

Quantifying Potential Urban Landscape Water Conservation through Billing Data Analysis in Layton, Utah

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ABSTRACT: Increasing water demand due to landscape irrigation in many urbanizing areas in the West is straining supplies and forcing water purveyors to implement water conservation measures without knowing who should be conserving and how much water is potential conservable. We used aerial false-color imagery to determine irrigated landscaped area for a section of Layton, Utah and estimated the amount of potentially conservable water in urban landscapes. False color images of a subsample area consisting of commercial and residential areas were collected in late summer 1998. A geographic information systems parcel-boundary layer was overlaid on the images and landscaped area was determined by counting the number of vegetation pixels within each parcel. Water billing data averaged over 1996-98 was then normalized to depth units with the calculated landscaped areas and then compared to estimated water needs derived from local evapotranspiration rates. Residential landscaped area determined from aerial image analysis was verified with ground measurements of area, and landscaped area correlated well with total lot size. Commercial water users, particularly retail establishments, applied water in excess of estimated needs, 70% versus 14% for subsample of the residential water users. Excess irrigation was highest in midsummer through early fall for both residential and commercial landscapes. The high excess irrigation, particularly among retail businesses, was likely due to high expectations for an attractive landscape and the prevalence of automated systems that allowed unmonitored irrigation that was not changed in response to lower plant water needs during late season. The lower excess irrigation among the residential water users was probably due to older housing with fewer automated systems and lowered landscape appearance expectations. In this study, the potential water savings for approximately 300 businesses in the study would require similar savings from 6000 residential customers when extrapolated beyond the study area. Excess residential irrigation would likely be higher in newer and more affluent areas.

KEY TERMS: Evapotranspiration, landscape irrigation, water conservation, remote sensing

INTRODUCTION

Interest in landscape irrigation water conservation is increasing throughout the US. In the Arid West, rapidly growing urban areas are straining already limited water supplies. Even in high-rainfall regions east of the 100th meridian, landscape irrigation is an increasing concern. Severe drought along the eastern seaboard in 1999 resulted in the banning of lawn irrigation in many areas. However, landscape water conservation programs to manage long-term supplies or response to drought are often without a clear goal. Water purveyors frequently set target levels of conservation based on water savings achieved under extreme water shortages. Such savings based on a crisis response are, by their very nature, not sustainable. End water users sacrifice a desirable good, their landscapes, in order to save water. Long-term landscape water savings are best achieved where there are target levels of water savings where the end user can anticipate, hence accept, the consequences of reducing water use.

Landscape water demand analysis applies a budget approach to landscape water use whereby target levels of water savings can be set based on actual plant water needs. Analyzing landscape water demand involves comparing purveyor water billing data obtained from meter readings to estimated landscape water needs based on the product of local evapotranspiration rate and irrigated landscaped area. Estimated water needs can then be corrected for non-uniformity of application for a more accurate measurement. This analysis is essentially an audit, and can be performed for individual users, or with

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proper processing such as with a geographical information systems (GIS) database, up to a city-wide basis. This paper reports on quantifying potentially conservable landscape water in a suburb of Salt Lake City, Utah through use analysis of billing data and irrigated landscaped area.

METHODS

Multitemporal, multispectral airborne digital images were collected over urban landscaped areas in the city of Layton, Utah, approximately 20 miles north of Salt Lake City, in June, July and August 1998 (Figure 1). Images were acquired at 1-meter pixel resolution, and the different surface covers in the images were represented by different-colored pixels. The spectral images were then registered into 3-band images and then overlaid and rectified individually to digital 7.5 minutes quad maps (1:24000 scale) using Universal Transfers Mercator (UTM) projection. The images rectified to the quad maps were then mosaicked by stitching together along flightlines into image strips of 6-8 images each. The strips were joined together into a large image mosaic covering the entire urban area. The final image was transformed to the State Plane coordinate system to match the GIS data from city of Layton. The pixels

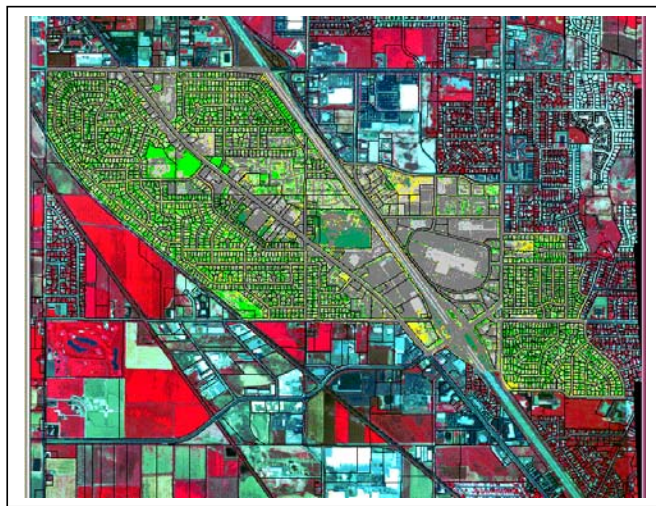


Figure 1. Aerial false-color image of Layton, UT. Red-blue section of image is original 3-band image; green section is the classified image overlaid with a GIS parcel-boundary layer delineating individual properties.

