Urban Lawn and Turf Irrigation Monitoring and Assessment (ULTIMA)

By John Horn

Abstract

The southwestern United States faces water shortages, yet over 50% of home water use is allocated to irrigating turf grass (Gimmond and Oke 1986, Mayer et al, 1999). The purpose of this project is to develop that a novel combination of satellite and ground sensors are capable of monitoring the irrigation rates of household lawns within urban areas at high temporal resolution, spatial resolution, and low cost. The study area will expand in three stages: the initial study will take place in Orange County, CA using household water use data to ground-truth irrigation estimates, the study area will then expand to California in order to test the algorithm in a wide range of climates and utilize ET stations in the California Irrigation Management Information System (CIMIS), and finally will progress to cover the United States as the procedure becomes increasingly automated and calibrated. This study will provide the first active monitoring system to identify over irrigation, observe the effectiveness of outdoor water-use bans, and provide this information in real time through the web. A website containing real-time irrigation feedback will be made accessible to the community and irrigation rates will be updated at the individual house scale. The satellite that will be used to observe turf NDVI signal is Landsat using visible and thermal imagery obtained automatically from Google Earth Engine. The Johnson/Belitz algorithm designed by the USGS will be used to estimate irrigation rates using these Landsat images. While satellite images provide a general estimate of irrigation rates from above these instruments are still limited in spatial and temporal resolution. Therefore a device utilizing an NDVI sensor and multiple IR thermometers will be used to measure the health, area, and thermal signatures of lawns measured by a moving vehicle that scans lawns as it passes by. Fescue grass plots at the UCI Arboretum will be used as a control to calibrate thermal and NDVI proxy estimates of irrigation rates. Preliminary results show that the optimal time to take thermal ground-based measurements of lawns is from 2pm - 4pm. Using household water use data from multiple counties this experiment will test the range of accuracy of the Johnson-Belitz method to remotely assess irrigation rates. This experiment will also test the range of accuracy to estimate lawn irrigation rates based on surface temperature measurements. The goal of the methods to be developed is to allow city officials and the public better plan and monitor allocation of water resources under scenarios of drought and water use bans. This project will also close the urban hydrologic budget by better understanding outdoor water use.

Introduction

The problem that this project addresses is quantifying, in high spatial and temporal resolution, urban irrigation rates. Studies have shown that the average household uses more than 50% of total water per year to irrigate outdoor lawns (Gimmond and Oke 1986, Mayer et al, 1999). Outdoor water use is connected to multiple regional and local environmental issues including irrigation runoff, the urban heat island effect or UHI, and the future sustainability of water extraction and groundwater pumping rates. Outdoor water use has been positively correlated with home property square footage (Mayer et al, 1999). Individuals and neighborhoods using disproportionate amounts of water for outdoor irrigation will affect the cost structure and availability of water for the entire community in the future. The time-series results from this novel and integrative remotely sensed data will advance the field of hydrology by providing higher precision outdoor irrigation patterns to urban runoff modeling, direct observation of neighborhood spatial autocorrelation and clustered patterns of over/under irrigation, better estimates of climate and regional socio-economic effects on outdoor irrigation practices, and the effects of population growth on water-demand for urban irrigation. Results will be communicated to the public through a simple and intuitive web interface displaying irrigation rates at the neighborhood scale. This web application will provide the first feedback system for communities to make educated decisions on the scale of their lawns and irrigation practices and observe the economic and water resources needed to maintain these lawns.

Overview

Currently large scale irrigated surface estimation is estimated using proxies such as landscape cover (Milesi et al. 2005) or by infrequent and dated surveys (Siebert et al, 2005). These methods offer snapshots in time of irrigated land and are not dynamic. Obtaining irrigation estimates entirely from individually metered water records would be ideal, however, due to privacy issues, inadequate records, and the lack of a standardized billing between water agencies this is method is limited (Rockaway et al, 2011). This study will establish and test the accuracy of a method to quantify urban irrigation using an improved surface temperature and Normalized Difference Vegetation Index (NDVI) based proxy.

Current studies that try to estimate biogeochemical cycling of turf grass assume a constant irrigation rate for all homes in the continental US (Milesi et al. 2005). This novel remote sensing method can advance urban biogeochemical cycle studies by delivering high-resolution irrigation rates to these models with high temporal frequency. The current urban runoff model being used by the modeling community is the storm water management model (SWMM). However it has been noted by other studies that this model and others like it do not take into account the effects of water consumption, changing climate, and heterogeneous urban landscape on water demand (House-Peters and Chang, 2011). The lack of real time data on urban irrigation rates leaves a gap in current storm water modeling systems. This system addresses the lack of dynamic watering data through remote and ground based sensing. Implications of large areas with irrigated lawns include mitigation of the Urban Heat Island effect (UHI). It has been shown that irrigated spaces in neighborhoods are highly correlated with decreased air temperatures and on average reduces air temperatures by 1-2 degrees (Spronken-Smith and Oke 1998, Gill et al. 2007). It is unknown if this cooling effect is detectable at an individual lawn level and if a statistically significant correlation exists between surface temperature and irrigation rates.

