Variation in Urban ET to Determine Weather Station Siting

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Abstract. *The Water My Yard program was created to provide simple weekly evapotranspiration (ET) based irrigation recommendations for homeowners by providing irrigation runtimes (minutes) rather than irrigation amount (inches) needed. Since Texas has no state supported ET network, cities are required to purchase and install their own ET weather stations. However, during the planning stage prospective participants ask how many weather stations does the city need and where should they be placed? To answer these questions, a system was developed using landsat imaging to determine surface land temperatures and macro climates in an urban area.*

Keywords. Urban irrigation, evapotranspiration, weather stations, conservation programs.

Background

Many municipalities and water utilities have struggled to develop effective water conservation programs to address the excessive use of water in landscape irrigation. Most automatic irrigation systems are improperly programmed and "over-irrigate" (and waste) 20%-60% of the water applied. While research and demonstration projects have consistently shown that using ET (evapotranspiration) based irrigation schedules saves significant amounts of water, getting typical homeowners to understand and use ET-based irrigation schedules has proven challenging.

Conventional ET-based programs tell homeowners how much water (in inches) is needed to supplement rainfall for maintaining a healthy lawn. The problem is that each irrigation system has a different precipitation rate. Most homeowners do not know their precipitation rate, how to determine runtimes based on inches of water needed, or how to make adjustments to runtimes for soils and root zone depth.

The Water My Yard program was initiated in 2013 to help cities and utilities promote ET-based irrigation programs by providing homeowner weekly irrigation runtimes customized for their irrigation systems. However for a utility to participate in the Water My Yard program, ETo and rainfall data must be

available for their service area. As Texas has no state funded ET Network, utilities are required to purchase and install their own weather stations for inclusion to the program. No methodology currently exists for determining the number and locations of weathers station in urban areas for irrigation.

Methodology

In the standardized Penman Monteith equation, the four climatic drivers of ETo are temperature, wind, relative humidity (dew point) and solar radiation. In this study, we focused on use of temperature. Space borne satellite thermal infrared imagery can be used to derive large aerial coverage of land surface temperatures (LST), making thermal image analysis a valuable tool for determining weather station siting. In this paper, thermal analysis was conducted for Dallas County.

Thermal image analysis and research consisted of the following:

- Acquiring satellite images on cloudless days during the turf irrigation season.
- Conducting radiometric calibration of images, atmospheric correction, bright/temperature processing, and surface temperature analysis.
- Collection of ground level temperatures at the time of the Landsat image flyover to validate the thermal images estimation.

Landsat 8 imagery was acquired during three satellite passes over Dallas as given in Table 1.

Table 1. Information on the LandSat-8 Satellite scene collected over Dallas County

County	**City**	**Path/Row**	**Cloud Cover**	**LANDSAT8_SCENE_ID**	**DATE ACQUIRED**
Dallas	Dallas	27/37	0.28	LC80270372015201LGN00	7/20/2015
Dallas	Dallas	27/37	0.53	LC80270372014294LGN00	10/21/2014
Dallas	Dallas	27/37	0.18	LC80270372013243LGN00	8/31/2013

Landsat-8 is the most recent Landsat satellite launched on February 2013. Its payload produces two imagers; the Operational Land Imager (OLI) that has nine shortwave bands (15-30m resolution) and the Thermal Infrared Sensor (TIRS) that has two longwave bands (Band 10 and Band 11 both at 100 m resolution). The TIRS have various applications in the field of agriculture, irrigation and water resources engineering. Landsat-8 has a temporal resolution of 16 days and collect more scenes than its predecessors: Landsat Multispectral Scanner (MSS) four spectral bands, Landsat Thematic Mapper (TM) seven spectral bands, and Landsat Enhanced Thematic Mapper Plus (ETM+) eight spectral bands. Land surface temperature (LST) is the temperature emitted by the surface, and its computation from satellite data requires thermal bands and surface emissivity.

