# Sustainable landscapes for residential neighborhoods in Dubai: An analysis of the relationship between ambient temperature and water requirements of landscape

التنسيق الطبيعي المستدام لأحياء سكنية في دبي:
تحليل الصلة بين درجة الحرارة و الاحتياجات المائية للتنسيق الطبيعي

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Research Project submitted in partial fulfillment of the requirements for the degree of MSc Sustainable Design of the Built Environment

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# Table of Contents

## Executive Summary

'Greening' is a concept associated with sustainable design worldwide. When this is applied to the context of a hot climate zone of Dubai, it becomes a challenge to 'Green the desert' considering the limited resources of water. The benefits of landscape are manifold, in all aspects of sustainable design. The environmental aspects include temperature reduction, mitigation of urban heat island effect, optimal micro- climatic conditions for better outdoor thermal comfort and enables bio-diversity. Better quality of life and healthier lifestyles of the residents contribute to the social benefits of having these green open areas. This also makes economic sense when the energy consumption is reduced due to the shading provided by the vegetation on the building surfaces.

The aim of this research was to assess how the landscape contributes to reducing the temperature in an urban context, whilst balancing the water requirements of the vegetation species used to create the landscape. Two separate streets in separate residential neighborhoods in Dubai, 'The Greens' and 'Al Karama' are introduced as case studies to assess the impacts of landscape on temperature alteration versus water consumption. The methodology combines simulation, numerical analysis and relevant literature review to analyze systematically the effects of landscape on the temperature and water consumption in the residential neighborhoods of Dubai.

The results obtained indicate that landscape is a major contributor to altering the surface temperature and hence influences the micro-climate of the subject area. Subsequently the water consumption of the landscape can be optimized through thoughtful selection of species of plants that are either native or adaptive to the region. The landscape alterations in the two locations are demonstrated and the changes are compared to conclude that although landscape is a major contributor to temperature changes, there are other on-site parameters that can influence the temperatures. The conclusion provides a summary of the findings and also tries to provide responses to the research questions.

The findings from the study indicate that significant reduction in water consumption is dependent on the choice of vegetation species and on how the open spaces are treated. Water consumption is dependent on the species of the plant and by using a combination of native and adaptive species water consumption can be optimized. The efficiency of the irrigation system is also crucial in determining the water consumption rates.

*Keywords:* Sustainable landscapes, Vegetation species, temperature, ENVI-met simulations, greening, irrigation, water consumption

**الملخص التنفيذي**

"التخضير" مفهوم مرتبط بالتصميم المستدام حول العالم, لكن تطبيقه في نطاق مناخ دبي الساخن و تخضير الصحراء يمثل تحديا نظرا لشح مصادر المياه. للتنسيق الطبيعي منافع عدة في كل نواحي التصميم المستدام, النواحي البيئية تتضمن تخفيض الحرارة, الحد من تأثير الجزيرة الحراري المدني و الأحوال المناخية المثلى لراحة حرارية أفضل و تمكين التنوع البيولوجي. ان مستوى حياة أفضل و صحي أكثر للسكان يسهم في الفوائد الإجتماعية الناتجة عن وجود هذه المناطق الخضراء المفتوحة مما يمثل فائدة اقتصادية نظرا لتخفيض استهلاك الطاقة الناتج عن تظليل الغطاء النباتي لأسطح المباني.

يهدف هذا البحث الى تقييم اسهام التنسيق الطبيعي في خفض الحرارة في سياق مدني مع موازنة الاحتياجات المائية للنباتات المستخدمة. تم تقديم شارعين في منطقتين سكنيتين مختلفتين في دبي "الكرامة" و "الروضة" كحالتي بحث لتقييم تأثير التنسيق الطبيعي على الحرارة مقابل الاستهلاك المائي.

المنهجية تدمج المحاكاة, التحليل الرقمي و المنشورات ذات الصلة للتحليل المنظم لآثار التنسيق الطبيعي على الحرارة و استهلاك المياه في مناطق دبي السكنية.

النتائج المتحصل عليها تشير الى ان التنسيق الطبيعي مساهم كبير في تغيير درجة حرارة السطح و بالتالي يؤثر على المناخ المصغر للمنطقة قيد البحث.من ثم يمكن تحسين الاستهلاك المائي للتنسيق الطبيعي من خلال الاختيار الدقيق لنوعية النباتات المحلية للمنطقة أو تلك التي لديها قدرة على التأقلم.

تغييرات التنسيق الطبيعي في المنطقتين المختلفتين ممثلة و التغييرات مقارنة ببعضها لاستنتاج انه مساهم كبير لتغييرات الحرارة كما توجد عوامل أخرى مؤثرة خاصة بالمنطقة. الخاتمة تقدم خلاصة الاستنتاجات كما تحاول تقديم اجابات لأسئلة البحث.

نتائج الدراسة تشير الى ان التخفيض الملموس في استهلاك المياه يعتمد على اختيار فصائل النباتات و كيفية معالجة المناطق المفتوحة. يمكن تحسين استهلاك المياه عن طريق استخدام مجموعة من النباتات المحلية و الفصائل التي لديها القدرة على التأقلم, كما أن كفاءة نظام الري حاسمة في تحديد مناسيب استهلاك المياه.

*الكلمات الرئيسية: التنسيق الطبيعي المستدام, فصائل النباتات, درجة الحرارة, التخضير, الري, استهلاك المياه.*

**Dedication**

I dedicate this work to my daughters Naysa and Myrna, who inspired and supported me in completing this project. This study would not have been possible without the dedicated support and patience of my better half, Philip. This is also dedicated to my pillars of strength, my parents who instilled in me to be tough when the going gets tough. I thank the Almighty for providing me the strength to endure this journey to completion.

**Acknowledgement**

I take this opportunity to thank all the staff at The British University in Dubai and especially the Faculty of Engineering Department for their support in successful completion of this report. I would like to thank Dr. Bassam Abu-Hijleh for his patience and support during the course of this project. I take this opportunity to thank all my friends and colleagues at The British University in Dubai for their support.

## List of Figures



## List of Tables

## 1. Introduction

**Sustainable landscapes for residential neighborhoods in Dubai: An analysis of the relationship between ambient temperature and water requirements of landscape.**

United Nations (2008) in their report on world urbanization stated that  more than 50% of the world's population now live in urban areas and this number will continue to increase, particularly in developing countries. Urbanization leads to change in the pattern of the city with increased infrastructure, buildings and fewer open spaces. This increases the urban temperatures as compared to the rural areas. There is a growing concern worldwide in combating the effects of urbanization and creating better cities that can not only enhance the quality of life but also create less impact on the environment. The effects of urbanization also impact the economic aspects of any country, with increased density the infrastructure and the resource would need to be maintained for these cities. Therefore sustainability makes sense in all aspects of social, economical and most importantly environmental. Ong, (2003) in his paper states that the main cause of heat build-up in cities is insulation, the absorption of solar radiation by the asphalted roads and buildings in the city and the storage of this heat in the building material and its re-radiation.

The importance of weaving green space into the urban fabric is relevant in urban planning as much as is it is with the built form. ‘Sustainable development’ or ‘greening the cities’ have increased interest in the recent times due to the raising environmental concerns. The benefits of having plants in the urban area are not just environmental but also recreational, aesthetic and emotional (Ong, 2003).

Jabareen (2006) has included “Greening of the city” as one the design concepts for creating sustainable urban forms and emphasizes the many benefits of creating such spaces.  Urban living around the world is also at the increase and this emphasizes the role that cities should play in solving the pressing global problems. The existing urban form of any city today is related to the activities of its inhabitants with the passage of time, hence design considerations should be holistically integrated at all levels and disciplines.

The colour “green” personifies sustainability and hence a great significance is entrusted upon making places at all scales green. However, the current composition of the urban fabric in many parts of the world, with minimal vegetation has created the urban heat islands (UHI) (Santamouris, 2007). This can, to an extent be mitigated through thoughtful landscape design which in turn impacts the sustainability of the urban form. Planting of "urban trees" and using "high-albedo" surfaces decreases the ambient temperatures during summer (Santamouris, 2007) which enhances the urban environment.

The distribution and amount of landscape in city in parallel with the built forms can influence the ambient temperature of the area. These temperatures can influence the thermal comfort of the users of the space and hence it is significant to understand how the design of these spaces can alter the temperatures.

Dubai is the second largest emirate of the United Arab Emirates (UAE) comprising of seven other emirates. The climate of Dubai is hot and dry and is situated 25 degrees north and 55 degrees east, within a sub-region of the northern desert belt . It has summer during the months of May to September and winter through October to April.  The winds are mainly north-westerly known as the "shammal" winds.  Concern over sustainable practices and sustainability as a whole has been prioritized in UAE since the reports on the high rates of water consumption and greenhouse gas emissions as compared to other countries. The population is mostly transient consisting 80% expatriates and 20 % Emiratis. The city of Dubai has been a canvas for architects from different regions to explore their creativity therefore the style o f architecture cannot be defined for the cosmopolitan city of Dubai.

The urban form of the communities that have been built has not entirely considered the principles of sustainability. 'Estidama' which means sustainability in Arabic under the initiative of the Urban Planning Council of Abu Dhabi ensures through a rating system, that built forms and communities incorporate sustainability principles into their design. Dubai municipality has also included requirements in the regulations to address the sustainability practices for the construction sector.  The treatment of open spaces in Dubai is yet another area of interest particularly concerning this study. Inspired by the landscapes around the world and aspiring to recreate similar spaces here has led to an extensive demand on the depleting water resources. Treated sewage effluent (TSE) is used for irrigation of most public areas and potable water for the private gardens. The water from the supply is through an energy intensive process of desalination of sea water.  Water is a precious resource in this region.

Numerous studies have shown evidence of how landscapes help in altering the microclimate of the particular area, mainly temperature reduction. The motivation behind this study is to understand if by creating these lush landscapes for reduced temperatures, is there an increase in the water use. If so, what are the means we can strike a balance between the two.

Dubai is situated 25 degrees north and 55 degrees east, within a sub-region of the northern desert belt and has summer during the months of May to September and winter through October to April. The winds are mainly north-westerly known as the “shammal” winds. Dubai experiences a hot and dry climate.

## 2. Literature Review

### 1.1 Literature review of the role of landscape in the urban environments

The role of green spaces for reducing the ambient temperature , thereby improving the microclimate of the subject area has been studied for many years now and it has been observed that irrespective of the region these green spaces exists and in whichever form they are, they offer multiple benefits. Improvement in the ambient temperature reduces the urban heat Island effect making spaces usable in the urban setting.

From a social perspective these green spaces in the urban fabric not only lead to better quality of life for its residents but also provide a healthy environment through its diverse land uses and opportunities for different activities that promotes active lifestyles (Levent, Vreeker and Nijkamp, 2009). In another study by Chen et.al (2009) he emphasizes the impact of the landscape, which includes both vegetation and water bodies, on the microclimate of a community and how this can be an efficient system to provide cooling for the communities. This is much needed in the cities where impermeable concrete built form and roads are the major make-up of the city; the landscape provides a relief from both a visual and functional perspective.

Tratalos et al. (2007) in their study emphasizes that the quality of the ecosystem tend to decline constantly as the urban density of the city increases although at any given urban density, there still exists a considerable scope for maximizing the ecological performance through appropriate thoughtfulness to the proportion and configuration of green space and tree cover.

The lifestyle choice of the residents too demands for higher standards of outdoor environment quality in their communities (Chen et.al, 2009). Hence this provides a direction to the planners and designers to create a balanced community through the arrangement of the different elements of the built form and the landscape. Chen et.al, (2009) adopted a field measurement experimental approach to analyze the microclimate of the areas under study which he then validated via simulation using the CFD software.

The social aspects of landscape are many as where Chiesura (2004) in her study explains the emotional dimension involved in the experience of nature and its importance for people's general well being. Through her study she affirms that experience of nature in the urban environment is source of positive feelings and beneficial services. Picot (2004) explains that vegetation growth has impact on users' comfort and suggests the use of vegetation as a tool in microclimatic control that considers the shading performance of vegetation. Azwar & Ghani (2009) establishes a link between green spaces and its influence on the resident's attitude towards their perception of urban quality.

On an urban scale, vegetation affects the thermal environment, air quality and noise levels in an urban environment (Nikolopoulo & Dimoudi, 2003). Nikolopoulo & Dimoudi (2003) in their study explains the microclimatic effects of vegetation in reducing air temperature which then reduces the urban heat island effect predominant in the cities. The microclimatic effect of trees are obtained, firstly by the shade it provides to windows, walls, roofs etc. and secondly through the phenomenon of evapotranspiration through the leaves of the vegetation that adds moisture to the air, thereby increasing the latent cooling.

Hitchmough (2011) defined in the following the key attributes for plants to be sustainable:

- plants should be well integrated to the landscape and be strong to continue and maintain their populations over time through self seeding or vegetative means,
- These plants- with careful consideration of the species should be manageable in the long term with relatively low inputs of resources, water, nutrients, carbon expenditures, and maintenance time,
- The plants should support the native animal biodiversity as much as possible.

Plants should be aesthetically pleasing and meaningful to the residents and where appropriate these plants are required to reflect or reinforce the character of a particular place. In their study Nikolopoulo & Dimoudi (2003) have determined the following parameters that affect the temperature in a landscaped area

**Evapotranspiration** - evapotranspiration rates vary depending on the type of vegetation and the volume of air with which the cooled air is mixed, per unit time. The evapotranspiration (Etc) from a given vegetation type, can be determined by multiplying the reference evapotranspiration by the crop coefficient, Kc;

ETc = Kc x ET0

Kc – crop coefficient

ET0- reference evapotranspiration

Temperature reductions due to evapotranspiration are critical.

**Transmission** – is the effect of vegetation on solar and daylight access which varies with season, particularly for deciduous trees. The shading effect of vegetation on nearby buildings and open spaces is also important to evaluate the temperature reductions.

**Albedo** - is an important parameter for the thermal characteristics of the vegetation as it impacts the amount of incoming radiation on the site that is removed by evapotranspiration. Species in hot-dry climates with low rainfall and high evaporative demand have higher albedo which then tends to reduce their solar heat load.

**Permeability** - parameter relates to how permeable the vegetation is to the wind.

The above parameters are critical in determining the overall temperature reduction achieved by the landscape for the chosen area.

These studies separately highlight the many benefits of urban landscapes for the community, and the factors that are considered for creating the desired microclimate that improves the thermal comfort of the users. However, what these studies do not clearly indicate is the resources used to create these landscapes and how they can be sustained with time without depending much on the depleting sources. This is where this study takes its root from, to enable to assess the impacts, if any, on the resources and if a different option exists to have the same look achieved with reduced dependencies.

Ecology and sustainability of cities can be improved by understanding the effects of landscape pattern on urban heat island –UHI (Li et al., 2011). Through the analysis of land surface temperature (LST) in relation to normalized difference vegetation index (NDVI), vegetation fraction (Fv), and percent impervious surface area (ISA), Li et al. (2011) concluded that both the composition and configuration of urban landscape significantly influence UHI.

While vegetation has proven to mitigate UHI, ISA increases it and residential land use is the prime contributor to UHI, followed by industrial land use. The study also highlights that residential areas with low to mid-rise buildings with low vegetation cover results in strong UHI effects.

Akbari, Pomerantz & Taha, (2001) states that summer heat islands are created mainly by the lack of vegetation and by the high solar radiation absorptance by urban surfaces. The significant impacts of urban heat island effects can be mitigated through Vegetation and high albedo surfaces. Trees interrupt the sunlight before it reaches a building which reduces the heat received on the building.  Akbari, Pomerantz & Taha, (2001) highlights that urban trees offer considerable benefits with respect to lowering air temperature and improving the air quality by reducing the smog.

Ong (2003) introduced the Green Plot Ratio (GPR) which is the average LAI of the greenery on site is being used as an architectural and planning metric for determining the greenery in cities and buildings based on a the parameter called the leaf area index (LAI), which is defined as the single-side leaf area per unit ground area.GPR provides a more specific regulation of greenery on site .It has proven to provide flexibility to the designer while concurrently protecting the green proportion in the design.

Giridharan, et al. (2008) in their study investigates the impact of on-site variables, such as surface albedo, sky view factor, altitude, shrub cover, tree cover and average height to floor area ratio, on the influence of vegetation in lowering outdoor temperature.  The study explains that a noticeable reduction in outdoor temperature can be achieved when vegetation along with other on-site variables like sky view factor and altitude are cautiously managed.

Taha (1997) in his study suggests that reasonable raise in urban albedo can decrease the air temperature up to 2°C and with a greater increase in albedo, it can reach up to reduction of 4°C. The study also highlights that vegetation in urban areas can reduce the air temperature by 2°C.

Shashua-Bar, Pearlmutter &Erell (2009) has done a study through controlled experiment to assess six landscape strategies using different combinations of trees, lawn, and an overhead shade mesh for outdoor cooling in a hot-arid region, whilst considering the efficiency of water use.

This study revealed that unshaded grass caused only a small air temperature difference but has the highest water requirement, but when shaded it produced greater cooling as well as reduced the total water use by 50%.

Latent heat represented the amount of water required for landscape irrigation.

“Cooling efficiency” was proposed as a criterion for evaluating landscape strategies in arid regions, where water resources are scarce, which is calculated as the ratio between the sensible heat removed from the space and the latent heat of evaporation.

The study shed light to separate combination of plants to achieve effective temperature reduction. In their study it was observed that the air temperature was reduced to 2k by a combination of shade trees over grass and was the most effective landscape strategy in terms of the cooling provided.

It was concluded that trees provide the most efficient means of reducing outdoor air temperature, as measured by water consumption.

## 1.2 Literature review on the methodology

The effects of landscape on the ambient temperature and the challenging aspects of water consumption of the plant species selected should be considered in parallel, since water scarcity is a major concern in Dubai (Al- Sallal, 2012). In his study of reducing the overall energy consumption of an eco-house by the use of landscaping, Al-Sallal (2012) has simulated along with other passive systems, different landscape elements with appropriate plant species that consume less water. He also highlights the directives by the Dubai Municipality and Estidama in Abu Dhabi to integrate green roofs and external landscaping into the new building design to mitigate the heat island effects.

Chow & Brazel, (2012), in their study, used ENVI-met to generate xeriscaping scenarios in two residential areas with different existing surface vegetation cover and then examined the resulting impacts of xeriscaping on near-surface temperatures and outdoor thermal comfort over different spatial scales and temporal periods. Similar simulation studies with different landscape treatments were conducted using the Enerwin-EC software to assess the reduction in the energy consumption of the Eco-house. The tangible results obtained through the simulation of the separate landscape elements enabled a comparative analysis with a base case.

Ozkeresteci et.al (2003) evaluated the adaptive use of the climatic modeling software ENVI-met as a planning and environmental design tool to assist Phoenix metropolitan area planners. In Ozkeresteci et.al (2003) view, environmental modeling as a scientific approach helps in understanding and solving the complex issues at the urban scale. Their study aims to fulfill the shortcomings on the use of the modeling within a real-world environmental and community plan design systems. The study has been designed according to the three objectives of using environmental models for research:

1. Future predictions on actions to make informed decision
2. Identify patterns for further observation
3. Understanding of the observations within a set parameters in the model

Ozkeresteci et.al (2003) reinforces that the benefits of such a climate model are significant in extreme desert climates. It also states that, this model can help in understanding the critical trade-offs between vegetation for cooling and costs of water, and also heat retention as they affect the areas entire climate regime.

In their study, Chow& Brazel (2012) analyzed the Metropolitan Phoenix to mitigate UHI effects through sustainable methods like xeriscaping. This application has the potential to reduce urban water use, urban temperatures and outdoor thermal discomfort.

ENVI-met was used to generate xeriscaping scenarios in two residential areas with different existing surface vegetation cover and the resulting impacts of xeriscaping on near-surface temperatures and outdoor thermal comfort were assessed over different spatial scales and sequential periods.

The main result from this study is that the application and careful management of shade trees are therefore vital in not only reducing near-surface temperatures in xeric residential neighborhoods but also improving outdoor thermal comfort.

The results concluded that increased xeriscaping resulted in net warming which increased the thermal discomfort over the existing landscape over all spatial scales and temporal period of the residential neighborhoods. Further investigation was recommended to assess the potential tradeoffs between microclimate cooling vs. neighborhood water use.

## 2 Aims and Objectives

The primary aim of this study is to understand the relationship between temperature and water consumption of the planted landscapes and if a balance between these two factors impacts the sustainability of the urban environment at the neighborhood scale.

The purpose of this research also aims to evaluate the relevance of creating such sustainable landscapes that considers both the benefits of these green spaces and also how it can be sustained with time. The following research questions are aimed to be answered through this study.

- How sustainable are the landscapes of Dubai's residential communities?
- What factors should be considered for creating these sustainable green spaces?
- While creating microclimates that reduce ambient temperatures, does the maintenance of these green spaces create an imbalance in the water consumption?
- In what ways can the temperature reduction by the vegetation be balanced with the water consumption?
- What are the landscape species that are to be used?

The research objectives are firstly to identify how much of an impact vegetation has in reducing the temperature. Secondly, the research study aims to understand if the species of plants used in the landscape should be native or can exotic species be considered to create sustainable landscapes. Thirdly, whilst the temperature reductions occur, is there a strain or imbalance in the consumption of water resources.

As stated earlier, there are many benefits associated with landscape but with these benefits, we have to consider the sustainability of these landscapes. This is similar to creating an aesthetically pleasing glazed building in the desert without fully comprehending the increase in energy consumption.

The research looks to shed light on what can make landscapes sustainable in the time to come while still retaining its properties of temperature reduction, cleaning the air and creating quality spaces.

# 3 Methodology

The methodology developed for this study uses ENVI-met software which includes Leornado for visualization. It is a micro-scale urban climate model that can be used to generate the existing and different landscape scenarios in two residential areas with different surface vegetation cover and subsequently examine the resulting impacts of these landscapes on near-surface temperatures for the summer period of June. In parallel to these simulations, water consumption using the guidelines specified by the U.S. Department of Energy, for a whole year is calculated.

This investigation therefore takes an experimental approach with simulation using the software ENVI-met and a case study strategy for two residential neighborhoods. Previous similar research reaffirms the theory of creating landscapes in the cities to combat urban heat island effects. This research is to further test this hypothesis and reach valid conclusions on the relationships between the dependent variables.

The first scenario will analyze the two neighborhoods with their existing landscape and obtain data on the temperatures and water usage during the different times of the year. The second scenario aims to determine solutions by altering the landscape and then simulating it to find the temperature and water usage.