Research Objectives

There is potential to use the heat absorbed by water in the form of latent heat, in combination with the NDVI signal, as a measure of over-watering of lawns at a neighborhood scale. This project will test the hypothesis that higher irrigation rates the cool the surface temperature of the grass surface. The timing, extent, and range of sensitivity of this physical proxy to actual irrigation rates are unknown. This study will ascertain the accuracy of a combined remote sensing and ground-based urban irrigation assessment method.

The novel method for quantifying urban irrigation was taught by the two creators of the Johnson-Belitz method for quantifying urban irrigation rates using remote sensing at the USGS field office in San Diego. This study uses the thermal infrared band from Landsat 5 as an additional parameter to complement the NDVI based Johnson-Belitz method. Both the remotely sensed method and the ground-based method described above are novel and have never been combined to study irrigation rates. What distinguishes this project from past thermal attempts at quantifying urban water use is the addition of household water use data to ground truth the thermal measurements (Spronken-Smith and Oke 1998). This project will test if surface temperatures correlate with irrigation rates and if this measurement is statistically significant. This project also will determine to what scale, if any, the 30m resolution Landsat images are accurate in determining irrigation rates using the NDVI metric and the thermal band.

Remote Sensing Methods

The method of NDVI Surplus developed by Johnson and Belitz (2011) introduced a novel proxy for estimating urban irrigation rates using irrigated endmembers such as golf courses and parks for fully irrigated lands and hardscape for little to no irrigation. This method involves finding land that is fully irrigated, e.g. a golf course or park, and assigning that irrigated area an "Irr" endmember designation. The next step is to find a non-irrigated area of land, e.g. an open field that receives irrigation primarily from precipitation, and assigning that non-irrigated land a "Non-Irr" end-member designation.

Landsat produces images every 16 days with a spatial resolution of 30m. This study advances the work of Johnson and Belitz by taking their algorithm, automating it, and combining readings with ground measurements. One limitation of Landsat images is that a 30m pixel can encompass multiple household lawns thus ground measurements are needed to help resolve mixed pixels. I also tested the feasibility of using MODIS satellite imagery.

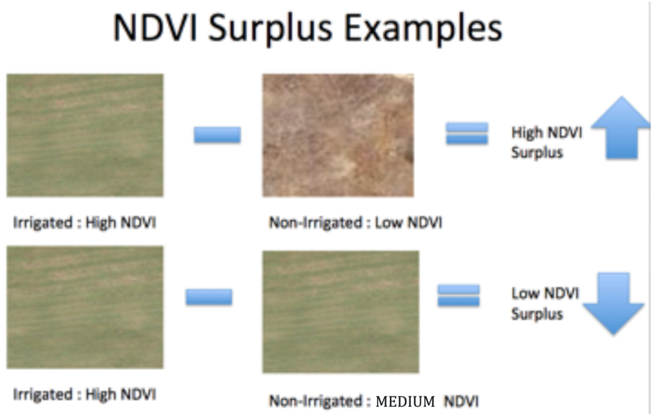

Figure 1: An example of how NDVI Surplus is derived. Non-irrigated areas that have a large amount of precipitation will have a Low NDVI Surplus or a low amount of irrigation needed to sustain healthy vegetation.

The NDVI Surplus metric is the most important part of this remote sensing algorithm. The top row shows the difference between an irrigated and non-irrigated pixel in a semi-arid region. Since the difference is large the NDVI Surplus is also large. In a region that receives ample precipitation the difference between irrigated and non-irrigated area is smaller and NDVI Surplus is lower. High NDVI surplus is an indicator for high irrigation rates needed to sustain the high NDVI signal.

The following is a break down of the remotely sensed end-member pixels and how they were chosen in Orange County as an initial test:

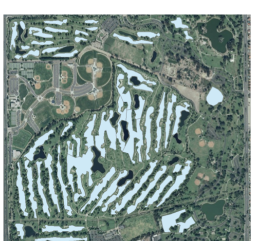

Fig 2: This map shows golf course polygons used to extract pixels.

Irrigated Landscape (Irr) Landsat

Golf Courses and Parks were used as proxies for fully irrigated endmembers because these areas are intensely irrigated to maintain a constant greenness.

Fig 3: The grass on the John Wayne Runway is a non-irrigated area.

Non-Irrigated Landscape (Non-Irr) - Landsat
The grass between runway spaces at most airports is not irrigated in order to deter sprinkler debris from entering jet engines. This area is ideally suited for a long time series analysis because the land is undisturbed for long periods of time.

