Rainwater as Potential Resource

For Water Independence in Tucson's Communities

26 February 2019

Making Action Possible

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photograph: southernarizonaguide.com John Edwards


Over the next 20 years, the EPA estimates
that Arizona's water delivery infrastructure
will require an added investment of over
$7.44 billion

In 2016, Tucson residential water demand was over

87 thousand acre-feet.

Approximately a third is imported or

29 thousand acre-feet.

In 2016, Tucson was supplied with over

125 thousand acre-feet of rainfall.

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144% of Tucson's annual water demand.

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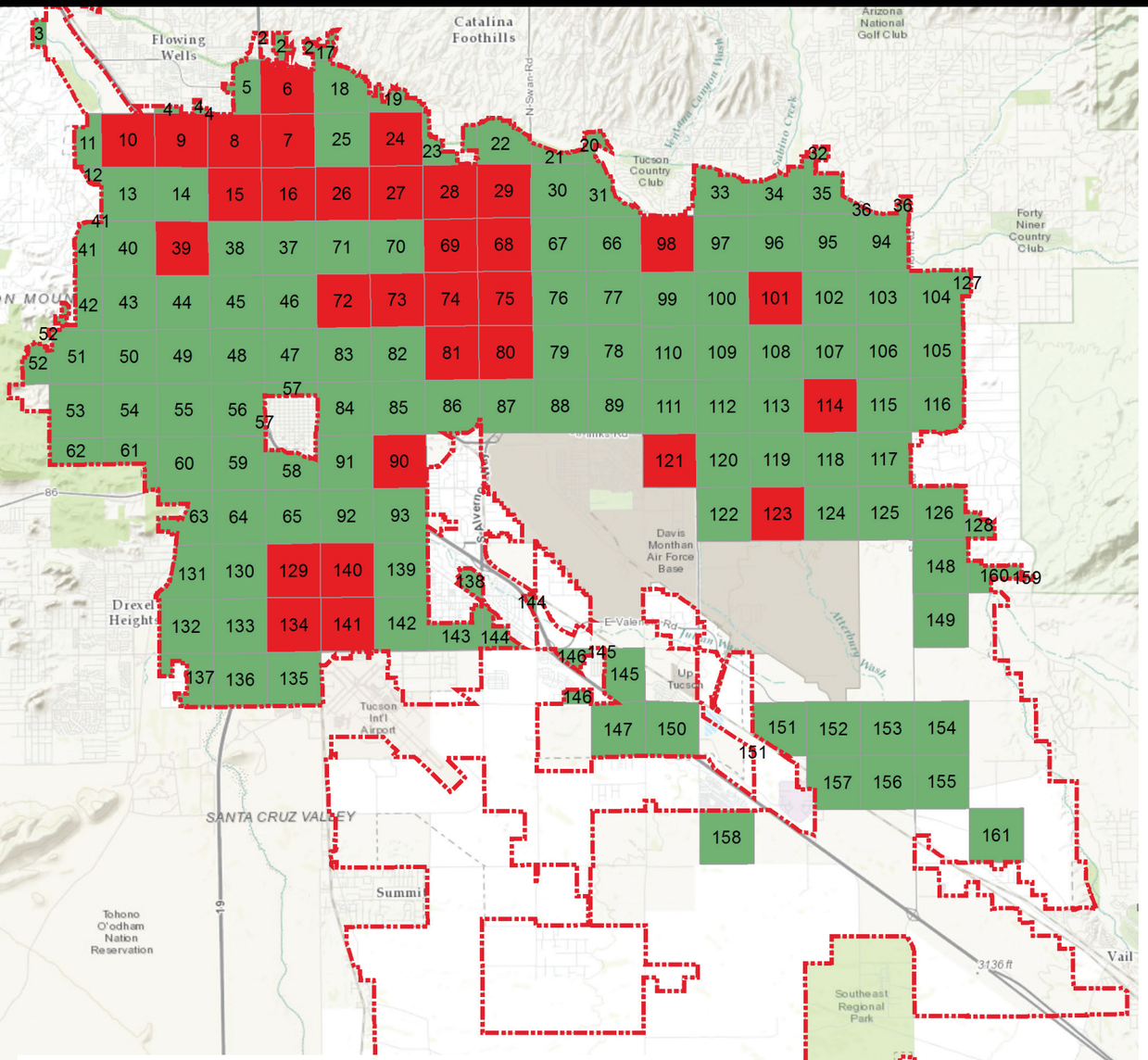
125 thousand acre-feet of rainfall.

144% of Tucson's annual water demand.

430% of Tucson's annual imported water.

