A Water Budget Calculator Created for Residential Urban Landscapes Using Novel Approaches

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Abstract. *We created a water budget web interface that allows users in Albuquerque, New Mexico to calculate their landscape water budgets using current, historical, and El Niño Southern Oscillation phases reference evapotranspiration data. Three water budget calculation methods are available at the web interface. A Modified Water Budget approach uses the total parcel landscaped area and zip code-specific mixed landscape coefficient (K_c). A Vegetation Fragmented Water Budget approach uses the total area of trees, shrubs, or grasses within the landscape and vegetation type-dependent K_cs. A Species Fragmented Water Budget uses the landscape areas of each species and specific K_cs for each species. Residents can input a specific address and digitize the parcel image of that address. Outputs from the digitizing process can be used to calculate the landscape water budget.*

Keywords. Water budget calculations, residential landscapes, spatial and temporal ET_o.

Introduction

A landscape water budget is the amount of water required to maintain the residential landscape (Bennett and Hazinski, 1993). People tend to irrigate landscapes at 50% higher than their actual water requirements (Pittenger and Shaw, 2010) even though most landscape species will perform acceptably when irrigated within 18-80% of reference evapotranspiration (ET_o) (Pittenger and Shaw, 2004). Thus, a lack of knowledge of landscape water budget leads to water waste and the depletion of states' water reservoirs (Hurd and Smith, 2005), while accurate water budgets help municipalities cope with drought (King County, 2007) and craft urban water conservation plans (Kenney et al., 2004). Developing a science-based water budget calculation program with accessibility to different users may serve to monitor landscape irrigation and promote city-wide water conservation efforts.

For uniform plant cover, a water budget may be determined by multiplying ET_o by the crop coefficient (K_c). But considering the mixed landscape plants in residential sites as a single big leaf may under- or over-estimate the residential landscape water budget. Xie (2009) cautioned against using a single K_c for landscapes, since they consist of a heterogeneous mix of vegetation with various water requirements (Costello and Jones, 2000). Another calculation method is to multiply the landscaped area by ET_o and a landscape adjustment factor (AF) (King County, 2007; White et al., 2004). This approach is simple, but the AF's are neither science-based (White et al., 2004) nor site specific.

Existing water budget calculators (City of Boulder, Colorado, 2010; The Irrigation Water Management Association, 2010; United States Environmental Protection Agency, 2009) use fixed landscape AF's and ignore the variability in plant water requirements and ET_o. Urban areas that include considerable vegetation cover, such as residential landscapes (Zmyslony and Gagnon, 1998; Richards et al., 1984), show spatial variation in evapotranspiration rates (Grimmond and Oke, 1999). For example, reference evapotranspiration rates differed significantly among zip codes of Albuquerque, NM (Al-Kofahi, 2011). Thus, using a single ET_o value to calculate water budgets on a city scale is inexact (Xie, 2009). In addition, weather anomalies lead to differences in ET_o (Meza, 2005), such as the global El Niño Southern Oscillation (ENSO) phase ET_o (Sabziparvar et al. 2010). So, using the spatial and temporal ET_o

data is potentially important for irrigation management and water resources planning on a city scale.

This research aimed to develop novel approaches to water budget calculation that would satisfy a wider range of users and exploit the spatial and temporal variability in ET_o in urban areas.

Methodology

Study Area

Albuquerque is New Mexico's largest city. It is home to 529,219 residents (U.S. Census Bureau, 2011) that represent 90% of Bernalillo County's population. The city receives around 9.05 in of annual precipitation (Earp et al., 2006), and ground water is the city's main source of water (United States Geological Survey 1996). In 2007, Per Capita Water Use (PCWU) in 2007 was 167 gallons /day (City of Albuquerque 2010).