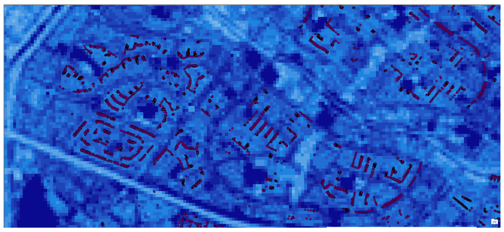

Fig 4: The purple dots correspond to homes with household water use data.

Neighborhoods (NHoods) - Landsat
The addresses of Orange County single family households and their corresponding monthly water use was analyzed. The NDVI signatures from these pixels are used a proxy for irrigation.

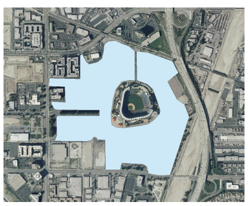

Fig 5: An example of hardscape pixels is Angels Stadium parking lot in Anaheim, CA.

HardScape (HrdScp)
Parking lots serve as exemplary hardscape end-members due to their large area and consistency though time since image analysis may span decades. The image on the left is the Anaheim Stadium parking lot used for hardscape.

(1) $$NDVI_p = \frac{NIR_p - Red_p}{NIR_p + Red_p}$$

(2) $$F_{irr}(t) = \frac{NDVI_{2end}(t) - NDVI_{impv}(t)}{NDVI_{irr}(t) - NDVI_{impv}(t)}$$

(3) $$\overline{F_{irr}} = \frac{1}{n}\sum_{i=0}^{n} F_{irr}(t)$$

(4) $$NDVI\_S_{nhood}(t) = NDVI\_S(t) * \overline{F_{irr}}$$

(5) $$a = \frac{ET_{Lmax}}{e^{b*NDVI\_S_{max}}}, \quad b = \frac{\ln(ET_{Lmax}) - \ln(ET_{Lmin})}{NDVI\_S_{max} - NDVI\_S_{min}}$$

(6) $$Irr(t) = ae^{b*NDVI\_S(t)}$$
$$Irr_F(t) = Irr(t)\ x\ F_{irr}(t)$$

F_irr represents in equations 2-6 represents the fraction of irrigated land. By subtracting the average NDVI from the "Non-Irr" endmember from the average "Irr" endmember one can find the NDVI surplus or NDVI_S, which acts as an irrigation demand metric that seasonally varies with multiple weather-based parameters. ET_L represents evapotranspiration for landscaped vegetation and is implemented in equation 5. $NDVI\_2_{end}$ represents the NDVI signal of the target landscape or lawn. By taking the NDVI of a target lawn ($NDVI_{2nd}$) used in equation 2 in combination with the NDVI surplus, used in equations 4 and 5, an irrigation proxy or Irr_f is produced which correlates with how much water was used to irrigate grass in the Landsat pixel. The crop coefficient of 0.65 used in this study was found to best represent grass in an urban setting (Johnson and Belitz, 2012).

The advantage of the remotely sensed method is that a wide breadth of area can be automatically scanned. One key advantage is the utilization of Google Earth Engine. In the past one had to manually download Landsat images from NASA and unlike MODIS imagery a tool does not exist to make the download process programmable and automated. This means that rather than having to download large individual files and process these images on one's system the files remain on Google's server, are processed there, and a much smaller file with results is downloaded to the user's system allowing for large areas to be covered efficiently.

Field Methods

In order to test the validity of the hypothesis that lawns irrigated more have lower surface temperatures than lawns irrigated less a calibration test at the UCI arboretum was implemented using 32 plots of fescue grass at different irrigation rates. The purpose of this control was to quantify the statistical significance of the correlation between surface temperature and irrigation rates. Because the grass encountered in the field may have different levels of greenness and health the 32 plots will be separated into four categories of Very Green, Green, Brown, and Yellow and four irrigation scenarios. These categories were grouped based on the morning and afternoon surface temperatures of non-irrigated plots. The pairing of visual inspection and surface temperature showed early in the experiment that albedo is directly correlated with grass health and color. The evidence for this correlation is expanded upon in the results. The four different irrigation scenarios are based on CIMIS evapotranspiration measurements. In this experiment since thermal measurements took place from late May 2013 to early June 2013 the June ET signal from the Irvine CIMIS site was averaged over the last four years to produce a 100% ET estimate. This 100% ET value, in units of inches height, was then used to produce other irrigation scenarios that varied from 0% - 300% ET.

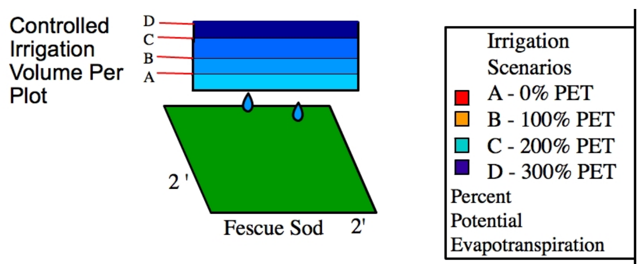

Fig 6: The sod will be hand irrigated so that a fixed amount of water is dedicated to each plot.

