Estimated Water Savings from Requiring Soil Moisture Sensors in Irrigation Systems for Homes in HOA Districts in Cedar Park, TX

by Heather Rose, December 2019

Abstract

This research is a case study aimed to estimate water savings from incorporating soil moisture sensors into irrigation systems of single family homes within HOA districts of Cedar Park TX. The critical element to determining water savings from these devices is the soil type of the irrigated turf. For instance, soils that are loam based can absorb significantly more water than soils that are clay based. To find the dominant soil type in each HOA district, GIS soil survey data was obtained from the USGS SSURGO website for Williamson and Travis County. Along with city GIS data from the City of Cedar Park, I was able to determine the dominant soil type within each HOA boundary. With this information I calculated the expected water savings from requiring soil moisture sensors for all single family homes within the HOA boundaries. The total estimated water savings was 450 acre-feet per year for single family homes located within HOA's in Cedar Park, TX. The methods developed in this research can be applied to other government entities in the US where the necessary GIS data are available.

Motivation

As water security becomes a growing concern in Central Texas, cities experiencing rapid growth are investigating ways to conserve water. Outdoor watering makes up for the majority of residential single family water use, averaging at 31% dedicated to outdoor irrigation (TWDB 2012). Overwatering irrigated turf is a major contributor to water waste in the residential sector. Soil moisture sensors can prevent over watering as they shut off the irrigation system when soil moisture is sufficient due to rain events or previous irrigation events. Different soil types can conduct and retain water in different ways. For example, loam based soils can retain adequate soil moisture for approximately three days after a rain event, whereas clay can only retain moisture for two days. In order to estimate the water savings from soil moisture sensors, the dominant soil type of the property must be known.

This research aimed to seamlessly identify the dominant soil types within Homeowners Association (HOA) boundaries in Cedar Park Texas using GIS data from the US Geological Survey (USGS), and city GIS data provided by the city of Cedar Park. Once a dominant soil type was identified, I created a model to estimate water savings from soil moisture sensors. These water savings were then plotted in ArcMap to show which HOA districts could expect to see the biggest water savings by mandating soil moisture sensors in irrigation systems.

Study Area and Data Descriptions

The City of Cedar Park was chosen for this study as it is representative of a city experiencing rapid growth. Since the year 2000 Cedar Park has seen a population growth of over 200% (World Population Review 2019). Cedar Park is also located in Central Texas, where future water security is a growing concern.

The City of Cedar Park was also chosen for this study because GIS data on city limits and HOA boundaries was made easily available on the city's website. The city's HOA GIS data also included the number of single family homes within each district boundary, which significantly improved the accuracy of the water savings model.
Single family homes located within HOA boundaries were considered for this research due to the unique enforcement capabilities that HOA organizations have. If a city or water provider wanted to incorporate a soil moisture sensor mandate in irrigation systems, HOA's already have the enforcement structures in place to oversee homes and fine property owners if they aren't in compliance with the policy.

The USGS has GIS data by county across the US available on their Web Soil Survey. These data include shape files of polygons for all soil types studied in the county. The metadata includes the soil type key and descriptions of each soil type. For this research soil survey GIS data were downloaded for Williamson and Travis counties as Cedar Park city limits are within these two counties.

Identifying Soil Types

I first plotted all soil types from the soil survey GIS data within Cedar Park city limits. Figure 1 below shows the soil map of soil types in Cedar Park. See Appendix C for soil descriptions based on the abbreviation codes.