A comparison of the results of the two aforementioned scenarios will be used to conclude and make recommendations on what constitutes sustainable landscapes for similar residential neighborhoods in Dubai.

## 3.1 Case Study

For the purpose of this research, two residential neighborhoods that are similar in its area, land-use, scale and population are chosen to assess the landscape and its sustainable factors. A south facing street is chosen for study in both the locations. The first neighborhood is in The Greens (G), which is relatively a new development in Dubai, and the other is in Al Karama (K) which forms part of the old Dubai. The criterion for selection is based on the land use, population and the relevance of the community in creating trends in the evolution of Dubai as a city. These have been chosen for their similar scale of buildings and land-use, where the former has extensive landscape areas that were designed and the latter is devoid of any such treatment. Al Karama has green open spaces that are scattered and is predominantly dominated by asphalted roads.

### 3.2 Data Analysis

The temperature, water usage and vegetation species data collected is primarily quantitative in nature. The water usage of each of the spaces with specified combination of plant species is calculated to understand the irrigation requirements annually.

The above results are compared to understand how the configuration and distribution of species of plants can impact both the temperatures and water consumption. The data collected for each of the streets are into the ENVI-met software. The evaluative study will attempt to provide answers to the research questions and also provide recommendations for further study and implementation.

The study focused on a south oriented street with buildings abutting either side in these communities. The landscape treatment of the street was used to understand the annual irrigation needs of the plants and simulations were conducted on the same streets to analyze the temperature influences by these landscapes.

The species of plants were identified through field study during which photographs were taken and then the species characteristics were researched using the book on landscape plants in the Arab region (Jubran & Hozon).

## 3.3 Case Study Areas

### 3.3.1 The Greens - G

The Greens forms the new part of Dubai which is off Sheikh Zayed Road on route to Abu Dhabi. It is a preferred community of expats mainly due to its lush landscape which is distinctive in nature. The accessibility and proximity to landmarks and amenities too makes it a preferred choice for many working in Dubai and also in Abu Dhabi. Figure 1 and 2 indicates the location of The Greens.

Figure 1: The Greens location

Figure 2: The Greens neighborhood

### 3.3.2 Al Karama – K

The other community chosen is in the old part of Dubai called Karama where most of the South Asian expats reside. This mixed use community mostly consists of 3- 5 storied residential buildings with retail at the ground level.

The landscape treatment of these two communities is different; while the former has a few landscaped open areas which evolved after the community developed; the latter had an ideal landscape design which includes a lake and variety of plant species included in the defined open spaces.

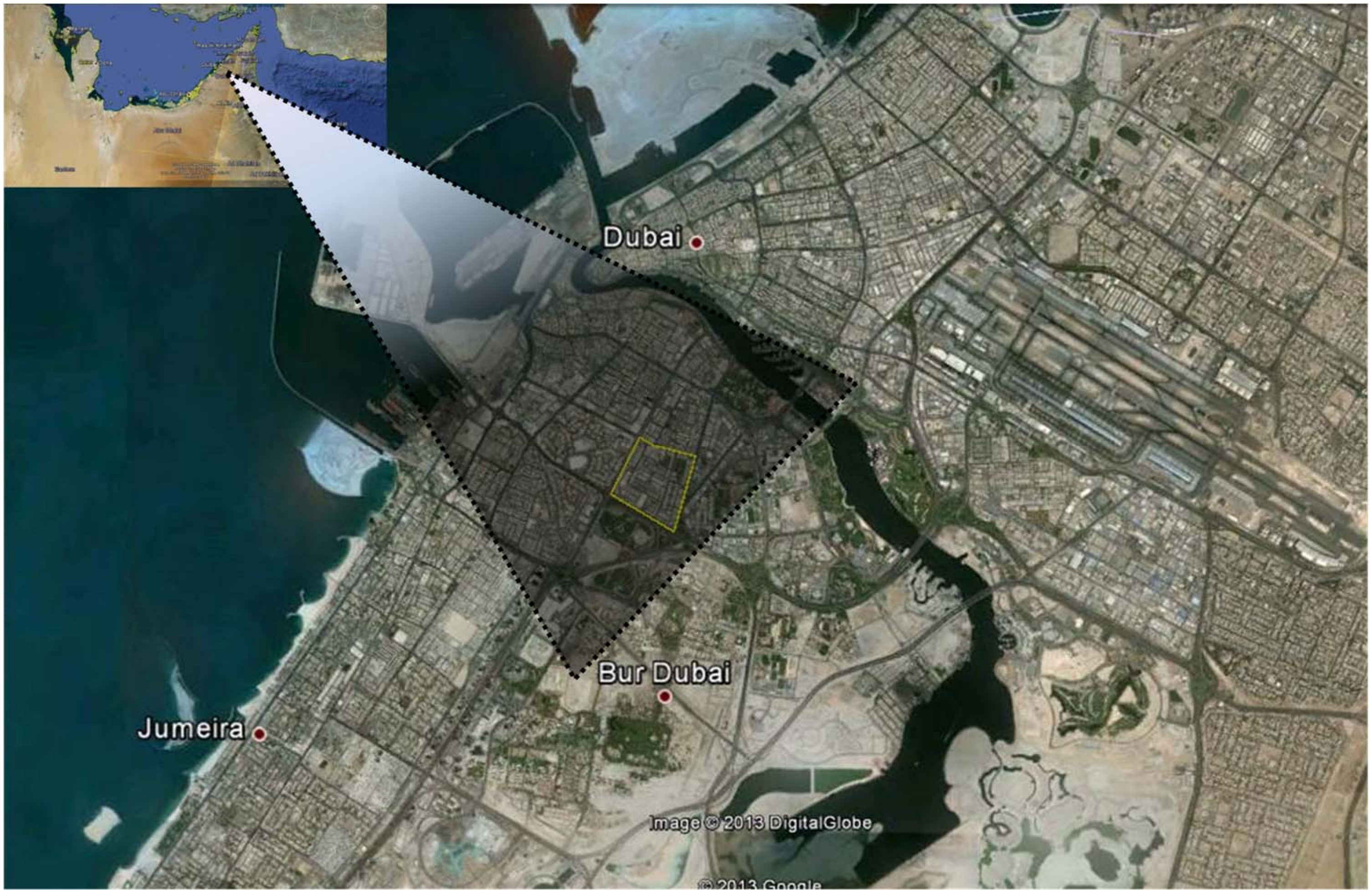


Figure 3 : Al Karama location

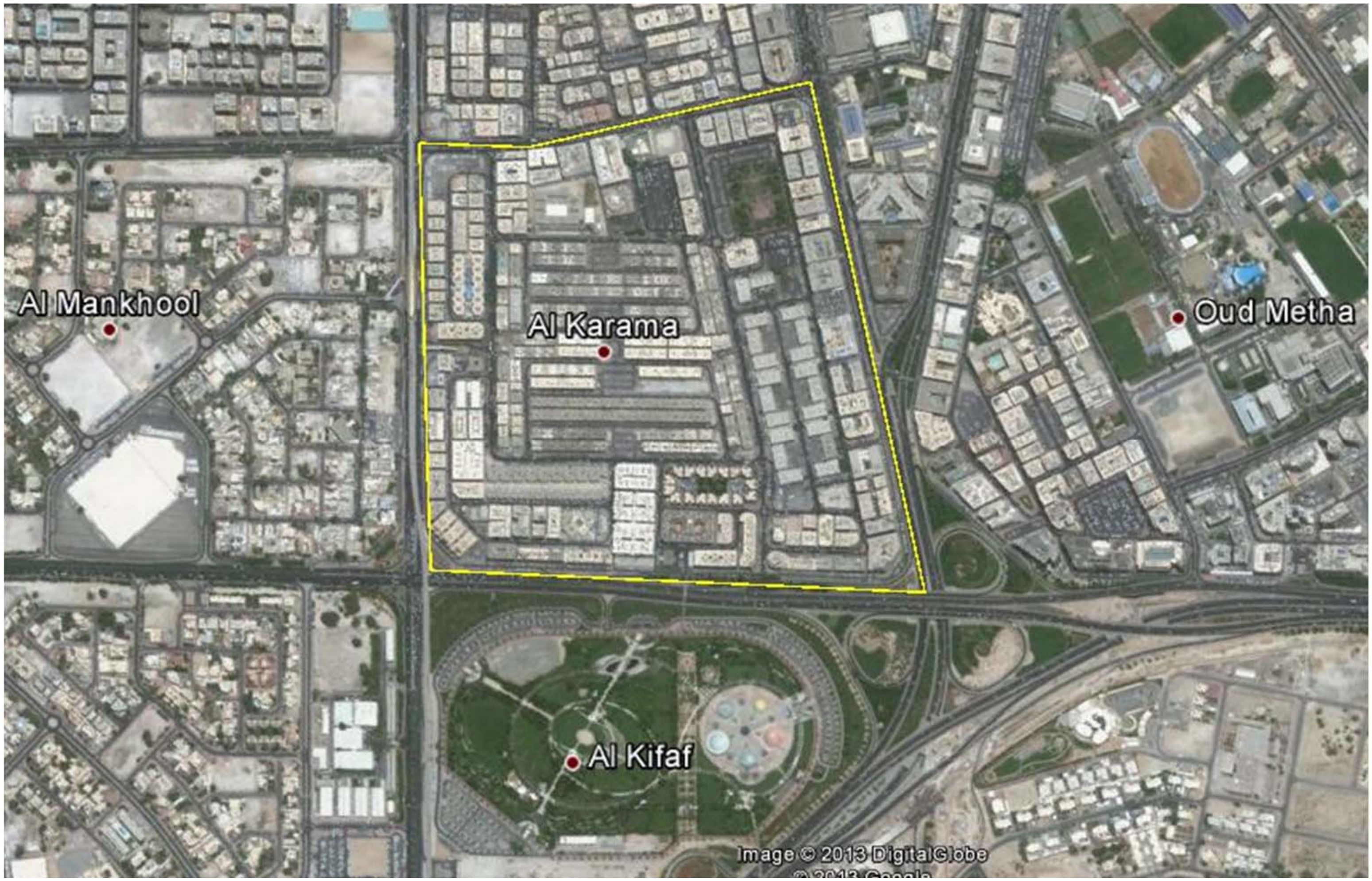


Figure 4: Al Karama neighborhood

## 3.4 Identification of Plant Species

The photographs of plant species from the Greens were taken and these were identified as per the botanical /local name, their water/light requirements and tolerance to wind, sun and drought as shown in Table 1 (Jubran & Hozon).

After a critical analysis of this table with species and their requirements, it has been identified that Bermuda grass, Poison bulb and India rubber vine have the highest requirement of water as compared to other species used. Bermuda grass is covered for the largest area in Greens and therefore this could also have the greatest influence over water consumption for that location. Poison bulb with its high water requirement has also low tolerance to wind, salinity and drought, which does not seem suitable for use in the landscape of the subject area.

This table enables to understand the distribution of the species in the subject are and also helps to decide on the which plants can be reduced per square meter area for reducing the overall water consumption.

Use of native or adaptive species can help to reduce the water consumption whereas exotic species may create a strain on the water resources, due to the higher requirements and also intolerance to the harsh weather of Dubai. This poses a problem with long term maintenance of the plants which affects the principles of sustainability which is to maintain the resources without depleting them for the future.

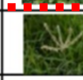
| No. | Species - Botanical name | Common name | Local name | Size | Requirements | | Tolerance | | | Type | Area | | Image |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | Light | Wind | Salinity | Drought | | Nos. | Area | |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | high | high | high | high | Tree | 6 | 24 |  |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | high | high | medium | high | Tree | 30 | 120 |  |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | high | high | medium | high | Shrub | | 27.5 |  |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | high | medium | medium | low | Shrub | | 42.5 |  |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | high | high | low | high | Ground cover | | 144 |  |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | high | high | medium | medium | Shrub | | 92.5 |  |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | high | high | high | high | Ground cover | | 825 |  |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | medium | low | low | low | Ground cover | | 42.5 |  |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | high | high | low | low | Shrub | | 6 |  |

Table 1: Plant Species

### 3.5 Methodology of calculation of landscape water requirements

U.S. Department of Energy (2010), FEMP provides the guidelines for estimating unmetered landscaping water use for the states of USA. This has been compared to the city of Dubai for determining the water use for the landscape.

Annual irrigation requirements were calculated in the following order:

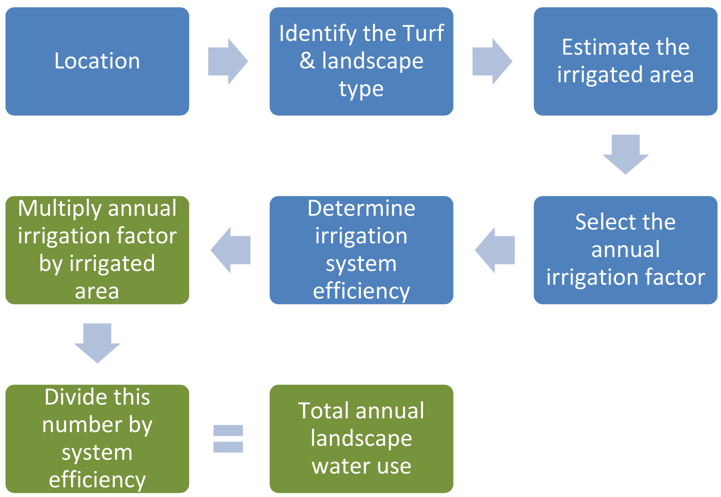



Table 2 : Irrigation requirements calculations

The above figure explains the process followed to calculate the total annual landscape water use for both the locations.

Step 1 - The best match to the city of Dubai is identified as Las Vegas with respect to its climate zone which is classified as desert. This also indicates that Dubai has similar irrigation requirements to Las Vegas.

Step 2 – Here the landscape type is identified based on the landscape water requirements, planting density and microclimate which is explained below.

The water requirements of the landscape can range from low, moderate and high water requirements. The native or well adapted species generally would have low water requirements as compared to the other species.

The planting density parameter defines the number of plants in the area relative to the total area. It is low density if the plants are immature and sparsely planted; average density, when one type of vegetation is predominantly is used for full coverage and high density when the landscape consists of mixture of plants (trees, shrubs, and flowers) with full coverage.

The microclimate parameter considers the environment the landscape is planted in- protected, open and intense exposure. Depending on how the landscape is shaded or exposed this parameter is defined for the area.

Step 3- The area of the irrigated area is then calculated in square feet using the Google map image of the two locations.

Step 4- The annual irrigation factor is the amount of annual additional water required to maintain the landscaped area. This factor is determined based on the landscape type described in Step 2.

Step 5- The efficiency of the irrigation system is determined by how much irrigation water is actually been used by the plants which is dependent on the type of irrigation system installed as well as maintenance and scheduling of the system. Efficiency ranges from 50%, 65% & 85% depending on the sprinkler or micro irrigation system installed.

Step 6- The total annual irrigation is then calculated using he formula below:

| | |
|---|---|
| Annual landscape water use (gallons per year) = | $\frac{\text{Annual irrigation factor (gal/sq.ft./year) x Irrigation Area (sq.ft.)}}{\text{Irrigation system Efficiency}}$ |

### 3.6 Description of ENVI-met simulation software

ENVI-met software was used to run simulations for both the locations during the summer month of June from 7am -8pm. June was selected as it was considered to experience the summer peak of all the months.

An advanced 3D-4D numerical model is generated using the ENVI-met and the results are translated and visualized in LEONARDO. It can simulate the surface-plant-air interactions inside urban environments on a three- dimensional rectangular grid with variable spacing in x-, y- and z-directions, the model is able to function over a range of spatial scales. The benefits of ENVI-met are significant in extreme desert climates.

ENVI-met version 3.1 is a 3-dimensional non-hydrostatic microclimate model that is able to calculate and simulate climate in urban areas. This software can calculate the dynamics of microclimate during a diurnal cycle (24 – 48 hrs) using fundamental laws of fluid dynamics and thermo dynamics. The ENVI-met climate model was applied to simulate the temperatures for the existing and the altered conditions. The software typically models soil-air-vegetation-building interactions at horizontal spatial resolutions of between 0.5 and 10 m. Simulations can be run from 24 – 48 hours with time intervals of 1 and 10 seconds. The output data can be interpreted and visualized in LEONARDO which is part of the ENVI-met software.

However, there are several limitations of ENVI-met which must be discussed at this point. First, the simplified 1-d atmospheric inflow model which is up to the model's upper boundary of 2500 m a.s.l. restricts the ability to dynamically simulate regional/micro scale thermal and turbulence exchanges that potentially influence micro-scale climates.

This may be cause issues if regional weather conditions vary significantly over the model simulation period. The building facades all through the model environment are parameterized with a single mean heat transmission value, which oversimplifies the heterogeneity of the urban environment. Third, the inadequacy of horizontal soil transfer within the model can affect accurate calculations of soil heat storage. Besides these limitations, ENVI-met has been commonly used in urban climatology, building design and planning research at micro-scales which demonstrates the model's capability.

### 3.7 Description of Scenarios 1 and 2

Two scenarios are selected to test and compare the results of temperature and water consumption. This enables to understand the impacts of landscape on the surface temperature and subsequently the water consumption.

#### 3.7.1 Scenario 1

In this scenario the selected street for both locations G and K were simulated using the existing conditions – G1 and K1. The street was modeled in the area input file of ENVI-met.