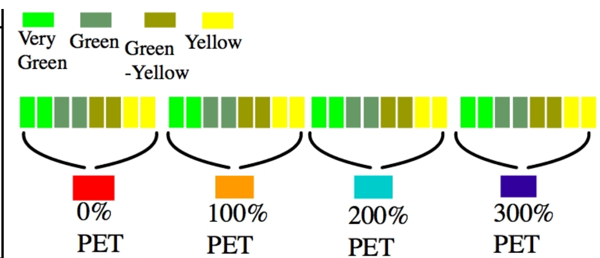

Fig 7: For every irrigation rate scenario there are two very green, green, green-yellow, and yellow plots for a total of 32 plots and four irrigation rates.

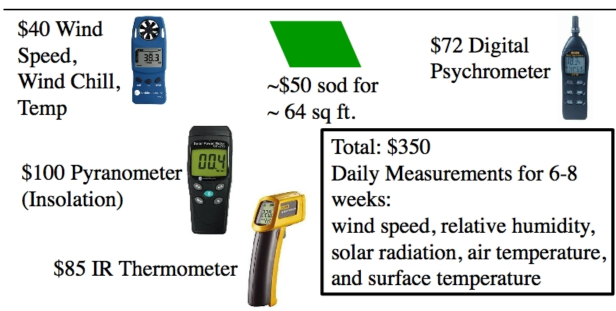

Fig 8: Handheld tools to be used in the field to take weather and thermal measurements

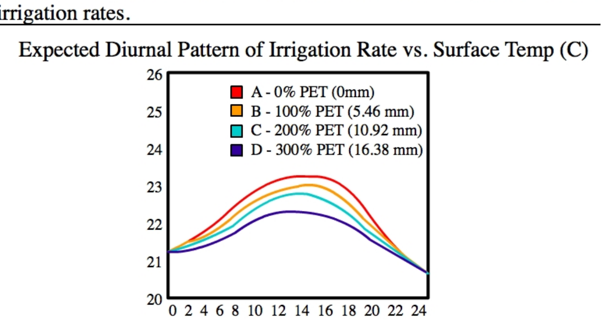

Fig 9: It is hypothesized that a unique diurnal thermal signature will be observed for each irrigation scheme.

After irrigating for 10 days and allowing the roots of the plots to settle into the soil the plots were irrigated at 8:30am according to their irrigation scenario. It was observed that albedo and grass color were varied even before the irrigation scenario began. Starting at 9:00am a series of ground measurements were repeated every hour until 5:00 pm. A FLIR IR thermometer measured the surface temperature and the mean temperature and range are recorded. A pyranometer was used to observe insolation. A handheld wind anemometer was used to capture wind speed and ambient temperature. A digital psychrometer was used to observe relative humidity, web bulb temperature, dry bulb temperature, and dew point. The reason a combination of measurements was taken is so that environmental factors and weather can be better modeled in urban hydrology. The advantage of this method over the current method of assuming constant irrigation rates at all households (Milesi et al. 2005) is that spatial and temporal differences can be identified at a resolution never before seen to better inform public planning. Ground measurements complement the remote sensing method in that the 30m Landsat pixels often encompass multiple lawns and therefore provide a mixed signal. By non-intrusively taking thermal measurements individual homes that are over-irrigating can be identified.

Results Comparison with Previous Work – Remote Sensing

Winter Landsat (Johnson and Belitz)

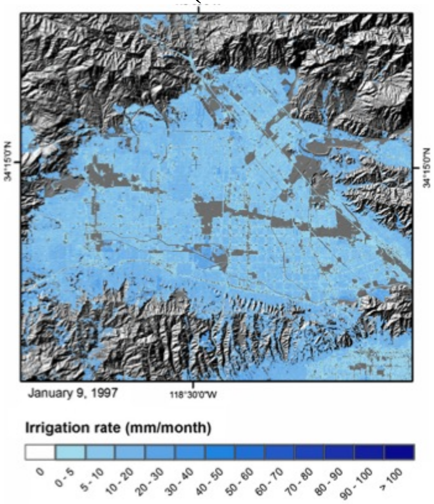

Fig 10: Irrigation 1/9/1997, courtesy of Johnson-Belitz

Winter MODIS (Horn)

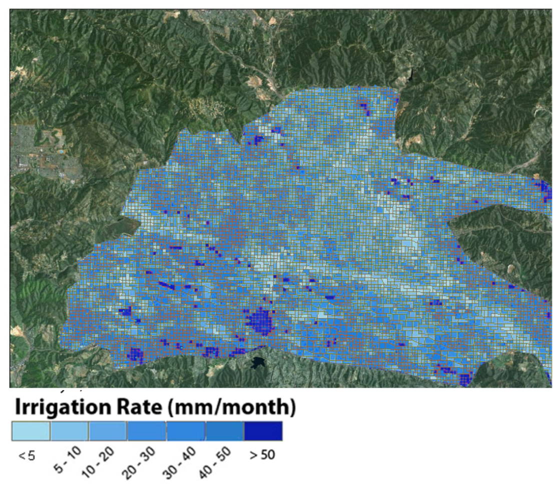

Fig 11: Irrigation 1/9/2002 determined by MODIS.