CONTEXT LIMITATION



SUPPLY vs DEMAND: ANNUAL

Legend

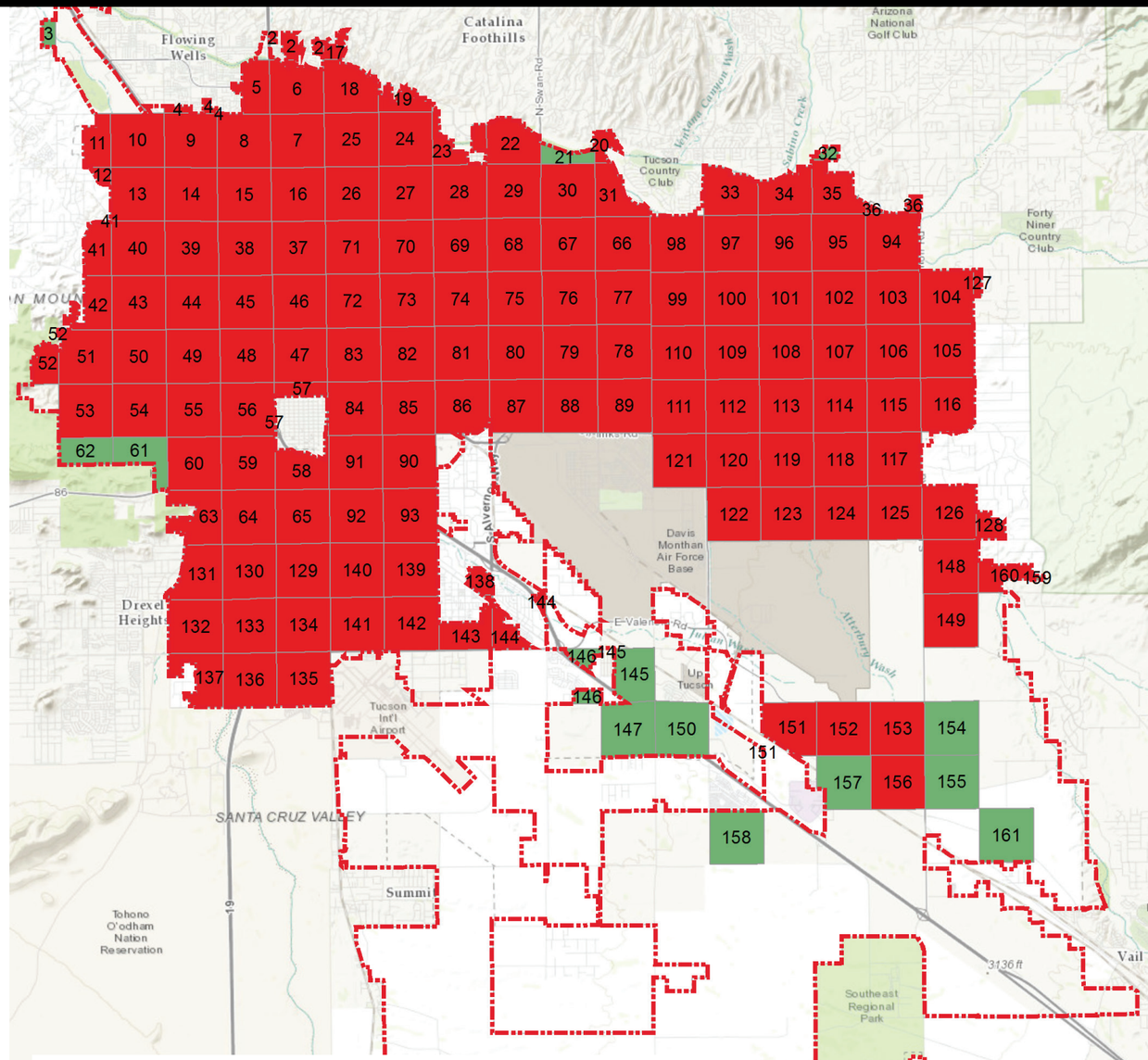
City Boundary of Tucson

Rainfall vs Demand by Year

< 0

> 0

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community



SUPPLY vs DEMAND: JUNE

Legend

City Boundary of Tucson

Rainfall vs Demand by June

< 0

> 0

Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

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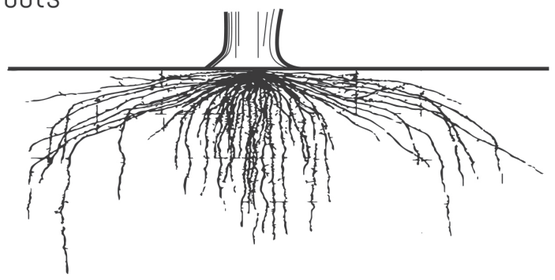
INFRASTRUCTURE LIMITATION: system components

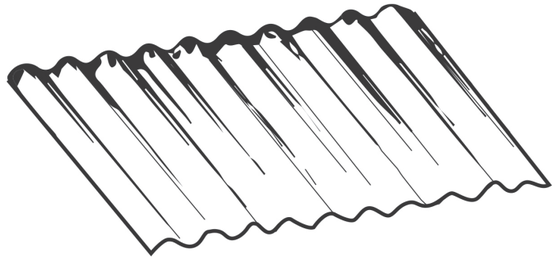
CATCHMENT

mountain watershed

roots

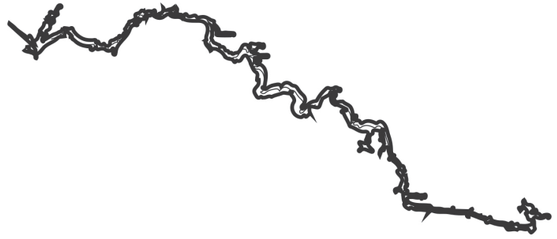


roof

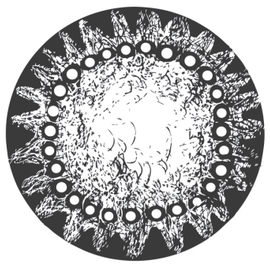


CONVEYANCE

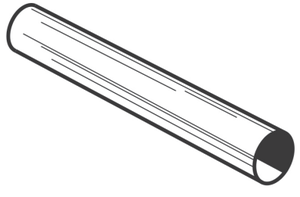
river valley



veins



pipe

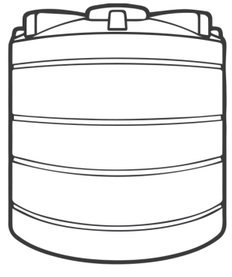


STORAGE

lake reservoir

tissue

cistern



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INFRASTRUCTURE LIMITATION: system components

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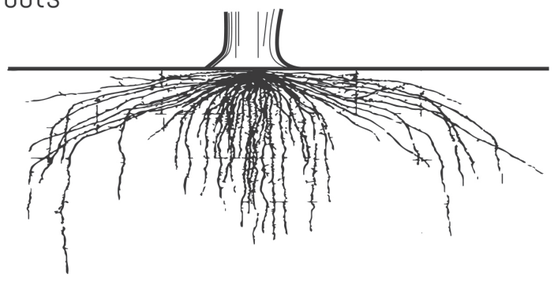
roots



