Landscape Coefficients Derived by Soil Water Balance in Xeriscape Plantings

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Abstract. Four foot deep profile soil moisture sensors (each with 5 measurement segments) were installed in 8 unique drip-irrigated Xeriscape Gardens at Northern Water in August 2011. Plant groupings (no turf) represented a spectrum of plant sizes and types in the Xeriscape Gardens. Soil moisture was monitored weekly until November 2011, when monitoring intervals were lengthened to 2-3 weeks through the winter. Plant condition was routinely observed during the growing season. Bi-weekly readings were resumed at the beginning of April 2012 and weekly readings resumed in May 2012. A soil water balance was calculated for irrigation and precipitation-free time periods and compared to ETrs and ETos reference evapotranspiration calculated from an adjacent weather station to derive landscape coefficients. Soil moisture drawdown at each of the 5 soil depth intervals was observed for each plant grouping, with inference for rooting depths and soil water extraction zones.

Keywords. Landscape ET, landscape coefficient, landscape irrigation, landscape water use.

Introduction

Xeriscaping is promoted as a set of landscape water conservation principles. Efficient irrigation systems, non-turf irrigation zones separate from turf zones, and plant selection are some of the principles of water-efficient landscaping. However, plant selection is often heavily emphasized, while irrigation needs are mostly not quantified. Urban residential landscapes are each unique, with varying microclimates, exposures, and plant selections. Therefore, it is difficult to quantify irrigation needs in ways that are easy to understand and implement. Frequently, plants are categorized as having very low, low, medium, or high water requirements. The categories typically refer to percentage of reference evapotranspiration (ET) (0-25%, 25-50%, 50-75%, 75-100%).

Other complexities in developing irrigation guidelines for landscapes include the fact that many landscapes contain mixed plant types (trees, shrubs, perennial plants). Xeriscape irrigation recommendations usually stress that plants of different water needs be in separate hydrozones.

One method of estimating landscape water needs was presented by University of California Cooperative Extension California Department of Water Resources (2000). This document presents the Landscape Coefficient method of estimating irrigation needs and WUCOLS III, the acronym for Water Use Classifications of Landscape Species. The landscape coefficient method borrows extensively from the agriculture crop coefficient methodology, with the limitation that landscapes are usually not monocultures as are agriculture fields. While the crop coefficient methods work well for turf, mixed species and non-uniform landscapes are not well-suited for this approach. Other techniques for quantification of mixed-species landscape water are being developed and tested.

In Texas, Pannkuk et al (2010) found that mixed-species urban landscapes on non-sodic sites ranged from 0.5 to 0.7 K_L (based on ETo) under well-watered conditions, stating that landscape irrigation based on reference evapotranspiration can achieve significant water savings.

Sun et al (2012) found that under well-watered conditions, plant water requirement categories were not the controlling factor in determining landscape water use. Instead, plant canopy cover determined water use for woody species and perennials. It was suggested that adjusting planting density could achieve water savings in the well-watered urban landscape. Drought-adapted plant selection was acknowledged to likely play a bigger role in maintaining an attractive landscape with reduced irrigation and water-deficit conditions. Plant factors (K_P) in the well-watered, replicated landscapes ranged from 0.3 to 0.9 (woody plants) and 0.2 to 0.5 for perennials. After adjustment for canopy cover, well-watered landscape factors ($K_{L,}$ based on ETo) ranged from 0.6 to 0.8.

Recently, efforts to quantify xeric landscape irrigation needs in northwestern New Mexico were presented by Smeal et al (2010), who recommended an average landscape coefficient (K_L) of 0.3 ETrs (tall canopy reference evapotranspiration , ASCE-EWRI, 2005). Visual quality was the key factor in determining the appropriate irrigation level. Many of the plants grown in Smeal et al (2010) are available and viable in Northern Colorado; therefore the K_L selected in that study was considered an appropriate starting point for xeric landscape irrigation in Colorado.

As in Smeal et al (1010), however, our study is also not a replicated study. It is, instead, an investigation of eight xeric landscape responses in northern Colorado to irrigations at approximately 0.3*ETrs. The objectives of the project were to: to evaluate plant complex water use via soil water balance, to infer active rooting depths from soil moisture changes at different depths in the soil profile, and to evaluate the irrigation practices in the landscapes with regard to maintaining landscapes for low water use or demand, as well as appearance.