Summer Landsat (Johnson and Belitz)

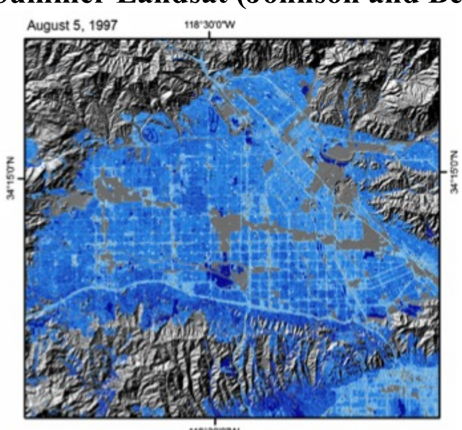

Fig 12: Irrigation 8/5/1997, courtesy of Johnson-Belitz

Summer MODIS (Horn)

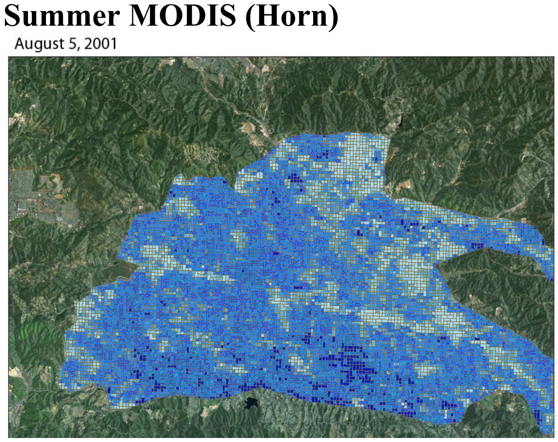

Fig 13: Irrigation 8/5/2001 determined by MODIS

The reason the MODIS maps do not match the date of the Landsat maps created by Johnson-Belitz is because MODIS did not begin operation until 1999. The preliminary results show the potential for MODIS images to help fill in gaps for Landsat imagery. The summer shows increased irrigation rates and winter shows decreased irrigation rates for both Landsat and

MODIS. While these initial results show the potential for MODIS to fill in Landsat gaps this study will focus on using Landsat images. The primary reason MODIS will not be used initially is that the 250m resolution of MODIS limits the ability to observe irrigation rates at a finer scale.

Fig 14: Spring 2010 – Estimated irrigation rate (mm/month), Landsat

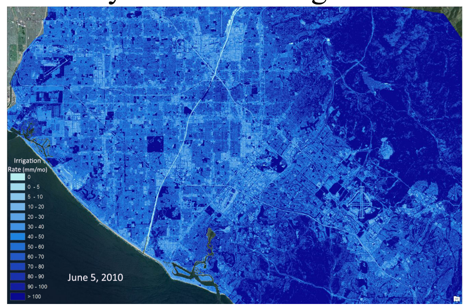

Fig 15: Summer 2010 – Estimated irrigation rate (mm/month), Landsat

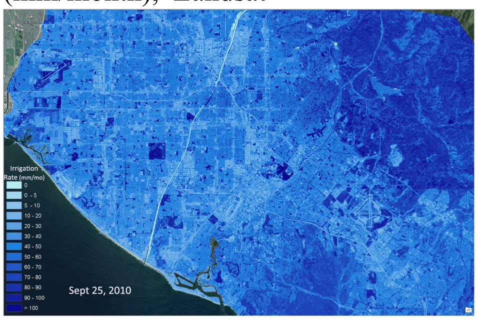

Fig 16: Autumn 2010 – Estimated irrigation rate (mm/month) , Landsat

Fig 17: Winter 2010 – Estimated irrigation rate (mm/month) , Landsat

Figures 14 – 17 show the Johnson-Belitz method applied in Orange County. One key improvement made was that I created an atmospheric correction model based on Dark Object Subtraction in Python so that the imagery is comparable under different atmospheric conditions (Chavez 1988). A simple function was created in which household water use was evaluated based on six independent variables. The dependent variable is Outdoor Irrigation, which was derived from Irvine household water use data. The outdoor water use data, processed by Dr. Neeta Bijoor, was determined by subtracting the winter minimum water use from total water use to come at a rough estimate for outdoor water use. This estimate is based on the assumption that outdoor irrigation is at a minimum during winter. Three of the independent variables including turf area, tree area, and pool area were obtained from the Irvine Ranch Water District. The two remotely sensed independent variables are "Irr_{Remote}", which is based on the NDVI surplus proxy and Surface Temp, which is based on Landsat 5 thermal band. The sixth variable was spatial ET extrapolated from the California Irrigation Management Information System or CIMIS.

