Use of Remote Sensing to Identify Urban Landscape Water Use in Sacramento, California

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Abstract
The traditional approach to estimating evapotranspiration (ET) originating from applied irrigation water is to apply crop coefficients (Kc) to land use types and then multiply by reference ET (ETo). However, the Kc X ETo approach can be subject to significant uncertainty due various factors including land use and water management. Remote sensing, using satellite imagery and ancillary weather data combined with proven energy balance algorithms offers a new tool for estimating plant ET. Evapotranspiration estimated from remote sensing is combined with GIS coverage of land use, to determine plant factors (Kcs). Factors influencing ET are inherently accounted for in this approach. Water conservation professionals can use the information to help irrigation managers better match plant water needs with available supplies and to target irrigation system improvements. In addition, spatial and temporal coverage can be used for viewing on Google Earth.

Keywords. remote sensing, evapotranspiration, irrigation, urban landsacpe

Introduction
Urban landscape water use in the Sacramento area is thought account for over 50% of the total water consumption in the region. Recent state legislation and renewed awareness of water conservation have highlighted the need to reduce the amount of water used for landscape irrigation.

The traditional approach to estimating evapotranspiration (ET) begins by surveying land use to define the areas occupied by different types of crops or vegetation over time. Water use for each crop and land use type is then computed by multiplying reference ET (computed from weather data) by crop- and land use-specific coefficients (Kc values). These Kc values are often developed through research at small-scale controlled plots. Land use surveys are extremely labor intensive, time consuming and costly, and the ET estimates derived from them are subject to significant uncertainty due to difficulties involved with accounting for the effects of irrigation management practices, soil and water salinity, water supply adequacy, presence of shallow groundwater, and other spatially variable influences on ET. There is sufficient knowledge available in the scientific community regarding coefficients (Kc) for crops grown under pristine conditions; however, Kc values for non-pristine agricultural conditions and for non-agricultural water depletion processes are not adequately defined at this time.

Remote sensing offers a new means of estimating ET, using digital satellite imagery combined with tested processing algorithms. WaterWatch of The Netherlands (www.waterwatch.nl) has developed the Surface Energy Balance Algorithm for Land (SEBAL) to calculate the potential and actual ET of each pixel in a satellite image. The ET is calculated based on radiances recorded by digital images along with some ground based ancillary weather data and is independent of crop and land use type. SEBAL has been applied in numerous countries around the world, including the U.S. and has been independently validated for a variety of land cover types, climatic conditions and spatial scales (Bastiaanssen, et. al., 2005). In California, SEBAL (www.sebal.us) has been applied to improve ET estimates for several agricultural areas (Wijsman, 2005); however, use in an urban area has not been examined.

Combining GIS coverage (e.g. landuse, water and irrigation districts and agencies boundaries) with ET estimates from SEBAL allows water managers to view and understand the spatial and temporal distributions of actual ET and Kcs values to support water management decisions. Also, exporting data to a viewer such as Google Earth allows for better visualization. Additionally, data can be exported to spreadsheets for combination with metered water use for analysis.

Data and Methods

Data required for this project include detailed land use information in a GIS format, monthly water delivery data for various connection types, meteorological data from California Irrigation Management Information System (CIMIS, www.cimis.water.ca.gov) and satellite imagery in visible, near-infrared and thermal spectrum from LANDSAT (http://glovis.usgs.gov). Satellite images were processed, using SEBAL, to calculate the residual energy of incoming solar radiation after accounting for atmospheric absorption and transference, outgoing and reflected radiation, heat to the soil and heat to the air. The LANDSAT imagery utilized has a 30m resolution in visible and near-infrared bands and 120m (resampled to 60m) for the thermal band. The major SEBAL model outputs include ET actual, (ETa), crop coefficients (Kc & Ks), and normalized difference vegetation index (NDVI) at 30m resolution. Reference ET was also estimated within SEBAL using spatially distributed weather data from CIMIS.

LANDSAT Images and SEBAL

Eight LANDSAT satellite images from 2007 covering Sacramento County (Row 33.5 and Path 44, shifted scene) were utilized (Table 1). Each image was processed using SEBAL to compute actual ET for each pixel in each image set. The individual image results were used to develop period estimates of ETa that were summed to obtain a seasonal total ETa covering the period March 16 through September 30, 2007.