Methods

Eight mini-landscapes were built from 2004-2005 at Northern Water's headquarters in Berthoud, CO. Each landscape was designed with a 'shrub' zone and a turf zone, each with different themes, plant mixtures, and irrigation zones. ('Shrub' zones included small trees, shrubs, and perennial plants.) All plants included were 'Colorado-friendly', meaning that plants could survive in Colorado's semi-arid climate with considerably less irrigation than cool-season turf. Each 'shrub' irrigation zone contains mixed small trees or large shrubs, ornamental grasses of varying heights, or other small xeric plants.

The native soil is a Nunn Clay Loam (Fine, smectitic, mesic Aridic Argiustolls), which was amended with high quality organic matter. All turf zones were irrigated separately from the plant/shrub zones. Seven of eight non-turf zones are irrigated with some form of drip irrigation and scheduled separately from turf.

In 2011, 24 four-foot long MoisturePoint (E.S.I. Environmental Sensors, Inc., Sydney, BC, Canada) soil moisture sensors were installed in the eight landscapes. Three probes were installed in 6 landscapes; 4 in a seventh zone, and 2 in an eighth zone. Each sensor had 5 measurement zones, beginning with two six inch zones for the top foot, while each zone below was 12" in length. Soil moisture data were collected weekly with the MP-917 data-viewing instrument, starting on 9 August, 2011 through October, 2011, and continuing throughout the fall and winter with less frequency. In Spring, 2012, data collection intervals were more frequent and based more on bracketing irrigation events and rainfall events, when feasible.

A simple soil water balance was calculated for all measurement intervals, resulting in an ET estimate for the time interval. Intervals selected for analysis had very little (< 0.25 inches) precipitation or irrigation. Calculation depths were limited to those depths with both end point soil moisture values less than field capacity (0.35 in/in), when drainage was considered to be zero. Estimated ET was then compared to ETrs at selected times throughout 2012. This paper primarily references ETrs for consistency with the methods of Smeal et al (2010), though K_L values were also calculated for ETos.

Two landscapes were chosen for analysis for this paper: B, a landscape that contains plants and turf native to the Intermountain West, and C, a landscape that contains native trees and shrubs as well as numerous yucca species. Within each landscape, one of the three MoisturePoint sensors was chosen for analysis. The plant complex at sensor B1 was: Pawnee Buttes Sandcherry (*Prunus besseyi 'Pawnee Buttes')*, Dakota Sunspot Potentilla (*Potentilla fruiticosa 'Fargo')*, and Prairie Sky Switchgrass (*Panicum virgatum 'Prairie Sky'),* Figure 1. At sensor C1, the plant complex consisted of New Mexico Privet (*Forestiera neomexicana)* Figure 2.

Figure 1. Location of B1 MoisturePoint sensor. The plant complex consists of Pawnee Buttes Sandcherry (*Prunus besseyi 'Pawnee Buttes')* in the foreground, Dakota Sunspot Potentilla (*Potentilla fruiticosa 'Fargo'),* just above the Sand Cherry in the photo, and Prairie Sky Switchgrass (*Panicum virgatum 'Prairie Sky',* just behind the white sensor cap.

Figure 2. Location of C1 MoisturePoint sensor. The plant complex consists of New Mexico Privet (*Forestiera neomexicana).* Note the white sensor cap in the lower left third of the photo.

Results

Soil Moisture Trends

A check of soil moisture patterns from installation through September, 2012, suggests that both plant complexes were dormant for most of the winter and into spring (Figures 3 and 4). New Mexico Privet soil moisture (Figure 4) showed no decline from early January 2012 through early May, 2012 at depths to 3 feet.

Soil moisture increased in mid to late spring at the 4 foot depth. Soil moisture was at field capacity at the 2 and 3 foot depths; soil moisture was less than field capacity for most of the winter and early spring, suggesting that drainage was not usually occurring through the top two feet.