Water Budget Calculation Approaches

Common Landscape Water Budget (CLWB) method (Eq. 1) (Xie, 2009; St. Hilaire et al., 2008; King County, 2007; White et al., 2004) contain an assumed mixed landscape coefficient (K_c) and irrigation efficiency (IE) merged into an AF (AF= K_c/IE). We eliminated the IE from our basic equations since it is variable and location-specific. We used the finest scale of residential landscape vegetation (species) and developed the Species Fragmented Water Budget approach (SFWB) to account for each species' water requirement level, coefficients, (K_c) (Eq. 2) and areas.

The complexity of accounting for all residential landscape's species' water requirements (Pittenger and Shaw, 2004), necessitated some simplification. We considered the residential landscape as subunits of different vegetation types (trees, shrubs and grasses), and we included generic vegetation coefficients for trees (0.37), shrubs (0.38), and grasses (0.53) calculated for Albuquerque (Al-Kofahi, 2011). We called this approach, the Vegetation Fragmented Water Budget approach (VFWB) (Eq. 3).

Municipalities and homeowners may require a ground-sensed quick water budget calculation approach that is applicable to all parcels in specific residential areas (i.e. zip code). To assist with this approach, we classified residential landscape vegetation components of Albuquerque zip codes into tree, shrubs, and grass cover. Four hundred and eighty parcels were selected randomly from Albuquerque's sixteen zip codes. Around thirty residential landscapes in each zip code were classified using object-based supervised classification module in ENVI EX 4.7.1 software and very high spatial resolution (0.5 foot) true color aerial photographs, captured in 2008. Error matrix was used to assess the classification accuracy.

We used the generic vegetation coefficients and the zip codes' vegetation percentages to develop a mixed K_c for each zip code (Eq. 4). In the Modified Landscape Water Budget approach (MLWB) (Eq. 5), the mixed K_c replaced the AF in the CLWB formula.

Reference Evapotranspiration (ET_o)

Five points (locations) were selected purposively in each zip code of Albuquerque using Geographic Information System and the zip code vector layer (City of Albuquerque, 2008). For each point, hourly weather data was downloaded from the National Weather Service Forecast Office and used to calculate hourly ET_o using Penman-Monteith equations (Snyder and Eching, 2002). The program calculates the daily ET_o for each point using the three weather forecasts closest to the day of interest. Each zip code's daily ET_o values were averaged and summed to determine the zip code's monthly ET_o.

We obtained historical minimum and maximum temperatures (1931-2009) and used Hargreaves equation (Allen et al. 1998) (Eq. 6) to calculate historical ET_o for Albuquerque using those data. We obtained 1931-2009 monthly ENSO signals (Climate Prediction Center, 2009) and used the historical monthly ET_o to obtain monthly and yearly historical ENSO phases ET_o.

$$ET_0 = 0.0023(T_{mean} + 17.8)(T_{\max} - T_{\min})^{0.5} Ra \quad (6)$$

Where:

ET_0 = Reference evapotranspiration $(mm \cdot day^{-1})$;

T_{mean} = Average air temperature $(°C)$;

$T_{\max}$ = Maximum air temperature $(°C)$;

$T_{\min}$ = Minimum air temperature $(°C)$;

Ra = Extraterrestrial radiation $(MJ \cdot m^{-2} \cdot day^{-1})$.

Statistical Analysis

We assessed the differences among different ENSO phases ET_o using historical monthly ET_o estimates for each phase. Each combination of signal and month was fitted a mean using PROC AUTOREG. The analysis accounted for the autocorrelation and heterogeneity of variance. Estimated means and the estimated variance matrix were used to generate specific PROC IML tests.

