Effect of Irrigation Systems and Landscape Species on Irrigation Water Requirements Simulated by the Irrigation Management System (IManSys)

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Abstract. *Accurate landscape Irrigation Requirements (IRRs) determination is needed to help optimize landscape water use. Landscape evapotranspiration data are limited for many species, geographic locations, and for different irrigation systems. Efforts have been spent to determine values of landscape coefficient to estimate landscape evapotranspiration. IManSys, a water allocation model that uses specific edaphic parameters, weather data, and plant water use values was used to determine effect of different irrigation systems (drip, sprinkler and flood irrigation), and landscape coefficients on IRRs for different landscape mixtures under three major US metropolitan areas (Houston, Texas; Tampa Bay, Florida; and Honolulu, Hawaii). Weather data, soil physical properties, and values of landscape coefficients were used as input for IManSys to simulate irrigation water requirements for several major landscape mixtures. Rainfall and irrigation system efficiency are the major factors impacting IRRs followed by landscape coefficient, irrespective of the location. IManSys proves to be useful tool to determine and study IRRs under different conditions.*

Keywords. IRRs, IManSys, irrigation system, landscape

Introduction

Maintenance of landscape requires large amounts of water, particularly in areas with low rainfall. In fact, in urban environments of arid regions of the U.S., landscape irrigation consumes about 40% of all residential water use (Ferguson, 1987). Thus, proper system of landscape irrigation should be used to conserve water in landscaping. Proper irrigation system provides the right amount of water at the right time and place, for optimal growth of plants. Different irrigation systems are used to irrigate landscape planting. Trickle (drip) irrigation applies small volumes of water and can operate under low pressure. Drip irrigation is the most efficient and has become more popular for irrigating landscapes in and around urban centers. Sprinkler irrigation systems are used for turf areas, very large trees, and areas that require a high level of moisture, such as planter beds. Sprinklers are very inefficient, where large amount of water can be lost through evaporation and falling on non-targeted areas (e.g., roadways, sidewalks). Flood irrigation is a simple and cheap method that allows water to flow on the soil surface to where the plants are. Flooding provides deep watering; however, about one-half of the water usually ends up not getting to the crops and even some of the excess water washes away nutrient from the root zone. The selection of irrigation system depends on a number of factors, such as the size of the landscape area, landscape plant type, geographical location, underground utilities, and environmental regulations. Accurate landscape IRRs determination is needed to help optimize landscape water use. Thus, the main objective of this study is to determine the effect of different irrigation systems (drip, sprinkler and flood irrigation), and landscape coefficients on IRRs for different landscape situations in three metropolitan areas in Houston, Texas; Tampa Bay, Florida; and Honolulu, Hawaii using IManSys.

Materials and Methods

Study Area

This study was conducted in three major metropolitan areas in Houston, Texas; Tampa Bay, Florida; and Honolulu, Hawaii. Comparative climatic data for these three metropolitan areas (NOAA, 2013) are shown in Table 1. The annual average rainfall of Honolulu is comparatively lower, while its daily mean temperature is the highest amount these three areas.

Table 1. Comparative climatic data of three metropolitan areas (NOAA, 2013)

Metropolitan	Daily mean temperature (°F)	Annual average rainfall (inch)	Annual average wind speed (MPH)	Annual average relative humidity (%)	
				Morning	Afternoon
Honolulu	77.7	17.1	11.2	71	56
Houston	69.5	52.7	7.6	88	70
Tampa Bay	73.4	46.3	8.3	86	58

A summary of selected climate stations, climate data range, soil type, hydrologic group and runoff curve number for these three metropolitan areas are shown in Table 2. The daily climate data of Waikiki (Station ID: GHCND:USC00519397) and Houston Intercontinental Airport (Station ID: GHCND:USW00012960) were downloaded from the webpage of National Climatic Data Center (NCDC) and the climate data for Balm (Station ID: 350) was downloaded from the Florida Automated Weather Network (FAWN) website.