boundary information was obtained from the city of Layton for their residential customers, but they did not have an up-to-date parcel boundary layer for their commercial, institutional, and industrial (CII) accounts. This parcel boundary layer was overlaid on the classified image in geographical information systems software (GIS; Arcview, ESRI Inc., Redlands CA). The number of pixels in each vegetative category within a defined parcel boundary was counted and converted to area. Actual landscaped area was determined by measuring the landscaped area 55 residences with a wheel measure (this sample was taken from the survey subsample population), and was then related to landscaped area determined from GIS analysis. We measured all commercial landscaped areas in the study area by hand with a wheel measure because the absence of an up-to-date parcel boundary layer precluded GIS analysis of the classified image.

The volume of estimated landscape water needs was then calculated as the product of GIS-derived irrigated landscaped area and the estimated depth of landscape water use. Depth of landscape water use was determined by taking reference evapotranspiration (ET_o) times a landscape water use multiplier that was assumed to be 80% of ET_o. Reference ET was calculated using the Penman-Monteith equation as water lost from a hypothetical 12 cm high clipped cool-season turfgrass obtained from a weather station in Salt Lake City over the growing season of April-September. In the initial analysis presented here, average historical ET_o April-September is approximately 40 inches. This amount times the 0.8 turf water

in the image that represent spectral signatures of the different surface covers were then classified as to actual surface cover. An investigative trip to the urban areas within the city of Layton was carried out to collect ground truth information for the image acquired in August 1998. More than 400 classes (signatures) were extracted visually and iteratively from the image to cover most of the urban areas. The signature classes were reduced to grass, trees and shrubs, roofs with different covers, concrete, asphalt, bare soil, shadow, water and meadow.

To estimate the average volume of landscape water consumed, the areas of different types of grass (green, sparse and stressed) and the areas of trees and shrubs were obtained from the classified image for the residential areas only. A GIS database layer containing parcel

use correction factor minus average historical of rain of 13 inches for the same period gives 19 inches. The product of this net estimated water needs and 1.6 correction factor (62% application uniformity) for irrigation system non-uniformity yields approximately 30 inches of water needed to irrigate turfgrass in this area of Utah on an average year. In analyzing water use in this study, we assumed a worst-case scenario of a hot and dry growing season with half the normal precipitation such that water needs were 25 inches, or 40 inches corrected for irrigation system non-uniformity. Forty inches to irrigate turf is a substantially large amount of water that, in a normal year, would be enough to support rice.

Actual water applied derived from a separate water billing database for the years of 1995-98 was also obtained from Layton City. Water meter readings were taken every two months through the year for residential water users, and monthly for CII water users. Actual landscape water use was calculated as the amount of water applied monthly over the growing season minus baseline (indoor) water use during winter months when there is no landscape irrigation. This assumes that indoor water use is constant through the year. However, Layton city does not actually measure water use during the winter for residential customers but instead assumes an average 14,000 gallons consumer per two-month billing period per household, so we used this assumed amount. Once the water needs for a particular area is calculated and actual usage determined, the amount of conservable water applied in excess of estimated water needs can be determined by comparing, or auditing, actual usage to estimated needs.

A survey of behavior and attitudes regarding water was also conducted. In August 1999, a subsample of 300 residential water users in the study area was randomly selected. A survey instrument consisting of questions regarding demographics, irrigation system type, irrigation practices, level of knowledge about plant water needs, and attitudes towards water was given to each user in the subsample. The subsample population was given several days to complete the survey, after which time it was retrieved. Among the CII water users, only the commercial establishments were surveyed because they composed the largest group, and initial inspection of water billing data indicated that they had substantially higher water use than industrial and institutional water users. Because most business water users did not maintain their own landscape, both the business occupying a site and using water and the landscaper responsible to managing the irrigation were surveyed with an instrument similar to the residential water users.