Table 1. Periods represented by Each LANDSAT image date.

Image Date	Period Represented	Total No. of Days
March 31st , 2007	March 16th – March 31st	16
April 16th , 2007	April 1st – April 30th	30
May 10th , 2007	May 1st – May 31st	31
June 19th , 2007	June 1st – June 30th	30
July 5th , 2007	July 1st – July 15th	15
July 21st , 2007	July 16th – July 31st	16
August 22nd , 2007	August 1st – August 31st	31
September 7th , 2007	September 1st – September 30th	30

Land use GIS coverage for the greater Sacramento region was combined with the ETa determined with SEBAL to obtain period and seasonal ETa values for each land use type. Additional outputs included, Kc, Ks, and NDVI, and biomass production for each pixel in the study area for each image date. An ESRI shapefile containing points located at the center of each satellite pixel within the study area was generated for extracting ET and other spatial data. The extracted spatial data was exported and stored in a database (Table 2).

Table 2. Format of database with pixel-Scale SEBAL daily and periodic results.

Parameter or Data Field	Units	Data Type
Pixel x-coordinate	m	float
Pixel y-coordinate	m	float
Field or Polygon ID	-	integer
Water Purveyor	-	text
Land Use Type	-	text
Image Date	-	date
Period Represented	-	text
Daily ETa, Kc, Ks & NDVI	mm	float
Period ETa Kc, Ks & NDVI	mm	float

Land Use Shape files
Land use shape files were collected from water suppliers and other governmental agencies with land use planning responsibilities. Specific land use types were available for golf courses, cemeteries, regional parks, agricultural areas, and political boundaries. For some entities political boundaries include residential sub-divisions or neighborhoods, industrial zones etc. National Agricultural Statistics Service (NASS) Landuse grid for 2007 was used to delineate agricultural land use type. All the land use data were in an ESRI polygon shapefile format except the NASS data which were in a grid format with a spatial resolution of 30m x 30m. The NASS data utilized in the present study was developed by US Department of Agriculture using Landsat images for the growing season of 2007.

CIMIS Data
Measurements of incoming solar radiation, air temperature, relative humidity, and wind speed were used in the SEBAL analysis. These meteorological data were analyzed at instantaneous (time of the satellite overpass), daily (average for the image date), and periodic (average for the period represented by an individual image date) time steps. These parameters were obtained from twenty-five CIMIS stations within or surrounding the Landsat scene (DWR, 2011).

Weather data from each station were reviewed and corrected when necessary, following accepted, procedures (Allen, et al 1998 and Allen et al., 2005). Weather observations from ground stations represent point measurements that may be representative of the surrounding area; however, in many cases, particularly for heterogeneous regions, the point data may not be suitable to represent weather conditions of the surrounding area. To overcome this limitation, spatially distributed weather grids were developed using MeteoLook (Voogt, M.P., 2006). This model interpolates point weather observations based on the knowledge of surface and terrain characteristics coupled with physically-based models. Processes that influence surface weather conditions such as elevation, surface roughness, albedo, incoming radiation, land wetness, and distance to water bodies are included in MeteoLook.

Reference ET (ETo) was estimated from spatially distributed weather data using the ASCE Standardized Penman–Monteith grass reference equation (Allen et al., 2005). The actual crop water use coefficients were then developed using the spatially distributed ETa and ETo data. For the ETa analysis, and for specifying water use budgets, the spatially distributed reference ET (ETo) data was used to develop crop water use coefficients. ETo for the analysis period, represented by the Fair Oaks CIMIS station, totaled 41.2 inches (Table 3). Rainfall for the same period totaled 2.72 inches.

Table 3. Rainfall and reference evapotranspiration form the Fair Oaks CIMIS station, Fair Oaks CA.

Period Represented	Rain	Reference ET (ETo)
	inches	
March 1-15*	0.04	1.54
March 16-31	0.53	2.13
April 1-30	1.73	4.88
May 1-31	0.39	6.99
June 1-30	0	7.71
July 1-15	0	3.9
July 16-31	0	3.79
August 1-31	0	7.14
September 1-30	0.07	4.66
Total	2.72	41.2

*Not used in the analysis or included in the totals.

