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Custom Software Application for Analyzing Urban Landscape Water Use

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Abstract A custom software application was developed to estimate urban landscape water use in a GIS environment using landscape vegetation areas classified from high-resolution airborne multispectral imagery, coupled with ground-based reference evapotranspiration data. Estimates of parcel irrigation water demand were compared with measured volumes obtained by mining urban water billing data. The software tool allows for quick visual identification of high-end users and queries to the spatial database.

Key words remote sensing; landscape vegetation evapotranspiration, urban water use

INTRODUCTION

Municipalities in the western United States are often subject to water shortages caused by the arid environment and periodic drought cycles. Important water sources in the Intermountain West, like the Colorado River and related reservoirs such as Lake Mead and Lake Powell, have been at record lows during the past decade. In order to combat recurring water shortages, new strategies must be employed to meet competing demands of municipal, industrial, agricultural and environmental uses in this water-short region. Demand management will require effective policies and intervention strategies that can help water agencies increase water use efficiency (Western Water Policy Review Advisory Commission, 1998; US Dept of the Interior, 2005; Standish-Lee *et al.*, 2006; Western Governors' Association, 2006, 2008; National Research Council, 2007).

Promoting water conservation as a demand management strategy has been pursued by many of the region's municipalities (Western Resource Advocates, 2003). Water conservation programmes generally consist of broad public appeals about the need to conserve, dissemination of educational materials on ways to conserve, and delivery of services such as water audits or rebates for installing water efficient appliances or fixtures (Vickers, 2001). These programmes are most often offered on a voluntary basis and are seldom targeted and tailored to specific individuals and locations in order to yield the greatest water savings and justify the costs of programme provision. Municipalities lack the ability to identify locations with high capacity to conserve (where conservation interventions are likely to produce the greatest water savings) or to assess the effectiveness in terms of water savings of the conservation programs that they do implement.

This paper reports on a software application developed to produce city-wide analyses of potential capacity to conserve water used on urban residential landscapes. The software builds upon Utah State University (USU) research work that uses remote sensing and GIS technologies to determine landscape water use in relation to plant need, establishes landscape irrigation ratios and benchmarks for assessing the appropriateness of landscape water use, and explains variations in water use patterns in relation to these measurements (Kjelgren *et al.*, 2000, 2002; Kilgren, 2001; Farag, 2003; Klien, 2004; Endter-Wada *et al.*, 2008; Kilgren *et al.*, 2010; Farag *et al.*, 2011). Much of this research involved intensive manipulation of billing data and analysis of site characteristics on a case-by-case basis with data obtained through household visits. The purpose and contribution of this software application is to automate the analysis of landscape water use developed at USU for application to city-wide databases. This software program/decision tool is designed to help water managers visualize and investigate spatial and temporal patterns of landscape water use in urban environments, identify locations with capacity to conserve, and deliver landscape water conservation programs to targeted locations.

MODEL DEVELOPMENT

This research integrates GIS data, remotely-sensed data, weather data and municipal water billing data into a dynamic software application using the Visual Studio and VB.NET programming language. The software is a standalone application that directly accesses the programs needed to run and store the spatial data (MS Access; ArcGIS) without having to open them. This creates an easy-to-use interface that allows the software to run faster and more efficiently than if it was embedded in another application.

Using remote sensing data to identify urban cover types

High spatial resolution (1-m pixels) airborne multispectral imagery was obtained over Logan City, Utah, in 2004 with the USU Airborne Multispectral Digital System. The system acquires digital imagery in the green, red and near infrared bands of the electromagnetic spectrum. Images were corrected for lens vignetting effects and stacked into 3-band images and rectified to an image map base using common control points, then were stitched together into a mosaic covering the entire Logan City municipal area. The image was calibrated in terms of reflectance using a similar system calibration technique as described in Neale & Crowther (1994). The image was then classified using supervised classification techniques to obtain specific cover types relevant to the urban environment (Fig. 1). Due to the high resolution of the imagery and the bi-directional nature of some of the surfaces, 140 signatures were extracted to capture the variability in the high resolution imagery. The classes were eventually combined into nine major cover types (Fig. 1).