Table 1: Correlation and Statistical Significance Summary

Variable	Turf Area	Tree Area	Irr_{Remote}	ET_{CIMIS}	Pool Area	Surface Temp
Pearson Coeff:	0.185	0.178	0.156	0.149	0.108	0.003
p	$< 2.2 e^{-16}$	$< 2.2 e^{-16}$	$< 2.2 e^{-16}$	$< 2.2 e^{-16}$	$< 2.2 e^{-16}$	0.1382
R^2	0.034	0.032	0.024	0.022	0.012	0.00

It appears that the turf area accounts for the variability of water use the most followed by tree area, remotely sensed irrigation, ET, and pool area. Surface temperature as sensed by the Landsat 5 thermal band, with a 60m resolution, does not appear to correlate strongly with outdoor irrigation use. All parameters except surface temperature were significantly correlated with outdoor water use measured in 100 cubic feet monthly. A Bayesian Information Criteria was conducted to simplify the model and select the best parameters however no parameters were eliminated from this statistical method. A condition number of 19.4 was observed for this model which means that the level of multicollinearity was not high and parameters were sufficiently independent of one another. The R^2 values appear relatively low using this model.

Results Comparison with Previous Work – Ground Data

No scientific work has focused directly on lawn thermal signatures. Qualitative work has been conducted on park thermal signatures in urban areas (Spronken-Smith and Oke 1998)

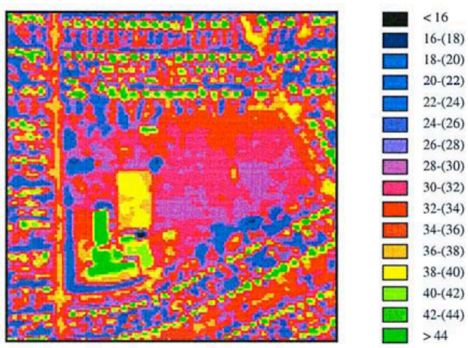

Fig 18: Apparent surface temperature aerial photograph (Spronken-Smith and Oke 1998)

Figure 18 shows the apparent surface temperature taken from a thermal imager aboard a helicopter at 2pm in Vancouver, CA (Spronken-Smith and Oke 1998). Neighborhood lawns surrounding Trafalgar park appear to have a lower temperature than the surrounding landscape. In the early afternoon the range of surface temperatures is very large, about 30° Celsius (Spronken-Smith and Oke 1998).

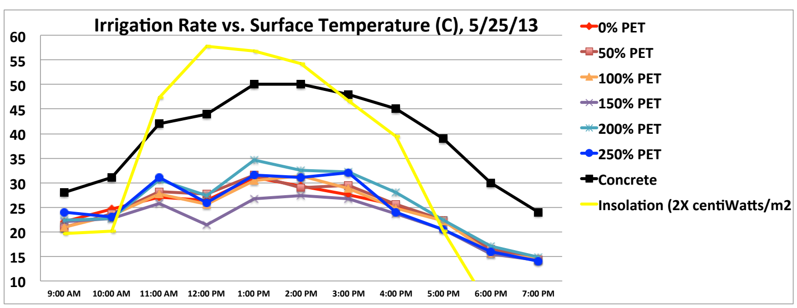

Fig 19: The first irrigation experiment displayed mixed temperature trends. Grass greenness was responsible thus Very Green, Green, Green-Yellow, and Yellow grass was distributed evenly among samples seen in Fig 7.

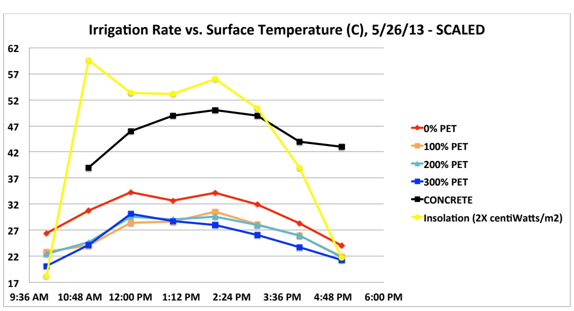

Fig 20: It appears that the optimal time to observe temperature differences is between 2pm and 4pm.

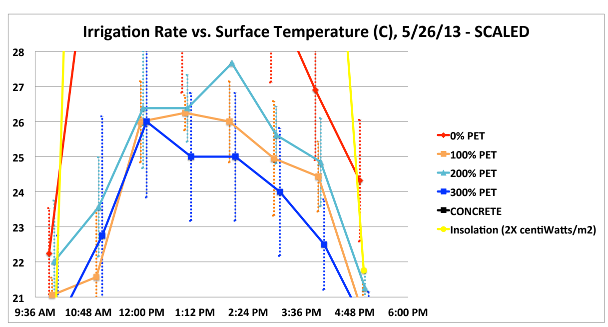

Fig 21: Because the standard deviations in figure 20 are difficult to distinguish they are highlighted here.