Figure 1. Satellite Aerial Image of Dallas County

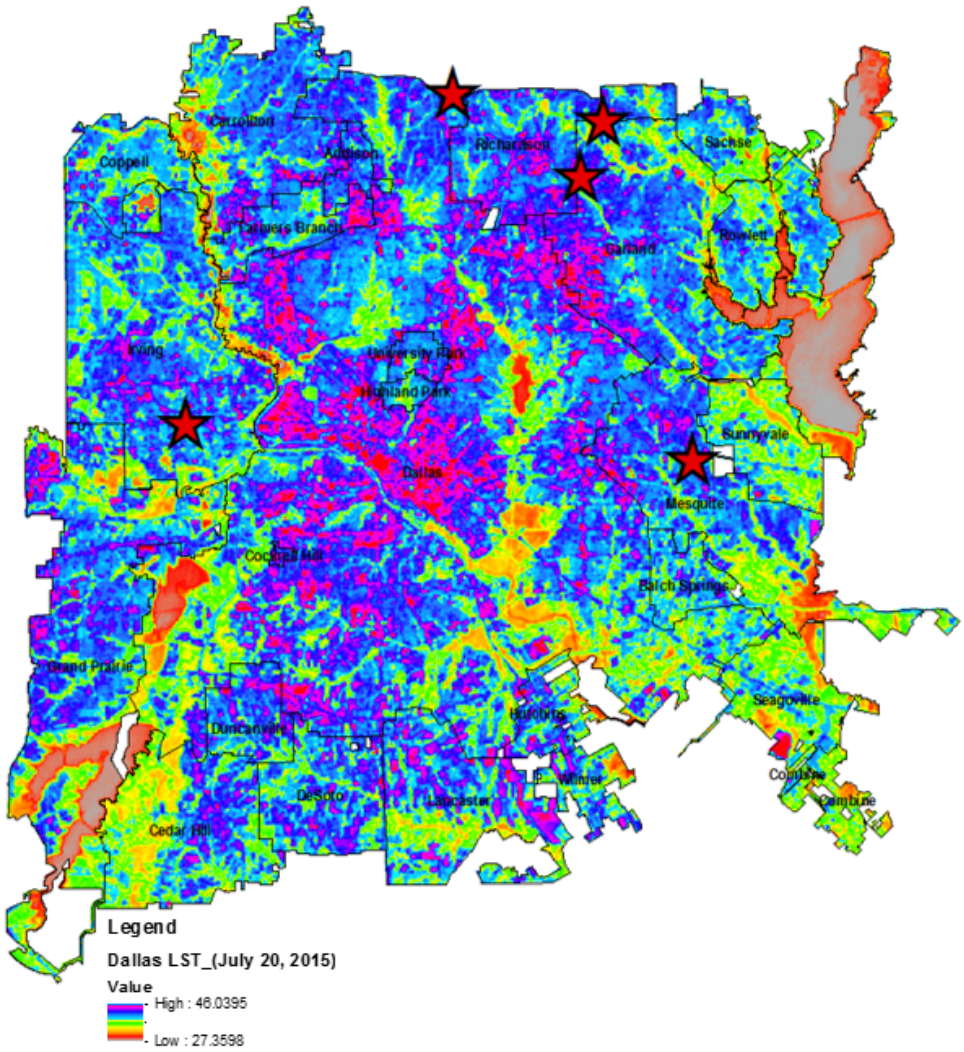

Figure 2. Land Surface Temperature Analysis of Dallas County (July 20, 2015)

In this present study, we used the TIRS band 10 to derive LST. Details of the image processing will be reported in a future paper. The ENVI5.3+IDL (Interactive data language) programming was used to compute the LST and land surface vegetation indexes. In addition, ArcGIS was used for the raster statistics to compute the minimum values, maximum, mean, standard deviation calculation and the correlation between two raster layers (LST and NDVI).