Table 2. Summary of data

State	Location	Climate data	Soil type	Hydrologic group	Runoff curve number	Curve type and hydrologic condition
Hawaii	Honolulu	1965 – 2011 (Waikiki)	Kawaihapai	B	70	Residential districts by average lot size: 1/2 acre
Texas	Houston	1984 – 2010 (Houston IA)	Wockley	C	80	" "
Florida	Tampa Bay	2004 – 2011 (Balm)	Candler	A	54	" "

Irrigation Management System (IManSys) Model

Plant irrigation requirement is the amount of water, excluding rainfall that should be applied to meet a plant's water demand without any significant yield reduction. There are several models that have been used in plant water allocation, e.g., AFSIRS (Smajstrla, 1990), IManSys (Fares and Fares, 2012). IManSys is a numerical simulation model used to calculate IRRs for different plants. Irrigation requirements calculated using IManSys are more realistic for areas where runoff and rainfall canopy interception are dominants. In addition, it also includes other features such as evapotranspiration calculation using different models (e.g., Penman-Monteith Equation (Monteith, 1965), ETM (Fares, 1996), and Hargreaves-Samani Equation (Hargreaves and Samani, 1982)) with either complete daily weather data or just minimum and maximum temperatures.

IManSys has several databases of, e.g., soil and plant growth parameters, irrigation systems, canopy interception. IManSys was implemented in JAVA object oriented language. IManSys output includes detailed net and gross IRRs, and all water budget components at different time scales (daily, weekly, biweekly, monthly, and annually) based on non-exceedance drought probability which is calculated from a conditional probability model that uses the type I extreme value distribution for positive non-zero irrigation values (Fares and Fares, 2012).

IManSys model uses the water balance approach with a two-layer soil profile to simulate the irrigation water requirement for specific plants on a daily basis. The plant specific irrigation requirements are calculated based on plant physiology, soil, irrigation system, growing season, climate and basic irrigation management practice. The daily water balance equation for the soil column defined by the plant root zone expressed in terms of equivalent water depth per unit area (cm) is:

$$\Delta S = P + G_w + IRR_{net} - \left(Q_D + Q_R + ET_c + I\right) \tag{1}$$

where ΔS is the change in soil water storage expressed as equivalent water depth (cm), P is the gross rainfall (cm), G_w is the groundwater contribution (cm) from shallow water table, IRR_{net} is the net irrigation water requirement (cm), (Q_D + Q_R) is the summation of groundwater drainage and surface water runoff (cm), ET_c is the plant evapotranspiration (cm) and I is the canopy rainfall interception (cm).

The water storage capacity is amount of water that is available for plant uptake. It is calculated as the equivalent water between field capacity and permanent wilting point for a given soil multiplied by the depth of the root zone.

Thus, gross irrigation water requirement ($GIRR$) is calculated as follows:

$$GIRR = \frac{ET_c - \left(P + G_W - Q_R - Q_D - I\right)}{(1 - LR).f_i} \tag{2}$$

where f_i is the irrigation efficiency, and LR is the leaching requirement to avoid salt built up in root zone.

IManSys calculates runoff, drainage, canopy interception, and effective rainfall based on plant growth parameters, soil properties, irrigation system, water management practices and long-term weather data (rain, evapotranspiration, and temperature). The detail of model can be found in Fares and Fares (2012). In all locations, simulations were carried out using different landscape coefficients and three different irrigation systems (Multiple sprinkler, Trickle (drip), and Flood). Irrigation system application efficiency of multiple sprinklers, trickle (drip) and flood irrigation are 0.75, 0.85 and 0.5, respectively.

Landscape Coefficient

Crop coefficients used for agricultural crops and turf grasses are different for landscape. Crop coefficient does not consider the variety of species, crop density, and micro-climate. Landscape plantings are typically composed of more than one species. Vegetation density varies considerably in landscapes. Landscapes environment is heterogeneous; it is subject to a wide range of micro-climates that varies due to variable shading, wind, and relative humidity. The collective effects of all environmental factors make landscape plantings quite different from agricultural crops and turf grasses. Realistic landscape coefficients account for these differences (Costello et al., 2000). Estimation of water requirements of urban landscape plants using landscape coefficient was close to result of actual irrigation records (Nouri et al., 2013). Estimated landscape evapotranspiration (ET_L) is the product of reference evapotranspiration (ET_O) and landscape coefficient (K_L) as follows:

$$ET_L = K_L \times ET_O \tag{3}$$

The landscape coefficient is a function of species factor (k_s), density factor (k_d) and microclimate factor (k_{mc}) that vary between and within different landscape vegetation types:

$$K_L = k_s \times k_d \times k_{mc} \tag{4}$$

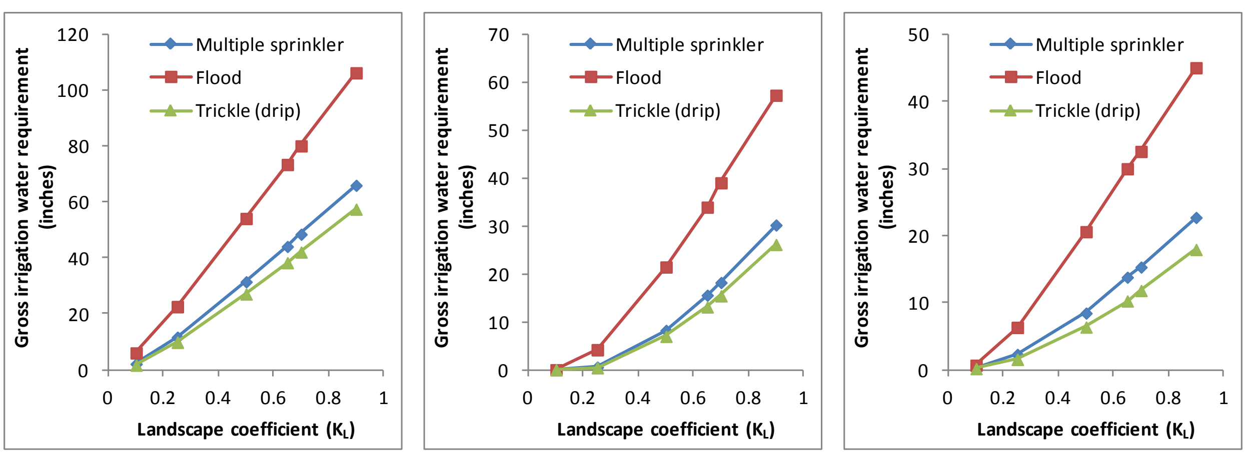
The reported ranges of different landscape coefficient factors can be as low as less than 0.1 and as high as 1.4 (Costello et al., 2000). Seven different cases of landscape coefficient were developed by combining three different landscape coefficient factors resulting in a landscape factor ranging between 0.1 and 0.9.

Results and Discussions

Gross irrigation water requirement

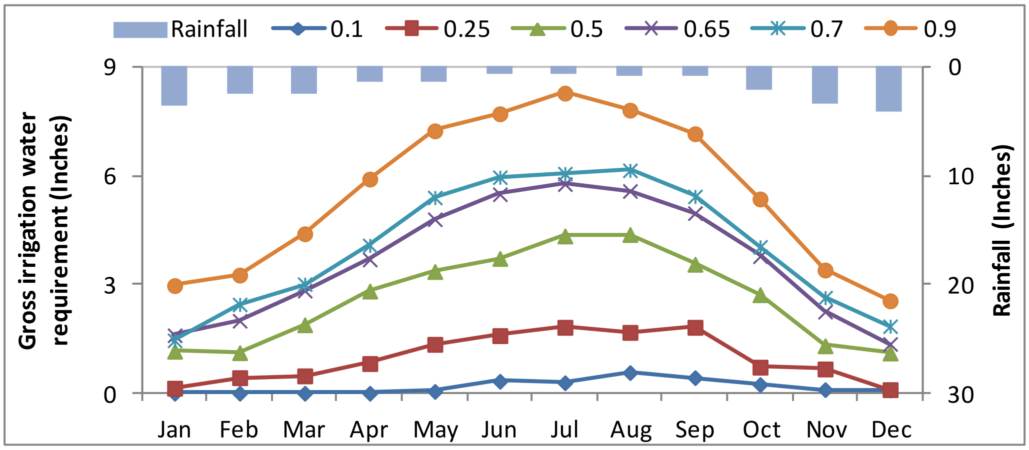
Gross irrigation water requirements (GIRRs) vary according to irrigation system (Fig. 1). Irrigation water requirement is higher for flood irrigation system compare to multiple sprinkler and trickle (drip) irrigation system. Flood irrigation system has lower irrigation application efficiency. Trickle (drip) irrigation system is much more efficient than flood irrigation system. When landscape coefficient is smaller the difference in irrigation water requirement for different irrigation system is also smaller; however, this difference is higher for landscape with higher landscape coefficient. GIRR for Honolulu (For $K_L = 0.9$) is 1.9 – 2.2 times higher than that for Houston and 2.4 – 3.2 times higher than that for Tampa Bay for different irrigation systems. The annual average rainfall of Houston and Tampa Bay is more than three times higher than that of Honolulu.

GIRRs vary from month to month according to variation of monthly rainfall (Fig. 2). When the magnitude of rainfall is lower, the GIRR is higher. GIRR is higher for the period of June – September at Honolulu and Houston whereas it is higher for the period of March – June at Tampa Bay.

