D LN	TU	[illegible]	20070823	20070924	6
14492	C...D LN	TU	[illegible]	20070924	20071024	5
14492	C...D LN	TU	[illegible]	20071024	20071126	7
14492	C...D LN	TU	[illegible]	20071126	20071226	4
14492	C...D LN	TU	[illegible]	20071226	20080125	6

StreetAddr	CityName	AccNumber	Month	MonthlyCCF
14492 C...D LN	TUSTIN	[illegible]	2007-01-01	5.09375
14492 C...D LN	TUSTIN	[illegible]	2007-02-01	4.63038793
14492 C...D LN	TUSTIN	[illegible]	2007-03-01	7.13793103
14492 C...D LN	TUSTIN	[illegible]	2007-04-01	5.17241379
14492 C...D LN	TUSTIN	[illegible]	2007-05-01	5.21551724
14492 C...D LN	TUSTIN	[illegible]	2007-06-01	5.15
14492 C...D LN	TUSTIN	[illegible]	2007-07-01	7.28965517
14492 C...D LN	TUSTIN	[illegible]	2007-08-01	6.99784483
14492 C...D LN	TUSTIN	[illegible]	2007-09-01	5.47916667
14492 C...D LN	TUSTIN	[illegible]	2007-10-01	5.53030303
14492 C...D LN	TUSTIN	[illegible]	2007-11-01	5.96969697
14492 C...D LN	TUSTIN	[illegible]	2007-12-01	4.53333333



Includes removal of anomalous data

Outdoor Water Use Estimation



Blue - Total Water Use

Red - Indoor Water Use (Minimum Month Method)

Criteria – Minimum Month was selected from winter months (Dec, Jan, Feb)

Outdoor Water Use = Total Water Use – Indoor Water Use

Outdoor Water Use (CCF) Estimation

- The method is a **conservative** estimate of outdoor water use, as winter watering may occur.
- Indoor use may be overestimated and outdoor use may be underestimated.

Depth of Outdoor Water Use (in.) Calculation

- Outdoor water use volume was divided by irrigable land (turf, tree, and pool) areas to obtain depth of irrigation

Example: Orange County Parcel Analysis

- Turf, tree, and pool areas per parcel provided by Municipal Water District of Orange County
- Used National Agriculture Imagery Program (NAIP) 1-meter resolution data
- Total average error is 7.5%
- 68% of IRWD homes (~33,000) were matched

Irrigation Demand Calculation

Irrigation Demand =

Landscape Evapotranspiration (ET_L) – Effective Precipitation (P_e)

Landscape Evapotranspiration (ET_L) =

$$(ET_R * k_{c\text{-}turf} * \text{turf fractional area})/SE_{turf} +$$
$$(ET_R * k_{c\text{-}tree} * \text{tree fractional area})/SE_{tree} +$$
$$(ET_R * k_{c\text{-}pool} * \text{pool fractional area})$$

ET_R – reference evapotranspiration
k_c – crop/pool coefficient
SE – sprinkler efficiency

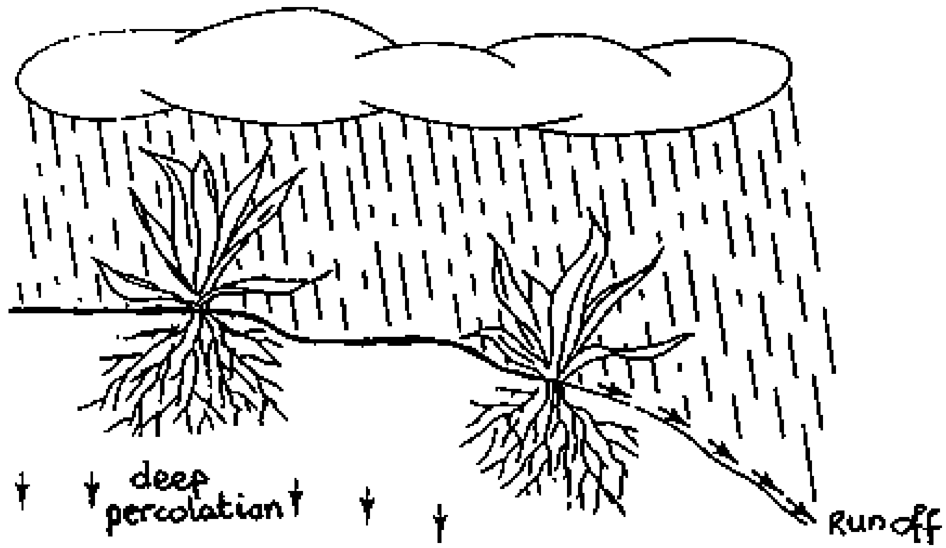
$k_{c\text{-}turf}$ = average 0.8 (depends on month)

$k_{c\text{-}tree}$ = 0.5

$k_{c\text{-}pool}$ = 1

Used Hargreaves method to estimate ET_R. This calculation depends on Solar Radiation (obtained from CIMIS) and Air T (calculated based on station data).

Effective Precipitation (P_e)

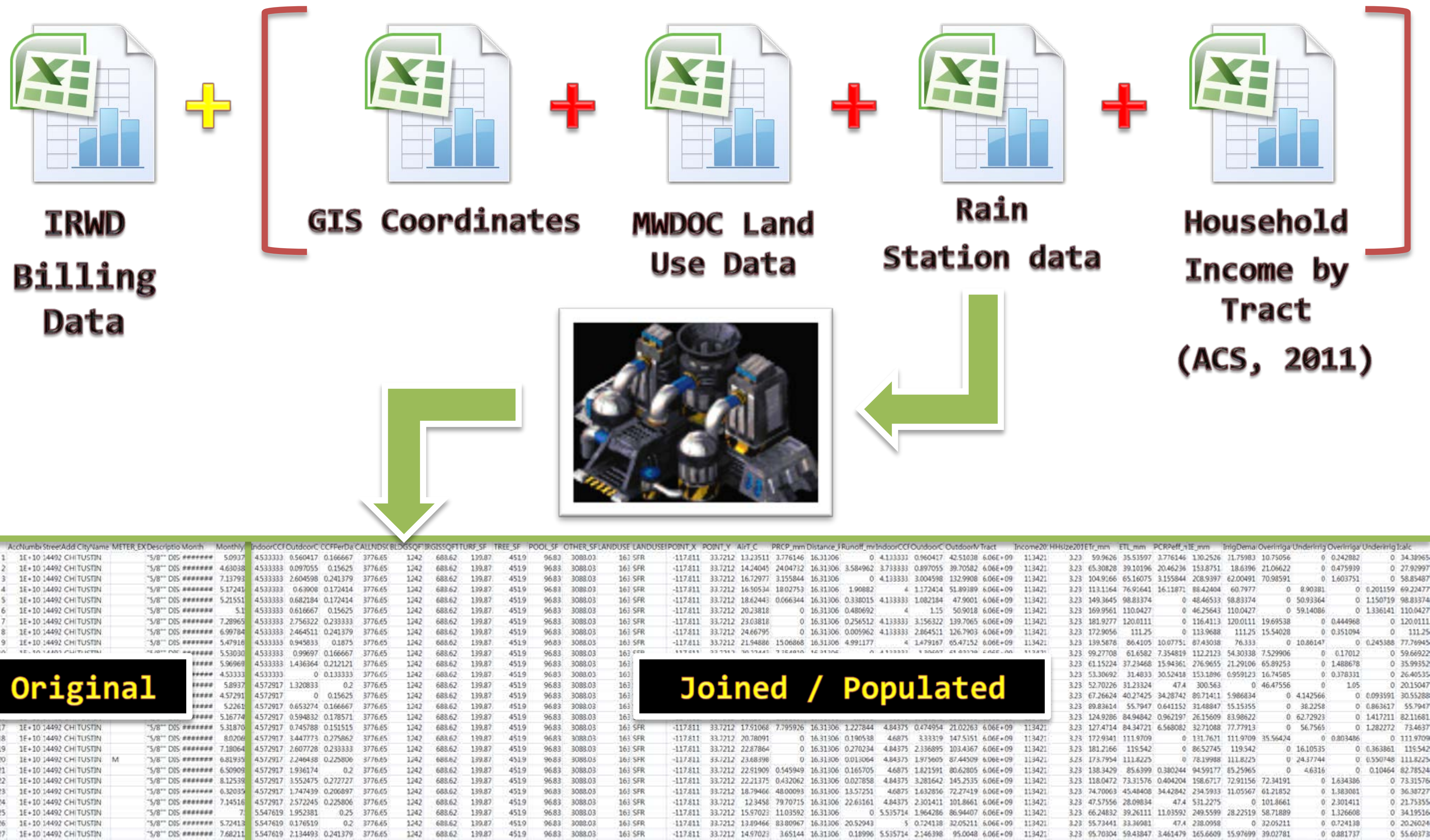


P_e is the part of rainfall that can be used to meet the evapotranspiration of plants. It does not include surface runoff or percolation below the plant root zone.