Sample Output

Sample output was prepared for several different land use applications; residential neighborhoods, a golf course, and a park. Output includes figures that show the type of data available along with spatial and temporal out.

Google Earth Overlay

Images exported from the GIS can be imported as overlays in Google Earth (Figure 1). This output can be used to navigate an area to look for high water use area which is particularly important in areas without meters (Figure 2). A qualitative comparison between Figures 1 & 2 indicates that there is considerable more ET in Figure 2, a neighborhood without meters to residential connections. A noticeable difference in the two developments is the density of tree canopy.

EvapoTranspiration and Plant Factor (Crop) Coefficients

Temporal and spatial output of both ET and Kcs are available. Eight time periods (Table 1) of ETa were analyzed, with each image date representing between 15 and 31 days. The initial time period (March 16-31) represents leaf out for trees in the region whereas subsequent images are considered to be at full leaf out. ETa for the individual periods were added spatially to obtain a seasonal total representing a period of March 16 – September 30, 2007. The Kcs were estimated for the each of the respective image dates (Table 1).

The data presented in Figure 3 are the same that are shown in Figures 1 and 2 but are put on a scale of area. The metered neighborhood had a greater percent the total area with lower ETa than the neighborhood without meters. Also shown in Figure 3 is the distribution of seasonal ETa from a riparian forest located at the confluence of two drainages in the southern section of Sacramento County. The average ETa in the metered neighborhood is 25.3 inches and 39.3 inches in the unmetered neighborhood. ETa of the riparian forest is 43.2 inches. Data can also be plotted by period (Fig. 4). The utility of plotting data in this manner is that the ETa variability is evident and a user can compare the consumptive use against CIMIS.

Actual plant mix coefficients are the ratio of ETa to ETo, where ETo is estimated within SEBAL using spatially distributed CIMIS weather data. Figure 5 is Google Earth output of a public park. The top portion shows the land use in the park and the bottom has the Kcs values from the September 7, 2007 image date. In a small park such as this, the 30 m -120m resolution of the input data results in overlaps that combine mixed uses. For example, the tennis courts in the image show up as having Kc values around 0.6-0.8 but this is a result of the trees surrounding the tennis courts. The lower baseball field is large enough for several measurements but without viewing the outline of the pixels it is unknown if the measurement can be considered reliable because they may contain portions of the houses, the ball field or the road. Figure 6 presents Kcs distribution (for the area shown in Figure 4) for 9/7/07 plotted along with the range of values that the State published in their guidance documents (Costello, 2000). The minimum Kc value is 0.57 and the maximum is 1.3.