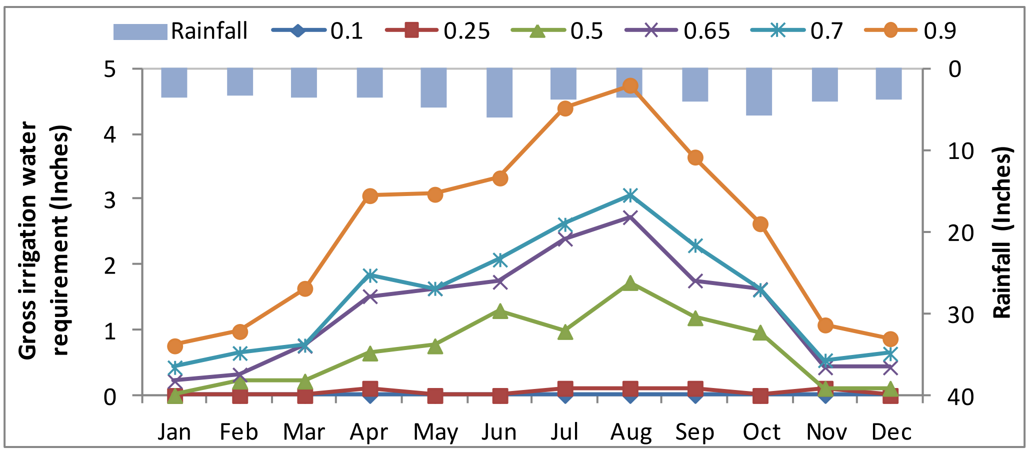


a. Honolulu, Hawaii b. Houston, Texas c. Tampa Bay, Florida

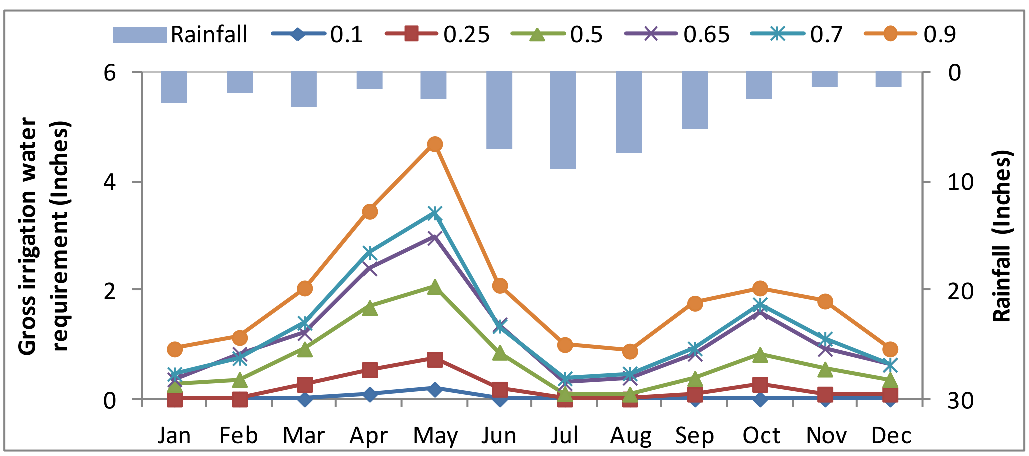
Figure 1. Gross irrigation water requirements for different irrigation systems



a. Honolulu, Hawaii



b. Houston, Texas



c. Tampa Bay, Florida

Figure 2. Monthly variation of irrigation water requirements for different landscape coefficients (Irrigation system: Multiple sprinkler)

Evapotranspiration

In IManSys, daily landscape evapotranspiration is the product of reference potential evapotranspiration and landscape coefficient. The annual average landscape evapotranspiration and reference evapotranspiration for the three locations under different landscape coefficients is shown in Fig. 3. The annual average reference evapotranspiration of Honolulu, Houston and Tampa Bay are 70.9, 60.3 and 44.6 inch, respectively. The landscape evapotranspiration at Tampa Bay is comparatively lower than the other two locations due to its microclimate.

