ARIZONA COOPERATIVE EXTENSION
THE UNIVERSITY OF ARIZONA
College of Agriculture and Life Sciences
AZ1381 06/06

Evaluation of ADWR Water Duties for Large Turf Facilities

Introduction

The Arizona Department of Water Resources (ADWR) limits the amount of groundwater large turf facilities (LTFs; ≥10 acres of turf) may use for irrigation in the Tucson and Phoenix Active Management Area (AMAs). Current ADWR regulations effectively cap groundwater use at 4.6 and 4.9 acre-feet per acre per year (af/a/yr) for turfgrass grown within the Tucson and Phoenix AMAs, respectively. Operators of LTFs have expressed concerns that ADWR regulations (water duties) are too stringent and provide insufficient water to: 1) produce acceptable quality turfgrass and 2) sustain leaching requirements necessary to avoid problems with salinity. University of Arizona research appears to support the concerns of LTFs. Brown et al. (2001) conducted a three-year study to develop crop coefficients (Kcs) for the typical desert turf system consisting of bermudagrass in summer and overseeded ryegrass in winter. Crop coefficients are adjustment factors that when used in conjunction with weather-based estimates of reference evapotranspiration (ETo) provide accurate estimates of turf water use (ETt). When the Kcs developed by Brown et al. were applied to long term averages of ETo available from the Arizona Meteorological Network (AZMET), annual ETt was projected to approach 4.9 af/a/yr in both the Tucson and Phoenix AMAs, indicating annual evaporative demand equals (Phoenix) or exceeds (Tucson) the water duties in the two AMAs. If these projections prove to be true, operators of LTFs would have to rely on precipitation (P) to offset soil water deficits resulting from the duties and facilitate deep percolation required to remove (leach) salts from the turf root zone.

In an effort to help clarify this issue, a study was initiated on the large weighing lysimeters located at the University of Arizona Karsten Turf Research Facility in Tucson. The objective of the three-year study was to determine if the ADWR turf water duty for the Tucson AMA provided sufficient water to: 1) sustain acceptable quality turfgrass and 2) support acceptable levels of leaching when turfgrass was irrigated using the Kcs recommended by Brown et al. This report first summarizes the results of this Tucson study, then concludes with a discussion of how to translate the study results to LTFs in both the Tucson and Phoenix AMAs.

Materials & Methods

The study was conducted between 1 October 1997 and 30 September 2000 at the University of Arizona Karsten Desert Turf Research Facility located in Tucson, AZ. Two large weighing lysimeters, centrally located within a 5 acre (2.2 ha) field research area, were used to monitor the water balance of a desert turf system, consisting of 'Tifway' bermudagrass in summer and overseeded 'Froghair' intermediate ryegrass in winter. The lysimeters are cylindrical in shape with diameter and depth equal to 8.2′ (2.5 m) and 13.2′ (4 m), respectively. The lysimeter soil is uniform with depth and is classified as a Vinton fine sand.

Each lysimeter rests on a modified truck scale which is connected to a load cell. An automated data logger is used to monitor the output signals from the load cells. The data logger is programmed to sample load cell outputs every 2 seconds and compute 10-minute averages of lysimeter mass. Scale accuracy is about +/- 0.66 lb (300 g) which is equivalent to a depth of 0.0024″ (0.06 mm) of water. Water draining to the bottom of the lysimeters is removed using a vacuum pump that is attached to a series of suction candles. Drainage water is stored in onboard tanks until removed and quantified by lysimeter technicians.

A dual irrigation system serves the lysimeter area, allowing the use of tertiary effluent or potable groundwater for irrigation. One lysimeter was irrigated with effluent while the other was irrigated with groundwater. The quality of the two water sources differed in two important categories: electrical conductivity (0.4 dS/m for groundwater and 1.0 dS/m for effluent) and total nitrogen (N; 3 mg N per liter for groundwater and 13 mg N per liter for effluent). Irrigation was supplied to each lysimeter using low trajectory Rain Bird 1804 Series pop-up sprinkler heads with head spacing set at 12′ [3.45 m (square spacing)]. The precipitation rate of the sprinkler system averaged 2.09″/hr (53 mm/hr) and irrigation non-uniformity averaged 0.93 using Christiansen's Coefficient of Uniformity (CU; Christiansen, 1942). Irrigation was regulated using a Rain Bird Maxi-5 irrigation control system and its attendant weather station. The Maxi-5 weather station generates estimates of ETo which must be multiplied by 0.90 to make them equivalent to ETo as computed by the Arizona Meteorological Network (ETоa). Irrigation was applied

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, James A. Christenson, Director, Cooperative Extension, College of Agriculture & Life Sciences, The University of Arizona.

daily in the predawn hours with amount set equal to 72% of ETοa in winter (Nov-May) and 77% of ETοa in summer (Jun-Oct). A different irrigation regime was implemented during the period of overseed establishment which occurred during the latter half of October in each year. During this two-week establishment period, light irrigations were applied 5-7 times per day to maintain a moist surface and encourage rapid and uniform germination. The irrigation rate during the period of overseed establishment period averaged ~0.20"/dy (5.08 mm/dy) which was ~102% of ETοa.

During periods of rainfall, irrigation amount was determined by subtracting rainfall from ETοa during the previous 24-hr period. Irrigations were eliminated on days when rainfall exceeded ETοa. Rainfall amounts in excess of ETοa were assumed stored in the soil and used to offset future evaporative demand with the proviso that stored rainwater could never exceed 0.5" (12.7 mm). Irrigation was resumed once this stored supply of rainwater was depleted.

The turf received N at a rate of approximately 31 lb/a/month (35 kg/ha/month) from irrigation water and chemical fertilizer (NH_4SO_4 in liquid form). Monthly applications of fertilizer N were adjusted based on the irrigation rate and N concentration in the irrigation water. Potassium (K) and phosphorus (P) were applied every six weeks at rates of 21.6 and 14.4 lb/a (24 and 16 kg/ha), respectively. Granular K_2SO_4 (0-0-52) and $Ca(H_2PO_4)_2$ (0-20-0) served as fertilizer sources for K and P, respectively. The turf was mowed two to three times per week during the summer and one to two times per week during the winter with a reel mower. Mowing height was set at 0.875" (22 mm) in summer and 1.0" (25 mm) in winter.