Soil moisture at times declined below field capacity in the 0-36” depths in B1 and C1; however soil moisture was slow to decline to less than saturated conditions in the 4 foot depth. This is in part due to installation technique; the MoisturePoint probe is driven into a pilot hole, but in the heavy clay loam soils, water had to be added to lubricate the hole. While the 0-36” depths seemed to equilibrate in several weeks, the 4 foot depth has been very slow to drain and equilibrate. The data also indicate that at times soil moisture exceeds field capacity; therefore drainage from one depth to the next may be occurring.

Soil moisture at the 4 foot depth in B1 and C1 decreased throughout the summer of 2012. Provided that large precipitation events do not drain through the soil profile, that depth may become a working depth for plant soil water balance accounting in future years.

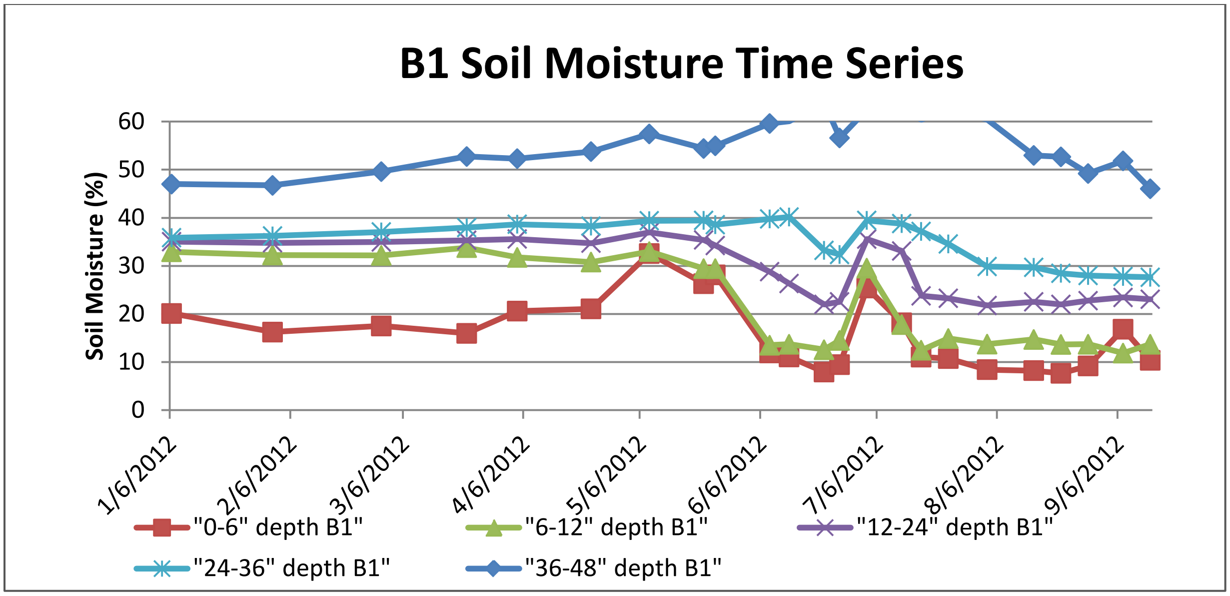

Figure 3. Soil moisture time series at each depth interval in the Pawnee Buttes Sand Cherry plant complex.