RESULTS

AREA. Calibration of residential landscaped areas derived from overlaying the GIS parcel boundary layer on the classified image showed good agreement with ground measured landscaped area ($a=1458$ $b=0.76$. $n=55$ $r^2=0.71$) for a small population of residential water users in the survey subsample. Most residential areas were ranged from 3000-7000 feet², but several larger landscapes up to 14,00 feet², which improved the relationship. Landscaped area was closely related to total parcel size, both derived from GIS analysis, for the same population. This relationship, with an intercept of -3049 and a slope of 0.94, ($n=54$ $r^2=0.72$), can potentially be used to estimate landscaped area elsewhere when lot size is known.

Average GIS-estimated total lot size and landscaped area was 9400 feet² and 6200 feet², respectively, or as a percentage averaged over the subsample population, landscaped area was 62% of total lot area.

Landscaped area of the 298 CII water users in the study area differed substantially from that of the residential water users (Table 1). Analysis of landscape water use of the commercial-institutional-industrial water users was based on dividing the CII users into five groups based on Layton city zoning regulations: Institutional (parks, schools, and churches), industrial-manufacturing businesses, apartments,

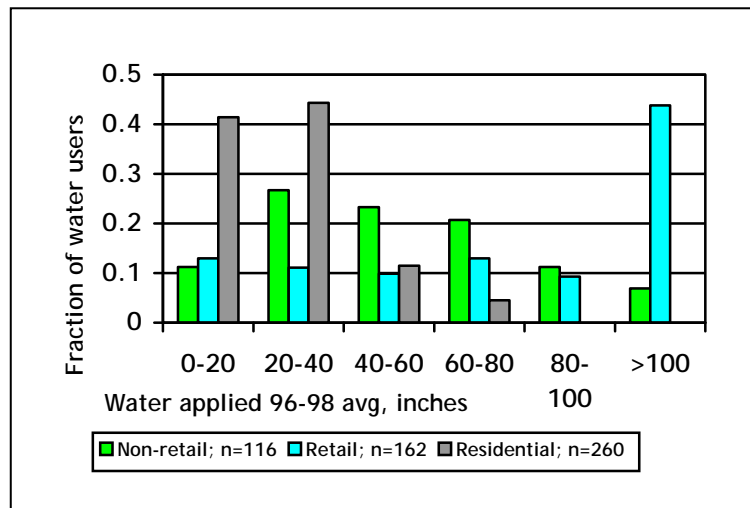
Table 1. Number of users and average landscape size of 278 landscape water users in five commercial-institutional-industrial land use zones.

Zoned Land Use	Users, number	Ave. Size, ft ²
Institutional—parks, churches, schools	28	200,000
Manufacturing businesses	19	9,000
Multi-family—apartments	69	15,000
Local retail businesses	81	6,000
Regional retail businesses	81	16,000

local retail businesses, and regional retail businesses. Local businesses had the smallest landscaped areas while regional businesses and apartments had similar landscape areas, more than twice that of retail businesses, while manufacturing was intermediate. Institutional landscapes had the largest landscaped area due to the presence of parks.

WATER USE FREQUENCY

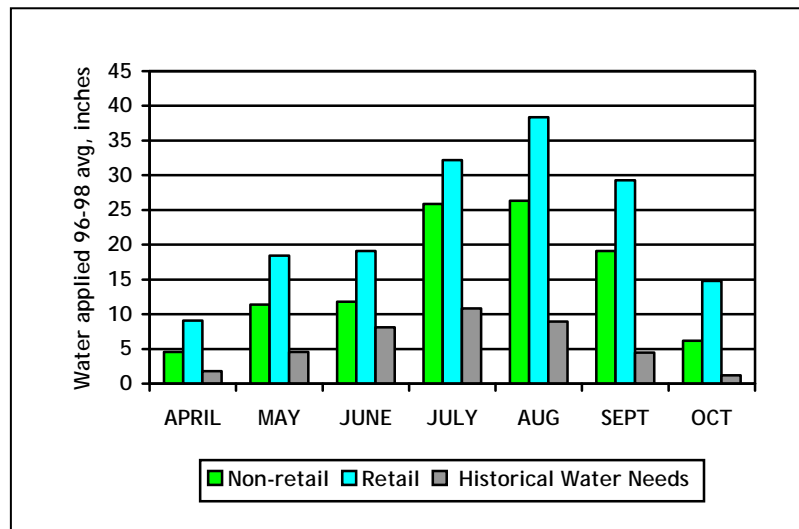
DISTRIBUTION. The amount of water applied to the landscape for the CII users varied with the type of land use. Again, setting 40 inches as the maximum of water any turf should need, only the institutional water users irrigated their landscapes efficiently, as 56% of them applied less than 40 inches yearly. The most inefficient water users were all the regional businesses, as only 16% applied below 40 inches of water, and actually 44% (36 users) applied over 100 inches yearly. Many of these



high-end water users were franchise restaurants with high expectations for their landscapes and where the water bills are paid out of state. Overall, 70% of the CII users applied water in excess of landscape water needs. In contrast to CII users, the majority of residential water users applied water to their landscapes efficiently. Approximately 86% applied 40 inches a year or less, and only one user out of nearly 300 applied over 100 inches. In fact, about 65 users applied less than 30 inches, which is a more reasonable estimate of landscape water needs in a normal year.