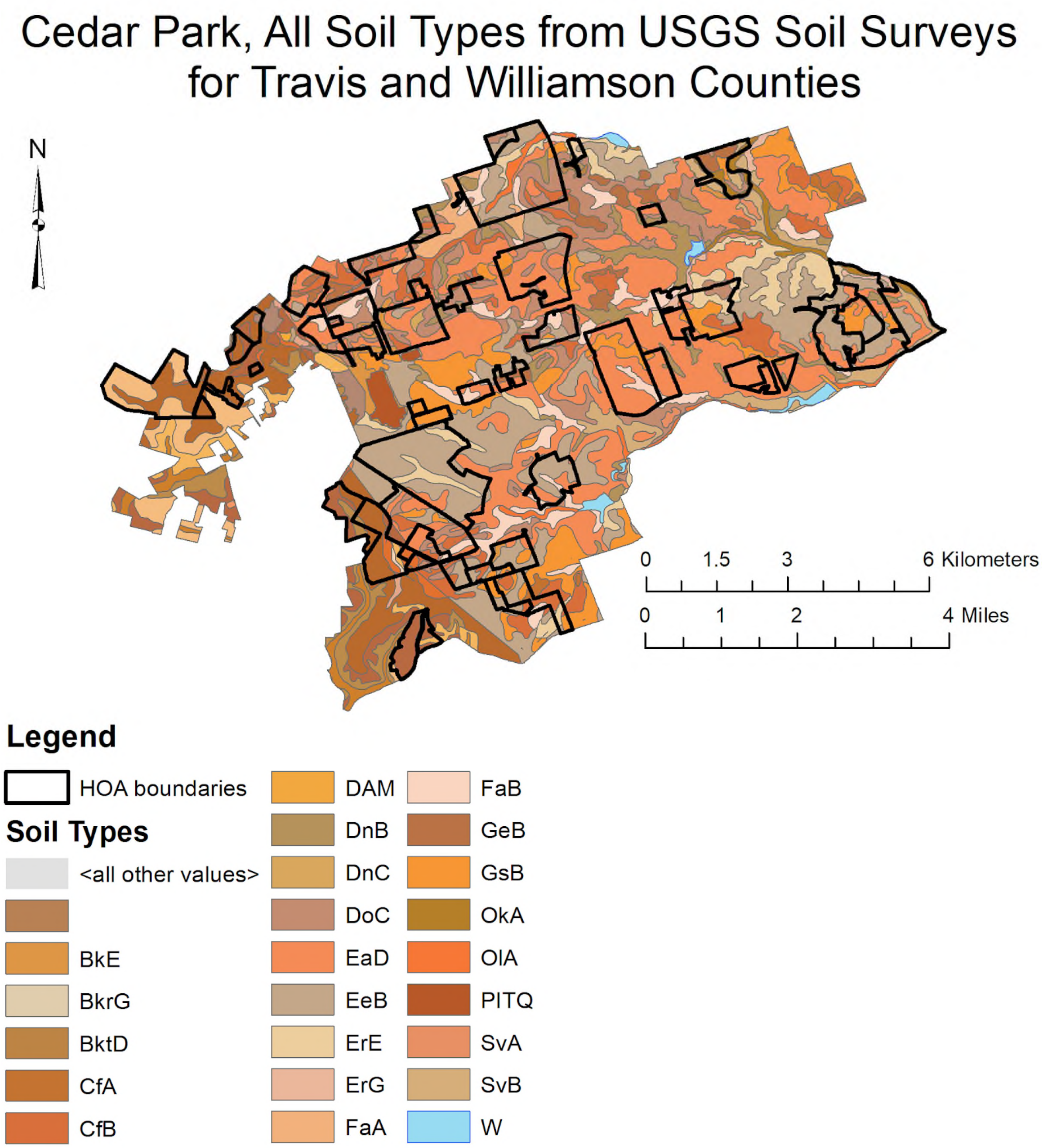


Figure 1: Soil map within Cedar Park City Limits.
See Appendix C for Soil Key with soil symbols and descriptions.

The soil map layer included in its attribute table a soil type abbreviation code for all soil types in the layer. This included 36 different codes that can be seen on the soil map in Figure 1. To simplify soil types I created nine different soil categories for each soil type to fall into. These were Loamy Sand, Sandy Loam, Loam, Silt Loam, Silt, Clay Loam, Silty Clay Loam, Silty Clay and Clay. These categories were based on the soil textural triangle adapted from Soil Survey Staff (USDA 2012). From the metadata containing the soil descriptions by abbreviation code, I tagged a soil type to one of the nine categories based on the description using Excel. If the descriptive text included “clay” in the description, then the Soil Category was marked as clay, similarly for loam and silt. If a soil description contained multiple categories, such as silt, clay and loam, then the ultimate soil category was considered to be the combination of these, or silty clay loam for instance. For descriptions that did not include any of the nine key terms the category was marked as Unknown. See Appendix C for table with soil types and associated categories.