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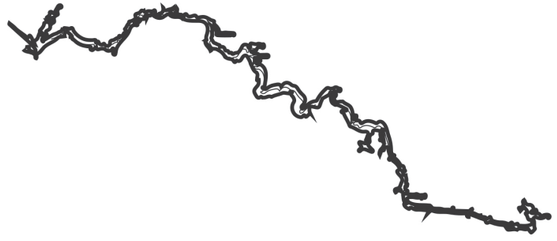

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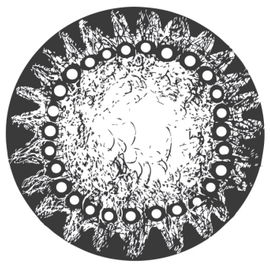
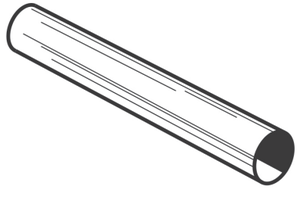


pipe



STORAGE

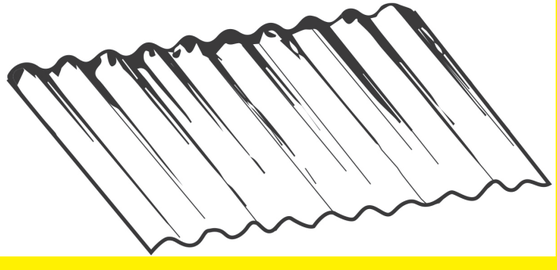
lake reservoir

tissue

CATCHMENT

LIMITING FACTOR

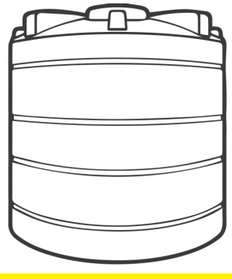
roof



STORAGE

LIMITING FACTOR

cistern



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Given these limitations,
does Tucson have the capacity to achieve

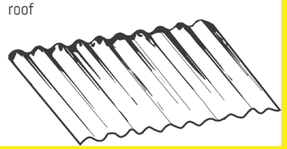
WATER INDEPENDENCE

through its rainwater resources?

METHOD

FIXED PARAMETER

roof



OPTIMIZED VARIABLE

cistern

SUPPLY: RAINWATER HARVESTING POTENTIAL

see Figure 7 for detail

- roof catchment *active system — see Figure 7&9 for detail
- impervious (non-roof) catchment *passive system
- pervious catchment

see Figure 7&9 for detail

DEMAND: WATER USE ESTIMATES

- irrigation consumption *16 categories
- residential consumption

see Figure 17 for detail

WATER INDEPENDENCE MODEL :
optimized storage volume for townships

see Figure 22 for detail

SCENARIO AND POLICY ANALYSIS

- **rates of poverty** overlaid with optimal RWH townships — see Figure 27
- **rebate adoption sites** overlaid on optimal RWH sites — see Figure 25&26
- **food desert** areas overlaid on optimal RWH townships — future work
- **flood prone** areas overlaid on optimal RWH townships — future work
- **heat island intense** areas overlaid on optimal RWH townships — future work

Research Team:
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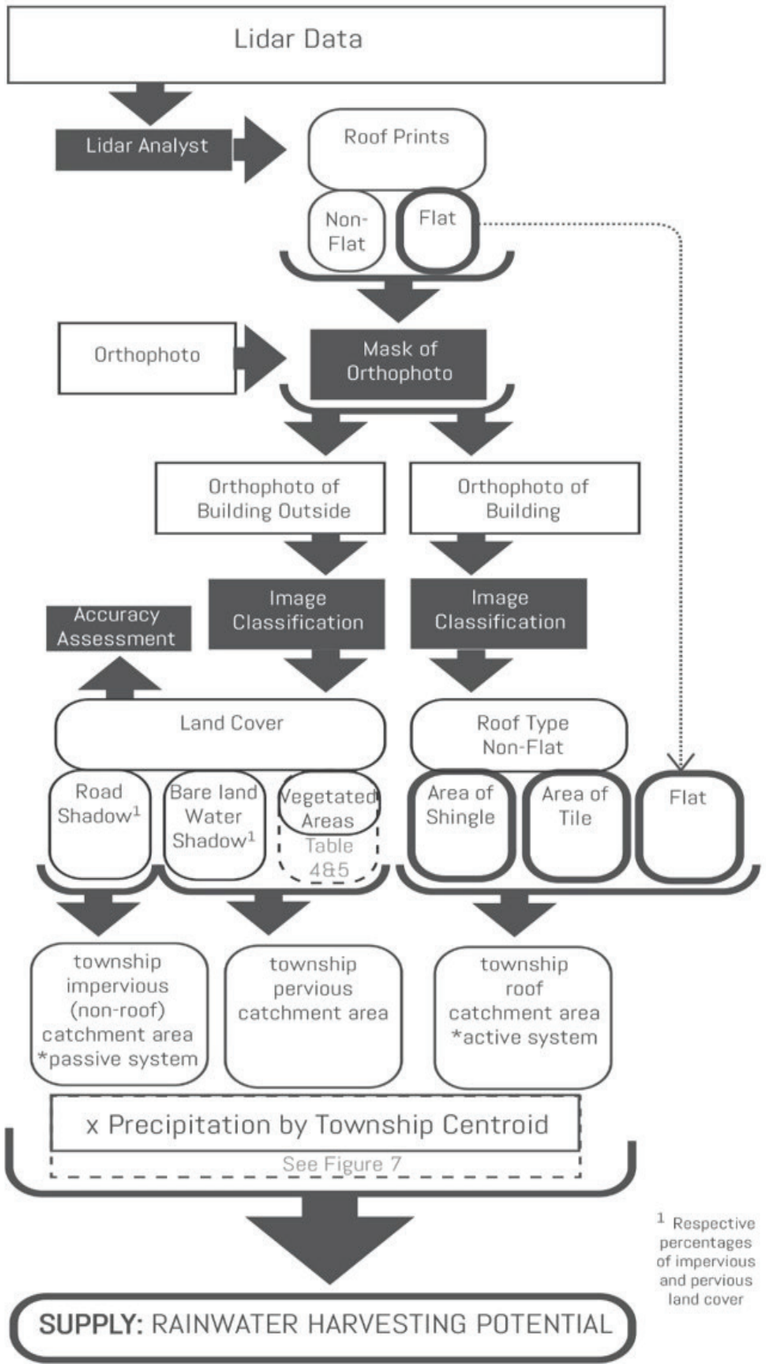
Qing Zhong, PhD Student
Yinan Zhang, PhD Student