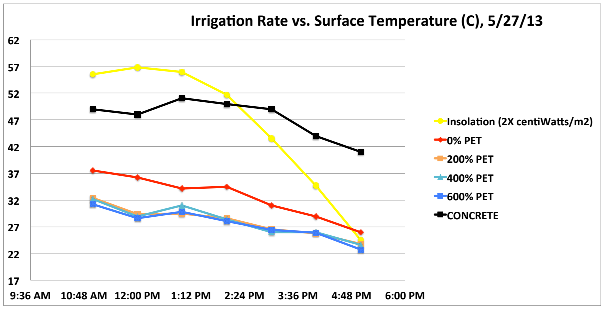

Fig 22: It appears that over-irrigation above 200% is thermally indistinguishable due to Latent Heat.

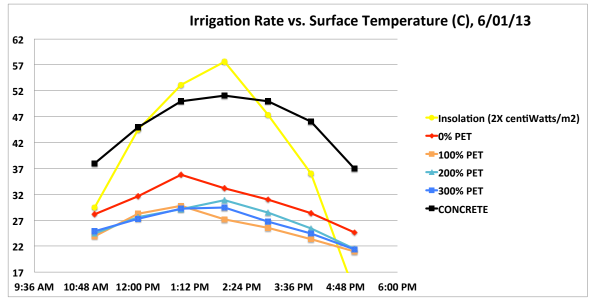

Fig 23: Once again 2-4pm is an optimal observation time. The 100% PET trend line appears anomalous.

The ability to thermally distinguish over-irrigation may disappear above 200% PET due to latent heat constraints, however it is important to note that the concrete thermal signature that day shows different heat absorption rates compared to fig 20 and 21. Because of these inconsistencies and overlapping standard deviations shown in fig 21 more trials are needed with larger plot sizes.

Expected significance of results

Upon larger plot sizes and sample sizes it is expected that the statistical significance of thermal readings will be enhanced and will no longer overlap. Because simultaneous weather and asphalt thermal properties were taken it is expected that this set of results will allow others in the field to make similar observations, while calibrating for varying weather conditions, and derive fescue irrigation rates in urban areas. The product of this analysis will be an assessment of method accuracy for different sized irrigated spaces ranging from fields to lawns.

Relationship to existing research efforts

This work expands upon the qualitative observation that parks and lawns produce a cooling effect called the "Park Cool Island" effect or PCI (Spronken-Smith and Oke 1998). While previous work mentioned above uses in-situ helicopter thermal measurements of parks it does not utilize a control from which to infer irrigation rates. This project differentiates itself by calibrating thermal measurements with a controlled irrigation experiment, utilizing a new Lansat-based remote sensing algorithm (Johnson and Belitz 2012), and using more cost-efficient methods of taking surface temperature readings.

Benefits to scientific community

When looking for models to improve resource efficiency previous studies in the field of energy efficiency have shown that the addition of community feedback and neighborhood progress, in the form of a web application, has been successful in increasing efficiency and decreasing energy use (Alcott 2011). However, in the water use space, there is currently no large-scale program that can measure outdoor water use and provide community feedback and progress on outdoor water use efficiency. This study fulfills this need by providing scientific data not only for the hydrological and geochemical modeling community but also for the community at large. By establishing a cost-effective means of measuring irrigation rates of grass scientists, public utilities, and citizens can more easily identify inefficiencies and over-irrigation in urban space within a known range of accuracy.

Schedule and Deliverables

Figure 24: The fescue grass plots from the Alpha Calibration are located in the UCI Arboretum. Three plots are each dedicated to a 0%, 100%, 200%, and 300% PET irrigation scenario as outlined in figure 7.

If this initial hypothesis shows statistically encouraging results then a Beta Calibration test that uses more irrigation scenarios and larger grass plots will be conducted. Also different slabs of asphalt and concrete with varying emissivity and albedo will be placed near these grass plots in order to absorb solar irradiance. These asphalt slabs simulate the road in neighborhoods and may serve as indirect proxy for local weather and insolation. These asphalt proxies for local weather may allow field measurements to be normalized given that local temperature, cloud cover, and weather may vary day to day.

Device Build Alpha ($1900)

The initial hypothesis is that irrigation rate is correlated with surface temperature. If the Alpha Calibration and Beta Calibration prove successful then a $1200 FLIR Scout Thermal Imager and a $700 NDVI camera will be utilized to begin taking household lawn readings from a moving vehicle. GPS locations will simultaneously be taken during each measurement and will be mapped using GIS. This will allow for spatial analysis and identification of over-irrigation in different neighborhoods.