With this new Soil Category column created in Excel, I added this to the soil layer in ArcMap. I then plotted the dissolved polygons by soil categories which can be seen in Figure 2 below:

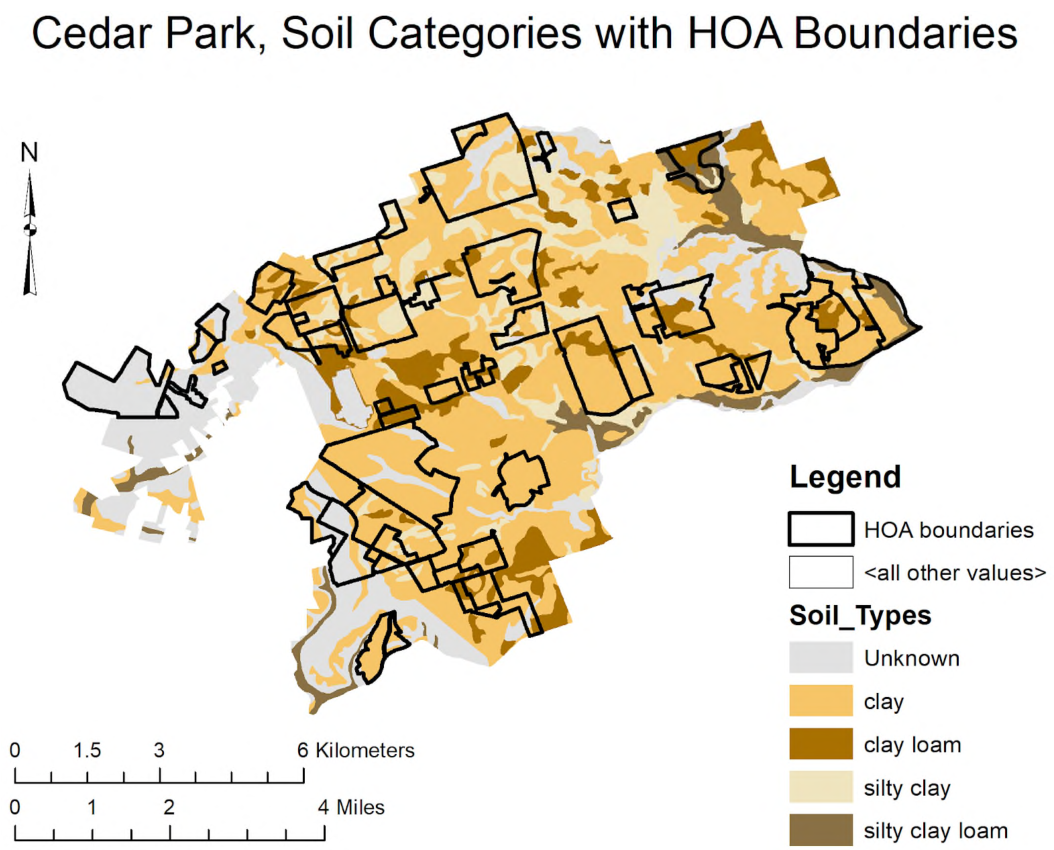


Figure 2: Soil categories map within Cedar Park City Limits.
For Unknown soil categories, the USDA soil survey reports were consulted.

To identify the dominant soil type within an HOA boundary I visually inspected which soil category dominated the area within a specific HOA boundary and noted this in the Excel spreadsheet. For the HOA boundaries where an unknown soil category dominated the area, I referred to the undissolved soil map with the abbreviation codes. I then consulted USDA reports for soil surveys in Williamson and Travis county, searched for the soil key that dominated the HOA boundary and made an educated guess on what the soil category should be based on the report (USDA 1974, USDA 1983).

With the soil categories known for each HOA boundary, I was then ready to apply the water savings model from soil moisture sensors to homes within the HOA boundaries based on their soil category.