Funded by:
Making Action Possible (MAP) and Pima Association of Governments (PAG)

METHOD: data collected

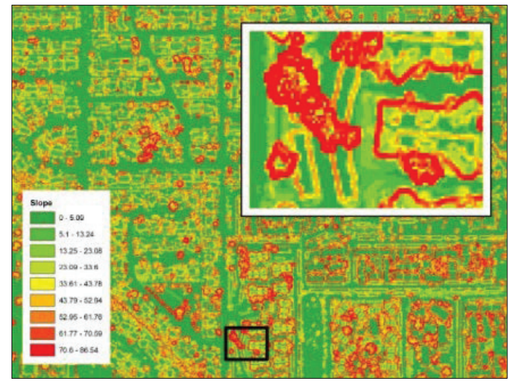
Data	Description	Data Source
LiDAR LAS (Log ASCII Standard) files	Point clouds with x (longitude), y (latitude), and z (elevation) coordinates for 161 Tucson residential township sections	Pima Association of Governments (PAG) LiDAR data accessed from the University of Arizona Libraries
Parcel data	Parcel polygons shapefile, metadata, and parcel use code descriptions	Pima County GIS ftp server
Socioeconomic data	Number of residents and workers by sex, number of households, poverty	U.S. Census Bureau, 2011-2015 ACS 5-Year Estimates
Remote sensing data	High Resolution Orthoimagery (HRO) from PAG with a spatial resolution of 6 inches. The orthophoto was taken in 2015 between May and June, with 4 bands covering RGB and NIR. The radiometric resolution is 8-bit unsigned.	PAG orthophoto accessed from University of Arizona Library
Global Historical Climate Network Daily (GHCN-Daily) Precipitation data	Daily rainfall gauge observation from 2007 to 2016 with the unit of inch in the format of csv. A total of 200 stations' daily precipitation was included.	National Oceanic and Atmospheric Administration (NOAA)
Normalized Difference Vegetation Index (NDVI) data	An indicator used to identify vegetated areas and their conditions	PAG
Tucson Rainwater Harvesting Rebate adoption sites	Point locations within the City that have used Tucson Water's Rainwater Harvesting Rebate program to install active systems in the last four years	Tucson Water
Tucson food desert current areas	Areas of the City that experience food desert conditions or geographically isolated location where access to healthy, affordable food is absent or limited.	Bao and Tong 2017

SUPPLY METHOD: rainwater harvesting potential

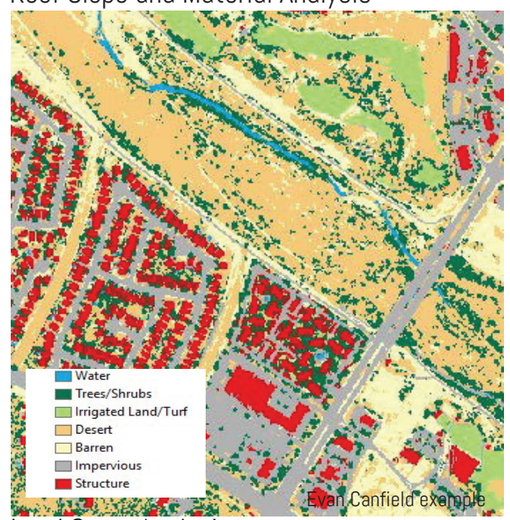


Remote sensing and GIS techniques:

Roof Area Analysis



Roof Slope and Material Analysis



Land Cover Analysis

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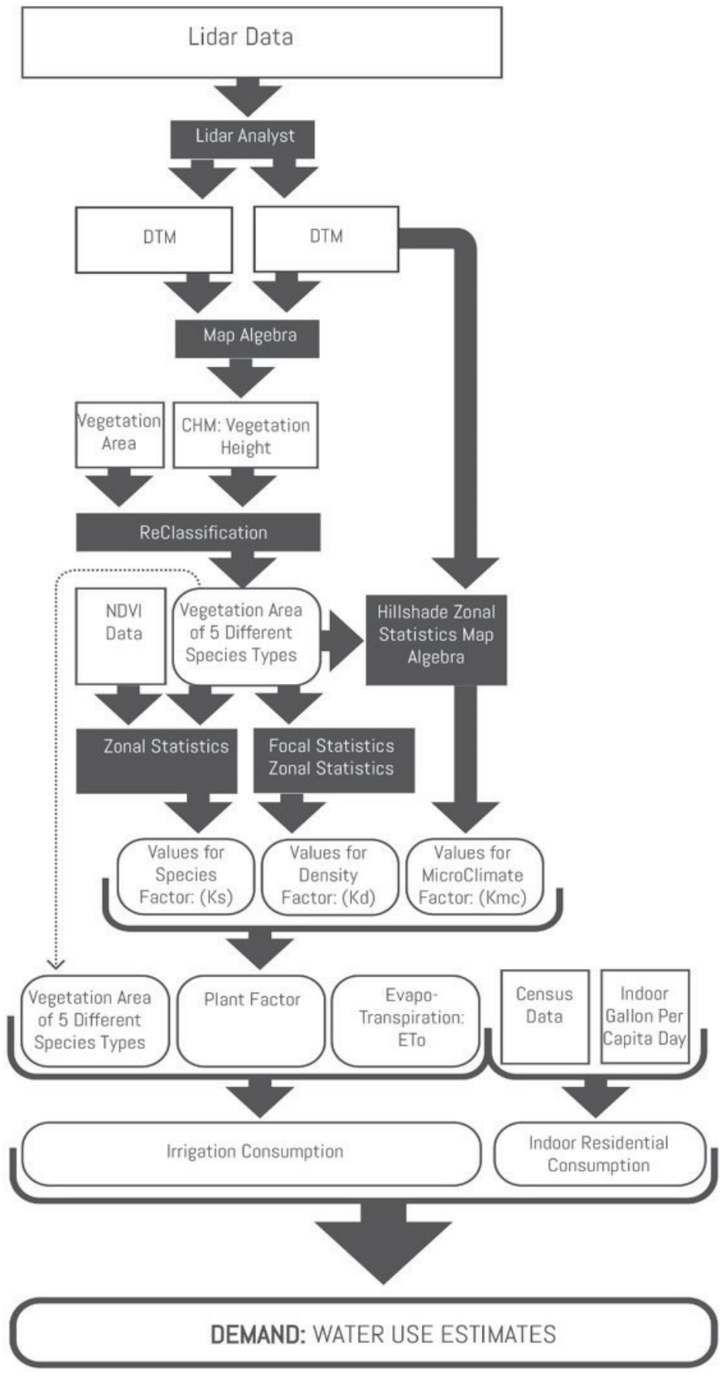
DEMAND METHOD: water use estimation



OUTDOOR WATER USE ESTIMATION

Three factors were considered:

1) Species Factor

Height	Vegetation type
< 6"	Contiguous area as turf
6" - 3'	Forbs and shrubs
3 - 15'	Large shrubs and small trees
15 - 40'	Medium trees
> 40'	Large trees

2) Density Factor
=mean density of each vegetation area

3)Microclimate Factor
=Hillshade analysis

Calculation:

$T = (A*(ETL/IE))*CE*0.6233$

where

T = total water consumption

A = area (sq. ft.)

KL = landscape coefficient; KL = ks*kd*kmc

ET0 = reference evapotranspiration in July; ET0 = 7.9

ETL = project specific evapotranspiration; ETL = ET0*KL

IE = 0.625

CE = Controller Efficiency; CE = 1

METHOD: water independence systems model

PASSIVE
RAINWATER HARVESTING

ACTIVE
RAINWATER HARVESTING

impervious (non-roof)

Impervious Catchment (:,Day)=C*R*Ro*7.48

R=Daily Rain Fall (ft)
C=Impervious Catchment Area (ft²)
Ro=Runoff coefficient
DCp= Daily impervious Catchment (gal)

pervious surface

Pervious Catchment (:,day)=C*R*Ro*7.48

R=Daily Rain Fall (ft)
C=Pervious Catchment Area (ft²)
Ro=Runoff coefficient
DCp= Daily pervious Catchment (gal)

roof surface

Roof Catchment volume (:,day)=C*R*Ro*7.48

R=Daily Rain Fall (ft)
C=Catchment Area (ft²)
Ro=Runoff coefficient
DCr= Daily roof Catchment volume (gal)

overflow to infiltration

storage capacity
(optimized variable)

irrigation

residential

Irrigation Demand (:,day)=(Eto*PF*PA*0.62) / IE

Eto (:,month)= Evapotranspiration factor for site
PF= Plant factor=Ks*Kmc*Kd
PA= Area of planting (sf)
IE= Irrigation Efficiency
ID = Daily Irrigation Demand (gal)
Ks=Species Factor
Kmc=Microclimate Factor
Kd=Density Factor

R = Residential Demand (gal/day)

P=Population of Township (PC)
W=Per Capita Daily Indoor Water Use (GPCD)

CisternVolume(:,day)=Cistern(:,day-1)+(DCr(:,time))
-(R(:,day))-(max(0,((DI(:,day))-(DCp(:,day))-(DCi(:,time)))))

DailyCisternVolume(:,day)=max(0,min(CV(:,day),CC)

Overflow(:,day)=DCV-CC
when CV > cistern capacity, overflow occurs
Municipal(:,day)=max(-CisternVolume,0)
when CV < zero, requires supplemental water from municipal sys

CV= Cistern Volume (gal)
DCV= Daily Cistern volume (gal)
CC=Cistern capacity (gal)
ID=Daily irrigation demand (gal)
M=Municpal requirement [model solves for zero] (gal)

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RESULTS: all residential + irrigation demand

Analyzed 10 years (2007-2016) of

Daily rainfall (interpolated from nearest weather stations) for

1 mile x 1mile township squares for

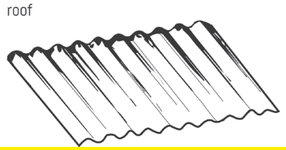
Average Indoor Residential + Outdoor Irrigation water demand.

For every 1,000 square feet of roof catchment,

a minimum storage capacity is needed to reach water independence in each township.