Future Methodology

If the results prove successful in Orange County than further focus will be directed towards creating mobile sensors that can be attached to city street sweepers and automatically send field measurements to a central server. A real time update could then be posted to a website showing houses that are either over-irrigating or irrigating during inefficient times due to high insolation and evaporation.

Project Management and Collaborations

Due to the vastness and large scope of this project collaboration with the scientific, municipal, and private industry communities is essential. A point of contact was established with the nations largest integrative landscaping and design company ValleyCrest Design Group to understand irrigation practices at different scales from homeowners to golf courses. This connection also serves as an education source and point of access to Home Owners Associations which are influential with regards to urban irrigation. This study is being guided by the Urban Irrigation expertise and Interactive Web Mapping experience found at the University of California Center for Hydrologic Modeling UCCHM. The public utility data for Irvine single family house hold water use will be used to train and ground truth the mapping algorithm. The novel method for quantifying urban irrigation was taught by the two creators of the Johnson-Belitz method for quantifying urban irrigation rates using remote sensing at the USGS field office in San Diego.

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Education

Stanford University, Stanford CA — **2010 - 2012**
M.S. in Civil and Environmental Engineering – Atmosphere / Energy
Conferred 04/05/2012

University of California, San Diego — **2006 - 2010**
B.S. in Biochemistry/Chemistry
Conferred 06/11/2010

Projects

Created Custom GIS/Remote Sensing Tool for USGS to process Satellite Images — **2012**
- Using Python and Arcmap Model Builder, created a tool that allows for more efficient processing of satellite images. This tool converts satellite radiance to surface reflectance and corrects for atmospheric effects and haze. It allows one to quickly conduct landuse characterizations using remotely sensed data within ESRI ArcMap GIS software.

Created Statistical GIS application to map optimal wind farm locations for Stanford Univ. — **2011**
- Using the R statistical software package in combination with ArcMap GIS, assessed the optimal wind farm locations in the continental United States using transmission line, road, wind speed, state renewable incentives, endangered species, and topo spatial data.

Competed in National Entrepreneurship Competition at Stanford University — **2011**
- Competed in a highly selective national entrepreneurship competition called BASES Entrepreneurship Bootcamp hosted by Stanford. Worked on a team to build a program that lets users track their carbon footprint and compare with friends.

Created a Novel Depth Analysis Program for the United States Geological Survey — **2010**
- Within three months programmed a user interface in Excel Visual Basic that gathers thousands of ground water data sets and finds trends in chemicals at varying depths.

Research on the Chemistry of Atmospheric Sulfate and Aerosols — **2009 – 2010**
- Worked on a research team of five, as a lab assistant, conducting physical experiments that characterized the reaction rate of sulfur dioxide being oxidized to sulfate when exposed to the surface of aerosols.

Developed Atmospheric Engineering Project with High Tech High Students — **2009 - 2010**
- Built a device that captures atmospheric pollutants in the air at different elevations in order to improve the modeling of pollutant life cycles. Students were organized into specialized groups entitled payload, flight, tracking, landing, and electrical.

Skills and Qualifications

- Technical expertise in ArcGIS, Remote Sensing, Python, Matlab, Excel Visual Basic, R Statistical Software, Analytical Chemistry, Photoshop, Flash, Microsoft Office Suite
- Coursework in Energy Resources, Energy Processes, Building Systems, Greenhouse Gas Mitigation, GIS, Remote Sensing, Modeling, Advanced Statistics, Hydrology, Pollution
- Experienced Grant Writer – Awarded UCSD Belkin Research Fellowship, Stanford Engineering Dean's 3D Fellowship, Association of Env. Professionals Scholarship, Marine Technology Society Scholarship, and Environmental Defense Fund Lokey Finalist

Leadership Activities

- Science in Service – Teach science to local underserved high school students — **2011**
- Stanford Solar Wind Energy Project team member — **2010 - 2012**
- Management Member for Greater San Diego Science and Engineering Fair — **2003 - 2010**
- Worked with High Tech High school to send instrument into stratosphere — **2009 - 2010**

Honors

- Eagle Scout
- Cozzarelli Prize – National Academy of Sciences – Physical and Mathematical Sciences — **2010**
- Published Co-author Proceedings of the National Academy of Sciences — **Oct, 2010**
- Published Co-author of "Quantitative analysis of antigen-specific antibodies" — **Nov, 2006**
- Published Co-author of Perspectives of San Diego Bay: A Field Guide 0-9762706-5-x — **Feb, 2006**

Additional

• Hydrological Internship with the United States Geological Survey - GAMA project	**2010 - Present**
• Atmospheric Chemistry internship studying pollutants under Dr. Mark Thiemens	**2009 – 2010**
• Biotech internship at La Jolla Bio Engineering Institute	**2005**
• R&D Engineering Internship at Sontek/YSI, helped in R&D	**2005**