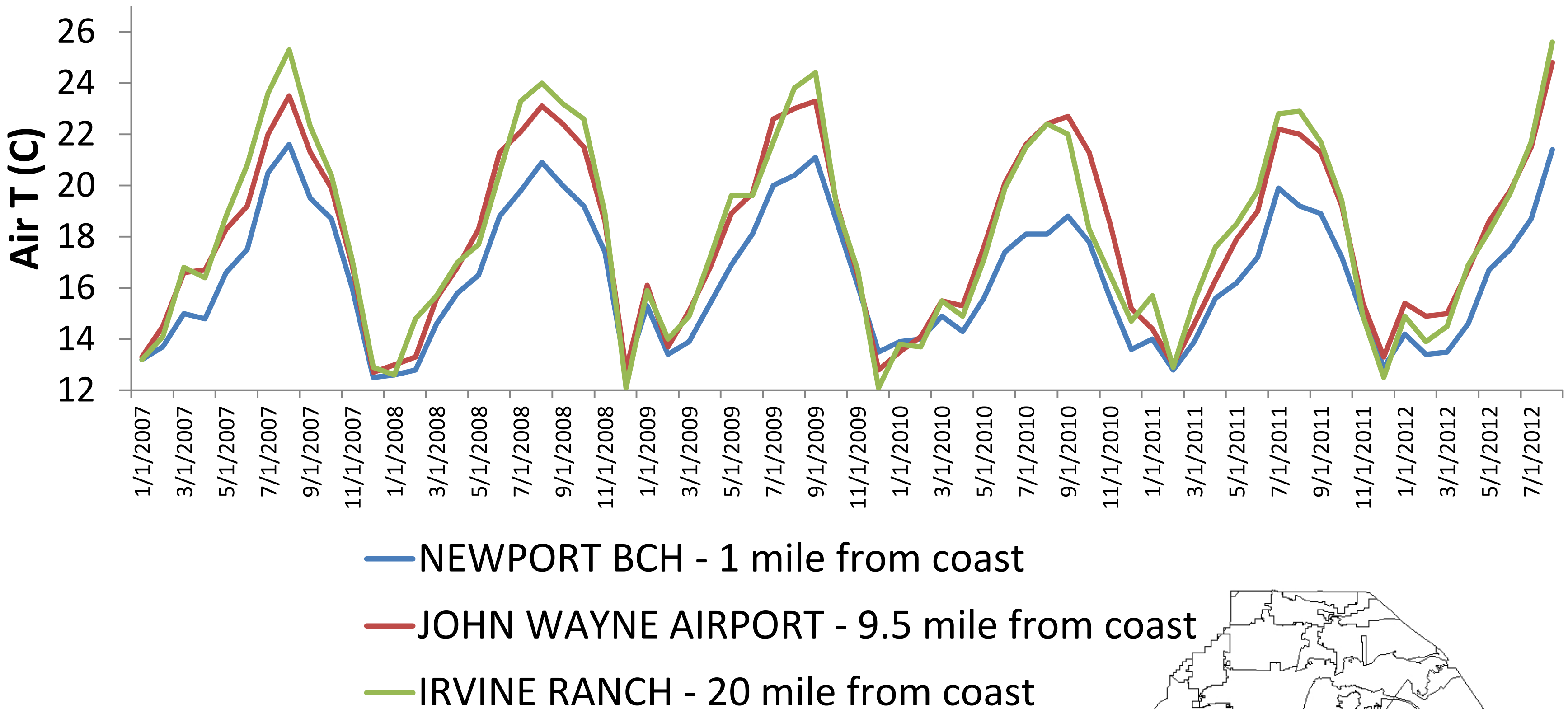
P_e = Precipitation – Runoff – Deep Percolation

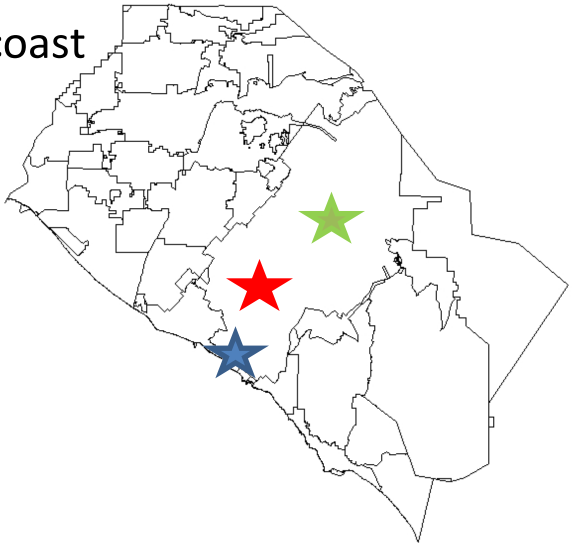
Used USDA methodology to calculate P_e (USDA, 1993)