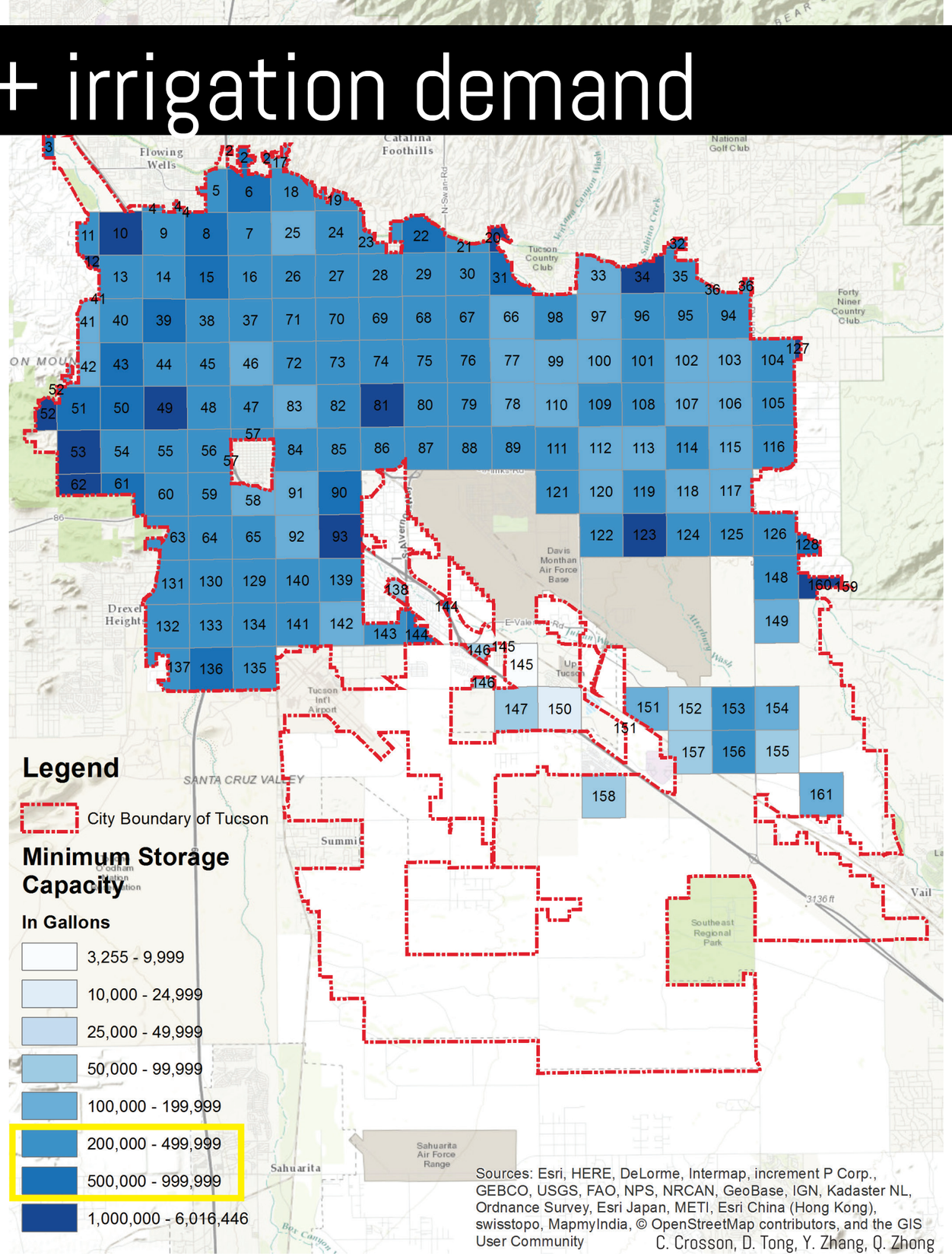
FIXED PARAMETER

roof



OPTIMIZED VARIABLE

cistern



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RESULTS: all imported water demand

Analyzed 10 years (2007-2016) of

Daily rainfall (interpolated from nearest weather stations) for

1 mile x 1mile township squares for

Average Indoor Residential + Outdoor Irrigation water demand with

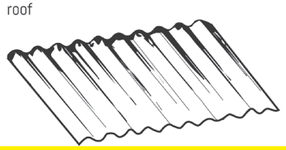
RWH rebate adopters since 2012.

For every 1,000 square feet of roof catchment,

a minimum storage capacity is needed to reach water independence in each township.