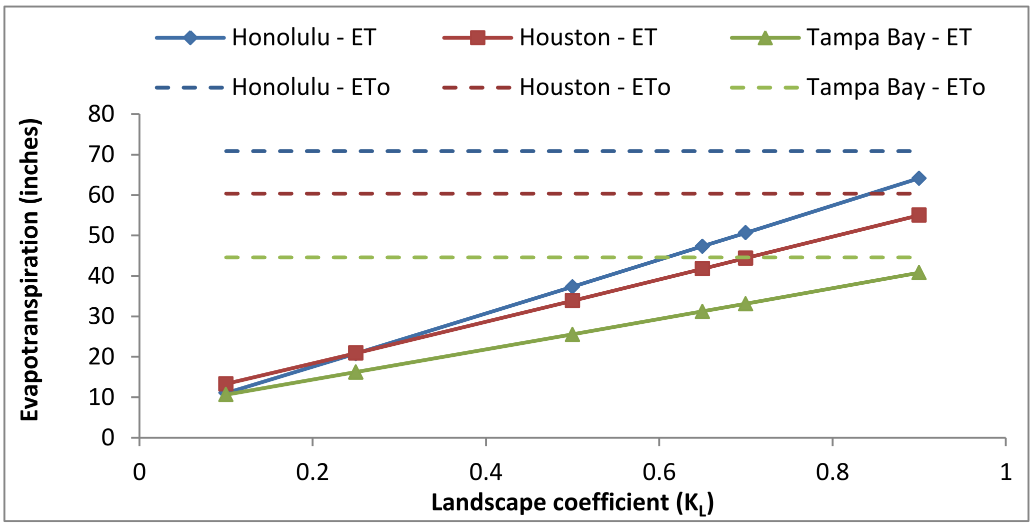
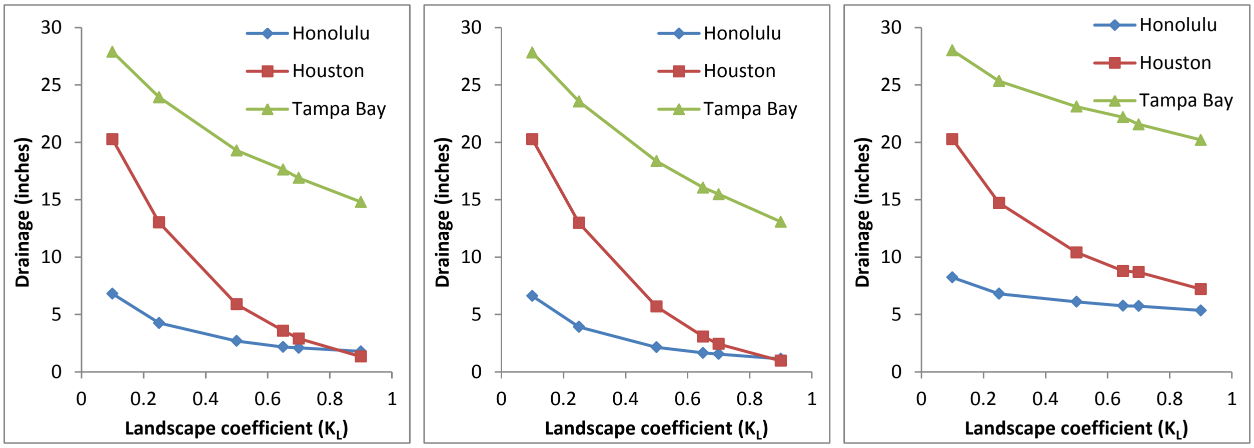


Figure 3. Plant evapotranspiration and potential evapotranspiration for different landscape coefficient

Drainage

Drainage is higher for lower landscape coefficients. Drainage in flood irrigation system is higher than that for the other irrigation systems. In terms of location, the value of drainage for landscape grown in Houston is between those of Honolulu and Tampa Bay for different landscape coefficient.