Each house was assigned with climate and income data



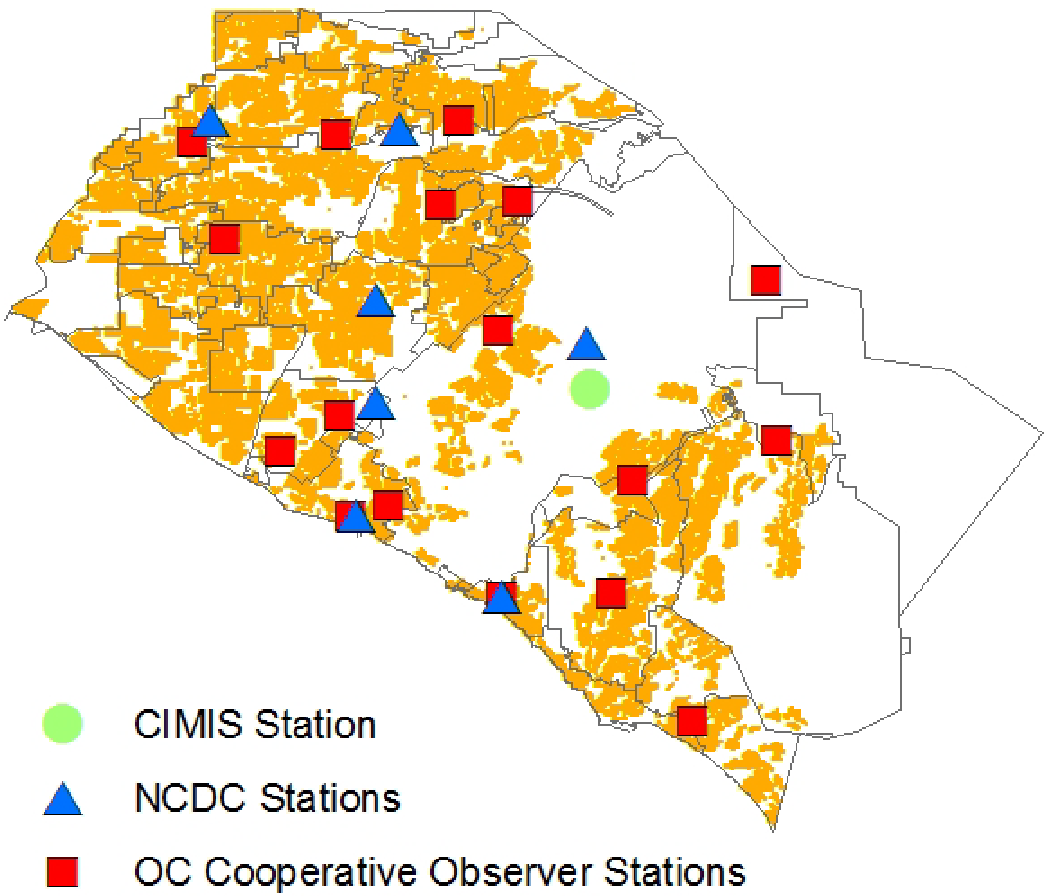
Air T calculation





Used distance from coast to interpolate temperature

Assigned precipitation values with inverse distance weighting



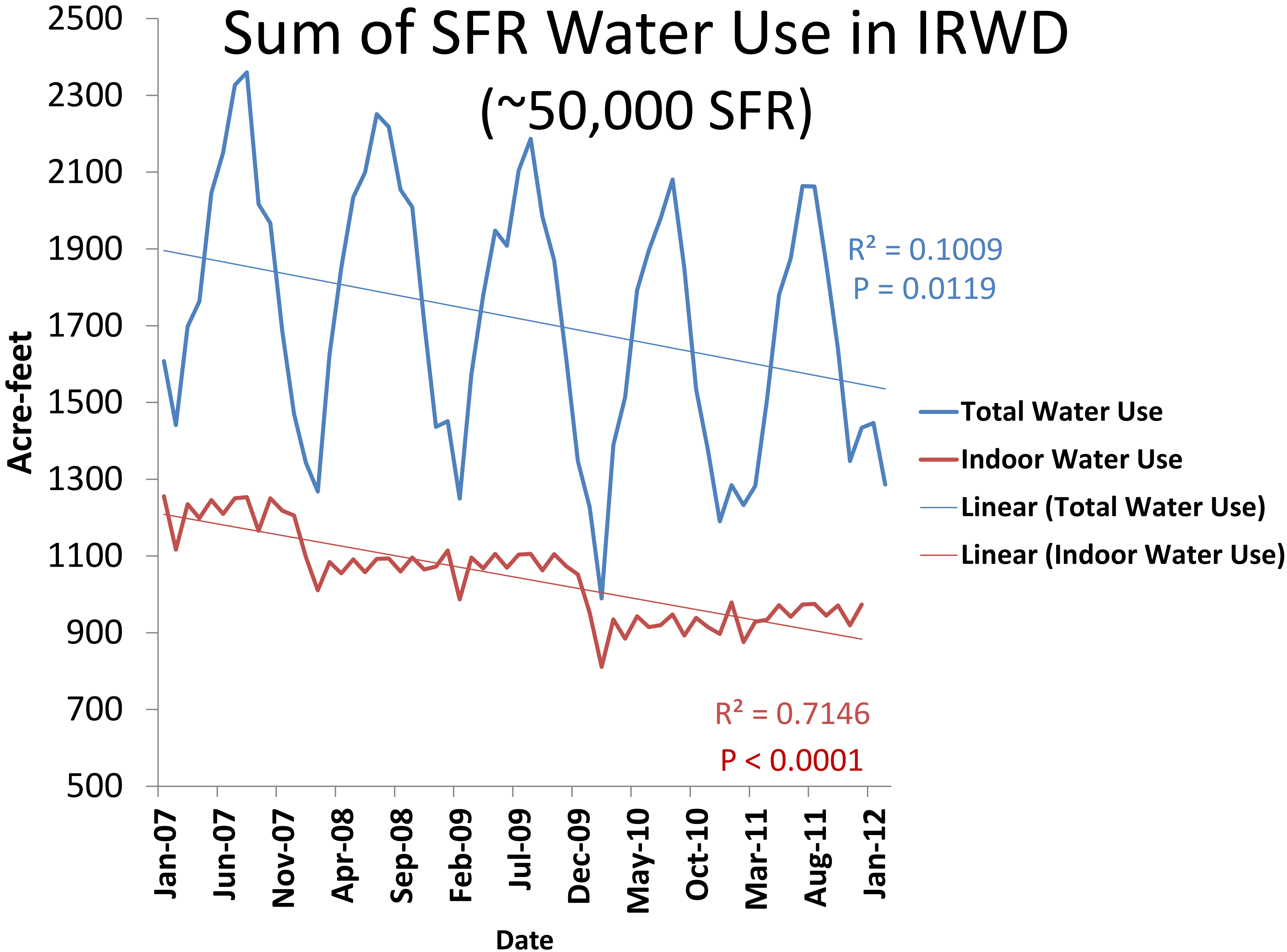
Normally, it is useful to constrain computation to points in a neighborhood of the location for which we wish to obtain a value.

$$x = \sum_{i=1}^{n} (Z_i/D_i) \Big/ \sum_{i=1}^{n} ({}^{1}/_{D_i})$$

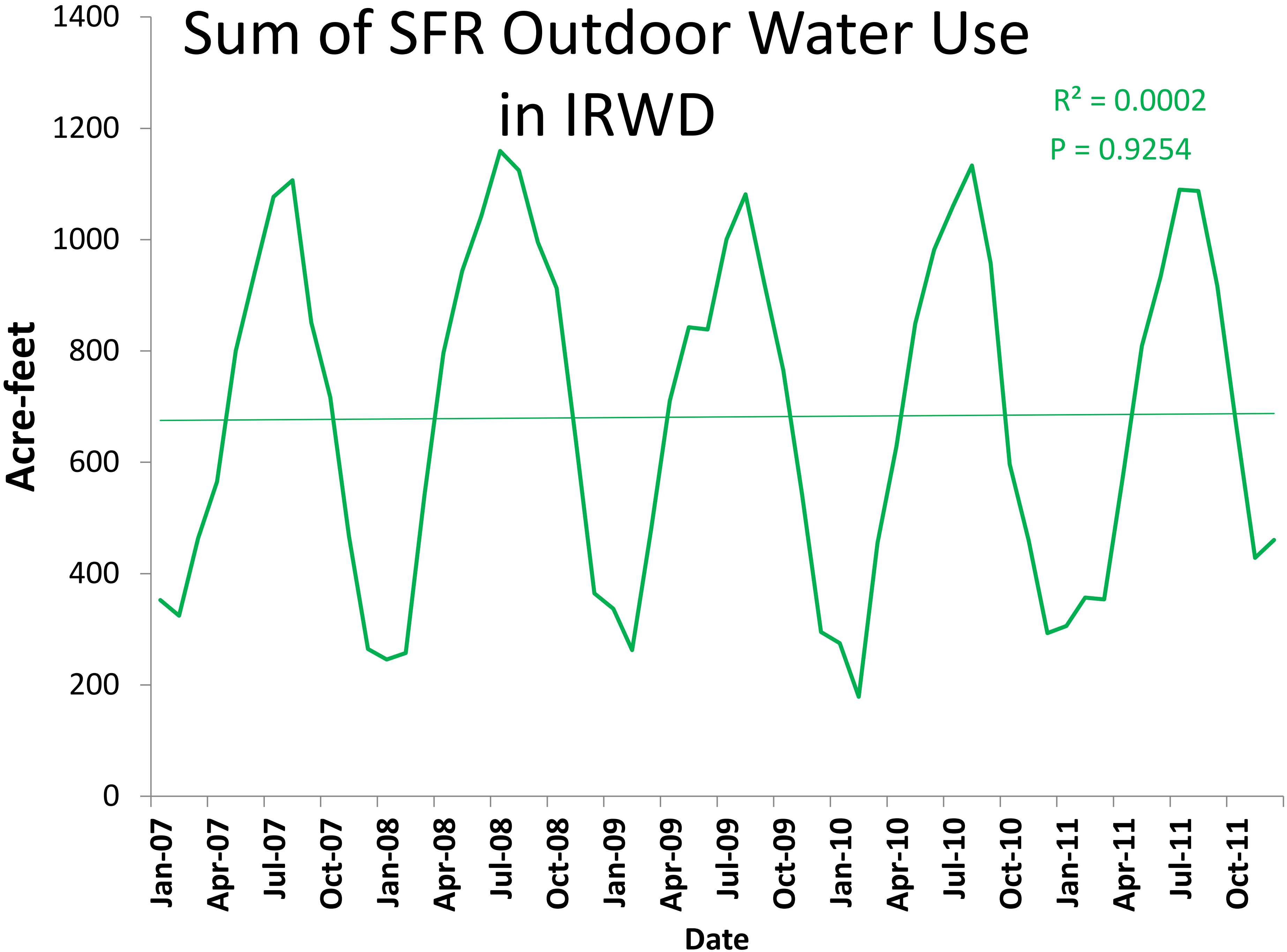
Where,

- **x = interpolated value,**
- **Zi = data value, of which there are n in the neighborhood of Z,**
- **Di = distance between x and each data point.**

Intuitively, this represents the average of the values of the surrounding points, weighted by the inverse of the distance to those points.