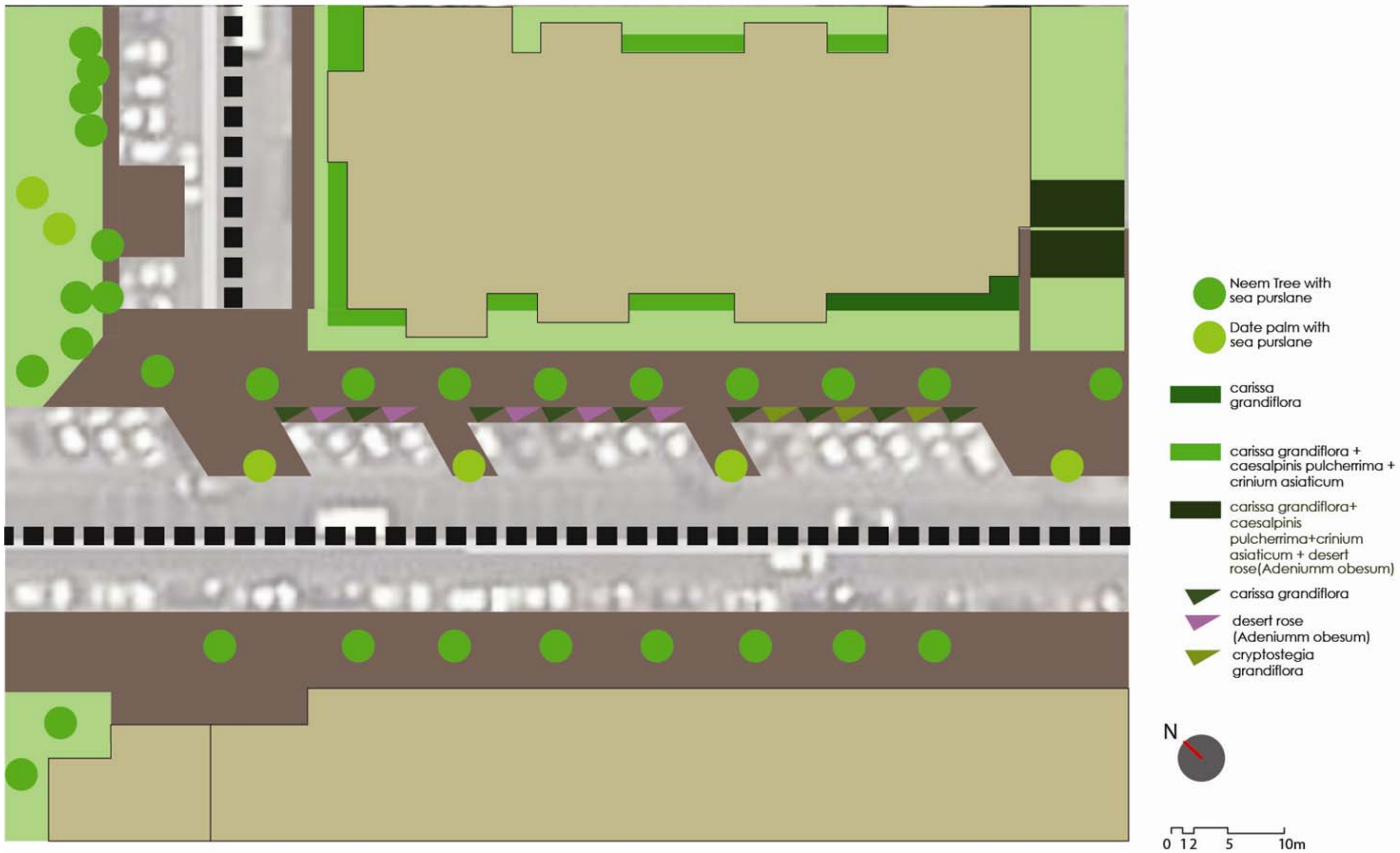


Figure 5 :The Greens Street – Scenario 1 – G1

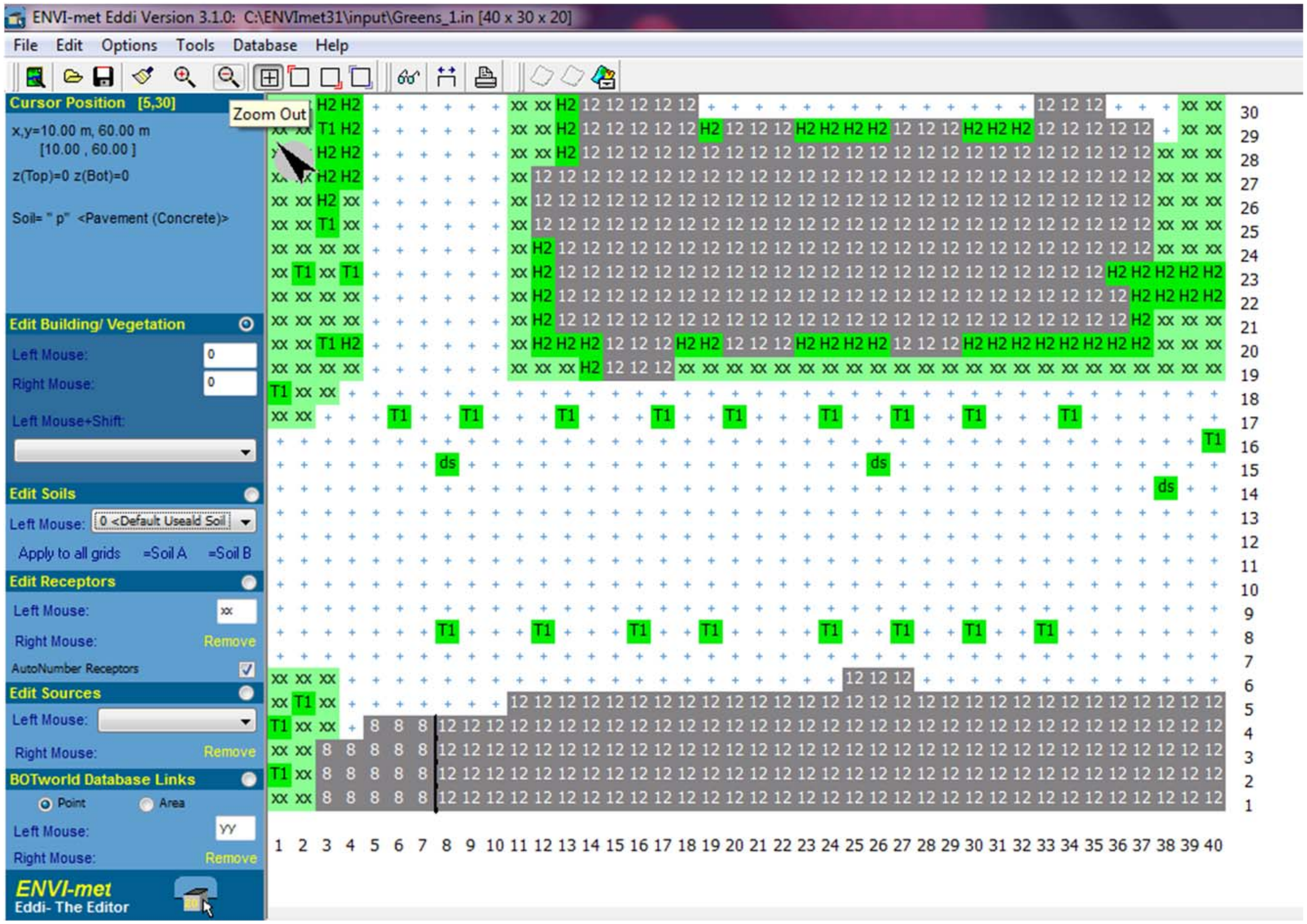


Figure 6 :The Greens street – Scenario 1 – G1 – ENVI-met area input file

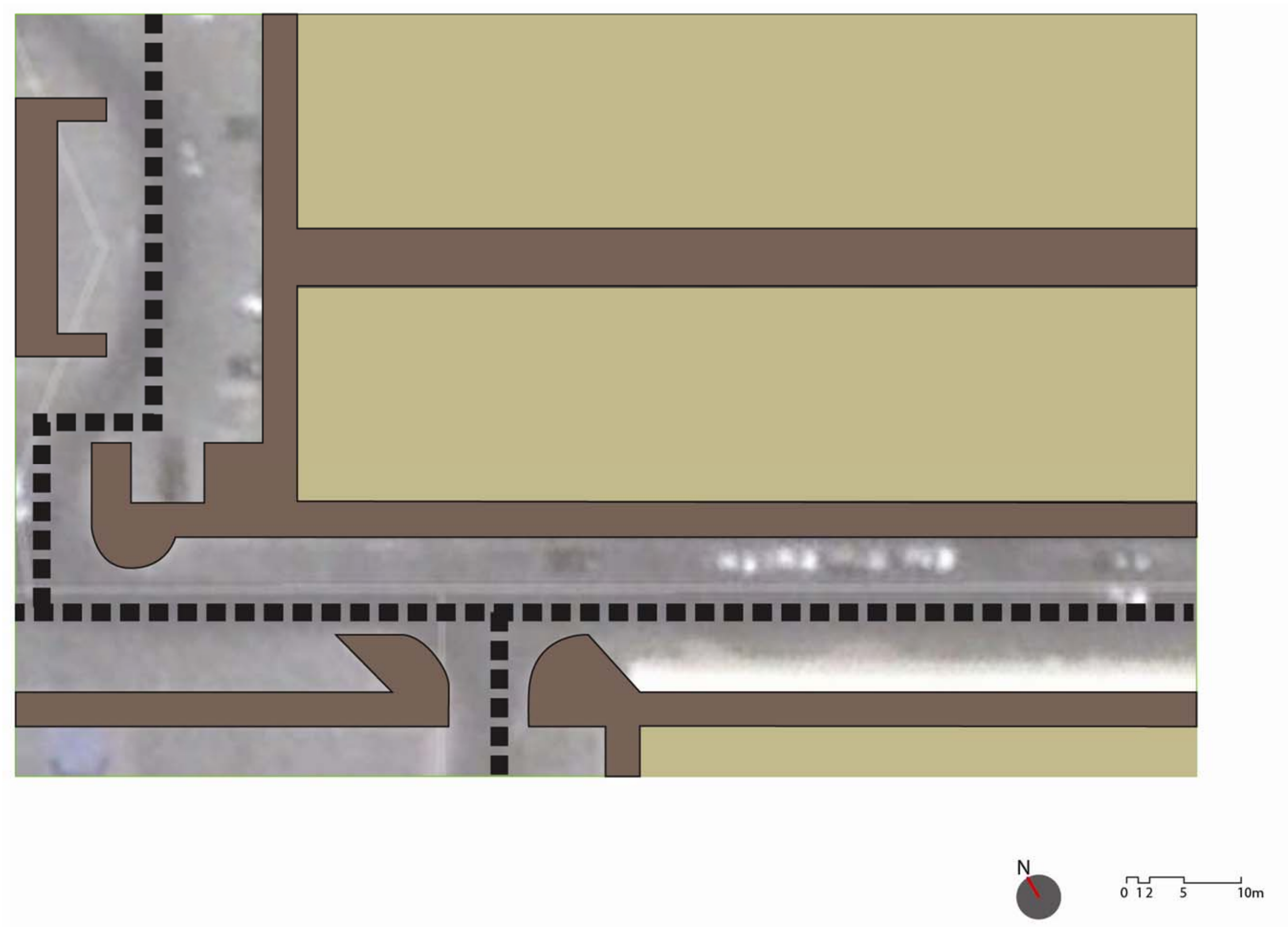


Figure 7: Al Karama Street- Scenario 1 – K1

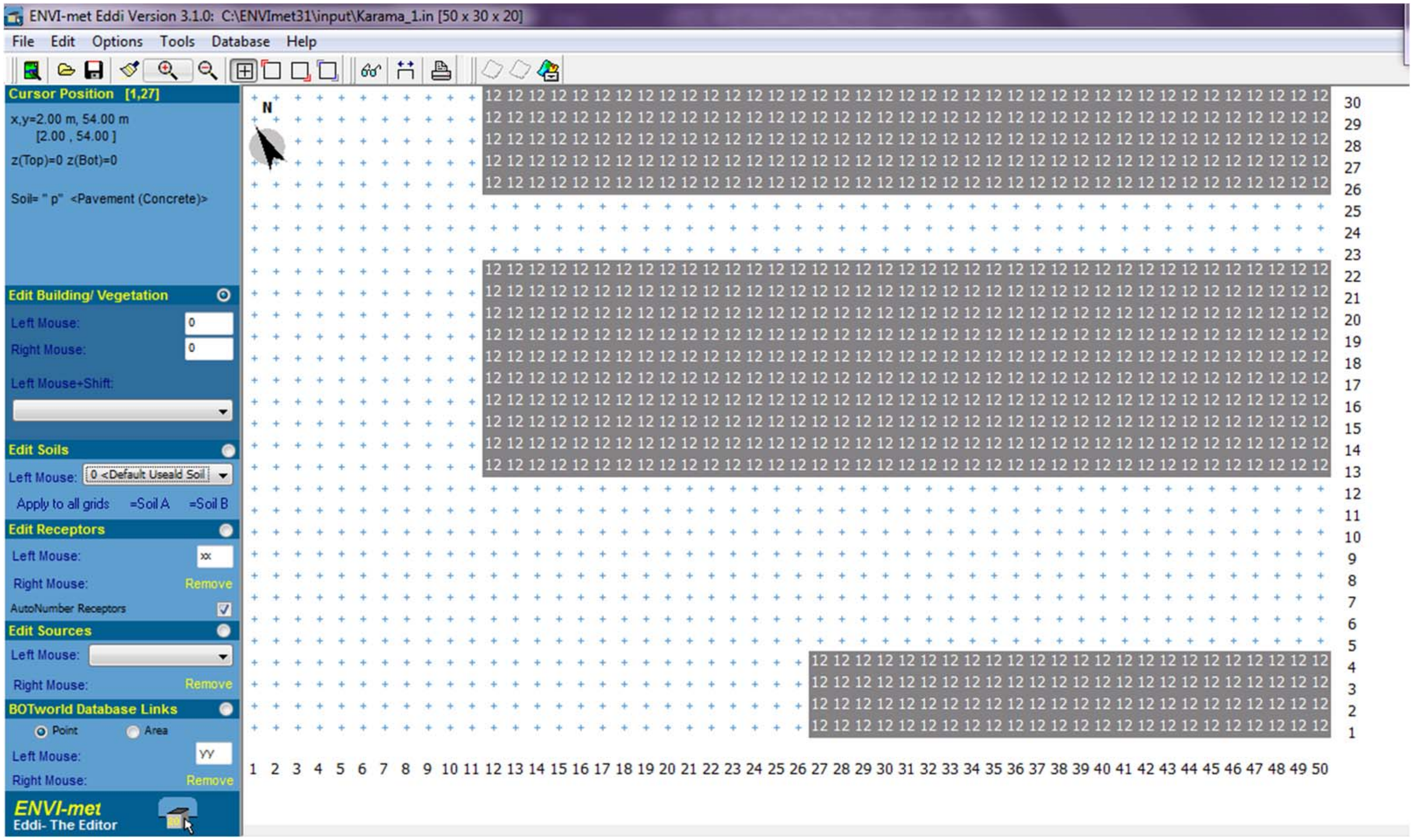



Figure 8: Al Karama Street- Scenario 1 – K1- ENVI-met

### 3.7.2 Scenario 2

Scenario 2 makes alteration to the existing conditions with respect to the treatment of the streets with landscape as discussed in the following:

Location 1- G2 - date palm trees were removed and landscaped area with grass cover was replaced with sand.

Location 2 - K2- Street trees were added with hedges and simulation was run to assess the change in the ambient temperature.