Results

We developed three water budget calculation approaches (SFWB, VFWB, and MLWB) for residential landscapes in Albuquerque. The accuracy of residential vegetation classification was 89%. We calculated mixed landscape coefficients for each zip code based on the zip codes' residential vegetation proportions and vegetation generic coefficients (Eq. 4). The common water budget formula over-estimated the actual water budget (Table 1).

$$Common\ Landscape\ Water\ Budget\ (CLWB) = ET_o \times AF \times LA \times CF \quad (1)$$

$$Species\ Fragmented\ Water\ Budget\ (SFWB) = \sum_{i=1}^{3}\sum_{j=1}^{n} ET_o \times CF \times A_{ij} \times K_{c\,ij} \quad (2)$$

$$Vegetation\ Fragmented\ Water\ Budget\ (VFWB) = \sum_{i=1}^{3} ET_o \times CF \times A_i \times GK_c(i) \quad (3)$$

$$\text{Zip code Mixed Landscape Coefficient } (\text{ZK}_\text{c}) = \sum_{i=1}^{3} GK_c(i) \times \frac{A_i}{TA} \quad (4)$$

$$Modified\ Landscape\ Water\ Budget\ (MLWB) = ET_o \times ZK_c \times LA \times CF \quad (5)$$

Where:

AF= Adjustment factor;

A_i = Area of (i);

A_{ij} = Landscaped area of j^{th} Species within the i^{th} vegetation type (ft^2);

CF= Conversion factor (0.632 $gal/ft^2.in$);

ET_o = Monthly or yearly reference evapotranspiration (in);

j = Individual species;

i = 1: Trees, 2: Shrubs, and 3: Grass (ft^2);

$GK_c(i)$= Generic vegetation (i) coefficient;

$K_{c\,ij}$ = Species coefficient;

LA= Landscape area (ft^2);

TA = Total landscape area (ft^2);

ZK_c = Zip code-specific coefficient (0.38-0.42).

Albuquerque's monthly and yearly historical ET_o were 5.1 and 61.24 inches respectively. Historical monthly and yearly ET_o are commonly used to calculate water budgets. Historical ET_o is the average of the historical ET_o values regardless of ENSO phases and the frequency of each

Table 1: Annual water budget calculation of a residential landscape in Albuquerque using different water budget calculation approaches.

Approach	Historical ET_o (in)	Conversion Factor ($gal/ft^2.in$)	Coefficient used		K_c	Landscaped area (ft^2)	Water budget (gal/year)	Total water budget (gal/year)	Difference from CLWB (gal/year)
CLWB[1]	61.24	0.632	Common		0.50	2002*	38,742	38,742	0
MLWB[2]	61.24	0.632	Mixed		0.42	2002	32,544	32,544	-6,198
VFWB[3]	61.24	0.632	Generic Tree		0.37	952	13,638		
			Generic Shrub		0.38	179	2,631		
			Generic turf		0.53	871	17,861	34,131	-4,611
SFWB[4]	61.24	0.632	Species:	*Juniperus spp.*	0.20	179	1,389		
				Thuja orientalis	0.35	174	2,351		
				Prunus spp.	0.50	195	3,777		
				Punica granatum	0.20	182	1,409		
				Cupressus arizonica	0.10	191	738		
				Iris spp.	0.20	8	65		
				Rhaphiolepis indica	0.20	56	432		
				Thuja occidentalis	0.50	98	1,896		
				Salvia greggii	0.20	22	172		
				Rosa minitifolia	0.35	19	254		
				Stipa pulchra	0.20	8	59		
				Turf grass	0.53	871	17,861	30,403	-8,339

[1]CLWB = Common water budget formula; [2]MLWB = Modified water budget formula; [3]VFWB = Vegetation fragmented water budget formula; [4]SFWB = Species fragmented water budget formula; *2002 ft^2 is the average landscaped area of Albuquerque average parcel size of 8008 ft^2.

signal. Monthly ET_o of El Niño signal was significantly lower than that of Neutral (p=0.0002) and La Niña (p=0.0006) signals. In addition, the frequencies of ENSO phases along the 78 years examined were not equal (Table 2). The overall monthly historical ET_o was higher than monthly historical El Niño ET_o and lower than La Niña and Neutral ET_o in most of the months (Fig. 1).

Table 2: Historical El Niño Southern Oscillation (ENSO) signals ET_o over all months.

Signals[1]	Average Monthly ET_o (in)	Standard Errors	Frequency
El Niño	4.967 b[2]	0.039	21.4%
La Niña	5.129 a	0.040	20.2%
Neutral	5.123 a	0.023	58.4%

[1]Signals ET_o averages were based on 78 years of record; [2]Averages with different letters are significantly different.