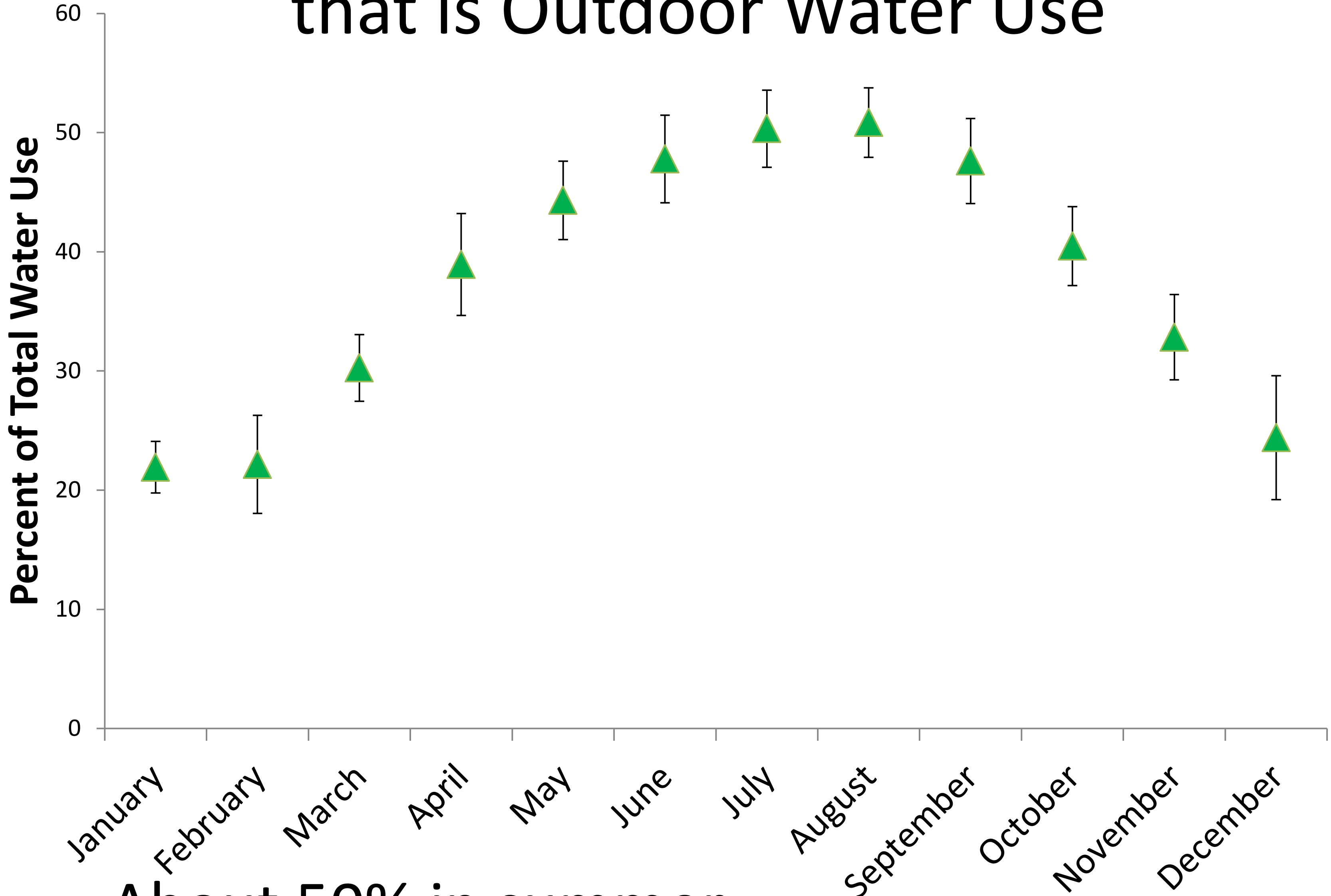


Sum of SFR Water Use in IRWD
(~50,000 SFR)
2500
2300
2100
1900
1700
1500
1300
1100
900
700
500
Acre-feet
Jan-07
Jun-07
Nov-07
Apr-08
Sep-08
Feb-09
Jul-09
Dec-09
May-10
Oct-10
Mar-11
Aug-11
Jan-12
Date
R² = 0.1009
P = 0.0119
R² = 0.7146
P < 0.0001
Total Water Use
Indoor Water Use
Linear (Total Water Use)
Linear (Indoor Water Use)



Sum of SFR Outdoor Water Use in IRWD
R^2 = 0.0002
P = 0.9254
Acre-feet
1400
1200
1000
800
600
400
200
0
Jan-07
Apr-07
Jul-07
Oct-07
Jan-08
Apr-08
Jul-08
Oct-08
Jan-09
Apr-09
Jul-09
Oct-09
Jan-10
Apr-10
Jul-10
Oct-10
Jan-11
Apr-11
Jul-11
Oct-11
Date

Percent of Total SFR Water Use that is Outdoor Water Use



- About 50% in summer
- About 20% in winter

Over-Irrigation Estimation Under Two Scenarios

Over-irrigation is defined as use above irrigation requirements

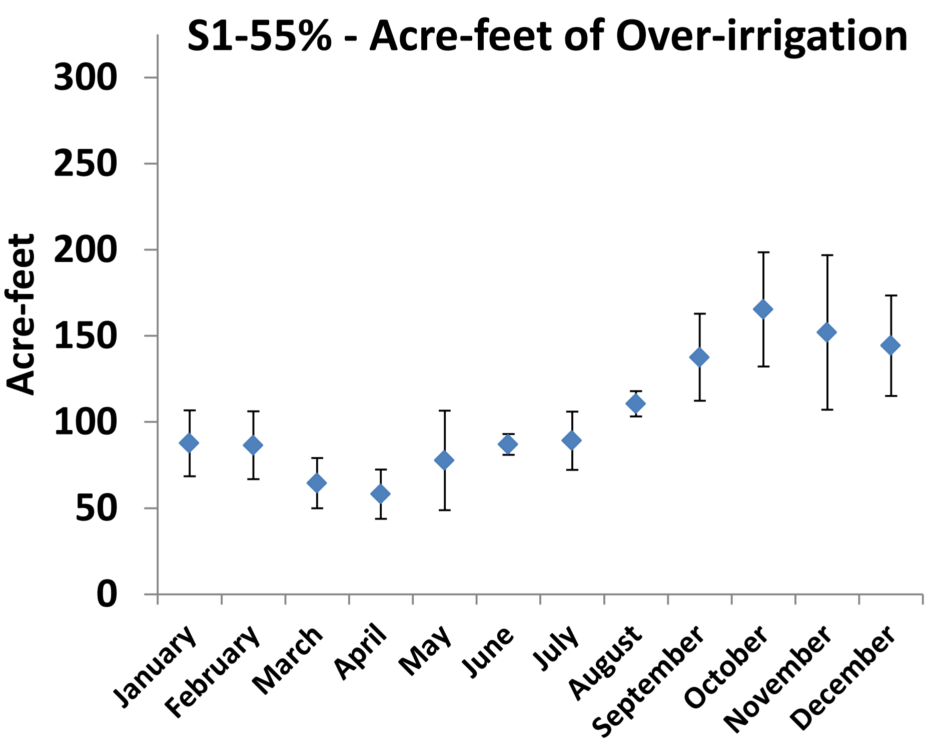
Scenario 1 (S1-55%) – Irrigation System Efficiency may be 55%