Turf evapotranspiration (ETt) was determined daily in units of mm/d for the 24-hr period ending at midnight using the soil water balance equation:

$$ETt = I + P - S - D \quad (1)$$

where I is the amount of irrigation, P is precipitation, S is the daily change in soil moisture storage and D is the amount of drainage. Irrigation was applied on most days during a 15-minute period before sunrise. The gain in lysimeter mass during this period was set equal to the amount of irrigation (evaporation assumed negligible). Precipitation was measured in two ways: 1) from the increase in lysimeter mass during precipitation events, and 2) using a tipping bucket rain gauge. The greater of the two precipitation measurements was set equal to P. The change in lysimeter mass for the day was assumed equal to S, and D was obtained by multiplying the volume of drainage water in liters (L) by a specific gravity of 1.0 kg/L.

Tifway bermudagrass, established on the lysimeters and the surrounding 10000 ft^2 (0.09 ha) area by sprigging during the summer of 1994, served as the turf surface during the summers of 1998,1999 and 2000. Froghair intermediate ryegrass was overseeded into the bermudagrass at a rate of 600 lb/a (670 kg/ha) on a pure live seed basis in mid-October of each year and served as the turf surface during the winter. Dates of overseeding were 13,15 and 13 October of 1997, 1998 and 1999, respectively.

Results & Discussion

The lysimeter facility allows one to accurately quantify the water balance of the standard desert turf system consisting of bermudagrass in summer and overseeded ryegrass in winter. Components of the water balance include precipitation and irrigation as inputs, and evapotranspiration (ETt) and deep percolation (drainage) as losses (Fig. 1). The difference between inputs and losses represents the change in soil moisture storage over the course of the year. For this study, a "turf year" begins on 1 Oct and concludes on 30 Sep of the following year. The abbreviations TY98, TY99, and TY00 are used to designate the periods 1 Oct 1997 - 30 Sep 1998, 1 Oct 1998 - 30 Sep 1999, and 1 Oct 1999 - 30 Sep 2000, respectively. Tables 1-3 provide a numerical summary of the water balance components by year while Figures 2-4 present these same results in a graphical format. Average values of the water balance components over the course of the study (3 years) are provided in Table 4 and Figure 5. The tables provide the components for the individual lysimeters as well as average values of each component (mean from both lysimeters). The figures simply present the average values for each component.

Turf Performance

Turf performance over the period of study was rated as acceptable or higher with the exception of some finite periods of weaker turf performance associated with spring and fall transition. Early June proved to be the period where poor turf performance was observed in the spring. Spring transition is often delayed at the study location due to cool night temperatures. Poorer turf performance was also evident in late October and early November during the period of overseed establishment. Given that turf performance is commonly inferior during these spring and fall transition periods, it was concluded that the irrigation regime utilized in this study did not negatively impact turf performance.

Turf Evapotranspiration

Turf ET varied from 56.2" (1428 mm) in TY98 to 62.4" (1584.4 mm) in TY00 and averaged 59.2"/yr (1504 mm/yr) over the period of study. The ETt values recorded from the two lysimeters were remarkably consistent and varied by less than 2"/yr (50.8 mm) over the course of the study (see Tables 1-3). Turf ET exceeded the Tucson water duty (55.2"/yr or 1402 mm) in each year of the study, providing clear evidence that the quantity of water available from the Tucson duty is insufficient in most years to fully offset evaporative demand. Over the course of this study, ETt exceeded the water duty by an average of 4.0"/yr (101.6 mm) which represents the average water deficit that must be made up from precipitation. Table 5 provides ETt, ETοa and the ratio of ETt to ETοa for each year of the study.

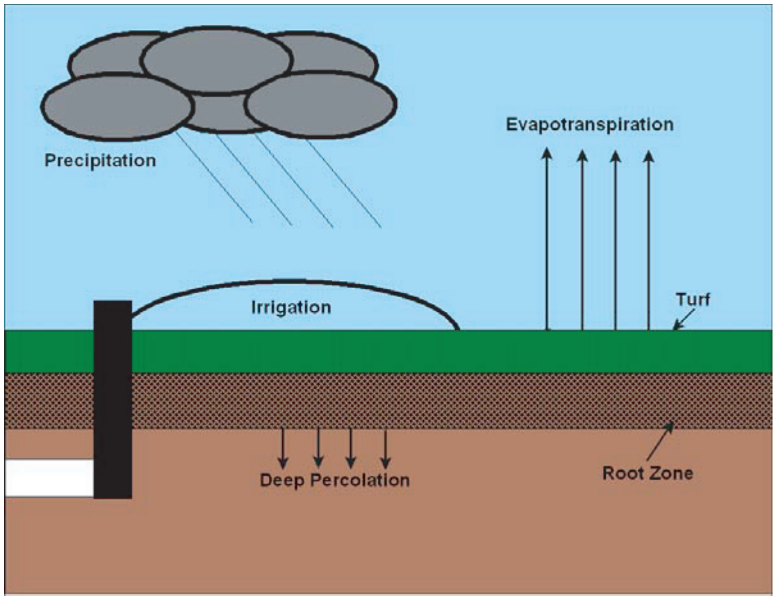

Figure 1. Graphical depiction of the soil water balance for a turf system. Precipitation and irrigation serve as inputs of water into the system. Water is lost from the system through deep percolation and turf evapotranspiration.