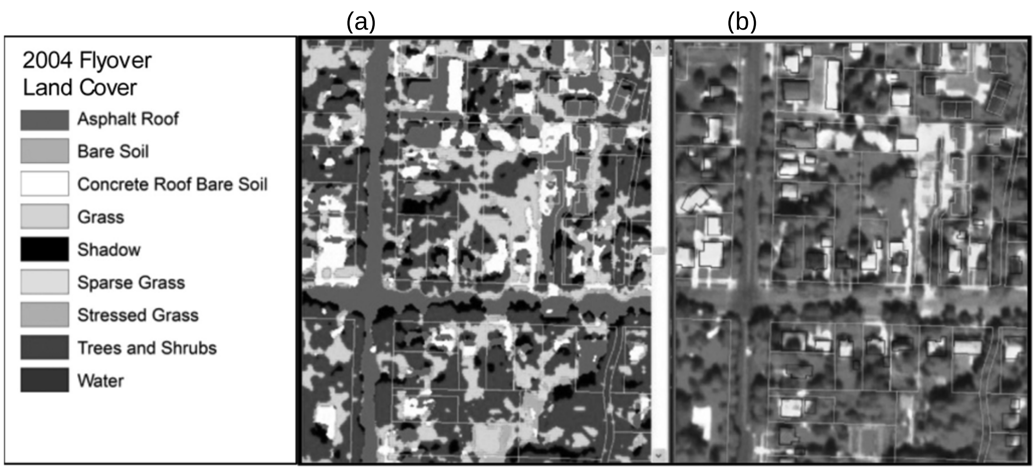

Fig. 1 Portion of the 3-band multispectral image mosaic (b) along with the classified and recoded image (a) overlaid with the parcel boundary GIS layer.

Linking landscape cover types to city databases

Raw water billing data normally maintained in a row format in city databases is not conducive to being directly used with GIS data but must be rearranged to a columnar format so that the two databases can be joined. The software application rearranges water billing data (Fig. 2) through a complex coding scheme utilizing ADO.NET and the Microsoft Access software. This portion of the software package is accessed behind the scene without the need to open it. Because billing data is primarily organized to link meter readings to particular customers for billing purposes, the software resolves issues that are problematic from a data analysis viewpoint, such as meter changes, multiple meters, and residential mobility to produce complete and temporally continuous data representing metered water use for each location receiving municipal water.

The linearized water billing data are joined to the appropriate GIS layers using a common linking variable to make a master file. Water billing data need a geographic reference to be used in analyses of irrigation water use. This was accomplished by associating the water meter data to the

Rate	LocID	DSPR	Jan	JanR	Feb
RS	2517	33	6	17	6
RS	2517	37	7	18	5
RS	2517	0	0	16	6
RS	8356	38	1	19	0
RS	8356	64	1	18	1
RS	16694	302	0	0	0
RS	15922	37	8	18	5
RS	8299	38	11	19	5
RS	20947	215	0	0	0
RS	18217	34	6	18	5
RS	18217	38	5	19	4
RS	18217	0	0	14	5

Fig. 2 Sample of linearized billing data for multiple years (rows) with monthly readings in columns.