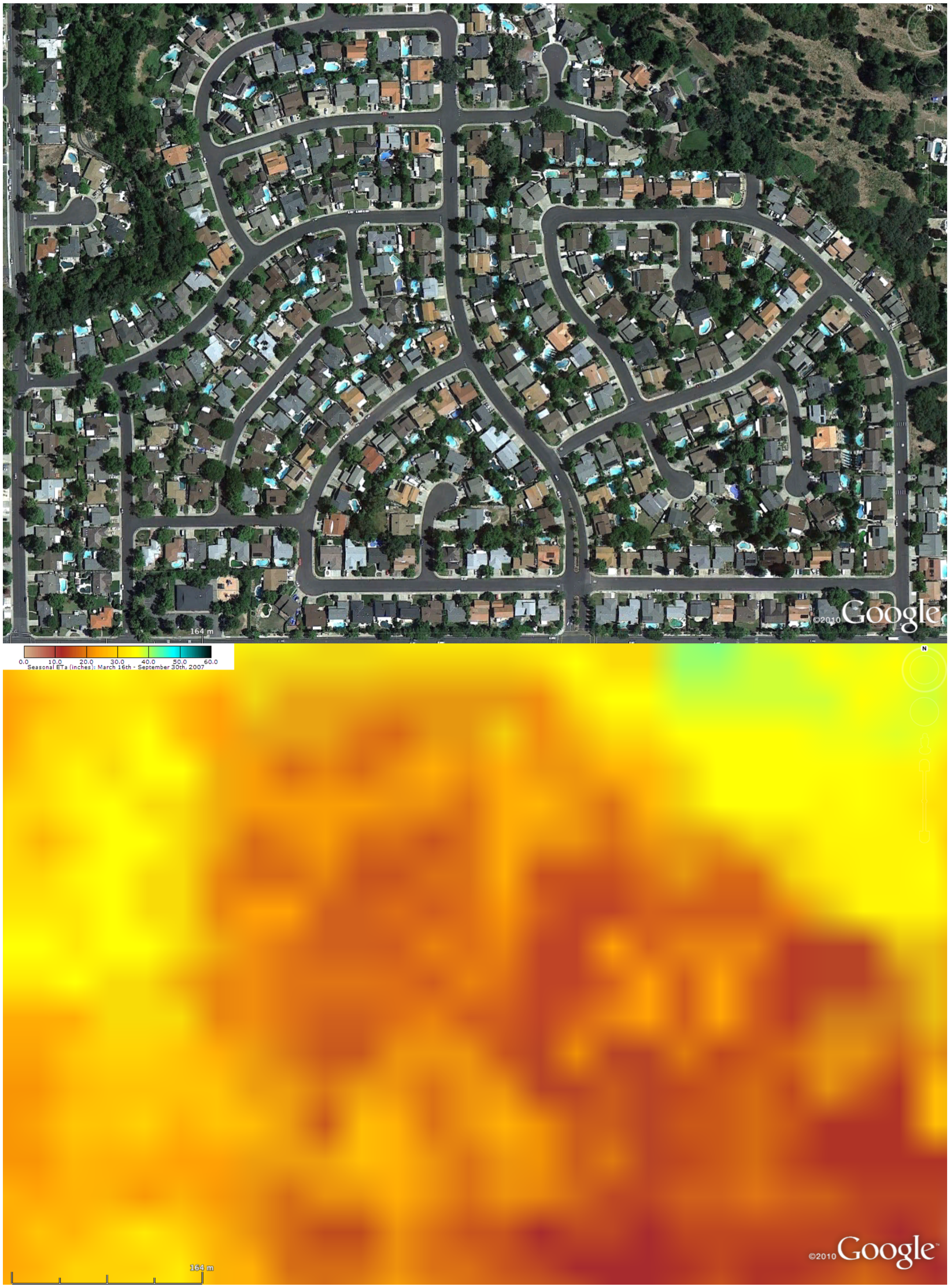

Figure 1. Google Earth with SEBAL based seasonal ETa from a metered residential neighborhood in the greater Sacramento region. Average ETa for the analysis period is 25.3 inches. The average age of homes in the area is about seventy years.