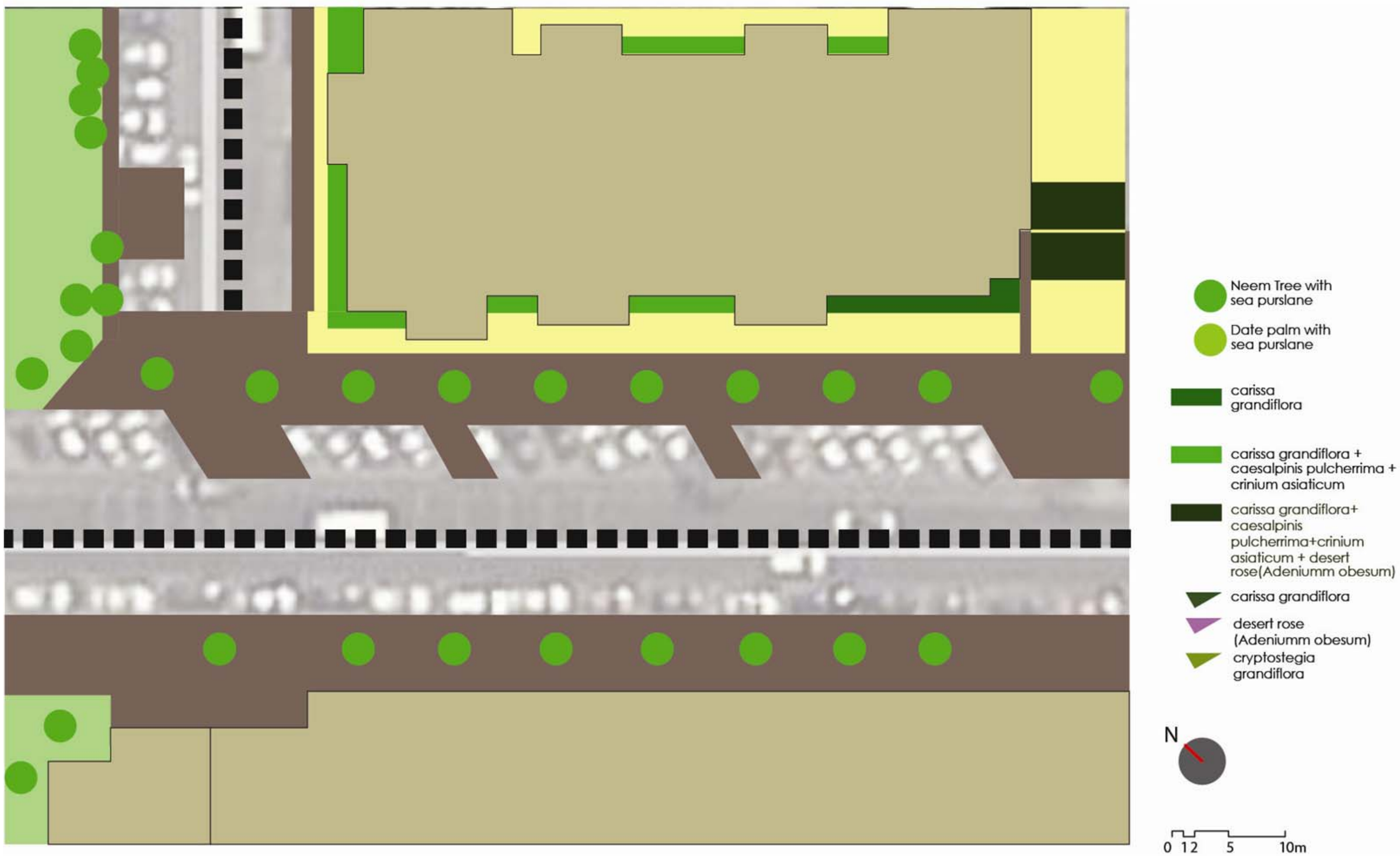



Figure 9: The Greens Street- Scenario 2 – G2

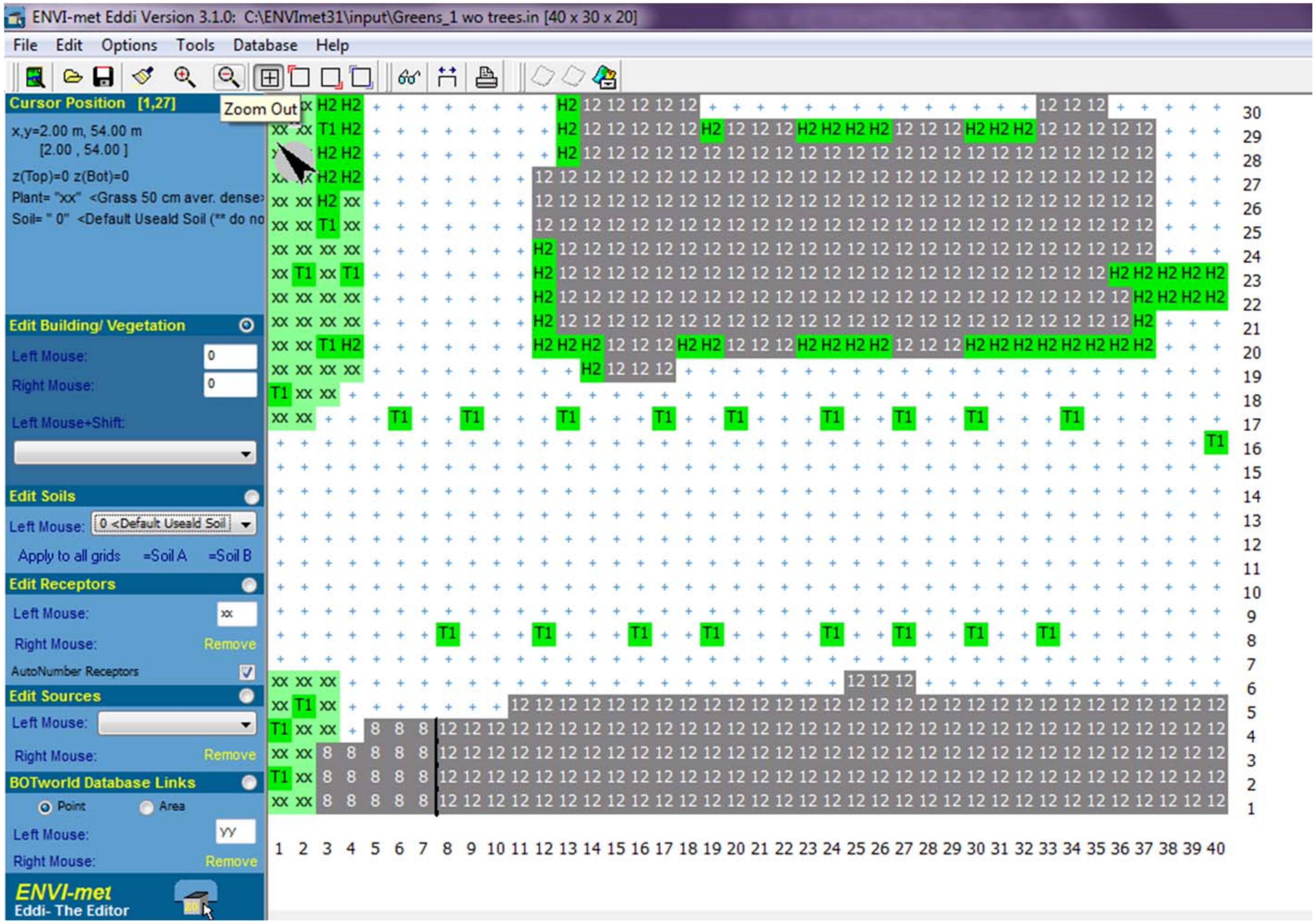


Figure 10: The Greens Street- Scenario 2 – G2 – ENVI-met

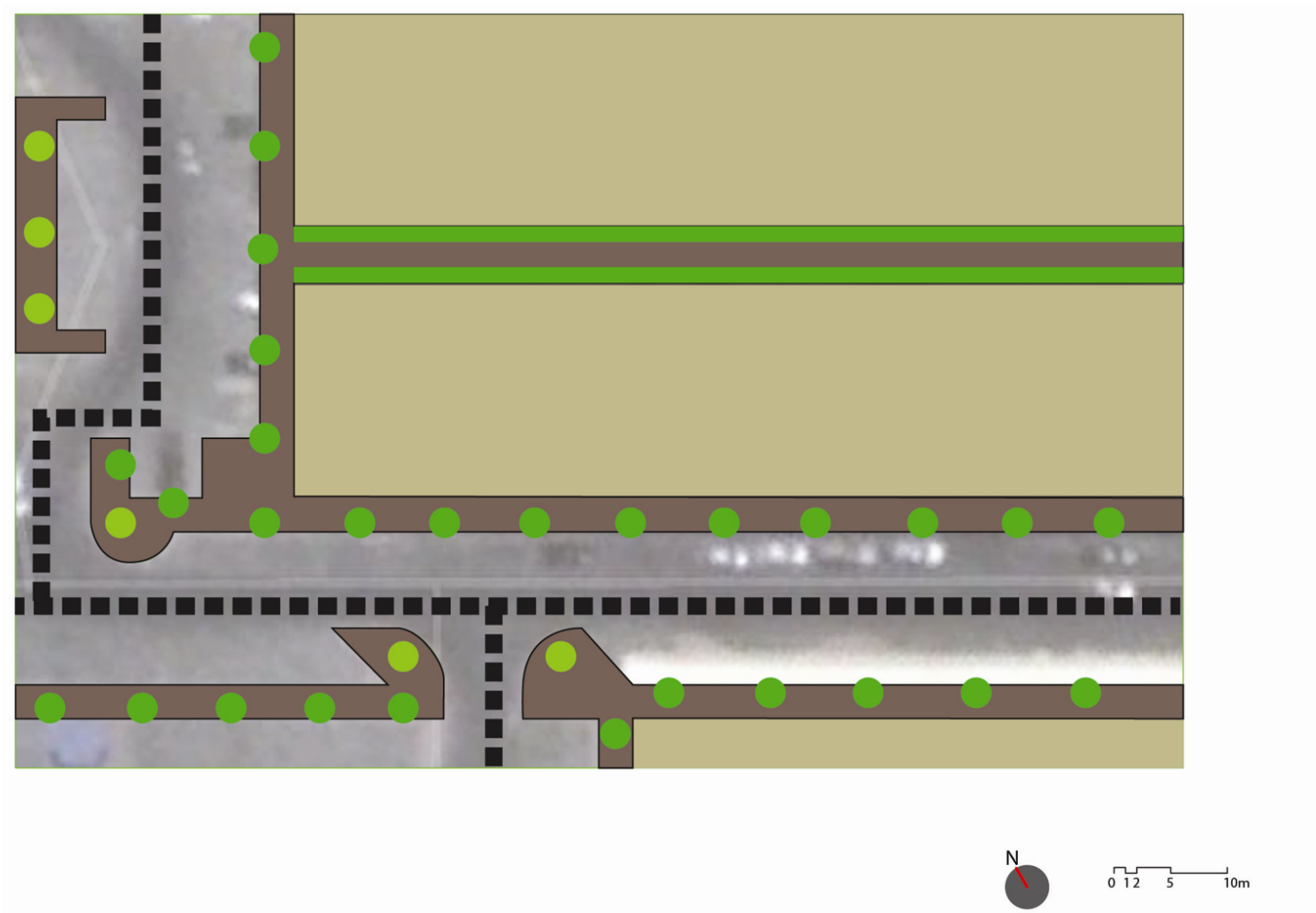



Figure 11: Al Karama Street- Scenario 2 – K2

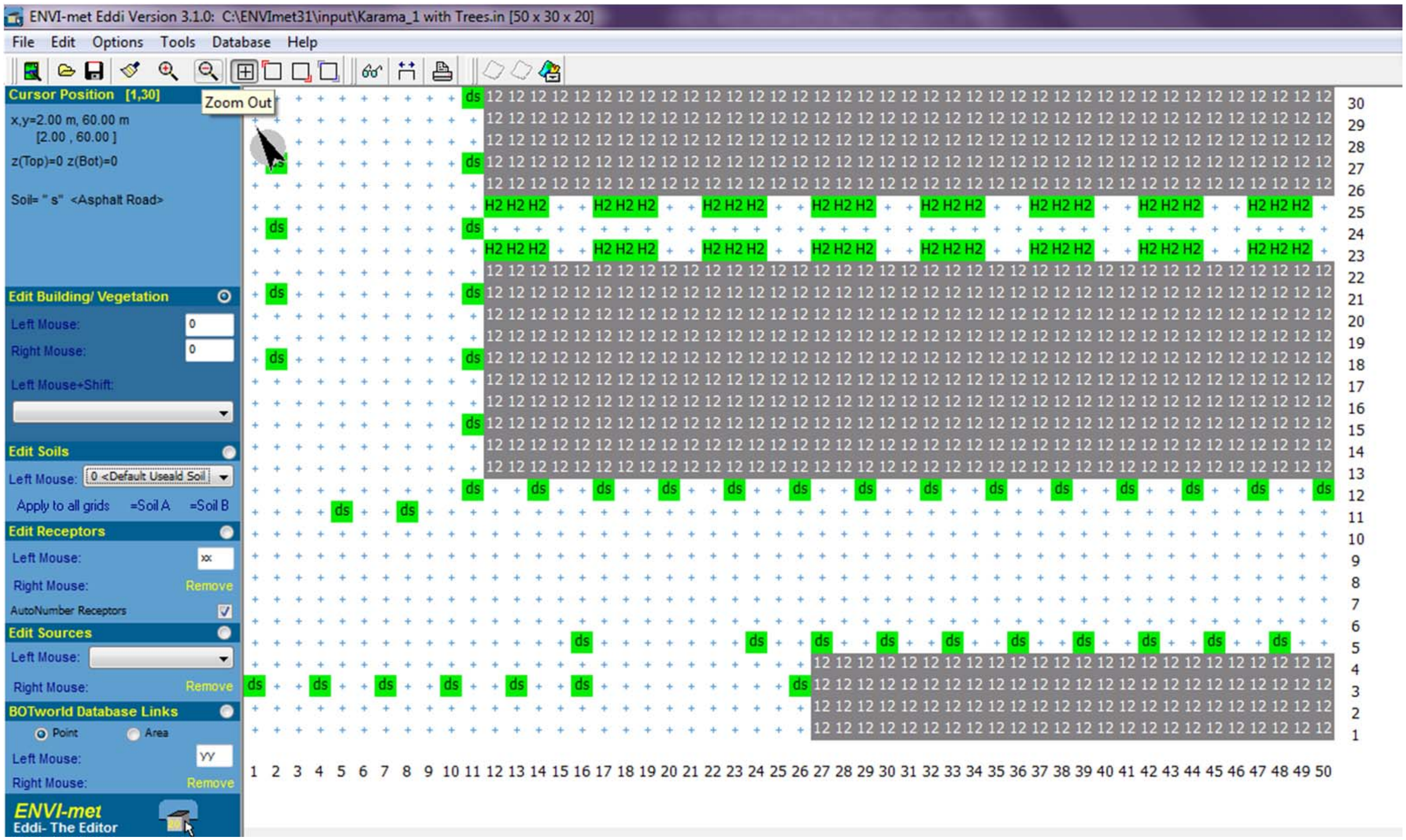



Figure 12: Al Karama Street- Scenario 2 – K2 – ENVI-met

# 4 Results and Analysis

## 4.1 ENVI-met Simulation Results

Every ENVI-met simulation requires a user-specified area input file which defines the 3-dimensional geometry of the study. This includes building dimensions of height and width, soil type and texture, surface treatment and the vegetation types.

For both the locations 'The Greens' and 'Al Karama' four separate area input files were created.

This study applied a local vegetation parameterization scheme based on leaf area densities of typical flora observed in residential landscapes within the two locations of Greens and Karama. Whilst Greens had enough data, Al Karama did not have any vegetation on the street chosen. The size of each individual model grid cell was selected to match the neighborhood spatial scale (2m –X axis, 2m- Y axis, Z axis- 1 m), and the total model environment size was 40x30x20 cells for Greens and 50x30x20 cells for Karama, where each cell represent a unit of 2m in the X and Y directions and 1m in the Z direction.

Each study are also required a configuration file containing the local soil, meteorological and building input data for model initialization. All model simulations were run from 5am to 2200 hours (17 h), with updated surface data every 60 s, starting from sunrise 5 am on June 21 2012. The hours shown in the tables are from 7 am to 6 pm due to the first and last 2 hours were initialization periods which did not have any valid data measured.

The simulation produced the spatial distribution of potential temperatures throughout the model environment, which were then converted to absolute near surface (2 m a.s.l. –above sea level) temperatures ($T_2m$) through Poisson's equation. A comparison between model outputs of each scenario was done with base simulations for the existing land and vegetation parameters.

The vegetation species were parameterized for ENVI-met simulations based on the observed leaf area density (LAD) measurements of mature trees and these data were applied in the simulations.

The results obtained through the simulations were compared in the following order to understand the implications of the vegetation on both the locations.

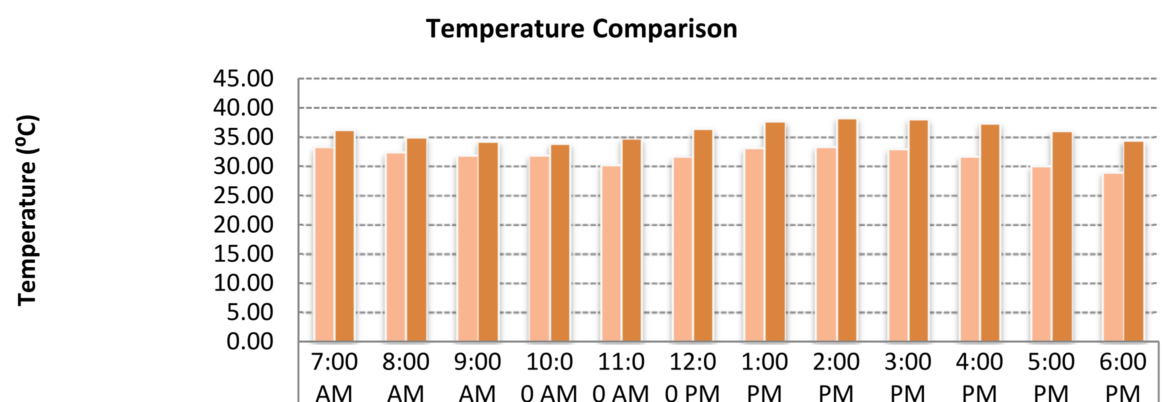
### 4.1.1 Temperature and wind speed comparison between G1 and K1

Scenario 1 for both the locations G and K yielded the following results shown in Table 2. The observed difference in the temperatures between the two locations is 4.9°C at the highest for both at 14:00 hours and 5.35°C at the lowest at 18:00 hours. This is a significant difference between these similar streets, where it is due to the difference in the landscape treatment of the street. The extensive landscaped areas of 'The Greens' comparatively provides much cooler ambient temperature than the landscape void area of Karama. It can also be discussed at this point that due to the prominence of asphalted roads and built forms which radiates heat back into the air adds to the increase in the ambient temperature. Since the process of evapotranspiration is close to zero in Al Karama, the air in this area is expected to be dry and laden with dust.

From this result it can be inferred that vegetation does play a major role in reducing the temperature in a given area through the process of evapotranspiration and also enables the air to permeate the foliage to reduce the dust contained in it.

Other factors like the direction of the wind, the shading from the buildings, the building materials, could also influence the temperatures but have not been considered for this study.

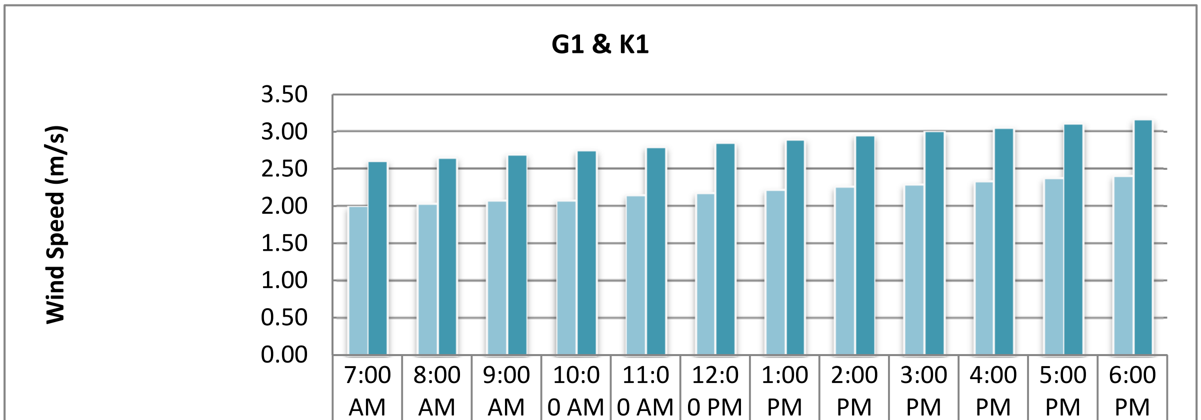
The street is south-facing as mentioned earlier, while Greens is at 45° from the true North; Karama is at 60° from the true North. This difference is considered for the simulation and may also have impacted the temperature difference.




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 - Temperature (°C) | 33.30 | 32.38 | 31.84 | 31.84 | 30.31 | 31.66 | 33.18 | 33.43 | 32.99 | 31.72 | 30.14 | 29.09 |
| K1 - Temperature (°C) | 36.32 | 35.00 | 34.22 | 33.93 | 34.75 | 36.42 | 37.74 | 38.30 | 38.06 | 37.37 | 36.08 | 34.44 |

Table 3: Temperature Comparison between G1 and K1. Temperature difference varies from 3°C to 5°C between G1 & K1

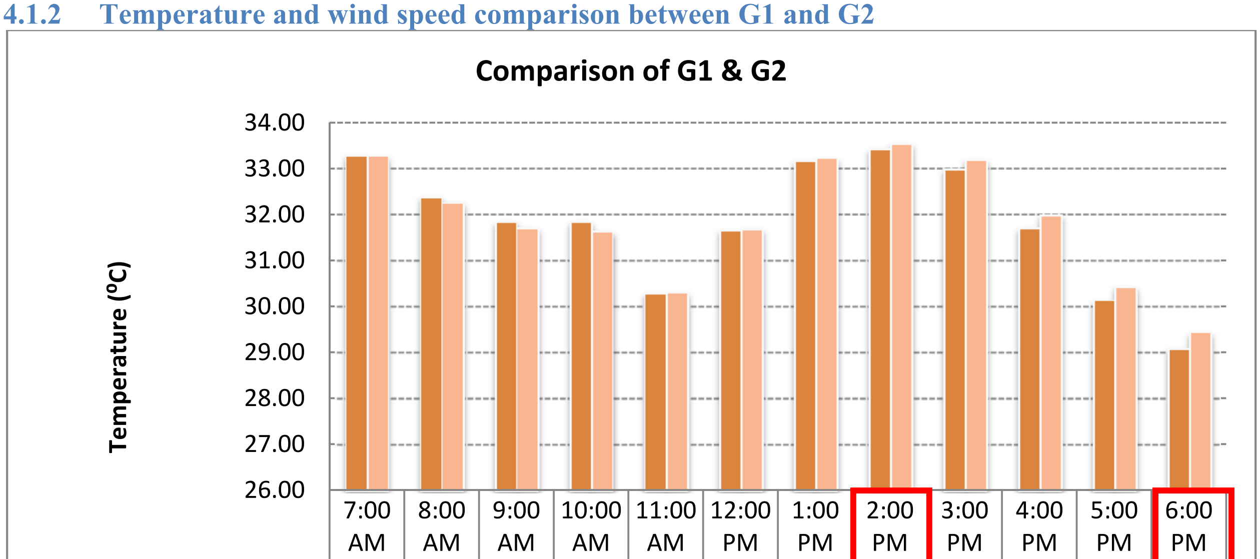
The wind speeds at these locations are also presented in Table 3. The average 0.7 m/s difference in the wind speed between the two locations is the influence of the plants where the permeability factor of the vegetation is vital. Studies indicate that the temperatures are influenced by the speed of the wind. However, in the study  the higher wind speeds in Karama does not reduce the temperature as can be seen when comparing the temperature and the corresponding wind speeds from Table 1 and 2 respectively.




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 - Wind Speed (m/s) | 2.00 | 2.04 | 2.07 | 2.07 | 2.15 | 2.19 | 2.22 | 2.26 | 2.30 | 2.34 | 2.37 | 2.41 |
| K1-Wind Speed (m/s) | 2.608 | 2.652 | 2.699 | 2.749 | 2.799 | 2.850 | 2.900 | 2.951 | 3.003 | 3.056 | 3.109 | 3.161 |

Table 4: Wind Speed Comparison between G1 and K1.

### 4.1.2 Temperature and wind speed comparison between G1 and G2

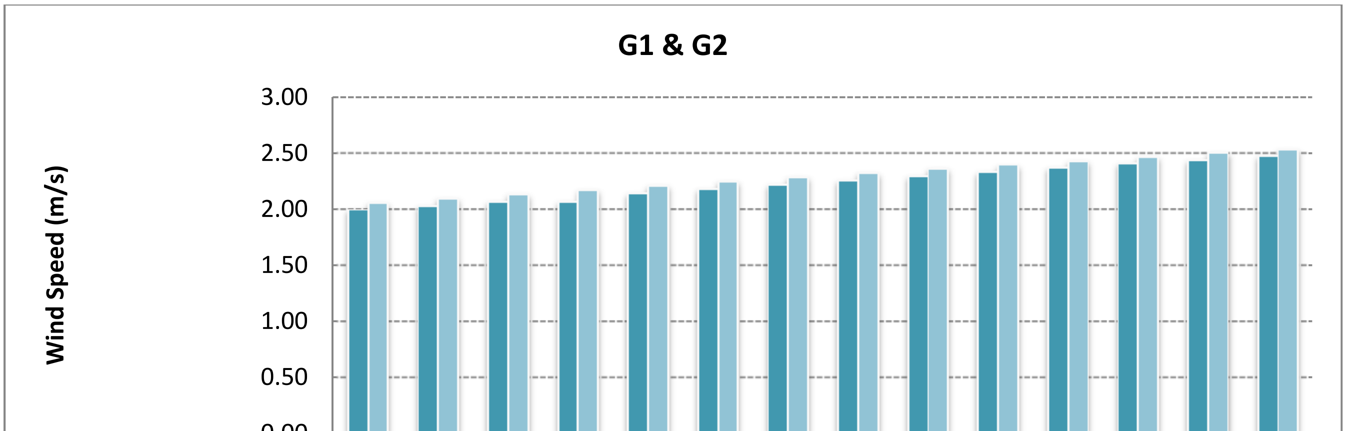



| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 - Temperature (°C) | 33.30 | 32.38 | 31.84 | 31.84 | 30.31 | 31.66 | 33.18 | 33.43 | 32.99 | 31.72 | 30.14 | 29.09 |
| G2 - Temperature (°C) | 33.28 | 32.26 | 31.71 | 31.64 | 30.32 | 31.69 | 33.23 | 33.54 | 33.20 | 32.00 | 30.43 | 29.45 |

Table 5: Temperature Comparison between G1 and G2. Temperature difference varies from 0.08° - 0.2 °C from the morning to the evening hours

Table 4 compares the temperatures for the Greens for between the existing conditions to that of the altered condition- Scenario 2 which is replacing the existing Bermuda grass with sand and removing the date palms. The highest temperature at 14:00 hours shows a variation of 0.1°C while the lowest temperature at 18:00 hours shows a difference of 0.36°C.

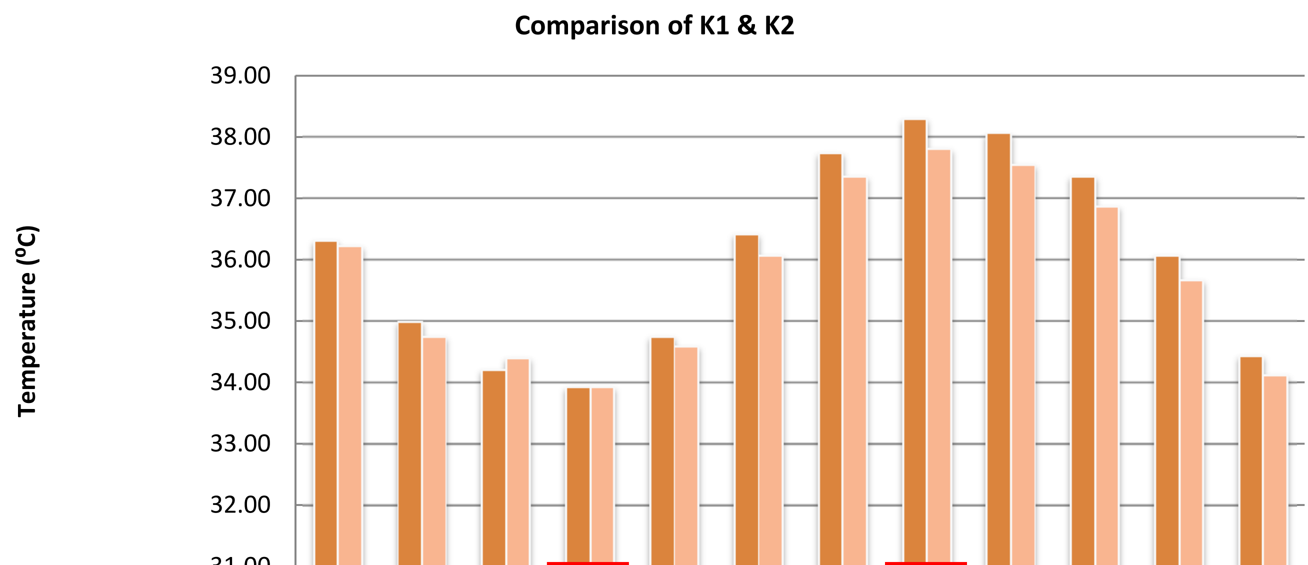
This result above further confirms the role plants have in altering the temperature at the subject area. However, this change is insignificant when compared to the reduction in the irrigation requirements which is explained in section 5.2. With the changes made in Scenario 2 the wind speed have an average change of 0.05 m/s as shown in Table 5.




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM | 7:00 PM | 8:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 - Wind Speed (m/s) | 2.00 | 2.04 | 2.07 | 2.07 | 2.15 | 2.19 | 2.22 | 2.26 | 2.30 | 2.34 | 2.37 | 2.41 | 2.44 | 2.48 |
| G2 - Wind Speed (m/s) | 2.063 | 2.101 | 2.138 | 2.176 | 2.214 | 2.251 | 2.288 | 2.325 | 2.362 | 2.398 | 2.434 | 2.470 | 2.504 | 2.538 |

Table 6: Wind Speed Comparison between G1 and G2.

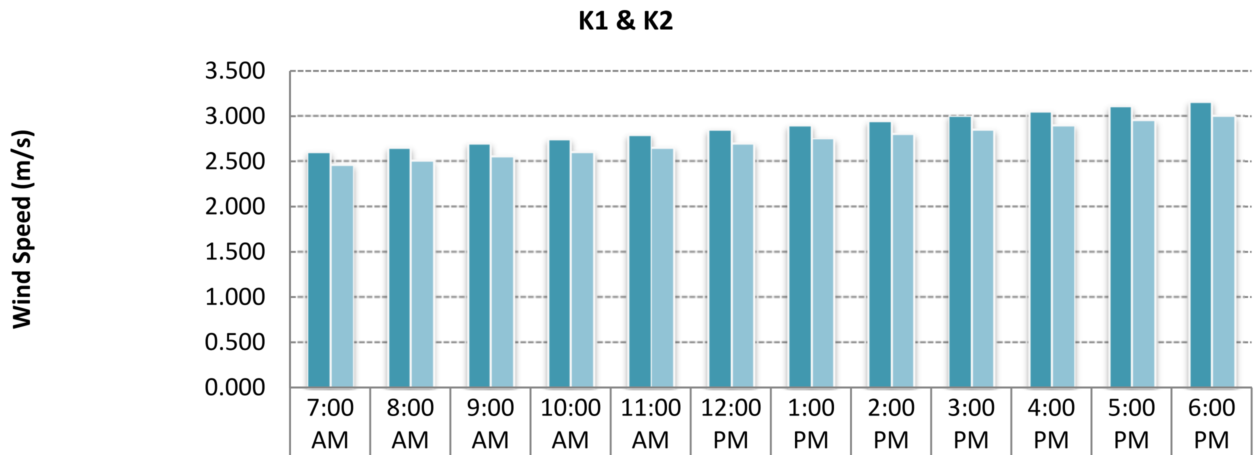
### 4.1.3 Temperature and wind speed comparison between K1 and K2




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K1 - Temperature (°C) | 36.32 | 35.00 | 34.22 | 33.93 | 34.75 | 36.42 | 37.74 | 38.30 | 38.06 | 37.37 | 36.08 | 34.44 |
| K2 - Temperature (°C) | 36.23 | 34.75 | 34.40 | 33.93 | 34.60 | 36.08 | 37.36 | 37.81 | 37.55 | 36.87 | 35.67 | 34.13 |

Table 7: Temperature Comparison between K1 & K2. Temperature difference varies from 0.09°C to 0.5°C between K1 & K2

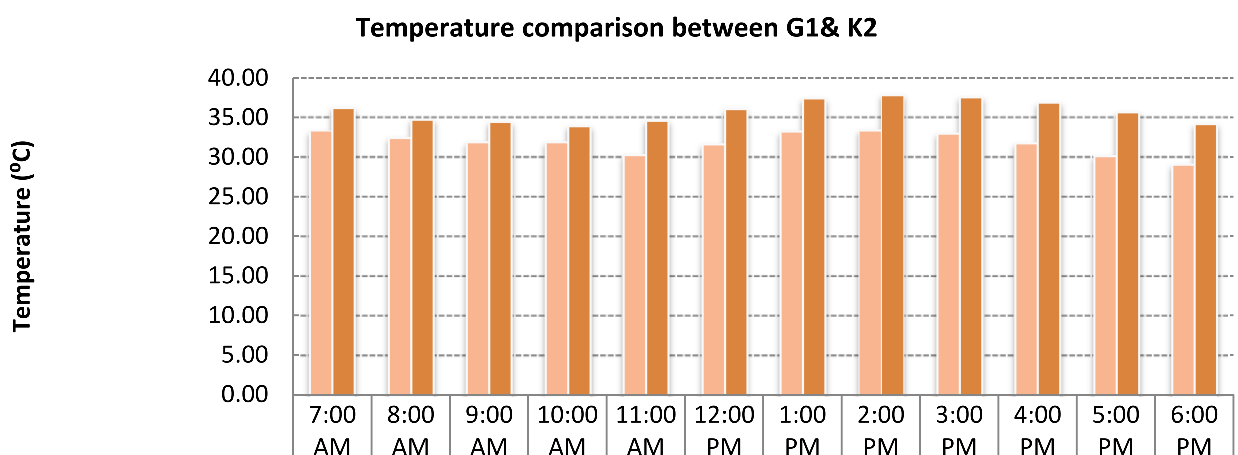
The temperature comparison of Karama between the existing condition and the altered condition of Scenario 2 where the date palm and neem tree species of trees were planted at spacing similar to the Greens areas and inclusion of hedges which included the sea purslane and natal plum at the spaces in between the buildings, indicates that a temperature difference of average 0.5°C. As can be seen from the table the difference in temperature is not significant during the time from 9:00 – 11:00 am. This can be attributed to the fact that other factors besides vegetation also impact the temperature. The significant reduction of 0.5°C is at 14:00 h which indicates the highest temperature of the day and continues through the evening. This infers that while other factors are involved in reducing temperature plants also play a significant role when the temperatures are at the highest. This again confirms the influence of the vegetation on temperature of the subject area.