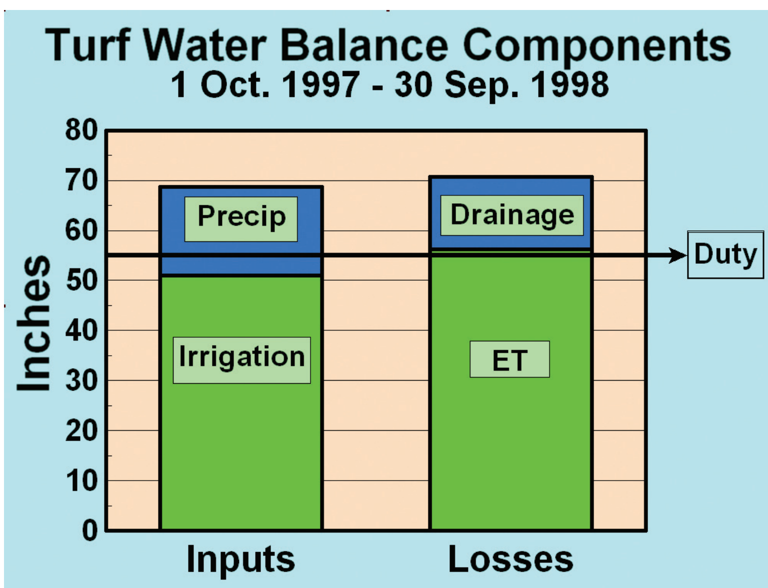

Figure 2. Components of the soil water balance for TY98. The arrow indicates the quantity of water provided in ADWR's water duty for LTFs in Tucson.

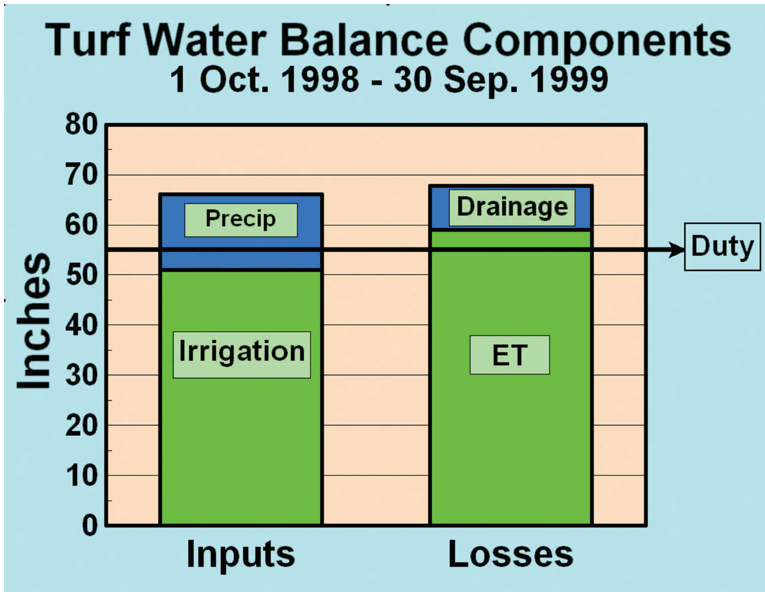

Figure 3. Components of the soil water balance for TY99. The arrow indicates the quantity of water provided in ADWR's water duty for LTFs in Tucson.

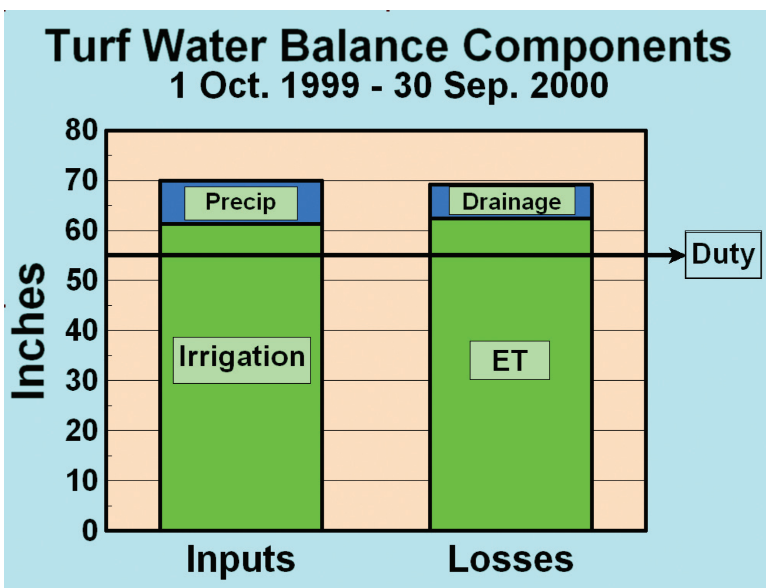

Figure 4. Components of the soil water balance for TY00. The arrow indicates the quantity of water provided in ADWR's water duty for LTFs in Tucson.

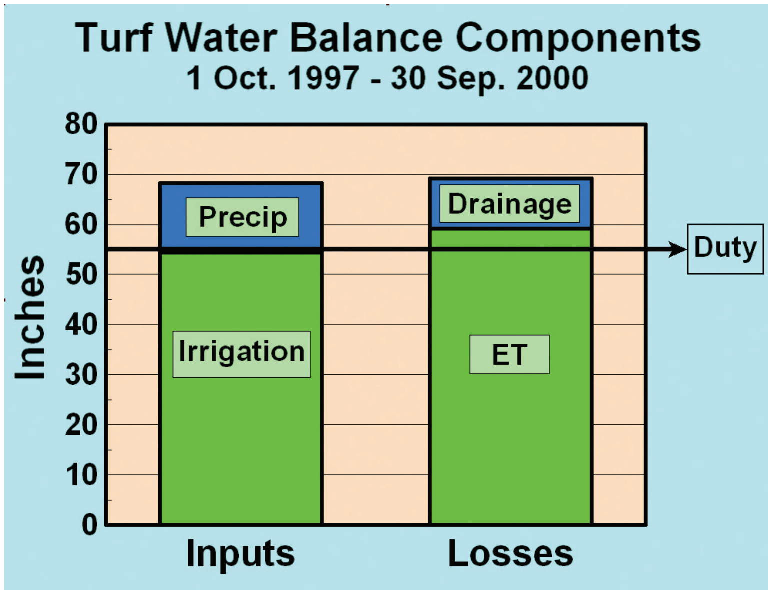

Figure 5. Components of the soil water balance for the period 1 Oct 1997 to 30 Sep 2000. The arrow indicates the quantity of water provided in ADWR's water duty for LTFs in Tucson.