Water Savings Analysis

The LCRA water savings model for soil moisture sensors is based on the reduction of irrigation events due to sufficient soil moisture from rain events. First I assumed a base case irrigation requirement for single family homes within the HOA boundaries. The City of Cedar Park enforces a twice weekly year-round watering schedule where homes are allotted two watering days per week (Water Thrifty Cedar Park). With this watering schedule I assumed that homes within the HOA boundaries water their turf twice a week for 52 weeks at 0.5 inches per watering. I also assumed 70% of the home's yard acreage was irrigated turf, or 0.12 acres of irrigated turf for the average size lot in Texas (Home Advisor). I then multiplied these factors by the number of homes within the HOA district to estimate the basecase irrigation requirement for homes within the HOA. See Equation 1 below:

$$Irrigation_{basecase}\left(\frac{acre-feet}{year}\right) = 52\ \frac{weeks}{year} \times \frac{1\ inch\ water}{week} \times \frac{1\ ft}{12\ inches} \times 0.12\ \frac{acres}{house} \times (No. of\ Homes)$$

(Eq.1)

For the reduced irrigation model, I used historical weather data from an LCRA weather station in Cedar Park where an average of 7 weeks out of the year receive a net 0.125 inches of rain after accounting for evapotranspiration. According to the LCRA model, clay based soils allow for an average reduced irrigation requirement of 0.715 inches per week on rainweeks (assuming one rain event per week). Similarly, loam based soils allow for reduced irrigation requirement of 0.57 inches per week on rainweeks. Soil moisture retention data was not available for silt based soils, so an average irrigation reduction was taken between the clay and loam irrigation reduction factors. See Appendix B for more details on this model. With these reductions and the same assumptions made for the basecase, I calculated a reduced irrigation requirement equation that can be seen in Equation 2 below:

$$Irrigation_{reduced}\left(\frac{acre-feet}{year}\right) = 45\ \frac{weeks}{year} \times \frac{1\ inch\ water}{week} \times \frac{1\ ft}{12\ inches} \times 0.12\ \frac{acres}{house} \times (No. of\ Homes) \ + \ 7\ \frac{rainweeks}{year} \times \frac{SM_{reduced}\ inch\ water}{week} \times \frac{1\ ft}{12\ inches} \times 0.12\ \frac{acres}{house} \times (No. of\ Homes) \qquad \text{(Eq. 2)}$$

Where

$$SM_{reduced} = Soil\ Moisture\ reduced\ watering\ factor$$
$$= 0.715\ inches\ for\ clay\ based\ soils, 0.57\ inches\ for\ loam\ based\ soils, and\ 0.643\ inches\ for\ silt\ based\ soils$$

The water savings was then considered to be the difference between the basecase irrigation demand and the reduced irrigation demand, or

$$Water\ Savings\ \left(\frac{acre-feet}{year}\right) = Irrigation_{basecase} - Irrigation_{reduced} \qquad \text{(Eq. 3)}$$

Using Equations 1, 2 and 3, I calculated the estimated annual water savings by requiring a soil moisture sensor for each HOA district. I added these values to a new column in an Excel spreadsheet created by exporting the HOA boundary layer attribute table. I then joined this updated spreadsheet to the attribute table of the HOA boundary layer in Arcmap so I could plot a heatmap of estimated water savings by HOA district. Figure 3 below shows the HOA boundary polygons symbolized by quantities where the selected value was the district's estimated water savings from requiring soil moisture sensors for all homes. The total estimated water savings for all HOA districts within Cedar Parks city limits was 450 acre-feet per year.