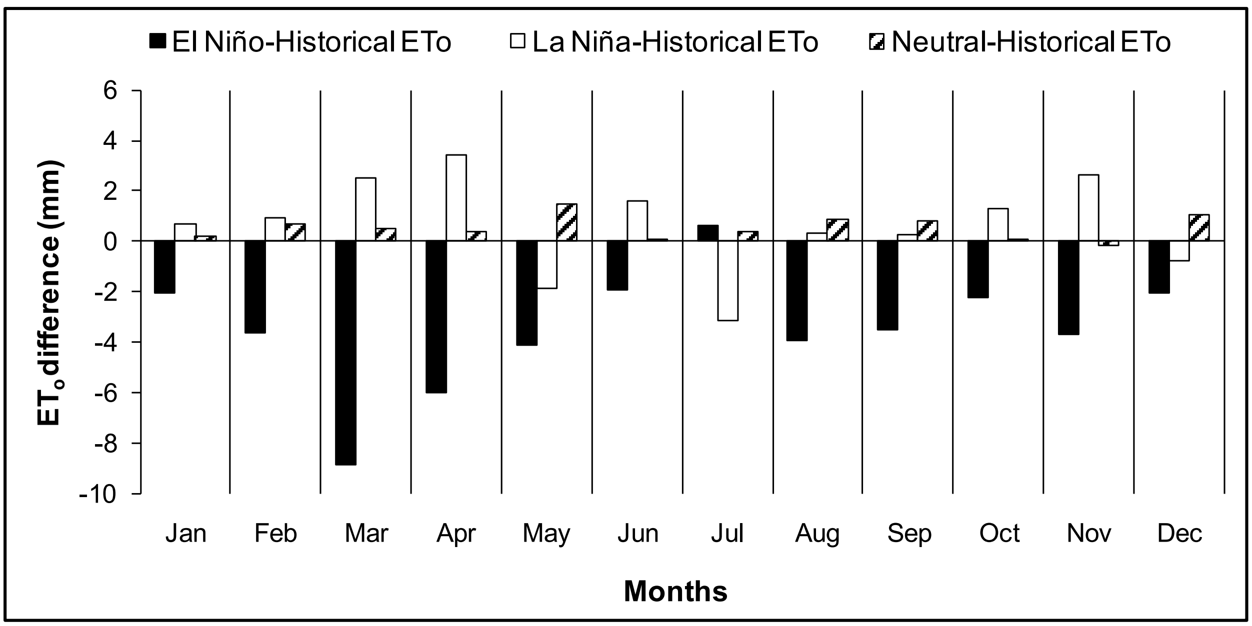

Figure 1: Monthly historical El Niño Southern Oscillation (ENSO) signals ET_o subtracted from the overall historical ET_o; mm=0.03937 in.

The three water budget calculation approaches were incorporated in an interface that allows Albuquerque users access and usage by inputting an address and browsing its top-view from Google Maps imagery. Imagery could be digitized to calculate the total landscape area, vegetation areas or species areas. Historical ET_o, spatial current, and temporal ET_o (ENSO phases) were provided to calculate the landscape water budget.

Discussion

For multiple reasons, residential landscape irrigation consumes a considerable portion of states' water resources (Hurd and Smith, 2005). First, the landscape represents a major component of urban vegetation (Larsen and Harlan, 2006). Second, 40 to 70% of household water-use in the United States goes to landscape irrigation (Ferguson, 1987). Third, people tend to over-irrigate residential landscapes (Pittenger and Shaw, 2010). To address these situations, we developed science-based water budget approaches with accessibility to users of differing levels of sophistication. Unlike other approaches, our method estimates the water budget using ground-proofed vegetation components data and considers species' water requirements. Furthermore, our approaches showed potential reductions in water budget estimates compared to the methods researchers commonly use (City of Roseville 2010; Pittenger et al. 2010; King County 2007; Pittenger and Shaw 2004; White et al. 2004). For example, water budget calculations of the SFWB, VFWB, and MLWB showed reductions of 21%, 12%, and 16% of the water budget, respectively, relative to those based on the common formula (Table 1). Our research indicates that the methods commonly used for estimating landscape water budgets need fine-tuning, whereas, the new calculation methods can potentially generate huge water savings, especially on a city scale.