Table 1. Summary of turf water balance components for TY98. Individual components consisting of irrigation, precipitation, drainage, ETt, and change in soil moisture storage are presented in units of inches and mm for each lysimeter. Mean values for each component are presented in the last two columns of the table and represent the average of the two lysimeters.

Components of Water Balance	LYSIMETER IRRIGATED WITH...				Mean Values	
	Groundwater		Effluent			
Inputs of Water	In	mm	In	mm	In	mm
Irrigation	51.0	1296.7	50.9	1292.6	51.0	1294.6
Precipitation	17.6	448.4	17.8	451.0	17.7	449.7
Total Inputs	68.7	1745.1	68.6	1743.6	68.7	1744.3
Losses of Water						
Drainage	16.4	417.6	12.5	317.0	14.5	367.3
ETt	55.2	1402.5	57.2	1453.6	56.2	1428.0
Total Losses	71.7	1820.1	69.7	1770.6	70.7	1795.3
Change in Storage	-3.0	-75.0	-1.1	-27.0	-2.0	-51.0

Table 2. Summary of turf water balance components for TY99. Individual components consisting of irrigation, precipitation, drainage, ETt and change in soil moisture storage are presented in units of inches and mm for each lysimeter. Mean values for each component are presented in the last two columns of the table and represent the average of the two lysimeters.

Components of Water Balance	LYSIMETER IRRIGATED WITH...				Mean Values	
	Groundwater		Effluent			
Inputs of Water	In	mm	In	mm	In	mm
Irrigation	51.9	1319.3	50.1	1272.8	51.0	1296.0
Precipitation	15.2	384.9	15.1	384.5	15.1	384.7
Total Inputs	67.1	1704.2	65.2	1657.3	66.2	1680.8
Losses of Water						
Drainage	10.2	257.9	7.4	187.2	8.8	222.6
ETt	59.1	1500.0	59.0	1499.5	59.0	1499.8
Total Losses	69.3	1757.9	66.4	1686.7	67.8	1722.4
Change in Storage	-2.2	-53.7	-1.2	-29.4	-1.6	-41.6

Table 3. Summary of turf water balance components for TY00. Individual components consisting of irrigation, precipitation, drainage, ETt and change in soil moisture storage are presented in units of inches and mm for each lysimeter. Mean values for each component are presented in the last two columns of the table and represent the average of the two lysimeters.

Components of Water Balance	LYSIMETER IRRIGATED WITH...				Mean Values	
	Groundwater		Effluent			
Inputs of Water	In	mm	In	mm	In	mm
Irrigation	61.6	1563.6	61.1	1552.6	61.3	1558.1
Precipitation	8.6	218.4	8.7	220.0	8.6	219.2
Total Inputs	70.2	1782.0	69.8	1772.6	70.0	1777.3
Losses of Water						
Drainage	7.7	196.4	5.6	142.7	6.7	169.6
ETt	61.9	1573.1	62.8	1595.6	62.4	1584.4
Total Losses	69.7	1769.5	68.4	1738.3	69.1	1754.0
Change in Storage	0.5	12.5	1.4	34.3	0.9	23.3

Table 4. Summary of turf water balance components for the three year period from 1 October1997 to 30 September 2000. Individual components consisting of irrigation, precipitation, drainage, ETt and change in soil moisture storage are presented in units of inches and mm for each lysimeter. Mean values for each component are presented in the last two columns of the table and represent the average of the two lysimeters.

Components of Water Balance	LYSIMETER IRRIGATED WITH...				Mean Values	
	Groundwater		Effluent			
Inputs of Water	In	mm	In	mm	In	mm
Irrigation	54.8	1393.2	54.0	1372.7	54.4	1383.0
Precipitation	13.8	350.6	13.8	351.8	13.8	351.2
Total Inputs	68.6	1743.8	67.9	1724.5	68.3	1734.2
Losses of Water						
Drainage	11.4	290.6	8.5	215.6	10.0	253.1
ETt	58.7	1491.9	59.7	1516.2	59.2	1504.0
Total Losses	70.2	1782.5	68.2	1731.9	69.2	1757.2
Change in Storage	-1.5	-38.7	-0.3	-7.4	-0.9	-23.0

Table 5. Turf evapotranspiration (ETt), reference evapotranspiration (ETоa), and the ratio of ETt to ETоa for TYs 98, 99, and 00.

YEAR	ETt		ETоa		Ratio (ETt:ETоa)
	In	mm	In	mm	
TY98	56.2	1427.5	74.5	1892.3	0.75
TY99	59.0	1498.6	78.4	1991.4	0.75
TY00	62.4	1585.0	82.8	2103.1	0.75
Mean	59.2	1503.7	78.6	1996.4	0.75

While annual values of ETt and ETo a differed by as much as 6.2″ (157.5 mm) and 8.3″ (210.8 mm), respectively, the ratio of ETt to ETo a averaged a consistent 0.75. This ratio is by definition a crop coefficient; thus, it appears that 0.75 serves as an excellent annual Kc value for a bermudagrass turf system that is overseeded in winter with ryegrass.