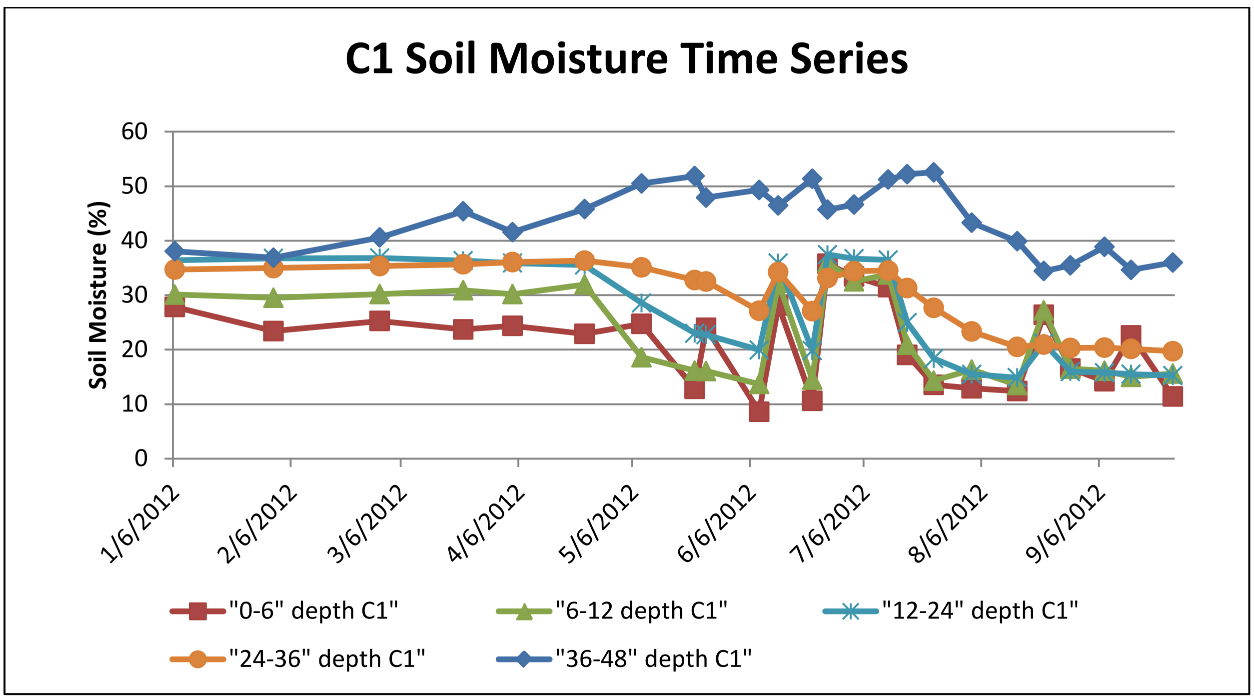

Figure 4. Soil moisture time series at each depth interval in the New Mexico Privet plant complex.

Soil Water Balance

A simple soil water balance was calculated for selected intervals during 2012. Intervals had very little or no precipitation or irrigation and soil depths included in each interval had soil moisture values less than field capacity. Filtered thus, drainage was assumed to be zero in the depths analyzed. The minimal precipitation and irrigation were accounted for in the soil water balance. Table 1 shows calculated ET from the soil water balance and ratio to ETrs for New Mexico Privet (C1).

Table 1. Estimated ET from soil water balance for the C1 (New Mexico Privet) landscape. Values in bold are the soil moisture depth increments used in the water balance in each date interval. The maximum and mean soil moisture values in each interval are shown.

Date Interval	Depth (in)	ET from SWB (in)	K_L (ETrs)	ETrs (in)	K_L (ETos)	ETos (in)	SM 0-6” (Max*/ Mean) *in interval	SM 6-12” (Max*/ Mean)	SM 12-24” (Max*/ Mean)	SM 24-36” (Max*/ Mean)
9/7-9/13/2011	36	0.74	0.63	1.18	0.76	0.97	**10.5/9.03**	**15.2/14.1**	**19.5/18.3**	**24.9/24.3**
2/29-3/22/2012	12	0.03	0.008	3.96	0.01	2.99	**25.3/24.5**	**30.9/30.6**	36.8/36.6	35.6/35.5
5/8/-5/22/2012	24	1.33	0.41	3.26	0.50	2.59	**24.7/18.8**	**18.6/17.4**	**28.6/25.8**	35.1/33.9
5/25-6/8/2012	24	1.33	0.45	2.96	0.58	2.29	**24.0/16.3**	**16.1/14.9**	**22.7/21.3**	32.5/29.8
6/13-6/22/2012	12	2.13	0.69	3.07	0.89	2.40	**28.1/19.4**	**28.1/23.4**	35.9/27.9	34.2/30.7
7/12-7/17/2012	12	1.38	0.91	1.51	1.15	1.20	**31.5/25.3**	**33.8/27.4**	36.5/30.7	34.5/32.9
7/17-7/24/2012	36	1.75	0.75	2.33	0.94	1.87	**19.0/16.3**	**20.9/17.6**	**25.0/21.7**	**31.3/29.5**
8/3-8/15/2012	24	0.23	0.07	3.24	0.09	2.56	**12.9/12.7**	**16.3/14.9**	**15.5/15.2**	23.3/21.9
8/22-8/29/2012	36	1.71	0.93	1.83	1.17	1.46	**26.4/21.5**	**27.2/21.9**	**21.2/18.6**	**20.9/20.6**