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| K1-Wind Speed (m/s) | 2.608 | 2.652 | 2.699 | 2.749 | 2.799 | 2.850 | 2.900 | 2.951 | 3.003 | 3.056 | 3.109 | 3.161 |
| K2- Wind Speed (m/s) | 2.466 | 2.510 | 2.557 | 2.606 | 2.656 | 2.706 | 2.756 | 2.806 | 2.856 | 2.907 | 2.959 | 3.006 |

Table 8: Wind Speed Comparison between K1 and K2.

The wind speeds differed at an average of 0.1 m/s between the two scenarios, which indicates that permeability of the vegetation does bring about a change in the wind speed. As discussed earlier, the effect of wind and its speed is not included in the scope of this study. The results have been shown to imply that vegetation can also influence the wind speeds which may have impacts on the temperature. This is recommended for further studies.




| | 7:00 AM | 8:00 AM | 9:00 AM | 10:00 AM | 11:00 AM | 12:00 PM | 1:00 PM | 2:00 PM | 3:00 PM | 4:00 PM | 5:00 PM | 6:00 PM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| G1 - Temperature ($^{0}$C) | 33.30 | 32.38 | 31.84 | 31.84 | 30.31 | 31.66 | 33.18 | 33.43 | 32.99 | 31.72 | 30.14 | 29.09 |
| K2 - Temperature ($^{0}$C) | 36.23 | 34.75 | 34.40 | 33.93 | 34.60 | 36.08 | 37.36 | 37.81 | 37.55 | 36.87 | 35.67 | 34.13 |

Table 9: Temperature Comparison between G1 and K2. Temperature difference varies from 3°C to 5°C between G1 & K2

Table 8 compares the existing Scenario 1 of The Greens to the modified Scenario 2 of Al Karama, and it has been observed that the temperature variation between these have remained the same, which implies that a significant reduction in temperature can be attained with more extensive landscape treatment, but from the study it is found that this will increase the water consumption for which the existing conditions in Karama has no water consumption. The treatment of the pedestrian area can contribute to the temperature reduction which for cooler surface should have high -albedo material that have a high solar reflective index (SRI) over 25. This property of the material indicates the amount of solar radiation the material can reflect back without absorbing it.

## 4.2 Irrigation water requirements calculations

### 4.2.1 The Greens

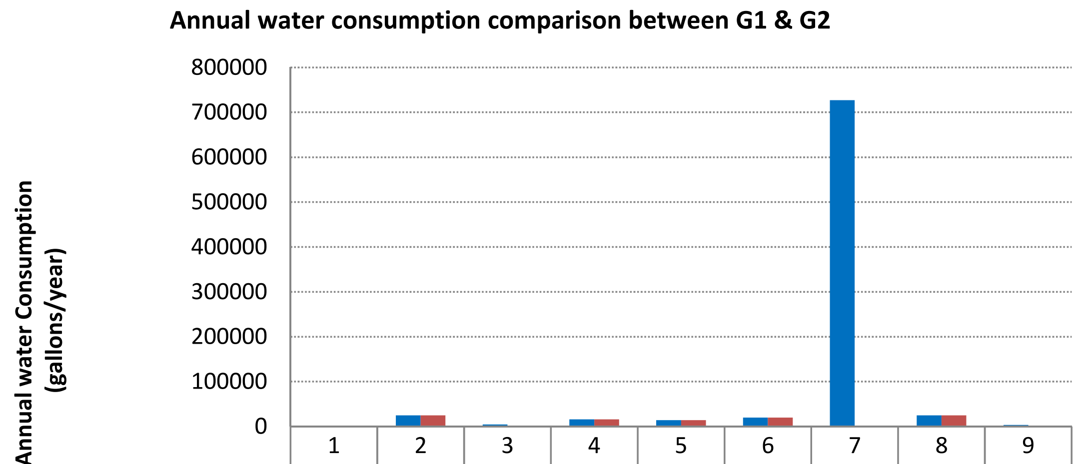
The irrigation requirements were calculated annually in gallons as described in section 4.4. As is observed in Table 8 for Scenario 1 – G1, the highest water consumption is taken up by the ground cover species Bermuda grass – 727, 342 gallons/ year. The largest area is also covered by this ground cover. The total irrigation requirement for the subject area Greens 1 is 837,178 gallons/ year.

In Scenario 2 this Bermuda grass is replaced with sand and the date palm is also removed to check if this impacts the water consumption. The result yielded indicates (Table 9) a significant reduction in irrigation requirements of about 737,730 gallons/ year. This substantial water savings from Scenario 2 would thus be beneficial for improving the sustainability.

This is compared against the temperature difference explained in Section 5.1.2.

| No. | Species - Botanical name | Common name | Local name | Size | Requirements | Type | Landscape Area | | | Calculation | | | | Scene 1 - G1 | Scene 2 - G2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | | Nos. | sq.m. | sq.ft. | Planting density | Microclimate | Annual irrigaton factor | Irrigation system efficiency | Annual landscape water use | Annual landscape water use |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | Tree | 6 | 24 | 258.3 | avg | intense exposure | 7.83 | 85% | 2380 | |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | Tree | 30 | 120 | 1291.7 | high | intense exposure | 16.29 | 85% | 24754 | 24754 |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | Shrub | | 27.5 | 296.0 | low | intense exposure | 13 | 85% | 4527 | |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise, peacock flower, pride of barbados | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | Shrub | | 42.5 | 457.5 | low | intense exposure | 29.5 | 85% | 15877 | 15877 |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | Ground cover | | 144 | 1550.0 | avg | intense exposure | 7.83 | 85% | 14278 | 14278 |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | Shrub | | 92.5 | 995.7 | avg | intense exposure | 16.97 | 85% | 19878 | 19878 |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | Ground cover | | 825 | 8880.2 | high | intense exposure | 69.62 | 85% | 727342 | |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | Ground cover | | 42.5 | 457.5 | low | intense exposure | 45.82 | 85% | 24660 | 24660 |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | Shrub | | 6 | 64.6 | low | intense exposure | 45.82 | 85% | 3481 | |
| | | | | | | | | | | | | | | 837178 | 99448 |
| | | | | | | | | | | | | | | | 737730 |

Table 10: Plant Species water calculation for The Greens – Scenario 1 & 2




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| Scene 1 - G1 Annual landscape water use | 2380 | 24754 | 4527 | 15877 | 14278 | 19878 | 727342 | 24660 | 3481 |
| Scene 2 - G2 Annual landscape water use | | 24754 | | 15877 | 14278 | 19878 | | 24660 | |

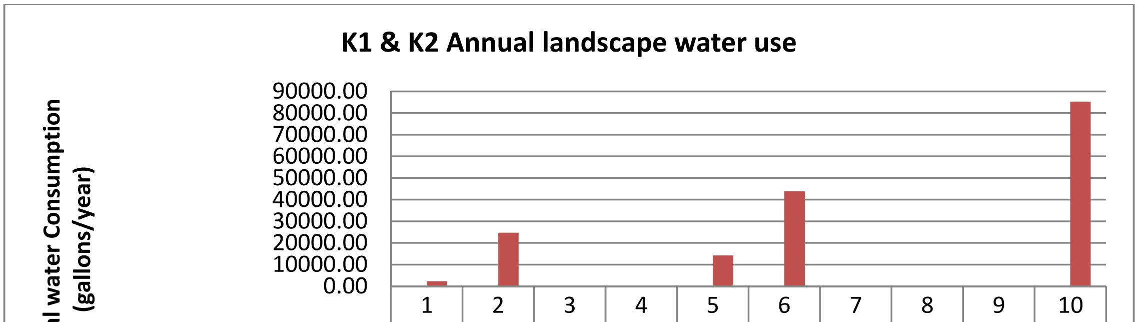
Table 11: Plant Species water calculation for The Greens – Scenario 1 & 2

### 4.2.2 Al - Karama

| No. | Species - Botanical name | Common name | Local name | Size | Requireme | Type | Landscape Area | | | Calculation | | | | Scene 1 - K1 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | | Nos. | sq.ft. | K2 sq.ft. | Planting density | Microclimate | Annual irrigaton factor | Irrigation system efficiency | Annual landscape water use | Annual landscape water use |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | Tree | 6 | 258.3 | | avg | intense exposure | 7.83 | 85% | 0.00 | 2380 |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | Tree | 30 | 1291.7 | | high | intense exposure | 16.29 | 85% | 0.00 | 24754 |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | Shrub | | 296.0 | | low | intense exposure | 13 | 85% | 0.00 | |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise, peacock flower, pride of barbados | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | Shrub | | 457.5 | | low | intense exposure | 29.5 | 85% | 0.00 | |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | Ground cover | | 1550.0 | | avg | intense exposure | 7.83 | 85% | 0.00 | 14278 |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | Shrub | | 995.7 | 2195.8 | avg | intense exposure | 16.97 | 85% | 0.00 | 43839 |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | Ground cover | | 8880.2 | | high | intense exposure | 69.62 | 85% | 0.00 | |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | Ground cover | | 457.5 | | low | intense exposure | 45.82 | 85% | 0.00 | |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | Shrub | | 64.6 | | low | intense exposure | 45.82 | 85% | 0.00 | |
| | | | | | | | | | | | | | | 0.00 | 85252 |

Table 12: Plant Species water calculation for Al Karama– Scenario 1 & 2

The altered Scenario 2 for Al Karama introduced the species of date palm and neem tree for trees and Sea purlane and Natal plum for the hedges. From the existing conditions of no vegetation and therefore no irrigation requirement, the altered scenario has a requirement of 85,251 gallons/ year. This is then compared to the temperature alteration to understand if the vegetation had any impact.




| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Scene 1 - K1 Annual landscape water use | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Scene 2 - K2 Annual landscape water use | 2380 | 24754 | | | 14278 | 43839 | | | | 85252 |

Table 13: Plant Species water calculation for Al Karama– Scenario 1 & 2

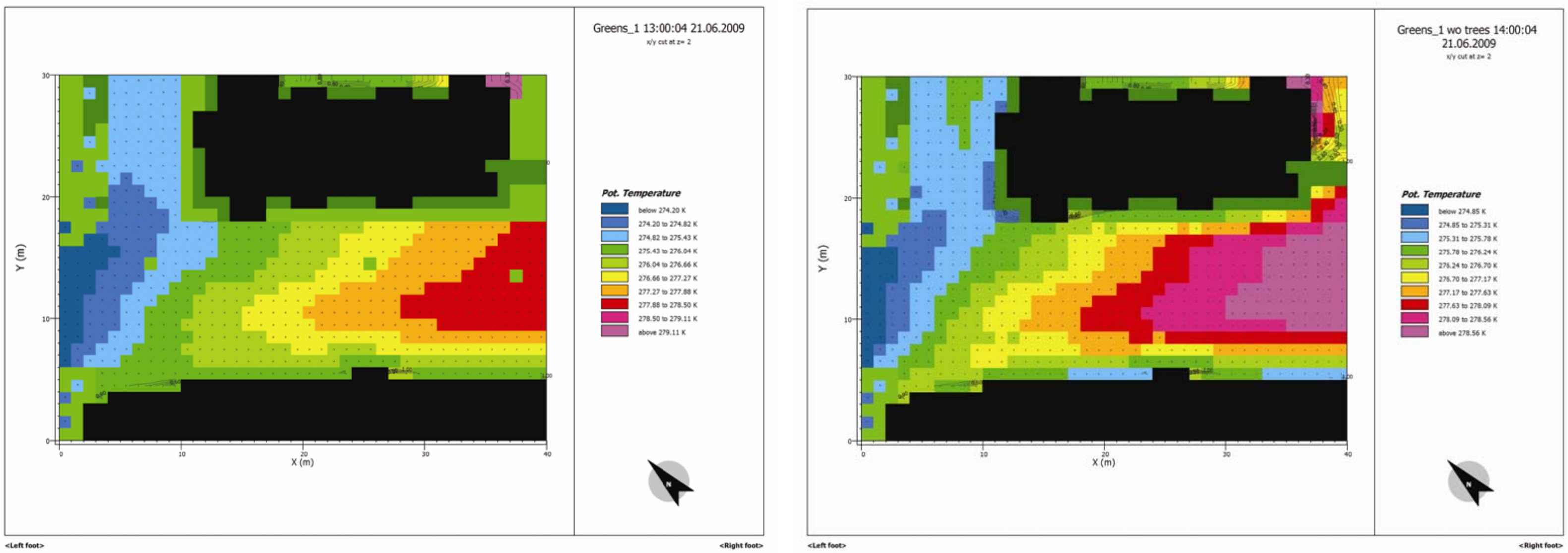



Figure 13: LEONARDO visualizations of the derived results from ENVI-met. This shows the results from at 2pm on 21 June for the ‘The Greens’ for G1 & G2

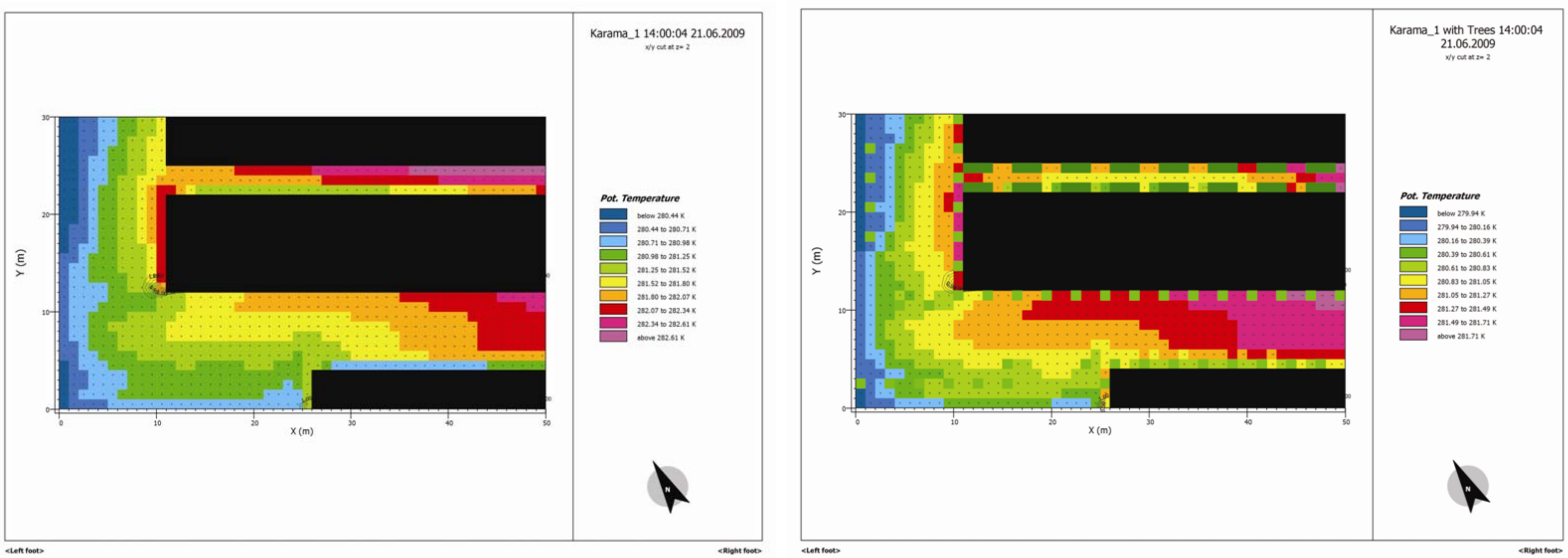



Figure 14: LEONARDO visualizations of the derived results from ENVI-met. This shows the results from at 2pm on 21 June for the 'Al Karama' for K1 & K2

# 5 Conclusions and Recommendations

From the results obtained and analyzed, this study intends to explain the main findings and correlate it to the research questions that were initiated at the beginning of this study.

The primary aim was to understand if a balance between temperature reduction and water consumption of the planted landscapes can be achieved in the urban environment at a neighborhood scale in the emirate of Dubai.

From the study it is evident that landscape impacts the temperature and helps to reduce it, subsequently creating a balance in the water consumption is possible through thoughtful selection of the species and also by the treatment of the ground. It has been observed from the results that native or adaptive species can be used to create this balance, due to their lower rates on water consumption.

How sustainable are the landscapes of Dubai's residential communities?

The landscape in the selected neighborhood of Greens has been observed to be extensive corresponding to a high amount of water consumption. When the alteration was made the water consumption was significantly reduced.

What factors should be considered for creating these sustainable green spaces?

Thoughtful selection of the plant species and grouping of the species based on their water requirements can ensure maximum benefit from these plants while making them sustainable in the long term.

The main findings are as follows:

| Location | G1 | G2 | K1 | K2 | Difference |
|---|---|---|---|---|---|
| Average Temperature (°C) | 31.82 | 31.90 | 36.05 | 35.78 | G1-G2 = -0.08°C<br>K1- K2 = +0.27°C |
| Irrigation Requirements (g/year) | 837,178 | 99,448 | 0 | 85,252 | G1-G2 = +737,730<br>K1- K2 = - 85,252 |

Table 14: Comparison of temperature and water consumption of The Greens and Al Karama in both Scenario 1 & 2.

Table 13 summarizes the main findings of this study which implies that for the location 'The Greens' the temperature is raised by 0.08°C when the landscape design is altered which subsequent decrease in annual irrigation requirement of a significant amount of 737,730 gallons/ year. This significant reduction in water consumption explains that the choice of vegetation species and the treatment of the open spaces can help in achieving optimal temperatures with minimal water requirements.

The comparison of Scenarios in Al Karama indicates that including vegetation to the street has reduced the average temperature by 0.27°C whilst the annual irrigation requirement is now 85,252 gallons/ year.

Therefore from the above findings it can be inferred that temperature reductions occur with vegetation, because of the evapotranspiration process of these plants which releases moisture into the air which then cools the air that it surrounds. This process of evapotranspiration requires transfer of water from the leaves of the plants, which means this is provided by the water that is supplied to the plants. These processes are interrelated and hence the irrigation requirements of the species are a determining factor for how temperature reductions occur.

Water consumption is dependent on the species of the plant and by using a combination of native and adaptive species proves useful in reducing the water consumptions. The irrigation system is also crucial in determining the water consumption due to the efficiency of the system.

Temperature reductions are dependent on many factors besides the landscape alone. Though vegetation has a major contribution, the landscape treatment, landscape materials and the spread of trees and plants can have influence on the temperature. There are numerous studies that have researched this and it still continues to be researched.

This study has tried to explain how landscapes in Dubai can have impact on the temperature and the water usage in a neighborhood, which intends to guide professionals in the related field to provide thoughtful planning measures in these open areas which can contribute to all aspects of sustainability. The improvement in the quality of life of the residents can be achieved through providing these open spaces as buffer zones that can prevent them from the scorching sun during summer. The energy consumption in these residential areas can be reduced due to the reduced temperature which translates into economic benefits for both the residents and also the government. The aesthetics of landscape is a well-studied area and the influence it has over environment is manifold. These landscaped areas create eco-systems and enhances the bio-diversity of the area. This treatment also reduces the urban heat island effect and becomes a sink for the green house gas emissions.

The methodology of this study has not been combined with field measurements to validate the results obtained through ENVI-met simulations. Therefore it recommended to conduct future research which includes field measurements.

This study has only considered the summer condition since it is the harshest than the other seasons. Therefore this study can be further investigated to include the field measurements during different seasons to better understand the intertwined and intricate relationships and interactions of the landscaped opens spaces with the environment.

Using this study as a basis, further research can be done to identify the other factors that can influence the temperature like the shading from the building during the different times of the day, as is seen in the results where no change in temperature occurred even with the addition of plants.

Ong, (2003) states that carbon storage and sequestration are directly associated to plant metabolism and photosynthesis in particular , therefore using this study as a basis further research can be done to understand which other benefits can be derived from these landscaped areas.

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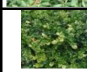
# 7 Appendix

Appendix 1 – Plant Species

Appendix 2 – Guidelines for Estimating Unmetered Landscaping Water Use

Appendix 3– Water Calculations for ‘The Greens’ –G

Appendix 4– Water Calculations for ‘Al Karama’ –K

| No. | Species - Botanical name | Common name | Local name | Size | Requirements | | Tolerance | | | Type | Image |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | Light | Wind | Salinity | Drought | | |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | high | high | high | high | Tree |  |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | high | high | medium | high | Tree |  |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | high | high | medium | high | Shrub |  |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise, peacock flower, pride of barbados | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | high | medium | medium | low | Shrub |  |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | high | high | low | high | Ground cover |  |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | high | high | medium | medium | Shrub |  |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | high | high | high | high | Ground cover |  |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | medium | low | low | low | Ground cover |  |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | high | high | low | low | Shrub |  |

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
FEDERAL ENERGY MANAGEMENT PROGRAM

# Guidelines for Estimating Unmetered Landscaping Water Use

FEMP Federal Energy Management Program

July 2010

# Summary

Executive Order 13514 requires Federal agencies to develop a baseline for industrial, landscaping, and agricultural water use in fiscal year 2010. Measuring actual water use through flow meters is the best method to develop this baseline. But there are instances where Federal sites do not meter these applications, so developing a baseline will be problematic. Therefore the intent of this document is to assist Federal agencies in the baseline development by providing a methodology to calculate unmetered sources of landscaping water use utilizing engineering estimates.