SEASONAL CHANGES IN

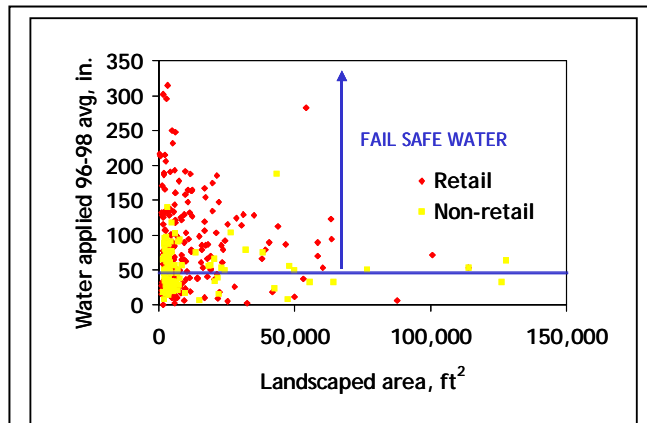
WATER USE. The timing of excess irrigation was similar in both CII and residential water users. Among the CII users, the industrial, local business, and particularly regional businesses applied the most water in excess of ETo. Except for the industrial water users whose water use peaked in July, water applied was the highest in August for the remaining CII groups, even though the average historical ET rate in August is similar to that in June. Application rates continued to be high in September for almost all CII users despite ET falling to levels similar to May. High water application rates in late summer is likely due to time clocks set for midsummer are left unchanged as ETo declines in late summer. Residential water users are more efficient than the CII users, as water use averaged over the residential subsample was close to water needs estimated from ETo. The average of the entire study group actually did not irrigate in excess during the late spring billing period. During the mid-summer and late summer billing periods, average water use of the subsample population was only a few inches in excess of estimated needs through the summer. For those residential water users who apply more than 40 total inches a year (n=38), their excess irrigation is on par with the CII water users, applying over 10 inches in excess of plant water needs during each of the



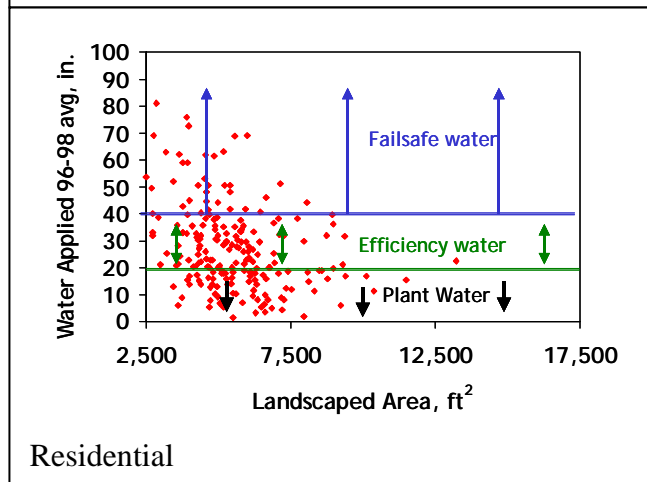
summer billing periods. Again, even though the ET rate in late summer is similar to late spring, applied water August-October declined little from early to midsummer water use.

WATER USE VERSUS LANDSCAPED AREA.

The amount of water applied to landscapes was related to the size of the area irrigated. For both CII and residential waters, there was a declining water use ceiling as landscaped area increased. The spread for the CII users was much greater than for residential users, 500-130,000 ft² versus 2,000-14,000 ft², as the institutional users included parks and schools with large irrigated areas as well as the small landscapes associated with retail businesses, particularly franchise restaurants. Residential landscaped areas had a much smaller range, likely due to the greater homogeneity of residential lot sizes. Declining water use with landscaped area is probably due to the greater maintenance needs of larger landscapes that require more attention of the landscape manager. Hence the irrigation system is more likely to be tended and time clock runtimes and frequencies changed with seasonal changes in ETo. Water bills would also be higher for larger landscapes, getting the attention of those paying the bill and who are more likely to be responsible for the landscape. Smaller retail landscapes, by contrast, are more likely to have the water bill paid separately from the landscape



Commercial



Residential

maintenance firm that is responsible for managing the irrigation system, so the water bill cannot provide a feedback signal indicating excess irrigation practices.