FIXED PARAMETER

roof



OPTIMIZED VARIABLE

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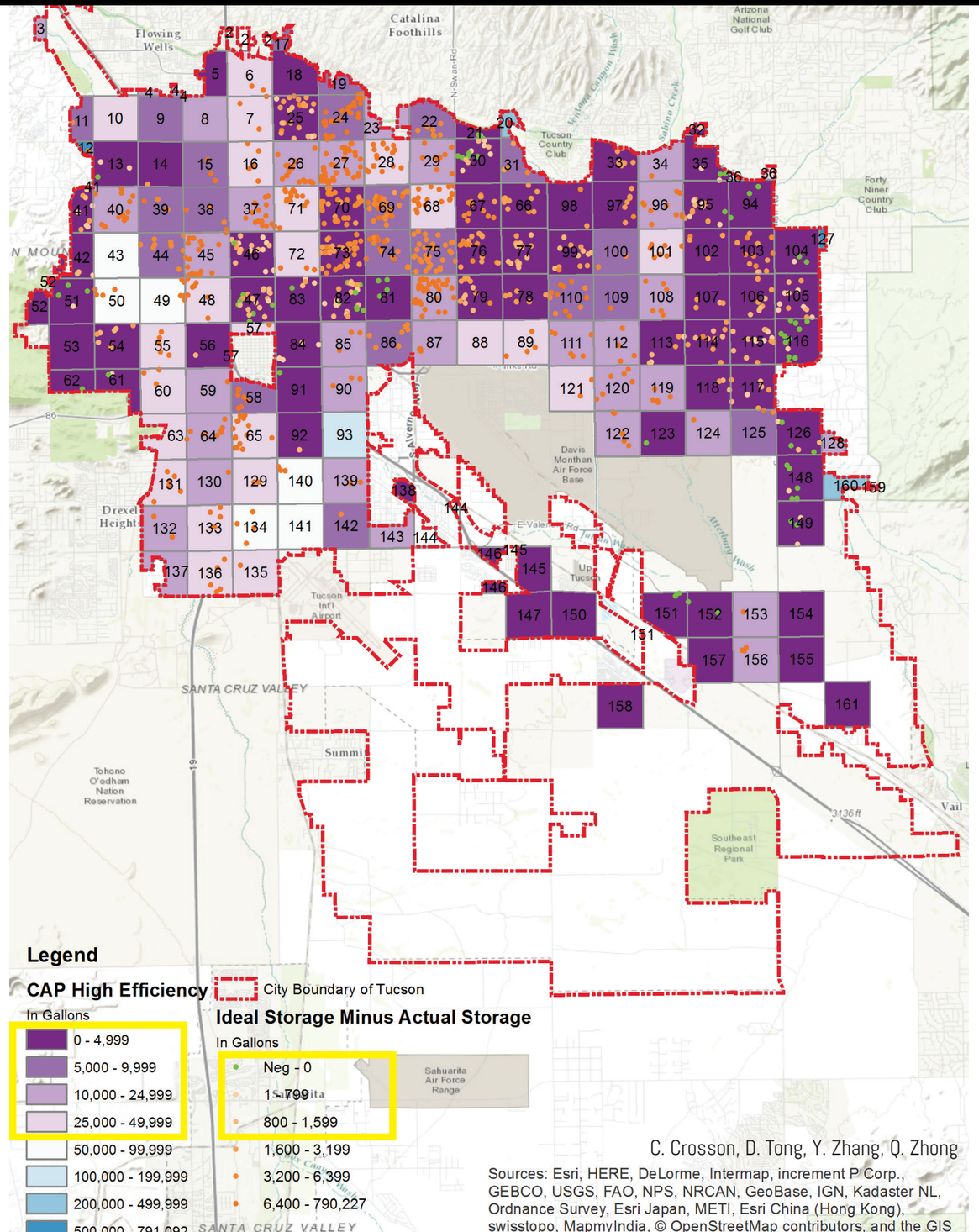
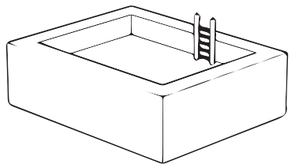
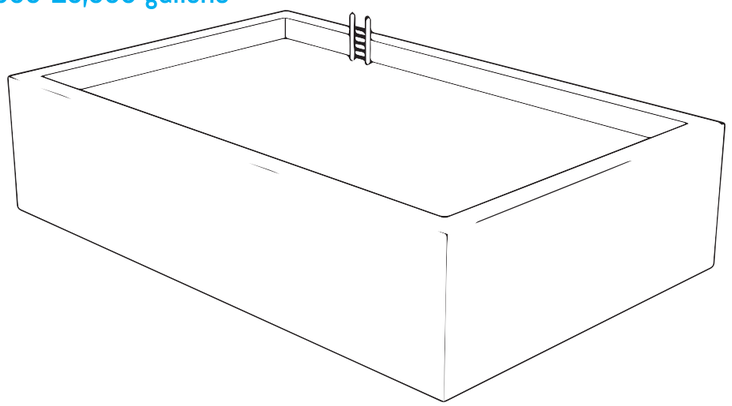