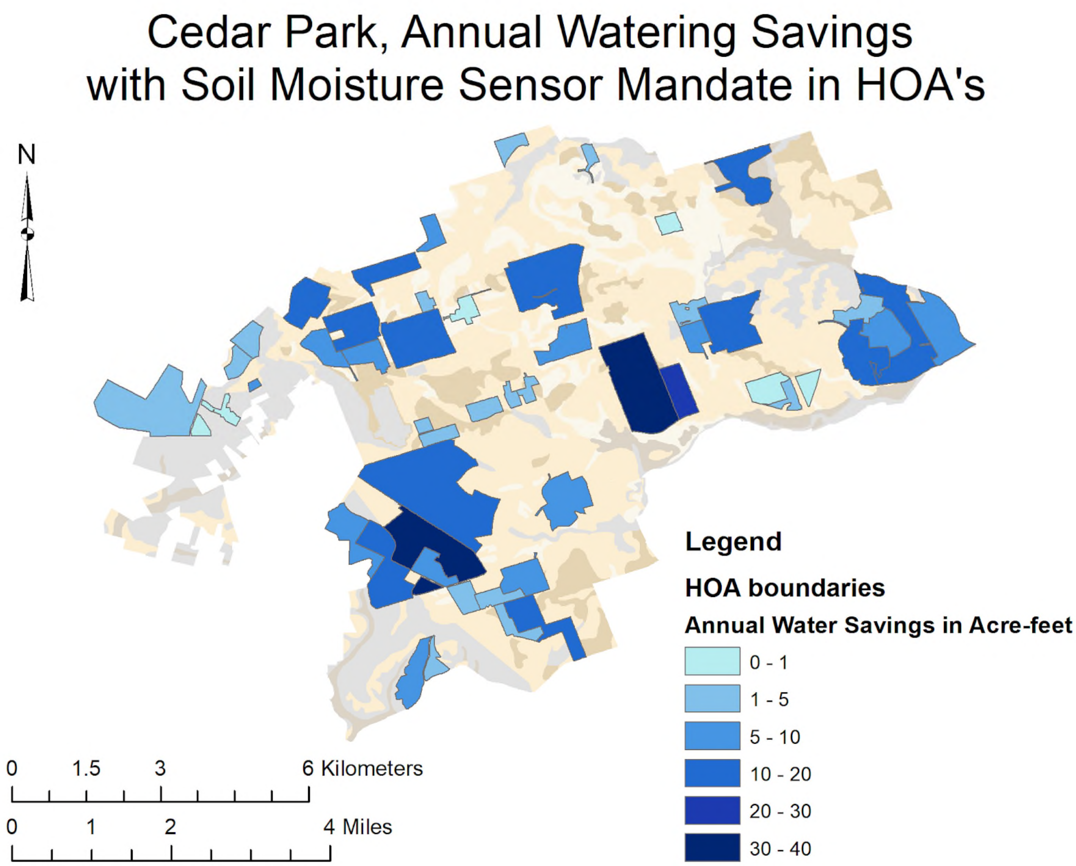


Figure 3: Estimated annual water savings in acre-feet for HOA districts using LCRA's model for water savings from soil moisture sensors. Note: 1 acre-feet = 325,851 gallons

Discussion

There are some significant limitations to this model that I will discuss.
Determining the dominant soil category for HOA boundaries was very challenging. As we can see from Figure 1, most boundary lines contain a mix of soil categories so determining the dominant category was a rough estimate. Many homes within the boundary lines likely have a different soil type on their property than the one that was determined to be dominant for the district. Unfortunately the polygons of individual property lines were not available for this research, so determining the soil type by individual property was not an option. Having this information would have helped increase the accuracy of the water savings model.

Another limitation to this model is the lack of soil moisture retention data for the nine different soil categories. Many of the soil categories were mixed (silty clay or clay loam for instance). The soil moisture retention data obtained from LCRA was for strictly clay or loam soil. Therefore the soil moisture retention for mixed soils are likely to vary from these data. To improve the accuracy of the estimated water savings further research should be conducted in soil moisture retention for the nine soil types listed above.

The USGS GIS data for the soil surveys were originally created twenty years before this study. Due to the rapid growth in the area over the past two decades, it is likely that soil type boundaries have changed some. However, on a geological time scale twenty years is not considered significant. For this research, I have assumed the shape files of the soil type polygons are still relevant today, despite being drawn twenty years ago.

Despite these limitations, the work here still provides an order of magnitude estimate of water savings if HOA's were to require a working soil moisture sensor be incorporated in irrigation systems for all homes within their district. This research can help cities like Cedar Park decide if they should require HOA's or all homes within the city limits to incorporate soil moisture sensors. These methods can assist with determining if such a measure is worth the cost (both financial and political) of adding further regulations on top of a twice weekly watering schedule.