TOTAL CONSERVABLE WATER. Potential water savings among the study group of nearly 300 of residential water users is much less than the CII users. Most of the CII water users applied water far in excess of the estimated landscape water needs. As a percentage of total seasonal water use, institutional and multi-family landscapes were the most efficient groups among the CII water users but they still applied about 25% more water than they needed, similar to the level of excess irrigation observed in the residential users. The manufacturing and local/regional businesses applied about 50% more water on average than needed. The total amount of CII landscape water used was the highest for the regional businesses, even though the average landscape size of the regional businesses was similar to multi-family landscapes. Overall, these nearly 300 CII water users could save nearly 500 acre feet of water if their irrigation were brought back in line with a 40 inches water use ceiling that could amply irrigate any all-turf landscape.

The pattern of lower residential water use is evident in total water use numbers. For the subsample population, 63% of the total seasonal (April-October) water use was applied to the landscape and can be partitioned between 43% below and 20% in excess of the estimated 40 inch water-needs ceiling. This translates to 25 acre-feet of potential water savings if the 38 users applying above 40 inches of water were to water at estimated needs. Extrapolating from the subsample to the entire residential population of

Table 1. Total, winter, actual water needed by landscapes as estimated by average seasonal ET (40"), and water applied in excess of estimated needs, 1996-97, for 297 residential water users in Layton, UT.

	GALLONS	ACRE-FT	% of total
Total	41,841,000	128	100
Winter baseline	15,457,000	47	0.37
Landscape	18,178,000	56	0.43
Land Use Zone	Total Seasonal Water Use, gallons	Water Applied in Excess of Needs	Fraction of Total Seasonal Water Use that is Wasted
OVERALL	406,137,000	155,174,000	0.38
OVERALL (ACRE- FEET)	(1,246)	(476)	
INSTITUTIONAL	113,760,000	34,926,000	0.31
MULTI-FAMILY	86,731,000	19,612,000	0.23
INDUSTRIAL	8,492,000	4,468,000	0.53
LOCAL BUSINESS	49,382,000	22,140,000	0.45
REGIONAL BUSINESS	147,772,000	74,028,000	0.50

approximately 6000 in the study area, the potential savings would be about 500 acre-feet, approximately the same potential savings among the 300 CII users. However, not all residential areas along the Wasatch Front contain a majority of users who water below 40 inches. The city of North Salt generously provided water use data for their 10 highest residential water users located in an upscale neighborhood from the year 2000. The inverse relationship between water applied and landscaped area seen in Layton was found in this group, as two landscapes at approximately 1.5 acres applied around 50 inches, while the five landscapes that were 1/3-1/2 acre in size applied from 160-210 inches.

PRELIMINARY SURVEY RESULTS. Initial analysis of residential survey data showed that the subsample was middle income with less than half with automated, in-ground irrigation systems. The higher water users tended to be higher income, long-term residents with automated systems. Initial analysis of the commercial water users indicates that almost all have automated irrigation systems. The business owners felt that the cost of water was insignificant, even though many felt they were paying too much, and that having an attractive, well-watered landscape water was very important. Landscapers maintaining these landscapes knew that they were overwatering, but felt that competitive pressure and business expectations forced them to overwater.

CONCLUSION

In our study in Layton, affluence-related high expectations of landscape appearance and automated systems are the primary reasons for excess irrigation. Image-conscious businesses and homeowners have a large stake in current cultural ethic of uniform turfgrass landscapes, and automated irrigation systems allow the ethic to be realized by their ease of applying more than enough water. However, because automated systems are set to run frequently with long durations that are not changed in accordance with changes in ET, the commercial users had the greatest potential for water savings, particularly those with smaller landscapes. Older landscapes without automated irrigation systems are less likely to be wasting water. This includes the residential water users in the study area with older homes with lower expectations of appearance that are less likely to have an automated irrigation system and are more likely manually pull hoses to irrigate. Manual irrigation may result in long run times, but much less frequent applications because of the extra labor costs that result in lower overall water use. The landscapes most likely to waste landscape irrigation water are those that are smaller with automated systems, have high expectations for appearance, and are sufficiently affluent that the cost of wasting water at existing price rates is not enough to get their attention. The greatest timing for water savings is from mid to late summer when run times for automated systems are not being reduced as ET declines.