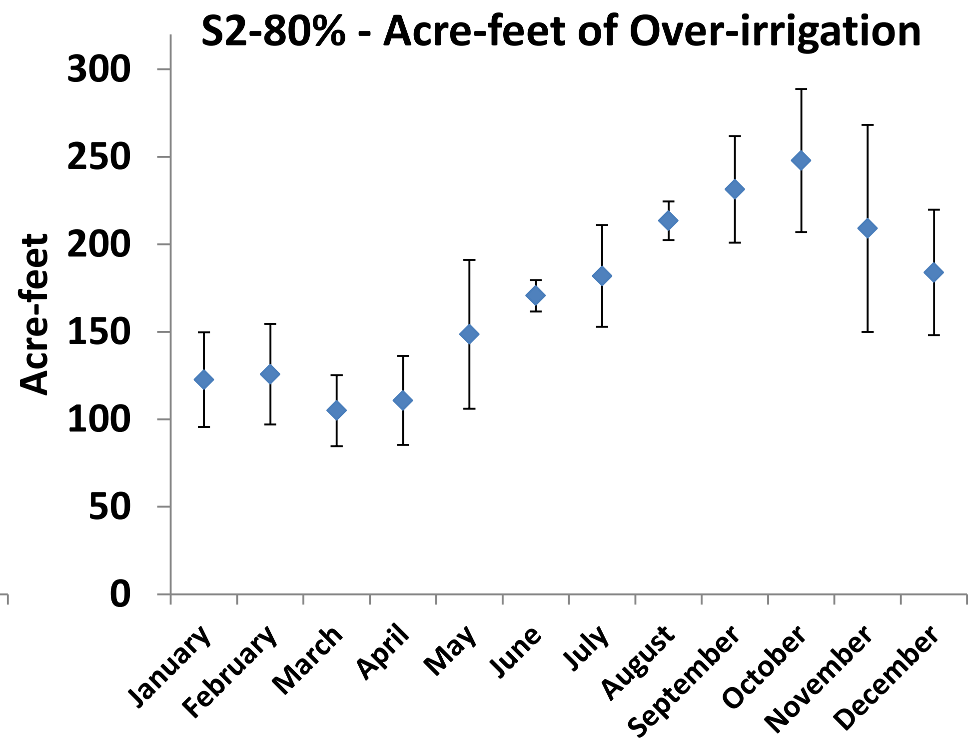
- This represents *possible* current irrigation system efficiency
- Actual current irrigation system efficiency is unknown

Scenario 2 (S2-80%) – Irrigation System Efficiency could be 80%

- This represents what irrigation system efficiency could be for a well-maintained irrigation system
- Leaves room for improvement

Sum of Total Over-Irrigation (65% SFRs)

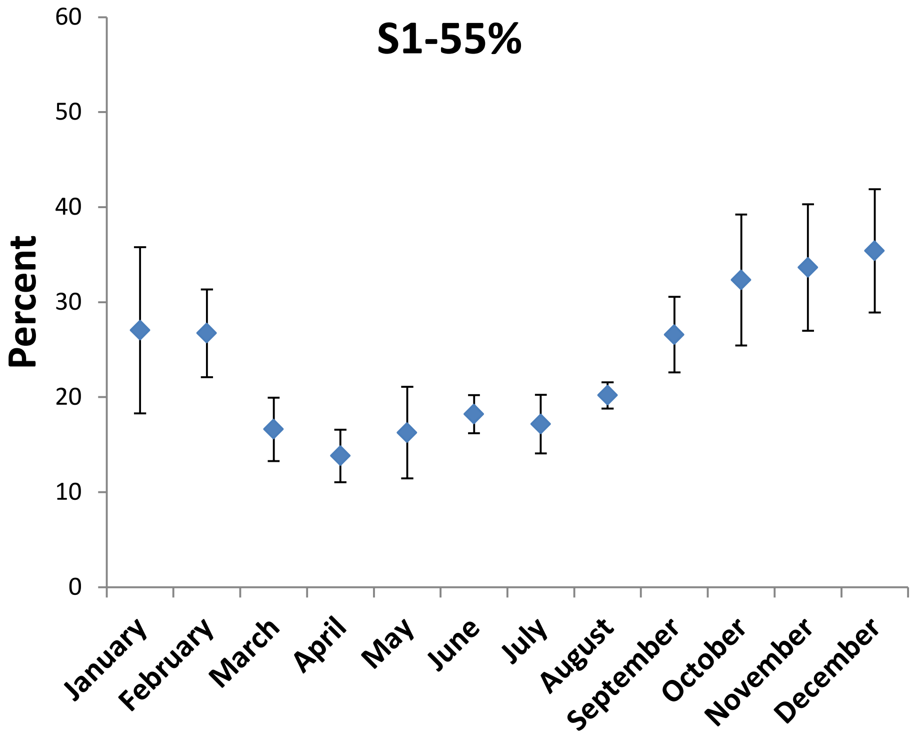


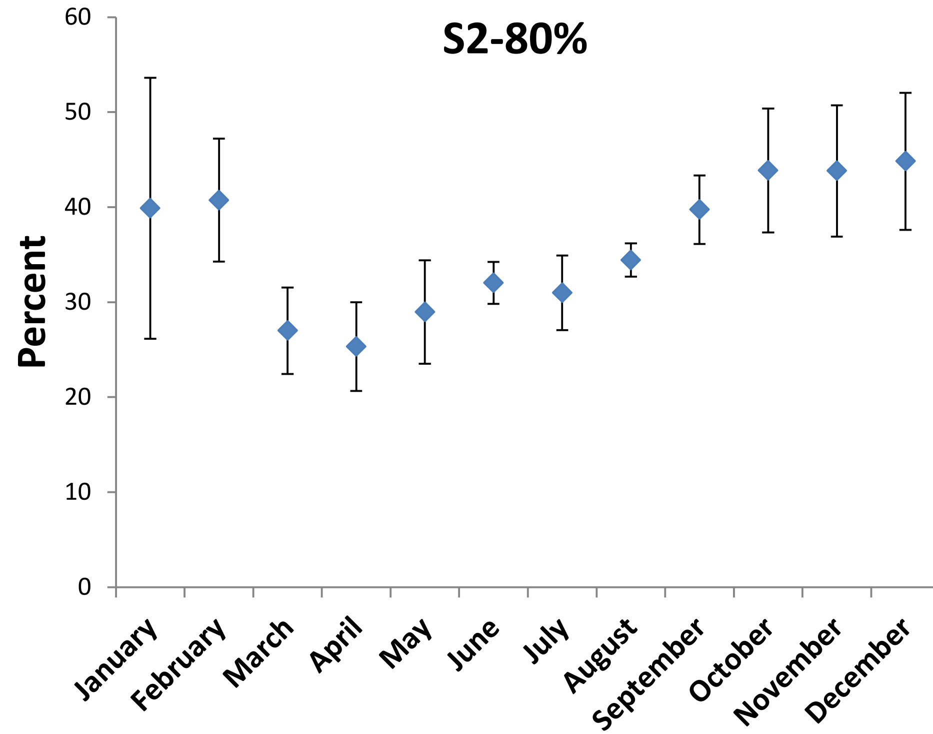


- S1-55% - Over-irrigation is 80 acre-feet/month in spring & summer
  Over-irrigation is 130 acre-feet/month in fall & winter
  Annual sum: 1260 Acre-feet (~2000 AF for IRWD)

- S2-80% - Over-irrigation is 155 acre-feet/month in spring & summer
  Over-irrigation is 190 acre-feet/month in fall & winter
  Annual sum: 2050 Acre-feet (~3000 AF for IRWD)