Amount of Applied Irrigation and Precipitation

The amount of irrigation water applied ranged from 51.0″ (1296 mm) in both TY98 and TY99 to 61.3″ (1558.1 mm) in TY00 and averaged 54.4″ (1383 mm) over the period of study. During two years of the study and on average over the course of the study, the amount of irrigation water applied was less than the water duty of 55.2″/yr (1402 mm). Similar amounts of irrigation water were applied to each lysimeter during individual turf years and over the course of the study (Tables 1-4). The large difference in the level of irrigation water applied between TYs 98 and 99, and TY00 results from differing levels of precipitation. Above normal precipitation was recorded at the study site in both TYs 98 and 99 and helped to lower irrigation demand. In contrast, precipitation was below normal during TY00 when irrigation demand was highest. It is also interesting to note the impact of precipitation on evaporative demand as indicated by ETo a. ETo a totaled 74.5″ (1892.3 mm), 78.4″ (1991.4 mm) and 82.8″ (2103.1 mm) during TYs 98, 99 and 00 when precipitation totaled 17.7″ (449.7 mm), 15.1“ (384.7 mm) and 8.6″ (219.2 mm), respectively. A more in-depth evaluation of the relationship between precipitation and ETo a was performed using 15-17 years of data available from AZMET. This analysis confirmed an inverse relationship between annual values of precipitation and ETo a exists in both the Tucson and Phoenix areas, suggesting precipitation impacts the amount of applied irrigation water in both a direct and indirect manner. The direct impact is obvious as precipitation replaces water that would otherwise come from irrigation. The less obvious indirect impact is that precipitation with its associated cloudiness and higher humidity lowers ETo a.

Drainage and Leaching Fractions

Drainage or water lost to deep percolation serves as the final important component of the water balance. Drainage is required to minimize the accumulation of soluble salts in the root zone and thereby avoid salinity problems. Drainage ranged from 6.7″ (169.6 mm) during TY00 to 14.5″(367.3 mm) during TY98 and averaged 10.0″/yr (253.1 mm/yr) over the course of the study. The high rates of drainage in TY98 appear to include some residual drainage from the previous study where higher rates of irrigation maintained soil moisture at higher levels. Changes in stored soil moisture suggest this residual drainage totaled -2.0″ (-51.0 mm) in TY98 (see next section).

Proper assessment of drainage requires one to convert drainage values to leaching fractions and then assess for a given turfgrass and irrigation water quality whether the leaching fraction is adequate. The leaching fraction is defined as the fraction of applied water that passes through the entire root zone and is lost to deep percolation. Leaching fractions for TYs 98, 99, and 00 were 0.21, 0.13, and 0.096, respectively, and averaged 0.15 during the entire period of study. Bermudagrass is rated as tolerant to salinity while ryegrass is rated as moderately tolerant; both grasses therefore have a low leaching requirement when irrigated with good quality water. The electrical conductivity of the irrigation water used in this study averaged 0.4 dS/m for the lysimeter irrigated with groundwater and 1.0 dS/m for the lysimeter irrigated with effluent. The resulting leaching requirements for bermudagrass irrigated with groundwater and effluent were 0.012 and 0.03, respectively. The leaching requirements for ryegrass equal 0.014 and 0.037 when using groundwater and effluent, respectively. Leaching was clearly adequate to avoid salinity problems in this study.

Changes in Soil Moisture Storage

Stored soil moisture remained fairly constant over the course of the study. Over the three years of study, moisture storage declined 0.9″ (-23 mm). Annual changes in soil moisture storage ranged from -2.0″ in TY98 to +0.9″ in TY00. It is important to realize that these changes in soil moisture pertain to the entire lysimeter soil profile which has a depth of 12.3′ (3.75 m). The total amount of soil moisture storage in the lysimeter profile at field capacity is ~17.7″ (450 mm); thus, the annual changes in soil moisture storage represent no more than 12% of soil moisture at field capacity. The largest decline in soil moisture storage occurred at the beginning of TY98 and may reflect some residual drainage from the previous study where higher rates of irrigation maintained soil moisture at higher levels.

Translation of Results to Large Turf Facilities

The results presented in the previous section of this report appear to provide good evidence that ADWR water duties when combined with normal to above normal levels of precipitation provide sufficient water to support year round green turf while preventing future problems associated with excessive soil salinity. However, such a conclusion may be called into question when one attempts to transfer these results to LTFs. One important issue impacting the translation of these results to LTFs pertains to the procedures used to quantify the amount of applied irrigation water in this study. The daily gain in lysimeter mass during the brief (~15 minute) early morning irrigation window was used as the daily irrigation rate. In effect, this methodology measures the amount of water reaching the turf, not necessarily the total amount of water used in the irrigation process. This is an important distinction since ADWR monitors water used at the well head or diversion point, not water that reaches the turf. The amount of irrigation water reaching turf is always less than the water used at the well head or diversion point due to system leaks, evaporation while the water is in transit from the irrigation head to the turf, and drift off target (to non-turf areas). These losses of water along with other losses associated with runoff and deep percolation represent the main factors impacting irrigation efficiency which can be defined as the percentage of total applied water that is put to beneficial use.

Another irrigation related factor that may impact the translation of these results to LTFs relates to irrigation non-uniformity. No irrigation system applies water over an area in a perfectly uniform manner. This non-uniformity is assessed via an irrigation audit which involves setting out an array of catch cans prior to an irrigation event to quantify the variation in precipitation resulting from system operation. Irrigation audits were run on the lysimeter irrigation systems and non-uniformity averaged 0.93 using Christiansen's Uniformity Coefficient (Christiansen, 1942). While it is common to increase irrigation run time to offset non-uniform irrigation, such a strategy was not employed in this study. Given that we did not observe any serious problems with turf performance in this study, it is tempting to assume that the results of this study are valid for irrigation systems exhibiting CU values approaching 0.90. However, it is questionable whether one can directly extrapolate the relationship between turf performance and irrigation non-uniformity found in small plots such as the lysimeters to LTFs. One reason such an extrapolation is unreasonable is that the high CU values obtained in this study are difficult (if not impossible) to replicate for LTF irrigation systems. A second reason such an extrapolation is questionable is that in small plots, turf root systems may be able to exhibit sufficient horizontal growth to offset the apparent limitations associated with non-uniform irrigation. For example, if 10% of the lysimeter received insufficient irrigation to support optimal growth, the total area under watered would be 5.3 ft^2 (0.5 m^2). If the entire under watered area was located in one square block of turf, the dimension of the block would be 2.3' x 2.3'(0.7 m x 0.7 m). Presumably, the turf in this small block could extend its roots outward in an horizontal manner and pick up water from adjacent areas receiving higher watering rates and turf performance would not greatly suffer. If however this same scenario is used on a 4-acre golf fairway, the area under watered is 17424 ft^2. If this under watered area were divided into 10 blocks of equal size (174.2 ft^2), then the dimensions of the block would be 13.2' x 13.2' (4 m x 4 m). In this case, it is unlikely turf in the middle of the block would be able to extend its root system into adjacent areas for supplemental water and thus would remain stressed and exhibit a lower visual quality.