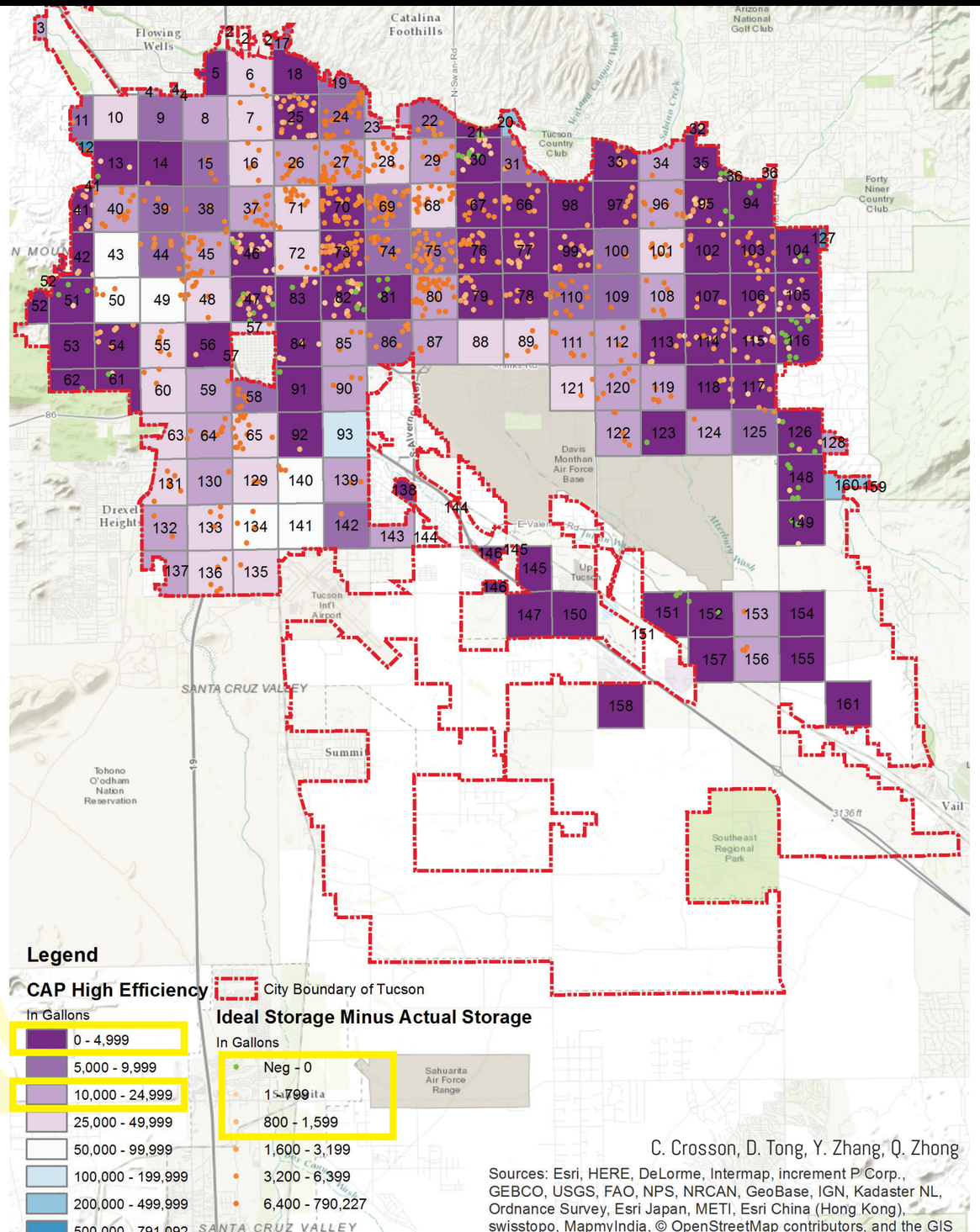
RESULTS: storage sizing

AVERAGE HOT TUB
500-1,000 gallons



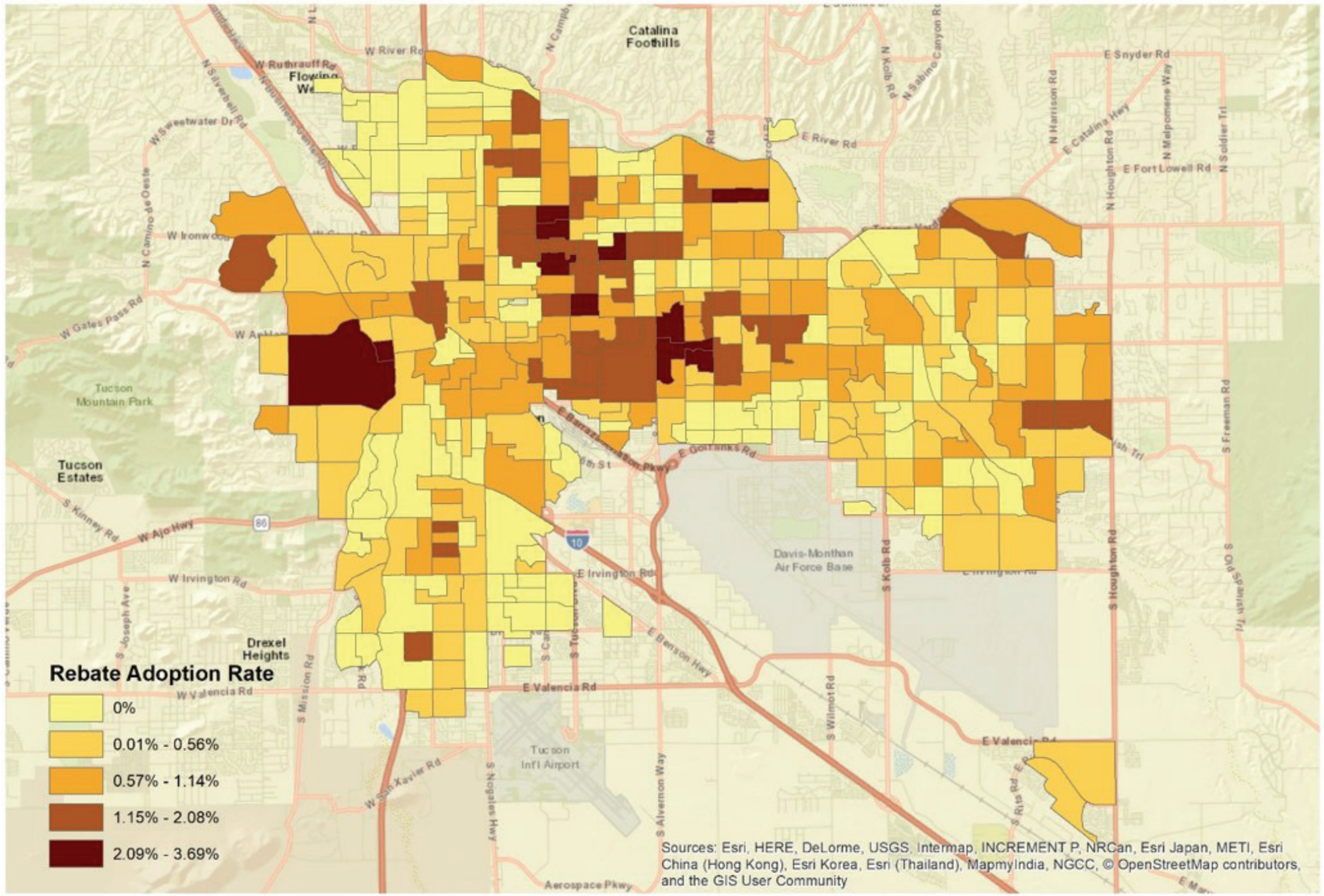
AVERAGE POOL
10,000-15,000 gallons





REBATE PROGRAM ANALYSIS

Rebate Adoption Rate by Census Block Group



Thank you.

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Acknowledgments:

Qing Zhong (research assistant, UA Geography PhD student)

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photograph: John Edwards