The SFWB approach is considered the most accurate approach because it accommodates all residential landscape species and addresses speciess differences. Plant water requirements range from low to high (Bennett and Hazinski, 1993), a simple fact that must be accounted for in estimating water budgets. Pittenger and Shaw (2004) reported that it is difficult to calculate residential landscape water budgets while accounting for species water requirements. However, the inclusion of landscape plant species lists, their K_cs, and generic K_cs for unknown or unlisted species on the interface overcomes that limitation.

The VFWB and MLWB are simple approaches that incorporate some generic science-based coefficients to help homeowners and residents easily estimate residential landscape water budgets. A simple, but accurate water budget calculation approach is critical to water conservation efforts. For example, the City of Albuquerque is targeting a PCWU of 155 gallons/day by 2024 (City of Albuquerque 2010) and residents' participation will be crucial to reaching that goal. If homeowners participate in the water conservation through efficient residential landscape irrigation, then water conservation efforts are more likely to succeed (Grisham and Fleming, 1989).

Residential landscape styles tend to resemble each other within spatially close areas, but as the area becomes larger, they become varied (Zmyslony and Gagnon, 1998). For the MLWB, we used a specific mixed K_c for each zip code. That mixed K_c was calculated based on each zip code's vegetation component. This approach could allow municipalities to assess residential landscape water use before issuing building permits, and determine whether high water use of parcels reflects outdoor or indoor activities.

The water budget approaches, landscape coefficients, and evapotranspiration data were incorporated into a user-friendly interface, accessible at www.nmclimate.nmsu.edu/wb. The interface includes a step-by-step help tool, previews of the residential landscape image based on the address, and digitization tools that allow areas of residential landscape features to be calculated. For example, the digitization tools can be used to obtain total landscaped areas, vegetation types, species or water body areas in a parcel. All data can be inputs for water budget calculation.

The interface offers different sources of ET_o to satisfy multiple users' goals and objectives. For example, landscape planners, decision makers, and municipalities often use historical ET_o for water budget calculations in long term plans, simulations, and water use projections. However, global weather anomalies might impact some water budget calculation inputs, and such potential changes need to be considered (Meza, 2005). For example, global land evapotranspiration rates showed an increasing trend from 1982 to 1997 that stopped from 1998 to 2008; that period (1998-2008) was synchronized with the major global El Niño event (Jung et al., 2010). In Maipo River Basin, Chile, ENSO phases influenced ET_o values and consequently lead to differences in plant water requirements during the prevalence of different ENSO signals (Meza, 2005). Hence, using historical ENSO phases ET_o may ensure that the required amount of irrigation water is applied without over-estimation during El Niño phase. On the other hand, using the historical ET_o to estimate water budgets during La Niño and Neutral phases may jeopardize the landscape because of the under-estimation of plant water requirements.

The interface provides the monthly (January-December) historical ET_o for each ENSO signal as our ENSO phases ET_o data confirm the variability of ET_o values among different signals (times) for Albuquerque. However, ET_o varies spatially, and that variability has hydrological, horticultural, and ecological implications for urban areas (Grimmond and Oke, 1999). Current ET_o values were spatially variable within locations in Albuquerque. To account for this, we included the current ET_o values for each zip code.