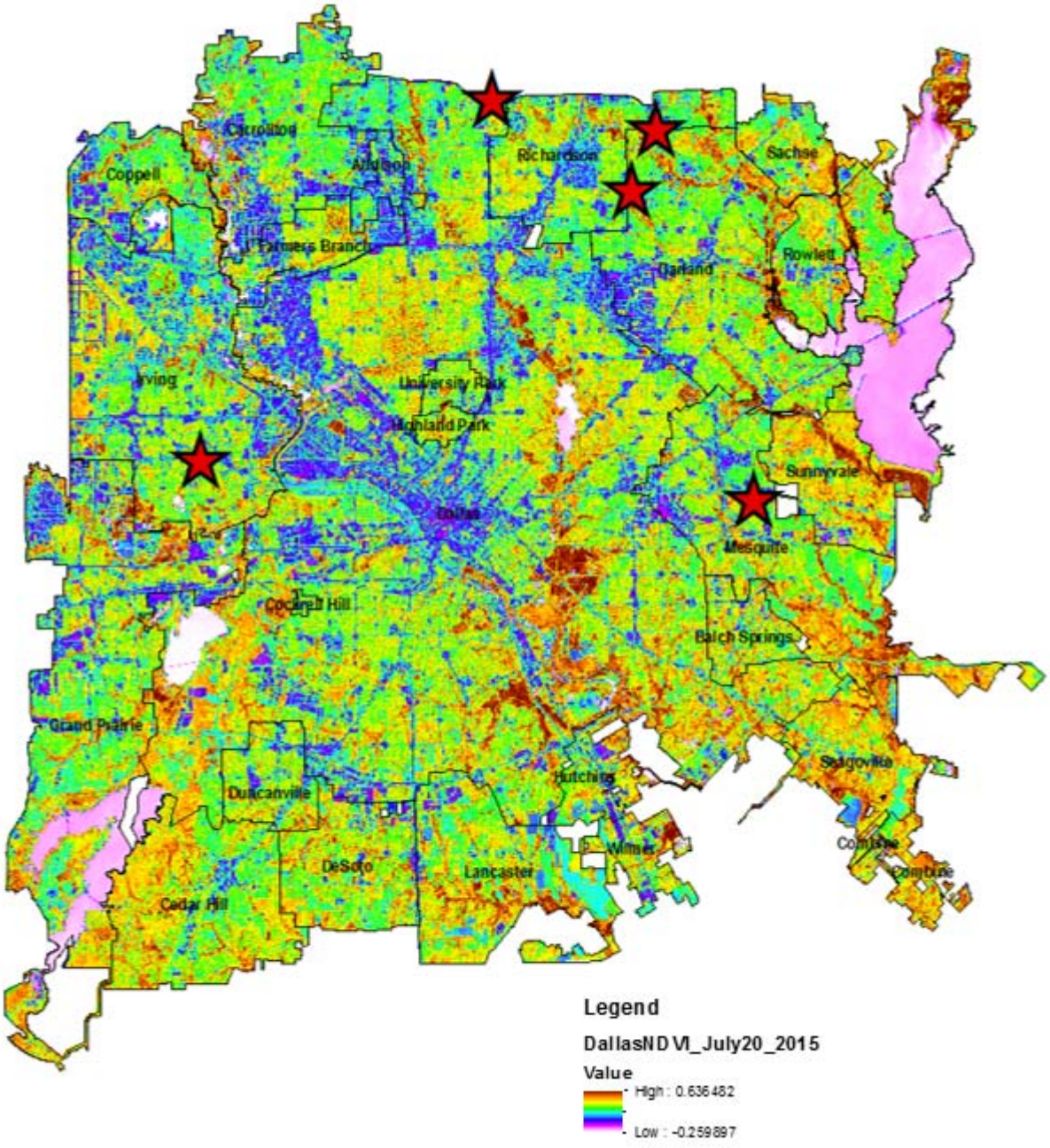

Figure 3. Normalized Difference Vegetation Index for Dallas County (July 20, 2015)

Results

A negative correlation was found between the LST and NDVI value in Dallas County (R^2=-0.19). The coefficients of correlations found showed clearly the degree of dependency between LST and NDVI layers. The negative correlations found in this study mean that the LST values change inversely to the NDVI over the urban landscape environment. Thus, vegetative cover as measured over the NDVI scale is directly related to surface temperatures. For example, the more vegetation measured, the lower the surface temperature, and the less vegetation (ie hardscapes & buildings) the higher the surface

temperature. This relationship is extremely important when siting ET weather stations in urban area by providing a guide for areas to avoid and target areas for station siting.

Table 2. LST and NDVI spectral statistics for Dallas County (July 20, 2015).

City	Year	Layer	MIN	MAX	MEAN	STD	Correlation (LST vs. NDVI)
Dallas	2015	LST	27.3501	**53.8542**	38.1932	3.1403	**-0.198067**
Dallas	2015	NDVI	-0.2599	0.6365	0.2725	0.1365	
Dallas	2014	LST	28.2987	51.8112	38.8378	2.8682	**-0.10557**
Dallas	2014	NDVI	-0.2473	0.6159	0.2287	0.105	
Dallas	2013	LST	28.3100	51.7812	37.7218	2.9244	**-0.11652**
Dallas	2013	NDVI	0.2466	0.6159	0.3527	0.2036	

NB: LST (Land surface temperature) in degree Celsius; MIN, MAX and MEAN stand for Minimum, Maximum and Mean temperature, respectively. STD represent the standard deviation. NDVI stands for the normalized difference vegetation index that vary between -1 and+1 (Higher the NDVI index, greener is the land surface. A zero means no vegetation and close to +1 (0.8 - 0.9) indicates the highest possible density of green leaves.)

During the July 20, 2015 Landsat 8 path over Dallas County, multiple ground temperature measurements were collected at the projected path time. These measurements were compared to a thermal analysis to verify processing accuracy. Table 3 shows the ground measured versus landsat calculated surface temperature. Processing was shown to be very accurate, resulting in an average difference of 1.2 degree Celsius.

Table 3. Landsat8 temperature estimate versus and ground measured temperatures in Dallas (2015-07-29)

OBJECT ID	**Latitude**	**Longitude**	**Ground measured temperature (°C)**	**Landsat Raster values (°C)**	**Difference (LandsatRaster – ground Measured)**
1	33.00106	-96.81278	35.9	34.812469	-1.1
2	32.99382	-96.79143	43.0	39.306183	-3.7
3	32.97892	-96.76953	39.0	42.293518	3.3
5	32.98589	-96.76533	36.6	39.080597	2.5
6	32.98198	-96.72872	35.9	37.320099	1.4
7	33.00033	-96.73797	36.4	41.223785	4.8
Average			37.8	39.0	1.2

Conclusion

Image processing and ground measurement analysis show that satellite thermal imagery can be a valuable tool for measuring surface temperature. This process can be adopted by utilities and state agencies for identifying potential ET weather station sites when developing urban ET based water conservation programs. Further analysis is needed to develop processing indexes to define the characteristics of temperature based microclimates across urban areas.