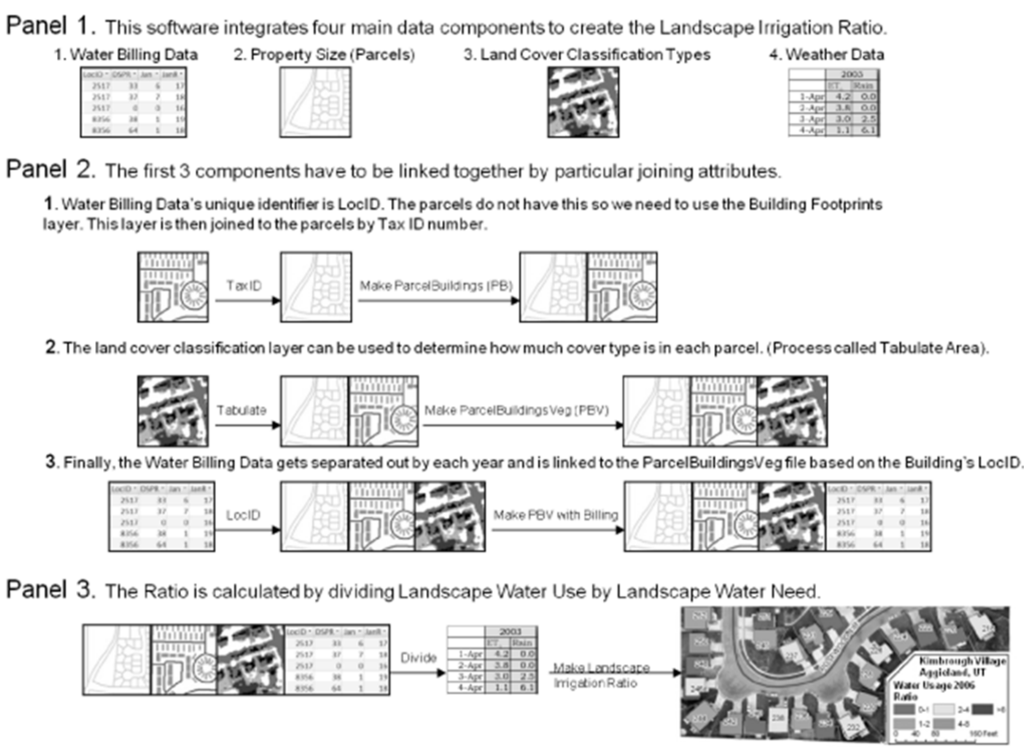

Fig. 3 Conceptual flow chart of software to calculate and display landscape irrigation ratios.

property through the cadastre parcel layer provided by the City of Logan (Fig. 3, *Panel 1.2*). However, in the case of Logan City, the parcel data did not have a direct link to the water meter billing data (Fig. 3, *Panel 1.1*) thus an intermediate GIS file was used (the building footprint layer), which had a linking variable called the property tax ID number. The building footprint layer was joined with the parcel layer using the property tax ID number (Fig. 3, *Panel 2.1*) to create a ParcelBuildings (PB) layer file. The classified and recoded airborne image was used along with the parcel GIS layer to extract the area of each landscape vegetation class for each parcel. This tabulated information is joined with the ParcelBuildings layer to create a ParcelBuildingsVeg (PBV) layer (Fig. 3, *Panel 2.2*). Finally, the linearized water billing data is separated out by each year and joined with the ParcelBuildingsVeg (PBV) file (Fig. 3, *Panel 2.3*).

Calculating landscape irrigation ratios

An annual landscape irrigation ratio is determined for each parcel by dividing landscape water use by landscape water need. Landscape water use is an estimation from water meter billing data of how much irrigation water was applied to the landscape during the irrigation season (assumed to be 1 April–31 October) after subtracting indoor water use. Landscape water need is determined by estimating evapotranspiration of the different landscape classes and taking into account local reference evapotranspiration and the area of each landscape class within each parcel. We use common evapotranspiration coefficients for grass (0.8) and trees/shrubs (0.5) in the calculations and assume an irrigation application/distribution efficiency of 0.8 and 34% of tree cover for the area of grass growing under the trees (see Farag *et al.*, 2011).