GIS Data Sources

Cedar Park City Limits Shape File
Description: City Limits and ETJ for the City of Cedar Park. Data maintained by the Applications Division of the City of Cedar Parks' Information Services Department.
Created: 3/7/2018, *Extent*: -97.907682 W, -97.744415 E, 30.560744 N, 30.444455 S
Source link:
https://cedarparkatlas.com/atlas.aspx?Section=DataPortal

Cedar Park HOA Boundaries Shape File
Description: Neighborhoods with an organization or HOA. Built and maintained by the Applications Division of the City of Cedar Park's Information Services Department.
Created: 1/18/2018, *Extent*: -97.907528 W, -97.744544 E, 30.560744 N, 30.450576 S
Source link:
https://cedarparkatlas.com/atlas.aspx?Section=DataPortal

USGS Soil Survey Data, Travis County
Description: See Appendix D
Created: 9/10/1999, *Extent*: -98.173 W, -97.369 E, 30.628 N, 30.023 S
Source link:
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

USGS Soil Survey Data, Williamson County
Description: See Appendix E
Created: 8/18/1999, *Extent*: -98.050 W, -97.155 E, 30.908 N, 30.403 S
Source link:
https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

References:

Home Advisor. *The United States Ranked by Yard Size*
https://www.homeadvisor.com/r/average-yard-size-by-state/

TWDB (2012). *The Grass is Always Greener...Outdoor Residential Water Use in Texas.*
http://www.twdb.texas.gov/publications/reports/technical_notes/doc/SeasonalWaterUseReport-final.pdf

USDA (2012). *Field Book for Describing and Sampling Soils.* National Soil Survey Center. Natural Resources Conservation Service.
https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052523.pdf

USDA (1983). *Soil Survey of Williamson County, Texas*
https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/texas/TX491/0/williamson.pdf

USDA (1974). *Soil Survey of Travis County, Texas.*
https://www.nrcs.usda.gov/Internet/FSE_MANUSCRIPTS/texas/TX453/0/Travis.pdf

Water Thrifty Cedar Park. *A little water goes a long way.*
http://waterthriftycedarpark.org/

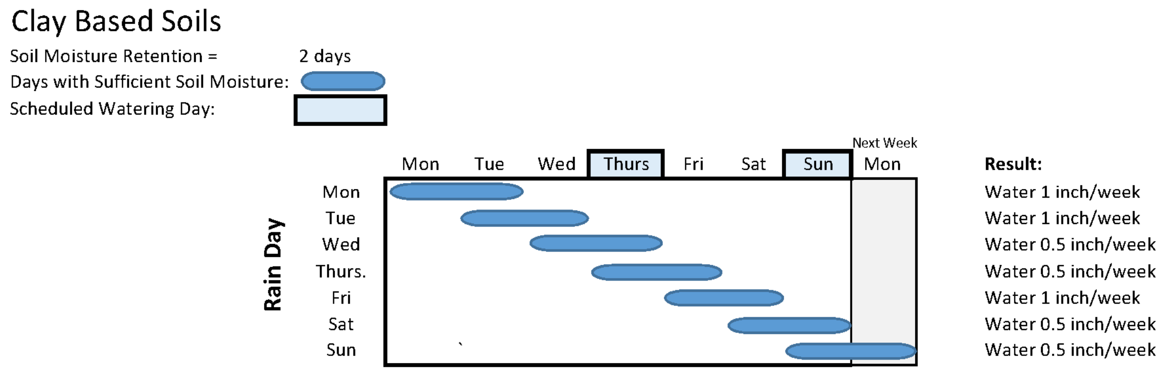
World Population Review (2019). *Cedar Park, Texas Population 2019*
http://worldpopulationreview.com/us-cities/cedar-park-tx-population/

Appendix A: Python Code for Merging Dataframes

```
#This code merges two csv files, one containing the soil keys of the
soil types within the soil map plotted in Arcmap
#The other contains the soil descriptions of the soil keys, taken from
the metadata of the Soil Surveys

#Import Pandas Package
import pandas as pd
from functools import reduce

#Import attribute table exported from Soil type map layer in Arcmap,
used for soil keys within the area of interest
Soil_Map_Travis = pd.read_csv('CP_Soil_Map_Travis.csv')


#Import Soil Key with descriptions from Travis County Soil Survey,
taken from metadata
Soil_Key_Travis = pd.read_csv('Soil_Key_Travis_County.csv')

#define dataframes to be merged
data_frames = [Soil_Map_Travis, Soil_Key_Travis]

#Define merge variable
df_merged = reduce(lambda  left,right:
pd.merge(left,right,on=['Soil_Symbol'],
                                            how='outer'),
data_frames).fillna('')


#Export merged dataframes to new csv
df_merged.to_csv('Soil_Types_and_Categories_Travis_County.csv')

#Repeat for Williamson County Data
```