Conclusion

We developed new water budget calculation approaches (SFWB, VFWB, and MLWB) to facilitate the estimation of residential landscapes' water budgets, improve their accuracy, and support water conservation efforts. These approaches accounted for the vegetation types and water requirements variability. Landscape plant species K_cs, generic vegetation-type K_cs, and zip code-specific mixed K_cs were used. The CLWB approach showed over-estimation in the water budget compared to the new calculations methods. The three calculation approaches, current, historical, and ENSO phases ET_o data were incorporated in to a web interface to allow users access to estimate their residential landscape water budget. Reference evapotranspiration varied among spatial scales (locations) and temporal scales (ENSO phases) within Albuquerque. We also accounted for this in our water budget calculator web interface.

References

Al-Kofahi, S. 2011. Mapping landcover in urban residential landscapes: implications for water budget calculations. Doctoral Dissertation, New Mexico State University, May 2011.

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

Bennett, R., and M. Hazinski. 1993. Water – Efficient Landscape Guidelines. American Water Works Association. Denver, CO 80235 – USA. ISBN 0-89867-679-7.

City of Albuquerque. 2008. Geographic Information System for the City of Albuquerque. Available at: http://www.cabq.gov/gis/download.html (Verified 9 February 2008).

City of Albuquerque. 2010. Albuquerque Progress Report. Available at: http://www.cabq.gov/progress/environmental-protection-enhancement/dcc-31/indicator-31-2 (Verified 6 April 2010).

City of Boulder, Colorado. 2010. Water Budget Map. Available at: http://www.iwms.org/calculators.htm (Verified 30 March 2010).

City of Roseville, California. 2010. Landscape Water Use Calculation Examples. Planning and Redevelopment Department, http://www.roseville.ca.us/civica/filebank/blobdload.asp?BlobID=15669 (Verified 12 August 2010).

Climate Prediction Center, National Weather Services, NOAA. 2009. Southern Oscillation Index. http://www.cpc.ncep.noaa.gov/data/indices/ (Verified 7 March 2009).

Costello, L., and K. Jones. 2000. A Guide to Estimating Irrigation Water Needs of Landscape Plantings in California. The Landscape Coefficient Method and Water Use Classification of Landscape Species. University of California Cooperative Extension and California Department of Water Resources. Available at: http://www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf (Verified 14 June 2010).

Earp, D., J. Postlethwait, and J. Witherspoon. 2006. Albuquerque's environmental story, educating for a sustainable community, Environmental Topic: Water. Available at: http://www.cabq.gov/aes/s5water.html (Verified 20 August 2010).

Ferguson, B.K. 1987. Water conservation methods in urban landscape irrigation: An exploratory Overview. Water Resource Bulletin 23:147-152.

Grimmond, C. S. B., and T. R. Oke. 1999. Evapotranspiration rates in urban areas. In: Proc. Impacts of Urban Growth on Surface Water and Ground water Quality, IUGG 99 Symposium HSS. Birmingham, July 1998. IAHS Publication No. 259:235-243. Also at:

http://www.kcl.ac.uk/ip/suegrimmond/publishedpapers/GrimmondOkeIAHS1999.pdf (Verified 16 July 2011).

Grisham, A., and W.M. Fleming. 1989. Long-term options for municipal water conservation. Journal of American Water Works Association. 81:34-42.

Hurd, B., and J. Smith. 2005. Landscape Attitudes and Choices: A Survey of New Mexico Homeowners. Water Task Force Report 5, College of Agriculture and Home Economics, New Mexico State University, Las Cruces, NM. Available at: http://aces.nmsu.edu/pubs/taskforce/water/WTF_5.pdf (Verified 11 July 2010).

Jung, M., M. Reichstein, P. Ciais, S. I. Seneviratne, J. Sheffield, M. L. Goulden, G. Bonan, A. Cescatti, J. Chen, R. De Jeu et al. 2010. Nature 467:951-954.

Kenney, D., R. Klein, and M. Clark, M. 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. J. Am. Water Resour. Assoc. 40(1):77-87.

King County. 2007. Zoning code-Irrigation system requirements. Department of Development and Environmental Services. Renton, Washington. Available at: http://www.kingcounty.gov/property/permits/publications/~/media/property/permits/documents/bulletins/19a.ashx (Verified 19 February 2011).