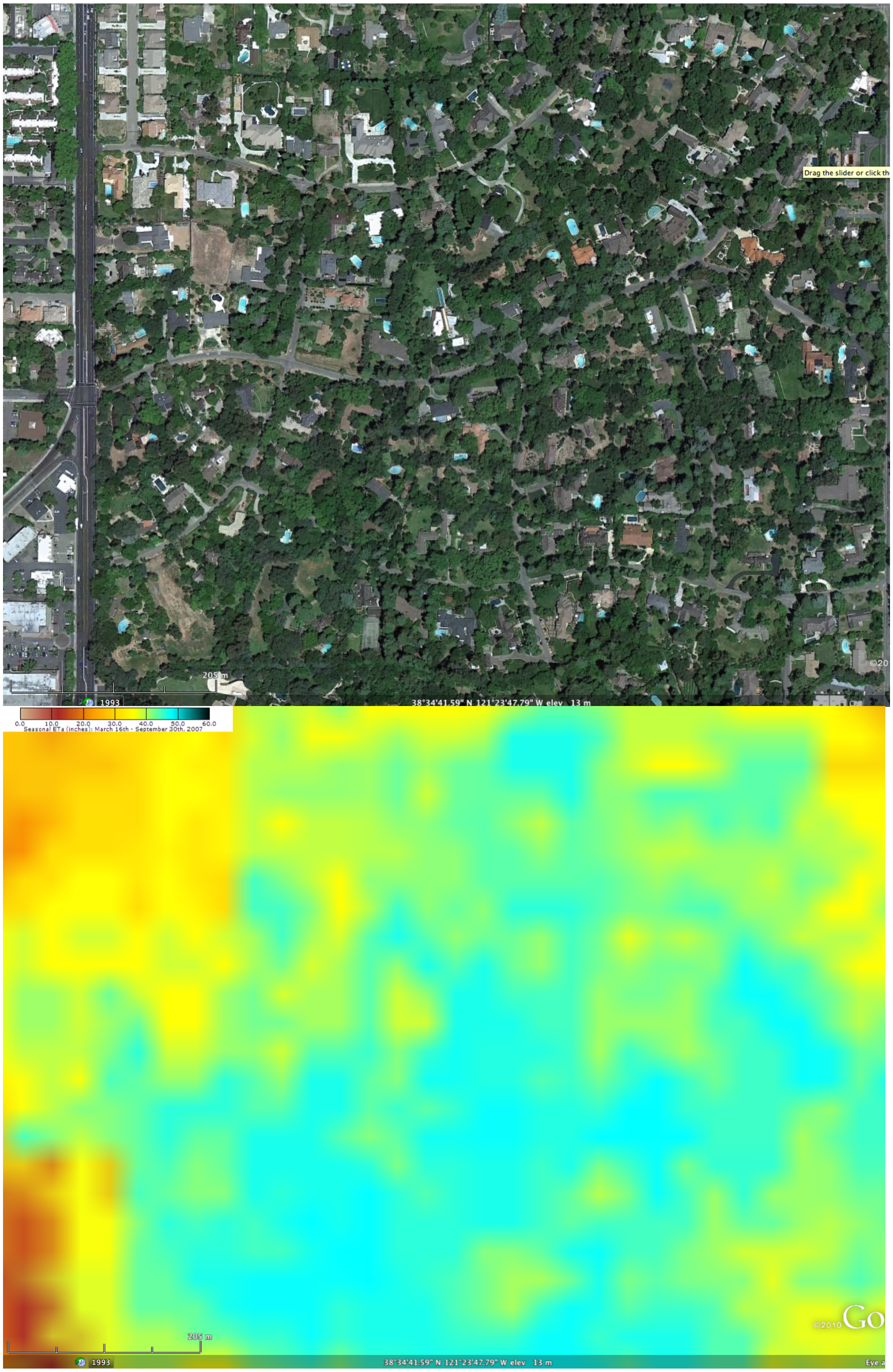

Figure 2. Google Earth with SEBAL based seasonal ETa from a non-metered residential neighborhood in the greater Sacramento region. Average ETa is 39.3 inches. The average age of homes in the area is about forty years.