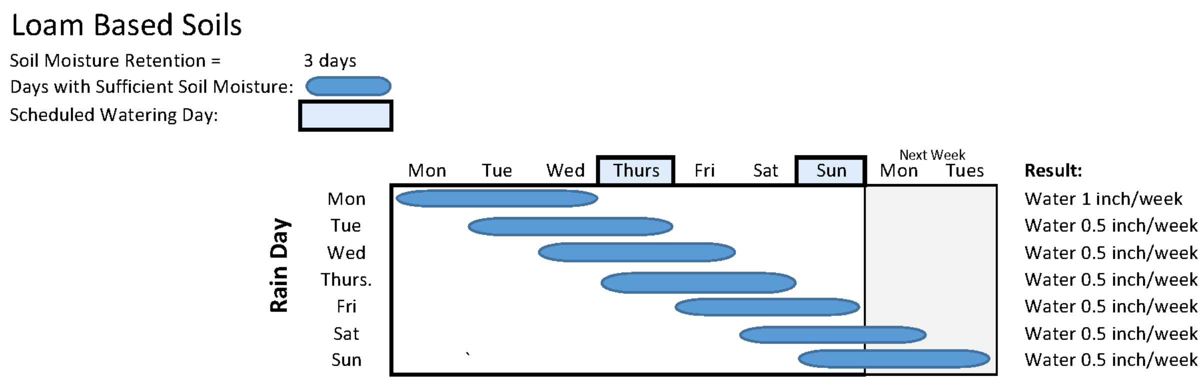
Appendix B: Water Savings from Soil Moisture Sensor Model

Skip pattern for weeks in the year with rain events of at least a net 0.125 inches after considering evapotranspiration loss. This assumes one rain event per week and equal probability of rain on any day of the week. Soil moisture retention days taken were from soil moisture sensor data.



Weighted Average for Required Watering for Rain Weeks for Clay Based Soils:

$$Watering\ Requirement\ on\ Rain\ Weeks$$
$$= (3/7)(1\ inches\ per\ week) + (4/7)(0.5\ inches\ per\ week)$$
$$= 0.714\ inches\ per\ week\ on\ rain\ weeks$$



Weighted Average for Required Watering for Rain Weeks for Loam Based Soils:

$$Watering\ Requirement\ on\ Rain\ Weeks$$
$$= (1/7)(1\ inches\ per\ week) + (6/7)(0.5\ inches\ per\ week)$$
$$= 0.57\ inches\ per\ week\ on\ rain\ weeks$$

Appendix C: Soil Symbol Key for Soils within Cedar Park City Limits

Abbreviation Code	Soil Description	Assigned Soil Category
BkE	Brackett gravelly clay loam, 3 to 12 percent slopes	clay loam
BkrG	Brackett-Rock outcrop-Real complex, 8 to 30 percent slopes	Unknown
BktD	Brackett association, 1 to 8 percent slopes	Unknown
BlD	Brackett-Rock outcrop complex, 1 to 12 percent slopes	Unknown
BoF	Brackett-Rock outcrop-Real complex, 8 to 30 percent slopes	Unknown
CfA	Crawford clay, 0 to 1 percent slopes	clay
CfB	Crawford clay, 1 to 3 percent slopes	clay
CrB	Crawford clay, 1 to 3 percent slopes	clay
DAM	Dams, 1 to 8 percent slopes	Unknown
DeB	Denton silty clay, 1 to 3 percent slopes	silty clay
DeC	Denton silty clay, 3 to 5 percent slopes	silty clay
DnB	Denton silty clay, 1 to 3 percent slopes	silty clay
DnC	Denton silty clay, 3 to 5 percent slopes	silty clay
DoC	Doss silty clay, moist, 1 to 5 percent slopes	silty clay
EaD	Eckrant cobbly clay, 1 to 8 percent slopes	clay
EeB	Eckrant extremely stony clay, 0 to 3 percent slopes	clay
ErE	Eckrant-Rock outcrop association, 1 to 10 percent slopes	Unknown
ErG	Eckrant-Rock outcrop association, 8 to 30 percent slopes	Unknown
FaA	Fairlie clay, 0 to 1 percent slopes	clay
FaB	Fairlie clay, 1 to 2 percent slopes	clay
GP	Pits, gravel, 1 to 90 percent slopes	Unknown
GeB	Georgetown clay loam, 0 to 2 percent slopes	clay loam
GsB	Georgetown stony clay loam, 1 to 3 percent slopes	clay loam
OkA	Oakalla silty clay loam, 0 to 2 percent slopes, frequently flooded	silty clay loam
OlA	Oakalla soils, 0 to 1 percent slopes, channeled, frequently flooded	Unknown
PITQ	Pits, quarries, 0 to 45 percent slopes	Unknown