Larsen, L., and S. Harlan. 2006. Desert dreamscapes: Residential landscape preference and behavior. Landscape Urban Plan. 78(1-2):85-100.

Meza, F. J. 2005. Variability of reference evapotranspiration and water demands, association to ENSO in the Maipo river basin, Chile. Global Planet. Change 47:212-220.

Pittenger, D. and D. Shaw. 2010. Review of Research on Water Needs of Landscape Plants. Available at: http://landscape.nmsu.edu/documents/dpittengerSympPaper.pdf (Verified 14 March 2010).

Pittenger, D., and D. Shaw. 2004. What we know about landscape water requirements. University of California Cooperative Extension Service. Co-Hort, 6.1. Available at: http://celosangeles.ucdavis.edu/newsletterfiles/Co-Hort11051.pdf (Verified 28 October 2009).

Pittenger, D., M. Henry, and D. Shaw. 2010. Water Needs of Landscape Plants. University of California Cooperative Extension-Center for Landscape and Urban Horticulture. Available at: http://groups.ucanr.org/CLUH/Water_Use_of_Turfgrass_and_Landscape_Plant_Materials/Water_Needs_of_Landscape_Plants_.htm (Verified 14 March 2010).

Richards, N. A., J. R. Mallette, R. J. Simpson, E. A. Macie. 1984. Residential greenspace and vegetation in a mature city: Syracuse, New York. Urban Ecol. 8:99-125.

Sabziparvar, A., S. Mirmasoudi, H. Tabari, M. Nazemosadat, and Z. Maryanaji. 2010. ENSO teleconnection impacts on reference evapotranspiration variability in some warm climates of Iran. Int. J. Climatol. DOI: 10.1002/joc.2187.

Snyder, L. R., and S. Eching. 2002. Penman-Monteith daily (24-hour) reference evapotranspiration equation for estimating ET_o, ET_r and HS ET_o with daily data. Available at: http://biomet.ucdavis.edu/Evapotranspiration/PMdayXLS/PMdayDoc.pdf (Updated: 2 February 2006; Verified 2 January 2009).

St. Hilaire, R., M. Arnold, D. Wilkerson, D. Devitt, B. Hurd, B. Lesikar, V. Lohr, C. Martin, G. McDonald, R. Morris et al. 2008. Efficient Water use in Residential Urban Landscapes. HortScience, 43(7):1-12.

The Irrigation Water Management Association. 2010. Landscape Irrigation Calculator. Available at: http://www.iwms.org/calculators.htm (Verified 30 March 2010).

United States Census Bureau. 2011. American Fact Finder, Population Finder: Population-Albuquerque City, New Mexico. Available at: http://2010.census.gov/news/releases/operations/cb11-cn87.html (Verified 11 April 2011).

United States Environmental Protection Agency. 2009. Water Sense Landscape Water Budget Tool. Available at: http://www.epa.gov/watersense/nhspecs/water_budget_tool.html (Verified 12 June 2009).

United States Geological Survey/United States Department of Interior. 1996. United States Geological Survey Programs in New Mexico. Fact Sheet-031-96. Available at: http://pubs.usgs.gov/fs/FS-031-96/fs-031-96.pdf (Verified 19 February 2011).

White, R., R. Havlak, J. Nations, T. Pannkuk, J. Thomas, D. Chalmers, and D. Dewey. 2004. How much water is enough? Using pet to develop water budgets for residential landscapes. Texas Water Resources Inst., Texas A&M University. Available at: http://repository.tamu.edu/bitstream/handle/1969.1/6100/tr271.pdf?sequence=1 (Verified: 19 February 2011).

Xie, H. 2009. Using remote sensing and GIS technology for an improved decision support: a case study of residential water use in El Paso, Texas. Civ. Eng. Environ. Syst. 26(1): 53-63.

Zmyslony, J., and D. Gagnon. 1998. Residential management of urban front-yard landscape: a random process? Landscape Urban Plan. 40:295-307.