Calculating outdoor landscape water use from culinary sources involves estimating how much of total water use relates to indoor *versus* outdoor uses. To incorporate this consideration into a large database (i.e. Logan City) where individualized household occupancy data is unavailable, we assumed and calculated indoor water use based upon the US Census average household size for Logan, Utah, of three people and the USA average indoor use of 70 gallons per person per day (Vickers, 2001). As Logan City transitions to reading water meters monthly, indoor water use calculations can be made more site-specific using billing data for winter months (when no landscape irrigation occurs). When water meter readings are less frequent than monthly and not of consistent intervals across locations (as was the case in Logan until 2010), then extrapolations have to be made. For Logan City, we assumed the irrigation season lasted from 1 April to 31 October (a generous assumption ensuring an adequate amount of water per irrigation season). Total seasonal landscape water use for a particular property was calculated as all water use between those dates after subtracting estimated indoor water use.

DISCUSSION

Once landscape water use ratios are determined for a city-wide database, municipal water departments can investigate patterns and trends in order to identify problem areas for planning purposes and to locate high end water users in order to target water conservation programmes to specific locations. Water leaks or other anomalies can be detected by running this software as well.

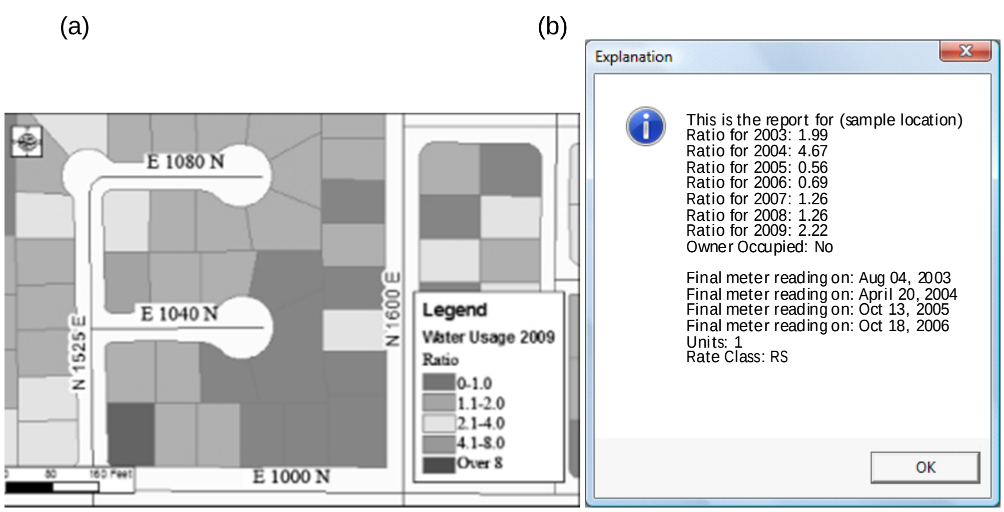

Fig. 4 (a) A section of a neighbourhood showing the colour-coded (shown in greyscale) landscape irrigation ratio in five different categories (see legend). This particular neighbourhood has a strong presence of efficient water users (majority with a landscape irrigation ratio < 2). (b) A brief history of one property's water usage, showing the ratio for each year as well as when final meter readings took place. A property that is not owner occupied will often have multiple final meter readings as well as variable water usage related to its occupancy by different renters.

Patterns can be analysed by looking at clusters, dispersions and trends both spatially and temporally. Questions related to factors that might be contributing to high water use, low water use, and high variations in water use can then be investigated. Such analyses can help cities determine, for instance, whether high water use is related to water infrastructure problems (e.g. leaks), neighbourhood or site-specific geographic conditions (e.g. poor soils, windy areas, high sun exposures, new neighbourhoods in the process of establishing landscapes), neighbourhood demographics and characteristics, or individual household-level human behaviours. Spatial patterns of similar water usage can be related to the age of the homes, geographic locations, demographics, or whether or not the property is owner occupied (Fig. 4(a)). Knowing the temporal history of a particular household can help in determining how the water use pattern has changed, possibly between one occupant and another (Fig. 4(b)). Municipal responses to water use inefficiencies would naturally vary depending upon the causes. Such information is valuable for helping cities decide not only where, but also when and how to take action to increase water use efficiency within their service areas.