The document lays-out step by step instructions to estimate landscaping water using two alternative approaches: evapotranspiration method and irrigation audit method. The evapotranspiration method option calculates the amount of water needed to maintain a healthy turf or landscaped area for a given location based on the amount of water transpired and evaporated from the plants. The evapotranspiration method offers a relatively easy "one-stop-shop" for Federal agencies to develop an initial estimate of annual landscape water use. The document presents *annual irrigation factors* for 36 cities across the U.S. that represents the gallons of irrigation required per square foot for distinct landscape types. By following the steps outlined in the document, the reader can choose a location that is a close match their location and landscape type to provide a rough estimate of annual irrigation needs without the need to research specific data on their site.

The second option presented in the document is the irrigation audit method, which is the physical measurement of water applied to landscaped areas through irrigation equipment. Steps to perform an irrigation audit are outlined in the document. An irrigation audit requires some knowledge on the specific procedures to accurately estimate how much water is being consumed by the irrigation equipment.

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# Contents

# Figures



# Tables

# 1.0 Background

Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*, was signed on October 5, 2009 by President Obama. EO 13514 has water provisions that require Federal agencies to improve water use efficiency and management as follows:

1. Reduce potable water consumption intensity by 2% annually through fiscal year (FY) 2020, or 26% by the end of fiscal year 2020, relative to a FY 2007 baseline.
2. Reduce agency industrial, landscaping, and agricultural water consumption 2% annually, or 20% by the end of fiscal year 2020, relative to a FY 2010 baseline.

The second provision listed above requires that Federal agencies develop a baseline for industrial, landscaping, and agricultural water use so that all efficiency efforts can be judged against this baseline. Each Federal site must develop a baseline for these industrial, landscaping, and agricultural uses and report the total FY 2010 consumption to their respective agency. Measuring actual water use through flow meters is the best method to develop the FY 2010 baseline. But there are instances where Federal sites do not meter these applications, so developing a baseline will be problematic. If permanent metering is not practical, then a temporary flow meter offers a sound solution. Temporary ultra-sonic flow meters can be installed to the outside of a pipe and do not require a disruption of the process. If large landscapes pull irrigation water from an on-site well that contain reliable pumping records, water use can be estimated by taking the pump flow rate at the given well depth multiplied by the annual runtime.

If these metering options are not applicable or practical and the landscaping water source is not from an on-site well with adequate pumping records, then an engineering estimate must be used to estimate annual water use. Therefore, the intent of this document is to assist Federal agencies in estimating unmetered sources of landscaping water use utilizing engineering estimates[1]. Two approaches are covered in this document:

1. Evapotranspiration Method – estimate of supplemental water requirements based on the amount of water transpired and evaporated from the plants for different locations across the U.S.
2. Irrigation Audit Method – physical measurement of water applied to landscaped areas through irrigation equipment

The evapotranspiration (ET) method provided in this document serves as an initial starting place for estimating landscaping water use baseline whereas the irrigation audit offers a method of spot measuring actual landscape water use. It should be noted that an irrigation audit requires knowledge on how to perform an audit and requires the purchase of some minor equipment. On the other hand, the ET method does not require training or purchase of equipment but does require some basic knowledge of the landscape and the use of specific calculations provided in this document. This document focuses on the ET method because it offers a relatively easy "one-stop-shop" for Federal agencies to develop an initial estimate of annual landscape water use for the FY 2010 baseline. The irrigation audit method is also

[1] Note, the Federal Energy Management Program has produced a companion document that provides a methodology on how to estimate unmetered industrial processes.

discussed so that both options can be considered. Note several assumptions are required to use the ET method in this document; therefore the estimated landscape water use can have a fairly wide range of possible values.

# 2.0 Option 1: Estimating Landscaping Water Use Using the Evapotranspiration Method

The evapotranspiration (ET) method calculates the amount of water needed to maintain a healthy turf or landscaped area for a given location based on the water requirements of the type of plants, specific conditions of the site, and precipitation received by the site.  ET represents the loss of water from the Earth's surface through the combined processes of evaporation (from soil and plant surfaces) and plant transpiration.

## 2.1 Getting Started

This document describes how to estimate annual supplemental irrigation requirements for:

- Cool and warm season turfgrasses
- Low water consuming landscaped area
- Moderate water consuming landscaped areas
- High water consuming landscaped areas

***Annual Irrigation Factor***:  This document provides *annual irrigation factors* for 36 cities across the U.S. that represents the gallons of irrigation required per square foot for distinct landscape and turf types in corresponding locations (shown in Tables 3 through 6 of this document).  ET and precipitation data was acquired for all 36 U.S. locations to estimate these annual irrigation factors.   Multiplying the appropriate factor by the square footage of your landscape or turfgrass area and dividing this value by the system efficiency will provide you an estimate of the annual irrigation requirements for a given location.  Through the process described in this document, you can estimate your irrigation requirements by choosing a U.S. location that closely matches your area.  This will give you an initial estimate for your landscaping water use baseline without the need to research and investigate your local ET and precipitation data*.

** The Appendix provides detailed information on how the annual irrigation factors were developed. If you want to calculate a more precise annual irrigation factor instead of choosing one from the 36 cities that are provided in Tables 3 through 6, collect local ET and precipitation data on your location for FY 2010 and follow the process in the Appendix.*

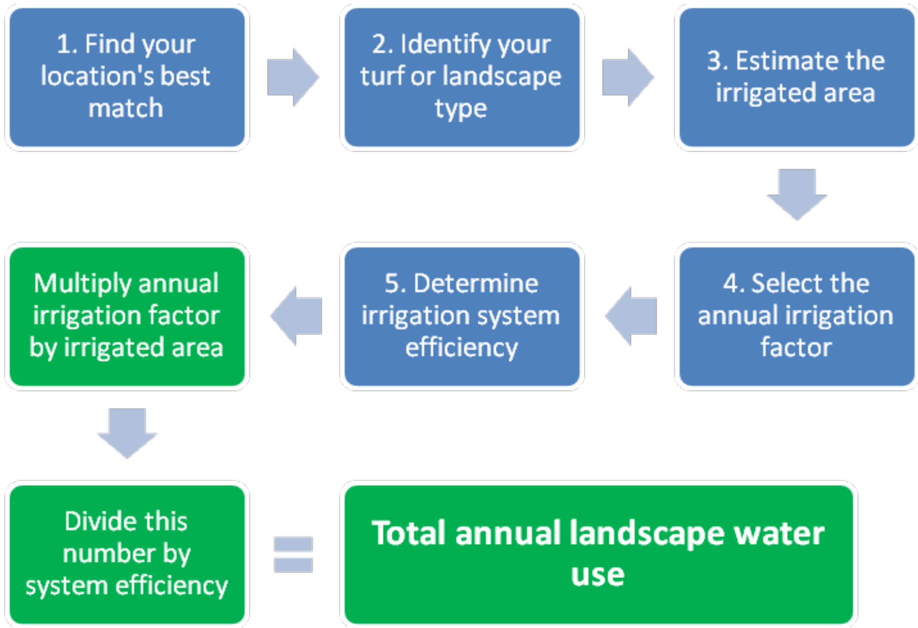
To use the process laid out in the document, you will need to perform six key steps to estimate your total annual landscaping water use:

1. Find the best match to your location
2. Identify your turf and landscape area type
3. Estimate your square footage of turf and landscaped areas
4. Select the appropriate annual irrigation factor from the tables in the document
5. Determine the irrigation system efficiency
6. Calculate your total annual irrigation

This information is utilized to estimate the total annual landscape water use by using the following formula:

$$Annual\ Landscape\ Water\ Use\ (gallons\ per\ year) = \frac{Annual\ Irrigation\ Factor\ \left(\frac{gal}{sqft - yr}\right) \times Irrigation\ Area\ (sqft)}{Irrigation\ System\ Efficiency}$$

These steps are outlined in the flowchart below:




The remainder of this section takes you through these steps.

## 2.2 Find the Best Match to your Location

The first step in this process is to pick a city in Figure 1 that best matches your location. Figure 1 shows general climate zones in the U.S. with several cities identified in each zone [ZenTech 2010]. This document provides the annual irrigation needs for different landscape types for each of these locations.

***It is very important to pick the best match to your location so that the irrigation estimate is as accurate as possible.*** To assist with this, a listing of the cities with associated climate zones, zip codes, peak reference evapotranspiration ($ET_o$) and rainfall values are provided in Table 1[2]. The peak $ET_o$ (referring to the month with the highest ET requirement) and rainfall data can be used to help identify the best match for your location's climate if you are unsure which city is most appropriate. First, go to the U.S. Environmental Protection Agency (EPA) WaterSense Program "Water Budget Data Finder" website: http://www.epa.gov/watersense/nhspecs/wb_data_finder.html Enter the zip code of your location in the box provided in the website. Note the peak $ET_o$ and rainfall value of your location. Then find a few locations in Table 1 that have similar $ET_o$ **and** rainfall values and pick the city that best matches this information and is in a similar climate zone. By doing this, you are choosing the city that has similar irrigation requirements to your location. See an example of this process at the end of this section.

[2] $ET_o$ refers to the reference evapotranspiration. More information is provided on $ET_o$ in the Glossary and Appendix of this document.

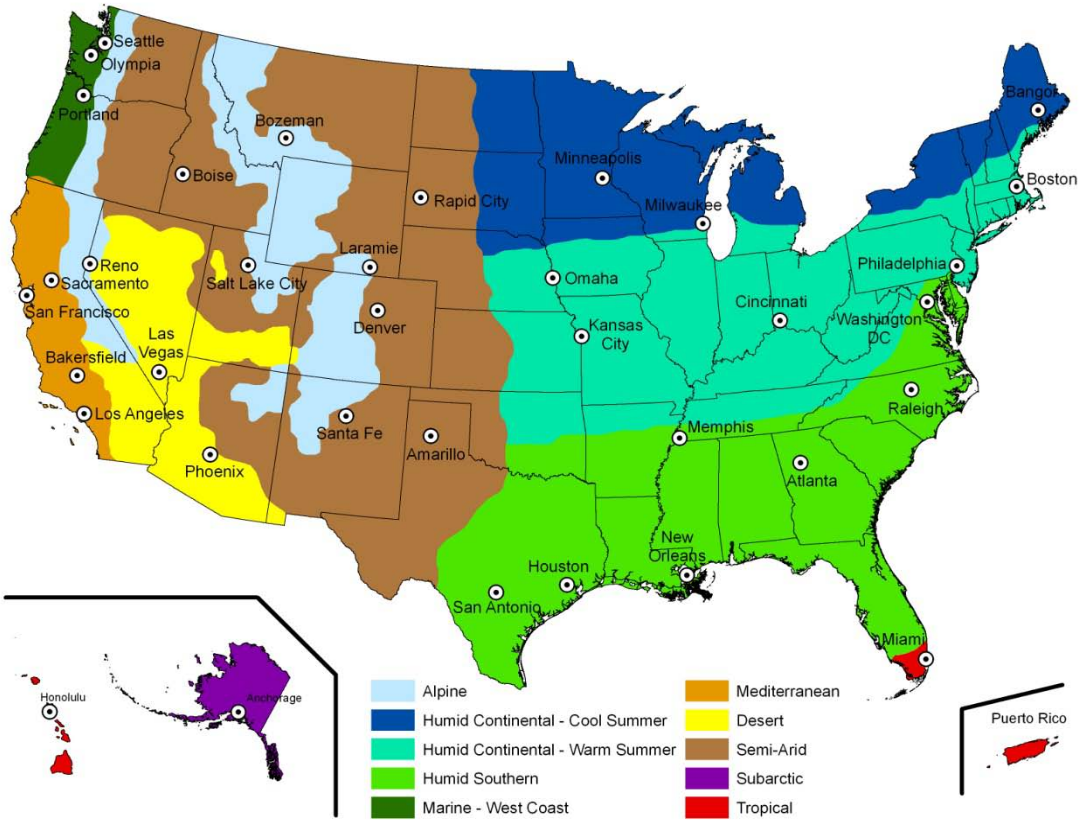



**Figure 1 - Climate Zones of the United States and Puerto Rico**

The Climate zones of the U.S. depicted in this map are:

- *Alpine*: high mountain regions of the Rocky Mountains, Sierra Nevada, and Cascade Mountain ranges
- *Desert*: regions of the U.S. that receive very little precipitation including southern Arizona, south eastern California, southern Utah, and Nevada
- *Humid Continental (cool summer):* northeastern areas of the U.S. that typically have cooler summers and harsh winters such as up-state New York, Vermont, Minnesota, and Wisconsin
- *Humid Continental (warm summer):* Midwestern and northeastern areas of the U.S. with hotter summers and milder winters such as Ohio, Indiana, and Pennsylvania
- *Humid Southern*: hot humid regions of the southern U.S. such as Mississippi, middle and eastern Texas, Georgia, and Florida
- *Mediterranean*: western regions of California
- *Marine - West Coast*: coastal regions of Oregon and Washington
- *Semi-arid*: regions of the U.S. which are characterized by grasslands or sparsely treed areas that have relatively low levels of precipitation such as western Kansas, New Mexico, Idaho, and eastern Wyoming and eastern Colorado
- *Subarctic*: Very cold regions, namely Alaska
- *Tropical*: regions in the U.S. that are hot and humid and have no significant seasonal changes including the southern tip of Florida, Hawaii, and Puerto Rico

Table 1 - City Locations by Climate Zone [ZenTech 2010]

| Climate Zone | City | State | Zip Code | Peak $ET_o$ (in/mo) | Peak Rainfall (in/mo) |
|---|---|---|---|---|---|
| Alpine | Bozeman | MT | 59715 | 7.37 | 1.44 |
| Alpine | Laramie | WY | 82051 | 7.44 | 1.33 |
| Alpine | Santa Fe | NM | 87501 | 7.75 | 1.16 |
| Desert | Bakersfield | CA | 93301 | 10.39 | 0.00 |
| Desert | Las Vegas | NV | 89044 | 13.03 | 0.03 |
| Desert | Phoenix | AZ | 85003 | 13.40 | 0.02 |
| Desert | Reno | NV | 89501 | 8.92 | 0.13 |
| Humid Continental - Cool Summer | Bangor | ME | 04401 | 4.80 | 3.03 |
| Humid Continental - Cool Summer | Milwaukee | WI | 53202 | 6.08 | 3.11 |
| Humid Continental - Cool Summer | Minneapolis | MN | 55401 | 6.85 | 3.41 |
| Humid Continental - Warm Summer | Boston | MA | 02108 | 6.18 | 2.66 |
| Humid Continental - Warm Summer | Cincinnati | OH | 45202 | 6.23 | 3.34 |
| Humid Continental - Warm Summer | Kansas City | MO | 64101 | 7.43 | 3.47 |
| Humid Continental - Warm Summer | Omaha | NE | 68102 | 7.15 | 3.14 |
| Humid Continental - Warm Summer | Philadelphia | PA | 19102 | 6.25 | 3.43 |
| Humid Southern | Atlanta | GA | 30303 | 6.48 | 3.29 |
| Humid Southern | Houston | TX | 77002 | 6.91 | 3.24 |
| Humid Southern | Memphis | TN | 38103 | 7.38 | 3.17 |
| Humid Southern | New Orleans | LA | 70116 | 6.13 | 4.08 |
| Humid Southern | Raleigh | NC | 27601 | 6.03 | 3.53 |
| Humid Southern | San Antonio | TX | 78205 | 8.42 | 0.87 |
| Humid Southern | Washington | DC | 20004 | 6.46 | 2.99 |
| Marine - West Coast | Olympia | WA | 98501 | 5.14 | 0.70 |
| Marine - West Coast | Portland | OR | 97086 | 6.20 | 0.58 |
| Marine - West Coast | Seattle | WA | 98101 | 5.44 | 0.65 |
| Mediterranean | Los Angeles | CA | 90001 | 6.59 | 0.00 |
| Mediterranean | Sacramento | CA | 95814 | 9.47 | 0.00 |
| Mediterranean | San Francisco | CA | 94102 | 5.24 | 0.04 |
| Semi-arid | Amarillo | TX | 79107 | 9.64 | 2.33 |
| Semi-arid | Boise | ID | 83601 | 7.76 | 0.45 |
| Semi-arid | Denver | CO | 80002 | 8.25 | 1.78 |
| Semi-arid | Rapid City | SD | 57701 | 7.86 | 2.01 |
| Semi-arid | Salt Lake City | UT | 84101 | 10.13 | 0.57 |
| Subarctic | Anchorage | AK | 99501 | 4.09 | 1.03 |
| Tropical | Honolulu | HI | 96853 | 7.44 | 5.87 |
| Tropical | Miami | FL | 33010 | 6.65 | 2.16 |

## 2.3 Identify your Turfgrass and Landscape Type

Next, you need to identify which areas are irrigated at your facility and if these areas are predominantly turfgrass or landscaped plants. For example, recreational and athletic fields are typically considered turfgrass area. Areas with a mixture of plants such as trees, shrubs, and flowerbeds are considered landscaped areas.

You need to identify the type of turfgrass and landscaped areas at your location. The next two sections help to direct you on how to do this.

### Turfgrass Type

In general, there are two types of turfgrass – cool and warm season. Cool season grasses thrive in cooler climates and generally require more water than warm season grass to thrive. Warm season grasses are better suited for hot summers and are generally more drought tolerant. You'll need to know which type of grass you irrigate. Your ground maintenance personnel should be able to identify which type of grass you have at your location. Table 2 lists common species of grass and their associated season. (See the section on Turfgrass Evapotranspiration in the Appendix to learn more about turfgrass water requirements.)

**Table 2 - Turfgrass Seasons [California Department of Water Resources 2000] [University of Florida 2009]**

| Turfgrass type | Season Type |
|---|---|
| annual bluegrass | cool |
| annual ryegrass | cool |
| Bermuda grass | warm |
| buffalo grass | warm |
| colonial bentgrass | cool |
| creeping bentgrass | cool |
| hard fescue | cool |
| highland bentgrass | cool |
| Kentucky bluegrass | cool |
| kikuyugrass | warm |
| meadow fescue | cool |
| perennial ryegrass | cool |
| red fescue | cool |
| rough-stalked | cool |
| seashore paspalum | warm |
| St. Augustinegrass | warm |
| tall fescue | cool |
| zoysiagrass | warm |

## Landscape Type

For landscape areas that are not exclusively turfgrass such as sites with trees, shrubs, and flowerbeds, there are three parameters that designate the amount of water necessary for plants to thrive:

1. Water requirements of the plant species (low, moderate, or high)
2. Density of plantings (low, average, or high)
3. Type of microclimate of the landscape (protected, open, or intense exposure)

These parameters are described below to help you identify which type you have at your facility.

### *Landscape Water Requirements*

Supplemental water requirements for landscape plants vary across the U.S. You need to determine the relative amount of irrigation that is required for your landscape. The ranges of watering requirements used in this document are low, moderate, or high water requirements. Keep in mind that the water requirements for your landscape are specific to your area. Plants that require low amounts of water are native or well adapted plants to a particular area (which is a good strategy to limit supplemental irrigation requirements). If your landscape does not include species that are native or drought tolerant in your area, then they likely are moderate to high water consuming plants. For example, a native tree to Tennessee, (e.g. White Oak), will require very little supplemental water in its home state, but will require large amounts of irrigation in an arid state such as Nevada to thrive.

To identify the level of supplemental water required for the plants in your landscape, contact your ground maintenance department. If you cannot get information on the general water requirements of your landscaped areas from staff on site, then you'll need to do some investigating. Local organizations such as a cooperative extension office of a local university may be a good starting place. The cooperative extension office in your area will likely have water requirements of specific plants. The U.S. Department of Agriculture has a website that identifies local cooperative extension offices across the country at: http://www.csrees.usda.gov/Extension/

Because each cooperative extension office will have a different set of information on their website, you'll likely save time by calling the office to talk to staff at the office about getting resources on water requirements rather than performing a web search. But before you call, you'll need to know the general types of plants that are in your landscaped areas. *Remember, you are trying to determine if your landscape area has low, moderate, or high water requirements for your location.*

### *Planting Density*

The second parameter you must identify to designate your landscape type is the number of plants in the area relative to the total area. In other words, how compactly planted is the landscape? Here are the three density levels to choose from:

- Low density: immature and sparsely planted landscape
- Average density: full coverage but predominantly one vegetation type
- High density: landscape with mixture of plant types with full coverage such as trees, flowers, and shrubs (as shown in Figure 2)

**Figure 2 - High Density Landscape Area**

### *Microclimate*

The last parameter you need to identify for determining your landscaped area type is the microclimate. Microclimate takes into consideration the environment in which the landscape is planted such as a shady or sunny location. Here are the three designated types of microclimates to choose from for your landscape:

- Protected: areas shaded from sunlight and protected from wind and heat gain such as a landscape on a north side of a building or with a protective wind barrier
- Open: areas that are in an open flat field such as a park or athletic field
- Intense Exposure: areas exposed to high heat gain or windy conditions such as a landscape with southern exposure or near highly reflective surface like a street median

## 2.4 Estimate Square Footage of the Irrigated Area

The next thing you need to identify to estimate the annual irrigation use is the total square footage of your landscape or turf area. It is important to carefully calculate this number. Some sites may have detailed drawings and plans that will indicate total area of landscape and turf. If you don't have this level of information, there are other techniques that can be used. For example, if you have the total lot size of your facility, subtract the footprint of any structure on the lot as well as any hardscape such as parking lots and sidewalks from the total lot area to determine the net area of landscaped space. Make sure that your units are consistent and that your final area is in square feet. Also, be certain that you are including only irrigated areas. Some locations may have a mixture of irrigated and non-irrigated sections.

There are online sources that can help identify total lot size. An example is a tool called *Draft Logic Google™ Maps Area Calculator Tool*. This online resource allows the user to hone in on a specific location on Google™ Maps and then define the area and automatically provides the total square feet of area of the defined lot. Find this tool at: http://www.daftlogic.com/projects-google-maps-area-calculator-tool.htm

Once you enter this website, switch the map to "satellite" mode by selecting it from the drop down list in the right hand corner. Then enter the zip code of your location. Zoom in on your location close enough so that you can see all the distinct points of your landscape area. Then select each major point of your landscape area. Lines will pop up as you select points that define the area you are selecting. The total area in square feet of your landscape will appear at the bottom of the map.