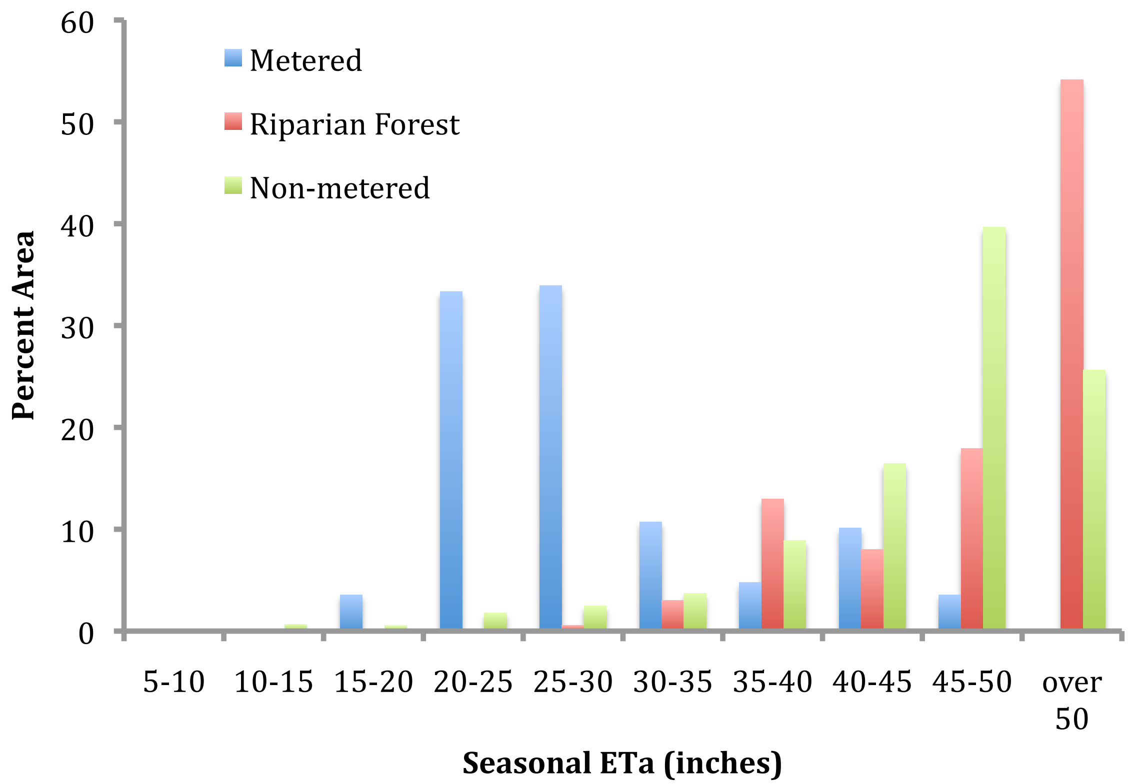

Figure 3. Distribution of seasonal ETa from a metered and an unmetered neighborhood. As a comparison, the ETa for a riparian forest in southern Sacramento County is also shown.

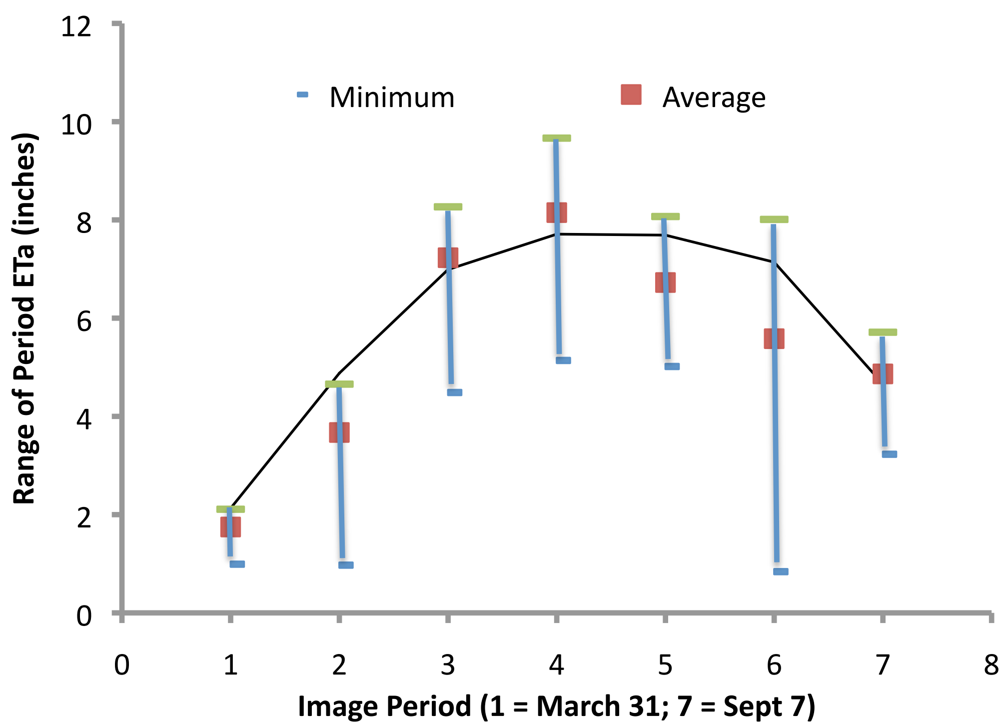

Figure 4. Range of period data and CIMIS data.

