Water Conservation in Urban Landscapes

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As in agriculture, amenity landscapes that have ornamental or utility value are irrigated when rain is insufficient to support expected growth. Irrigation to compensate for inadequate rainfall can be permanent in arid areas or temporary with short-term drought in high-summer-rainfall areas. Landscapes have additional irrigation requirements uncommon in agriculture. Most landscape plants need short-term irrigation following planting until they establish new roots in the surrounding soil. Also, plants can be placed in landscape situations of very limited soil-water availability, such as aboveground planters, that require permanent irrigation regardless of the climate.

Unlike agriculture, performance of an amenity landscape is not measured with a quantifiable yield. Applying a known amount of a resource, such as water, to an agricultural crop results in a predictable yield response. Consequently, resource input can be economically optimized for yield output. By contrast, landscape performance is measured by how well it meets expectations of the user or the individual paying for installation and maintenance, who may or may not be one and the same. Expectations include aesthetic appearance, utility, such as shading and ground cover, and recreation. Since landscape performance is based on expectations rather than an objective measure, there is no marketplace to assign economic value to the landscape. Without a market value of performance, the value of a resource input cannot be measured.

The absence of a quantitative relationship between input of a resource such as water and the performance of a landscape makes water conservation both difficult and easy. Developing quantitative management practices is difficult when water conservation is a goal for such a wide range of end users and expectations. Clear management recommendations are further complicated by the diversity of species and their water use characteristics, which makes determining irrigation requirements very complex. Alternatively, water conservation is easier in amenity landscapes because the species diversity available to meet subjective, and highly variable, expectations allows a wide range of water conservation options. Water can be conserved either by traditional conservation approaches or just by changing species or expectations.

LANDSCAPE WATER USE

Context of landscape water use

Urban water use is generally not a large percentage of total water consumption when compared with agriculture within a state or region. Water demand for a metropolitan region, particularly in arid regions, can be substantial on localized scales (Postel, 1992). Demand from industry, personal use, and amenity landscapes can require water from a vast number of local watersheds. Since the majority of the populations of many western U.S. states are concentrated in rapidly growing urban areas, water is critical in supporting those populations and can potentially govern future growth.

The amount of water applied to landscapes as a component of total urban water use can be quantified in temperate regions where irrigation is seasonal (Fig. 1, top). Metered municipal water use closely follows increased summer evapotranspiration (ET) rates relative to rainfall. The volume of water applied to landscapes can be estimated by assuming that winter water use reflects only indoor consumption, since cold temperatures and absence of plant growth reduce the need for irrigation. This assumption is not entirely accurate, as there are other seasonal water uses, such as evaporative coolers and swimming pools, but evidence indicates that landscape irrigation accounts for most of the seasonal increase in municipal water use. When a severe water shortage in Seattle, Wash., in Summer 1992 resulted in the banning of turfgrass irrigation, consequent municipal water use did not deviate from winter levels (Fig. 1, bottom), indicating that increased seasonal water use in Seattle indeed goes to landscapes.

Water consumption for landscape use varies with rain and ET (Table 1). Applying the subtraction method described above to data from six cities around the United States, those in the summer-rainfall region east of the Mississippi River increase water use about one-third during the spring to fall growing season. Summing the increased seasonal water use showed that landscapes account for approximately 10% of total seasonal water consumption for these cities, the rest going to indoor and other, nonirrigation, uses. In the arid Mountain West, seasonal water use increases nearly 3- to 4-fold during the growing season, and landscapes can account from a third to nearly half of the total municipal yearly water use (Vickers, 1991).

The amount of water applied to landscapes can be divided into three levels of usage. The first level is water needed to meet baseline physiological plant water needs. The second level is water needed to compensate for system nonuniformity to ensure that the all plants receive the baseline level, particularly in turf. The third is water applied in excess of that needed by plants or for system uniformity, which is potentially conservable.