## 2.5 Select the Annual Irrigation Factor

Next, select the appropriate annual irrigation factor. The annual irrigation factor is the amount of annual supplemental water required to maintain healthy turf or landscaped area. Below you'll find a series of four tables that provide this factor for cool and warm season turfgrasses as well as low, moderate, and high water consuming landscaped areas. The annual irrigation factor takes into account the typical growing season for each location as well the amount of effective precipitation received by the plants for the specific location. (See more details on these terms and methodology in the Glossary and Appendix.)

Here is a description of the tables provided and direction on how to use them:

- *Turfgrasses*: Table 3 shows the annual irrigation factor for both cool season and warm season turf types. Identify the season of your turf and find the nearest location. Note the annual irrigation factor.

- *Landscaped Areas*: Tables 4 through 6 show landscape types for high, moderate, and low water consuming plants. First, find the table that best suits the plants' water requirements (high, moderate, or low). Then, choose the landscape type that best suits your area in terms of density and microclimate. Note the annual irrigation factor for the nearest location. Here are the types of landscapes that are included in each table:
    - Low density and protected microclimate
    - Average density and open microclimate
    - High density and intense exposure microclimate

Your landscape may not be a perfect match to the scenarios in the table. For example, you may have low density plantings but intense exposure in your landscape. If this is the case, consider choosing two scenarios that closely meet your landscape type, and then select a factor that is in between this range to determine your annual water use. An example of this process is provided at the end of the section.

Note, if the annual irrigation factor in the table is zero, this means that there is typically no irrigation requirement for this type of landscape for the particular location because the area receives enough precipitation to meet watering requirements for the specific landscape type.

## Table 3 - Annual Irrigation Factor -- Turfgrass (gal/sqft/year)

| Climate Zone | City | State | cool season turf | warm season turf |
|---|---|---|---|---|
| Alpine | Bozeman | MT | 8.92 | 4.61 |
| Alpine | Laramie | WY | 11.62 | 8.62 |
| Alpine | Santa Fe | NM | 12.67 | 7.77 |
| Desert | Bakersfield | CA | 30.76 | 22.28 |
| Desert | Las Vegas | NV | 44.13 | 31.85 |
| Desert | Phoenix | AZ | 44.96 | 32.16 |
| Desert | Reno | NV | 20.22 | 14.78 |
| Humid Continental - Cool Summer | Bangor | ME | 0.85 | 0.05 |
| Humid Continental - Cool Summer | Milwaukee | WI | 3.63 | 0.73 |
| Humid Continental - Cool Summer | Minneapolis | MN | 5.30 | 0.73 |
| Humid Continental - Warm Summer | Boston | MA | 4.63 | 0.97 |
| Humid Continental - Warm Summer | Cincinnati | OH | 3.66 | 0.47 |
| Humid Continental - Warm Summer | Kansas City | MO | 4.31 | 0.81 |
| Humid Continental - Warm Summer | Omaha | NE | 5.67 | 1.75 |
| Humid Continental - Warm Summer | Philadelphia | PA | 3.31 | 0.37 |
| Humid Southern | Atlanta | GA | 4.55 | 0.70 |
| Humid Southern | Houston | TX | 6.50 | 1.15 |
| Humid Southern | Memphis | TN | 7.35 | 3.22 |
| Humid Southern | New Orleans | LA | 1.47 | 0.10 |
| Humid Southern | San Antonio | TX | 19.37 | 10.82 |
| Humid Southern | Raleigh | NC | 3.33 | 0.20 |
| Humid Southern | Washington | DC | 5.20 | 0.91 |
| Marine - West Coast | Olympia | WA | 6.03 | 3.28 |
| Marine - West Coast | Portland | OR | 7.20 | 4.10 |
| Marine - West Coast | Seattle | WA | 7.45 | 4.43 |
| Mediterranean | Los Angeles | CA | 20.72 | 14.64 |
| Mediterranean | Sacramento | CA | 22.86 | 17.35 |
| Mediterranean | San Francisco | CA | 14.13 | 10.34 |
| Semi-arid | Amarillo | TX | 25.53 | 15.47 |
| Semi-arid | Boise | ID | 13.68 | 9.41 |
| Semi-arid | Denver | CO | 14.30 | 9.57 |
| Semi-arid | Rapid City | SD | 11.98 | 6.78 |
| Semi-arid | Salt Lake City | UT | 18.83 | 13.24 |
| Subarctic | Anchorage | AK | 3.49 | 1.78 |
| Tropical | Honolulu | HI | 0.34 | 0.00 |
| Tropical | Miami | FL | 7.92 | 3.30 |

**Table 4 - Annual Irrigation Factor -- Landscaped Areas with *<u>High</u>* Water Requirements (gal/sqft/yr)**

| Climate Zone | City | State | low density-protected microclimate | average density-open microclimate | high density-intense exposure |
|---|---|---|---|---|---|
| Alpine | Bozeman | MT | 2.53 | 8.92 | 18.54 |
| Alpine | Laramie | WY | 5.57 | 13.27 | 22.13 |
| Alpine | Santa Fe | NM | 4.05 | 12.94 | 23.43 |
| Desert | Bakersfield | CA | 16.02 | 30.76 | 49.79 |
| Desert | Las Vegas | NV | 23.80 | 44.13 | 69.62 |
| Desert | Phoenix | AZ | 23.79 | 44.96 | 71.51 |
| Desert | Reno | NV | 10.78 | 20.22 | 32.33 |
| Humid Continental - Cool Summer | Bangor | ME | 0.00 | 0.85 | 7.16 |
| Humid Continental - Cool Summer | Milwaukee | WI | 0.03 | 3.67 | 12.51 |
| Humid Continental - Cool Summer | Minneapolis | MN | 0.03 | 5.57 | 14.55 |
| Humid Continental - Warm Summer | Boston | MA | 0.15 | 4.63 | 13.53 |
| Humid Continental - Warm Summer | Cincinnati | OH | 0.00 | 3.66 | 14.24 |
| Humid Continental - Warm Summer | Kansas City | MO | 0.07 | 4.31 | 16.48 |
| Humid Continental - Warm Summer | Omaha | NE | 0.11 | 5.96 | 17.41 |
| Humid Continental - Warm Summer | Philadelphia | PA | 0.00 | 3.31 | 13.98 |
| Humid Southern | Atlanta | GA | 0.03 | 4.76 | 16.58 |
| Humid Southern | Houston | TX | 0.09 | 6.50 | 20.73 |
| Humid Southern | Memphis | TN | 0.29 | 7.36 | 19.64 |
| Humid Southern | New Orleans | LA | 0.00 | 1.47 | 13.29 |
| Humid Southern | San Antonio | TX | 4.95 | 19.37 | 38.92 |
| Humid Southern | Raleigh | NC | 0.00 | 3.33 | 14.78 |
| Humid Southern | Washington | DC | 0.06 | 5.20 | 16.44 |
| Marine - West Coast | Olympia | WA | 1.70 | 6.03 | 12.78 |
| Marine - West Coast | Portland | OR | 2.60 | 7.28 | 15.19 |
| Marine - West Coast | Seattle | WA | 2.01 | 7.45 | 14.94 |
| Mediterranean | Los Angeles | CA | 10.59 | 20.94 | 36.62 |
| Mediterranean | Sacramento | CA | 12.03 | 23.70 | 38.67 |
| Mediterranean | San Francisco | CA | 7.31 | 14.73 | 24.57 |
| Semi-arid | Amarillo | TX | 8.81 | 25.53 | 44.38 |
| Semi-arid | Boise | ID | 5.62 | 14.19 | 23.06 |
| Semi-arid | Denver | CO | 6.03 | 14.68 | 25.55 |
| Semi-arid | Rapid City | SD | 3.90 | 11.98 | 21.94 |
| Semi-arid | Salt Lake City | UT | 9.07 | 18.70 | 31.27 |
| Subarctic | Anchorage | AK | 0.62 | 3.49 | 7.65 |
| Tropical | Honolulu | HI | 0.00 | 0.34 | 7.97 |
| Tropical | Miami | FL | 0.85 | 7.92 | 25.76 |

**Table 5 - Annual Irrigation Factor -- Landscaped Areas with *Moderate* Water Requirements (gal/sqft/yr)**

| Climate Zone | City | State | low density-protected microclimate | average density-open microclimate | high density-intense exposure |
|---|---|---|---|---|---|
| Alpine | Bozeman | MT | 0.39 | 3.15 | 8.66 |
| Alpine | Laramie | WY | 1.20 | 6.26 | 12.34 |
| Alpine | Santa Fe | NM | 1.04 | 4.73 | 12.59 |
| Desert | Bakersfield | CA | 9.17 | 17.81 | 29.57 |
| Desert | Las Vegas | NV | 13.77 | 26.30 | 43.27 |
| Desert | Phoenix | AZ | 13.46 | 26.39 | 44.06 |
| Desert | Reno | NV | 5.31 | 11.98 | 20.48 |
| Humid Continental - Cool Summer | Bangor | ME | 0.00 | 0.00 | 0.79 |
| Humid Continental - Cool Summer | Milwaukee | WI | 0.00 | 0.13 | 3.47 |
| Humid Continental - Cool Summer | Minneapolis | MN | 0.00 | 0.11 | 4.60 |
| Humid Continental - Warm Summer | Boston | MA | 0.00 | 0.37 | 4.44 |
| Humid Continental - Warm Summer | Cincinnati | OH | 0.00 | 0.04 | 3.45 |
| Humid Continental - Warm Summer | Kansas City | MO | 0.00 | 0.28 | 4.08 |
| Humid Continental - Warm Summer | Omaha | NE | 0.00 | 0.42 | 5.51 |
| Humid Continental - Warm Summer | Philadelphia | PA | 0.00 | 0.03 | 3.12 |
| Humid Southern | Atlanta | GA | 0.00 | 0.11 | 4.04 |
| Humid Southern | Houston | TX | 0.00 | 0.22 | 6.08 |
| Humid Southern | Memphis | TN | 0.00 | 0.89 | 6.61 |
| Humid Southern | New Orleans | LA | 0.00 | 0.01 | 1.36 |
| Humid Southern | San Antonio | TX | 1.58 | 6.93 | 18.82 |
| Humid Southern | Raleigh | NC | 0.00 | 0.02 | 2.91 |
| Humid Southern | Washington | DC | 0.00 | 0.15 | 4.50 |
| Marine - West Coast | Olympia | WA | 0.37 | 2.00 | 5.87 |
| Marine - West Coast | Portland | OR | 0.67 | 3.13 | 7.09 |
| Marine - West Coast | Seattle | WA | 0.46 | 2.83 | 7.25 |
| Mediterranean | Los Angeles | CA | 5.50 | 11.75 | 20.14 |
| Mediterranean | Sacramento | CA | 7.38 | 13.79 | 22.40 |
| Mediterranean | San Francisco | CA | 2.73 | 8.10 | 13.84 |
| Semi-arid | Amarillo | TX | 1.49 | 11.57 | 24.43 |
| Semi-arid | Boise | ID | 2.59 | 6.90 | 13.37 |
| Semi-arid | Denver | CO | 1.24 | 7.04 | 14.32 |
| Semi-arid | Rapid City | SD | 0.65 | 4.59 | 11.65 |
| Semi-arid | Salt Lake City | UT | 4.35 | 10.25 | 18.29 |
| Subarctic | Anchorage | AK | 0.12 | 0.75 | 3.21 |
| Tropical | Honolulu | HI | 0.00 | 0.00 | 0.29 |
| Tropical | Miami | FL | 0.04 | 1.20 | 7.61 |

### Table 6 - Annual Irrigation Factor -- Landscaped Areas with ***Low*** Water Requirements (gal/sqft/yr)

| Climate Zone | City | State | low density-protected microclimate | average density-open microclimate | high density-intense exposure |
|---|---|---|---|---|---|
| Alpine | Bozeman | MT | 0.00 | 0.04 | 0.66 |
| Alpine | Laramie | WY | 0.01 | 0.22 | 1.66 |
| Alpine | Santa Fe | NM | 0.01 | 0.19 | 1.87 |
| Desert | Bakersfield | CA | 2.01 | 5.64 | 11.00 |
| Desert | Las Vegas | NV | 3.29 | 8.46 | 16.29 |
| Desert | Phoenix | AZ | 3.05 | 6.99 | 16.02 |
| Desert | Reno | NV | 0.89 | 2.46 | 7.13 |
| Humid Continental - Cool Summer | Bangor | ME | 0.00 | 0.00 | 0.00 |
| Humid Continental - Cool Summer | Milwaukee | WI | 0.00 | 0.00 | 0.00 |
| Humid Continental - Cool Summer | Minneapolis | MN | 0.00 | 0.00 | 0.00 |
| Humid Continental - Warm Summer | Boston | MA | 0.00 | 0.00 | 0.00 |
| Humid Continental - Warm Summer | Cincinnati | OH | 0.00 | 0.00 | 0.00 |
| Humid Continental - Warm Summer | Kansas City | MO | 0.00 | 0.00 | 0.00 |
| Humid Continental - Warm Summer | Omaha | NE | 0.00 | 0.00 | 0.00 |
| Humid Continental - Warm Summer | Philadelphia | PA | 0.00 | 0.00 | 0.00 |
| Humid Southern | Atlanta | GA | 0.00 | 0.00 | 0.00 |
| Humid Southern | Houston | TX | 0.00 | 0.00 | 0.00 |
| Humid Southern | Memphis | TN | 0.00 | 0.00 | 0.00 |
| Humid Southern | New Orleans | LA | 0.00 | 0.00 | 0.00 |
| Humid Southern | San Antonio | TX | 0.06 | 0.34 | 2.02 |
| Humid Southern | Raleigh | NC | 0.00 | 0.00 | 0.00 |
| Humid Southern | Washington | DC | 0.00 | 0.00 | 0.00 |
| Marine - West Coast | Olympia | WA | 0.02 | 0.08 | 0.48 |
| Marine - West Coast | Portland | OR | 0.05 | 0.28 | 1.31 |
| Marine - West Coast | Seattle | WA | 0.03 | 0.11 | 0.71 |
| Mediterranean | Los Angeles | CA | 1.09 | 1.98 | 6.81 |
| Mediterranean | Sacramento | CA | 1.60 | 4.11 | 8.70 |
| Mediterranean | San Francisco | CA | 0.48 | 1.45 | 4.17 |
| Semi-arid | Amarillo | TX | 0.06 | 0.29 | 2.65 |
| Semi-arid | Boise | ID | 0.19 | 0.74 | 3.23 |
| Semi-arid | Denver | CO | 0.00 | 0.18 | 1.66 |
| Semi-arid | Rapid City | SD | 0.00 | 0.08 | 1.04 |
| Semi-arid | Salt Lake City | UT | 0.45 | 1.71 | 5.29 |
| Subarctic | Anchorage | AK | 0.00 | 0.02 | 0.20 |
| Tropical | Honolulu | HI | 0.00 | 0.00 | 0.00 |
| Tropical | Miami | FL | 0.00 | 0.00 | 0.14 |

## 2.6 Determine your Irrigation System Efficiency

After determining your irrigation factor, estimate the efficiency of your irrigation system. System efficiency relates to how much irrigation water is actually being used by your turf or plants. Your system efficiency is based on the type of irrigation equipment installed as well as the maintenance and scheduling of the system. A perfect system, operating at 100% efficiency, would have no leaks, losses, or waste. But no system is 100% efficient -- water is lost from runoff, leaks, and evaporation for example. Efficiency can also be impacted by poor maintenance such as broken sprinkler heads or caused by scheduling problems such as watering during windy periods.

The type of irrigation equipment that is used to water the landscape has a big impact on system efficiency. For turf and landscape irrigation, there are two main types of equipment:

- Sprinkler systems: water delivered across a wide area through sprinkler heads such as pop-up and rotor heads
- Micro irrigation: water delivered at lower pressures directly to the root zone of the plant via drip or micro-spray equipment

Sprinkler systems tend to have a lower equipment efficiency ranging between 50% to 70% where micro irrigation have less losses with efficiency ratings between 70% and 90%. [Alliance for Water Efficiency 2009]

To determine your system efficiency, choose the efficiency rating from the list below that best matches the characteristics of your system [Alliance for Water Efficiency 2009]:

- Low Efficiency – 50%: sprinkler type systems that are aging with poor maintenance and lack of proper scheduling
- Medium Efficiency – 65%: sprinkler type systems that have regular maintenance and proper scheduling
- High Efficiency – 85%: micro irrigation systems that have regular maintenance and proper scheduling

If you feel your system does not fall into one of these efficiency ratings, choose a number in between these values that best matches the scenario at your location.

## 2.7 Calculate your Total Annual Irrigation

The final step is to calculate the total irrigation requirements of your turf or landscaped area. To do this, multiply the annual irrigation factor by the landscaped area (in square feet) and divide by the system efficiency. This is represented in the following formula[3]:

$$Annual\ Landscape\ Water\ Use\ (gallons\ per\ year) = \frac{Annual\ Irrigation\ Factor\ \left(\frac{gal}{sqft - yr}\right) \times Irrigation\ Area\ (sqft)}{Irrigation\ System\ Efficiency}$$

[3] Note because several estimates are required to use this formula, there is a wide range of possible answers that can be developed, which may result in a low overall accuracy. So this method should be used as a starting place to develop an initial baseline and should not be considered a measurement of actual water use.

## Examples

Here are two examples to illustrate this process to estimate annual irrigation of turfgrass and landscaped areas:

### *Turfgrass Example*

A Federal facility located in Pittsburgh, PA has an 18-hole golf course with turfgrass that is combination of Kentucky bluegrass and fescue, covering 100 acres of turf. The golf course is supplied from an on-site non-potable well and therefore falls into the category of industrial, landscaping, and agricultural water use -- a baseline for FY 2010 is required per EO 13514. The well is not metered. The irrigation system and controls are fairly old and are in disrepair. A contractor manages the turf at the golf course and does not have any contractual obligation for maintaining an efficient system.

To estimate the amount of irrigation applied to this landscape using the method in this report, here are the steps to take to:

1. **Find the best match for your location**: *The best match to Pittsburgh's climate is Philadelphia.* Pittsburgh is located in the humid continental part of the US with warmer summers (as shown in Figure 1). The three cities that may have similar climate and irrigation requirement to Pittsburgh are Philadelphia, PA, Cincinnati, OH, and Washington DC. To figure out the best matching city, a comparison is made of peak $ET_o$ and rainfall data to Pittsburgh. The peak $ET_o$ and rainfall data for Pittsburgh is 5.70 and 3.59 inches per month respectively[4]. Comparing Pittsburgh data to the values in Table 1 for Philadelphia, Cincinnati, and Washington DC show that Philadelphia's peak $ET_o$ and rainfall values are the closest to Pittsburgh's values (6.25 and 3.43, respectively).
2. **Identify the turfgrass type**: The turfgrass type for this location is *cool season turf*, which is identified in Table 2 of the report.
3. **Estimate square footage of turf area**: The total square footage of the golf course is *4,356,000 sqft* (1 acre equals 43,560 sqft)
4. **Select the appropriate annual irrigation factor**: The annual irrigation factor appropriate for this example is found in Table 3 under the column titled *"cool season turf" for Philadelphia: 3.31 gal/sqft/yr*.
5. **Determine the efficiency of your irrigation system**: *A low system efficiency of 50%* was chosen because the irrigation system and controls are old and are not maintained well.

Applying this information to the following formula yields the estimated annual irrigation requirements for this golf course:

$$3.31\ \frac{gallons}{sqft-year} \times 4{,}356{,}000\ sqft\ \div 0.50 = 28{,}836{,}720\ \frac{gallons}{year}$$

[4] Peak $ET_o$ and rainfall data was obtained through the WaterSense Water Budget Data Finder Website: http://www.epa.gov/watersense/nhspecs/wb_data_finder.html

### *Landscaped Area Example*

A Federal facility located in Colorado Springs, CO has a landscape area around a building that is irrigated with non-potable water. This irrigation is required to be included in the industrial, landscaping, and agricultural water use FY 2010 baseline. The landscaped area is a mixture of shrubs and perennials that are not native to the Colorado Springs area and have moderate water requirements. The landscape area is located near a building and receives southern exposure and is irrigated with pop-up style sprinkler heads. Grounds maintenance personnel calculated the area to be 10,500 square feet by manually measuring the border of the landscape. The system is maintained moderately well with well trained grounds maintenance personnel that are mindful to proper scheduling.

Here are the steps to take to determine the annual irrigation requirement for this area:

6. **Find the best match for your location**: *The best match to Colorado Springs' climate is Laramie, WY.* Colorado Springs is located on the border of the alpine and semi-arid climate zone (see Figure 1 for climate zone map). The three nearest cities to Colorado Springs shown on the climate map are Denver, CO, Santa Fe, NM and Laramie, WY. To figure out the best matching city, a comparison is made of peak $ET_o$ and rainfall data to Colorado Springs. The peak $ET_o$ and rainfall data for Colorado Springs is 7.45 and 1.73 inches per month respectively[5]. Comparing Colorado Springs data to the values in Table 1 for Denver, Santa Fe, and Laramie show that Laramie has the closest match of peak $ET_o$ and rainfall values of 7.44 and 1.33, respectively.
7. **Identify the landscape type:** *The landscape type is moderate water use with average density and intense exposure* because it is located next to a building with southern exposure.
8. **Estimate square footage of landscaped area**: *10,500 sqft*
9. **Select the appropriate annual irrigation factor**: Table 5 is the appropriate table for this landscape because the plants have moderate water requirements. Because the landscaped area has an average density and intense exposure, the appropriate factor is a value between Laramie's average density-open microclimate and high density-intense exposure annual irrigation factor. *The mid-point between these two factors is 9.3*, which was used for this landscape.
10. **Determine the efficiency of your irrigation system**: *A medium system efficiency of 65% was chosen* because pop-up sprinkler heads typically are moderately efficient and the system is fairly well maintained with good scheduling.

Applying this information to the following formula yields the estimated annual irrigation requirements for this landscaped area:

$$9.3\,\frac{gallons}{sqft - year} \times 10{,}500\ sqft\ \div 0.65 = 150{,}231\,\frac{gallons}{year}$$

[5] Peak $ET_o$ and rainfall data was obtained through the WaterSense Water Budget Data Finder Website: http://www.epa.gov/watersense/nhspecs/wb_data_finder.html

# 3.0 Option 2: Estimating Landscaping Water Use Using the Irrigation Audit Method

Estimating landscaping water use through the irrigation audit method requires the physical measurement of irrigation water applied to the landscape.