The ET values show water used in the interval at the particular drainage-free soil depth. The K_L value puts the ET in perspective and indicates that when soil water is available, New Mexico Privet can use as much water as turf (K_L of 0.91 from 7/12-7/17/2012). Yet, when soil water becomes more limiting, as between 8/3 and 8/15/2012, ET is very low at 9% of ETrs. The highest K_L values occurred in periods after an irrigation or rainfall, when soil moisture was high. Maximum and mean soil moisture values in each depth interval help illustrate this point.
The B1 plant complex, of much smaller statures than New Mexico Privet, used water at lower rates than New Mexico Privet (Table 2). Highest K_L values occurred in the interval after heavy precipitation or irrigation (7/12-7/17/2012).

It is apparent that K_L varies from interval to interval depending primarily on the availability of soil moisture. Lowest soil moistures tend to limit water use; this is expected from a native plant in the Intermountain West. An opportunistic water use pattern is also observed among many native plants in this region.

From 5/8-5/22, however, soil moisture was relatively high, but water use was low. This suggests that the B1 plant complex had not yet broken dormancy and begun using soil moisture. Photo documentary from 4 May, 2011 showed Pawnee Butte Sand Cherry blooming but nearly leafless, so it is plausible that the 5/8-5/22 2012 interval reflects a near-zero transpiration rate.

Table 2. Estimated ET from soil water balance for the B1 (Pawnee Butte Sand Cherry complex) landscape. Values in bold are the soil moisture depth increments used in the water balance in each date interval. The maximum and mean soil moisture values in each interval are shown.

Date Interval	To depth (in)	ET from SWB (in)	K_L (ETrs)	ETrs (in)	K_L (ETos)	ETos (in)	SM 0-6" (Max*/ Mean) *in interval	SM 6-12" (Max/ Mean)	SM 12-24" (Max/ Mean)	SM 24-36" (Max/ Mean)
9/7-9/13/2011	24	0.02	0.017	1.18	0.02	0.97	**6.6/6.2**	**15.2/14.8**	**24.3/24.0**	34.7/32.3
5/8/-5/22/2012	12	0.12	0.04	3.26	0.05	2.59	**32.6/29.4**	**33.8/31.2**	37.0/36.2	39.5/39.4
5/25-6/8/2012	12	1.56	0.53	2.96	0.68	2.29	**28.1/20.0**	**29.4/21.5**	34.2/31.5	39.8/39.1
6/13-6/26/2012	24	0.71	0.15	4.6	0.20	3.59	**11.1/9.5**	**13.7/13.1**	**26.3/24.2**	40.2/36.7
7/12-7/17/2012	12	0.93	0.62	1.51	0.78	1.20	**25.4/21.8**	**29.5/23.7**	35.6/34.3	39.4/39.1
7/17-7/24/2012	24	1.07	0.46	2.33	0.57	1.87	**18.2/14.6**	**17.8/15.1**	**33.1/28.4**	38.8/37.0
8/3-8/15/2012	24	0.10	0.03	3.24	0.04	2.56	**10.7/9.5**	**14.9/14.3**	**23.3/22.5**	34.6/32.2
8/22-8/29/2012	36	0.13	0.07	1.83	0.09	1.46	**8.2/8.0**	**14.7/14.2**	**22.5/22.3**	**29.7/29.1**

Not accounting for possible periodic drainage from 5/8/2012 to 9/25/2012, seasonal water use from the top 2 feet in the B landscape was 14.7 inches. ETrs for the period was 38.14 inches; therefore the seasonal K_L from the soil water balance was 0.385. The C landscape seasonal ET from the soil water balance was 12.9 inches; K_L was 0.34.

The ratio of applied irrigation plus precipitation to ETrs from May through September (K_L) was 0.37 for the B landscape and 0.35 for the C landscape.