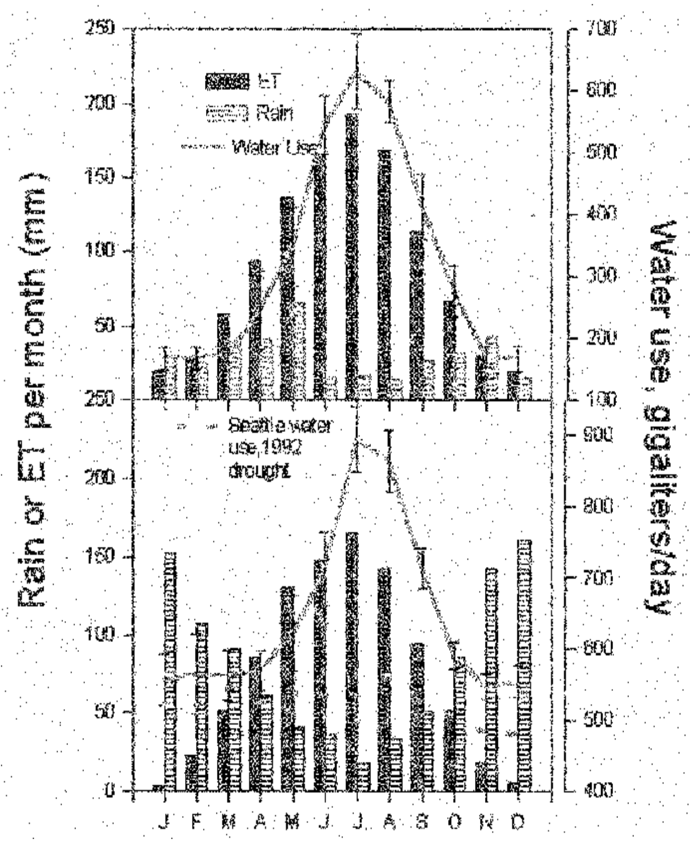

Fig. 1. Average monthly rainfall and reference evapotranspiration (ET; see Allen et al., 1994) and average daily municipal water use, plus standard deviation for (**top**) Salt Lake City, Utah, for the period 1990–94 (Source: Salt Lake City Water Conservancy District), and (**bottom**) for Seattle, Wash., for the period 1988–91, and water use during the drought year 1992 when lawn watering was banned. (Source: Seattle City Water Dept.).

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Table 1. Water balance, June, July, and August rainfall, reference evapotranspiration, and municipal water use for selected cities in the United States.

City	Rain[z] (mm)	ET[y] (mm)	Municipal water use ratio[x] (summer : winter)	Landscape water use[w] (% of total)
Detroit	268	537	1.37	11
Atlanta	297	563	1.26	9
Washington, D.C.	302	549	1.35	13
Seattle	86	454	1.48	14
Denver	166	547	2.61	35
Salt Lake City	63	594	3.52	48

[z] Data taken from soil surveys of the counties in which each city is located.

[y] For 0.12-m-high clipped fescue turf calculated as per Allen et al. (1994).

[x] June, July, and August municipal water use divided by the winter baseline (December–February) water use.

[w] Estimated as a percentage of total yearly water use by subtracting average winter water use from water use April–September, summing over those months, then dividing by total yearly water use.

Plant water needs

Landscape plant cover. Landscapes are composed of plants such as turf, woody plants, herbaceous perennials, and annuals, and hardscape such as rocks, pavers, and mulch. Extent and type of plant cover varies enormously with the landscape. Parks and recreational areas are covered almost entirely with turfgrass, while for a typical residential lot half of the area is covered with a mixture of turf and woody plants (Limaye, 1996). Most of the plant cover in a landscape is turfgrass or trees imbedded in a turfgrass landscape, although the percentage of landscaped area composed of woody plants or herbaceous perennials may be larger in certain parts of the country.

Plant water loss. The physiological water needs of plants vary with atmospheric demand for water and plant characteristics. Atmospheric, or evaporative, demand for water is a function of radiation, humidity, air temperature, and wind. Plants regulate demand by varying leaf size and orientation, stomatal aperature, and total leaf area. Directly measuring plant water use for the practical purpose of replacing that water by irrigation is a difficult task. A more practical approach is relating actual plant water loss to a standard measure of atmospheric demand for water, such as an open pan of water, where:

$$\text{actual plant water loss} \div \text{pan evaporation} = \text{Kc}$$

where Kc is a proportionality factor, multiplier, or water loss coefficient. Kc is used to estimate water loss of a given plant or crop type if the standardized measure of atmospheric water demand is known. Pan evaporation often gave inconsistent results because of variation in local climatic and management conditions (Chiew and McMahon, 1991) and is now less widely used.

The advent of automated weather stations has allowed ready measurement of the atmospheric factors controlling evapotranspiration, and thus the development of a more robust standardized measure. The United Nations Food and Agricultural Organization has adopted the water loss rate of a hypothetical, uniform cool-season turf clipped at 0.12 m as the standard measure of reference evapotranspiration (ETo) using the Penman–Monteith equation (Allen et al., 1994). By holding plant-water-loss characteristics constant, a common measure of reference water loss can be compared among areas with different climates. The inputs needed to calculate ETo are wind, radiation, air temperature, and atmospheric humidity.