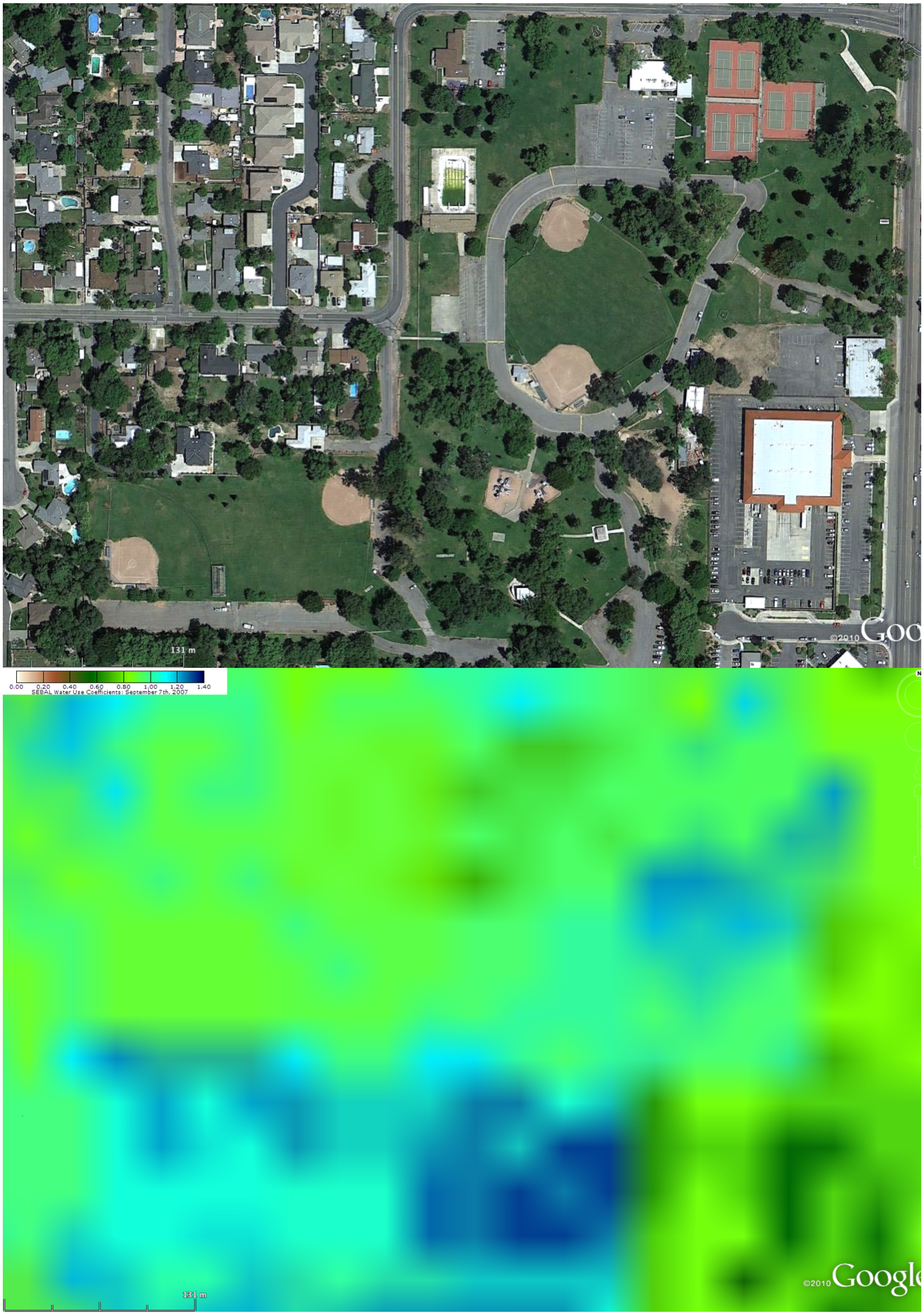

Figure 5. Google Earth with SEBAL based Kcs for the September 7, 2007 image from a public park. This park has mixed use areas.