One final issue that may impact translation of study results to LTFs involves topography and soil type. The lysimeter facility provides an experimental setup consisting of a level turf surface combined with a soil that supports a high water infiltration rate. This combination provides a best case scenario for infiltration of both irrigation water and precipitation. Often, LTFs must contend with one or both of the following features: 1) complex topographical features that include areas with steep slopes, and 2) soils with either fine textured or compacted surface layers that do not support high rates of water infiltration. These real world topographical and soil infiltration characteristics will lead to higher rates of runoff during irrigation and rainfall events with the overall impact being a reduction in available water supply for turf.

The previous paragraphs present what appears to be a conflict between what the study results indicate is possible in small plot studies versus the practical realities of translating these results to LTFs. To help clarify this conflict, a simple model was devised to assess the overall water balance of a unit area of turf in a LTF setting in the Tucson and Phoenix areas. The model estimates the net water balance of a turf area subjected to three scenario climate regimes (dry, normal, and wet) when irrigation system performance and runoff limit the amount of water that infiltrates the soil supporting the turfgrass. Input data required to run the model are presented in Table 6 and include precipitation, ETt, and the amount of water available from ADWR water duties. Wet and dry years were assigned precipitation values equal to 133% and 67% of normal, respectively. Annual values of ETt were assumed equal to 75% of ETоa. ETоa for the three precipitation regimes was determined from least squares regression lines relating annual ETоa to annual precipitation for the Tucson and Phoenix areas.

The model projects the net water balance for the turf system when various percentages of the available water supply (irrigation water and precipitation) infiltrate the soil supporting the turf. Runoff from precipitation events was allowed to range from 0 - 50% of the annual precipitation amount in increments of 10%. The model assumes a LTF applies 100% of its allotted duty through the irrigation system but varies the percentage of this water that infiltrates into the unit area of turf from 75-100% in 5% increments. The output from the model is the net water balance (WB) for the turf system which is defined as the amount of irrigation (I) and precipitation (P) water that enters the turf system minus the ETt for the year:

$$WB = (f_i{*}I + f_p{*}P) - ETt \qquad (2)$$

where:

WB is the annual water balance of the unit turf area (in or mm)

f_i is the fraction of irrigation water duty that infiltrates into the turf area

I is the amount of water applied via irrigation (ADWR water duty, in or mm)

f_p is the fraction of precipitation that infiltrates into the turf area

P is the annual amount of precipitation (in or mm)

ETt is the annual rate of turf evapotranspiration (in or mm)

Positive water balance values indicate a surplus of available water. This surplus water, if actually applied, would be lost to deep percolation and thus assist with control of soil salinity. Negative balances indicate an insufficient water supply which may generate less acceptable turf and inadequate leaching to prevent the buildup of soil salinity.

Table 6. Input data used to model turf water balances at LTFs in the Tucson and Phoenix AMAs.

Location	Water Duty		Precipitation Regime						Turf Evapotranspiration (ETt)					
			Dry		Normal		Wet		Dry		Normal		Wet	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
Tucson	55.2	1402	8	203	12	305	16	404	59.4	1509	57.3	1455	55.2	1402
Phoenix	58.8	1494	5	127	7.5	190	10	254	58.3	1481	57.6	1463	56.9	1445

Turf Water Balance Estimates: Tucson

The results of this modeling effort for the Tucson area are presented in Table 7. Model scenarios that generated surpluses in the water balance are presented in blue text while scenarios generating deficits in the water balance are presented in red text. One immediate observation from Table 7 is the impact of precipitation on the water balance of the turf. During dry years, the water balance of the turf system is negative under nearly all water supply scenarios with the exception of situations where a LTF irrigation system can deliver 95-100% of the water duty to the turf. As indicated earlier in this report, evaporation, drift off target, runoff and leaks ensure that a facility will not be able to apply 100% of the water duty to the turf system.

The water balance improves substantially when precipitation is normal for the year. LTFs irrigation systems that can deliver a high percentage of the water duty to the turf and are not subjected to severe problems with runoff would be able to maintain a positive water balance in years with near normal precipitation. Facilities that can not deliver a high fraction of the water duty to the turf or have significant problems with infiltration would likely encounter a soil moisture deficit in normal years.

The soil water balances are generally positive in wet years. Presumably, most LTFs could maintain a positive water balance in these wet years. Only LTFs with very difficult infiltration problems or problem irrigation systems would be expected to run a deficit in wet years.

Turf Water Balance Estimates: Phoenix

The results of this modeling effort for the Phoenix area are presented in Table 8. The scenario precipitation regimes did not impact the Phoenix turf water balance estimates to the same degree as was observed for the Tucson area. Two factors explain why the Phoenix estimates are not as responsive to the precipitation regimes: 1) the difference in precipitation between regimes was just 2.5" compared with 4.0" for Tucson; and 2) the impact of annual precipitation on ETt is not as large in Phoenix as in Tucson. Nevertheless, the trend at Phoenix still follows the general trend observed for Tucson. During dry years, only LTFs with irrigation systems that can deliver 95-100% of the water duty would be able to maintain a positive water balance.

The additional 2.5" of precipitation expected in a normal year in Phoenix improves the water balances only slightly. LTFs with irrigation systems that can deliver 90% of the water duty to the turf and are not prone to severe runoff problems would be added to the group of LTFs that could sustain positive turf water balances. Wet years produce further improvements in turf water balances, but the results suggest LTFs that can not deliver in excess of 80% of the water duty to the turf, or are subject to severe problems with infiltration would continue to run a water deficit in wet years.