To use this method, you will be required to follow five steps:

1. Perform an irrigation audit
2. Calculate the precipitation rate of your equipment
3. Estimate annual runtime of your equipment
4. Estimate total area of your landscape
5. Calculate total annual irrigation

## 3.1 Perform an Irrigation Audit

An irrigation audit requires specific procedures to accurately estimate how much water is being consumed by your equipment. It is suggested that the *Recommended Audit Guidelines* produced by the Irrigation Association are followed when performing an irrigation audit[6]. [Irrigation Association 2009] The Irrigation Association has developed standard protocols for irrigation audits and also provides irrigation auditor certification training. The basic procedures outlined in these guidelines include the following steps:

- Obtain catchment devices, called “catch cans”, which will be used to measure water from the system. (Irrigation audit catch cans can be purchased through internet sources. Pre-calibrated plastic rain gauges can also be used.)
- Measure the area of the “throat” of the catch can in square inches. The throat is the opening of the catch can.
- Perform a pre-inspection audit, testing for basic operational performance of the system and identifying problems such as broken heads. Make necessary repairs and adjustments.
- Place catch cans in a uniform pattern on the landscape area. Follow the Irrigation Association guidelines that specify spacing requirements for different types of sprinkler system equipment.
- Run the irrigation system over a given period of time – note the time period (typically done in 15 minute intervals).
- Test the system under normal operating conditions and with minimum wind (less than 5 miles per hour).
- Measure the volume of water in each catch can (typically measured in milliliters).

## 3.2 Calculate your Precipitation Rate

The basic goal of an irrigation audit is to determine your irrigation equipment’s precipitation rate. The precipitation rate is the amount of water that is delivered to your landscape area over a given period of time, provided in inches per hour. The method described in this section only applies to sprinkler systems and not drip irrigation. Also, this method is best used for irrigation systems where the sprinkler heads provide similar precipitation rates. For example, if a landscape area has a mixture of rotor and pop up spray heads, estimating the

[6] The Recommended Audit Guidelines produced by the Irrigation Association is available at: www.irrigation.org/certification/pdf/AuditGuidelines_final.pdf

precipitation rate of the system using an irrigation audit will not reflect the actual water consumption. Precipitation rates vary between different types of sprinkler heads ranging between 1.0 to 2.5 inches per hour for pop-up spray heads and 0.1 to 1.5 inches per hour for rotor type heads[7]. [Alliance for Water Efficiency 2009]

The precipitation rate can be calculated using the following formula:

$$Precipitation\ Rate\left(\frac{inches}{hour}\right) = \frac{Total\ Volume\ of\ Catch\ Cans\ (milliliters) \times 3.66}{Test\ Runtime\ (minutes) \times Throat\ Area\ of\ Catch\ Can\ (square\ inches)}$$

*The factor 3.66 converts water volume of milliliters to cubic inches and runtime minutes to hours.*

## 3.3 Estimate your Annual Runtime

Along with the precipitation rate, you also need to know the annual runtime of your system to estimate the annual landscape water use. The annual runtime of your system can be estimated by understanding your monthly or weekly irrigation schedule. Take the number of hours your system runs each week or month and multiply this number by the number of weeks or months your irrigation system operates throughout the year. (Note, many areas of the U.S. do not require irrigation during the cooler times of the year, so make sure to account for only the irrigation season of your landscape.) For example, if a system operates from April through September for 12 hours each month, then the annual runtime of the system is 72 hours.

## 3.4 Estimate Square Footage of the Irrigated Area

The other parameter that is required for estimating the annual landscape water use using the irrigation audit method is the total landscape area in square feet. Find information on this procedure that is described in section 2.4 titled *Estimate Square Footage of the Irrigated Area.*

## 3.5 Calculate your Total Annual Irrigation

To calculate the total annual landscape water use, utilize this formula:

$$Annual\ Landscape\ Water\ Use\ (gallons\ per\ year) = Precipitation\ Rate\left(\frac{inches}{hour}\right) \times Annual\ Runtime\left(\frac{hours}{year}\right) \times Landscape\ Area\ (sqft) \times 0.6233$$

*Note, the factor of 0.6233 converts volume of water to gallons from 1 square foot and 1 inch deep.*

An irrigation audit will not only provide the precipitation rate of your system, but it can also provide the overall effectiveness of your system. A proper irrigation audit investigates how well the irrigation system is watering your landscape and can identify problem areas so repairs and adjustments can be made. If you choose the irrigation audit method, consider contracting a certified irrigation auditor or a WaterSense irrigation partner. Hiring a trained professional will ensure that the recommended Irrigation Association guidelines are followed appropriately and that you gain beneficial information on your irrigation system. To get more information on the

[7] A good resource to get basic information on irrigation equipment, go to the Alliance for Water Efficiency website at: http://allianceforwaterefficiency.org/Irrigation_System_Heads_Introduction.aspx

Irrigation Association, go to: http://www.irrigation.org And to get further information on how to locate a WaterSense irrigation partners, go to: http://www.epa.gov/watersense/meet_our_partners.html

Also, some state and local organizations may offer free irrigation audits as part of water conservation programs. Check with your water provider to see if these services may be available in your area. You may want to start your search through the EPA WaterSense program's website that provides a portal to access information on water efficiency rebates across the US at:

http://www.epa.gov/watersense/rebate_finder_saving_money_water.html

# 4.0 Subsequent Reporting Years

Now that you've estimated your baseline for unmetered landscape water use, how will you document changes in water use for subsequent reporting years? The best approach is to install meters on these applications. This will offer you a way to check your baseline estimate and also accurately report any consumption changes in future years. If metering is not practical, you can use this document to report changes in water use by utilizing these same methodologies. This will not be entirely accurate, but it can provide you a methodology to estimate changes in irrigation. The following list provides some scenarios for estimating future changes in water use for unmetered landscape irrigation using either the ET method or irrigation audit method:

*Evapotranspiration Method:*

- If turf or landscape plants have been replaced with new species, choose a new annual irrigation factor that reflects the new landscape type and apply this factor to the annual landscape water use formula.
- If the operating efficiency has changed due to better scheduling or maintenance of the irrigation equipment, select a higher efficiency rating and apply to the annual landscape water use formula.

*Irrigation Audit Method:*

- If operating runtime changes, apply the new runtime to the annual landscape water use formula
- If the irrigation equipment has been repaired, perform another irrigation audit to estimate a new precipitation rate and apply to the given formulas.

# 5.0 Glossary

**Annual Irrigation Factor:** This factor represents supplemental water requirements for turf or landscaped areas in gallons per square feet per year. The supplemental irrigation represents the amount of water needed during a typical growing season that is not satisfied by precipitation.

**Effective Precipitation (EP)**: Effective precipitation is defined in this document as the amount of precipitation that is absorbed and stored in the soil, available for plants.

**Evapotranspiration (ET):** ET represents the loss of water from the Earth's surface through the combined processes of evaporation (from soil and plant surfaces) and plant transpiration (i.e., internal evaporation). [Irrigation Association 2001]

**Irrigation System Efficiency**: This term represents the percentage of beneficial irrigated water that reaches the turf or landscaped plants. For example, a system efficiency of 50% equates to half of the water applied to the landscape area reaches the plants while the other half of the irrigated water is wasted through inefficiencies such as runoff, broken sprinkler heads, and improper scheduling.

**Landscape Water Consumption:** This term is defined as the controlled application of water to outdoor spaces that have been designed to achieve socio-behavioral, environmental, and/or aesthetic outcomes to supplement water requirements not satisfied by rainfall. Examples of landscaping water consumption include (but are not limited to) irrigation of turf or landscaped beds and recreational fields.

**Precipitation Rate**: Precipitation rate is the amount of water that is applied to landscaped areas over a specific length of time through irrigation equipment measured typically in inches per hour.

**Reference Evapotranspiration ($ET_o$):** The reference ET rate provides the total amount of water needed to grow high water consuming alfalfa grass during a specific time frame and location under conditions of that area (including variables such as humidity, temperature, and wind speed). $ET_o$ does not include rainfall received in that area. This term specifically is the amount of water that evaporates from 4- to 7-inch tall alfalfa growing in an open-field condition over a given time frame under specific conditions for a particular location. The units of $ET_o$ are typically provided in inches. [California Department of Water Resources 2000]

# 6.0 Resources

The following links provide resources for researching water efficient strategies for landscaping and irrigation.

**Alliance for Water Efficiency** Resource Library on Landscape, Irrigation, and Outdoor Water Use:
http://allianceforwaterefficiency.org/Landscape_and_Irrigation_Library_Content_Listing.aspx

**Irrigation Association -** Smart Water Applications Technologies (SWAT):
http://www.irrigation.org/SWAT/Industry/

**WaterSense** Water Budget Tool: http://www.epa.gov/watersense/nhspecs/water_budget_tool.html

**Watersmart Guidebook:** A Water-Use Efficiency Plan Review Guide for New Businesses by East Bay Municipal Utility District:
http://www.allianceforwaterefficiency.org/WaterSmart_Guidebook_for_Businesses.aspx

**University of California Cooperative Extension** Center for Landscape and Urban Horticulture:
http://groups.ucanr.org/CLUH/Landscape_Irrigation_Management_and_Conservation/

# 7.0 References


Alliance for Water Efficiency. 2009. *Irrigation Equipment Introduction Website*, Chicago, IL – provided typical efficiency of irrigation systems: http://allianceforwaterefficiency.org/Irrigation_Equipment_Introduction.aspx . Accessed July 2010.

California Department of Water Resources. August 2000. **A Guide to Estimating Irrigation Water Needs of Landscape Planting in California – The Landscape Coefficient Method and WUCOLS III**, University of California Cooperative Extension, Sacramento, CA – provided basic methodology for calculating annual irrigation factors: www.water.ca.gov/wateruseefficiency/docs/wucols00.pdf. Accessed July 2010.

Irrigation Association. December 2001. **The ASCE Standardized Reference Evapotranspiration Equation**, Falls Church, VA – provided definition of evapotranspiration: http://www.irrigation.org/defaultcontent.aspx?id=844&terms=ASCE+Standardized+Reference+Evapotranspiration. Accessed July 2010.

Irrigation Association. September 2009. **Recommended Audit Guidelines**, Falls Church, VA –provided steps for irrigation auditing practices: http://www.irrigation.org/defaultcontent.aspx?id=842&terms=Audit+guidelines. Accessed July 2010.

University of Florida, Irrigation Research, Southwest Florida Water Management District. 2009. *Turfgrass Crop Coefficients Website, Institute of Food and Agricultural Sciences Extension*, Gainesville, FL – provided turfgrass crop coefficients: http://irrigation.ifas.ufl.edu/turfgrass/turfgrass-crop-coefficient.shtml. Accessed July 2010.

U.S. Environmental Protection Agency. March 2010. *Water Budget Tool Website*, N.W. Washington, D.C. – provided reference evapotranspiration and precipitation data: http://www.epa.gov/watersense/nhspecs/wb_data_finder.html. Accessed July 2010.

ZenTech. 2010. *Climate Guide Website*, Japan – provided the climate map: http://www2m.biglobe.ne.jp/%257eZenTech/English/Climate/USA/index.htm. Accessed July 2010.

# Appendix -- Calculations for the Annual Irrigation Factor Tables

Information provided in the Appendix documents the approach taken to calculate the annual irrigation factors. It is not necessary to read the Appendix to use the process outlined in the main body of the document. But, if the reader wishes to calculate the annual irrigation factor using precise ET data of a given location instead of utilizing the annual irrigation factors provided Tables 3 – 6 in the main body of the report, then the Appendix can serve as a model to prepare the necessary calculations.

The type of data needed to calculate the annual irrigation factors are the following:

- Reference Evapotranspiration
- Turfgrass Evapotranspiration (also called crop evapotranspiration)
- Landscape Evapotranspiration
- Turfgrass and Landscape Coefficients
- Precipitation

The following section details these factors and equations used to develop the annual irrigation factor.

## Evapotranspiration

The evapotranspiration method was used to develop the data to calculate the annual irrigation factors. This approach utilizes information on actual water requirements for specific landscape types based on the evaporation and transpiration of the plants in the landscape.

### Turfgrass Evapotranspiration

The general equation used to calculate water requirements for turfgrass is as follows [Irrigation Association 2001]:

$$ET_c = K_c \text{ x } ET_o$$

Where:

$ET_c$ = Turfgrass Evapotranspiration (also known as crop evapotranspiration)
$K_c$ = Turfgrass Coefficient (also known as crop coefficient)
$ET_o$ = Reference Evapotranspiration

The turfgrass evapotranspiration is amount of water (typically in inches over a given time period) needed to maintain healthy turf for a given location. This value is adjusted based on a "reference crop". The reference crop is alfalfa, which is a high water-consuming grass. In other words, water required for all turf types whether it is Kentucky bluegrass or Bermuda grass is compared to the water needs of alfalfa. So, the reference evapotranspiration is the total amount of water needed to grow alfalfa grass during a specific time frame and location under typical regional conditions for that area (including variables such as humidity, temperature, and wind speed).

The turfgrass coefficient indicates the relative amount of water needed for the landscape compared to the reference crop (which has a $K_c$ of 1). This term is also referred to as crop coefficient and represents the fraction of water lost from different species of turfgrass relative to the reference evapotranspiration. Cool season grasses, such as fescue, have a $K_c$ of 0.8, while warm season grasses have a $K_c$ of 0.6. This means that cool season grasses typically require about 80% of the water of alfalfa to retain a healthy state while warm season grasses such as Bermuda and zoysiagrass need about 60% of the water. [California Department of Water Resources 2000] Note the turfgrass evapotranspiration does not include precipitation received by the location.

## Landscape Evapotranspiration

The general equation used to calculate water requirements of landscaped areas which includes a combination of plants such as shrubs, flowers, and trees is as follows [California Department of Water Resources 2000]:

$$ET_L = K_L \times ET_o$$

Where:

$ET_L$ = Landscape Evapotranspiration
$K_L$ = Landscape Coefficient
$ET_o$ = Reference Evapotranspiration

Similar to the description above for turfgrass, landscape evapotranspiration calculates the amount of water needed to maintain a healthy landscape. The landscape coefficient reflects the fraction of water needed to maintain the health of a given landscape relative to the amount of water needed for the reference crop of alfalfa. The landscape coefficient is based on three factors: 1) type of species, 2) density of plants in the landscape, and 3) the microclimate of the landscape (e.g. protected vs. exposed). Each of these factors are multiplied together to determine the overall landscape coefficient. Here is the equation for landscape coefficient [California Department of Water Resources 2000]:

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

Where:

$k_s$ = Species Factor
$k_d$ = Density Factor
$k_{mc}$ = Microclimate Factor

The factors are explained below:

### *Species Factor ($k_s$)*

The species factor is defined by the water needs of the plants in the landscape for the given location. The following species factors can be applied to three general landscape types:

- Low $k_s$: Plants with minimal water needs have a low $k_s$ ranging between 0.1 and 0.3
- Average $k_s$: Plants with moderate water needs have an average $k_s$ of between 0.4 and 0.6

- High $k_s$: Plants with elevated water requirements have a high $k_s$ of between 0.7 and 0.9.

Note, if there is a mixture of plants with differing water needs, the species factor is chosen for the plant type with the highest water requirement.

### *Density Factor ($k_d$)*

The density factor determines how densely populated the plants are in the landscape.  The following density factors can be applied to three general landscape types:

- Low $k_d$: Immature and sparsely planted landscape have a low $k_d$ ranging between 0.5 and 0.9
- Average $k_d$: Predominantly one vegetation type have an average $k_d$ of 1
- High $k_d$: Landscape with mixture of plant types with full coverage have a high $k_d$ ranging between 1.1 and 1.3.

### *Microclimate Factor ($k_{mc}$)*

The microclimate factor takes into consideration the environment in which the landscape is planted. Factors determining $k_{mc}$ include effects of temperature, wind, and amount of sunlight.  The following microclimate factors can be applied to three general landscape types:

- Low $k_{mc}$: Areas shaded from sunlight and protected from wind and heat gain have a low $k_{mc}$ ranging between 0.5 and 0.9
- Average $k_{mc}$: Landscape areas that are in an open flat field (the same as the reference conditions) have an average $k_{mc}$ of 1
- High $k_{mc}$: Landscape areas with intense exposure to the elements such as high heat gain or windy conditions have a high $k_{mc}$ ranging between 1.1 and 1.4.

## Reference $ET_o$ Rates and Precipitation Data

The reference evapotranspiration ($ET_o$)and precipitation data used in this document was provided through the U.S. Environmental Protection Agency's WaterSense program.  WaterSense has developed a tool called the WaterSense Landscape Water Budget Tool (http://www.epa.gov/watersense/nhspecs/water_budget_tool.html). [U.S. Environmental Protection Agency 2010]  This tool utilizes $ET_o$ rates and precipitation developed by the International Water Management Institute (IWMI) Climate Atlas.  The IWMI Climate Atlas utilizes 30 years of historical climate data.  The data includes information by location on factors including precipitation, temperature, humidity levels, and evaporation rates to calculate the $ET_o$ for specific locations.

WaterSense provided monthly $ET_o$ and precipitation data for specific locations which were included in the tables of this document.  The growing season for each location was determined to be those months where reference evapotranspiration exceeded precipitation.  Also, the effective precipitation was taken into account as well in the model which assumed that 85% of the precipitation that was received by the landscape area was absorbed by the soil and usable by the plants.

## Annual Irrigation Factor

The annual irrigation factor provided in tables of this document represents the amount of water in gallons per square foot required to maintain a healthy landscaped or turf area over 1 year. The annual irrigation factor takes into account the growing season for the location and plant type as well as the amount of effective precipitation that is typically received in that area on a monthly basis. The following formula represents the annual irrigation factor:

$$Annual\,Irrigation\,Factor\,\frac{gallons}{sqft - year} = \left[\sum monthly\,ETc - \sum monthly\,precipitation \times EP\right] \times Cu$$

Where:

Annual Irrigation Factor (gallons per square foot per year) = supplemental water required to maintain healthy landscape per square foot of landscaped area

$\sum ET_c$ = sum of monthly crop or landscape coefficients during the growing season for the specific location, in inches per month.

∑Rainfall = sum of monthly historical rainfall received during the growing season for the specific location, in inches per month.

EP = effective precipitation factor representing the amount of precipitation that is actually absorbed by the soil for plant growth

$C_u$ = conversion factor of 0.6233 to convert annual irrigation from inches to gallons

The annual irrigation factor represents the sum of monthly supplemental water requirements to maintain a healthy landscape or turf area, shown in the Tables 3 through 6 of the document. The user of the document then multiplies the annual irrigation factor by the landscape area (square feet) and divides by the system efficiency to calculate the estimated total irrigation needed for the year.

EERE Information Center
1-877-EERE-INF (1-877-337-3463)
*www.eere.energy.gov/informationcenter*

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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PNNL-19498

| No. | Species - Botanical name | Common name | Local name | Size | Requireme | Type | Landscape Area | | | Calculation | | | | Scene 1 - G1 | Scene 2 - G2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | | Nos. | sq.m. | sq.ft. | Planting density | Microclimate | Annual irrigaton factor | Irrigation system efficiency | Annual landscape water use | Annual landscape water use |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | Tree | 6 | 24 | 258.3 | avg | intense exposure | 7.83 | 85% | 2380 | |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | Tree | 30 | 120 | 1291.7 | high | intense exposure | 16.29 | 85% | 24754 | 24754 |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | Shrub | | 27.5 | 296.0 | low | intense exposure | 13 | 85% | 4527 | |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise, peacock flower, pride of barbados | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | Shrub | | 42.5 | 457.5 | low | intense exposure | 29.5 | 85% | 15877 | 15877 |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | Ground cover | | 144 | 1550.0 | avg | intense exposure | 7.83 | 85% | 14278 | 14278 |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | Shrub | | 92.5 | 995.7 | avg | intense exposure | 16.97 | 85% | 19878 | 19878 |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | Ground cover | | 825 | 8880.2 | high | intense exposure | 69.62 | 85% | 727342 | |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | Ground cover | | 42.5 | 457.5 | low | intense exposure | 45.82 | 85% | 24660 | 24660 |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | Shrub | | 6 | 64.6 | low | intense exposure | 45.82 | 85% | 3481 | |
| | | | | | | | | | | | | | | 837178 | 99448 |

**Water calculations for G1 and G2**

| No. | Species - Botanical name | Common name | Local name | Size | Requireme | Type | Landscape Area | | | Calculation | | | | Scene 1 - K1 | Scene 2 - K2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Water | | Nos. | sq.ft. | K2 sq.ft. | Planting density | Microclimate | Annual irrigaton factor | Irrigation system efficiency | **Annual landscape water use** | **Annual landscape water use** |
| 1 | Phoenix Dactylifera | date plam | Nakhil al balah | 18-25m high, 12m spread | low | Tree | 6 | 258.3 | | avg | intense exposure | 7.83 | 85% | 0.00 | 2380 |
| 2 | Azadirachta indica | Neem tree | | 6-8m spreading crown | low | Tree | 30 | 1291.7 | | high | intense exposure | 16.29 | 85% | 0.00 | 24754 |
| 3 | Adenium Obesum | Desert rose | Adanah | 5 m high 3m spread | low | Shrub | | 296.0 | | low | intense exposure | 13 | 85% | 0.00 | |
| 4 | Caesalpinia Pulcherrima | Red Bird of Paradise, peacock flower, pride of barbados | Zahrat Al Tawose, Abu Shawarib | 3m high, 3m spread | medium | Shrub | | 457.5 | | low | intense exposure | 29.5 | 85% | 0.00 | |
| 5 | Sesuvium Portulacastrum | sea purslane | | 0.15m high, 0.18m spread | low | Ground cover | | 1550.0 | | avg | intense exposure | 7.83 | 85% | 0.00 | 14278 |
| 6 | Carissa Grandiflora | natal plum | Karisah | 1-3m high, 1-2m spread | medium | Shrub | | 995.7 | 2195.8 | avg | intense exposure | 16.97 | 85% | 0.00 | 43839 |
| 7 | Cynodon dactylon | bermuda grass | najeel baladi, thayel | 0.125m high | high | Ground cover | | 8880.2 | | high | intense exposure | 69.62 | 85% | 0.00 | |
| 8 | Crinum asiaticum | St.John lily, Poison bulb | Krenum, narjes | | high | Ground cover | | 457.5 | | low | intense exposure | 45.82 | 85% | 0.00 | |
| 9 | Cryptostegia Grandiflora | India rubber vine | Kribtostagiah | 10-15m high | high | Shrub | | 64.6 | | low | intense exposure | 45.82 | 85% | 0.00 | |
| | | | | | | | | | | | | | | 0.00 | 85252 |

**Water calculations for K1 and K2**