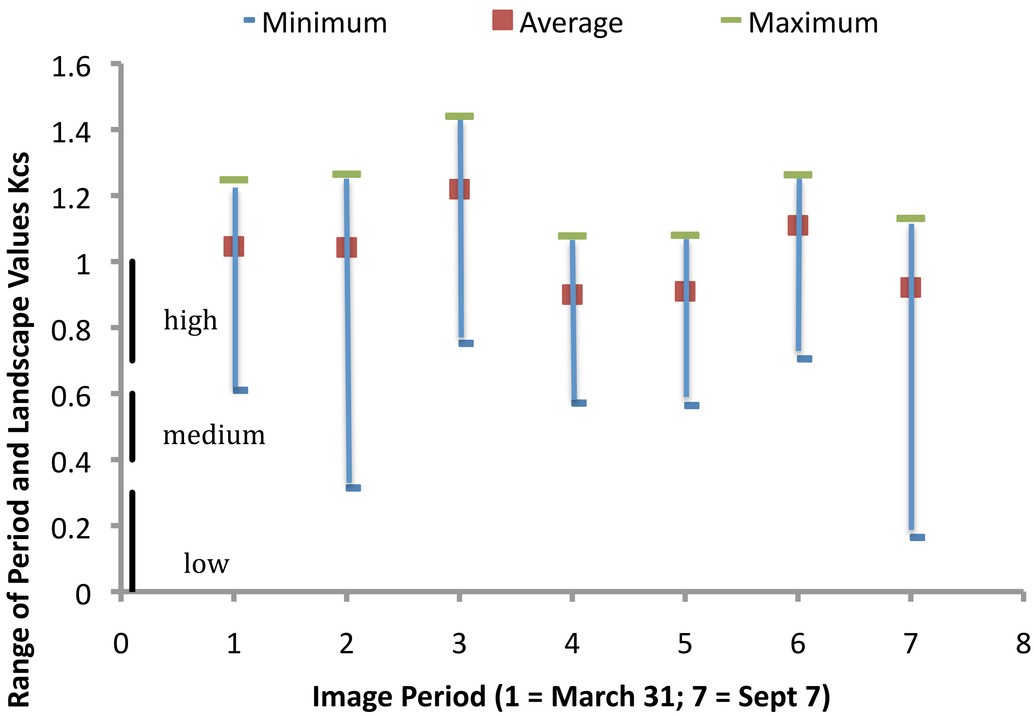

Figure 6. Range of Kcs values for September 7, 2007 from a public park. This park has mixed use areas that include sports fields, tennis courts, and picnic areas.

Conclusion

Remote sensing provides temporal and spatial ET information that is not available through other means. The level of resolution used in this analysis is adequate for large landscapes but not for smaller parks but can be used to evaluate the ET rates of larger landscape areas in urban settings. In unmetered areas, remote sensing allows for analysis of outdoor water use and for agencies to target outreach and education services.

References

Allen, R.G., Pereira, L.S., Raes, D., and Smith, M. (1998). "Crop evapotranspiration, guidelines for computing crop water requirements." FAO Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations (FAO), Rome.

Allen, R.G., Walter. I. A., Elliot, R., Howell, T., Itenfisu, D., Jensen, M. (2005). The ASCE Standardized Reference Evapotranspiration Equation.

Bastiaanssen, W.B., Noordman, E.J.M., Pelgrum H., Davids, G., Thoreson, B.P., Allen, R.G., 2005. SEBAL Model with Remotely Sensed Data to Improve Water Resources Management under Actual Field Conditions. J. Irrig. Drain. Eng., 131(1), 85-93.

California Department of Water Resources (DWR). 2011. California Irrigation Management Information System (CIMIS) http://wwwcimis.water.ca.gov/cimis/welcome.jsp.

California Department of Water Resources (DWR). 2010. Model Water Efficient Landscape Ordinance AB 1881. http://www.water.ca.gov/wateruseefficiency/landscapeordinance/

Costello, L. 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California. The Landscape Coefficient Method and Water Use Classification of Landscape Species (WUCOLS III). Univ. of CA Coop. Ext.

Google Earth. 2011. www.earth.google.com.

Landsat. 2011. (www.landsat.org)

Voogt, M.P. 2006. Meteolook, a physically based regional distribution model for measured meteorological variables. MSc Thesis, TU Delft.

Wijsman, P. 2005. Taking a closer look at water transfers. MSc Thesis, Wageningen University, NL.