Percent of Homes that are Over-Irrigating

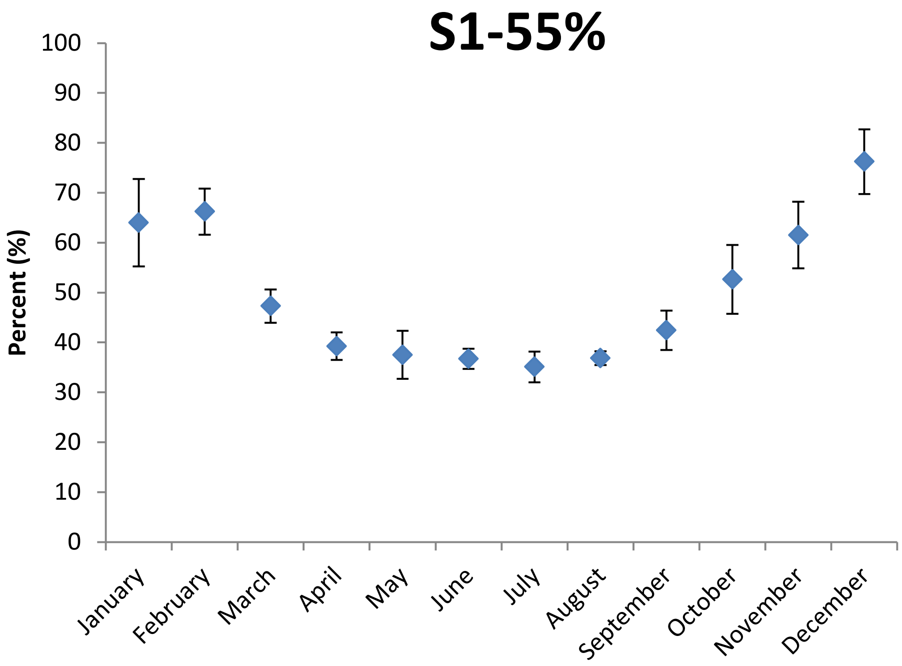


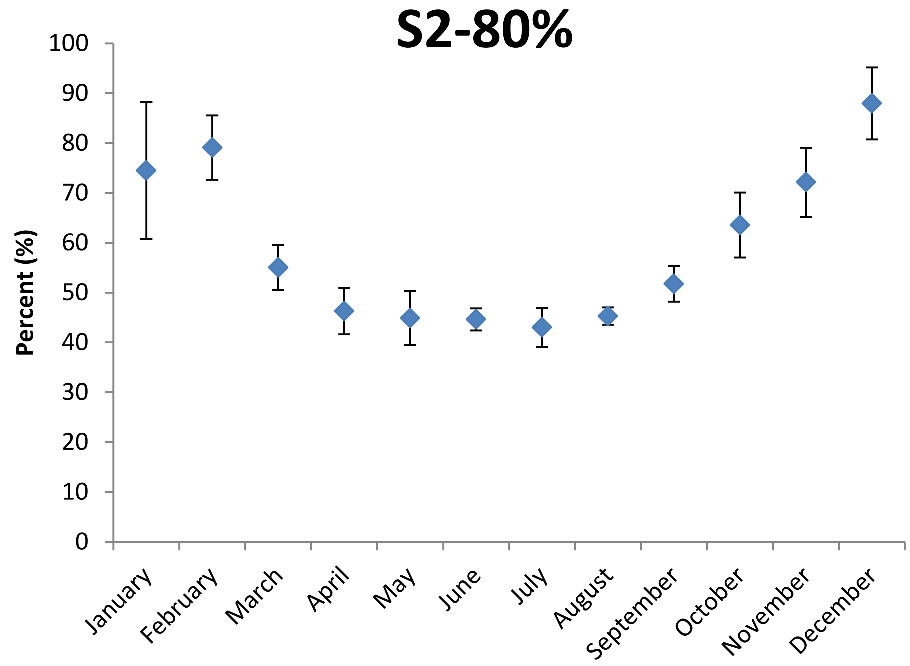


- S1-55% - About 17% of SFRs are over-irrigating in spring & summer
  About 30% of SFRs are over-irrigating in fall & winter

- S2-80% - About 30% of SFRs are over-irrigating in spring & summer
  About 42% of SFRs are over-irrigating in fall & winter

Percent of Outdoor Water Use that is Over-Irrigation (for Over-Irrigating Homes)

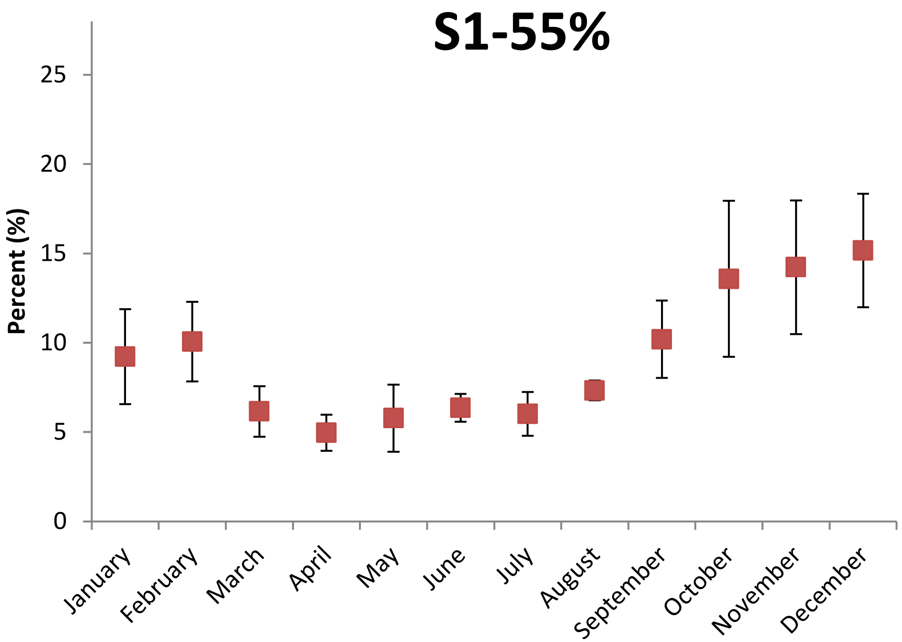


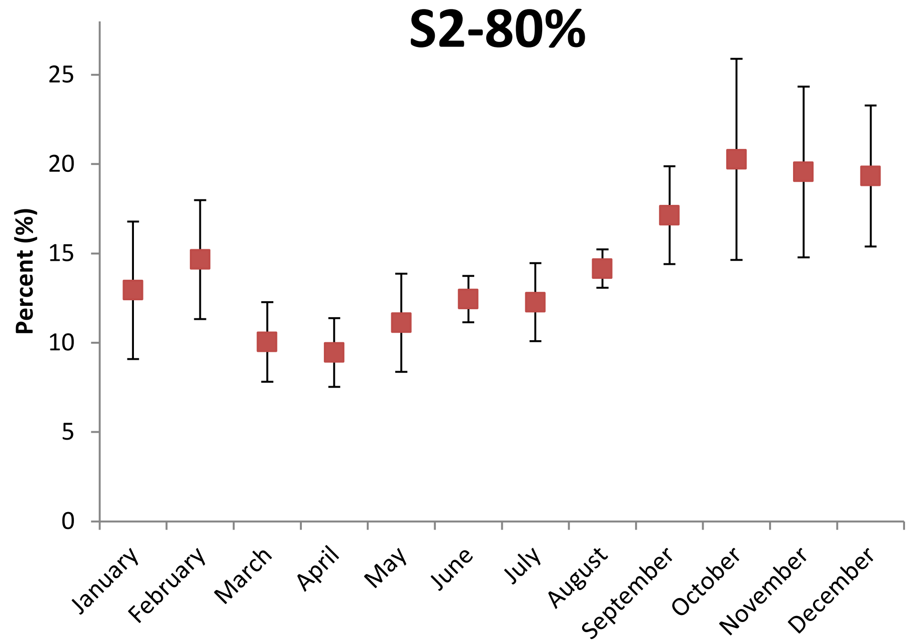


- S1-55% - 39% of SFR outdoor water use is over-irrigation in spring/summer
  61% of SFR outdoor water use is over-irrigation in winter/fall

- S2-80% - 47% of SFR outdoor water use is over-irrigation in spring/summer
  71% of SFR outdoor water use is over-irrigation in winter/fall

Percent of Total SFR Water Use that is Over-Irrigation





- S1-55% - 6% of SFR water use is over-irrigation in spring/summer
  12% of SFR water use is over-irrigation in winter/fall

- S2-80% - 12% of SFR water use is over-irrigation in spring/summer
  18% of SFR water use is over-irrigation in winter/fall

How does Climate and Income Influence Outdoor Water Use?