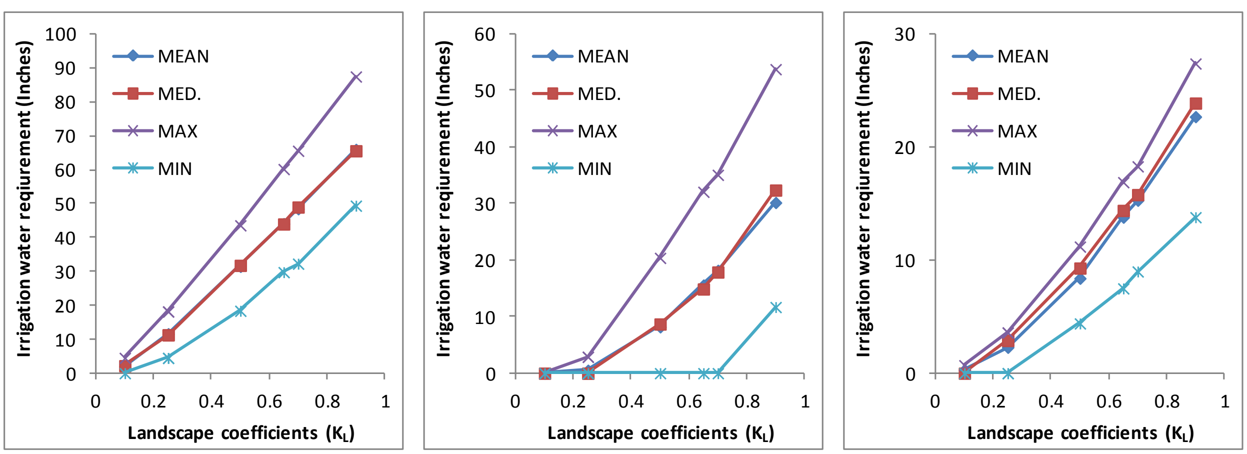


a. Multiple sprinkler b. Trickle (drip) c. Flood

Figure 4. Drainage under different irrigation systems

IRRs statistics (Mean, Median, Max. and Min.)

The range of IRRs is higher for higher landscape coefficients. The range of IRR at Tampa Bay is lower than that of the other two locations. This shows lower variation in IRRs at Tampa Bay compare to those at Houston and Honolulu.

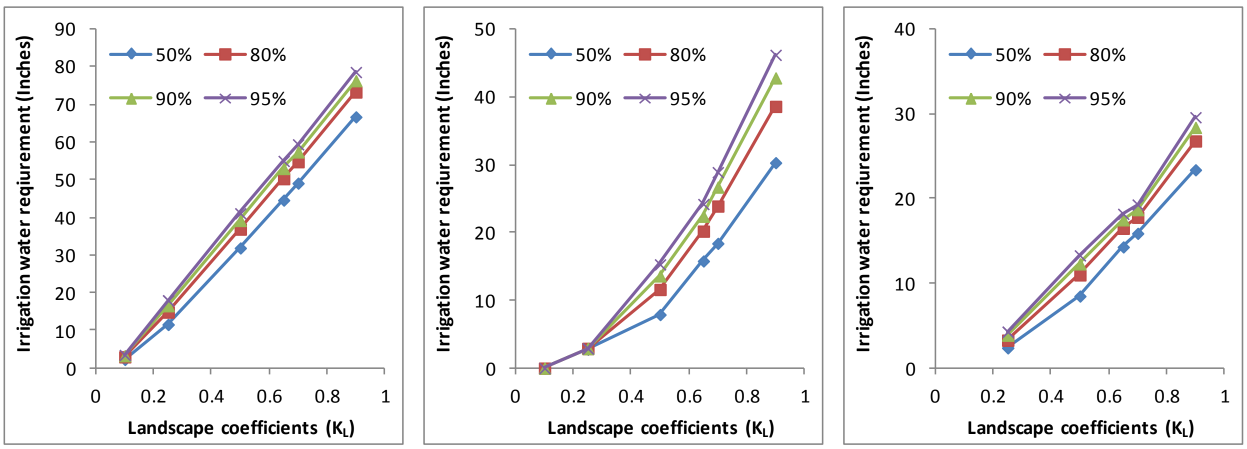


a. Honolulu, Hawaii b. Houston, Texas c. Tampa Bay, Florida

Figure 5. Irrigation Requirement Statistics (Irrigation system: Multiple sprinkler)

Irrigation water requirements for different return period

Irrigation requirements for different probability levels are also part of IManSys output. 50% (2 year return period), 80% (5 year return period), 90% (10 year return period) and 95% (20 year return period) probability of IRRS for all locations are shown in Fig. 6. For K_L = 0.9, 5 year return period IRRs are 73.3, 38.6 and 26.8 inches for Honolulu, Houston and Tampa Bay, respectively.



a. Honolulu, Hawaii b. Houston, Texas c. Tampa Bay, Florida

Figure 6. 50%, 80%, 90% and 95% Probability Level of Irrigation Water Requirements (Irrigation system: Multiple sprinkler)

Summary and Conclusions

Irrigation water requirements for several major landscape mixtures at different locations were simulated using IManSys. Weather data, soil properties, and values of landscape coefficients were used as input for IManSys. IRR varies with location, landscape coefficient, and irrigation system. Rainfall and irrigation system efficiency are the major factors impacting IRRs followed by landscape coefficient, irrespective of the location. IManSys proves to be a very useful tool to determine and study IRRs under different conditions.

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