Water loss coefficients, Kc's, have been developed mostly for turfgrass because of turf's prevalence in most landscapes and its very close relationship to ETo. Values of Kc for cool-season turfgrass range from 85% to 100% of ETo while those for warm-season turf are 80% to 90% (65% to 80% and 55% to 65%, respectively, of evaporation pans) (Kneebone et al., 1992). Cultivar variability in Kc within a species is high, varying by 15% to 20% for several cool-season species (Shearman, 1989, 1991) and up to 60% for Kentucky bluegrass (*Poa pratensis* L.) (Shearman, 1986).

There are few coefficients for nonturf landscape plants because of the great diversity of species and the difficulty in quantifying Kc values. For many woody species, rates of water loss are not a linear function of ETo. Stomatal sensitivity to high vapor pressure deficits (Turner et al., 1984) and close coupling to atmospheric conditions (Jarvis and McNaughton, 1986) result in a declining rate of water loss at high ETo rates (Choudhury and Monteith, 1986). Such nonlinearity suggests a wide range of Kc's, depending on ET conditions. Coefficients ranging from 0.2 to 0.8 of clipped fescue ETo have been suggested for woody plants (Costello et al., 1992). Limited experimental evidence indicates that water loss rates for temperate-climate woody species do indeed vary widely with both plant and environmental factors (Buwalda and Lenz, 1993; Kjelgren and Montague, 1996; Lindsay and Bassuk, 1991), but in general are lower than for turfgrass.

Irrigation system nonuniformity

The amount of water applied to amenity landscapes is nearly always increased over baseline plant water needs to account for nonuniformity in application. Again, the widespread use of turfgrass in such landscapes dictates performance that is measured by color and uniformity. To achieve a uniform appearance, the depth of water applied to turfgrass needs to be the same throughout the area in turf. Sprinkler irrigation is the most effective means of applying water uniformly. Uneven sprinkler application due to poor design or maintenance results in some areas receiving less water than others. Such areas have limited opportunity to exploit further water supplies during soil drying. Turf roots are circumscribed by competition with other plants laterally and are genetically limited in rooting depth. Consequently, nonuniform water application to turf is clearly evident in areas receiving less water, becoming, in general, unacceptably discolored from drought-induced dormancy.

Distribution uniformity (DU) for sprinkler irrigation is determined by a catch-can test. The depth of water in a number of cups spread evenly over the turf area is measured after the system has been operated for a fixed period of time. Such measurements are more feasible when a small sample area is used rather than the entire landscape. Fractional uniformity, between 0–1, is calculated as the average depth of water in the 25% of the cups receiving the least amount of water divided by the average for all the cups. A sprinkler system that applies the same depth of water over the entire coverage area would have a DU of 100%. By contrast, a DU of 50% means that part of the turf receives half the average amount (Goldhamer and Snyder, 1989). A lawn irrigated with a system with a DU of 50% would need twice the amount of water to ensure that the dry areas received enough than if the system had a DU of 100%.

The DU of a sprinkler system varies with the type of sprinkler head. With optimum design, DU values of impact/gear drive sprinklers for large turf areas can be up to 90%, while those of spray heads in small turf areas rarely exceed 75%. In reality, DU values will vary widely within a head type because of numerous factors. We measured sprinkler DU of both impact and spray heads for 30 elementary schools in the metropolitan region of Salt Lake City, Utah (Table 2). Twenty of the schools had irrigation systems where sprinkler heads were moved manually around the landscape. Ten of the schools had automated irrigation systems where operation of all heads was controlled by a time clock attached to solenoid valves. Schools with automated systems had somewhat higher uniformity for both head types because they were installed more recently than were those at schools with older, manual systems. The range of uniformities for spray heads was greater than for impact sprinklers because of erratic replacement of broken spray heads with different makes that may have had higher or lower output than the original heads. Few schools had a DU above 80% for either head type.

Conservable water

Water applied in excess of plant water needs and expected system uniformity can be conserved. For a given landscape, the amount of conservable water can be calculated with an auditing approach. The volume of water applied to the landscape can be determined as described for Fig. 1 from water meter data for temperate regions without year-round irrigation. Dividing the volume of water estimated to be used on the landscape by the irrigated area gives the depth of applied water. This depth of water can then be compared with needs derived from the base plant water needs plus the amount needed to correct for system nonuniformity.