Proportional soil water extraction by 12 inch increments in B1 and C1 for the 7/12-7/24 period is shown in Table 3. Potential drainage was neglected in the calculations, but would likely have been minimal for both locations. The third foot in the soil profile was more subject to potential drainage, but the data infer that far less soil water was extracted from this layer by the plant complex. Any soil water change in the 36-48 inch soil profile was considered to be drainage, as soil moistures were above field capacity on these dates. Soil moisture on 7/12/2012 was fairly high, but had decreased considerably in the 0-12 inch soil layer by 7/17/2012. Performing the same analysis for the 7/17-9/25/2012 interval showed a different distribution of soil water extraction (Table 3). As soil moisture decreased closer to the soil surface, soil water extraction tended to be greater from lower soil depths. A similar, but not as strong trend, was apparent for C1.

Table 3. Proportional soil water extraction by each 12 inch layer in the soil profile.

B1	0-12”	12-24”	24-36”
7/12-7/17/2012	75 %	19.7%	5.3%
7/17-7/24/2012	38.2%	52.8%	9.0%
C1			
7/12-7/17/2012	46.2%	42.2%	11.6%
7/17-7/24/2012	36.5%	41.1%	22.4%

Conclusions

Two plant complexes native to the Intermountain West were chosen to 1) to evaluate plant complex water use via soil water balance; 2) to infer active rooting depths from soil moisture changes at different depths in the soil profile and 3) to evaluate the irrigation practices in the landscapes with regard to maintaining landscapes for low water use or demand. .

While plant complexes were not quantitatively rated for appearance, occasional visual monitoring affirmed that the mini-landscapes remained in acceptable condition. Previous irrigation practices had generally followed the 25-50% of reference ET plant water need category, so this irrigation regime was not dissimilar to past years.

The ratio of applied irrigation plus precipitation to ETrs for the Pawnee Butte Sand Cherry complex in the B landscape was 0.37. The ratio of applied irrigation plus precipitation to ETrs for the New Mexico Privet complex in the C landscape was 0.35.

Soil water extraction was greatest in the top 12 inches when soil moisture was higher; as soil moisture decreased in the upper 12 inches, soil water extraction by plants increased at deeper depths. Understanding soil water extraction patterns will help irrigation scheduling and soil moisture sensor placement in landscapes with soil-moisture based controllers.

Seasonal water use for the B1 plant complex was 14.7 inches; the seasonal water use for the C1 plant complex was 12.9 inches. The K_Ls developed from a simple seasonal water balance, neglecting drainage, were 0.385 for the B1 plant complex and 0.34 for the C1 plant complex, very similar to the ratios of applied irrigation plus precipitation to ETrs. The estimated ET and K_L values in each time interval indicated that plants used water when available, but readily adapted to low soil moisture by reducing ET. The similarity of applied irrigation plus precipitation : ETrs ratios to the K_L values developed from the soil water balance implies that water applied will be water used, if drainage or runoff are not large factors.

It was apparent from the soil water extraction patterns that the plant complexes in this analysis were able to acquire moisture from soil depths of at least 24-36 inches. Also, weekly soil water measurement intervals revealed that the plant complexes used soil water heavily from the top 12 inches of the soil profile the first week after irrigation or precipitation events. Soil moisture was then extracted from the 12-24 inch soil depth in the second week.

Irrigation scheduling refinements may include extending the interval between irrigations. This analysis has not yet been extended to the smaller, shallower rooted plants. It is possible that plants with shallower root systems than shrubs, small trees, or tall grasses may not maintain appearance in an extended irrigation interval. Extension of the irrigation interval for the shrub, small tree, or large grasses will mean reduced ET over a longer period as the plants go into a soil-water-deficit induced dormancy state.

Further refinements to this project include modeling the drainage component to more thoroughly quantify the seasonal and interval soil water balances, and extending the analysis to every sensor in the eight mini-landscapes. Accounting for drainage will likely reduce the soil-water balance based K_L values. The results of the refinements will be used to modify irrigation and water conservation practices and recommendations. Reduction of total applied irrigation is also a goal, based on the current analysis.

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