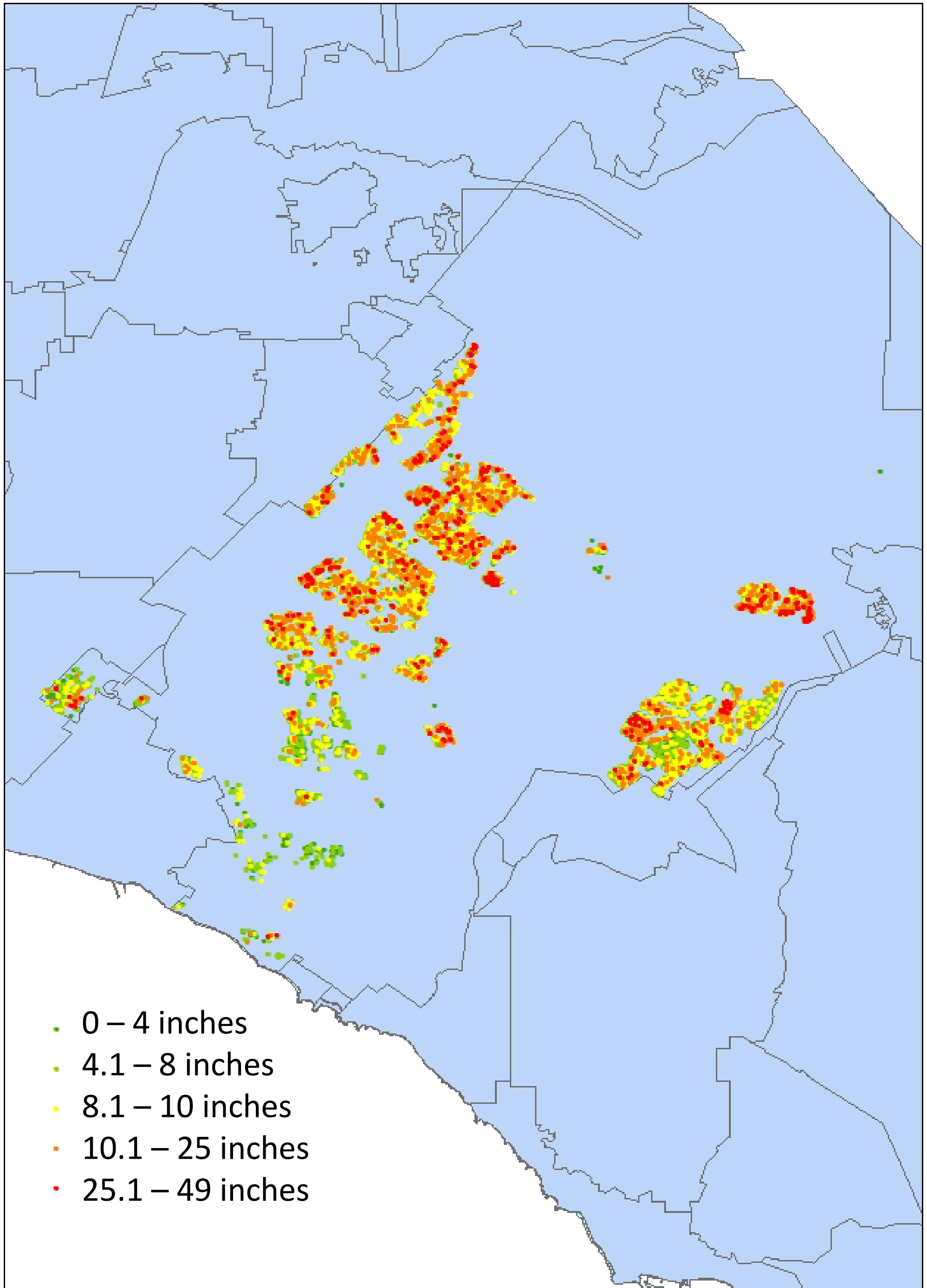
A multiple regression model of outdoor water use depth at the census tract level with Air Temperature, Precipitation, and Income showed an R^2 of 0.67.

Variable	R^2	P- value
Air Temperature	0.653	< 0.0001
Income	0.008	< 0.0001
Precipitation	0.026	< 0.0001

Increasing air temperature explains 65% of the **increase** in outdoor water use.

Increasing income explains 0.8% of the **decrease** in outdoor water use.

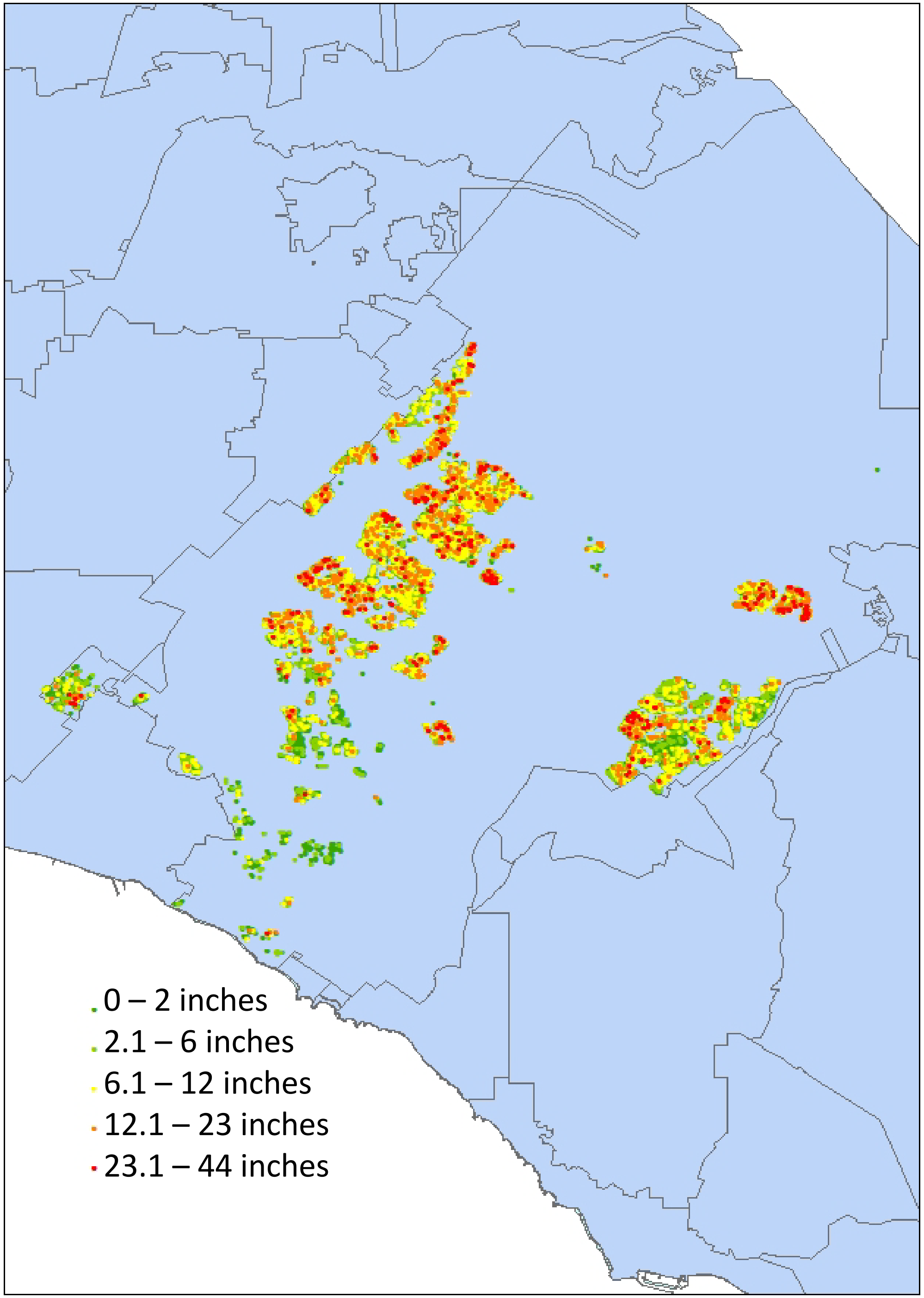
Increasing rain explains 2.6% of the **decrease** in outdoor water use.