It is important to note when examining the results of this modeling exercise that the model does not directly address the issue of irrigation non-uniformity. The results are for turf areas receiving irrigation at the mean precipitation rate of the irrigation system (some fraction of 4.6 (Tucson) or 4.9 (Phoenix) af/a/yr). In reality, approximately half the area would receive more than the mean precipitation rate and would produce a more positive water balance while the other half of the area will receive less than this mean rate, thus generating a less favorable balance. A common engineering approach to this non-uniformity problem is to obtain a measure of non-uniformity from an irrigation audit and then increase the irrigation rate in a manner that minimizes the amount of area that is under watered. This approach generates very high levels of water use and often produces excessive wetness which can limit the usefulness or "playability" of turf. Many sports related LTFs do not use this approach to address irrigation non-uniformity because of: 1) playability issues and 2) water supply limitations (system capacity and/or water duties). Instead, these facilities "pull hoses" and hand water or extend run times on selected heads or zones to add moisture to drier areas. The water used in such "unscheduled" irrigations would count against the water duty and would lower the amount of water that could be applied via the irrigation system. If for example 5% of a LTF's total water duty was applied via unscheduled irrigations, then only 4.37 af/a (52.4" or 1332mm in Tucson) to 4.66 af/a (55.9" or 1419 mm in Phoenix) could be applied

Table 7. Projected turf water balances in inches and millimeters for LTFs in the Tucson AMA, assuming: 1) the indicated percentages of the annual water duty infiltrate the soil and 2) the indicated percentages of annual precipitation are lost to runoff. Results assume a LTF applies its entire water duty each year. See Table 6 for assumptions regarding annual rates of turf evapotranspiration (ETt) and precipitation. Positive water balances are presented in blue text; negative water balances are presented in red text.

Projected Turf Water Balances: Tucson

% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Dry Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	3.8	97.5	3.0	77.1	2.2	56.7	1.4	36.3	0.6	15.8	-0.2	-4.6
95	1.1	27.4	0.3	7.0	-0.5	-13.4	-1.3	-33.8	-2.1	-54.3	-2.9	-74.7
90	-1.7	-42.7	-2.5	-63.1	-3.3	-83.5	-4.1	-103.9	-4.9	-124.4	-5.7	-144.8
85	-4.4	-112.8	-5.2	-133.2	-6.0	-153.6	-6.9	-174.0	-7.7	-194.5	-8.5	-214.9
80	-7.2	-182.9	-8.0	-203.3	-8.8	-223.7	-9.6	-244.1	-10.4	-264.6	-11.2	-285.0
75	-10.0	-253.0	-10.8	-273.4	-11.6	-293.8	-12.4	-314.2	-13.2	-334.7	-14.0	-355.1
% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Normal Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	9.8	249.9	8.6	219.5	7.4	189.0	6.2	158.5	5.0	128.0	3.8	97.5
95	7.1	179.8	5.9	149.4	4.7	118.9	3.5	88.4	2.3	57.9	1.1	27.4
90	4.3	109.7	3.1	79.2	1.9	48.8	0.7	18.3	-0.5	-12.2	-1.7	-42.7
85	1.6	39.6	0.4	9.1	-0.8	-21.3	-2.0	-51.8	-3.2	-82.3	-4.4	-112.8
80	-1.2	-30.5	-2.4	-61.0	-3.6	-91.4	-4.8	-121.9	-6.0	-152.4	-7.2	-182.9
75	-4.0	-100.6	-5.2	-131.1	-6.4	-161.5	-7.6	-192.0	-8.8	-222.5	-10.0	-253.0
% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Wet Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	16.0	405.4	14.4	364.8	12.8	324.3	11.2	283.8	9.6	243.2	8.0	202.7
95	13.2	335.3	11.6	294.7	10.0	254.2	8.4	213.7	6.8	173.1	5.2	132.6
90	10.4	265.2	8.8	224.6	7.2	184.1	5.7	143.6	4.1	103.0	2.5	62.5
85	7.7	195.1	6.1	154.5	4.5	114.0	2.9	73.5	1.3	32.9	-0.3	-7.6
80	4.9	125.0	3.3	84.4	1.7	43.9	0.1	3.4	-1.5	-37.2	-3.1	-77.7
75	2.2	54.9	0.6	14.3	-1.0	-26.2	-2.6	-66.8	-4.2	-107.3	-5.8	-147.8

Table 8. Projected turf water balances in inches and millimeters for LTFs in the Phoenix AMA, assuming: 1) the indicated percentages of the annual water duty infiltrate the soil and 2) the indicated percentages of annual precipitation are lost to runoff. Results assume a LTF applies its entire water duty each year. See Table 6 for assumptions regarding annual rates of turf evapotranspiration (ETt) and precipitation. Positive water balances are presented in blue text; negative water balances are presented in red text.

Project Turf Water Balances: Phoenix

% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Dry Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	5.5	140.2	5.0	127.4	4.5	114.6	4.0	101.8	3.5	89.0	3.0	76.2
95	2.6	65.5	2.1	52.7	1.6	39.9	1.1	27.1	0.6	14.3	0.1	1.5
90	-0.4	-9.1	-0.9	-21.9	-1.4	-34.7	-1.9	-47.5	-2.4	-60.4	-2.9	-73.2
85	-3.3	-83.8	-3.8	-96.6	-4.3	-109.4	-4.8	-122.2	-5.3	-135.0	-5.8	-147.8
80	-6.2	-158.5	-6.7	-171.3	-7.2	-184.1	-7.8	-196.9	-8.3	-209.7	-8.8	-222.5
75	-9.2	-233.2	-9.7	-246.0	-10.2	-258.8	-10.7	-271.6	-11.2	-284.4	-11.7	-297.2

% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Normal Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	8.6	219.5	7.9	200.6	7.2	181.7	6.4	162.8	5.7	143.9	4.9	125.0
95	5.7	144.8	5.0	125.9	4.2	107.0	3.5	88.1	2.7	69.2	2.0	50.3
90	2.8	70.1	2.0	51.2	1.3	32.3	0.5	13.4	-0.2	-5.5	-1.0	-24.4
85	-0.2	-4.6	-0.9	-23.5	-1.7	-42.4	-2.4	-61.3	-3.2	-80.2	-3.9	-99.1
80	-3.1	-79.2	-3.9	-98.1	-4.6	-117.0	-5.4	-135.9	-6.1	-154.8	-6.8	-173.7
75	-6.1	-153.9	-6.8	-172.8	-7.5	-191.7	-8.3	-210.6	-9.0	-229.5	-9.8	-248.4

% of Duty Infiltrating Soil	% of Precipitation Lost to Runoff (Wet Year)											
	0		10		20		30		40		50	
	In	mm	In	mm	In	mm	In	mm	In	mm	In	mm
100	11.9	301.8	10.9	276.5	9.9	251.2	8.9	225.9	7.9	200.6	6.9	175.3
95	8.9	227.1	7.9	201.8	6.9	176.5	6.0	151.2	5.0	125.9	4.0	100.6
90	6.0	152.4	5.0	127.1	4.0	101.8	3.0	76.5	2.0	51.2	1.0	25.6
85	3.1	77.7	2.1	52.4	1.1	27.1	0.1	1.8	-0.9	-23.5	-1.9	-48.8
80	0.1	3.0	-0.9	-22.3	-1.9	-47.5	-2.9	-72.8	-3.9	-98.1	-4.9	-123.4
75	-2.8	-71.6	-3.8	-96.9	-4.8	-122.2	-5.8	-147.5	-6.8	-172.8	-7.8	-198.1

through the irrigation system. Because the hand watering would be targeted for areas receiving less than the mean precipitation rate, the water balances presented in Tables 7 & 8 would be less favorable by an amount approaching 2.5" (64 mm).

Concluding Remarks

The results of this study provide additional evidence that ADWR turf water duties provide significant challenges for LTFs that wish to maintain a year round green turf surface. Turf ET over the course of the three year study averaged 59.2"/yr (1504 mm/yr) or 4"/yr (101.6 mm/yr) above the current water duty for the Tucson area. The amount of water supplied via irrigation averaged 54.4"/yr (1383 mm/yr)) or 0.8"/yr (20.3 mm/yr) less that the ADWR water duty. Precipitation supplied the additional water required to: 1) prevent to development soil moisture deficits and 2) support deep percolation required to minimize the buildup of salinity. While the study results suggest that ADWR water duties supply adequate water to sustain year round turf in the Tucson area, when the study results are adjusted to accommodate runoff during precipitation events and the inefficiencies in LTF irrigation systems (e.g., leaks, evaporation, drift, non-uniformity), precipitation becomes the critical factor that determines whether the ADWR water duty is adequate to support year round turf. Results from a simple water balance model suggest the water duties will prove inadequate for nearly all Tucson and Phoenix LTFs in dry years. The adequacy of the water duties in normal years appears to be "facility dependent" in both locations. LTFs with efficient irrigation systems and soils that support high rates of infiltration could get by with the water duty in years with normal precipitation. Facilities with less efficient irrigation systems and/or soil with poor infiltration characteristics would likely find the duties inadequate in normal years. In wet years, modeling efforts indicate the water duties should be adequate for most LTFs in the Tucson area, but remain "facility dependent" in the Phoenix area.

Future Research Needs

The modeling effort used to translate the results of this study to LTFs reveals several important issues that must be resolved to make a more definitive statement regarding the adequacy of ADWR water duties for turfgrass. One issue pertains to the fraction of pumped or diverted water that reaches the turf surface in a well managed and maintained irrigation system. As stated earlier, leaks, drift off target and evaporation (while water is in transit from the irrigation head to the turf) are the potential causes for such losses. The modeling results in Tables 7 and 8 indicate such losses play a critical role in determining the adequacy of the water duties. Results from some preliminary UA studies and comments from other researchers in turf irrigation indicate losses approaching 20% are not uncommon. If such losses do approach 20%, then the water duties would prove inadequate in most circumstances (see Tables 7 & 8). Studies that can accurately quantify these losses represent an important area of future research.

Salinity represents the second important issue of importance for the future. The modeling results presented in Tables 7 & 8 indicate whether the annual balance between water supply and water use is positive or negative. A positive balance would support deep percolation and minimize problems with soil salinity. Model scenarios that predict a negative water balance would indicate deep percolation is inadequate, thus leading to future problems with salinity. As indicated earlier in this report, irrigation non-uniformity will ensure that close to half of the turf at a LTF will receive less than the mean rate of irrigation indicated in Tables 7 and 8. Such areas should be more vulnerable to the buildup of soil salinity and will likely exhibit higher levels of soil salinity. An assessment of soil salinity at LTFs should therefore provide additional important information regarding the adequacy of ADWR turf water duties. If these assessments reveal evidence of salinity problems (e.g., high levels of surface soil salinity and inverted soil salinity profiles) at LTFs employing efficient irrigation practices, such results would indicate the water duty is inadequate to support year round turf.

References

Brown, P.W., C.F. Mancino, M..H. Young, T.L. Thompson, P.J. Wierenga, and D.M. Kopec. 2001. Penman Monteith Crop Coefficients for Use With Desert Turf Systems. Crop Science 41:1197-1206.

Christainsen, J.E. 1942. Irrigation by Sprinkling. California Agr. Exp. Stn. Bull. 670. Univ. of CA, Berkeley, CA.

06/2006 **AZ1381**

The University of Arizona
College of Agriculture and Life Sciences
Tucson, Arizona 85721

Paul W. Brown
Extension Specialist, Biometeorology

This information has been reviewed by university faculty.

cals.arizona.edu/pubs/water/az1381.pdf