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REFERENCES

Endter-Wada, J., Kurtzman, J., Keenan, S. P., Kjelgren, R. K. & Neale, C. M. U. (2008) Situational waste in landscape watering: residential and business water use in an urban Utah community. *JAWRA* 44(4), 902–920.

Farag, F. A., Neale, C. M. U., Kjelgren, R. & Endter-Wada, J. (2011) Quantifying urban landscape water conservation potential using high resolution remote sensing and GIS. *Photogrammetric Engineering and Remote Sensing Journal* 77(11), 1113–1122.

Farag, F. A. (2003) Estimating farm and landscape water use at the rural-urban interface using remote sensing and geographic information systems. PhD Dissertation, Utah State University, Logan, Utah, USA.

Farag, F., Neale, C. M. U. & Kjelgren, R. (2001) Development of a GIS-based model to estimate landscape water demand in the urban/rural interface. In: *Remote Sensing and Hydrology 2000* (ed. by M. Owe, K. Brubaker, J. Richtie & A. Rango). IAHS Publ. 267 (2001), ISBN 1-901502-46-5.

Kilgren, D. (2001) Implementing water conservation in an institutional setting. MS Thesis, Utah State University. Logan, USA.

Kilgren, D., J. Endter-Wada, Kjelgren, R. K. & Johnson, P. G. (2010) Implementing landscape water conservation in public school institutional settings: a case for situational problem solving. *JAWRA* 46(6), 1205–1220.

Kjelgren, R., Rupp, L. & Kilgren, D. (2000) Water conservation in urban landscapes. *HortScience* 35(6), 1037–1040.

Kjelgren, R., Farag, F. A., Neale, C. M. U., Endter-Wada, J., Kurtzman, J. (2002) Quantifying potential urban landscape water conservation through billing data analysis in Layton, Utah. In: Proceedings, American Water Works Association Sources 2002: Reuse, Resources, Conservation (27–31 January, Las Vegas, Nevada).

Klien, C. (2004) Understanding household landscape water conservation. MS Thesis, Utah State University, Logan, Utah, USA.

National Research Council (2007) *Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability*. Prepared by the Committee on the Scientific Bases of Colorado River Basin Water Management. Washington, DC, The National Academy Press.

Neale, C. M. U. & Crowther. B. G. (1994) An airborne multispectral video/radiometer remote sensing system: Development and calibration. *Remote Sensing of Environment* 49(3), 187–194.

Standish-Lee, P., Loboschefsky, E. & Lecina, K. (2006) "Half Full or Half Empty? Either Way It's Time to Plan." *Journal of American Water Works Association* 98(6), 76–79.

United States Department of the Interior (2005) *Water 2025: Preventing Crises and Conflict in the West - August 2005 Report*. Accessed 10/02/08 at: http://www.usbr.gov/water2025/report.html.

Vickers, A. (2001) *Handbook of Water Use and Conservation: Homes, Landscapes, Businesses, Industries, and Farms.* Water-Plow Press, Amherst, Massachusetts, USA.

Western Resource Advocates (2003) *Smart Water: A Comparative Study of Urban Water Use Across the Southwest*. Western Resource Advocates, Boulder, Colorado. Available at: http://www.westernresourceadvocates.org/water/smartwater.php.

Western Governors' Association (2006) *Water Needs and Strategies for a Sustainable Future.* Prepared by Western Governors' Association (Denver, Colorado) in cooperation with the Western States Water Council (Midvale, Utah). Accessed 10/02/08 at: http://www.westgov.org/wga/publicat/Water06.pdf.

Western Governors' Association (2008) *Water Needs and Strategies for a Sustainable Future: Next Steps*. Prepared by Western Governors' Association (Denver, Colorado) in cooperation with the Western States Water Council (Midvale, Utah). Accessed 10/02/08 at: http://www.westgov.org/wga/publicat/water08.pdf.

Western Water Policy Review Advisory Commission (1998) *Water in the West: Challenge for the Next Century*. Final Report, Western Water Policy Review Advisory Commission.