PuC	Purves clay, 1 to 5 percent slopes	clay
QU	Quarry, 1 to 40 percent slopes	Unknown
SpB	Speck clay loam, 1 to 3 percent slopes	clay loam
SvA	Sunev silty clay loam, 0 to 1 percent slopes	silty clay loam
SvB	Sunev silty clay loam, 1 to 3 percent slopes	silty clay loam
TaD	Eckrant very stony clay, 5 to 18 percent slopes	clay
TcA	Eckrant and Speck soils, 0 to 2 percent slopes	Unknown
TdF	Eckrant-Rock outcrop complex, 18 to 50 percent slopes	Unknown
VoD	Volente silty clay loam, 1 to 8 percent slopes	silty clay loam
W	Water	Not Applicable

Appendix D: Metadata for Soil Survey of Travis County

Originator:
U.S. Department of Agriculture, Natural Resources
Conservation Service
Publication_Date: 20190912
Title:
Soil Survey Geographic (SSURGO) database for
Travis County, Texas
Publication_Information:
Publication_Place: Fort Worth, Texas
Publisher:
U.S. Department of Agriculture, Natural Resources
Conservation Service
Other_Citation_Details: tx453
Online_Linkage: https://websoilsurvey.sc.egov.usda.gov/
Description:
This data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetric correct base and digitizing, or by revising digitized maps using remotely sensed and other information.

This data set consists of georeferenced digital map data and computerized attribute data. The map data are in a soil survey area extent format and include a detailed, field verified inventory of soils and miscellaneous areas that normally occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. A special soil features layer (point and line features) is optional. This layer displays the location of features too small to delineate at the mapping scale, but they are large enough and contrasting enough to significantly influence use and management. The soil map units are linked to attributes in the National Soil Information System relational database, which gives the proportionate extent of the component soils and their properties.
Purpose:
SSURGO depicts information about the kinds and distribution of soils on the landscape. The soil map and data used in the SSURGO product were prepared by soil scientists as part of the National Cooperative Soil Survey.

Appendix E: Metadata for Soil Survey of Williamson County

Originator:
U.S. Department of Agriculture, Natural Resources Conservation Service
Publication_Date: 20190912
Title:
Soil Survey Geographic (SSURGO) database for Williamson County, Texas
Publication_Information:
Publication_Place: Fort Worth, Texas
Publisher:
U.S. Department of Agriculture, Natural Resources Conservation Service
Other_Citation_Details: tx491
Online_Linkage: https://websoilsurvey.sc.egov.usda.gov/

Description:
This data set is a digital soil survey and generally is the most detailed level of soil geographic data developed by the National Cooperative Soil Survey. The information was prepared by digitizing maps, by compiling information onto a planimetric correct base and digitizing, or by revising digitized maps using remotely sensed and other information.

This data set consists of georeferenced digital map data and computerized attribute data. The map data are in a soil survey area extent format and include a detailed, field verified inventory of soils and miscellaneous areas that normally occur in a repeatable pattern on the landscape and that can be cartographically shown at the scale mapped. A special soil features layer (point and line features) is optional. This layer displays the location of features too small to delineate at the mapping scale, but they are large enough and contrasting enough to significantly influence use and management. The soil map units are linked to attributes in the National Soil Information System relational database, which gives the proportionate extent of the component soils and their properties.
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