August 2011
Outdoor Water Use

- Maps can be made for any month to show indoor, outdoor, total, over-irrigation, under-irrigation
- Can also be averaged by tract

August 2011
Over-Irrigation



Conclusions

- Total water use is declining, primarily due to indoor water use decline. Outdoor water use has not significantly changed.
- About 50% of total SFR water use is used outdoors in summer, and about 20% in winter.
- Over-irrigation is 80-155 AF/month in spring & summer for 65% of IRWD homes, and is 130-190 AF/month in fall & winter. The annual sum is 1260 – 2050 AF (2000-3000 AF for all of IRWD).
- Up to 20% of household water use is applied in excess to landscapes.
- Air temperature is the primary driver of outdoor irrigation.
- One degree F increase in temperature leads to approximately 103 AF increase in outdoor water use for 65% of IRWD homes. This would be about 160 AF for 100% of homes.

Applications

- Improving water use efficiency programs
- Billing penalties for customers with consistent wasteful use
- Targeted public awareness campaigns
- Understanding where rebate programs for “smart” irrigation sensors would be helpful
- Developing policies to reduce water use, such as regulations for
  - turf area/lot size
  - pool covering
  - landscape type
  - Irrigation timing
- Planning for the future
- Up to government agencies

Acknowledgements

Irvine Ranch Water District (IRWD)
Fiona Sanchez, Nathan Adams

Municipal Water District of Orange County (MWDOC)
Joe Berg, Melissa Baum-Haley

Thank you

I’ll be happy to answer questions.

Contact:

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Irrigation Demand Calculation

Irrigation Demand =

Landscape Evapotranspiration (ET_L) – Effective Precipitation

Landscape Evapotranspiration (ET_L) =

$(ET_R * k_{c\text{-}turf} * \text{turf fractional area})/SE_{turf}$ +

$(ET_R * k_{c\text{-}tree} * \text{tree fractional area})/SE_{tree}$ +

$(ET_R * k_{c\text{-}pool} * \text{pool fractional area})$

ET_R – reference evapotranspiration
k_c – crop/pool coefficient
SE – sprinkler efficiency

$k_{c\text{-}turf}$ = average 0.8 (depends on month)

$k_{c\text{-}tree}$ = 0.5

$k_{c\text{-}pool}$ = 1

Used Hargreaves equation to estimate ET_R. This equation depends on Solar Radiation (obtained from CIMIS) and Air T (calculated based on station data). $ET_R = 0.0135*(\text{Air T} + 17.78)*\text{Solar Radiation}$

Effective Precipitation (P_e)

- Used the USDA method to estimate P_e
- Scientifically tested method

$$P_e = SF\left(0.70917 P_t^{0.82416} - 0.11556\right)\left(10^{0.02426\,ET_c}\right)$$

where:

P_e = average monthly effective monthly precipitation (in)

P_t = monthly mean precipitation (in)

ET_c = average monthly crop evapotranspiration (in)

SF = soil water storage factor

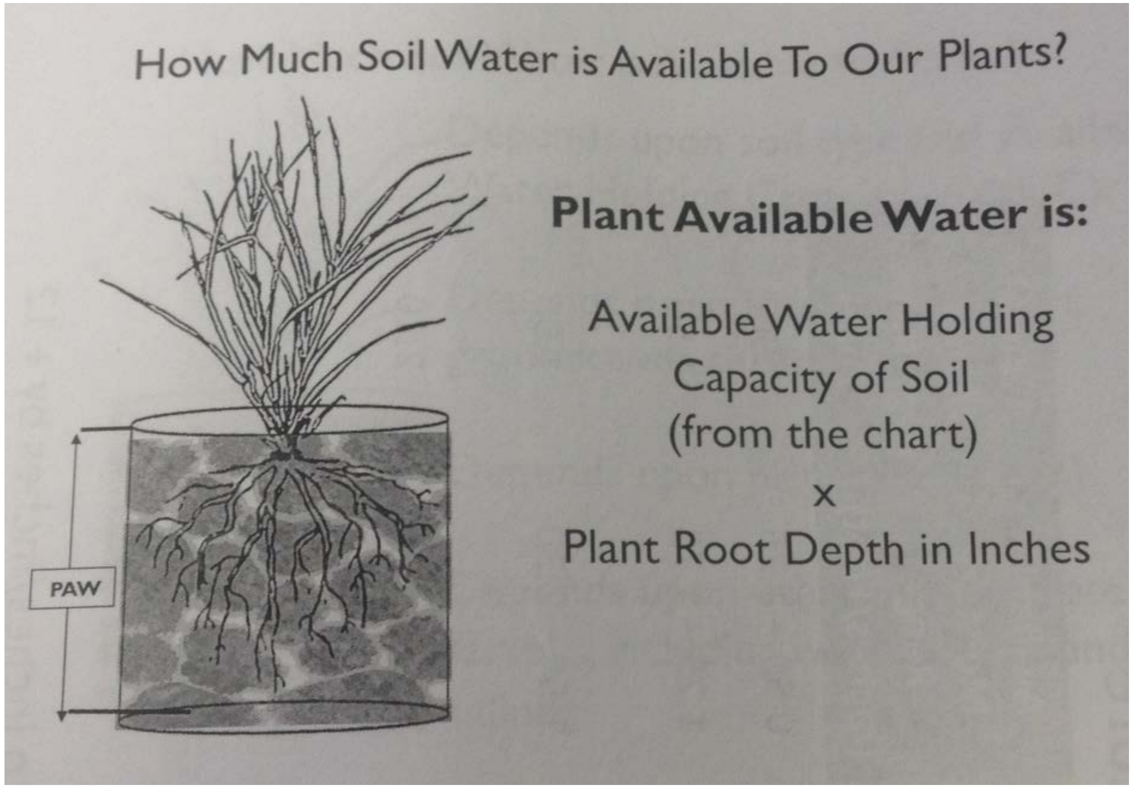
The soil water storage factor was defined by:

$$SF = \left(0.531747 + 0.295164\,D - 0.057697\,D^2 + 0.003804\,D^3\right)$$

where:

D = the usable soil water storage (in)

Usable soil water storage (D)



Courtesy: Baum-Haley

I assume
- most landscape species have an average rooting depth of 30 cm (Bijoor et al. 2008)
- an average Available Water Holding Capacity of soil to be 1.9 inches/foot or 0.158cm/cm

This is for medium textured soils.

The Usable Soil Water Storage is

0.158 cm/cm * 30 cm = 4.74 cm or 47.4 mm or 1.9 in

Outlier check

- Houses with excessively high outdoor water use (in.) were excluded from analysis (>5 SD above the mean, or above 49 in./mo., which exceeds annual landscape ET_R). Low end outliers not removed.
- 806 houses were excluded. This was 2.4% of the houses.
- These houses may have unusually high outdoor water use (in.) due to any of the following:
  - Leaks
  - Mismanagement by homeowner
  - Inefficient sprinkler system
  - Inaccurate estimations of irrigated area (if the area is underestimated, then outdoor water use depth could be overestimated)
- A list of these houses were provided to IRWD.